Plenary Session I

Chair *Gregory Dudek, McGill University*
Co-Chair

09:15–10:15	MoPL.1*

Challenges for Deep Learning towards AI

Yoshua Bengio, U. Montreal

PODS: Monday Session I

Chair

Co-Chair

Robot Learning I - 1.1.01

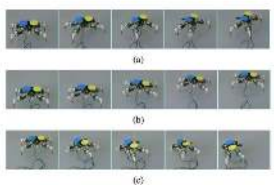
Chair
Co-Chair

10:45–12:00 MoA1.1

Trajectory-based Probabilistic Policy Gradient for Learning Locomotion Behaviors

Sungjoon Choi and Joohyung Kim
Disney Research, USA

- We propose a trajectory-based reinforcement learning method named deep latent policy gradient (DLPG) for learning locomotion skills.
- The policy is defined as a probability distribution over trajectories.
- We show sample-efficiency of the proposed method in two locomotion tasks in simulated environments.
- Snapbot successfully learns desired locomotion skills with moderate sample complexity for rollouts (<2hours).

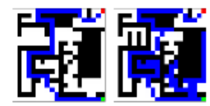

Snapbot (a) turning left, (b) going straight, and (c) turning right

10:45–12:00 MoA1.2

Learning Motion Planning Policies in Uncertain Environments through Repeated Task Executions

Florence Tsang, Ryan A. Macdonald, and Stephen L. Smith
Electrical and Computer Engineering, University of Waterloo, Canada

- Our planner minimizes the average cost to execute a movement task over a given number of task executions
- The environment in each task execution may contain unknown obstacles
- The robot learns how to identify and navigate recurring environments based off past task executions
- Shows significant performance improvement over reactive planning

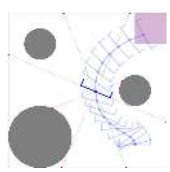

Left: Policy path,
Right: Reactive path

10:45–12:00 MoA1.3

BaRC: Backward Reachability Curriculum for Robotic Reinforcement Learning

Boris Ivanovic[1], James Harrison[2], Apoorva Sharma[1], Mo Chen[3], Marco Pavone[1]
[1]Stanford University, Department of Aeronautics and Astronautics
[2]Stanford University, Department of Mechanical Engineering
[3]Simon Fraser University, School of Computer Science

- Reinforcement Learning (RL) is a promising approach for robotic policy learning.
- However, sparse rewards make the learning process challenging and inefficient.
- We present BaRC, a curriculum generation method that enables efficient learning in sparse reward MDPs.
- BaRC uses approximate backward reachable sets to achieve strong improvement over previous state-of-the-art curriculum strategies.

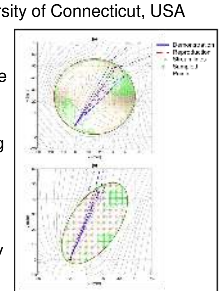

BaRC allows a simulated quadrotor system to efficiently solve sparse reward RL problems.

10:45–12:00 MoA1.4

Active Sampling based Safe Identification of Dynamical Systems using Extreme Learning Machines and Barrier Certificates

Iman Salehi, Gang Yao, and Ashwin P. Dani
Electrical and Computer Engineering, University of Connecticut, USA

- A dynamical systems model learning method is developed which preserves the trajectories of the system that are starting in a compact set to that set.
- The DS is approximated using Extreme Learning Machine, and a parameter learning problem subject to Barrier constraints is solved.
- An active sampling method is proposed for enforcing Barrier constraints at advantageous points in the prescribed compact set to efficiently solve the optimization problem.


An Illustration of model learning using active sampling strategy

10:45–12:00 MoA1.5

Navigating Dynamically Unknown Environments Leveraging Past Experience

Sterling McLeod
Computer Science, University of North Carolina at Charlotte, USA
Jing Xiao
Computer Science and Robotics Engineering, Worcester Polytechnic Institute, USA

- Utilize past information about an environment to inform future planning decisions
- Combine probabilistic data about the occupancy of an environment and real sensing data
- Evaluate trajectories based on possible future collision

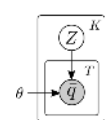

Use probabilistic data for unsensed regions of the environment

10:45–12:00 MoA1.6

VPE: Variational Policy Embedding for Transfer Reinforcement Learning

Isac Arnekvist and Danica Kragic
RPL, Royal Institute of Technology, Sweden
Johannes A. Stork
AASS, Örebro University, Sweden

- Unsupervised learning to find low dimensional task parameterizations allows for fast transfer
- Enables learning from contradicting teacher policies where traditional supervised learning fails
- Evidence lower bound optimization that works for both stochastic and deterministic teacher policies



Q-functions are considered as generated from some latent variable Z

Object Recognition I - 1.1.02

Chair
Co-Chair

10:45–12:00	MoA1.1

Automatic Labeled LiDAR Data Generation based on Precise Human Model

Wonjik Kim, Masayuki Tanaka, and Masatoshi Okutomi
Systems and Control Engineering, Tokyo Institute of Technology, Japan
Yoko Sasaki
National Institute of Advanced Industrial Science and Technology, Japan

- We have proposed automatic generation of labeled depth map without involving manual label.
- We are providing 500K+ data generated by proposed pipeline.
- We also researched about the data with diverse approaches

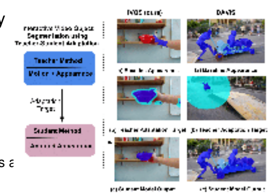

Example of generated LiDAR data

10:45–12:00	MoA1.2

Video Object Segmentation using Teacher-Student Adaptation in HRI Setting

Mennatullah Siam, Chen Jiang, Steven Lu, Laura Petrich, Martin Jagersand
University of Alberta, Canada
Mohamed Elhoseiny — Facebook AI Research, US
Mahmoud Gamal — Cairo University, Egypt

- We propose a method to incrementally learn video object segmentation using human robot interaction.
- The method goes through 3 phases:
  A) Training Phase, where teacher model learns to segment based on motion.
  B) Teaching Phase, where teacher model provides a adaptation target to the student model.
  C) Inference, where adapted student model predicts the segmented object.
- We introduce a dataset for interactive video object segmentation (IVOS dataset)

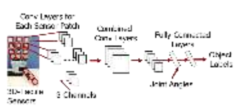

Method Overview

10:45–12:00	MoA1.3

Morphology-Specific Convolutional Neural Networks for Tactile Object Recognition with a Multi-Fingered Hand

Satoshi Funabashi, Gang Yan, Andreas Geier, Alexander Schmitz, Tetsuya Ogata and Shigeki Sugano
Dept. of Mechanical Engineering and Intermedia Art and Science, Waseda University, Japan

- Allegro Hand provides 720 force (15 patches x 6 triaxial force of uSkin) and 16 joint angle
- Inputs with 3 channels (x, y and z) are used due to 3D (x, y, z) vector tactile information
- Consecutive layers in the CNN get input from parts of one finger segment, one finger, and the whole hand.
- An over-95% object recognition rate with 20 objects was achieved, with input of only one random time.


Convolution layers are prepared for each tactile sensor patch and combined in a latter convolution layer

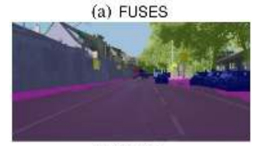
10:45–12:00	MoA1.4

Accelerated Inference in Markov Random Fields via Smooth Riemannian Optimization

Siyi Hu and Luca Carlone
Laboratory for Information & Decision Systems
Massachusetts Institute of Technology, USA

- Markov Random Fields (MRF) are a popular model for pattern recognition in robotics and computer vision
- We propose two MRF solvers: the *Dual Ascent Riemannian Staircase* (DARS) and the *Fast Unconstrained SEmidefinite Solver* (FUSES).
- DARS and FUSES compute near-optimal solutions, attaining an objective within 0.1% of the optimum.
- FUSES solves large MRFs in milliseconds and is faster than local search methods while being a global solver.


(a) FUSES

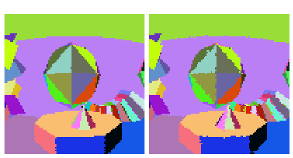

(b) DARS

10:45–12:00	MoA1.5

A Maximum Likelihood Approach to Extract Finite Planes from 3-D Laser Scans

Alexander Schaefer, Johan Vertens, Daniel Büscher, Wolfram Burgard
Department of Computer Science, University of Freiburg, Germany

- Strictly probabilistic method based on clustering
- Considers ray path information instead of point-to-plane distance
- Requires only one parameter as stopping criterion for clustering
- Comes with synthetic benchmarking dataset


Ground truth Segmentation

10:45–12:00	MoA1.6

Position Estimation for Multiple Robots: Practical Provable Approximation

Dan Feldman, Jeryes Danial and Ariel Hutterer
Computer Science Department
University of Haifa
Israel

- Motivation: track multiple moving *k* objects based on registered markers on each.
- Input: An ordered set *P* of *n* (registered) points, and a set *Q* of *n* (observed) points.
- Output: Translation vector *t* and matching between every point in P to Q-*t*
- Goal: minimize sum of squared distances between the paired points
- Result: Provable constant factor approx.

Biologically-Inspired Robots - 1.1.03

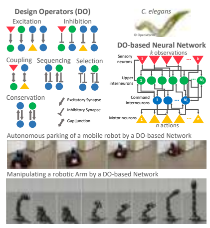
Chair
Co-Chair

10:45–12:00 MoA1.1

Designing Worm-inspired Neural Networks for Interpretable Robotic Control

Mathias Lechner[1,3*], Ramin Hasani[1*],
Manuel Zimmer[2,4], Thomas Henzinger[3], Radu Grosu[1]
[*]Equal Contributions
[1]CPS, Vienna University of Technology (TU Wien), Austria
[2]Department of Neurobiology, University of Vienna,Austria
[3]Institute of Science and Technology (IST), Austria
[4]Research Institute of Molecular Pathology (IMP), Vienna Biocenter, Austria

- Design compact, interpretable and noise-robust neural controllers to control robots
- Introducing novel network-design principles for a continuous-time recurrent neuronal network, and equipping the designed network with a search-based learning algorithm, to govern robotic tasks.

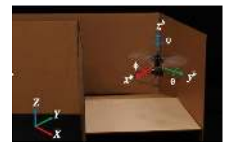


10:45–12:00 MoA1.2

Acting Is Seeing: Navigating Tight Space Using Flapping Wings

Zhan Tu, Fan Fei, Jian Zhang and Xinyan Deng
School of Mechanical Engineering, Purdue University, US

- The first flapping-wing robot that uses its wing loading variation to sense the surroundings, and navigate in the tight space without vision.
- Proposed sensing and navigation approach is experimentally validated by several flight tests, including terrain following, wall following, and going through a narrow corridor.
- A robust controller is designed to reject unforeseen disturbances.
- The platform has a wingspan of 17cm, weighs 12 grams. Wingbeat frequency is up to 40Hz. A 12cm diameter landing gear is attached for safe takeoff and landing.



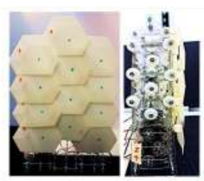
Purdue Hummingbird was navigating a 1ft width corridor, guided by loading variations on the flapping wings.

10:45–12:00 MoA1.3

Design and Characterization of a Novel Robotic Surface for Application to Compressed Physical Environments

Yixiao Wang, Richa Sirohi, Liheng Li, and Keith Green
Dept. of Design and Env. Analysis, Cornell University, USA
Chase Frazelle and Ian Walker
ECE Department, Clemson University, USA

- Introduction of a nature inspired robotic surface for reshaping of habitable space
- Describe the mechanical design, range of motion, and potential applications
- Develop and compare kinematic model for describing the motion and shape of CompResS



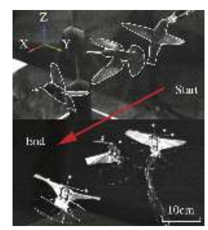
CompResS—a Compressed Robotic Surface

10:45–12:00 MoA1.4

Learning Extreme Hummingbird Maneuvers on Flapping Wing Robots

Fan Fei, Zhan Tu, Jian Zhang and Xinyan Deng
School of Mechanical Engineering, Purdue University, US

- Underactuated hummingbird robot with only 2 actuators
- Use reinforcement learning to optimize a maneuver policy given the movement goal
- Manifested kinematic behavior similar to real Magnificent Hummingbirds
- Sim-to-real transfer demonstrated on an at-scale hummingbird robot



Hummingbird vs robot escape maneuver

10:45–12:00 MoA1.5

Caterpillar-inspired Crawling Robot using Both Compression and Bending Deformations

Takuya Umedachi[1], Masahiro Shimizu[2] and Yoshihiro Kawahara[1]
[1] Graduate School of Information Science and Technology, The University of Tokyo, Japan
[2] Graduate School of Engineering Science, Osaka University, Japan

- **Multimodal deformations** of soft materials (compression and bending) are a common on soft-bodied animals.
- **The robot to use the multiple deformation modes** is presented.
- The multiple deformation modes can **contribute to the locomotion speed** increase in the simulation and experiment with the prototype.

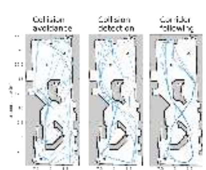
The prototype uses **compression** and bending of the beams.

10:45–12:00 MoA1.6

A Biomimetic Radar System for Autonomous Navigation

Girmi Schouten and Jan Steckel
Faculty of Applied Engineering, University of Antwerp, Belgium

- Introducing a biologically-inspired radar sensor based on bat echolocation
- Binaural differences and acoustic flow as cues to sense and avoid obstacles
- Autonomous navigation in unknown environments using subsumption architecture
- Topological SLAM based on spectrogram representations of the radar signals



Autonomous navigation performance

SLAM - Session I - 1.1.04

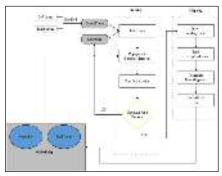
Chair
Co-Chair

10:45–12:00 MoA1.1

FMD Stereo SLAM: Fusing MVG and Direct Formulation Towards Accurate and Fast Stereo SLAM

Fulin Tang, Heping Li and Yihong Wu
National Laboratory of Pattern Recognition, Institute of Automation, Chinese Academy of Sciences,
University of Chinese Academy of Sciences,China

- A novel stereo visual SLAM framework, FMD SLAM, is proposed considering both accuracy and speed
- The front-end makes our system fast, which performs direct formulation mainly
- The back-end makes our system accurate, which uses MVG and keeps a global map
- Experimental results on EuRoC dataset shows our method is faster and more accurate


The proposed framework: tracking and mapping pipelines

10:45–12:00 MoA1.2

ScalableFusion: High-resolution Mesh-based Real-time 3D Reconstruction

Simon Schreiberhuber and Johann Prankl and Timothy Patten and Markus Vincze
V4R ACIN, TU Wien, Austria

- ***Directly reconstructing*** on ***meshes*** and ***textures*** from RGB-D input.
- ***Decoupling*** of ***geometry and color resolution*** by texturing scheme.
- ***Level of Detail*** (***LoD***) system enables capture of big scenes without wasting GPU memory.
- ***Efficient meshing*** scheme for extending existing reconstruction by harnessing ***pixel-neighborhood***.

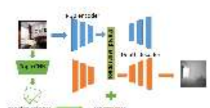

LoD system in action: Low-res on the left and currently captured high-res on the right.

10:45–12:00 MoA1.3

GEN-SLAM: Generative Modeling for Monocular Simultaneous Localization and Mapping

Punarjay Chakravarty and Praveen Narayanan
Autonomous Vehicles, Ford Motor Company, USA.
Tom Roussel
PSI-VISICS, ESAT, KU Leuven, Belgium.

- Generative Model: Twin VAE conditioned on topological map location converts single image to depth. One can sample from learnt model that internalizes the connection between location and scene geometry
- Topo-CNN trained on images from environment converts RGB image to topological pose
- CVAE model with Topo-CNN is able to determine both location information and depth map from a single image
- Experiments show effectiveness of method in simulated and real environments


The GEN-SLAM architecture.

10:45–12:00 MoA1.4

RESLAM
A real-time robust edge-based SLAM system

Fabian Schenk and Friedrich Fraundorfer
ICG, Graz University of Technolgy, Austria

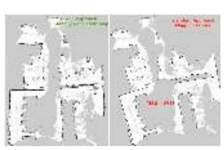
- Edge-based RGBD SLAM system with windowed optimization, loop closure and relocalization
- State-of-the-art performance
- Real-time on a CPU
- Code: https://github.com/fabianschenk/RESLAM

10:45–12:00 MoA1.5

Robust Pose-Graph SLAM using Absolute Orientation Sensing

Saurav Agarwal, Karthikeya Parunandi and Suman Chakravorty
Aerospace Engineering, Texas A&M University, USA

- First of its kind method to infuse absolute orientation from structural cues into 2D pose-graph SLAM.
- High localization accuracy in the front-end and a computationally efficient linearized least-squares solution in the back-end.
- Demonstrates with simulations and real-world experiments conducted using ceiling lighting pattern for absolute orientation estimation.
- Zero failure rate as compared to state-of-the-art that fail 40%-50% of the times.

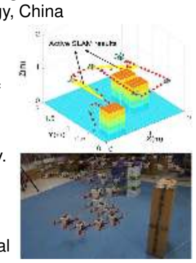

Our approach (left) vs standard SLAM with correlative scan matching in the front-end and G2O in the back-end (right)

10:45–12:00 MoA1.6

Online 3D active pose-graph SLAM based on key poses using graph topology and sub-maps

Yongbo Chen, Shoudong Huang, Robert Fitch, Liang Zhao
CAS, University of Technology Sydney, Australia
Huan Yu and Di Yang
Beijing Institute of Technology, China

- Hierarchical evaluation based on weighted node degree for all candidate paths, and weighted tree-connectivity for a selected set of paths.
- Application of sub-map planning and estimation, to improve computational efficiency.
- Application of real-time sampling-based planning and continuous-time optimization in active SLAM.
- Introduction of key poses to build a hierarchical framework.


On-line active SLAM

Manipulation Planning - 1.1.05

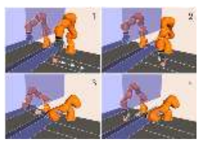
Chair
Co-Chair

10:45–12:00	MoA1.1

Modeling and Planning Manipulation in Dynamic Environments

P. S. Schmitt, F. Wirnshofer, K. M. Wurm, G. v. Wichert
Siemens AG Corporate Technology, Germany
W. Burgard
Autonomous Intelligent Systems, University of Freiburg, Germany

- We propose a feedback planner to reactively manipulate objects in dynamic environments
- This enables manipulation in time-variant environments with on-line collision-avoidance
- The proposed planner operates on a novel and highly general domain-model
- We validated our approach in extensive simulations and on a real dual-arm robot



Reactive manipulation in a time-variant environment

10:45–12:00	MoA1.2

Efficient Obstacle Rearrangement for Object Manipulation Tasks in Cluttered Environments

Jinhwi Lee and Jonghyeon Park
Hanyang University, South Korea
Younggil Cho, Changjoo Nam and Changhwan Kim
Korea Institute of Science and Technology, South Korea

- We consider **complex and cluttered environments** in everyday like such as a fridge or a shelf populated with **various objects arranged irregularly** like right figure.
- We present a **complete** and **polynomial-time algorithm** that decides obstacles to be removed to grasp the target **without collisions**.
- We describe **a modified version of VFH+** in order for the robot to recognize the environment to choose the obstacles to be relocated.

An example of the grasping task in clutter. The target object (green) is surrounded by obstacles (red) on the table.

10:45–12:00	MoA1.3

MoveIt! Task Constructor For Task-Level Motion Planning

Michael Görner* and Robert Haschke†
Helge Ritter†, Jianwei Zhang*
* TAMS, Hamburg University, Germany
† NeuroInformatics, Bielefeld University, Germany

- Modular & flexible system for planning multi-step motion sequences
- Robot agnostic, Integrated with various systems
- Intuitive introspection support
- Hierarchical containers for sequential and parallel composition of planning stages
- Open Source
- Primitive planning stages are provided

Visualization of a task involving picking a bottle, pouring, and placing

10:45–12:00	MoA1.4

Exploiting Environment Contacts of Serial Manipulators

Pouya Mohammadi, Daniel Kubus and Jochen J. Steil
The Institute for Robotics and Process Control,
Technische Universität Braunschweig, Germany

- The characteristics of secondary contacts when applying EE forces is explored
- Leaning its body on a surface, the robot can reduce its overall effort
- However, not every contact is good contact
- Rigorous mathematical analysis identifying advantageous and disadvantageous contacts is presented

advantageous and disadvantageous contacts

10:45–12:00	MoA1.5

Optimization-Based Human-in-the-Loop Manipulation Using Joint Space Polytopes

Philip Long, Tarik Kelestemur, Aykut Ozgun Onol and Taskin Padir
Department of Electrical and Computer Engineering,
Northeastern University, USA

- Trajectory optimization in cluttered environments for human-in-the-loop manipulation tasks.
- Constrained manipulability polytopes are used to represent the volume of free space.
- Polytopes embed the obstacle distance, the distance to joint limits and the distance to singular configurations
- Optimization maximizes this volume and displays a Cartesian space polytope to tele-operator during task

Resulting virtual fixtures

10:45–12:00	MoA1.6

Large-Scale Multi-Object Rearrangement

Eric Huang and Zhenzhong Jia and Matthew T. Mason
Robotics Institute, Carnegie Mellon University, USA

- Novel algorithm for rearranging objects using only **pushing actions**
- Iterated Local Search with an **epsilon-greedy** pushing policy
- Rearrange up to **100** objects with a packing factor of up to **40%** in simulation
- Validated in real-world problems with 32 objects

Sorting 32 blocks by color

Micro/Nano Robots I - 1.1.06

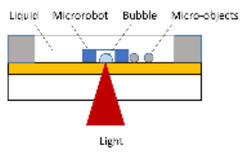
Chair
Co-Chair

10:45–12:00	MoA1.1

Manipulation Using Microrobot Driven by Optothermally Generated Surface Bubble

Liguo Dai,[1,2,3] Zhixing Ge,[1,2,3] Niandong Jiao,[1,2] Jialin Shi,[1,2] and Lianqing Liu[1,2]
1. State Key Laboratory of Robotics, Institute of Automation, Chinese Academy of Sciences, Shenyang 110016, China
2. Institutes for Robotics and Intelligent Manufacturing, Chinese Academy of Sciences, Shenyang 110016, China
3. University of Chinese Academy of Sciences, Beijing 100049, China

- Generation and control of the surface bubble with optothermal effect
- Manipulation of hydrogel microstructures by the bubble
- Manipulation by the hydrogel microrobots actuated by bubbles

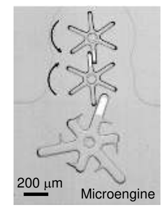


10:45–12:00	MoA1.2

Compound Micromachines Powered by Acoustic Streaming

Murat Kaynak, Furkan Ayhan and Mahmut Selman Sakar
Institute of Mechanical Engineering, Ecole Polytechnique Fédérale de Lausanne, Switzerland

- Compound hydrogel micromachines are fabricated directly inside microchannels using maskless digital photolithography
- Micromachines are actuated using an acoustic transducer at their resonant frequencies
- Vibration of sharp-edged structures generates steady streaming
- Microscale turbines, engines and transmission mechanisms are presented

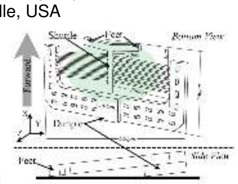


10:45–12:00	MoA1.3

ChevBot – An Untethered Microrobot Powered by Laser for Microfactory Applications

Ruoshi Zhang, Andriy Sherehiy, Zhong Yang, Danming Wei, Cindy K Harnett and Dan O. Popa
Electrical and Computer Engineering Department, University of Louisville, USA

- Chevbot is a novel laser-driven microrobot for actuation in dry-environments.
- A stick-and-slip opto-thermo-mechanical model was proposed to estimate the actuation velocity on a silicon substrate.
- Experiments with a 532nm green Nd:Yag laser confirm velocities of 46µm per second can be achieved.



ChevBot with dimensions 520 µm x 260 µm fabricated on 20 µm thick Silicon on Insulator wafer.

10:45–12:00	MoA1.4

Capillary Ionic Transistor and Precise Transport Control for Nano Manipulation

Yuqing Lin, Xiaoming Liu and Tatsuo Arai
Advance Innovation Center for Intelligent Robots and Systems, Beijing Institute of Technology, China

- None-Contact method for nano-scale object manipulation
- Single particle resolution with simultaneous measurement of size and velocity
- Versatile range of objects applicable: 50-500nm, from liposomes to nonorganic nanoparticles
- Extremely localized targeting with precise orientation control

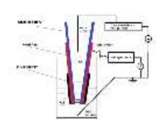


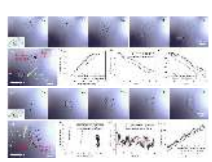
diagram of a capillary ionic transistor

10:45–12:00	MoA1.5

Self-Assembly Magnetic Chain Unit for Bulk Biomaterial Actuation

Haojian Lu, Yanting Liu, Yuanyuan Yang, Xiong Yang, Rong Tan and Yajing Shen
City University of Hong Kong, Hong Kong

- The tanglesome bulk fiber fabrication method is developed based on flow-focusing microcapillary system
- Magnetic chain unit self-assembly mechanism is introduced
- Cilia inspired dependent paramecium swimming mechanism is applied
- The self-assembly magnetic chain unit and actuation experiments are conducted for demonstration



Experimental results of the magnetic chain unit actuation

Humanoid Robots I - 1.1.07

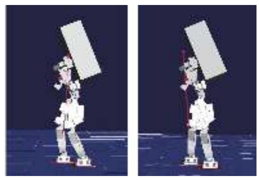
Chair
Co-Chair

10:45–12:00 MoA1.1

Resolved Viscoelasticity Control Considering Singularity for Knee-stretched Walking of a Humanoid

Kazuya Murotani, Ko Yamamoto, Tianyi Ko, Yoshihiko Nakamura
Department of Mechano-informatics, The University of Tokyo, Japan

- Extension of RVC method considering kinematic singularity is proposed
- Robust standing balance and **stable knee-stretched walking** is achieved in the simulation
- **Knee torque** is reduced up to **63 %** in the simulation
- **Experimental validation** is shown for both standing balance and knee-stretched walking



Left: Knee-bent,
Right: Knee-stretched

10:45–12:00 MoA1.2

Versatile Reactive Bipedal Locomotion Planning Through Hierarchical Optimization

Jiatao Ding[1,2], Chengxu Zhou[2,3], Zhao Guo[1], Xiaohui Xiao[1], Nikos Tsagarakis[2]
1, School of Power and Mechanical Engineering, Wuhan University, China
2, HHCM, Istituto Italiano di Tecnologia, Italy.
3, School of Mechanical Engineering, University of Leeds, UK

- Two Nonlinear Programming Problems (NLPs) are solved by SQP until meeting termination condition
- First-layer NLP deals with step time and step location optimization
- Second-layer nonlinear model predictive control deals with vertical height and angular momentum adaptation
- Hight-robust feasible walking patterns are obtained with low time cost

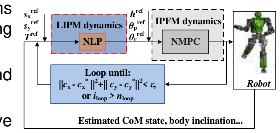


Figure 1, Overall framework

10:45–12:00 MoA1.3

Using Deep Reinforcement Learning to Learn High-Level Policies on the ATRIAS Biped

Tianyu Li, Hartmut Geyer, Christopher Atkeson
Carnegie Mellon University, USA
Akshara Rai
Facebook AI Research

- Learning controllers for bipedal robots is a challenging problem, especially because of simulation-hardware mismatch
- We present a structured neural network (NN) policy which can be trained in simulation and executed on hardware.
- Our experiments show that a structured NN policy leads to a more robust and interpretable controller, as compared to a general NN policy.

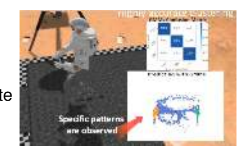
Our test platform:
The ATRIAS robot

10:45–12:00 MoA1.4

Unsupervised Gait Phase Estimation for Humanoid Robot Walking

Stylianos Piperakis, Stavros Timotheatos and Panos Trahanias
Foundation for Research and Technology – Hellas
and
Department of Computer Science, University of Crete, Greece

- Introduction of an unsupervised learning framework for gait phase estimation.
- The framework employs a PCA-based 2D latent space and GMMs to facilitate accurate prediction/classification of the gait phase.
- The Gait-phase Estimation Module (GEM), an open-source ROS/Python package is released (https://github.com/mrsp/gem).



GMMs predicting the gait phase in real-time.

10:45–12:00 MoA1.5

Stair Climbing Stabilization of the HRP-4 Humanoid Robot using Whole-Body Admittance Control

Stéphane Caron Abderrahmane Kheddar Olivier Tempier
CNRS–UM LIRMM, France

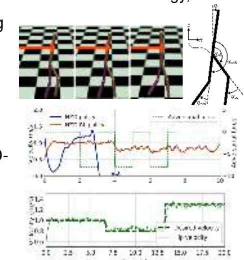
- Dynamic stair climbing experiments with the position-controlled HRP-4 humanoid robot
- Extend LIPM tracking by QP-based wrench distribution and whole-body admittance control
- Admittance control realized by both end-effector and CoM feedback strategies
- Demonstrated in real-world use case at Airbus factory in Saint-Nazaire, France

10:45–12:00 MoA1.6

Reinforcement Learning Meets Hybrid Zero Dynamics: A Case Study for RABBIT

[1]Guillermo A. Castillo, [1]Bowen Weng, [2]Ayonga Hereid, [3]Zheng Wang, and [1,4]Wei Zhang
[1]Department of ECE, Ohio State University, USA
[2]Department of ECE, University of Michigan, USA
[3]Department of Mechanical Engineering, University of Hong Kong, China
[4]SUSTech Inst. of Robotics, Southern Univ. of Science and Technology, China

- Novel model-free Reinforcement Learning (RL) approach that embeds the Hybrid Zero Dynamics (HZD) into the learning process.
- Better sample efficiency than most RL approaches for bipedal walking.
- Improved robustness over traditional HZD-based controller under disturbances.
- Among the few RL-based policies for bipedal robots that can track variable reference speed.



Localization I - 1.1.08

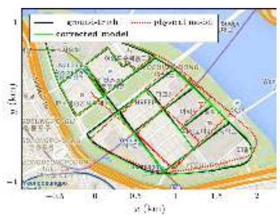
Chair
Co-Chair

10:45–12:00	MoA1.1

Learning Wheel Odometry and IMU Errors for Localization

Martin Brossard and Silvère Bonnabel
Centre for Robotics , MINES ParisTech, France

- Designing a robust odometry system is challenging when camera and LiDAR are unavailable
- We leverage advances in deep learning and variational inference to correct dynamical and observation models for state-space systems
- The methodology is applied for wheeled robot navigation
- Experimental results demonstrate that the corrected models is accurate than its original counterparts

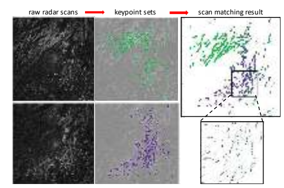


10:45–12:00	MoA1.2

Radar-only ego-motion estimation in difficult settings via graph matching

Sarah H. Cen
Electrical Engineering and Computer Science, MIT, USA
Paul Newman
Oxford Robotics Institute, University of Oxford, UK

- Demonstrates radar-only odometry that is highly robust to radar artifacts (e.g., speckle noise and false positives) and requires only one input parameter.
- Presents algorithms for keypoint extraction and data association (based on graph matching).
- Tests on diverse settings with scan matching accuracies of ~5.20 cm and ~0.0929 deg when comparing against GPS for ground truth.



Demonstration of our radar-only odometry pipeline on two radar scans (250x250 m) taken 0.25 s apart while driving over uneven terrain.

10:45–12:00	MoA1.3

Recursive Integrity Monitoring for Mobile Robot Localization Safety

Guillermo D. Arana, Osama A. Hafez, and Matthew Spenko
Mechanical and Aerospace Dept., Illinois Institute of Technology, USA
Mathieu Joerger
Aerospace and Mechanical Dept., University of Arizona, USA

- This paper presents a new method to quantify localization integrity for terrestrial robots
- Integrity is a common aviation metric recently brought to robotics
- An extended Kalman filter is used for localization and a sequence of innovations for fault detection
- The method directly monitors faults during a preceding horizon while being robust against prior faults

Alert limits in aerial and terrestrial robots

10:45–12:00	MoA1.4

Four-Wheeled Dead-Reckoning Model Calibration using RTS Smoothing

Anthony Welte, Philippe Xu and Philippe Bonnifait
Heudiasyc, CNRS, Université de Technologie de Compiègne, France

- A dead-reckoning model using wheel encoders, a gyro and the steering wheel angle is proposed
- Calibration of the parameters remains a critical issue for accurate odometric navigation
- We propose to calibrate the model using Rauch-Tung-Striebel smoothing on a recorded trajectory with low-cost GNSS receiver
- Thanks to experiments on public roads we show that the drift is in the order of 0.8% with production car sensors

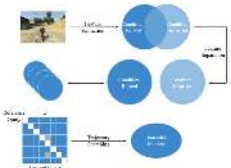
Trajectory driven during the experiments

10:45–12:00	MoA1.5

A Multi-Domain Feature Learning Method for Visual Place Recognition

Peng Yin, Lingyun Xu, Xueqian Li, Chen Yin, Yingli Li, Rangaprasad Arun Srivatsan, Lu Li, Jianming Ji, Yuqing He

- We propose the use of CapsuleNet-based feature extraction module, and show its robustness in the conditional feature learning for the visual place recognition task.
- We propose a feature separation method for the visual place recognition task, where features are indirectly separated based on the relationship between condition-related and condition-invariant features in an information-theoretic view.



(a) The framework of Multi-domain feature learning method.

10:45–12:00	MoA1.6

Event-based, Direct Camera Tracking from a Photometric 3D Map using Nonlinear Optimization

S. Bryner, G. Gallego, H. Rebecq, D. Scaramuzza
Dept. of Informatics, University of Zurich,
Dept. of Neuroinformatics, ETH and University of Zurich, Switzerland

- **6-DOF tracking** using an **event camera**
- **Maximum likelihood** estimation of the camera pose that best explains the events via a **generative event model**.
- **Robust tracking** that fully exploits intensity gradients and also estimates velocity.
- **Datasets released**: events, ground truth poses, images and 3D scene maps.

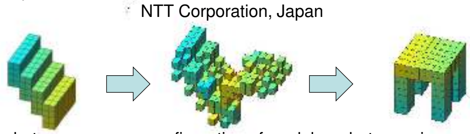
Cellular and Modular Robots - 1.1.09

Chair
Co-Chair

10:45–12:00	MoA1.1

Linear Heterogeneous Reconfiguration of Cubic Modular Robots via Simultaneous Tunneling and Permutation

Hiroshi Kawano
Department NameNTT Communication Science Laboratories,
NTT Corporation, Japan



- Previous heterogeneous reconfiguration of modular robots requires multiple separate processes for transformation and permutation and additional intermediate configurations for permutation. As a result, it is much more time- and space-consuming than homogeneous reconfiguration is.
- To save the operation time cost of reconfiguration, the proposed reconfiguration algorithm carries out tunneling-based transformation in which the permutation process is incorporated simultaneously.
- The reconfiguration by the proposed algorithm is carried out inside the space provided by the start and goal configurations.

10:45–12:00	MoA1.2

Autonomous Sheet Pile Driving Robots for Soil Stabilization

Nathan Melenbrink[1,2] and Justin Werfel[1]
1. Wyss Institute, Harvard University, USA
2. Institute for Computational Design, University of Stuttgart, Germany

- We present Romu, an autonomous robot capable of building continuous linear structures for soil stabilization.
- Romu uses a vibratory hammer to drive interlocking sheet piles into soil.
- We characterize hardware parameters for this essential construction task.
- We present simulations in which small swarms of robots build with sheet piles and quantify how well they mitigate hydraulic erosion.

Romu operating in a natural environment

10:45–12:00	MoA1.3

ModQuad-Vi: A Vision-Based Self-Assembling Modular Quadrotor

Guanrui Li, Bruno Gabrich, David Saldana, Vijay Kumar and Mark Yim
GRASP Lab, University of Pennsylvania, USA
Jnaneshwar Das
SESE, Arizona State University, USA

- ModQuad-Vi, a flying modular robot that is aimed to operate in outdoor environments.
- We propose a quadrotor platform with onboard computation and visual perception.
- Our vision-based control method is able to accurately align modules for docking actions.

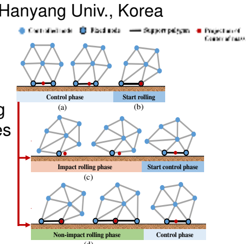
ModQuad-Vi on a vision-based docking action

10:45–12:00	MoA1.4

Optimization-based Non-Impact Rolling Locomotion of a Variable Geometry Truss

Sumin Park[1], Eugene Park[1], Mark Yim[2], Jongwon Kim[1], TaeWon Seo[3]
[1]School of Mechanical and Aerospace Engineering, Seoul Nat'l Univ., Korea
[2]School of Mechanical Engineering and Applied Mechanics, UPenn, USA
[3]School of Mechanical Engineering, Hanyang Univ., Korea

- Optimization-based rolling locomotion is simulated for variable geometry truss
- Non-impact motion is generated by dividing the locomotion by control and rolling phases
- Path tracking performance is enhanced by suggested locomotion algorithm
- Constraints are analyzed during the locomotion, and the performance enhancement is remaining future work



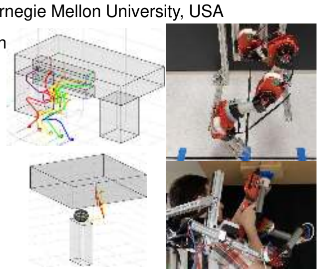
Locomotion of variable geometry truss

10:45–12:00	MoA1.5

Task-specific Manipulator Design and Trajectory Synthesis

Julian Whitman
Department of Mechanical Engineering, Carnegie Mellon University, USA
Howie Choset
The Robotics Institute, Carnegie Mellon University, USA

- Rapid prototyping and customization are useful for reconfigurable robots.
- We treat design variables as part of inverse kinematics, to jointly optimize manipulator design and trajectory.
- Then, we reduce the number of joints while maintaining ability to reach workspace task poses.
- With these tools, we iteratively optimize and simplify task-specialized manipulator designs.



Optimized design (left) and realization (right) of two customized manipulators

Medical Robotics I - 1.1.10

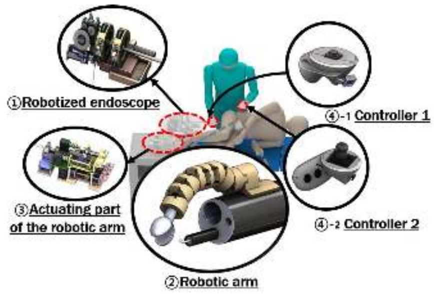
Chair

Co-Chair

10:45–12:00	MoA1.1

Robotic Endoscopy system (easyEndo) with a Robotic Arm Mountable on a Conventional Endoscope

Dong-Ho Lee, Minho Hwang, and Dong-Soo Kwon
KAIST(Korea Advanced Institute of Science and Technology), Korea



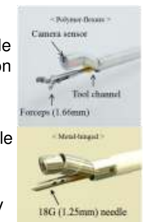
[System overview]

10:45–12:00	MoA1.2

Design and Fabrication of Transformable Head Structures for Endoscopic Catheters

Seong-il Kwon, Sung Hwa Choi, Keri Kim, Kyung Su Park, Sungchul Kang and Chunwoo Kim
Korea Institute of Science and Technology, Republic of Korea
Sara Van Kalker and Seok Chang Ryu
Mechanical Engineering, Texas A&M, U.S

- Transformable catheter head structure for endoscopic catheter allowing the simultaneous use of a camera module and a large tool channel introduced through a small incision
- Two types of head structure were introduced (Polymer flexure and Metal Hinge)
- Since directly fabricated on a polymer, it provides affordable and more compliant option to deliver a camera module
- The metal tube is more robust so that the opening window remains circular, therefore it allows larger size tool delivery



10:45–12:00	MoA1.3

A Rolling-Tip Flexible Instrument for Minimally Invasive Surgery

Andreas Schmitz, Shen Treratanakulchai, Pierre Berthet-Rayne and Guang-Zhong Yang Fellow IEEE
The Hamlyn Centre for Robotic Surgery,
Imperial College London, London, United Kingdom

- A snake-like robot that can perform a stable in-place rolling motion.
- Diameter of 4mm, 13 tendons and 6 degrees of freedom.
- The robot can bend and roll to high angles, and strongly improves the dexterity
- The rolling-tip gripper can rotate about 165° and is capable of applying forces up to 6.5N

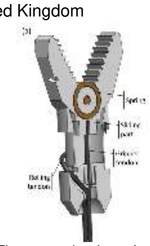


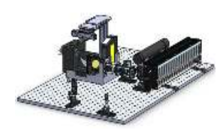
Figure caption is optional, use Arial 18pt

10:45–12:00	MoA1.4

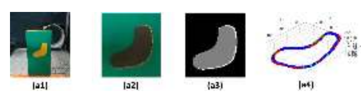
A Novel Laser Scalpel System for Computer-assisted Laser Surgery

Guangshen Ma*, Weston Ross*, Ian Hill, Narendran Narasimhan and Patrick Codd
Department of Mechanical Engineering and Material Scienc / Department of Neurosurgery
Duke University, USA

- A laser therapy platform integrates an RGB-D camera, 3D triangulation sensor, CO_2 laser
- 3D calibration between RGB-D camera and 3D triangulation sensor for human-in-the-loop guidance.
- 60 experimental results with < 2.0mm maximum positional error



Novel Laser Therapy Device



Computer-guidance improves accuracy of laser therapy for abnormally shaped regions.

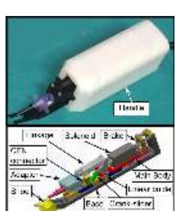
BRAIN TOOL LABORATORY DUKE UNIVERSITY
sites.duke.edu/braintool/

10:45–12:00	MoA1.5

A HAND-HELD ROBOT FOR PRECISE AND SAFE PIVC

Zhuoqi Cheng[1], Brian L. Davies[1,2], Darwin G. Caldwell[1] and Leonardo S. Mattos[1]
[1]Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy
[2]Mechanical Engineering Department, Imperial College London, U.K.

- CathBot: a hand-held robot for challenging Peripheral IntraVenous Catheterization (PIVC).
- Needle tip sensor for fast and accurate venipuncture detection.
- A cooperative mechanism for automating the cannula advancement and needle retraction.
- CathBot provides great improvement in PIVC success rate: from 12% to 86%.



CathBot

10:45–12:00	MoA1.6

Compensation of Environmental Influences on Sensorized-Forceps for Practical Surgical Tasks

Dong-Yeop Seok, Yong Bum Kim, Uikyum Kim, Seung Yeon Lee, and Hyouk Ryeol Choi*, Fellow, IEEE
Robotics Innovatory, Sungkyunkwan University, South Korea

- In robotic surgery, environmental influences are obstacle to force sensing
- Solutions for cutting off the environmental influences (humidity, temperature, pressure)
- Humidity compensation algorithm with embedded humidity sensing function
- AC shield and anodizing process is applied
- Ex vivo electro-cautery task were conducted to verify the solutions

Ex vivo electro-cautery experiment with abdominal cavity model

Telerobotics & Teleoperation I - 1.1.11

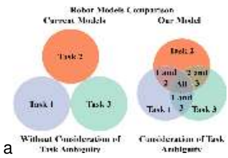
Chair
Co-Chair

10:45–12:00	MoA1.1

Intent-Uncertainty-Aware Grasp Planning for Robust Robot Assistance in Telemanipulation

Michael Bowman and Xiaoli Zhang
Mechanical Engineering, Colorado School of Mines, USA
Songpo Li
Mechanical Engineering and Material Science, Duke University, USA

- Modeling approach for a multi-task grasp model through common poses and task ambiguity
- Developed a planner aware of and incorporates ambiguous/uncertain human intent inference
- Ambiguous principle intent transformed to a more descriptive, inclusive labeling for better interpretation



10:45–12:00	MoA1.2

Vision-based Teleoperation of Shadow Dexterous Hand using End-to-End Deep Neural Network

Shuang Li[1†], Xiaojian Ma[2†], Hongzhuo Liang[1], Michael Görner[1], Philipp Ruppel[1], Bin Fang[2*], Fuchun Sun[2], Jianwei Zhang[1]
[1]Department of Informatics, Universität Hamburg, Germany
[2]Departmentof Computer Science and Technology, Tsinghua University, China

- We propose TeachNet, which directly maps the poses of human hand to a dexterous hand.
- The special structure of TeachNet is combined with a consistency loss function.
- A synchronized human-robot hand dataset with 400K depth images is generated.

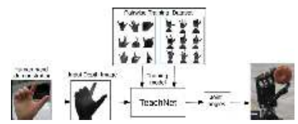


Fig1: The vision-based teleoperation architecture

10:45–12:00	MoA1.3

Energy-Shared Two-Layer Approach for Multi-Master-Multi-Slave Bilateral Teleoperation

Marco Minelli, Federica Ferraguti and Cristian Secchi
University of Modena and Reggio Emilia
Nicola Piccinelli and Riccardo Muradore
University of Verona

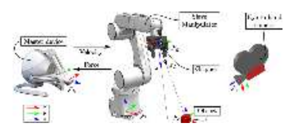
- Introduction to teleoperation systems and to the stability problem
- Passivity as a method to guarantee and preserve stability
- Standard two-layer architecture for single-master-single-slave bilateral teleoperation systems
- Energy-Shared two-layer architecture for multi-master-multi-slave bilateral teleoperation systems

10:45–12:00	MoA1.4

Passive Task-Prioritized Shared-Control Teleoperation with Haptic Guidance

M. Selvaggio, P. Robuffo Giordano, F. Ficuciello and B. Siciliano
D.I.E.T.I., University of Naples Federico II, Italy
CNRS, Univ Rennes, Inria, IRISA, Rennes, France

- A Task-prioritized shared-control teleoperation architecture for redundant slave robots is proposed
- A passivity analysis is performed and an energy-tanks passivity-based control method is developed
- Experiments mimicking a remote manipulation grasping task are performed



Experimental setup of the task-prioritized shared-control teleoperation

10:45–12:00	MoA1.5

Quasi-Direct Drive for Low-Cost Compliant Robotic Manipulation

David V. Gealy[1], Stephen McKinley[2], Brent Yi[3], Philipp Wu[1,3], Phillip R. Downey[1], Greg Balke[3], Allan Zhao[3], Menglong Guo[1], Rachel Thomasson[1], Anthony Sinclair[1], Peter Cuellar[1], Zoe McCarthy[3], and Pieter Abbeel[3]
[1]Mechanical Engineering, UC Berkeley, USA
[2]Industrial Engineering & Operations Research, UC Berkeley, USA
[3]Electrical Engineering & Computer Science, UC Berkeley, USA

- Robust force and impedance control through Quasi-Direct Drive actuation
- 7-DoF / 2 kg payload / .75m reach
- Target cost for researchers: < $5,000 per arm

Blue, a 7-DoF Quasi-Direct Drive robot arm

10:45–12:00	MoA1.6

Augmented Reality Predictive Displays to Help Mitigate the Effects of Delayed Telesurgery

Florian Richter, Yifei Zhang, Yuheng Zhi, Ryan K. Orosco and Michael C. Yip
University of California San Diego, USA

- Remote telesurgery is currently not feasible due to the latency
- This work proposes the first predictive display for teleoperated surgery utilizing Augmented Reality
- Implemented on da Vinci® Surgical System
- On average reduced time to complete task by 19%

Example of predicted AR rendering

Grasping I - 1.1.12

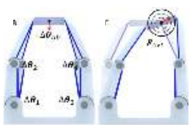
Chair
Co-Chair

10:45–12:00	MoA1.1

Stability Optimization of Two-Fingered Anthropomorphic Hands for Precision Grasping with a Single Actuator

Michael T. Leddy and Aaron M. Dollar
Department of Mechanical Engineering and Material Science, Yale University, USA

- Many underactuated prosthetic hand's precision grasps are not designed for post contact stability, variations in actuator force and object loading.
- Constrained optimization of key anthropomorphic parameters: transmission ratio, joint stiffness, link length ratio for a spectrum of hand sizes.
- Additional analysis to determine post contact object work and resistance to external wrenches.
- Optimization model is experimentally verified using an optimal solutions kinematic parameters.



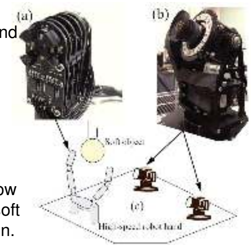
Analysis including post contact work and stability under external disturbances

10:45–12:00	MoA1.2

High-speed, Small-deformation Catching of Soft Objects based on Active Vision and Proximity Sensing

Keisuke Koyama, Kenichi Murakami, Makoto Shimojo and Masatoshi Ishikawa
Department of Creative Informatics, University of Tokyo,Japan

- We propose the combination of sensing and control modules for catching soft objects (i.e.,marshmallow and paper balloons) at a high speed with small deformation.
- (a)High-speed, high-precision proximity sensor, and (b) high-speed active-vision sensor.
- We demonstrate catching of a marshmallow and paper balloon that are exceptionally soft and difficult to catch with small deformation.



10:45–12:00	MoA1.3

Modeling Grasp Type Improves Learning-Based Grasp Planning

Qingkai Lu and Tucker Hermans
School of Computing and Robotics Center, University of Utah, USA

- Propose a probabilistic grasp planner that explicitly models grasp type
- Demonstrate the first supervised grasp learning approach that can explicitly plan both power and precision grasps for a given object
- Compare with a model that does not encode type and show that modeling grasp type improves the grasp success rates
- Show the benefit of learning a prior over grasp configurations to improve grasp inference

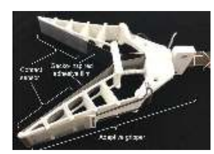
Precision (left) and power (right) grasps generated by our planner.

10:45–12:00	MoA1.4

Capacitive Sensing for a Gripper with Gecko-Inspired Adhesive

Jiro Hashizume
Research & Development Division, Hitachi America, Ltd., USA
Tae Myung Huh, Srinivasan A. Suresh and Mark R. Cutkosky
Center for Design Research, Stanford University, USA

- An adaptive soft exoskeleton gripper supports directional adhesive films to conform to objects.
- As the gripper grasps an object, the films pull the object toward the palm, increasing the contact area and adhesion.
- Capacitive sensors in the films monitor distributed contact areas and adhesion in real-time to predict grasp strength and impending failure.



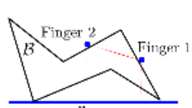
Adaptive compliant gripper with gecko-inspired adhesive films and capacitive contact sensors

10:45–12:00	MoA1.5

Toward Grasping Against the Environment: Locking Polygonal Objects Against a Wall Using Two-Finger Robot Hands

Hallel A. Bunis and Elon D. Rimon
Dept. of ME, Technion - Israel Institute of Technology

- We present an algorithm for caging and locking polygonal objects against a wall.
- The wall is treated as a third finger in an equivalent three-finger hand.
- The equivalent hand's fingers form similar trapezoidal cage formations around the object.
- We compute a graph in the hand's contact space to find the critical cage formation that allows the object to escape the hand.



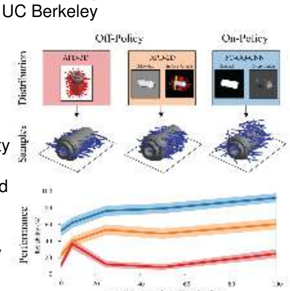
an object locked against a wall

10:45–12:00	MoA1.6

On-Policy Dataset Synthesis for Learning Robot Grasping Policies Using Fully Convolutional Deep Networks

Vishal Satish[1], Jeffrey Mahler[1,2], Ken Goldberg[1,2]
[1]Dept. of EECS , UC Berkeley
[2]Dept. of IEOR, UC Berkeley

- We propose to sample training actions from an on-policy training distribution in synthetic dataset generation.
- We use this to efficiently train a parallel 4-DOF Fully Convolutional Grasp Quality CNN (FC-GQ-CNN) that achieves 296 MPPH (Mean Picks Per Hour) compared to the 250 MPPH of iterative policies.
- We explore the effect of training distribution and action space granularity on FC-GQ-CNN performance.



Parallel Robots I - 1.1.13

Chair
Co-Chair

10:45–12:00	MoA1.1

A new Approach for an Adaptive Linear Quadratic Regulated Motion Cueing Algorithm for an 8 DoF Full Motion Driving Simulator

Tobias Miunske and Edwin Baumgartner
FKFS, University of Stuttgart, Germany
Christian Holzapfel and Hans-Christian Reuss
IVK, University of Stuttgart, Germany

- Full motion driving simulators represent real drives in a simulation environment
- The simulator used here consists of a hexapod and a simulator table
- The motion of the driving simulator is improved by a new adaptive algorithm
- An error model of the simulator table is used for a realistic motion simulation

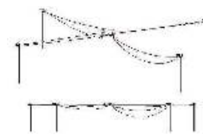
The Stuttgart full motion driving simulator

10:45–12:00	MoA1.2

Singularity of cable-driven parallel robot with sagging cables:preliminary investigation

Jean-Pierre Merlet
HEPHAISTOS project, INRIA, France

- Investigation of inverse kinematics (IK) and direct kinematics (DK) singularities for cable-driven parallel robots with sagging cable
- IK and DK share classical parallel robot singularities
- BUT both have additional singularities that correspond to intersection point of kinematic branches
- Numerically safe algorithm for finding these singularities is proposed



A non-parallel singularity,

10:45–12:00	MoA1.3

A defect identification approach of operations for the driving element of multi-duty PM

Shuai Fan, Shouwen Fan and Weibin Lan
School of Mechanical and Electrical Engineering, University of Electronic Science and Technology of China, People's Republic of China
Guangkui Song
School of Automation Engineering, University of Electronic Science and Technology of China, People's Republic of China

- The multi-duty parallel manipulators is investigated
- A demarcation diagram for distinguishing different duties is proposed
- A defect identification approach for driving element of multi-duty parallel manipulators is presented
- The 1PU+3UPS parallel manipulator is discussed

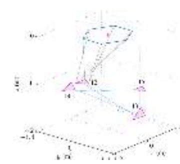
The Prototype of the 1PU+3UPS PM

10:45–12:00	MoA1.4

Dynamic Point-to-Point Trajectory Planning Beyond the Static Workspace for Six-DOF Cable-Suspended Parallel Robots

Xiaoling Jiang, Eric Barnett, and Clément Gosselin
Department of Mechanical Engineering, Université Laval, Canada

- A basis motion is developed and then applied to construct trajectory segments
- Each segment has zero translational and rotational velocity at its endpoints
- Spherical linear interpolation (SLERP) is used to produce the rotational component
- An experimental implementation is described, and a video shows the prototype following point-to-point trajectories



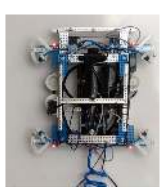
The six-DOF robot following a trajectory

10:45–12:00	MoA1.5

Active Damping of Parallel Robots Driven by Flexible Cables Using Cold-Gas Thrusters

Hugo Sellet, Imane Khayour, Loïc Cuvillon, Sylvain Durand and Jacques Gangloff
ICube Laboratory, University of Strasbourg, France

- Proof of concept : using embedded cold-gas thrusters to compensate for robot vibrations.
- Optimal thruster nozzle design.
- Two control laws : PWM and bang-bang.
- Visual feedback using a 500 Hz eye-to-hand camera.
- Stability analysis.
- Experimental validation on the PiSaRo3, a 3 dof planar suspended CDPR.



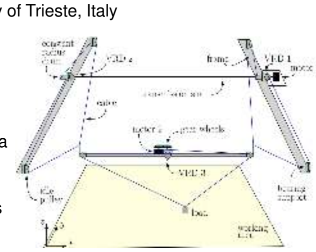
PiSaRo3 robot

10:45–12:00	MoA1.6

Cable-Based Robotic Crane (CBRC): Design and Implementation of Overhead Traveling Cranes Based on Variable Radius Drums

Lorenzo Scalera and Alessandro Gasparetto
University of Udine, Italy
Paolo Gallina and Stefano Seriani
University of Trieste, Italy

- Cable suspended robot based on Variable Radius Drums (VRD)
- In a VRD the spool radius varies along its profile
- The end-effector is moved along a planar working area using just 2 actuated DOF
- The experimental position error is less than 1% throughout the workspace



Cable-Based Robotic Crane

Exoskeletons I - 1.1.14

Chair
Co-Chair

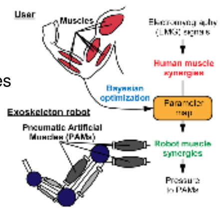
10:45–12:00	MoA1.1

Exploiting Human and Robot Muscle Synergies for Human-In-The-Loop Optimization of EMG-Based Assistive Strategies

Masashi Hamaya[1,2], Takamitsu Matsubara[1,3], Jun-ichiro Furukawa[1], Yuting Sun[2], Satoshi Yagi[2], Tatsuya Teramae[1], Tomoyuki Noda[1], Jun Morimoto[1]

[1]ATR, Japan, [2]Osaka Univ., Japan, [3]NAIST, Japan

- We propose a novel human-in-the-loop optimization approach for exoskeleton robot control.
- We exploit human and robot muscle synergies to reduce the number of control parameters.
- We adopt a Bayesian optimization method to acquire the parameters by the user's preferences.
- Our method successfully learned assistive strategies with a practical number of interactions.



Our proposed method

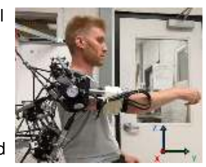
10:45–12:00	MoA1.2

A Low Inertia Parallel Actuated Shoulder Exoskeleton for Neuromuscular Property Characterization

Justin Hunt and Hyunglae Lee

School for Engineering of Matter, Transport, and Energy, Arizona State University (ASU),USA

- Introduction to a novel type of 4-bar spherical parallel manipulator (4B-SPM) design for wearable robotics
- Overview of a low inertia 4B-SPM shoulder exoskeleton prototype
- Evaluation of the prototype's performance through examination of position accuracy and step response.



10:45–12:00	MoA1.3

Effort Estimation in Robot-aided Training with a Neural Network

Ana C. De Oliveira, Kevin Warburton, James S. Sulzer, and Ashish D. Deshpande

Department of Mechanical Engineering, UT Austin, USA

- **Goal:** Estimate human active effort during robot-assisted movements
- **Challenge:** Isolation of volitional human torques from effects caused by residual dynamics and passive neuromuscular characteristics
- **Approach:** Estimate effects of the unknown factors with a neural network
- **Results:** Estimation closely matched effort measured through muscle activity and was sensitive to different effort levels

Harmony is a bimanual upper-body exoskeleton designed to actively control 7 DOF

10:45–12:00	MoA1.4

Characterizing Architectures of Soft Pneumatic Actuators for a Cable-Driven Shoulder Exoskeleton

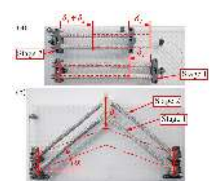
Nicholas Thompson and Ayush Sinha

Mechanical Science and Engineering, University of Illinois, USA

Girish Krishnan

Industrial and Enterprise Systems Engineering, University of Illinois, USA

- Soft pneumatic actuators can be tailored to an application using novel architectures
- Nested and pennate architectures of fiber-reinforced elastomeric enclosures (FREEs) compared for a cable-driven exoskeleton
- Tests include bench-top force-displacement testing and exoskeleton validation using a passive torso mannequin
- Nested actuators produced greater stroke in the application's required force range



(a) Nested linear and (b) pennate FREE architectures.

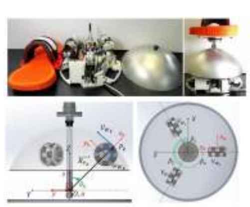
10:45–12:00	MoA1.5

Design and Implementation of a Two-DOF Robotic System with an Adjustable Force Limiting Mechanism for Ankle Rehabilitation

Vahid Mehrabi[1], S. Farokh Atashzar[2], H. Ali Talebi[3], Rajni V. Patel[1]

[1]University of Western Ontario, Canada; [2]Imperial College London, UK; [3]Amirkabir University of Technology, Iran,

- A novel light-weight back-drivable inherently-safe robotic mechanism for delivering ankle rehabilitation
- Friction-based safety feature
- Mechanical adjustment of the maximum amount of allowable transfer forces and torques to the patient's limb.
- Detail design, implementation procedure, control architecture and experimental validation



Software, Middleware and Programming Environments - 1.1.15

Chair
Co-Chair

10:45–12:00	MoA1.1

Rorg: Service Robot Software Management with Linux Containers

Shengye Wang, Xiao Liu, Jishen Zhao,
and Henrik I. Christensen
Contextual Robotics Institute, UC San Diego, United States

- The complexity of robot software components is challenging scaling up robot systems.
- Rorg is a Linux container-based scheme to manage, schedule, and monitor software components on robots.
- Rorg organizes the robot software into multiple containers and allows them to time-share computing resources.
- Rorg eases maintenance burden and reduces resource contention on service robots.

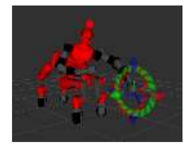
Rorg powers TritonBot, a receptionist and tour-guide robot.

10:45–12:00	MoA1.2

CartesI/O: A ROS Based Real-Time Capable Cartesian Control Framework

Arturo Laurenzi, Enrico Mingo Hoffman, Luca Muratore,
and Nikos Tsagarakis
HHCM Lab, Istituto Italiano di Tecnologia (IIT), Italy

- Novel framework for Cartesian Control of complex robotic platforms
- Main focus is *online* control, possibly under *real-time* constraints
- Complete ROS API allows for configuration and interaction with the controller via parameters, topics, services, actions, …
- Experiments on the wheeled-legged quadruped Centauro and humanoid Coman+



Online control of the Centauro robot via Rviz markers

10:45–12:00	MoA1.3

Synthesis of Real-Time Observers from Past-Time LTL and Timed Specification

Charles Lesire, Stéphanie Roussel,
David Doose, Christophe Grand
ONERA/DTIS, Université de Toulouse, France

- *Observers* allow to detect failures in order to trigger recovery mechanisms ; their accuracy relies on their real-time execution
- We propose *Past-Time LTL* patterns to design logical observers
- We define a *timed DSL* to design timed (compound) observers
- We develop a real-time implementation of such observers
- We benchmark this implementation versus more standard implementations and show that we can guarantee better performances

10:45–12:00	MoA1.4

Julia for robotics: simulation and real-time control in a high-level programming language

Twan Koolen and Robin Deits
CSAIL, MIT, USA

- Julia programming language promises both C-like performance and Python-like ease of use.
- Authors have developed Julia packages for dynamics, visualization, simulation, optimization, and control.
- Benchmarks show that RigidBodyDynamics.jl Julia dynamics package is competitive with RBDL.
- Balancing and walking controllers demonstrate feasibility for online control.

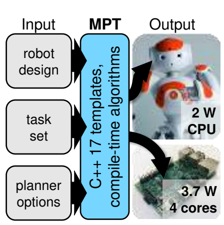
Atlas walking in Julia sim environment with pure-Julia controller (except QP solver)

10:45–12:00	MoA1.5

Motion Planning Templates:
A Motion Planning Framework for Robots with Low-power CPUs

Jeffrey Ichnowski and Ron Alterovitz
Dept. of Computer Science, University of North Carolina at Chapel Hill, USA

- C++ 17 template header-only library for fast, parallel, robot-specific, motion planners
- Compile-time algorithms generate run-time data structures and algorithms
- Outperforms motion planners based upon virtual methods and runtime polymorphism
- https://robotics.cs.unc.edu/mpt
  https://github.com/UNC-Robotics/mpt

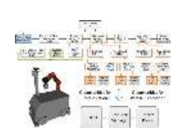


10:45–12:00	MoA1.6

Autonomous Parallelization of Resource-Aware Robotic Task Nodes

Sebastian Brunner and Andreas Dömel and Freek Stulp et al.
German Aerospace Center, Robotics and Mechatronics Center, Germany
Michael Beetz
University of Bremen, Institute for Artificial Intelligence, Germany

- Resource-Aware Task Nodes (RATNs): a powerful descriptive action model for robots
- Concurrent Dataflow Task Networks (CDTNs): robotic plans consisting of RATNs
- CDTNs allow for autonomous parallelization of actions and pre-calculation of intermediate task results
- Execution speedup of more than 25 % in simulated mobile manipulation scenarios



Conversion of a HSM to a Concurrent Dataflow Task Network

Novel Applications I - 1.1.16

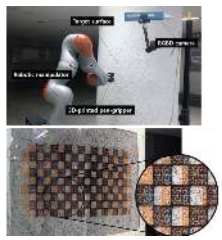
Chair
Co-Chair

10:45–12:00	MoA1.1

Distortion-free Robotic Surface-drawing using Conformal Mapping

Daeun Song and Young J. Kim
Computer Science and Engineering, Ewha Womans University, Republic of Korea

- Our system generates visually-pleasing, robotic pen drawings on general surfaces with minimal distortion.
- We use an idea of conformal mapping to preserve both angles and shapes of original 2D drawing when mapping it on to the target 3D surface.
- An impedance-control technique counteracts the potential uncertainties caused by the sensor noises as well as the numerical noises.



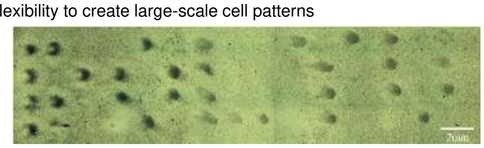
Robot Drawing Setup and Result

10:45–12:00	MoA1.2

Automated Cell Patterning System with a Microchip using Dielectrophoresis

Kaicheng Huang, Henry K. Chu, Bo Lu, Jiewen Lai and Li Cheng
Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hong Kong

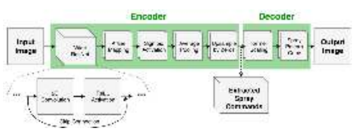
- A cell patterning system consisting of a height-adjustable microchip and a movable substrate was developed
- Negative dielectrophoresis was employed for cell patterning
- Tests were conducted to examine the effect of different experimental parameters
- This system provides a simple and non-contact method with high flexibility to create large-scale cell patterns



10:45–12:00	MoA1.3

Mobile Robotic Painting of Texture

Majed El Helou, EPFL, Switzerland
Stephan Mandt, UCI, United States of America
Andreas Krause, ETHZ, Switzerland
Paul Beardsley, Disney Research, Switzerland



- We aim to infer robot spray-painting commands to automatically recreate a desired target texture.
- A convolutional differentiable spray-painting simulator is created to enable end-to-end painting training in an autoencoder fashion.
- Inferring spraying commands, with controllable accuracy-efficiency tradeoffs, requires a simple pass through the encoder.

10:45–12:00	MoA1.4

Detecting Invasive Insects with Unmanned Aerial Vehicles

Brian Stumph, Marquette University
Miguel Hernandez Virto, Marquette University
Henry Medeiros, Marquette University
Amy Tabb, USDA-ARS-AFRS
Kevin Rice, United States Department of Agriculture Agricultural Research Se
Tracey Leskey, United States Department of Agriculture Agricultural Research Se

10:45–12:00	MoA1.5

Acausal Approach to Motion Cueing

Aman Sharma, Mohamed Sadiq Ikbal and Matteo Zoppi
PMAR Robotics Lab, University of Genoa, Italy

- Developed discrete-time (DT) model of classical motion cueing algorithm (MCA)
- Developed acausal cueing algorithm (ACA) to process future motion data using linear filters
- ACA introduced anticipatory dynamics (expectation) to motion cues
- Expectation cues were found to have a positive effect in the field of simulation

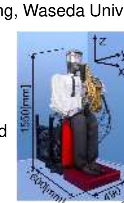
SP7 motion simulator

10:45–12:00	MoA1.6

Development of Performance System with Musical Dynamics Expression on Humanoid Saxophonist Robot

Jia-Yeu LIN, Mao KAWAI and Yuya NISHIO
Department of Integrative Bioscience and Biomedical Engineering, Waseda University, Japan.
Sarah COSENTINO, Atsuo TAKANISHI
Department of Modern Mechanical Engineering, Waseda University, Japan.

- Develop a control system allowing the saxophonist robot to perform with different sound pressure levels
- Construct a physical model describing the mouthpiece-reed-lip system during the sound production of a saxophone
- The model is double verified by simulation results and experiments on the robot-saxophone system



Body Parts	DoF
Lips	2
Oral Cavity	1
Tongue	1
Lung	2
Finger	19
Waist	1
Gaze	2
Eyebrow	1
Eyelid	2
Total	31

Waseda Anthropomorphic Saxophonist Robot Ver.5

Aerial Sytems: Perception I - 1.1.17

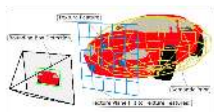
Chair
Co-Chair

10:45–12:00 MoA1.1

Robust Object-based SLAM for High-speed Autonomous Navigation

Kyel Ok*[1], Katherine Liu*[1,2], Kris Frey[2], Jonathan P. How[2], and Nicholas Roy[1,2]
[1]Computer Science and Artificial Intelligence Laboratory, MIT, USA
[2]Department of Aeronautics and Astronautics, MIT, USA

- Use a camera to build a map with semantic labels and geometric information
- Estimate objects as ellipsoids using bounding box detections, image texture, and semantic shape knowledge
- Overcome the observability problem in ellipsoid-based SLAM under common forward-translating vehicle motions

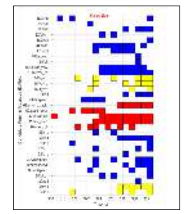


10:45–12:00 MoA1.2

A Fault Diagnosis Framework for MAVLink-Enabled UAVs Using Structural Analysis

Georgios Zogopoulos-Papaliakos, Michalis Logothetis and Kostas J. Kyriakopoulos
Department of Mechanical Engineering, NTU Athens, Greece

- MAVLink is the most popular UAV telemetry protocol, yet hasn't been exploited for diagnostic purposes.
- A Fault Diagnosis framework for UAVs is presented, applicable to general classes of airframes.
- Structural Analysis is employed to automatically generate residual signals, based on a generic UAV model and the available MAVLink telemetry.
- Case-study on an actual UAV crash provided



Diagnostic Method Output

10:45–12:00 MoA1.3

Real-Time Minimum Snap Trajectory Generation for Quadcopters: Algorithm Speed-up Through Machine Learning

Marcelino Almeida, Rahul Moghe and Maruthi Akella
Department of Aerospace Engineering and Engineering Mechanics,
University of Texas at Austin, USA

- We speed up the process of generating optimal trajectory for quadcopters. The main bottleneck on this process concerns of finding the optimal time to traverse waypoints.
- We use a dataset of over thirty thousand minimum snap trajectories for training a neural network for learning optimal time allocation solutions.
- Based on special properties of the minimum snap problem, our method presents how the input data should be pre-processed to be used as inputs to the neural network.
- The use of a neural network speeds up the process by two orders of magnitude at the cost of slightly sub-optimal solutions.

10:45–12:00 MoA1.4

Beauty and the Beast: Optimal Methods Meet Learning for Drone Racing

Elia Kaufmann*, Mathias Gehrig*, Philipp Foehn*, Rene Ranftl**, Alexey Dosovitskiy**, Vladlen Koltun**, Davide Scaramuzza*
*University of Zurich, Switzerland
**Intel Labs, Germany

- **DNN** predicts relative gate pose and measurement covariance
- **Kalman Filter** fuses measurement and prior map via covariance over time
- **MPC** generates **feasible** predictions and commands simultaneously
- Allows for **reactive** and **stable** control of dynamic systems with high-level **DNN**

10:45–12:00 MoA1.5

Detection & Reconstruction of Wires Using Cameras for Aircraft Safety Systems

Adam Stambler, Gary Sherwin, Patrick Rowe
Near Earth Autonomy, USA

- New technique to detect and reconstruct the location of wire hazards from a forward looking camera
- Wires detections at ranges of over 1km make the technique relevant to future aircraft safety systems.
- A new public dataset of over 40 approaches to wire hazards at 5 different locations

High tension power line detected (pink) at a range of over 750m in a helicopter's forward looking camera.

10:45–12:00 MoA1.6

Pose and Posture Estimation of Aerial Skeleton Systems for Outdoor Flying

Sangyul Park, Yonghan Lee, Jinuk Heo and Dongjun Lee
Department of Mechanical & Aerospace Engineering,
Seoul National University, Republic of Korea

- **Aerial skeleton system**: articulated aerial robot actuated by thrust of distributed rotors
- Propose novel state estimation algorithm for **IMU/GNSS**-based outdoor flight of aerial skeleton system
- **Constrained KF** based estimation combining individual SE(3)-pose estimation at each link and **kinematic constraint** of the entire system
- **Semi-distributed** version of the algorithm to endow with **scalability** when the number of link extremely increases

Outdoor flight experiment of 3-link aerial skeleton system

Aerial Systems: Application I - 1.1.18

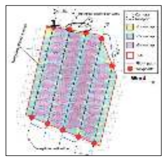
Chair
Co-Chair

10:45–12:00 MoA1.1

Flight Testing Boustrophedon Coverage Path Planning for Fixed Wing UAVs in Wind

Matthew Coombes, Wen-Hua Chen, Cunjia Liu
Aeronautical and Automotive Engineering, Loughborough University , UK

- Fixed wing UAV agricultural survey coverage path planning
- Flight test validation of flight time in wind model used in authors previous coverage path planner
- Multiple surveys (different angles and wind conditions) conducted, real flight times compared to times calculated from model
- Validation of steady uniform wind assumption using S1000 with ultrasonic wind sensor


Boustrophedon path with total image coverage of field with overlap

10:45–12:00 MoA1.2

Obstacle-aware Adaptive Informative Path Planning for UAV-based Target Search

Ajith Anil Meera, Marija Popovic
Alexander Millane and Roland Siegwart
Department of Mechanical Engineering, ETH Zurich, Switzerland

Autonomous target search algorithm considering:
- view occlusion,
- area coverage,
- information gain,
- obstacle avoidance,
- sensor uncertainty and
- height dependent sensor performance.

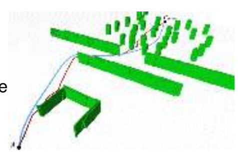

UAV searching for human targets.

10:45–12:00 MoA1.3

Real-Time Planning with Multi-Fidelity Models for Agile Flights in Unknown Environments

Jesus Tordesillas, Brett Lopez and Jonathan P How
Aerospace Controls Laboratory, MIT, USA
John Carter and John Ware
Robust Robotics Group, MIT, USA

- Address the negative interaction between the local and the global planners.
- Use multi-fidelity models to efficiently estimate the real cost-to-go of a trajectory.
- Simulation and hardware experiments, showing agile flights in unknown environments, with replanning times ≈5-40 ms.


In blue the optimal trajectory (world known) and in red our method (world unknown)

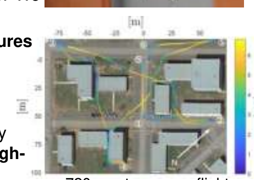
10:45–12:00 MoA1.4

Efficient Trajectory Planning for High Speed Flight in Unknown Environments

Markus Ryll[1], John Ware[1], John Carter[1] and Nick Roy[1]
[1]CSAIL, Massachusetts Institute of Technology, Cambridge, USA

We present a **receding-horizon planning architecture** for UAVs in unknown, urban environments that enables **fast replanning** necessary for reactive obstacle avoidance. We achieve this by:

- Efficient **spatial partitioning data structures** to reason about geometry in real-time
- **Dynamic velocity planning** according to obstacle density
- Receding horizon, minimum-jerk trajectory generation to **enable smooth, robust, high-speed flight**

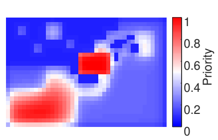

720m autonomous flight with peak velocities of 7m/s

10:45–12:00 MoA1.5

Priority Maps for Surveillance and Intervention of Wildfires and other Spreading Processes

Vera Somers and Ian Manchester
Australian Centre for Field Robotics, University of Sydney, Australia

- Creating priority maps for dynamic spreading processes for both surveillance and intervention purposes
- The framework utilizes the properties of positive systems to provide scalable algorithms
- Results of fictional landscapes convey the proposed method provides quick, good results
- The obtained priority maps can be used as an input for UAV path planning problems

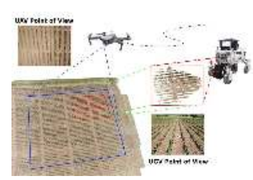


10:45–12:00 MoA1.6

AgriColMap: Aerial-Ground Collaborative 3D Mapping for Precision Farming

Ciro Potena[1], Raghav Khanna[2], Juan Nieto[2], Roland Siegwart[2], Daniele Nardi[1], and Alberto Pretto[1]
[1]Department of Computer, Control, and Management Engineering "Antonio Ruberti", Sapienza University of Rome, Italy
[2]Autonomous Systems Lab, ETH Zurich, Switzerland

- Novel **map registration framework** specifically designed for **heterogeneous robots** in an agricultural environment
- We cast the data association problem as a **multimodal, large displacement dense optical flow estimation**
- We evaluate our system using real world data for 3 fields with different crop species
- Datasets and open-source implementation released with this paper


AgriColMap enables to accurately merge maps independently built from UAVs and UGVs

Learning from Demonstration I - 1.1.19

Chair
Co-Chair

10:45–12:00	MoA1.1

A Practical Approach to Insertion with Variable Socket Position Using Deep Reinforcement Learning

Mel Vecerik, Oleg Sushkov, David Barker,
Thomas Rothörl, Todd Hester, Jon Scholz
DeepMind, UK

RL from Demonstration algorithm, using vision and force-feedback.

Learns robust controllers for difficult insertion tasks in under 20 minutes.

Does not require modeling, simulation, object trackers, reward shaping, or manual tuning of control parameters.

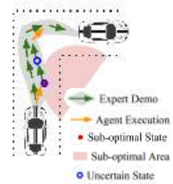
Deformable-clip insertion with variable socket pose

10:45–12:00	MoA1.2

Uncertainty-Aware Active Data Aggregation for Deep Imitation Learning

Yuchen Cui, Scott Niekum
Computer Science, University of Texas at Austin, USA
David Isele, Kikuo Fujimura
Honda Research Institute, USA

- UAIL is a data aggregation algorithm that aims to collect training data at uncertain points of a given deep model;
- During on-line data collection, UAIL utilizes predictive uncertainty to anticipate mistakes and switch control to a human expert;
- Given similar amount of human effort during data collection, the deep model trained with UAIL data outperforms alternative methods in our simulated driving tasks.

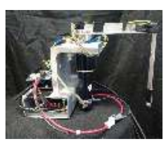


10:45–12:00	MoA1.3

Uncertainty Aware Learning from Demonstrations in Multiple Contexts using Bayesian Neural Networks

Sanjay Thakur, Juan Gamboa, David Meger, Doina Precup
Computer Science, McGill University, Canada
Herke Van Hoof
Informatics Institute, University of Amsterdam, Netherlands

- Neural network controllers can silently and unexpectedly fail when conditions change.
- We propose using Bayesian neural nets to quantify predictive uncertainty in the Learning from Demonstration setting.
- We show that predictive uncertainty can flag when the controller will likely fail.
- Requesting data only when failure is likely can reduce the amount of demonstrations necessary to learn a good controller.



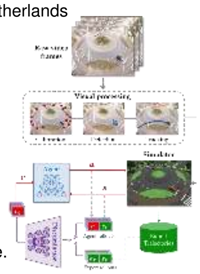
We demonstrate our method on a Furuta Pendulum.

10:45–12:00	MoA1.4

Learning from Demonstration in the Wild

Feryal Behbahani, Kyriacos Shiarlis, Xi Chen,
Vitaly Kurin, Sudhanshu Kasewa, Ciprian
Stirbu, João Gomes, Supratik Paul, Frans A.
Oliehoek, João Messias and Shimon Whiteson
Latent Logic, England; University of Oxford, England;
Delft University of Technology, Netherlands

- We propose video to behaviour (ViBe), a new approach to learn models of behaviour from unlabelled raw video data of a traffic scene collected from a single, monocular, uncalibrated camera with ordinary resolution.
- ViBe calibrates the camera, detects relevant objects, tracks them through time, and uses the resulting trajectories to perform LfD.
- We apply ViBe to raw videos of a traffic intersection and show that it can learn purely from videos, without additional expert knowledge.

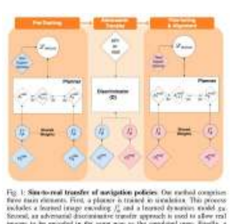


10:45–12:00	MoA1.5

A Data-Efficient Framework for Training and Sim-to-Real Transfer of Navigation Policies

Homanga Bharadhwaj*
Department of Computer Science, IIT Kanpur, India
Zihan Wang*
Engineering Division, University of Toronto, Canada
Liam Paull and Yoshua Bengio
Mila, Universite de Montreal, Canada

- We incorporate adversarial domain adaptation for developing a gradient-based planner that transfers well from simulation to the real environment
- We train our model primarily in a simulation environment using imitation learning and through domain adaptation and little fine-tuning in the real setup, show that the model transfers well.



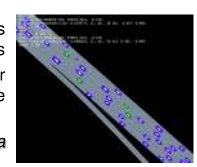
10:45–12:00	MoA1.6

Simulating Emergent Driving Properties Using Reward Augmented Imitation Learning

Raunak Bhattacharyya, Derek Phillips, Changliu Liu,
Jayesh Gupta, Katherine Driggs-Campbell and Mykel J. Kochenderfer
Stanford University, U.S.A

State of the art multi-agent imitation learning struggles to model emergent properties arising from interactions

- ***R**eward **A**ugmented **I**mitation **L**earning* allows for the learning agent to learn from domain knowledge as well as expert demonstrations
- Our method *captures unmodeled global phenomena* and emergent properties
- We demonstrate *improved imitation performance on real-world driving data* for local, global, and emergent driving properties



Snapshot of generated traffic scene from proposed model, capturing realistic, emergent driving phenomena in multi-agent settings

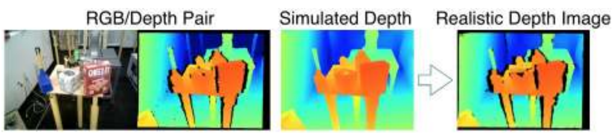
Deep Touch I - 1.1.20

Chair
Co-Chair

10:45–12:00	MoA1.1

A Supervised Approach to Predicting Noise in Depth Images

Chris Sweeney and Greg Izatt
EECS, MIT, US
Russ Tedrake
EECS, MIT, US



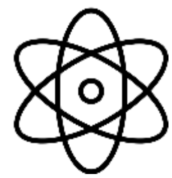
- Current depth simulations are too unrealistic to verify robotic tasks
- We use a CNN to learn and predict depth camera dropouts
- Our method closes the reality gap for practical perception tasks

10:45–12:00	MoA1.2

Quantum Computation in Robotic Science and Applications

Christina Petschnigg, Mathias Brandstötter*, Horst Pichler, Michael Hofbaur and Bernhard Dieber
Institute for Robotics and Mechatronics, JOANNEUM RESEARCH

- Position paper on the expected impact of quantum computing on the field of robotics
- Potential applications of quantum computing in key methodologies and components of robots are described
- Possible challenges related to the use of quantum computing in robotics are discussed
- Detail are given in artificial intelligence and machine learning, sensing and perception, kinematics as well as system diagnosis



10:45–12:00	MoA1.3

A Learning Framework for High Precision Industrial Assembly

Yongxiang Fan and Masayoshi Tomizuka
Mechanical Engineering, University of California, Berkeley, USA
Jieliang Luo
Media Arts & Technology, University of California, Santa Barbara, USA

- We propose a reinforcement learning (RL) framework called guided-DDPG for industrial assembly
- Guided-DDPG combines model-free RL (DDPG) and model-based RL (GPS).
- Guided-DDPG is more efficient than DDPG, and more reliable than GPS.
- The effectiveness is verified by both simulation and experiment.

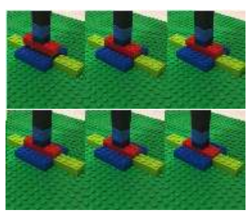
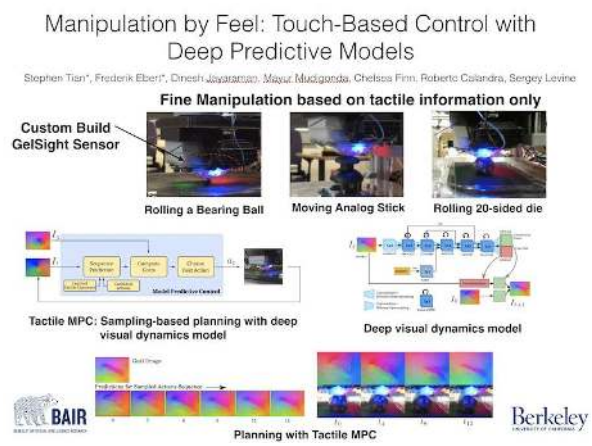


Figure: Guided-DDPG on Lego brick insertion.

10:45–12:00	MoA1.4

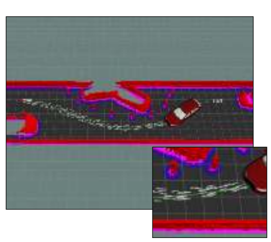


10:45–12:00	MoA1.5

Learning to Predict Ego-Vehicle Poses for Sampling-Based Nonholonomic Motion Planning

Holger Banzhaf, Paul Sanzenbacher, and Ulrich Baumann
Robert Bosch GmbH, Corporate Research, Germany
J. Marius Zöllner
FZI Research Center for Information Technology, Germany

- Prediction of future ego-vehicle poses given the current environment as well as the start and the goal state using a CNN
- Integration of those predictions into the sampling of Bidirectional RRT* to improve its efficiency in challenging automated driving scenarios
- Benchmark against uniform sampling and an A*-based heuristic

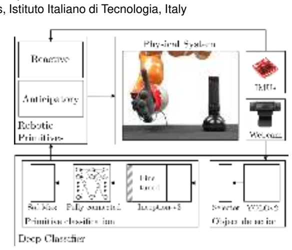


10:45–12:00	MoA1.6

Learning from humans how to grasp: a data-driven architecture for autonomous grasping with anthropomorphic soft hands

Cosimo Della Santina, Visar Arapi, Giuseppe Averta, Francesca Damiani, Gaia Fiore, Alessandro Settimi, and Matteo Bianchi
Centro E. Piaggio, University of Pisa, Italy
Davide Bacciu
Dipartimento di Informatica, University of Pisa, Italy
Manuel G. Catalano, Antonio Bicchi
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

- Soft hands come with clear advantages in terms of ease-to-use and robustness if compared with classic rigid hands, when operated by a human.
- However, their potential for autonomous grasping is still largely unexplored, due to the lack of suitable control strategies.
- We propose a human inspired multi-modal, multi-layer learning architecture that combines feedforward components with reactive sensor-triggered actions, able to exploit effectively the intelligence embodied in the soft hand to perform dexterous grasps.



Rehabilitation Robotics I - 1.1.21

Chair
Co-Chair

10:45–12:00	MoA1.1

3D Printed Soft Pneumatic Actuators with Intent Sensing for Hand Rehabilitative Exoskeletons

Benjamin W.K. Ang, Chen-Hua Yeow
Department of Biomedical Engineering, National University of Singapore, Singapore

- Soft pneumatic actuators are often limited to 1DoF bending and sensing.
- Adopting a dual chamber fold-based design allows for bidirectional bending and intent sensing for finger flexion-extension.
- Design, fabrication process of the actuators and the intent sensing mechanism are described.
- Characterization tests and evaluation of the actuator are also presented.

Bidirectional bending of fold-based design actuators with intent sensing

10:45–12:00	MoA1.2

On the Development of Adaptive, Tendon-Driven, Wearable Exo-Gloves for Grasping Capabilities Enhancement

Lucas Gerez, Junan Chen and Minas Liarokapis
Department of Mechanical Engineering, University of Auckland, New Zealand

- We propose two compact, affordable and lightweight assistive devices that provide grasping capabilities enhancement.
- The devices are experimentally tested through grasping tests, force exertion capability tests, and motion tracking.
- The body-powered device weighs 335 g, costs less than 100 USD to produce, and can exert more than 13 N.
- The EMG controlled motorized device weighs 562 g, costs less than 400 USD to produce and can exert more than 16 N.

Side view of the proposed exo-gloves: body-powered (top) and motorized (bottom).

10:45–12:00	MoA1.3

A Novel Skin-Stretch Haptic Device for Intuitive Control of Robotic Prostheses and Avatars

Nicoletta Colella[1], Matteo Bianchi[1,3], Giorgio Grioli[2], Antonio Bicchi[1,2,3] and Manuel G. Catalano[2]
[1]Research Center "E. Piaggio", Univ. of Pisa, Italy
[2]Soft Robotics for Human Cooperation and Rehabilitation Lab, IIT, Genoa, Italy
[3]Information Eng. Department, University of Pisa, 56122, Pisa, Italy

- A skin stretch-based wearable device to deliver proprioceptive information on artificial hand aperture
- Worn by a pilot of remote robotic avatars or integrated in a prosthetic socket
- Results suggest that the system could be a viable solution for proprioceptive feedback

10:45–12:00	MoA1.4

Gaze-based, Context-aware Robotic System for Assisted Reaching and Grasping

Ali Shafti, Pavel Orlov and A. Aldo Faisal
Department of Computing and Department of Bioengineering, Imperial College London, United Kingdom

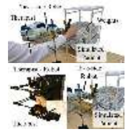
- Robotic solution for restoration of reaching and grasping capabilities
- Gaze and context-driven: Look at objects to activate complex sequences of action
- 3D gaze estimation method developed integrating eye-trackers with a depth camera
- Human action grammars used to implement task-level intelligence and automation

10:45–12:00	MoA1.5

Learning Patient-specific Intervention: Robotics- vs Telerobotics-mediated Hands-on Teaching

Jason Fong, Carlos Martinez and Mahdi Tavakoli
Electrical and Computer Engineering, University of Alberta, Canada

- The effectiveness of teaching a robot therapeutic behaviors through robotic and telerobotic interfaces is compared
- Robotics-mediated Kinesthetic Teaching (RMKT) may be more intuitive than its telerobotic equivalent, TMKT, providing better robotic reproductions of therapeutic behaviors
- A motion-following experiment shows that behaviors demonstrated in both modalities are able to be imitated accurately, but TMKT demonstrations have less repeatability



RMKT (top) and TMKT (bottom) setups for an example therapy task

10:45–12:00	MoA1.6

Development of a Force Sensing System to Measure the Ground Reaction Force of Rats with Complete SCI

Dollaporn Anopas, Eng Kiat Sei, and Wei Tech Ang
Mechanical Engineering, Nanyang Technological University, Singapore
Junquan Lin and Sing Yian Chew
Biomedical Engineering, Nanyang Technological University, Singapore
Seng Kwee Wee and Peh Er Tow
Tan Tock Seng Hospital, Singapore

- Developing force sensing system for measuring the ground reaction force of rats with severe SCI
- Testing with rehabilitated and non-rehabilitated spinalized rats with a full transection
- Rehabilitated rats were able to gradually exert more force as compared to non-rehabilitated rats.
- This system is feasible to evaluate the motor recovery of the hindlimbs in spinalized rats.

Experiment for force assessment of hindlimb

Medical Robotics II - 1.1.22

Chair
Co-Chair

10:45–12:00 MoA1.1

A Four-magnet System for 2D Wireless Open-Loop Control of Microrobots

Azaddien Zarrouk[a], Karim Belharet[b], Omar Tahri[a] and Antoine Ferreira[a]
[a] PRISME, INSA Centre Val de Loire, France
[b] PRISME, HEI campus Centre, France

- A novel permanent magnets based actuator capable of 2D wireless control the motion of microrobots,
- It creates local maxima of the magnetic fields magnitude at distance in a planar workspace,
- Trapping microrobots at distance makes their open-loop control possible in presence of reasonable perturbations,
- The workspace is reduced, the actuator displacement is simplified (No orientation is needed).

Four-magnet based actuator

10:45–12:00 MoA1.2

Nitinol Living Hinges for Millimeter-sized Robots and Medical Devices

Peter York and Robert Wood
John A. Paulson School of Engineering, Harvard University, USA

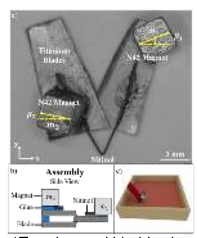
- Living hinges facilitate the creation of compact, large-range-of-motion transmissions.
- Manufacturing process is based on mechanical etching and laser micromachining.
- Can be properly sized using the processing parameters and stiffness model presented.
- Endoscopic wrist mechanism and laser beam steering device demonstrate the usefulness of these components.

10:45–12:00 MoA1.3

Tetherless Mobile Micro-Surgical Scissors Using Magnetic Actuation

Onaizah Onaizah and Eric Diller
Department of Mechanical and Industrial Engineering, University of Toronto, Canada

- Introducing a proof-of-concept prototype of the first completely wireless surgical scissors capable of dexterous motion .
- A 3D magnetic coil system is used to generate an external magnetic flux density of 20 mT and is used for cutting as well as orienting, moving and closing the scissors.
- The scissors can generate up to 75 mN of cutting force and are capable of cutting agar in a remote environment as a mobile microrobotic device.



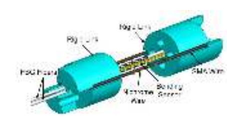
a)Top view and b) side view of the prototype scissors. c) 3D simulation of cutting.

10:45–12:00 MoA1.4

A Large-Deflection FBG Bending Sensor for SMA Bending Modules for Steerable Surgical Robots

Jun Sheng, Nancy J. Deaton, and Jaydev P. Desai,
Department of Biomedical Engineering, Georgia Institute of Technology, USA

- Developed a fiber Bragg grating (FBG) bending sensor for shape memory alloy (SMA) bending modules.
- By using an ultra-thin substrate and flexible adhesive, the sensor has low stiffness and can measure large curvatures.
- Due to orthogonal arrangement, the influence of temperature variation caused by SMA actuation can be compensated.



SMA Bending module integrated with the developed sensor

10:45–12:00 MoA1.5

Modular FBG Bending Sensor for Continuum Neurosurgical Robot

Nahian Rahman, Nancy Deaton, Jun Sheng, and Jaydev P. Desai
The Wallace H. Coulter Department of Biomedical Engineering, Georgia Institute of Technology, USA
Shing Shin Cheng
Mechanical and Automation Engineering, University of Hong Kong, China

- Bending sensor (1 mm diameter) comprised of a fiber Bragg grating (FBG) fiber, a Polydimethylsiloxane (PDMS) cylinder, and a superelastic spring
- The sensor does not require to be glued entirely with the robot-backbone and it adds insignificant rigidity (bending stiffness $\leq 3\times10^{-5}$ N/mm) to the robot
- The sensor is customizable, and it has been fabricated using 3D-printed molds

Bending sensor prototype (right)

10:45–12:00 MoA1.6

A Compact Dental Robotic System Using Soft Bracing Technique

Jing Li, Zhong Shen, Wen Yu Tian Xu and Zheng Wang*
Mechanical Engineering, the University of Hong Kong, China
Walter Yu Hang Lam and Edmond Ho Nang Pow
Discipline in Prosthodontics, Faculty of Dentistry, the University of Hong Kong, China
Richard Tai Chiu Hsung
Information Engineering, Guandong University of Technology, China
Kazuhiro Kosuge
Department of Robotics, Tohoku University, Japan

- A 6 DOF manipulator with optimized workspace for dental procedures.
- Compact structure realized by tendon-sheath mechanism.
- Bracing technique applied for increasing system stiffness.

Motion and Path Planning I - 1.1.23

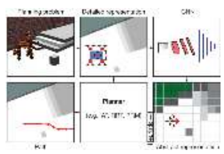
Chair
Co-Chair

10:45–12:00 MoA1.1

Towards Learning Abstract Representations for Locomotion Planning in High-dimensional State Spaces

Tobias Klamt and Sven Behnke
Autonomous Intelligent Systems, University of Bonn, Germany

- Generate an abstract representation for a high-dimensional planning problem
- Represent the cost function as a CNN to mitigate manual tuning efforts
- Use the abstract representation to generate an informed powerful heuristic
- Use heuristic to plan hybrid driving-stepping locomotion paths for large scenes in feasible times

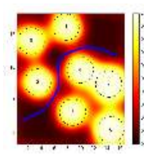

A traditional planner is supported by a heuristic based on a learned abstract representation

10:45–12:00 MoA1.2

Fast Stochastic Functional Path Planning in Occupancy Maps

Gilad Francis[1], Lionel Ott[1] and Fabio Ramos[1,2]
1. School of Computer Science, The University of Sydney, Australia
2. NVIDIA, USA

- Functional gradient path optimisation in continuous occupancy maps – instead of sampling-based methods (RRT, PRM, etc.)
- Utilises kernel approximation and stochastic gradient descent for a fast optimisation of an expressive and continuous path.
- Fixed computational complexity – instead of a cubic cost of a non-parametric representation.



10:45–12:00 MoA1.3

ework For Real-Time ıman Collision Avoidance

bert*, David Fridovich-Keil,
ar, Anca Dragan, Claire Tomlin
ıter Science, UC Berkeley, USA

- We enable fast human motion prediction by treating people independently, but
- We generate safe and real-time multi-robot trajectories by planning sequential
- We demonstrate our robust multi-human, multi-robot framework in hardware.

10:45–12:00 MoA1.4

Lazy Evaluation Of Goal Specifications Guided By Motion Planning

Juan David Hernández, Mark Moll, Lydia E. Kavraki
Computer Science, Rice University, USA

This work introduces a lazy grounding approach for dealing with multi-interpretation requests:

- Such requests are formulated as a motion planning problem, where interpretations are represented with goal regions.
- A new planner solves this start-to-goal-region problem.
- A reward-penalty strategy prioritizes promising goal regions.
- Experimental evaluation with simulation and real-world tests.

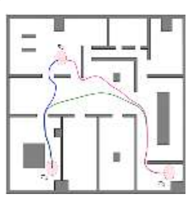

The manipulator arm of the Fetch Robot is instructed to "put a cup on the table," when multiple cups are available in the scene.

10:45–12:00 MoA1.5

Reconfigurable Motion Planning and Control in Obstacle Cluttered Environments under Timed Temporal Tasks

Christos K. Verginis and Dimos V. Dimarogonas
Decision and Control Systems, KTH, Sweden
Constantinos Vrohidis, Charalampos P. Bechlioulis, and Kostas J. Kyriakopoulos
Control Systems Laboratory, NTUA, Greece

- Timed temporal tasks over discretized obstacle environment subject to minimal control effort
- Formal verification and convex optimization techniques for timed plan derivation
- Employment of continuous control for navigation in prescribed time
- Iteration of plan derivation between transitions for control effort optimization


Execution of a time plan in 3 regions of interests

10:45–12:00 MoA1.6

Learning Navigation Behaviors End-to-End with AutoRL

Hao-Tien Lewis Chiang*, Aleksandra Faust*, Marek Fiser, Anthony Francis
Robotics at Google, Google AI, Mountain View, CA 94043, USA
*Authors contributed equally

- Learn end-to-end, point-to-point and path-following policies that avoid moving obstacles.
- AutoRL: evolutionary automation layer around deep Reinforcement Learning.
- Searches for best reward and neural network architecture that comples the task with large-scale hyper-parameter optimization.
- Learned policies >20% more successful, generalize to new envrionments, and are resilient to sensor and localization noise.


Moving obstacle avoidance in unstructured envrionments

Field Robotics I - 1.1.24

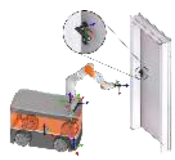
Chair
Co-Chair

10:45–12:00 MoA1.1

Door opening and traversal with an industrial cartesian impedance controlled mobile robot

Marvin Stuede, Kathrin Nuelle, Svenja Tappe and Tobias Ortmaier
Institute of Mechatronic Systems, Leibniz University Hannover, Germany

- Approach for autonomous door handle detection, door opening and traversal
- CNN in combination with depth data segmentation used for handle detection
- Door opening by task frame formalism based controller as outer loop for impedance control
- Evaluation for 12 different handles and 5 different doors



10:45–12:00 MoA1.2

An Algorithm for Odor Source Localization based on Source Term Estimation

Faezeh Rahbar, Ali Marjovi, Alcherio Martinoli
Distributed Intelligent Systems and Algorithms Laboratory,
School of Architecture, Civil and Environmental Engineering,
Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

- Design and evaluation of an algorithm based on source term estimation for odor source localization
- An innovative navigation strategy to balance exploration and exploitation
- Evaluated systematically through high-fidelity simulations and in a wind tunnel
- Studied the impact of multiple algorithmic and environmental parameters

The experimental environment with a Khepera IV robot and the emulated odor source

10:45–12:00 MoA1.3

Neural Network Pile Loading Controller Trained by Demonstration

Eric Halbach and Reza Ghabcheloo
Automation and Mechanical Engineering, Tampere University, Finland
Joni Kämäräinen
Computing Sciences, Tampere University, Finland

- Neural Network (NN) controllers were developed for automated scooping with a robotic wheel loader
- NNs were trained with recorded data from manually controlled scooping actions
- Comparisons in scooping performance were made between NNs with different training and structure
- A pile transfer test compared an NN controller, heuristic controller and manual control

10:45–12:00 MoA1.4

Dynamic Manipulation of Gear Ratio and Ride Height for a Novel Compliant Wheel using Pneumatic Actuators

Tim Hojnik and Paul Flick and Tirthankar Bandyopadhyay
Cyber Physical Systems, Data61, CSIRO, Australia
Jonathan Roberts
Science and Engineering, QUT, Australia

- Configurable wheel exhibits desired properties of varied radius wheels by adjusting ride height
- Uses pneumatic cylinders to move centre hub and exhibit compliance via air compressibility
- Kinematic model of the system presented for theoretical calculations and control system
- Controller and system built and demonstrated functionality with gravity loading results of manipulating the effective radius

Four wheels mounted to platform demonstrating ride height adjustment.

10:45–12:00 MoA1.5

A Model-Free Extremum-Seeking Approach to Autonomous Excavator Control Based on Output Power Maximization

Filippos E. Sotiropoulos and Harry H. Asada
Mechanical Engineering, MIT, USA

- Autonomous excavator trajectory planning is approached by maximizing mechanical power output to soil.
- Unique bucket depth for maximum power output proven.
- Extremum-seeking algorithm used to determine depth set-point online without bucket-soil model.
- Successfully implemented and tested on miniature electric excavator.

10:45–12:00 MoA1.6

The SlothBot: A Novel Design for a Wire-Traversing Robot

Gennaro Notomista, Yousef Emam and Magnus Egerstedt
Institute for Robotics and Intelligent Machines,
Georgia Institute of Technology, USA

- In this paper we present the SlothBot, a solar-powered, slow-paced, energy-efficient robot capable of moving on a mesh of wires.
- The SlothBot is suitable for long-term robotic tasks such as environmental monitoring and agriculture robotics applications.
- The design of a novel fail-safe wire-switching mechanism is presented, and it is tested on a robot prototype.
- The results of preliminary long-term monitoring experiments are also reported.

Path Planning for Multi-Robot Systems I - 1.1.25

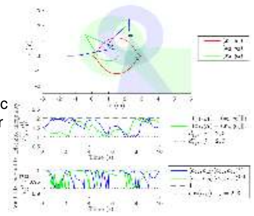
Chair
Co-Chair

10:45–12:00	MoA1.1

Feasible coordination of multiple heterogeneous mobile vehicles with various constraints

Zhiyong Sun, Marcus Greiff, Anders Robertsson and Rolf Johansson
LCCC Linnaeus Center and the ELLIIT Excellence Center
Department of Automatic Control, Lund University, Sweden

- Various constraints for mobile vehicle coordination involve holonomic/nonholonomic motion constraints, equality/inequality task constraints, etc.
- Via viability theory, we derive differential-algebraic equations to determine coordination feasibility for multiple homogeneous or heterogeneous mobile vehicles.
- A heuristic motion-generation algorithm is proposed to generate feasible trajectories for each individual vehicle.



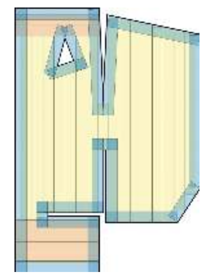
Coordinating three mobile vehicles with visibility and distance motion constraints.

10:45–12:00	MoA1.2

Turn-minimizing multirobot coverage

Isaac Vandermeulen and Roderich Groß
Automatic Control & Systems Engineering, University of Sheffield, UK
Andreas Kolling
iRobot, USA

- Environment is decomposed into sets of perimeter ranks and interior ranks
- Interior ranks cover a contracted rectilinear polygon and have orientation determined to minimize the number of turns needed
- Ranks converted into paths by solving the multiple traveling salesperson problem
- Used to compute vacuuming plans for the iRobot Roomba using real world maps

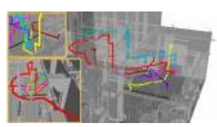


10:45–12:00	MoA1.3

Efficient Kinodynamic Multi-Robot Replanning in Known Workspaces

Arjav Desai, Matthew Collins, and Nathan Michael
The Robotics Institute, Carnegie Mellon University, U.S.A

- We leverage offline state lattice reachability analysis to decouple the kinodynamic planning problem into two sequential graph searches.
- The first graph search finds safe geometric paths in the geometric workspace graph.
- The second graph search assigns higher-order derivatives to the vertices of geometric paths.
- Without additional refinement, trajectories are dynamically feasible and safe even from non-stationary start states.
- The proposed approach can generate trajectories for up to 10 robots in under 1 s.



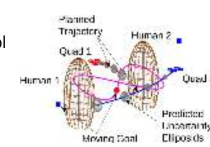
Trajectories for 10 robots in 3 dimensional warehouse environment from non-stationary initial states

10:45–12:00	MoA1.4

Chance-Constrained Collision Avoidance for MAVs in Dynamic Environments

Hai Zhu and Javier Alonso-Mora
Cognitive Robotics, Delft University of Technology, Netherlands

- Online collision avoidance for MAVs using chance-constrained model predictive control
- Collision probability is ensured to be below a user specified threshold
- A tighter bound for chance constraints over ellipsoidal obstacles, accounting for robot localization, sensing uncertainties
- Incorporation of chance constraints into three frameworks for multi-robot motion planning



Schematic of quadrotors, human, plans and uncertainties

10:45–12:00	MoA1.5

PRIMAL: Pathfinding via Reinforcement and Imitation Multi-Agent Learning

Guillaume Sartoretti, Justin Kerr, Yunfei Shi, and Howie Choset
Robotics Institute, Carnegie Mellon University, USA
Glenn Wagner
CSIRO, Australia
T. K. Satish Kumar and Sven Koenig
Computer Science Department, University of South California, USA

- Distributed reinforcement learning and imitation learning to online multi-agent path finding.
- Improved scalability (up to 1024 agents), no communication required among agents.
- Extensive experimental comparison with state-of-the-art planners (CBS / M* / ORCA).
- Outperforms every other planner in environments with low density of obstacles, but struggles in cluttered scenarios.
- Experimental validation on physical robots.

Team of 2 physical robots and 2 simulated robots planning paths in a factory mockup using PRIMAL.

10:45–12:00	MoA1.6

Multi-Robot Motion Planning with Dynamics via Coordinated Sampling-Based Expansion Guided by Multi-Agent Search

Duong Le and Erion Plaku
EECS, Catholic University of America, USA

- Combine sampling-based motion planning with multi-agent search
- Coordinated expansion of motion tree along routes obtained by multi-agent search
- Construct roadmap to provide suitable discrete abstraction
- Approach is shown to be significantly faster than related work

Multi-Robot Systems I - 1.1.26

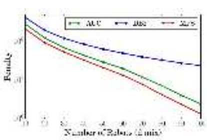
Chair
Co-Chair

10:45–12:00	MoA1.1

Cannot avoid penalty? Let's minimize

Chayan Sarkar and Marichi Agarwal
TCS Research & Innovation, India

- Scheduling a wave of tasks to a group of homogeneous robots in a warehouse, where a soft task deadline signifies the desired time by which it should be completed; otherwise, it incurs a penalty.
- During the peak times, a large number of tasks are bound to miss their deadline leading to a significant accumulation of penalty.
- We develop minimum penalty scheduling (MPS) that tries to minimize the overall penalty while completing all the tasks.
- MPS is robust, scalable and near optimal.



Performance comparison for 1000 tasks and linearly increasing robots.

10:45–12:00	MoA1.2

Mixed-Granularity Human-Swarm Interaction

Jayam Patel, WPI Yicong Xu, PTC Carlo Pinciroli, WPI

- We consider the problem of *an intuitive interface to interact with a robot swarm for accomplishing a complex task – collective transport.*
- We propose *an interface design to use multiple modalities of swarm control; robot-oriented and environment-oriented*
- We validate the interface with a user study and proved the importance of a mixed-granularity interface over using a single modality.

10:45–12:00	MoA1.3

End-Effector Pose Correction for Versatile Large-Scale Multi-Robotic Systems

Lukas Stadelmann, Timothy Sandy and Jonas Buchli
Agile & Dexterous Robotics Lab, ETH Zurich, Switzerland
Andreas Thoma
Gramazio Kohler Research, ETH Zurich, Switzerland

- We present a fully-integrated end-effector positioning system for large-scale multi-robotic setups.
- Static and dynamic correction is implemented using fused data of an external pose tracking system and an IMU.
- The capabilities of the conventional robot setup are extended and its usability and efficiency is fundamentally improved.

Robotic Fabrication Lab (RFL), ETH Zurich

10:45–12:00	MoA1.4

Flexible collaborative transportation by a team of rotorcraft

Hector Garcia de Marina[1] and Ewoud Smeur[2]
[1]UAS Center, University of Southern Denmark
[2]MAVLab, Department of Aerospace Engineering, TU Delft, the Netherlands

- Drones lifting and maneuvering **payloads** that are **impossible to handle for a single unit**.
- A distributed rigid formation controller keeps a desired shape, and **disagreements** among robots **create rigid motions** for the shape.
- The 3D acceleration signals generated by the formation-motion guidance algorithm are tracked by an **Incremental Nonlinear Dynamic Inversion controller**.
- **Worst-case analysis** involving ropes' tensions and payload is assessed to **guarantee nominal conditions** during the transportation.

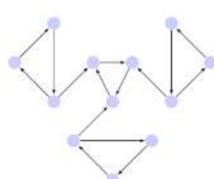
10:45–12:00	MoA1.5

Circular and Concentric Formation of Kinematic Unicycles

M.Iqbal[1], S.Azuma[2], J. Leth[3], T.D.Ngo[4]
[1]International Islamic University, Pakistan
[2]Nagoya University, Japan
[3]Aalborg University, Denmark
[4]University of Prince Edward Island, Canada

Circular formation and concentric formation stabilization problem of kinematic unicycles

- Distributed control laws driving unicycles to converge to a common circle.
- Velocity control law enabling unicycles to achieve a specific formation on the circle
- Concentric formation by dividing unicycles into groups.
- Distributed control laws reinforcing each group at a desired circular orbit from the stationary center.



HNCP with three groups of a beacon and three agents

10:45–12:00	MoA1.6

Navigation Functions With Time-Varying Destination Manifolds in Star Worlds

Caili Li and Herbert G. Tanner
Mechanical Engineering, University of Delaware, USA

- Robotic-assisted pediatric rehabilitation provides context for play-based child-robot interaction
- Robotic toy automation requires real-time navigation that adapts to child's actions
- Time-varying navigation functions are developed to facilitate dynamic robot-child interaction
- These functions provide feedback for robot control aimed at chasing a moving target in star-world environments
- Under certain conditions, gradient-based convergence is guaranteed

Chase and hide & seek games with infants require robots to navigate in complex dynamic environments

Award Session I

Chair *Jean-Paul Laumond, LAAS-CNRS*
Co-Chair *Clement Gosselin, Université Laval*

10:45–10:57 MoA2.1

LineRanger: Analysis and Field Testing of an Innovative Robot for Efficient Assessment of Bundled High-Voltage Powerlines

Pierre-Luc Richard, Nicolas Pouliot, François Morin, Marco Lepage, Philippe Hamelin, Marin Lagacé, Alex Sartor, Ghislain Lambert and Serge Montambault
Hydro-Québec's Research Institute, Canada

- New robotic rolling platform for high-voltage powerlines assessment
- Innovative mechanism allowing quick and easy obstacle crossing
- Mathematical analysis to ensure stability while rolling on cable bundles
- Prototype with cameras and sensors tested on a full scale mock up

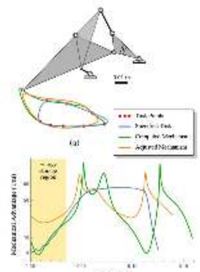

Prototype of the LineRanger

10:57–11:09 MoA2.2

Adjustable Power Modulation for a Leg Mechanism Suitable for Running

Mark Plecnik, Katherine M. Fearing, and Ronald S. Fearing
Dept. of EECS, University of California, Berkeley USA

- Power modulation previously used for high vertical agility jumping robots
- Here, power modulation provides energy storage during part of leg cycle in running
- Leg mechanism is designed with adjustable power modulation, suitable for different gaits and terrain types
- 1 leg prototype demonstrates both high and low power modes


Linkage design for task with energy storage

11:09–11:21 MoA2.3

Development and Experimental Validation of Aerial Vehicle with Passive Rotating Shell on Each Rotor

Carl John Salaan[1], Kenjiro Tadakuma[2], Yoshito Okada[1,2], Yusuke Sakai[2], Kazunori Ohno[1,3], and Satoshi Tadokoro[2]
[1]RIKEN Center for Advanced Intelligence Project, Japan
[2]Graduate School of Information Sciences, Tohoku Univ., Japan
[3]New Industry Creation Hatchery Center, Tohoku Univ., Japan

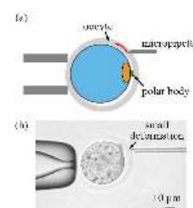
- A new idea is introduced in response to the limitations of aerial vehicle with a protective shell that can rotate passively.
- It is proposed to position two passive rotating hemispherical shells in each rotor.
- General concept, design and proof of concept are presented.
- Various experiments are conducted to demonstrate the advantages of the proposed flying robot.

11:21–11:33 MoA2.4

Robotic Orientation Control of Deformable Cells

Changsheng Dai, Zhuoran Zhang, Yuchen Lu, Guanqiao Shan, Xian Wang, Qili Zhao, and Yu Sun
Advanced Micro and Nanosystems Laboratory, University of Toronto, Canada

- Deep neural networks for polar body detection with an accuracy of 97.6%
- Modeling and path planning to determine the micropipette path to rotate the oocyte with minimal cell deformation
- Compensation controller to accommodate the variations of cell mechanical properties
- Accuracy of 0.7° in oocyte orientation control with maximum oocyte deformation of 2.69 μm



11:33–11:45 MoA2.5

Towards Robust Product Packing with a Minimalistic End-Effector

Rahul Shome, Wei N. Tang, Changkyu Song, Chaitanya Mitash, Chirs Kourtev, Jingjin Yu, Abdeslam Boularias, and Kostas E. Bekris
Computer Science Dept, Rutgers University, USA

- Complete hardware stack and software pipeline for developing and testing algorithmic solutions for robotic packing tasks.
- Explores the use of a minimalistic, suction-based, end-effector.
- Develops and evaluates corrective prehensile and non-prehensile manipulation primitives:
  - Toppling, robust placement via adaptive pushing, and corrective packing
- Experiments show that the primitives provide robustness to errors and failures


Initial scene

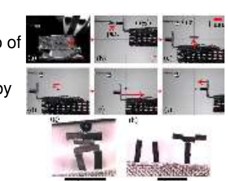

Final scene

11:45–11:57 MoA2.6

Contactless Robotic Micromanipulation in Air Using a Magneto-acoustic System

Omid Youssefi and Eric Diller
Department of Mechanical and Industrial Engineering, University of Toronto, Canada

- Micromanipulion tasks at sizes smaller than 3mm are challenging due to increasing ratio of surface to volumetric forces.
- Microcomponents are positioned vertically by an encapsulating acoustic field (levitated).
- A magnetic field constrains the pose of the levitated component.
- Using vision feedback, the components are assembled without direct physical contact.
- Potential for fully automated microassembly is demonstrated.


Microassembly Demo

Industry Forum and IERA Program - Session I

Chair

Co-Chair

Lunch with Leaders

Chair

Co-Chair

Lunch

Chair

Co-Chair

Keynote Session I

Chair *Jaydev P. Desai, Georgia Institute of Technology*
Co-Chair

13:45–14:30	MoKN1.1*

Move Fast and (Don't) Break Things: Commercializing Robotics at the Speed of Venture Capital

Ryan Gariepy, Clearpath Robotics Inc.

Keynote Session II

Chair *Gregory Dudek, McGill University*
Co-Chair

13:45–14:30	MoKN2.1*

Biomimetic Human Simulation and the Deep Learning of Neuromuscular and Sensorimotor Control

DEMETRI TERZOPOULOS, University of California, Los Angeles

PODS: Monday Session II

Chair

Co-Chair

Robust and Adaptive Control - 1.2.01

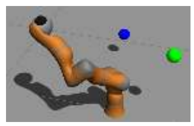
Chair
Co-Chair

14:40–15:55	MoB1.1

Dynamically-consistent Generalized Hierarchical Control

Niels Dehio[1,2] and Jochen J. Steil[2]
[1] Karlsruhe Institute for Technology, Germany
[2] Technical University Braunschweig, Germany

- Combine advantages from both classical soft and strict prioritization schemes for multi-objective robot control
- Extend Generalized Hierarchical Control by adding dynamic-consistency → DynGHC
- Reduce inertia coupling between tasks
- Smoothly rearrange task priorities online
- Matlab and C++ source code is available



14:40–15:55	MoB1.2

Robotic Joint Control System based on Analogue Spiking Neural Networks and SMA Actuators

Mircea Hulea, Adrian Burlacu and Constantin Florin Caruntu
Faculty of Automatic Control and Computer Engineering,
Gheorghe Asachi Technical University of Iasi, Romania

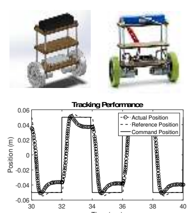
- Spiking neural networks control efficiently the contraction of the SMA actuators
- Neural network has bioinspired structure
- The spiking neural network uses inhibitory feedback to control precisely the robotic arm rotation
- The arm positioning precision is not affected by a small load or by the initial angle

14:40–15:55	MoB1.3

Model Reference Adaptive Control of a Two-Wheeled Mobile Robot

Hussein Al-Jlailaty and Daniel Asmar and Naseem Daher
Vision and Robotics Lab, American University of Beirut, Lebanon

- Formulates a design for a nonlinear controller to balance a two-wheeled mobile robot (TWMR) based on Model Reference Adaptive Control.
- The proposed solution overcomes the limitations of control systems that rely on fixed parameter controllers.
- Studying the influence that hidden dynamic effects can cause, we show the preference of the proposed controller over other designs.

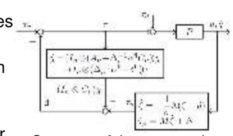


14:40–15:55	MoB1.4

A Robust Tracking Controller for Robot Manipulators: Embedding Internal Model of Disturbances

Wonseok Ha and Juhoon Back
School of Robotics, Kwangwoon University, Republic of Korea

- Robot manipulators have high nonlinearities, unknown disturbances, and large uncertainties by structural complexity.
- When this system operates, uncertainties can be regarded as sinusoidal disturbances depending on the speed.
- This research proposes a robust controller for uncertain robot manipulators subject to sinusoidal disturbances.
- The controller's stability is proved, and its performance is validated by the simulation.



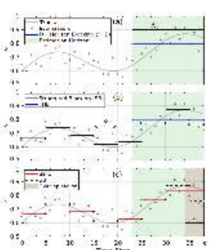
Structure of the proposed robust controller.

14:40–15:55	MoB1.5

Receding horizon estimation and control with structured noise blocking for mobile robot slip compensation

Nathan D. Wallace, He Kong, Andrew J. Hill and Salah Sukkarieh
ACFR, University of Sydney, Australia

- Receding horizon estimation and control (RHEC) is a powerful adaptive optimisation-based framework
- Slip experienced by a robot can be modelled as environmental noise in this framework
- Current methods assume constant slip over the estimation horizon, which is untrue at faster speeds
- Structured blocking is proposed to trade off computation for improved estimation accuracy



Structured blocking concept

14:40–15:55	MoB1.6

Decoupled Control of Position and / or Force of Tendon Driven Fingers

Friedrich Lange, Gabriel Quere, and Antonin Raffin
Institute of Robotics and Mechatronics, German Aerospace Center (DLR)

- Motors for finger motion are in the forearm or the palm.
- Tendons to distant joints pass by the more proximal joints and have an effect there.
- The resulting couplings are different for force control and for position control.
- A generic control law is presented that decouples in joint space or in task space.

DLR AWIWI II hand
of the DLR David robot

Deep Learning for Navigation I - 1.2.02

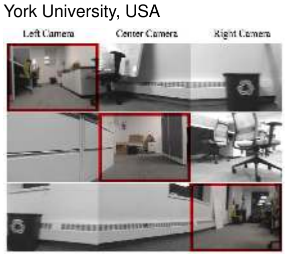
Chair
Co-Chair

14:40–15:55	MoB1.1

Reconfigurable Network for Efficient Inferencing In Autonomous Vehicles

Shihong Fang and Anna Choromanska
ECE Department, New York University, USA

- We propose the reconfigurable network for handling multiple sensors on autonomous platforms.
- We address the problem of inefficient inferencing when multiple sensors are used.
- The proposed network effectively selects the most relevant input and reduces computations.
- The network steers the UGV and chooses the relevant sensor for navigation in real time.



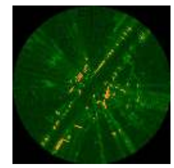
Exemplary images captured by the three cameras during autonomous driving when turning left, driving straight, and turning right. The inputs selected by the gating network are in red.

14:40–15:55	MoB1.2

Fast Radar Motion Estimation with a Learnt Focus of Attention using Weak Supervision

Roberto Aldera, Daniele De Martini, Matthew Gadd, and Paul Newman
Oxford Robotics Institute, Dept. Engineering Science, University of Oxford, UK

- We seek to **KEEP** features that are present in both the current and previous frames
- Using weak supervision, we train an image segmentation network to classify incoming returns
- Landmarks in the **KEEP** class are used for radar odometry and achieve consistent results
- By processing fewer measurements, we speed up radar-only motion estimation by a factor of 2.36



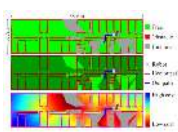
KEEP class is highlighted for returns that are wide-baseline visible

14:40–15:55	MoB1.3

Learned Map Prediction for Enhanced Mobile Robot Exploration

Rakesh Shrestha, Ping Tan and Richard Vaughan
School of Computing Science, Simon Fraser University, Canada
Fei-Peng Tian and Wei Feng
School of Computer Science and Technology, Tianjin University, China

- Autonomous ground robot capable of exploring unknown indoor environments for reconstructing their 2D maps
- Generative neural network to predict unknown regions which are used to enhance the exploration
- Evaluated in simulation on floor plans of real buildings demonstrating superior performance over traditional methods



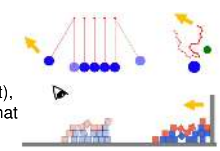
Deep learning based map prediction for autonomous exploration

14:40–15:55	MoB1.4

Propagation Networks for Model-Based Control Under Partial Observation

Yunzhu Li, Jiajun Wu, Jun-Yan Zhu, Joshua B. Tenenbaum, Antonio Torralba, and Russ Tedrake
MIT CSAIL

- We use machine learning to build dynamics models for tasks that current physical simulators cannot effectively deal with.
- We propose Propagation Networks (PropNet), a differentiable, learnable dynamics model that
  - handles partially observable scenarios,
  - enables instantaneous propagation of effects,
  - outperforms current learnable physics engines in both simulation and control.



Environments:
- Newton's Cradle
- Rope Manipulation
- Box Pushing

14:40–15:55	MoB1.5

Trajectory Prediction for Autonomous Driving via Recurrent Meta Induction Neural Network

Chiyu Dong[1], Yilun Chen[2] and John M. Dolan[2]
[1]ECE, [2]the Robotics Institute, Carnegie Mellon University, USA

- A behavioral and trajectory prediction for autonomous driving cars in urban areas.
- Captures mutual influences among all surrounding cars.
- Learns the interactive model from small datasets.
- Historical observations are used and contribute to the prediction of a target vehicles' future trajectory.

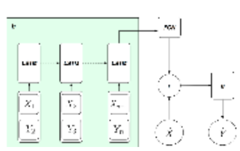


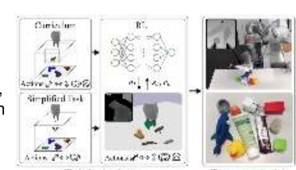
Fig. 1 The structure of the Recurrent Meta Induction Neural Network.

14:40–15:55	MoB1.6

Comparing Task Simplifications to Learn Closed-Loop Object Picking Using Deep Reinforcement Learning

Michel Breyer, Fadri Furrer, Tonci Novkovic, Roland Siegwart, and Juan Nieto
Autonomous Systems Lab, ETH Zurich, Switzerland

- We learn closed-loop policies for reaching, grasping and lifting objects.
- We compare different approaches, including a curriculum of tasks with increasing difficulty.
- Policies are trained in simulation and evaluated on a set of unseen objects, both in simulation and a real platform.



Mechanism Design I - 1.2.03

Chair
Co-Chair

14:40–15:55	MoB1.1

14:40–15:55	MoB1.2

Super Dragon: A 10 m-long Coupled Tendon-driven Articulated Manipulator

Gen Endo, Atsushi Horigome and Atsushi Takata
Dept. of Mechanical Engineering, Tokyo Institute of Technology, Japan

- Long-reach manipulator is required to investigate inside Fukushima Daiichi NPPs
- Coupled tendon-driven mechanism and a gravity compensation mechanism using synthetic fiber ropes are introduced
- Specifications are 10 m-long, 10 D.O.F, 10 kg payload and 350 kg weight (arm: 50 kg, base: 300kg)
- Basic experiments are carried out and its feasibility was demonstrated


Super Dragon keeping horizontal posture

14:40–15:55	MoB1.3

High Force Density Reflexive Gripping

Georgia Tech

Rianna Jitosho
Mechanical Engineering, Massachusetts Institute of Technology, USA
Kevin Choi, Adam Foris, and Anirban Mazumdar
Mechanical Engineering, Georgia Institute of Technology, USA

- Reflexive activation without sensing or actuation.
- Rapid grasp closure (0.15s).
- High hanging force density (15-28:1)
- Low power grasp opening using pneumatic actuation.
- Designed for use on mobile platforms.

CREATING THE NEXT

14:40–15:55	MoB1.4

Compliant Bistable Gripper for Aerial Perching and Grasping

Haijie Zhang, Jiefeng Sun and Jianguo Zhao
Mechanical Engineering, Colorado State University, USA

- We designed a bistable & passive gripper for aerial robot perching
- The gripper does not require external force to close
- This perching method can extend aerial robot's flight time in surveillance and monitoring tasks


Aerial robot perching system

14:40–15:55	MoB1.5

Overpressure Compensation for Hydraulic Hybrid Servo Booster Applied to Hydraulic Manipulator

Sang-Ho Hyon[1], Yuuki Taniai[1], Kazuyuki Hiranuma[2], Kazutoshi Yasunaga[3] and Harutsugu Mizui[1]
1 Ritsumeikan University, Japan
2 Fine Sinter Co., Ltd. , Japan
3 Tokyo Keiki Inc. , Japan

- Novel hydraulic hybrid servo drive is first applied to a robotic manipulator
- High-speed, large torque, high-precision control are possible at low cost
- A model-based compensation scheme to mitigate the overpressure is presented
- Position and torque control performance are demonstrated on a three-axis manipulator (video attached)

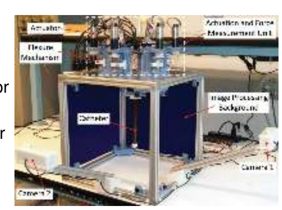

Torque-controllable hydraulic hybrid manipulator

14:40–15:55	MoB1.6

An Analytical Loading Model for n-Tendon Continuum Robots

Mohsen Moradi Dalvand
IISRI, Deakin University, Australia and SEAS, Harvard University, USA
Saeid Nahavandi — IISRI, Deakin University, Australia
Robert D. Howe — SEAS, Harvard University, USA

- An analytical tendon tension model for n-tendon catheters is developed.
- The model accounts for the bending and axial compliance of the manipulator as well as the tendon compliance.
- The model is experimentally verified for three- to six-tendon robots for different configurations in an open-loop control architecture



SLAM - Session II - 1.2.04

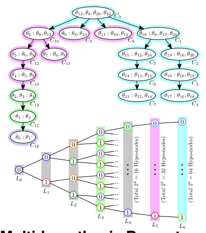
Chair
Co-Chair

14:40–15:55	MoB1.1

MH-iSAM2: Multi-hypothesis iSAM Using Bayes Tree and Hypo-tree

Ming Hsiao and Michael Kaess
Robotics Institute, Carnegie Mellon University, USA

- A novel **nonlinear incremental** solver that outputs **multi-hypothesis results** based on **ambiguous measurements** in SLAM.
- Modeling different types of ambiguities as **different types of multi-mode factors (MMF)**.
- Extending **Bayes tree** and combining it with **Hypo-tree** to solve mutli-hypothesis SLAM problems efficiently.
- Designing a **pruning algorithm** that prunes the unlikely/unwanted hypotheses to maintain robustness and efficiency.



Multi-hypothesis Bayes tree (MHBT) (top) and **Hypo-tree** (bottom) with their hypothesis associations shown in colors

14:40–15:55	MoB1.2

Improving Keypoint Matching Using a Landmark-Based Image Representation

Xinghong Huang, Zhuang Dai, Weinan Chen and Li He
Electromechanical Engineering, Guangdong University of Technology, China
Hong Zhang
Computing Science, University of Alberta, Canada

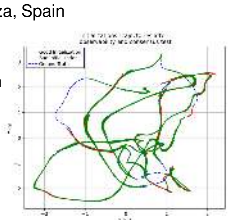
- Extracting landmark proposals from two images whose keypoints are being matched.
- Computing ConvNet features for detected landmarks and matching the landmarks between the two images.
- Matching keypoints within each pair of matched landmarks.
- Combining all the matched keypoints of the landmarks as putative matches between the two images and identifying inlier matches with MVG and RANSAC.

14:40–15:55	MoB1.3

Fast and Robust Initialization for Visual-Inertial SLAM

Carlos Campos, José M. M. Montiel, Juan D. Tardós
Universidad de Zaragoza, Spain

- Joint visual-inertial initialization in less than two seconds
- New observability and consensus tests to discard bad initializations, increasing robustness
- Scale error around 5% after initialization, and lower than 1% with BA after 10s
- Computationally efficient (max. 215ms)



Computed initialization trajectories on EuRoC V101

14:40–15:55	MoB1.4

Accurate Direct Visual-Laser Odometry with Explicit Occlusion Handling and Plane Detection

Kaihong Huang and Junhao Xiao
Institue of Inteligence Science, National Uni. of Defense Technology, China
Cyrill Stachniss
Institute of Geodesy and Geoinformation, University of Bonn, Germany

- A novel direct visual-laser odometry designed to maximize the information usage of both the image and the laser scan;
- Explicit plane detection in the motion estimation process to avoid discarding image pixels without depth information;
- A novel method for predicting occluded image pixels;

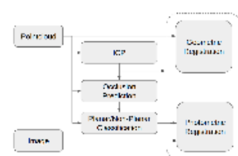


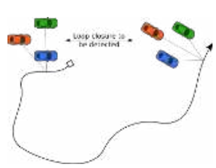
Fig. Algorithm overview.

14:40–15:55	MoB1.5

Efficient Constellation-Based Map-Merging for Semantic SLAM

Kristoffer M. Frey, Jonathan P. How
Department of Aerospace Engineering, MIT, USA
Ted J. Steiner
Charles Stark Draper Laboratory, USA

- Data association is hard, and SLAM systems must be cautious → "duplicate" landmarks
- We propose a mechanism for loop closure (constellation merging) **in the back end**
- Use only local information (**geometric consistency**) to apply probabilistic gating techniques **with minimal access** to the full joint covariance matrix
- Flexible correspondence graph formulation facilitates **efficient global search**



Estimate drift manifests itself as "duplicate" landmark constellations being added to the graph.

Manipulation I - 1.2.05

Chair
Co-Chair

14:40–15:55	MoB1.1

Learning Robust Manipulation Strategies with Multimodal State Transition Models and Recovery Heuristics

Austin S. Wang
Dept. of Mechanical Engineering, Carnegie Mellon Unviersity, USA
Oliver Kroemer
The Robotics Institute, Carnegie Mellon Unviersity, USA

- A general framework for learning skill-chaining policies in contact-rich tasks is proposed.
- Contact modes are observed and incorporated as auxiliary state information.
- Skills are modeled as funnels with multimodal output distributions.
- A heuristic is also presented to generate skills to recover from errors.
- Results on 3 simulated tasks demonstrate a significant increase in success rate

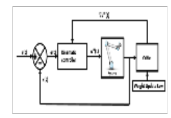
Robot attempting to open a drawer in simulation

14:40–15:55	MoB1.2

Adaptive Critic Based Optimal Kinematic Control for a Robot Manipulator

Aiswarya Menon, Ravi Prakash and Laxmidhar Behera
Electrical Department, Indian Institute of Technology Kanpur, India

- Optimal kinematic control of robot manipulator following task space trajectory is addressed using SNAC framework.
- Critic weight update law proposed ensures convergence to the desired optimal cost analytically; $\dot{\hat{W}}_c = \alpha \nabla\sigma_c J R^{-1} J^{\top} \nabla J_s(e)$
- Stability and performance of the closed loop kinematic control law: $\hat{u}^* = \frac{-1}{2} R^{-1} J^{\top} \nabla\sigma_c^{\top} \hat{w}_c$ has been guaranteed using Lyapunov approach.
- Proposed scheme is validated in simulations



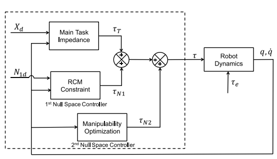
Kinematic control scheme for a robot manipulator using adaptive critic method

14:40–15:55	MoB1.3

Manipulability Optimization Control of a Serial Redundant Robot for Robot-assisted Minimally Invasive Surgery

Hang Su, Jagadesh Manivannan, Luca Bascetta, Giancarlo Ferrigno and Elena De Momi
Department of Electronics, Information and Bioengineering, Politecnico di Milano, Italy
Shuai Li
Hong Kong Polytechnic University, Hong Kong

- Hierarchical Control Architecture
- Remote center of motion
- Manipulation optimization
- RNN



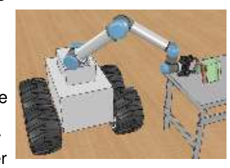
Hierarchical Control Architecture

14:40–15:55	MoB1.4

Accounting for Part Pose Estimation Uncertainties during Trajectory Generation for Part Pick-Up Using Mobile Manipulators

Shantanu Thakar, Pradeep Rajendran, Vivek Annem, Ariyan Kabir and Satyandra K. Gupta
Realization of Robotic Systems lab, University of Southern California, USA

- To minimize operation time, mobile manipulators need to pick-up parts while the mobile base and gripper are moving
- We present an active learning based approach to select permissible gripper velocities which ensure that the pick-up operations do not fail due to uncertainties in the part pose estimation
- Our approach allows computation of the velocity of the mobile base to achieve the desired gripper velocities
- We have demonstrated the technical feasibility of picking up parts with a moving mobile base using simulations and physical experiments



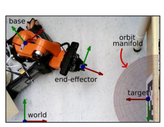
A moving mobile manipulator picking-up a part which has pose uncertainty

14:40–15:55	MoB1.5

Object centered teleoperation of mobile manipulators with RCM constraint

Manuel A. Ruiz Garcia and Rafael A. Rojas
Faculty of Sci. and Tech., Free University of Bozen-Bolzano, Italy
Fiora Pirri
DIAG, Sapienza University of Rome, Italy

- Reactive control scheme based on the remote center of motion constraints (RCM).
- Base and end-effector motions coupled be means of manipulability maximization and self-collision avoidance.
- Prioritized control scheme to enforce safety during the robot motion.



Illustrative setup of a teleoperated visual inspection task

14:40–15:55	MoB1.6

Adapting Everyday Manipulation Skills to Varied Scenarios

Paweł Gajewski, Paulo Ferreira, Georg Bartels, Chaozheng Wang Frank Guerin, Bipin Indurkhya, Michael Beetz, Bartłomiej Sniezynski
AGH Univ. of Sci. and Tech., Poland. University of Birmingham, UK. Universitat Bremen, Germany. University of Aberdeen, UK.

- Allow robot manipulation skills to be adapted to varied tools and target objects
- Skills: scraping material from a tool, scooping from a container, cutting.
- Robot vision extracts features of tool and object, robot motion parameterized to use these.

PR2 scraping off food from spatula to bowl.

Micro/Nano Robots II - 1.2.06

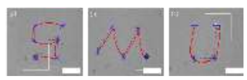
Chair
Co-Chair

14:40–15:55	MoB1.1

Feedback Control and 3D Motion of Heterogeneous Janus Particles

Louis William Rogowski, Xiao Zhang, Anuruddha Bhattacharjee, Jung Soo Lee, and Min Jun Kim
Mechanical Engineering, Southern Methodist University, USA
Li Huang and Aaron T. Becker
Electrical and Computer Engineering, University of Houston, USA

- This paper explores the viability of feedback control for heterogeneous Janus particles.
- Janus particles with magnetization vectors coincidental and offset to their propulsion vectors were fabricated.
- Analysis was performed on predicting Janus particle trajectories.
- 3D open loop control with Janus particle heterogeneity is discussed.



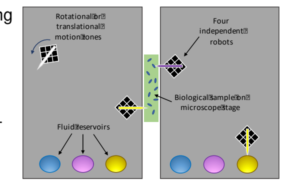
A 6 µm heterogeneous Janus particle performing arbitrary trajectories (red) and compared with the desired trajectory (blue)

14:40–15:55	MoB1.2

Nanoliter Fluid Handling for Microbiology via Levitated Magnetic Microrobots

Elizabeth E. Hunter, Edward B. Steager, and Vijay Kumar
GRASP Laboratory, University of Pennsylvania, USA
Allen Hsu, Annjoe Wong-Foy, and Ron Pelrine
Advanced Technology and Systems Division, SRI International, USA

- We develop a microrobotic fluid handling system consisting of diamagnetically levitated robots equipped with micropipette end-effectors.
- We show nanoliter fluid loading, transport, and release with micrometer-scale positioning.
- We demonstrate patterning fluorescent molecules on hydrogel substrates and induction of engineered bacterial cells with signaling molecules.



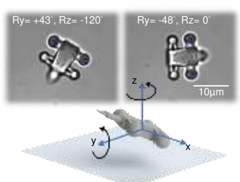
Microrobotic fluid handling system for microbiological experiments

14:40–15:55	MoB1.3

High-bandwidth 3D Multi-Trap Actuation Technique for 6-DoF Real-Time Control of Optical Robots

Edison Gerena, Stéphane Régnier and Sinan Haliyo
ISIR, Sorbonne Université, France

- New approach to generate and control several optical traps **in 3D** with **low latency** and **high bandwidth**
- True **6-DoF** control of an optical robot in a **teleoperated** scenario
- Optical robots for **biological applications:** dexterous single-cell handling

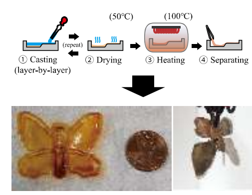


14:40–15:55	MoB1.4

IPMC Monolithic Thin Film Robots Fabricated through a Multi-Layer Casting Process

Akio Kodaira[1], Kinji Asaka[2], Tetsuya Horiuchi[2], Gen Endo[1], Hiroyuki Nabae[1] and Koichi Suzumori[1]
[1]Department of Mechanical Engineering, Tokyo Institute of Technology, Japan
[2]National Institute of Advanced Industrial Science and Technology, Japan

- IPMC actuator has a huge potential for soft robots and biomimetic systems.
- Multi-Layer Casting Process realizing the precise production of a quasi-three dimensional film.
- Fabrication of Monolithic Thin Film Robots which have bone and actuator parts in one film.
- Success in selective resonance and self-sustaining driving.



Schematic diagram of Multi-Layer Casting Process and fabricated Monolithic Thin Film Robot

14:40–15:55	MoB1.5

Four Wings: A New Insect-Sized Aerial Robot with Steering ability and Payload Capacity for Autonomy

Sawyer B. Fuller
Assistant Professor, University of Washington

- A four-winged robot slightly heavier than a honeybee
- new capabilities:
  - actuate about a vertical axis
  - greater payload capacity with more wings

Humanoid Robots II - 1.2.07

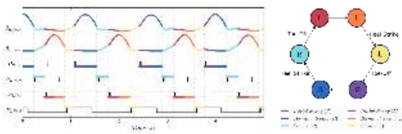
Chair
Co-Chair

14:40–15:55 MoB1.1

Data-Driven Gait Segmentation for Walking Assistance in a Lower-Limb Assistive Device

Aleksandra Kalinowska, Thomas A. Berrueta, Todd Murphey
Northwestern University, Chicago, IL
Adam Zoss
Ekso Bionics, Richmond, CA

- Hybrid systems, such as bipedal walkers, are challenging to control without a model of the transitions between modes.
- We propose an algorithm for determining switching conditions that can be used real-time for model predictive control.
- Based on experimental data from a lower-limb exoskeleton, we learn to predict gait transition events with only kinematic information.



14:40–15:55 MoB1.2

Closed-loop MPC with Dense Visual SLAM - Stability through Reactive Stepping

Arnaud Tanguy[1,2*], Daniele De Simone[4*], Andrew I. Comport[1], Giuseppe Oriolo[4] and Abderrahmane Kheddar[3,2]
1. CNRS-I3S/UCA, 2. CNRS-LIRMM/UMontpellier, 3. CNRS-AIST/JRL, 4. Sapienza University of Rome, DIAG.

- A closed-loop MPC scheme is proposed to estimate the robot's real state through :
  - Simultaneous Localization and Mapping (SLAM)
  - Proprioceptive sensors (force/torque).
- Robot is shown to react to pushing disturbances by stepping to recover.
- SLAM allows the robot to navigate to target positions in the environment without drift.

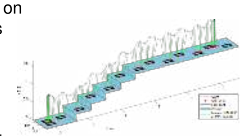
HRP4 walking with closed-loop SLAM MPC.

14:40–15:55 MoB1.3

Safe 3D Bipedal Walking through Linear MPC with 3D Capturability

Adrien Pajon and Pierre-Brice Wieber
Univ. Grenoble Alpes, Inria, 38000 Grenoble, France

- Linear MPC scheme to walk perfectly safely on a piecewise horizontal ground such as stairs
- Balance and Passive Safety guarantees are secured by enforcing a 3D capturability constraint
- Comparison between CoM and CoP trajectories involving exponentials instead of polynomials



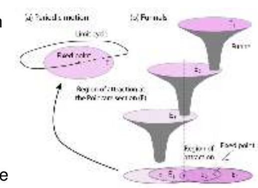
3D CoM trajectories when walking up stairs with the proposed linear MPC scheme

14:40–15:55 MoB1.4

Feedback Motion Planning of Legged Robots by Composing Orbital Lyapunov Functions Using Rapidly-Exploring Random Trees

Ali Zamani, Joseph D. Galloway, Pranav A. Bhounsule
Mechanical Engineering, University of Texas at San Antonio, USA

- Presenting a novel framework based on switching between limit cycles for feedback motion planning of legged robots
- Developing a control policy using deep neural networks
- Adopting rapidly-exploring random tree algorithm to plan transitions between the limit cycles using the regions of attraction



14:40–15:55 MoB1.5

Online Walking Pattern Generation for Humanoid Robot with Compliant Motion Control

Mingon Kim, Daegyu Lim and Jaeheung Park
Graduate School of Convergence Science and Technology, Seoul National University, South Korea

- This paper presents a real-time walking pattern generation method for humanoid robot with compliant motion control.
- The preview control based on the LIPM and the control performance model is proposed to consider the tracking performance of the robot by compliant motion control.
- The performance of the proposed method was demonstrated by improved stability during the walking with obstacles.

14:40–15:55 MoB1.6

Bayesian Optimization for Whole-Body Control of High-Degree-of-Freedom Robots through Reduction of Dimensionality

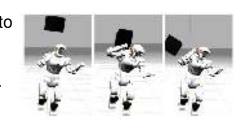
Kai Yuan, Iordanis Chatzinikolaidis, and Zhibin Li
School of Informatics, The University of Edinburgh

Typically, control parameters are in a scale up-to hundreds and often hand-tuned yielding sub-optimal performance.

We propose an *automatic* tuning framework for optimal parameters of whole-body control algorithms

Alternating Bayesian Optimization:

- *iteratively learns* parameters of sub-spaces from the whole high-dimensional parametric space through interactive trials
- is *sample efficient* and has *fast convergence*



Robust balancing against perturbations of Valkyrie using 36 **automatically** tuned control parameters.

Localization II - 1.2.08

Chair
Co-Chair

14:40–15:55 MoB1.1

A Kalman Filter-Based Algorithm for Simultaneous Time Synchronization and Localization in UWB Networks

Justin Cano, Saad Chidami and Jerome Le Ny
Dept. of Electrical Eng., Polytechnique Montréal, Canada

- Comprehensive localization system for robots based on UWB Decawave© modules and STM32F4© MCUs;
- Protocol based on Kalman filtering and TOA localization technique;
- Precise node synchronization and robot localization simultaneously managed;
- Experimental validation on UGV Husky© reaching 0.1m precision in LOS condition.

UWB module and UGV used for the validation.

14:40–15:55 MoB1.2

eRTIS: A Fully Embedded Real Time 3D Imaging Sonar Sensor for Robotic Applications

Robin Kerstens, Dennis Laurijssen, Jan Steckel
CoSys-Lab, Faculty of Applied Engineering, University of Antwerp and the Flanders Make Strategic Research Centre, Belgium

- An accurate 3D imaging in-air ultrasound sensor using a pseudo random microphone array is presented
- Two possible sensor architectures are investigated and compared
- The sensor's way of working is explained in detail
- Measurements from the sensor in an office environment are presented and discussed

A 3D imaging sonar sensor using a pseudo random microphone array

14:40–15:55 MoB1.3

LookUP: Vision-Only Real-Time Precise Underground Localisation for Autonomous Mining Vehicles

Fan Zeng[1], Adam Jacobson[1], David Smith[2], Nigel Boswell[2], Thierry Peynot[1] , Michael Milford[1]
[1]Queensland University of Technology, Australia
[2]Caterpillar

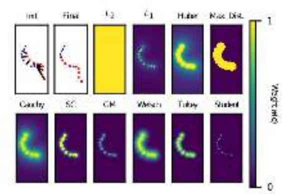
- Objective: Infrastructure-free underground autonomous operation of mining vehicles.
- Laser scanners and feature-based methods challenged by aliased tunnel environment.
- Coarse localisation system previously designed, accuracy needs to be improved.
- Refinement system uses ceiling images.
- Homography estimated based on pixel correspondence between query and reference.
- Neural network generates sample quality heat map to improve computation efficiency.

14:40–15:55 MoB1.4

Analysis of Robust Functions for Registration Algorithms

Philippe Babin, Philippe Giguère and François Pomerleau
Northern Robotics Laboratory, Université Laval, Canada

- There are no large scale analysis of outlier filters for ICP.
- We compare 14 outlier filters subject to more than two million registrations in different types of environment, different overlaps and subjected to large perturbation.
- For a better replication of our results, we provided the open-source implementations of the tested outlier filters.



The effect of different outlier filters on the registration of two overlapping curves.

14:40–15:55 MoB1.5

CoLo: A Performance Evaluation System for Multi-robot Cooperative Localization Algorithms

Shengkang Chen and Ankur Mehta
ECE Department, University of California Los Angeles, the United States

- CoLo is a performance evaluation system for localization algorithms available at *https://git.uclalemur.com/billyskc/CoLo*
- It allows users to easily add algorithms and test them extensively.
- CoLo-PE(Physical experiment) provides a framework to setup a robotic testbed.
- CoLo-AT(Analysis Tool) evaluates the performance of users' algorithms with real-world data.

CoLo-PE (the physical experiment part)

14:40–15:55 MoB1.6

Tightly-Coupled Visual-Inertial Localization and 3D Rigid-Body Target Tracking

Kevin Eckenhoff ,Yulin Yang, Patrick Geneva*, and Guoquan Huang
Dept. Mechanical Engineering, University of Delaware, USA
*Dept. Computer and Information Sciences, University of Delaware, USA

- Propose a MSCKF-based framework to perform both visual-inertial localization and tracking of a rigid-body moving object
- Jointly estimate the pose, local point cloud, and motion parameters of the object along with the standard VIO navigation states
- Allow for collecting target measurements even when viewing the object from different angles, and can be used for future target motion prediction

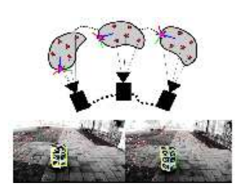


Illustration of the 3D rigid-body target tracking process

Physically Assistive Devices - 1.2.09

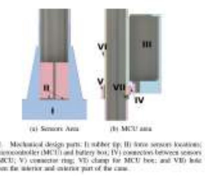
Chair
Co-Chair

14:40–15:55 MoB1.1

A cane-based low cost sensor to implement attention mechanisms in telecare robots

Joaquin Ballesteros[1], Alberto Tudela[2], Juan Rafael Caro-Romero[2] and Cristina Urdiales[2]
[1]*Division of Intelligent Future Technologies, Mälardalen University, Västerås*
[2]*Department of Electronic Technology, University of Malaga, Malaga, Spain*

- Attention mechanisms for Comprehensive Geriatric Assessment (CGA).
- Low cost force sensor system to detect user's trends.
- A system easily attachable to any standard commercial cane with reduced consumption.



14:40–15:55 MoB1.2

A Deployable Soft Robotic Arm with Stiffness Modulation for Assistive Living Applications

Jahanshah Fathi, Timo J. C. Oude Vrielink, Mark S. Runciman and George P. Mylonas LastName
Department of Surgery and Cancer, Imperial College London, United Kingdom

- Three tendon actuation with origami backbone
- Pneumatic stiffness modulation using a solenoid valve to regulate internal chamber pressures
- Length variation capabilities (15cm – 56 cm)
- Weight bearing capabilities of up to 500g and a packing efficiency of 73%


Demonstration of usability

14:40–15:55 MoB1.3

Interaction Force Estimation Using Extended State Observers: An Application to Impedance Based Assistive and Rehabilitation Robotics

Gijo Sebastian, Zeyu Li, Vincent Crocher, Demy Kremers, Ying Tan and Denny Oetomo
School of Engineering,
The University of Melbourne, Australia.

- In rehabilitation robotics, knowledge of interaction forces between patient and robot is critical
  - to quantify the motion capabilities
  - to provide an appropriate physical assistance
- We propose a model-based force observer with convergence proof to estimate the time-varying interaction forces
- Preliminary evaluations in clinical context are promising to estimate interaction forces

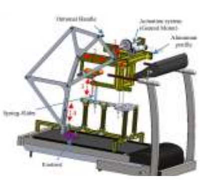

A subject with the EMU rehabilitation robot

14:40–15:55 MoB1.4

Development of a Novel Gait Rehab. Device with Hip Interaction and a Single DOF Mechanism

Mohammad Reza Sabaapour[1], Hosu Lee[2], Muhammad Raheel Afzal[3], Amre Eizad[4] and Jungwon Yoon[2]
[1]Fac. of Mech. and Energy Engg., Shahid Beheshti Univ., Iran; [2]Sch. of Int. Tech., Gwangju Inst. of Sci. and Tech., S. Korea; [3]Dept. of Mech. Engg., KU Leuven, Belgium; [4]Sch. of Mech. Engg., Gyeongsang Natl. Univ., S. Korea.

- A novel gait rehabilitation device using single DOF 8-bar Jansen mechanism is presented.
- The mechanism generates ankle trajectory during gait relative to the hip, in terms of both position and time.
- A seat-type weight support system is used to support weight of the user and mechanisms while providing interaction at the hip.
- A prototype is manufactured, and a pilot study with a healthy subject is conducted to demonstrate feasibility of the concept.


Detailed design of the prototype (mechanism of only one side is shown).

14:40–15:55 MoB1.5

Robot-Based Training for People with Mild Cognitive Impairment

D. Stogl, O. Armbruster, M. Mende, B. Hein, X. Wang
Institute for Anthropomatics and Robotics, Intelligent Process Automation and Robotics Lab (IAR-IPR), Karlsruhe Institute of Technology (KIT), Germany
P. Meyer
Department of Applied Psychology, SRH University, Germany

- Motor activation using a mobile robot
  → Possible influence on the cognitive level
- Guidance of the robotic device along the marked paths using force input
  → Passive controller with high-level modes
- Evaluation with 10 participants (66 – 78 years)
- Results: precision and time performance got better during the training; the participants felt safe and adapted to changing device behavior
  → Training with the device is feasible

14:40–15:55 MoB1.6

Differentially-Clutched Series Elastic Actuator for Robot-Aided Musculoskeletal Rehabilitation

Brayden DeBoon, Scott Nokleby and Carlos Rossa
Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Canada
Nicholas La Delfa
Faculty of Health Sciences, University of Ontario Institute of Technology, Canada

- DC motor, torsion spring, and a magnetic particle brake coupled through a differential gear.
- Able to infer output torque by measuring spring deflection.
- Three distinct operating modes suitable for human-robot interaction with focus on rehabilitation.


Differentially-Clutched Series Elastic Actuator

Medical Robotics III - 1.2.10

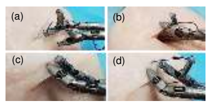
Chair
Co-Chair

14:40–15:55 MoB1.1

A Novel Robotic Suturing System for Flexible Endoscopic Surgery

Lin Cao, Xiaoguo Li, Phuoc Thien Phan, Anthony Meng Huat Tiong, Jiajun Liu and Soo Jay Phee
School of Mechanical and Aerospace Engineering
Nanyang Technological University, Singapore

- A robotic suturing system is developed to close perforations in flexible endoscopy
- A flexible, through-the-scope, dexterous suturing device (Ø4.4 mm) is proposed
- Ex-vivo trials demonstrate how surgical stitches and knots can be endoscopically created and secured
- The demonstrated endoscopic suturing is not possible with existing devices in the literature



Suturing process

14:40–15:55 MoB1.2

Noninvasive Approach to Recovering the Lost Force Feedback for a Robotic-Assisted Insertable Laparoscopic Surgical Camera

Ning Li and Jindong Tan
Biomedical Engineering, University of Tennessee, USA
Gregory J. Mancini
Graduate School of Medicine, University of Tennessee, USA

- Aims to recover the lost force feedback for an insertable laparoscopic **s**urgical **cam**ea (***sCAM***)
- A noninvasive force measurement approach was proposed, implemented and verified
- Experiments characterized camera-tissue contact forces (anchoring, translation, and rotation) and demonstrated effectiveness
- Force feedback enabled closed-loop camera control assisted by a robotic arm


Overview of the sCAM

14:40–15:55 MoB1.3

Development of a Multi-level Stiffness Soft Robotic Module with Force Haptic Feedback for Endoscopic Applications

H. Naghibi, M. W. Gifari, W. Hoitzing, J. W. Lageveen, D.M.M. van As, S. Stramigioli, M. Abayazid
Robotics and Mechatronics (RaM), University of Twente, The Netherlands

- An existing pneumatic endoscopic module was improved to achieve larger bending and multi-level stiffening.
- A force sensing module is mounted on the endoscopic tip, to estimate the tissue interaction force.
- A haptic-feedback control system in 3D was developed to increase the safety during the operation.

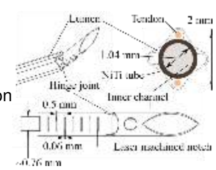

Soft endoscopic module with haptic feedback

14:40–15:55 MoB1.4

Feasibility Study of Robotic Needles with a Rotational Tip-Joint and Notch Patterns

Shivanand Pattanshetti, Abhishek Kottala and Seok Chang Ryu
Mechanical Engineering, Texas A&M University, USA
Read Sandström
Computer Science and Engineering, Texas A&M University, USA
Nancy Amato
Computer Science, University of Illinois Urbana-Champaign, USA

- Robotic steerable needle developed with an embedded tip joint, proximal notches and inner channel.
- Planning simulations run using Cosserat rod based mechanics model with Dynamic Region RRT.
- Steerability tested with 18 BWG needle in ballistic gelatin phantom.
- Minimum radius of curvature of ~12cm achieved.



14:40–15:55 MoB1.5

Autonomous Laparoscopic Robotic Suturing with a Novel Actuated Suturing Tool and 3D Endoscope

H. Saeidi[1], H. N. D. Le[2], J. D. Opfermann[3], S. Leonard[2], A. Kim[4], M. H. Hsieh[3], J. U. Kang[2], and A. Krieger[1]
[1]Dept. of Mechanical Engineering, Univ. of Maryland, College Park, USA; [2]Electrical and Computer Science Engineering Dept., Johns Hopkins University, USA; [3]Sheikh Zayed Institute for Pediatric Surgical Innov., Children's Nat'l Health System, USA; [4]University of Maryland School of Medicine, USA.

- Developed a new 3D imaging endoscope, an actuated laparoscopic suturing tool, and a suture planning strategy for the smart tissue anastomosis robot (STAR).
- Confirmed the feasibility of laparoscopic suturing with STAR using the new suturing tool and 3D endoscope.
- Achieved a superior consistency in suture spacing and minimized the suture repositioning compared to manual laparoscopic methods.

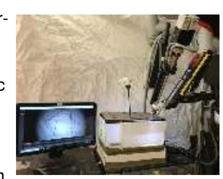

Robotic laparoscopic suturing system

14:40–15:55 MoB1.6

Play Me Back: A Unified Training Platform for Robotic and Laparoscopic Surgery

A. E. Abdelaal[1], M. Sakr[2], A. Avinash[1], S. K. Mohammed[1], A. K. Bajwa[1], M. Sahni[1], S. Hor[3], S. Fels[1], S. E. Salcudean[1]
[1]ECE Dept., University of British Columbia, Canada
[2]Mechanical Engineering Dept., University of British Columbia, Canada
[3]Electrical Engineering Dept., Stanford University, USA

- DisPlay training approach combines hand-over-hand and trial and error training approaches.
- User studies conducted to evaluate this approach for robotic and standard laparoscopic surgical training.
- DisPlay training leads to better accuracy and better transferable skills.
- The da Vinci can be used as a training platform for conventional laparoscopy.


The da Vinci as a conventional laparoscopy training platform.

Telerobotics & Teleoperation II - 1.2.11

Chair
Co-Chair

14:40–15:55 MoB1.1

Active Constraints for Tool-Shaft Collision Avoidance in Minimally Invasive Surgery

Artur Banach
ACRV, Queensland University of Technology, Australia
and Hamlyn Centre, Imperial College London, UK
Konrad Leibrandt, Maria Grammatikopoulou
and Guang-Zhong Yang
Hamlyn Centre, Imperial College London, UK

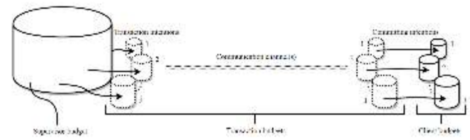
- Surgical tools collision-avoidance framework with frictional Forbidden Region Dynamic Active Constraints
- Frictional Active Constraints approach protecting delicate anatomy in Minimally Invasive Partial Nephrectomy
- Safe resolution of multiple, simultaneous opposing Active Constraint objectives

Teleoperation-based da Vinci Surgical System

14:40–15:55 MoB1.2

Energy Budget Transaction Protocol For Distributed Robotic Systems

Stefan S. Groothuis and Stefano Stramigioli
Robotics and Mechatronics, University of Twente, The Netherlands



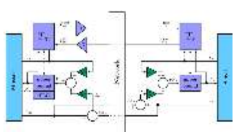
- Systems should be passive for guaranteed stability
- Energy-aware actuators can enforce passivity using energy budgets
- Naive unreliable communication of energy budgets may generate energy or be unnecessarily dissipative
- Transaction protocol developed and simulated to keep passivity in a system during energy communication

14:40–15:55 MoB1.3

Tele-Echography using a Two-Layer Teleoperation Algorithm with Energy Scaling

Enrico Sartori, Carlo Tadiello and Riccardo Muradore
Department of Computer Science, University of Verona, Italy
Cristian Secchi
DISMI Department, University of Modena and Reggio Emilia, Italy

- Passivity-based bilateral teleoperation architecture using the two-layer paradigm
- Scaling factors to cope with different kinds of robots at the master and slave side
- No mathematical models of the robots are required
- Transparent system for tele-echography with both soft and hard contacts

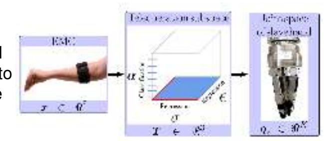


Bilateral Teleoperation Architecture with Scaling Factors

14:40–15:55 MoB1.4

EMG-Controlled Non-Anthropomorphic Hand Teleoperation Using a Continuous Teleoperation Subspace

Cassie Meeker and Matei Ciocarlie
Dept. of Mechanical Eng., Columbia University, USA



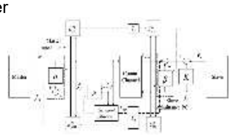
- We present a teleoperation control that projects from forearm EMG into a subspace and then into the pose space of a robot hand.
- We are the first to demonstrate **teleoperation of a non-anthropomorphic, multi-DOF robot hand using forearm EMG**.
- To increase robustness, we use a model which combines continuous and discrete predictors.
- Novice users completed tasks faster using our method than using state-of-the-art methods.

14:40–15:55 MoB1.5

Enhancing the Force Transparency of Time Domain Passivity Approach: Observer-Based Gradient Controller

Harsimran Singh
Institute of Robotics and Mechatronics, DLR, Germany
Aghil Jafari
Faculty of Environment and Technology, UWE, UK
Jee-Hwan Ryu
School of Mechanical Engineering, Koreatech, South Korea

- A new observer-based gradient controller to eliminate TDPA's force jittering on the master side is presented.
- It can be added to any teleoperator without having any prior system information and irrespective of its dynamics.
- Enhances intuitiveness of teleoperation by satisfying the user's expectation of force profile even under time-delayed communication.

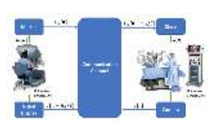


14:40–15:55 MoB1.6

Motion Scaling Solutions for Improved Performance in High Delay Surgical Teleoperation

Florian Richter, Ryan K. Orosco and Michael C. Yip
University of California San Diego, USA

- Remote telesurgery is currently not feasible due to the latency
- This work proposes three simple motion scaling solutions to reduce errors when operating under delay
- Conducted a user study on da Vinci® Surgical System to measure the proposed solutions effectiveness
- 16/17 participants performed best with regards to errors using one of the proposed solutions



Flow chart of teleoperated surgery under delay

Grasping II - 1.2.12

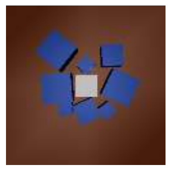
Chair
Co-Chair

14:40–15:55 MoB1.1

Robust object grasping in clutter via singulation

Kiatos Marios and Malassiotis Sotiris
Center of Research and Technology Hellas, Greece
Aristotle University of Thessaloniki, Greece

- We propose a strategy of singulating a target-object from its surrounding clutter
- Singulation is approximated by lateral pushing movements
- We trained an RL agent in simulation in order to obtain optimal push policies
- The robot learns to free the target-object with the minimum number of pushes and achieved a 97% success singulation in simulation
- The learned policy successfully transferred to a real world scenario



Simulated environemt for singulation of white cube

14:40–15:55 MoB1.2

Towards an Integrated Autonomous Data-Driven Grasping System with a Mobile Manipulator

Michael Hegedus[1], Kamal Gupta[1] and Mehran Mehrandezh[2]
[1] School of Engineering Science, Simon Fraser University, Canada
[2] Faculty of Engineering, University of Regina, Canada

- Combines next-best-view (NBV) for modeling with grasp planning and execution
- Eye-in-hand mobile manipulator
- Uses scan overlap as the key feature to improve scan registration for NBV
- Reconstructs an object and performs a grasp while experience base pose uncertainty

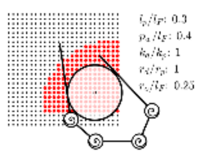
Fig. 1: Eye-in-hand Mobile Manipulator System

14:40–15:55 MoB1.3

Design Principles and Optimization of a Planar Underactuated Hand for Caging Grasps

Walter G. Bircher and Aaron M. Dollar
Department of Mechanical Engineering and Materials Science, Yale University, United States

- Simple underactuated hands can be designed to naturally cage objects as they close
- This behavior is greatly influenced by the chosen design parameters of the hand
- We describe a simple kinematic model to simulate this behavior, and a metric based on quality of cage
- A brute force design space search reveals guiding principles to aid in design of simple “made to cage” hands



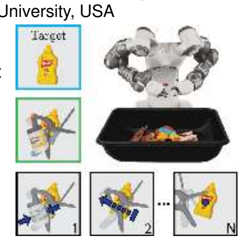
Two finger 2-link tendon driven underactuated hand caging an object

14:40–15:55 MoB1.4

Mechanical Search: Multi-Step Retrieval of a Target Object Occluded by Clutter

Michael Danielczuk[1]*, Andrey Kurenkov[2]*, Ashwin Balakrishna[1], Matthew Matl[1], David Wang[1], Roberto Martín-Martín[2], Animesh Garg[2], Silvio Savarese[2], Ken Goldberg[1]
[1]Electrical Engineering and Computer Science, UC Berkeley, USA
[2]Computer Science, Stanford University, USA

- Mechanical Search describes the class of tasks where the goal is to locate and extract a known target object.
- We present a study of 5 algorithmic policies for mechanical search for bin picking, with over 15,000 simulated trials and 300 physical trials.
- Results suggest that success can be achieved in this long-horizon task with algorithmic policies in over 95% of instances.



The system selects between grasping and pushing objects until the target object is extracted.

14:40–15:55 MoB1.5

Transferring Grasp Configurations using Active Learning and Local Replanning

Hao Tian, Changbo Wang and Xinyu Zhang
School of Computer Science and Software Engineering, East China Normal University, China
Dinesh Manocha
Department of Computer Science, University of Maryland, USA

- A new **hybrid grasp measure** for determining stable grasp configurations.
- Grasp transfer through **bijective contact mapping** and compute the corresponding grasps for novel objects.
- Assemble the individual parts and use local replanning to adjust grasp configurations.
- Our method can handle objects represented using mesh or point cloud and a variety of robotic hands.

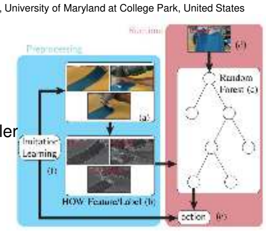
Grasp configurations of novel objects before and after part assembly and local replanning

14:40–15:55 MoB1.6

Cloth Manipulation Using Random-Forest-Based Controller Parametrization

Biao Jia
Department of Computer Science, University of at Maryland at College Park, United States
Zherong Pan
Department of Computer Science, University of North Carolina at Chapel Hill, United States
Zhe Hu
Department of Mechanical Biomedical Engineering, City University of Hong Kong, China
Jia Pan
Department of Computer Science, the University of Hong Kong, China
Dinesh Manocha
Departments of Computer Science and Electrical Computer Engineering, University of Maryland at College Park, United States

- A random-forest-based DOM-controller parametrization which is robust and less parameter-sensitive.
- An imitation learning algorithm based framework that trains robust DOM controller using a cloth simulator.
- Our approach performs equally well in a simulated environment and a real-world scenario.



Parallel Robots II - 1.2.13

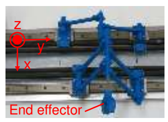
Chair
Co-Chair

14:40–15:55	MoB1.1

Kinematic Analysis of a 4-DOF Parallel Mechanism with Large Translational and Orientational Workspace

Shoichiro Kamada
Hitachi High-Technologies Corporation, Japan
Thierry Laliberté and Clément Gosselin
Départment de Génie Mécanique, Université Laval, Canada

- A novel 4-DOF parallel mechanism having 3 translational DOFs and 1 rotational DOF is introduced.
- The translational DOF along the y-axis and the rotational DOF around the x-axis are large.
- The kinematic equations of the mechanism are derived and the singularities are revealed.
- The geometric description of the boundaries of the workspace is given.



Prototype of one of the design examples

14:40–15:55	MoB1.2

Vision-Based Control and Stability Analysis of a Cable-Driven Parallel Robot

Zane ZAKE[1,2], François CHAUMETTE[3], Nicolò PEDEMONTE[2], and Stéphane CARO[1]

- Stability analysis of pose-based visual servoing control of a cable-driven parallel robot
- High robustness to coarse models and mis-calibrations
- Improved final accuracy when compared to a pure model-based control
- Experimentally validated on a 1m x 1m x 1m CDPR prototype ACROBOT

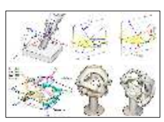
[1]CNRS, LS2N, Nantes, France
[2]IRT Jules Verne, Bouguenais, France
[3]Inria, Rennes, France
contact: stephane.caro@ls2n.fr

14:40–15:55	MoB1.3

Symmetric Subspace Motion Generators

Yuanqing WU and Marco Carricato
Department of Industrial Engineering, University of Bologna, Italy

- Modeling symmetric manipulation with symmetric subspaces of SE(3)
- How to design kinematic chains for a symmetric manipulation task
- How to design parallel manipulators for a symmetric manipulation task
- Potential applications


Pointing device is a particular example

14:40–15:55	MoB1.4

Kinematically Redundant (6+3)-dof Hybrid Parallel Robot with Large Orientational Workspace and Remotely Operated Gripper

Kefei Wen, David Harton, Thierry Laliberté and Clément Gosselin
Department of Mechanical Engineering, Université Laval, Canada

- Very simple type II singularity conditions
- Both type I and type II singularities are easily avoidable throughout the workspace
- The robot can produce a very large orientational workspace (>±90° tilt and torsion)
- The redundancies can be further utilized to operate a gripper on the moving platform from the base actuators

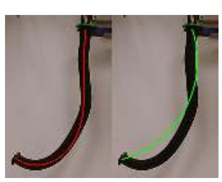

CAD model of the (6+3)-dof hybrid parallel robot including partial static balancing

14:40–15:55	MoB1.5

Modeling Variable Curvature Parallel Continuum Robots Using Euler Curves

Phanideep S. Gonthina, Apoorva D. Kapadia and Ian D. Walker
ECE Department, Clemson University, U.S.A
Isuru S. Godage
School of Computing, DePaul University, U.S.A

- Euler spirals, also termed Clothoids, are applied to the kinematic modeling of continuum robots for the first time.
- This new approach was applied to several continuum sections and compared with the constant curvature model.
- Mawby: A novel parallel Continuum gripper inspired by the Barrett Hand.
- Separating Sections: A squid inspired robot.

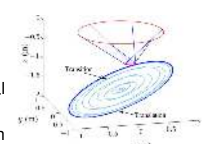

Euler vs constant curvature modeling

14:40–15:55	MoB1.6

Periodic Trajectory Planning Beyond the Static Workspace for Six-DOF Cable-Suspended Parallel Robots

Xiaoling Jiang, Eric Barnett, and Clément Gosselin
Department of Mechanical Engineering, Université Laval, Canada

- A passive mechanical system that is equivalent to this type of robot is introduced
- The dynamic differential equations are linearized and integrated, producing a general solution for periodic trajectories
- The solution is used to create complex motion with changes in position and orientation
- An experimental implementation is described, and a video shows the prototype following periodic trajectories


The six-DOF robot following a trajectory

Exoskeletons II - 1.2.14

Chair
Co-Chair

14:40–15:55	MoB1.1

Variable Damping Control of the Robotic Ankle Joint to Improve Trade-off between Performance and Stability

James Arnold, Harrison Hanzlick, and Hyunglae Lee*
School for Engineering of Matter, Transport and Energy
Arizona State University (ASU)

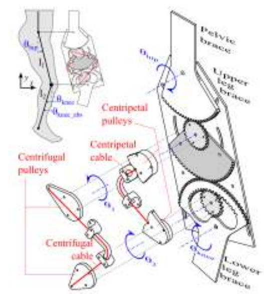
- This paper presents a variable damping control strategy to improve trade-off between agility/performance and stability in the control of the ankle exoskeleton robot.
- Depending on the user's intent of movement, the proposed variable damping controller determines the robotic ankle damping from negative to positive damping values.
- We demonstrated that humans could get benefits of not only positive damping to stabilize the ankle but also negative damping to enhance the agility of ankle movement as necessary during dynamic ankle movement.

14:40–15:55	MoB1.2

Design of a Compliant Mechanical Device for Upper-Leg Rehabilitation

Dmitri Fedorov and Lionel Birglen
Department of Mechanical Engineering, Polytechnique Montréal, Canada

- Entirely passive mechanism generating a potential energy field around a the human gait cycle.
- The elongations of two compliant cables are linked to the articular rotations.
- Non-circular pulleys are used to obtain the desired cable elongations.

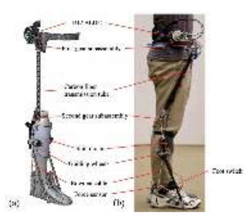


14:40–15:55	MoB1.3

An Autonomous Exoskeleton for Ankle Plantarflexion Assistance

Albert Wu
Dept. of EECS, M.I.T., U.S.A.
Xingbang Yang, Jiun-Yih Kuan, Hugh M. Herr
Media Lab, M.I.T., U.S.A.

- An autonomous exoskeleton with high efficiency transmission and low device inertia was developed.
- The exoskeleton has a torque bandwidth of 17.5Hz and can adaptively track walking biological torque.
- Augmentation Factor (AF) of the exoskeleton is 64.7W, demonstrating potential to reduce metabolic cost.
- The exoskeleton establishes an autonomous platform for ankle assistance experiments.



(a) Exoskeleton CAD and (b) Completed Exoskeleton

14:40–15:55	MoB1.4

Hybrid Open-Loop Closed-Loop Control of Coupled Human-Robot Balance During Assisted Stance Transition with Extra Robotic Legs

Daniel J. Gonzalez and H. Harry Asada
Department of Mechanical Engineering
Massachusetts Institute of Technology (MIT), USA

- Robot must balance itself while applying an upward assistive force to the human while they perform work near the ground.
- Robot controls its own balance and stability using position control of **X**, **Y**, **Roll**, and **Yaw.**
- Human determines the pace of squat transition motion (**Z**, **Pitch**) through force interaction.
- **Hybrid Open-Loop** / **Closed-Loop Architecture** allows for mixing both control goals in a systematic manner.

14:40–15:55	MoB1.5

Continuous-Phase Control of a Powered Knee–Ankle Prosthesis: Amputee Experiments Across Speeds and Inclines

David Quintero
Mechanical Engineering,
San Francisco State University, USA

Dario J. Villarreal
Electrical & Computer Engineering,
Southern Methodist University, USA

Daniel J. Lambert
Electrical Engineering,
University of Texas at Dallas, USA

Susan Kapp
Rehabilitation Medicine,
University of Washington, USA

Robert D. Gregg
Bioengineering,
University of Texas at Dallas, USA

- Controllers in robotic prosthetic legs typically divide the gait cycle into periods, resulting in several tunable parameters across users and activities.
- We present a controller that unifies the gait cycle of a robotic knee–ankle prosthesis using virtual constraints.
- These constraints characterize the desired joint trajectories as functions of a phase variable, computed from the amputee's residual thigh motion.
- The controller has a fixed set of control gains, across activities and users, and allowed three amputee subjects control over the timing of the prosthetic joint patterns at walking speeds from 0.67 to 1.21 m/s and slopes from -2.5° to $+9.0^\circ$.

Collision Avoidance - 1.2.15

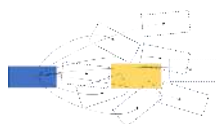
Chair
Co-Chair

14:40–15:55 MoB1.1

Analytic Collision Risk Calculation for Autonomous Vehicle Navigation

Andreas Philipp and Daniel Goehring
Computer Science Institute, Freie Universität Berlin, Germany

- Probabilistic Collision Risk Calculation is Mandatory for Autonomous Vehicles
- Rectangular Shape of the Vehicles Must Be Taken into Account in Dense Traffic
- Common Solutions Based on Monte Carlo Simulation are too Slow
- Fast Analytical Method has been Developed and Integrated into Self Driving Car Solution of the Freie Universität Berlin



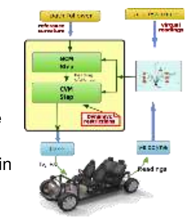
Samples of Predicted Poses of Moving Object

14:40–15:55 MoB1.2

A new approach to local navigation for autonomous driving vehicles based on the CVM.

J. López, C. Otero, R. Sanz and E. Paz
Dept. of Systems Eng. and Automation, University of Vigo, Spain
E. Molinos and R. Barea
Dept. of Electronics, University of Alcalá, Spain

- This paper presents a car navigation system to follow a road path consisting on a sequence of lanelets.
- Local Navigation loop is divided in two steps:
  - 1.- A pure pursuit method obtains a curvature reference to follow the planned path.
  - 2.- Using that reference, BCM keeps the car in the center of the free lane space avoiding obstacles that can partially block the lane.



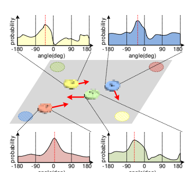
Local navigation obstacle avoidance step.

14:40–15:55 MoB1.3

Goal-Driven Navigation for Non-holonomic Multi-Robot System by Learning Collision

H. W. Jun, H. J. Kim and B. H. Lee
Department of Electrical and Computer Engineering, Seoul National University, South Korea

- The reinforcement learning based multi-robot collision avoidance approach named Collision Avoidance by Learning Collision (CALC) is proposed in the paper
- CALC learns collision and use the policy into goal-driven multi-robot collision avoidance problem
- The proposed method is validated both in the robot simulation with Gazebo simulator and real robot experiment with e-puck mobile robot



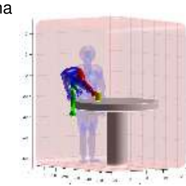
The concept of the proposed method

14:40–15:55 MoB1.4

Efficient Exact Collision Detection between Ellipsoids and Superquadrics via Closed-form Minkowski Sums

Sipu Ruan[1], Karen L. Poblete[1], Yingke Li[3], Qian Lin[3], Qianli Ma[4] and Gregory S. Chirikjian[1,2]
[1] Lab for Computational Sensing and Robotics, Johns Hopkins University, USA
[2] Dept. of Mechanical Engineering, National University of Singapore, Singapore
[3] Tsinghua University, China
[4] Aptiv, USA

- The closed-form Minkowski sum between an ellipsoid and any surface in $\mathbb{R}^n$ is reviewed;
- Point query for parametric surfaces is derived;
- An exact collision detection algorithm between ellipsoids and superquadrics is proposed;
- Algorithmic accuracy based on the Principal Kinematic Formula and running time efficiency are benchmarked.



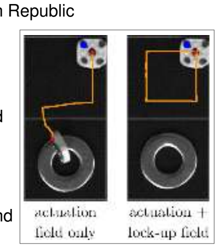
A poly-ellipsoidal humanoid robot is picking up a cup while avoiding collisions with the poly-superquadrics table.

14:40–15:55 MoB1.5

Positioning Uncertainty Reduction of Magnetically Guided Actuation on Planar Surfaces

Martin Jurik, Jiri Kuthan, Jiri Vlcek, Frantisek Mach
Faculty of Electrical Engineering, University of West Bohemia, Czech Republic

- Magnetic actuation of miniature robots based on the coplanar coils is discussed
- A major goal is to analyze key design and operation parameters towards the reduction of positioning uncertainty
- A technique based on superposition of actuation and lock-up field is proposed and experimentally tested



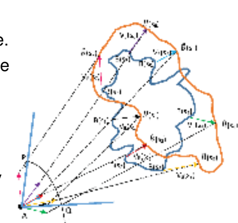
Miniature robot interaction with ferromagnetic barrier.

14:40–15:55 MoB1.6

Collision Avoidance of Arbitrarily Shaped Deforming Objects using Collision Cones

V. Sunkara[1], A. Chakravarthy[2], D. Ghose[3]
[1]Marine Science, University of Southern Mississippi, USA
[2]Mech. and Aero. Engineering, University of Texas at Arlington, USA
[3]Aerospace Engineering, Indian Institute of Science, India

- We consider collision avoidance of objects whose shape changes as a function of time.
- Such shape changing objects include snake robots, boundaries of vehicle swarms, boundaries of oil spills.
- Collision cone equations are developed for such deforming entities.
- These are then embedded into a Lyapunov framework to determine guidance laws for collision avoidance.



Agricultural Robotics - 1.2.16

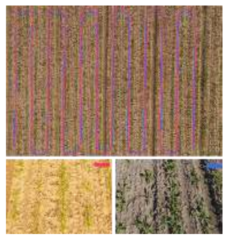
Chair
Co-Chair

14:40–15:55	MoB1.1

Robot Localization Based on Aerial Images for Precision Agriculture Tasks in Crop Fields

Nived Chebrolu, Philipp Lottes, Thomas Läbe and Cyrill Stachniss
University of Bonn, Germany

- Localization in **crop fields** over extended periods of time using aerial images as maps.
- Provides **crop-row** level accuracy for navigating in the field.
- Handles changing environment by exploiting **semantics** in the field.
- Supports localization over **multiple sessions** without requiring explicit remapping.



14:40–15:55	MoB1.2

Visual Appearance Analysis of Forest Scenes for Monocular SLAM

James Garforth and Barbara Webb
School of Informatics, University of Edinburgh, UK

- Performance of state of the art visual mapping systems is compared on forest datasets
- Visual scene statistics used to identify distinguishing traits of forests over "classic" urban scenes
- Photorealistic forest simulation proposed as testbed for developing improvements, but fails to reflect distinguishing statistics

14:40–15:55	MoB1.3

An Approach for Semantic Segmentation of Tree-like Vegetation

S. Tejaswi Digumarti, Lukas M. Schmid, Giuseppe M. Rizzi, Juan Nieto, Roland Siegwart, Cesar Cadena
Autonomous Systems Lab, ETH Zurich, Switzerland
Paul Beardsley
Disney Research, Zurich, Switzerland

- We present a deep learning approach to segment RGB-D images of vegetation into 4 components – trunk, branches, twigs, leaves.
- Late fusion of depth data, encoded as HHA images, to RGB images performs better than early fusion.
- Asynchronous training with different learning rates for the RGB and HHA sub-networks achieves best performance (92.5% accuracy).
- Training done on simulated tree data.

A sample result of the proposed approach

14:40–15:55	MoB1.4

Thermal Image Based Navigation System for Skid-Steering Mobile Robots in Sugarcane Crops

Marco Xaud and Pål From
Fac. of Sci. and Technology, Norwegian University of Life Sciences, Norway
Antonio Leite
Dep. Elect. Engineering, Pontifical Catholic University of Rio de Janeiro, Brazil

- Autonomous navigation of TIBA robot along row crop tunnels in sugarcane farms;
- Thermal IR imaging and deep learning for offset estimation and trajectory planning;
- Modeling and control design for mobile robots with the skid-steering driving profile;
- Numerical simulations and experimental tests for verification and validation.

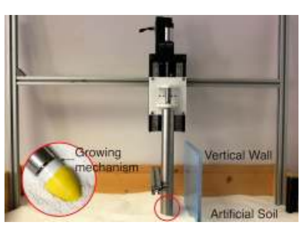
TIBA robot in sugarcane field; RGB and IR images.

14:40–15:55	MoB1.5

Dynamic Obstacles Detection for Robotic Soil Explorations

Francesco Visentin, Ali Sadeghi, and Barbara Mazzolai
Institute of Technology, Center for Micro-Biorobotics

- Robots can navigate complex and dynamic environments, but moving into soil is still a challenge.
- We propos a method to detect obstacles while moving into the soil by growing.
- By the use of a 6DOF force sensor we predict the relative position of the obstacle before touching it with the robot.

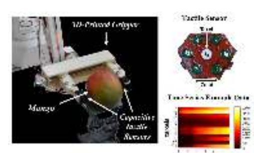


14:40–15:55	MoB1.6

Non-Destructive Robotic Assessment of Mango Ripeness via Multi-Point Soft Haptics

Luca Scimeca and Perla Maiolino and Fumiya Iida
Department of Engineering, University of Cambridge, United Kingdom
Biologically Inspired Robotics Laboratory

- There is a need to find alternatives to the destructive fruit ripeness estimation by penetrometer instruments.
- We propose a non-destructive alternative to mango ripeness estimation.
- A custom-made gripper, coupled with capacitive tactile sensor arrays performs soft-touch experiments on mangos.
- The method is capable of classifying mangos at different ripeness stages, without fruit damage.



Experimental set-up, tactile skin, and example sensor data

Aerial Systems: Perception II - 1.2.17

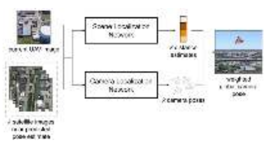
Chair
Co-Chair

14:40–15:55 MoB1.1

UAV Pose Estimation using Cross-view Geolocalization with Satellite Imagery

Akshay Shetty and Grace Xingxin Gao
Aerospace Engineering, University of Illinois Urbana-Champaign, USA

- Estimated global pose of a UAV using nearby satellite imagery
- Combined outputs from two neural network to obtain the pose output
- Integrated pose output with visual odometry
- Significantly reduced trajectory estimation errors compared to previous cross-view geolocalization methods



Global camera pose estimate from our cross-view geolocalization method

14:40–15:55 MoB1.2

The Open Vision Computer: An Integrated Sensing and Compute System for Mobile Robots

Morgan Quigley*, Kartik Mohta, Shreyas S. Shivakumar, Michael Watterson, Yash Mulgaonkar, Mikael Arguedas*, Ke Sun
*Open Source Robotics Foundation, Mountain View, USA
Sikang Liu, Bernd Pfrommer, Vijay Kumar and Camillo J. Taylor
GRASP Laboratory, University of Pennsylvania, USA

- Tightly integrated compute and sensing platform to support high speed, vision guided autonomous flight
- Sufficient computational power from NVIDIA TX2 and Cyclone V FPGA
- Efficiently runs real-time state estimation, mapping, planning, depth perception and learning based methods for object detection and segmentation
- Open source: http://open.vision.computer

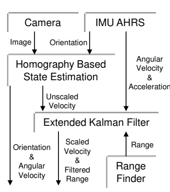
Open Vision Computer on our Falcon 250 Platform

14:40–15:55 MoB1.3

RaD-VIO: Rangefinder-aided Downward Visual-Inertial Odometry

Bo Fu, Kumar Shaurya Shankar, and Nathan Michael
Robotics Institute, Carnegie Mellon University, USA

- A direct frame-to-frame VIO algorithm that minimises a joint photometric and inertial cost function;
- An EKF structure to incorporate this with a single-beam rangefinder signal and estimate IMU bias;
- Extensive evaluation on a variety of environments with comparisons with state of the art algorithms.



System Diagram

14:40–15:55 MoB1.4

UVDAR System for Visual Relative Localization with Application to Leader-Follower Formations of Multirotor UAVs

Viktor Walter, Nicolas Staub, Martin Saska
Department of Cybernetics, Czech Technical University, Czech Republic
Antonio Franchi
LAAS-CNRS, Université de Toulouse

- UVDAR system for relative mutual localization of UAVs based on ultraviolet light and specialized image processing
- The system is robust to a range of outdoor conditions
- This paper demostrates the use of UVDAR in real-world setting, on an example of directed leader-follower flight, showing the retrieved knowledge of relative position and orientation of the leader

Example of trajectory derived from UVDAR data

14:40–15:55 MoB1.5

Communication-Efficient Planning and Mapping for Multi-Robot Exploration in Large Environments

Micah Corah, Cormac O'Meadhra, Kshitij Goel, and Nathan Michael
Robotics Institute, Carnegie Mellon University, Pittsburgh, PA

- Achieve communication-efficient multi-robot exploration via compact representations
- Gaussian mixture model efficiently approximates depth data for use in mapping
- A library of views represents the distribution of informative observations
- Robots maximize information gain and minimize distance to informative views on a local grid map

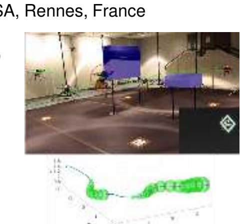
Three robots explore a warehouse environment

14:40–15:55 MoB1.6

Minimum-Time Trajectory Generation Under Intermittent Measurements

Bryan Penin[1], Paolo Robuffo Giordano[2], François Chaumette[1]
[1]Inria, Univ Rennes, CNRS, IRISA, Rennes, France
[2]CNRS, Univ Rennes, Inria, IRISA, Rennes, France

- Planning **minimum-time** and **feasible 3D** trajectories for **flat systems** (e.g., a quadrotor, a unicycle)
- Considering **intermittent visual measurements** function of the **system state** (from scattered visual targets)
- A **bi-directional** hybrid-A* **uncertainty-aware** algorithm is proposed
- Initial and final state **exact connection**
- **Experimental validation** on a quadrotor UAV with onboard camera



A quadrotor following a trajectory. State uncertainty is reduced when a landmark is visible

Aerial Systems: Applications II - 1.2.18

Chair
Co-Chair

14:40–15:55 MoB1.1

Learning to Capture a Film-Look Video with a Camera Drone

Chong Huang[1], Zhenyu Yang[1], Yan Kong[1], Peng Chen[2], Xin Yang[3], and Kwang-Ting (Tim) Cheng[4]

[1] University of California, Santa Barbara
[2] Zhejiang University of Technology
[3] Huazhong University of Science and Technology
[4] Hong Kong University of Science and Technology

- Propose a learning-based approach, which can imitate a professional cameraman's intention for capturing a film-look aerial footage of a single subject in real-time:
- 1) Train a network to predict the future image composition and camera position.
- 2) Generate control commands to achieve the desired shot framing.

Experimental Setup

14:40–15:55 MoB1.2

Design and Experiments for MultI-Section-Transformable (MIST)-UAV

Ruben D'Sa and Nikolaos Papanikolopoulos
Department of Computer Science and Engineering
University of Minnesota, USA

- Discussion of aerial robot design and hardware components.
- Overview of system modeling and control.
- Demonstration of multiple outdoor multi-rotor to fixed-wing to multi-rotor transformations.

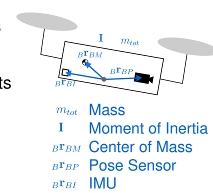
Multi-rotor to Fixed-wing Transformation

14:40–15:55 MoB1.3

Online Estimation of Geometric and Inertia Parameters for Multirotor Aerial Vehicles

Valentin Wüest[1], Vijay Kumar[1], Giuseppe Loianno[2]
[1] University of Pennsylvania, USA
[2] New York University, USA

- Flexible multirotor framework for onboard in-flight estimation of key dynamic parameters
- Recursive filtering on SO(3) to fuse motor speeds with IMU & pose sensor measurements
- Non-linear Observability Analysis providing insights into the role of each sensor module
- Experiments showing convergence and the ability to re-estimate parameters online

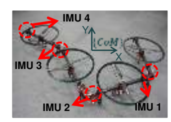


14:40–15:55 MoB1.4

External Wrench Estimation for Multilink Aerial Robot by Center of Mass Estimator Based on Distributed IMU System

Fan Shi, Moju Zhao, Tomoki Anzai, Xiangyu Chen, Kei Okada, Masayuki Inaba
Information Science and Technology, the University of Tokyo, Japan

- Estimate external force and torque based on distributed IMU systems
- Estimate contact position based on robot model and external wrench
- Design contact-aided strategy for aerial transformable robot to avoid collision
- Experimentally validate the framework on simulation and the real robot



The 4-links aerial transformable robot with distributed IMU sensors on each link

14:40–15:55 MoB1.5

A Novel Development of Robots with Cooperative Strategy for Long-term and Close-proximity Autonomous Transmission-line Inspection

Jiang Bian, Xiaolong Hui, Xiaoguang Zhao and Min Tan
The State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, China.

- We develop two cooperative robots for power transmission lines (PTLs) inspection.
- A light climbing robot (CBR) can stably move on the overhead ground wire (OGW).
- An unmanned aerial vehicle (UAV) with a grabbing mechanism can automatically put the CBR on the OGW and take it off.
- It is different from the existing transmission-line inspection methods and can satisfy the two challenging inspection requirements — long term and close proximity.

The UAV can automatically place and grab the CBR

14:40–15:55 MoB1.6

Hunting Drones with Other Drones: Tracking a Moving Radio Target

Louis Dressel and Mykel J. Kochenderfer
Aeronautics and Astronautics, Stanford University, USA

- Seeker drone tracks a moving target drone by its telemetry radio emissions
- Seeker drone has simple antennas and low-cost software-defined radios
- Seeker uses non-myopic planner to quickly localize target while reducing near-collisions
- Flight tests validate system but suggest unmodeled noise is present

Seeker drone (left) and target drone (right)

Force Control and Force Sensing - 1.2.19

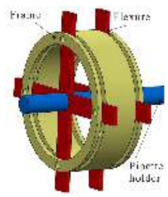
Chair
Co-Chair

14:40–15:55	MoB1.1

Design and Testing of a New Cell Microinjector with Embedded Soft Force Sensor

Yuzhang Wei and Qingsong Xu
Department of Electromechaincal Engineering, University of Macau, Macau, China

- A novel force-sensing cell injector is designed with piezoresistive force sensor embedded in soft materials
- The soft sensor acts as fixed-guided beams, which achieve uniaxial force measurement with high sensitivity
- The injector is developed by considering the installation and replacement issues of the micropipette and the connection issue of air tube
- A prototype is fabricated and experimental study is conducted to verify its performance

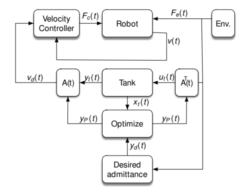


14:40–15:55	MoB1.2

Energy Optimization for a Robust and Flexible Interaction Control

Cristian Secchi, Federica Ferraguti
University of Modena and Reggio Emilia

- The possibility of adapting the behavior of a robot during the interaction is very important
- The robustness of admittance control is lost when trying to change the admittance dynamics
- An energy tank based architecture for ensuring an optimally robust and flexible behavior is proposed
- Experiments in physical human robot interaction are proposed

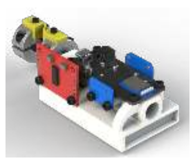


14:40–15:55	MoB1.3

Design of Versatile and Low-Cost Shaft Sensor for Health Monitoring

Erik Gest, Mikio Furokawa, and Kamal Youcef-Toumi
Mechanical Engineering, MIT, USA
Takayuki Hirano
The Japan Steel Works, LTD., Japan

- Measures torque, speed, vibration, and some modes of bending
- Transmits data wirelessly
- All components mounted on shaft; no stationary parts required
- Very low cost compared to other torque sensors



14:40–15:55	MoB1.4

Robust Execution of Contact-Rich Motion Plans by Hybrid Force-Velocity Control

Yifan Hou and Matt Mason
Robotics Institute, Carnegie Mellon University, United States

- Using hybrid force-velocity control, robots can execute contact-rich motion plans robustly.
- Velocity control is precise and robust against force disturbances. Force control is robust against positional uncertainties. We combine the best part of both worlds.
- We propose an algorithm to compute the best hybrid force-velocity control for given tasks
- Our method is experimentally tested on two tasks.

14:40–15:55	MoB1.5

Endoscope Force Generation and Intrinsic Sensing with Environmental Scaffolding

J. E. Bernth, J. Back, G. Abrahams, L. Lindenroth and H. Liu
Haptic Mechatronics and Medical Robotics Lab, King's College London, UK
B. Hayee
King's College Hospital, King's College London, UK

- Endoscopic surgery is becoming an increasingly popular alternative to laparoscopic techniques.
- The maximum force endoscopes can apply is limited due to flexibility and length.
- This paper presents techniques for intrinsically measuring contact forces in endoscopic robots and…
- How endoscopes can use the colon lumen to increase the maximum applied distal force.

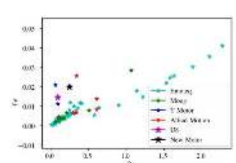
An endoscope using the environment to increase maximum palpation force.

14:40–15:55	MoB1.6

Task-Based Control and Design of a BLDC Actuator for Robotics

Avik De, Abriana Stewart-Height, and Daniel E. Koditschek
Electrical and Systems Engineering, University of Pennsylvania, USA

- We propose a new multi-input brushless DC motor control policy beyond a "torque amplifier" abstraction
- For force and power-constrained tasks, this controller achieves better empirical performance
- It retains torque-tracking and stability characteristics of the conventional strategy
- Non-conventional motor design optimizations are shown to vastly amplify the effectiveness of this new control strategy



Human Factors - 1.2.20

Chair
Co-Chair

14:40–15:55 MoB1.1

On the Combination of Gamification and Crowd Computation in Industrial Automation and Robotics Applications

Tom Bewley
Dept. of Computer Science, University of Bristol, United Kingdom
Minas Liarokapis
Dept. of Mechanical Engineering, University of Auckland, New Zealand

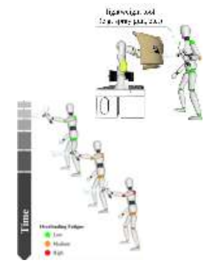
- We propose the use of video games to crowdsource the cognitive versatility and creativity of human players to solve complex problems in industrial automation and robotics applications.
- We introduce a theoretical framework in which robotics problems are embedded into video game environments and gameplay from crowds of players is aggregated to inform robot actions.
- Further work is needed to explore these wider implications, as well as to develop the technical theory behind the framework and build prototype applications.

14:40–15:55 MoB1.2

A New Overloading Fatigue Model for Ergonomic Risk Assessment in Human-Robot Collaboration

Marta Lorenzini, Wansoo Kim, and Arash Ajoudani
HRII Lab. of the Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Italy
Elena De Momi
Dept. of Electronics, Information and Bioengineering, Politecnico di Milano, Italy

- We propose a new whole-body fatigue model to evaluate the cumulative effect of the overloading torque induced on the joints over time by external lightweight payloads.
- The proposed model is integrated in a human-robot collaboration (HRC) framework to set the timing of a body posture optimisation procedure guided by the robot assistance.
- The robot guides the subject towards a more ergonomic body posture to reduce the risk of injuries while performing repetitive tasks.

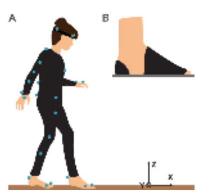


14:40–15:55 MoB1.3

Human-inspired balance model to account for foot-beam interaction mechanics

Jongwoo Lee[1], Meghan E. Huber[1], Enrico Chiovetto[2], Martin Giese[2], Dagmar Sternad[3], Neville Hogan[1,4]
[1]Department of Mechanical Engineering, MIT, USA, [2]Department of Cognitive Neurology, University Clinic Tübingen, Germany, [3]Departments of Biology, Electrical and Computer Engineering, and Physics, Northeastern University, USA, [4]Department of Brain and Cognitive Sciences, MIT, USA

- We examined human mediolateral balance when standing on a narrow beam.
- Our results show that foot-beam interaction dynamics critically influence balancing.
- A simplified model of foot-beam interaction added to a double inverted pendulum model could replicate the change in human behavior.
- Understanding human whole body coordination may inform the development of balance controllers for bipedal robots.



14:40–15:55 MoB1.4

Real-time Robot-Assisted Ergonomics

A. Shafti, A. Ataka, B. Urbistondo Lazpita, A. Shiva, H.A. Wurdemann and K.Althoefer
Imperial College London,
King's College London,
University College London,
Queen Mary University of London, United Kingdom

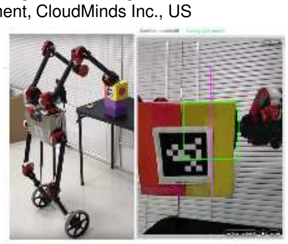
- Robotic system continuously inspects the user's postural ergonomics
- Human-robot interaction is driven by the user's comfort, continuously being optimised
- Organically leads to robot moving as desired and needed to fulfil the task at hand

14:40–15:55 MoB1.5

A Fog Robotic System for Dynamic Visual Servoing

Nan Tian, Ajay K. Tanwani, Ken Goldberg, Somayeh Sojoud
Department of EECS, UC Berkeley, US
Mas Ma, Robert Zhang, Bill Huang
Advanced Technology Department, CloudMinds Inc., US

- A Fog Robotic Cloud-Edge hybrid controller
- Cloud-based assisted teleoperation of a self-balancing robot
- A Fog Robotic image-based visual servoing (IBVS) module for automatic box pickups
- Automatic box pickups from a moving person



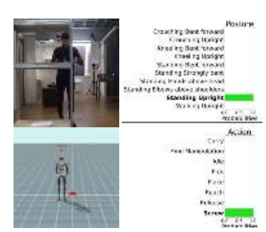
Automatic Box Pickup using a Dynamic Self-Balancing Robot

14:40–15:55 MoB1.6

Activity Recognition for Ergonomics Assessment of Industrial Tasks with Automatic Feature Selection

Adrien Malaisé, Pauline Maurice, Francis Colas, Serena Ivaldi
Inria Nancy, Université de Lorraine, Nancy, France

- Inferring postures and actions related to standard **ergonomic assessment** worksheet
- Identifying dedicated **sets of features** to be used for activity recognition models
- Human whole body motion capture data from 17 **inertial sensors** (Xsens suit)
- Classification based on **Hidden Markov Models** trained with supervised learning



Distributed Robots - 1.2.21

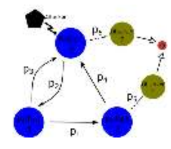
Chair
Co-Chair

14:40–15:55	MoB1.1

Approximate Probabilistic Security for Networked Multi-Robot Systems

Remy Wehbe and Ryan K. Williams
Department of Electrical and Computer Engineering, Virginia Tech, USA

- Formulating a combinatorial optimization problem for estimating the probability of security of a multi-robot system (MRS)
- Performing the necessary simplifications and presenting a solution to the optimization problem
- Introducing two approaches that allow the optimization algorithm to be applied to dynamic MRS
- Tracking the probability of security of an MRS performing a rendezvous objective.


Multi-Robot system with probabilistic interactions under attack

14:40–15:55	MoB1.2

A Decentralized Heterogeneous Control Strategy for a Class of Infinitesimally Shape-Similar Formations

Ian Buckley and Magnus Egerstedt
Institute of Robotics and Intelligent Machines,
Georgia Institute of Technology, USA

- Control of triangulations, a class of infinitesimally shape-similar formations, is considered.
- The multi-robot team is heterogeneous in terms of the sensing modalities available to the robots.
- By exploiting the structure, the formation can be maintained using bearing-only information.
- Limited access to distance information enables control of the formation's position, heading, and scale.

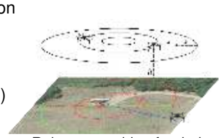

The decentralized formation control strategy is deployed on a team of differential-drive robots.

14:40–15:55	MoB1.3

Asynchronous Network Formation in Unknown Unbounded Environments

Selim Engin and Volkan Isler
Computer Science and Engineering, University of Minnesota, USA

- We study the problem of online network formation where the robots have bounded communication range and their locations are unknown
- We present an online algorithm whose competitive ratio is O(MH) for arbitrary and O(M) for uniformly random deployments, where M is the longest edge length in the MST of the initial configuration and H is the height of the tree
- The algorithm is demonstrated on a multi-UAV system in field experiments

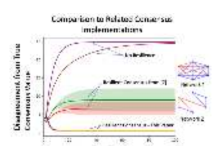

Robots searching for their peer robots who are inactive

14:40–15:55	MoB1.4

ICRA 2019 Digest
Switching Topology for Resilient Consensus using Wi-Fi Signals

Thomas Wheeler and Ezhil Bharathi and Stephanie Gil
CIDSE, Arizona State University, USA

- Distributed consensus is a fundamental algorithm to multi-robot coordination, but is vulnerable to Sybil attack.
- Build off prior work, leveraging physical information from commodity Wi-Fi chips to recognize malicious nodes.
- We achieve consensus through deliberate topology switching in a stochastic manner based off inter agent trust

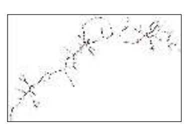


14:40–15:55	MoB1.5

Multi-Vehicle Trajectory Optimisation On Road Networks

Philip Gun, Andrew Hill, and Robin Vujanic
RTCMA, ACFR, University of Sydney, Australia

- Time-optimal trajectories planned for multiple cooperative agents along specified paths
- Trajectories are centrally optimised with MILP, and account for interactions at intersections
- Computational performance improved by reducing binary variables with iteratively applied targeted collision-avoidance constraints
- Simulation results compare proposed methods against a fast heuristic method and on-site practices

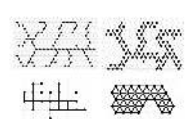

Mine road network graph. Trajectories are planned over coloured paths

14:40–15:55	MoB1.6

Design Guarantees for Resilient Robot Formations on Lattices

Luis Guerrero-Bonilla, David Saldaña, and Vijay Kumar
GRASP Laboratory, University of Pennsylvania, USA

- Robot formations with r-robust communication networks achieve consensus in the presence of malicious robots.
- We guarantee r-robust networks in robot formations over triangular and square lattices.
- Our design guarantees consider obstacles, number of robots, energy usage, heterogeneous communication ranges.


Examples of robot formations on lattices

Motion Control for Navigation - 1.2.22

Chair
Co-Chair

14:40–15:55	MoB1.1

Disturbance Compensation Based Control for an Indoor Blimp Robot

Yue Wang, Gang Zheng, Denis Efimov and Wilfrid Perruquetti
CRIStAL (CNRS UMR 9189), Centrale Lille, France
Non-A team, INRIA Lille, France

- Blimp robot dynamic model simplification and separation
- Homogeneous differentiator as observer
- Disturbance estimated then compensated in the controller
- Controller performance and robustness verified by real experiments

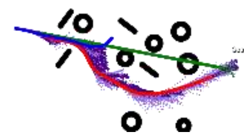
Non-A blimp V2 robot

14:40–15:55	MoB1.2

Informed Information Theoretic Model Predictive Control

Raphael Kusumoto[1] and Luigi Palmieri[2] and Markus Spies[3] and Akos Csiszar[1] and Kai. O. Arras[2]
[1] ISW, University of Stuttgart, Germany
[2] Robert Bosch GmbH, Corporate Research, Germany
[3] Robert Bosch GmbH, BCAI, Germany

- **Inform** sampling-based model predictive controllers with learned models
- **Learn generative models that draw samples in low-cost areas of the state-space**, conditioned on the contextual information of the task to solve
- An extensive evaluation suggests **our learned model considerably improves performance** in autonomous navigation settings



With our method (in red) the robot is capable of successfully navigating among obstacles differently from a state-of-the-art method IT-MPC (in blue), which could not find a solution.

14:40–15:55	MoB1.3

A Generic Optimization Based Cartesian Controller for Robotic Mobile Manipulation

Emilia Brzozowska
Department of Automatic Control and Robotics, UST AGH, Poland
Oscar Lima
DFKI Robotics Innovation Center, Germany
Rodrigo Ventura
Institute for Systems and Robotics, Instituto Superior Técnico, Portugal

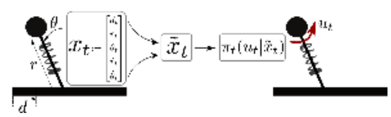
- Generic real time base + arm closed loop Cartesian velocity controller
- Nonlinear constrained optimization approach
- Experimental evaluation in simulation (Gazebo) and in a real robot (MBot), including a RoboCup@Home participation
- ROS based open-source implementation

MBot robot

14:40–15:55	MoB1.4

Task-Driven Estimation and Control via Information Bottlenecks

Vincent Pacelli and Anirudha Majumdar
Mechanical and Aerospace Engineering, Princeton University, USA



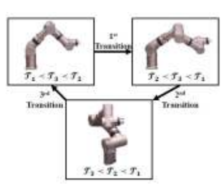
- Presents a framework for synthesizing low-dimensional task-relevant state representations sufficient for control.
- Rigorously characterizes the robustness of this framework to sensor modelling errors.
- Demonstrates efficacy of this method through numerical examples, including a spring-loaded inverted pendulum (SLIP) model.

14:40–15:55	MoB1.5

Continuous Task Transition Approach for Robot Controller based on Hierarchical Quadratic Programming

Sanghyun Kim [1], Keunwoo Jang [1], Suhan Park [1], Yisoo Lee [2], Sang Yup Lee [1], and Jaeheung Park [1]
[1] Seoul National University, South Korea
[2] Istituto Italiano di Tecnologia, Italy

- This paper presents a novel task transition strategy for the HQP-based controller to avoid the discontinuity of the control input.
- Our approach can handle both equality and inequality tasks by modifying the offset value of the existing tasks and the bound set of the new task with the activation parameter.
- Based on the proposed framework, various applications including the joint limit, singularity, and obstacle avoidance have been proposed.

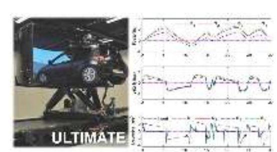


14:40–15:55	MoB1.6

Feasibility Analysis For Constrained Model Predictive Control Based Motion Cueing Algorithm

Carolina Rengifo[1,2], Jean-Rémy Chardonnet[2], Hakim Mohellebi[1], Damien Paillot[2] and Andras Kemeny[1,2]
[1]Virtual Reality and Immersive Simulation Center, Renault, France
[2]LISPEN EA7515, Arts et Métiers, Institut Image, France

- Implicit model predictive control based motion cueing algorithm for a dynamic driving simulator
- Comparison of four techniques to enforce feasibility and ensure stability
- Different simulations are carried out in the ULTIMATE simulator
- Only one technique can provide ensured closed loop stability by assuring feasibility over all the prediction horizon

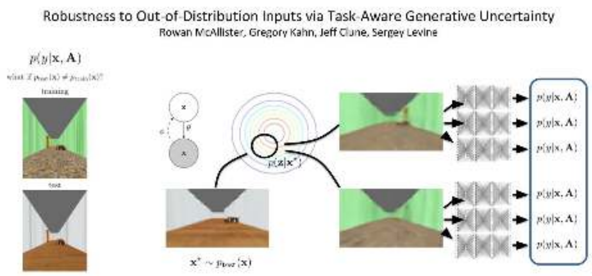


Comparison of four techniques for the longitudinal motion: position, velocity and acceleration in one scenario

Deep Learning for Navigation II - 1.2.23

Chair
Co-Chair

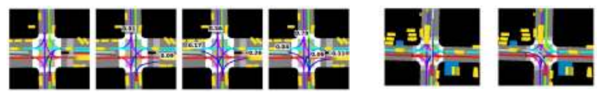
14:40–15:55	MoB1.1



14:40–15:55	MoB1.2

Multimodal Trajectory Predictions for Autonomous Driving using Deep Convolutional Networks

- We propose a method to infer multiple modes of movement of vehicle actors in traffic domain
- We show improvements over the state-of-the-art, and following offline tests successfully experimented on SDVs in closed-course tests



Output trajectories and corresponding probabilities for increasing number of modes M

Predicting trajectories using intended paths

14:40–15:55	MoB1.3

Classifying Pedestrian Actions In Advance Using Predicted Video Of Urban Driving Scenes

Pratik Gujjar and Richard Vaughan
School of Computing Science, Simon Fraser University, Canada

- Predict future video of driving scenes containing pedestrians.
- Recurrent convolutional decoder transforms features learnt by 3D convolutional encoder to the future.
- Takes 117 msec to predict 16 future frames on a commodity GPU, for an effective lookahead of 416 msec.
- Action classifier predicts pedestrians' crossing intent with an AP of 81% on JAAD dataset[1].

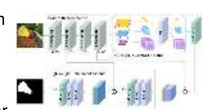
Correctly predicting pedestrians will step into the road

14:40–15:55	MoB1.4

Lightweight Contrast Modeling for Attention-Aware Visual Localization

Lili Huang, Guanbin Li and Liang Lin
Sun Yat-sen University, China
Ya Li
Guangzhou University, China

- We propose a novel end-to-end lightweight multi-scale network for salient object detection
- We introduce a lightweight bottleneck module for lowering computing cost to improve efficiency
- We introduce a multi-scale contrast module for capturing visual contrast to improve accuracy
- Experimental result demonstrates its superiority over state-of-the-art works



Overview of our proposed lightweight multi-scale network.

14:40–15:55	MoB1.5

Transformer Image-to-Motion Encoder-Decoder Network

Barry Ridge[1,2], Rok Pahič[2], Aleš Ude[2], and Jun Morimoto[1]
[1]ATR Computational Neuroscience Laboratories, Kyoto, Japan
[2]Dept. of Automatics, Biocybernetics, and Robotics, Jožef Stefan Institute, Ljubljana, Slovenia

- **Novel Architecture:** Spatial Transformer Image-to-Motion Encoder-Decoder Network (**STIMEDNet**)
- Learns to represent **affine-transformed digit images** in canonical form to predict **DMPs of rectified writing trajectories.**
- Experiment with **real Talos humanoid: human writes digit in arbitrary pose** on whiteboard; **robot draws its own digit in the same pose.**

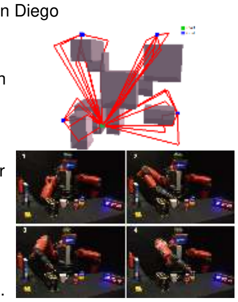
Talos humanoid robot writing a digit that it sees on a whiteboard.

14:40–15:55	MoB1.6

Motion Planning Network

Ahmed Qureshi, Anthony Simeonov, Mayur Bency, Michael Yip
University of California San Diego

- We present Motion Planning Networks (MPNet), a neural network-based novel motion planning algorithm.
- Has mean computation time ~1 sec (150x improvement over latest planning methods) for shown high-dimensional problems.
- $O(1)$ complexity during online execution.
- Generalizes to new unseen obstacle locations.
- Has completeness guarantees



7 DOF Baxter arm executing a motion planned by MPNet

Deep Touch II - 1.2.24

Chair
Co-Chair

14:40–15:55 MoB1.1

Improving Data Efficiency of Self-supervised Learning for Robotic Grasping

Lars Berscheid and Torsten Kröger
Karlsruhe Institute of Technology (KIT), Germany
Thomas Rühr
KUKA Deutschland GmbH, Germany

- Learning bin picking solely based on depth camera input and gripper force feedback
- Improvements regarding time and data efficiency:
  - Geometric consistency between orthographic depth image and fully-convolutional neural network
  - Active learning for grasp space exploration
- Training for 60h result in grasp rates of more than 95%
- Transfer and generalize knowledge to novel objects

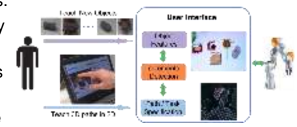
Setup for learning the skill of grasping objects from a densely filled bin

14:40–15:55 MoB1.2

Online Object and Task learning via HRI

Masood Dehghan*, Zichen Zhang*, Mennatullah Siam*, Jun Jin, Laura Petrich and Martin Jagersand
Computing Science, University of Alberta, Canada

- We present a system for incremental learning of objects and motion tasks.
- System allows a human to intuitively teach new objects to the robot.
- Human can specify 3D motion tasks on a 2D user interface.
- A hybrid force-vision control module performs compliant motions on unstructured surfaces.



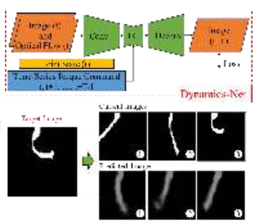
System Overview

14:40–15:55 MoB1.3

Dynamic Manipulation of Flexible Objects with Torque Sequence Using a Deep Neural Network

Kento Kawaharazuka,
Mechano-Informatics, The University of Tokyo, Japan
Toru Ogawa, Juntaro Tamura, Cota Nabeshima
Preferred Networks, Inc., Japan

- Dynamic manipulation of flexible objects
- **Dynamics-Net**: a network representing motion equation using vision image and time-series torque sequence
- Real-time calculation process of optimized torque command using **Dynamics-Net**
- Comparison with changes of parameters
- We realized manipulation of rigid object, flexible object, flexible object with environmental contact, and cloth in 3D.



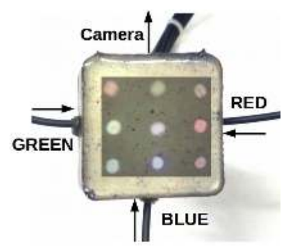
Dynamics-Net and dynamic manipulation

14:40–15:55 MoB1.4

Color-Coded Fiber-Optic Tactile Sensor for an Elastomeric Robot Skin

Zhanat Kappassov, Member, IEEE, Daulet Baimukashev, Zharaskhan Kuanyshuly, Student Members, IEEE, Yerzhan Massalin, Arshat Urazbayev and Huseyin Atakan Varol, Senior Member, IEEE
Department of Robotics, Nazarbayev University, Astana, Kazakhstan

- The sense of touch is essential for the robot that manipulate soft and rigid objects.
- We present a color-coded tactile sensor, incorporating plastic optical fibers, transparent silicone rubber and a camera.
- Classical machine learning techniques are used for contact localization.
- We achieved a force sensing range up to 18 N with the resolution of 3.6 N and the spatial resolution of 8 mm.



14:40–15:55 MoB1.5

Reinforcement Learning in Topology-based Representation for Human Body Movement with Whole Arm Manipulation

Weihao Yuan[1], Kaiyu Hang[2], Haoran Song[1], Danica Kragic[3], Michael Y. Wang[1] and Johannes A. Stork[4]
[1]Hong Kong University of Science and Technology, China
[2] Yale University, USA
[3] KTH Royal Institute of Technology, Sweden
[4] Örebro University, Sweden

- Moving a human body or a large object can require the strength of whole arm manipulation (WAM) which relies on global properties of the interaction to rather than local contacts.
- We use Writhe and Laplacian coordinates to model the task as reinforcement learning in a topology-based state space to learn a reactive controller that copes with external influences.
- The state captures spatial relations between body parts and allows transfer to unseen scenarios with different body shapes.

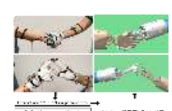
Sea rescue of a body moved by waves

14:40–15:55 MoB1.6

Demonstration-Guided DRL of Control Policies for Dexterous Human-Robot Interaction

Sammy Christen, Stefan Stevšić, Otmar Hilliges
Department of Computer Science, ETH Zurich, Switzerland

- We present a reward function for training a robot to perform hand interactions
- We analyze contributions of different terms in the reward function in an ablation study
- Large-scale user study shows that produced motions are perceived as natural
- We release a motion capture dataset of human hand interactions



Multi-Robot Systems II - 1.2.25

Chair
Co-Chair

14:40–15:55 MoB1.1

Team-based Robot Righting via Pushing and Shell Design

David McPherson and Ronald Fearing
Dept. of Electrical Engineering and CS, University of California, Berkeley, USA

- While exploring irregular terrain, minimalistic rovers can fall and get trapped on their backs
- Adding DoF to the robot could fix, but can be done more minimally through teamwork
- Designing robot hull shape is critical for directing reaction forces usefully
- With the designed shell an assisting robot can right another in 0.7 seconds with 87% success

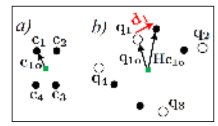
By carefully designing robot shape, robot teammates can add lost degrees of freedom to fallen compatriots

14:40–15:55 MoB1.2

Deformation-based shape control with a multirobot system

Miguel Aranda, Juan Antonio Corrales and Youcef Mezouar
SIGMA Clermont-Institut Pascal, Clermont-Ferrand, France

- We control a robotic team's 2D shape by minimizing a deformation metric
- Method is simple and produces tightly coordinated and efficient team motions
- It is particularly well-suited for multirobot manipulation of a deformable object
- One robot can steer the team's size and orientation in the workspace



Robot motions (e.g., d1) minimize deformation w.r.t. desired shape a)

14:40–15:55 MoB1.3

One-to-many bipartite matching based coalition formation for multi-robot task allocation

Ayan Dutta and Asai Asaithambi
School of Computing, University of North Florida, USA

- We study the multi-robot coalition formation problem for task allocation – an NP-hard problem.
- Our proposed algorithm is a variant of the classical bipartite matching technique – provides a linear (on edges) time complexity.
- The approach is scalable – takes less than 1 millisecond with 100 robots and 10 tasks.

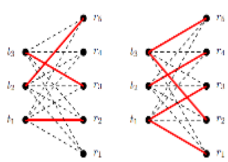


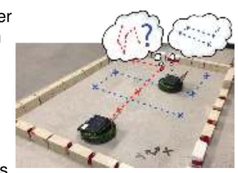
Fig.: (left) Classical and (right) One-to-many Bipartite Matching

14:40–15:55 MoB1.4

Coordinated multi-robot planning while preserving individual privacy

Li Li[1], Alfredo Bayuelo[2], Leonardo Bobadilla[1], Tauhidul Alam[3], and Dylan A. Shell[4]
[1]Florida International University, [2]National University of Colombia, [3]SUNY Old Westbury, [4]Texas A&M University.

- While planning, two robots communicate over Wi-Fi to detect whether there is any collision between their respective paths.
- The robots coordinate securely without revealing information or disclosing their own path to the other robot.
- Using garbled circuits and homomorphic encryption, we construct interactive protocols and algorithms, demonstrating them on rendezvous and persistent monitoring tasks.

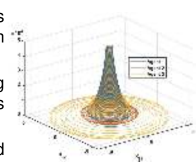


14:40–15:55 MoB1.5

Multi-Agent Synchronization Using Online Model-Free ADDHP Approach

Mohammed Abouheaf and Wail Gueaieb
School of Electrical Engineering & Computer Science, University of Ottawa, Canada

- The solving capabilities of ADDHP schemes for dynamic graphical games degrade in uncertain dynamical environments.
- An online model-free reinforcement learning solution based on policy iteration process is adopted to solve the graphical games.
- The duality between Bellman equation and Hamiltonian function's temporal difference solutions is explained.
- Adaptive critics is used to approximate the optimal value function and model-free control strategy for each agent.



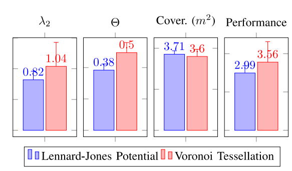
Synchronization among multi-agent system using ADDHP.

14:40–15:55 MoB1.6

Robust Area Coverage with Connectivity Maintenance

Luca Siligardi[a], Jacopo Panerati[b], Marcel Kaufmann[b], Marco Minelli[a], Cinara Ghedini[c], Lorenzo Sabattini[a], Giovanni Beltrame[b]
[a]Università degli Studi di Modena e Reggio Emilia, Italy
[b]Polytechnique Montréal, Québec, Canada
[c]Instituto Tecnológico de Aeronáutica, Brazil

- We study the problem of maintaining robust swarm connectivity while performing a coverage task
- We implement a tri-objective control law in a team of eight Khepera IV robots
- We show that exploiting the Voronoi tessellation of an area of interest outperforms potential-based coverage



Means and standard deviations of algebraic connectivity λ_2, robustness Θ, coverage, and performance metric. Potential- vs. Voronoi- based coverage.

Award Session II

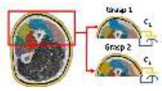
Chair *Rajnikant V. Patel, The University of Western Ontario*
Co-Chair *Julie A. Shah, MIT*

14:40–14:52 MoB2.1

Gesture Recognition via Flexible Capacitive Touch Electrodes

Louis Dankovich
Mechanical Engineering, University of Maryland College Park, United States
Sarah Bergbreiter
Mechanical Engineering, Carnegie Mellon University, United States

- Preliminary trial of Capacitive Touch (CT) sensing for wearable gesture recognition
- Novel wearable device using flexible CT electrode straps was prototyped
- Random Forest algorithm applied to data from 32 motions/gestures (including Cutkosky grasp taxonomy) achieved recognition rate of 95.6+/-0.06%



(a) ΔC with different grasps

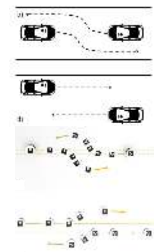
(b) Wearable armband with CT electrodes

14:52–15:04 MoB2.2

Deconfliction of Motion Paths with Traffic Inspired Rules in Robot–Robot and Human–Robot Interactions

Federico Celi and Lucia Pallottino
Research Centre E. Piaggio - Università di Pisa, Italy
Li Wang and Magnus Egerstedt
Georgia Institute of Technology, GA, USA

- Motion algorithms for autonomous vehicles are designed in compliance with traffic rules; however there are environments where rules are not as firm and they may be *broken* (e.g., parking lots)
- We consider mixed autonomous and human-driven vehicles where the rules of the road are less strict
- We ensure safety with Safety Barrier Certificates and disengage conflicting motions with traffic-like rules by perturbing the underlying problem formulation
- Results are verifies and tested on the Robotarium, a remotely accessible swarm robotics platform



15:04–15:16 MoB2.3

The Role of Closed-Loop Hand Control in Handshaking Interactions

Francesco Vigni[1], Espen Knoop[2], Domenico Prattichizzo[1,3] and Monica Malvezzi[1,3]
[1] University of Siena, Italy; [2] Disney Research, Switzerland; [3] IIT, Italy

- We implement and evaluate 3 different handshaking hand controllers combining open- and closed-loop contributions.
- A user study shows that controllers change perceived handshake quality and robot personality traits.
- Adding a controller delay (mimicking human CNS reaction time) is beneficial for making interactions more human-like.

We study open- and closed-loop controllers for hand forces in human-robot handshakes

15:16–15:28 MoB2.4

Soft Robotic Glove with Integrated Sensing for Intuitive Grasping Assistance Post Spinal Cord Injury

Yu Meng Zhou, Diana Wagner, Kristin Nuckols, Roman Heimgartner, Carolina Correia, Megan Clarke, Dorothy Orzel, Ciarán O'Neill, Ryan Solinsky, Sabrina Paganoni, and Conor J. Walsh
Harvard SEAS & Wyss Institute, Harvard University, MA, USA

- We present a fully-integrated soft robotic glove for grasping assistance for individuals with SCI.
- The glove is controlled through a state machine controller with contact detection by textile-elastomer sensors.
- Through human subject testing, participants operated the glove independently and improved grasping on select metrics.

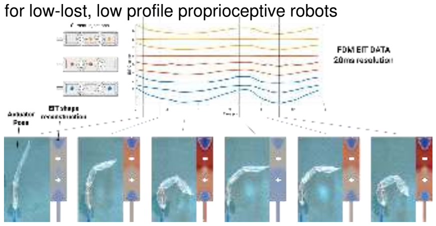
SCI participant wearing and operating the glove during human subject testing

15:28–15:40 MoB2.5

Shape Sensing of Variable Stiffness Soft Robots using Electrical Impedance Tomography

James Avery, Mark Runciman, Ara Darzi and George P. Mylonas
HARMS Lab, NIHR Imperial BRC, Imperial College London, United Kingdom

- Soft hinged actuators with internal electrodes and conductive working fluid
- Impedance measurements obtained using Frequency Division Multiplexed Electrical Impedance Tomography (FDM EIT)
- FDM EIT can infer shape changes with 20 ms temporal resolution
- Potential for low-lost, low profile proprioceptive robots

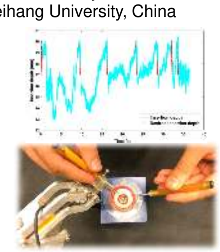


15:40–15:52 MoB2.6

Adaptive Control of Sclera Force and Insertion Depth for Safe Robot-Assisted Retinal Surgery

Ali Ebrahimi[1] and Niravkumar Patel[1] and Changyan He[3]
Peter Gehlbach[2] and Marin Kobilarov[1] and Iulian Iordachita[1]
[1] Dept. of Mechanical Engineering, Johns Hopkins University, USA
[2] School of Medicine, Johns Hopkins University, USA
[3] Dept. of Mechanical Engineering, Beihang University, China

- This paper addresses the safety issues in robot-assisted eye surgery.
- An adaptive control method is investigated to keep the sclera force and insertion depth in safe ranges.
- The control method makes the sclera force and insertion depth to follow desired and safe trajectories.
- After implementing the method on the eye surgical robot, it is observed that it can guarantee surgery safety.



Implementation results for the insertion depth control on the robot

Industry Forum and IERA Program - Session II

Chair
Co-Chair

PODS: Monday Session III

Chair

Co-Chair

Social HRI I - 1.3.01

Chair
Co-Chair

16:15–17:30	MoC1.1

Living with a Mobile Companion Robot in your Own Apartment - Final Implementation and Results of a 20-Weeks Field Study with 20 Seniors

H.-M. Gross, A. Scheidig, St. Müller, B. Schütz, Ch. Fricke*, S. Meyer*
TU Ilmenau, Cognitive Robotics & *SIBIS Institute for Social Research Berlin

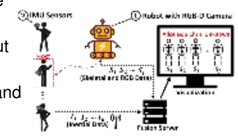
- 20 weeks field study in 20 single-person households (62-94 y.; mean 74 y.) with 2 robots without supervising/supporting persons on-site
- Overview of developed functional-emotional domestic robot companion incl. skills & behaviors
- Results re technical system robustness (25.4 km travelled, in 2,752 h more than 4,000 interactions)
- Results from social scientific analysis regarding acceptance of the robot & impact on daily routine

16:15–17:30	MoC1.2

Enabling Identity-Aware Tracking via Fusion of Visual and Inertial Features

Richard Yi-Chia Tsai, Hans Ting-Yuan Ke, Kate Ching-Ju Lin and Yu-Chee Tseng
Computer Science, National Chiao Tung University, Taiwan

- We propose a robot system named RCU that fuses visual data and internal data to enable reliable ID-aware tracking
- Our fusion algorithm can perform PIT without relying on biological features of human
- Our pairing framework considers historical and statistical measures to deal with ambiguous pairing and occlusion
- Our prototype evaluation shows the person identification rate of 95% and target following rate of 88%



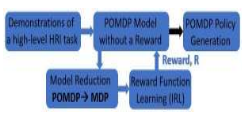
Architecture of RCU
(Robot Catch yoU)

16:15–17:30	MoC1.3

Inverse Reinforcement Learning of Interaction Dynamics from Demonstrations

Mostafa Hussein, Momotaz Begum, and Marek Petrik
Cognitive Assistive Robotics Laboratory, University of New Hampshire, USA

- A framework to learn the reward function underlying high-level sequential tasks that are typically modeled as POMDP.
- The core idea is to reduce the underlying POMDP to an MDP and apply any efficient MDP-IRL algorithm.
- Through a series of HRI experiments we show that the reward function learned this way generates POMDP policies that mimic the policies of the demonstrator well.
- Achieves better accuracy in learning than the existing IRL approaches for POMDPs.



IRL frame work for POMDP models for learning from demonstration

16:15–17:30	MoC1.4

Investigating Design Elements of Companion Robots for Older Adults

Young Hoon Oh
School of Integrated Technology, Yonsei University, Republic of Korea
Jaewoong Kim, Soyon Jeong, and Da Young Ju
Technology and Design Research Center, Yonsei Institute of Convergence Technology, Yonsei University, Republic of Korea

- Face-to-face Survey study 191 Older adults at 4 senior centers
- Investigated preference regarding the type, weight, and material of toy-sized robots
- Independent variable = age, gender, living arrangement
- Newborn baby was the most preferred type, and older adults prefer lightweight robot

Stuffed toys and a humanoid robot used in the experiment

16:15–17:30	MoC1.5

Deep Reinforcement Learning Robot for Search and Rescue Applications: Exploration in Unknown Cluttered Environments

Farzad Niroui, Kaicheng Zhang, Zendai Kashino, and Goldie Nejat
Autonomous Systems and Biomechatronics Laboratory, Department of Mechanical and Industrial Engineering, University of Toronto, Canada

- A novel exploration strategy for a robot to autonomously explore unknown cluttered environments is proposed using the unique combination of A3C deep reinforcement learning and frontier-based exploration.
- The proposed network architecture uses a robot's sensory data to determine the appropriate frontier locations to navigate.
- The robot learns from its own experiences to maximize its information gain early on during exploration to assist in faster victim recovery in search and rescue scenarios.
- The proposed method is robust to different cluttered environments with varying sizes and layouts, and is shown to outperform traditional exploration techniques.

Mobile robot exploring a cluttered environment

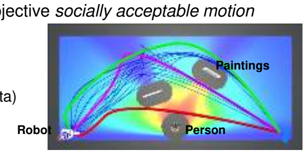
16:15–17:30	MoC1.6

Using Human Attention to Address Human-Robot Motion

Rémi Paulin, Thierry Fraichard and Patrick Reignier
Univ. Grenoble Alpes, INRIA, CNRS, Grenoble INP, LIG, Grenoble, France

- Human-Robot Motion (HRM) = study of how robots should move among people
- Research question: can human attention be useful to address HRM?
- Contrib. 1: *computational model of human visual attention*
- Contrib. 2: based on the concept of attention field, concept of *attentional properties of motions*, *e.g.* distraction, surprise
- Contrib. 3: proof-of-concept multi-objective *socially acceptable motion planner* on various scenarios

Fig.: motion examples: less distracting (green), shortest (red), trade-off (magenta)



Robotics in Hazardous Fields - 1.3.02

Chair
Co-Chair

16:15–17:30 MoC1.1

Development of Informative Path Planning for Inspection of the Hanford Tank Farm

Sebastian A. Zanlongo, Leonardo Bobadilla
SCIS, Florida International University, United States
Dwayne McDaniel, Yew Teck Tan
Applied Research Center, Florida International University, United States

- Adaptive sampling to localize leaks within nuclear waste tanks at the Hanford facility.
- Bayesian Optimization approach for selecting sampling locations also allows for prior knowledge to be incorporated.
- Allow for balancing of overall mapping vs rapid localization.
- Quickly reduces RMSE error around leak and shortens the distance the tethered robot must travel.

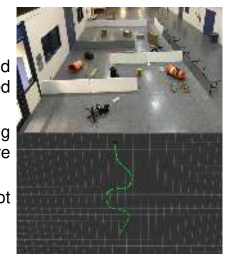
Time representation of a robot moving through refractory slots, vertical axis is time.

16:15–17:30 MoC1.2

A Fuzzy Based Accessibility Model for Disaster Environment

Karthika Balan, Melvin P Manuel, Mariam Faied, Mohan Krishnan, Michael Santora
Department of Electrical and Computer Engineering and Computer Science, University of Detroit Mercy, Detroit, Michigan, United States

- A new method to assess terrain accessibility index from obstacle distance is developed.
- A Fuzzy Inference System Vector Field Histogram (FISVFH) method for improved robot velocities is formulated.
- FISVFH testing results in four challenging environments and a disaster environment are presented.
- The generation of smooth and efficient robot trajectories by FISVFH is validated.

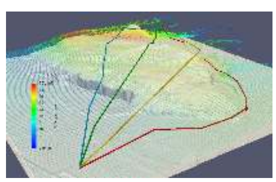


16:15–17:30 MoC1.3

Learning to Predict the Wind for Safe Aerial Vehicle Planning

Florian Achermann[1], Nicholas R.J. Lawrance[1], René Ranftl[2], Alexey Dosovitskiy[2], Jen Jen Chung[1], Roland Siegwart[1]
[1] Autonomous Systems Lab, ETH Zürich, Switzerland
[2] Intel Labs, Germany

- Aim is to predict wind around complex terrain for safer planning with small UAVs
- A convolutional neural network is trained using data generated from CFD simulations with terrain patches from Switzerland
- Evaluation using an RRT planner shows reduced prediction error and safer paths than existing methods



Paths planned using different wind predictions. Only the red one using the wind from the CNN is feasible

16:15–17:30 MoC1.4

Distributed Radiation Field Estimation for Nuclear Environment Characterization

Frank Mascarich, Christos Papachristos, Taylor Wilson and Kostas Alexis
Department of Computer Science, University of Nevada, Reno, USA

- Autonomous estimation of distributed radiation fields in GPS-denied environments using the RadMapper Robot
- Informative path planner guides the RadMapper to radiation-informative waypoints for efficient radiological characterization
- Custom three sensor apparatus for estimating instantaneous radiation field gradient
- Mapping and planning demonstrated in real experiments using unprocessed uranium and thorium ore

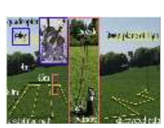
The RadMapper Robot

16:15–17:30 MoC1.5

Active Localization of Gas Leaks Using Fluid Simulation

Martin Asenov, Kartic Subr and Subramanian Ramamoorthy
Institute of Perception, Action and Behaviour, The University of Edinburgh, UK
Marius Rutkauskas and Derryck Reid
Institute of Photonics and Quantum Sciences, Heriot-Watt University, UK

- Formulate gas leak localization as model-based inference using a fluid simulator as the model
- Develop a practical optimization algorithm based on a single simulation per iteration
- Develop an online algorithm that locates gas leaks using active sensing
- Demonstrate that our algorithm results in acceptable localization error in real experiments



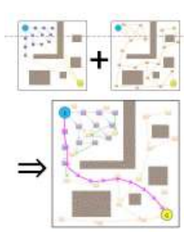
Gas-leak localization

16:15–17:30 MoC1.6

Bi-directional Value Learning for Risk-aware Planning Under Uncertainty

Sung-Kyun Kim
The Robotics Institute, CMU, USA
Rohan Thakker, Ali-akbar Agha-mohammadi
NASA-Jet Propulsion Laboratory, Caltech, USA

- Safety-critical large-scale POMDPs
  - Mars rover in obstacle-laden environments
- Bi-directional Value Learning
  - ***Forward*** short-range solver: Local but near-optimal online policy
  - ***Backward*** long-range solver: Approximate but risk-averse global policy
  - ***Bi-directional*** solver: Improves *scalability* and *optimality* by unifying the two solvers



Deep Learning for Computer Vision - 1.3.03

Chair

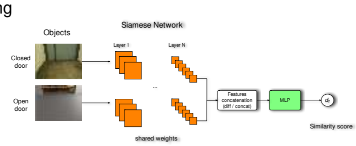
Co-Chair

16:15–17:30	MoC1.1

Visual Recognition in the Wild by Sampling Deep Similarity Functions

Mikhail Usvyatsov and Konrad Schindler
Civil, Environmental and Geomatic Engineering, ETH Zürich, Switzerland

- Problems: small dataset -> overfitting, not enough intra-class variability
- Solution: solve more difficult problem of learning similarity between random objects
- Reuse existing large-scale datasets for transfer learning



16:15–17:30	MoC1.2

Evaluating Merging Strategies for Sampling-based Uncertainty Techniques in Object Detection

Dimity Miller, Feras Dayoub, Michael Milford and Niko Sünderhauf
Queensland University of Technology, Australia

- It's unclear how to merge detection samples from sampling-based uncertainty techniques in object detection
- Poor merging strategies degrade detector performance and reliability of uncertainty measure
- We perform an in-depth investigation of merging strategies for MC Dropout with SSD
- We establish evaluation protocol and metrics for quality of uncertainty in object detection

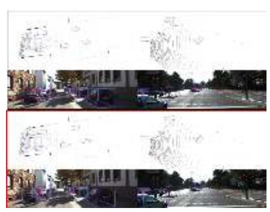
A good merging strategy should correctly cluster detection samples to obtain an accurate final detection and uncertainty.

16:15–17:30	MoC1.3

Focal Loss in 3D Object Detection

Peng Yun, Lei Tai, Yuan Wang and Ming Liu
ECE, HKUST, Hong Kong SAR, China
Chengju Liu
EIE, Tongji University, Shanghai, China

- We extend focal loss to 3D object detection to solve fore-background imbalance in one-stage detectors.
- We conduct experiments on 3D-FCN and VoxelNet, and the results demonstrate up to 11.2AP gains from the focal loss in a wide range of hyperparameters.
- We analyze its effect towards foreground and background estimations, and validate it plays a role similar to image-based detection.
- We demonstrate that the focal loss with the increasing hyperparameter decreases the estimation posterior probabilities.



Upper rows: trained with BCE loss
Lower rows: trained with focal loss.

16:15–17:30	MoC1.4

Vision-Based High Speed Driving With a Deep Dynamic Observer

Paul Drews and Grady Williams and Brian Goldfain and Evangelos A. Theodorou and James M. Rehg
Institute for Robotics and Intelligent Machines, Georgia Tech, USA

- We combine Deep Learning based road detection, Particle Filters, and Model Predictive Control
- An LSTM Encoder-Decoder detects track surface
- Aggressive driving using monocular cameras, IMU, and wheel speed sensors
- Performance beats the best lap time in our training dataset

AutoRally vehicle under autonomous control

16:15–17:30	MoC1.5

DispSegNet: Leveraging Semantics for End-to-End Learning of Disparity Estimation from Stereo Imagery

Junming Zhang
Electrical Engineering and Computer Science, University of Michigan, USA
Katherine A. Skinner
Robotics Institute, University of Michigan, USA
Ram Vasudevan
Mechanical Engineering, University of Michigan, USA
Matthew Johnson-Roberson
Naval Architecture and Marine Engineering, University of Michigan, USA

- This work designs a CNN architecture that focuses on unsupervised stereo matching guided with the semantic segmentation task
- The state-of-the-art results are shown on KITTI benchmark stereo matching task.

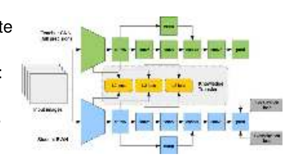
Architecture of DispSegNet

16:15–17:30	MoC1.6

Training a Binary Weight Object Detector by Knowledge Transfer for Autonomous Driving

Jiaolong Xu and Yiming Nie
Unmanned System Research Center, NIIDT, China
Antonio M. Lopez
Computer Vision Center, UAB, Spain

- Knowledge transfer from intermediate layers with L_2 loss
- Model compression (float vs binary):
  - Darknet-YOLO: 157MB vs 8.8 MB
  - Mobilenet-YOLO: 193 MB vs 7.9 MB
- Accuracy on KITTI (float vs binary):
  - Darknet-YOLO: 78% vs 76%
  - Mobilenet-YOLO: 78% vs 72%



The proposed knowledge transfer method for training **binary weight** YOLO object detector

SLAM - Session III - 1.3.04

Chair
Co-Chair

16:15–17:30 MoC1.1

Visual SLAM: Why Bundle Adjust?

Álvaro Parra, Tat-Jun Chin and Ian Reid
School of Computer Science, The University of Adelaide, Australia
Anders Eriksson
School of Electrical Engineering and Computer Science, QUT, Australia

- Alternative SLAM optimisation core: instead of bundle adjustment, we conduct rotation averaging to incrementally optimise only camera orientations.
- Given the orientations, we estimate the camera positions and 3D map via a quasi-convex formulation that can be solved efficiently and globally optimally.
- No need to estimate positions and 3D map at keyframe rate. More capable of handling slow motions or pure rotational motions.

Algorithm 2 L-infinity SLAM.

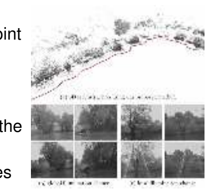
for each keyframe step $t = 1, 2, \ldots$ **do**
  $s \leftarrow t - (\text{window size}) + 1$.
  $\{\mathbf{R}_{j,k}\}_{j,k \in \mathsf{N}_{\text{win}}} \leftarrow \text{relative\_rotation}(\mathsf{Z}_{(s-1):t})$.
  $\mathbf{R}_{s:t} \leftarrow \text{rotation\_averaging}\left(\{\mathbf{R}_{j,k}\}_{j,k \in \mathsf{N}_{\text{win}}}\right)$.
  $\mathbf{t}_{s:t}, \mathsf{X} \leftarrow \text{known\_rotation\_prob}(\mathbf{R}_{s:t}, \mathsf{Z}_{0:t})$.
  if loop is detected in Z_t **then**
    $\{\mathbf{R}_{j,k}\}_{j,k \in \mathsf{N}_{\text{sys}}} \leftarrow \text{relative\_rotation}(\mathsf{Z}_{0:t})$.
    $\mathbf{R}_{1:t} \leftarrow \text{rotation\_averaging}\left(\{\mathbf{R}_{j,k}\}_{j,k \in \mathsf{N}_{\text{sys}}}\right)$.
    $\mathbf{t}_{1:t}, \mathsf{X} \leftarrow \text{known\_rotation\_prob}(\mathbf{R}_{1:t}, \mathsf{Z}_{0:t})$.
  end if
end for

16:15–17:30 MoC1.2

Illumination Robust Monocular Direct Visual Odometry for Outdoor Environment Mapping

Xiaolong Wu
ECE, Georgia Institute of Technoloty, United States
Cedric Pradalier
UMI2958 GeorgiaTech-CNRS, France

- Systematical evaluation of state-of-art illumination-robust costs in the monocular joint optimization framework
- A novel illumination-robust monocular VO system using pixel intensity and gradient
- An adaptive weighting strategy to preserve the convergence basin and tracking accuracy
- Treat sun flares as local illumination changes and prove its validity



16:15–17:30 MoC1.3

A Comparison of CNN-Based and Hand-Crafted Keypoint Descriptors

Zhuang Dai, Xinghong Huang, Weinan Chen and Li He
Computing Science, Guangdong University of Technology, China
Hong Zhang
Computing Science, University of Alberta, Canada

- In general CNN-based descriptors outperform hand-crafted descriptors
- Trained CNN descriptors perform better than pre-trained CNN descriptors with respect to viewpoint changes
- Pre-trained CNN descriptors perform better than trained CNN descriptors with respect to illumination changes

Figure Comparsion results of three classes of descriptors

16:15–17:30 MoC1.4

Environment Driven Underwater Camera-IMU Calibration for Monocular Visual-Inertial SLAM

Changjun Gu, Yang Cong and Gan Sun
State Key Laboratory of Robotics, Shenyang Institute of Automation, Chinese Academy of Sciences, China

- Nonlinear geometry transformation make the underwater Camera-IMU calibration more difficult than that in air.
- Establishing the Camera-IMU calibration relationships between in air and under water.
- Underwater Visual-Inertial algorithm combining the relationship of parameters between in air and under water.

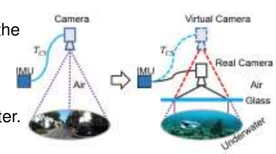


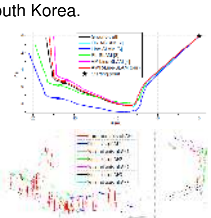
Illustration of the Camera-IMU model

16:15–17:30 MoC1.5

Leveraging Structural Regularity of Atlanta World for Monocular SLAM

Haoang Li[1], Yazhou Xing[2], Ji Zhao[3], Jean-Charles Bazin[4], Zhe Liu[1], and Yun-Hui Liu[1]
[1]Dept. of MAEG, CUHK, Hong Kong, China [2]HKUST, Hong Kong, China
[3]TuSimple, China [4]KAIST, South Korea.

- a robust image line clustering method and an accurate Atlanta frame (AF) computation approach that provides the global optimum in a non-iterative way
- a novel optimization strategy based on the maximum a posteriori estimation to refine the initial clusters and Atlanta frames alternately.
- We compute reliable global AFs and also optimize camera poses and 3D map under the directional constraints of Atlanta world



Estimated camera trajectories and reconstructed 3D line-based map

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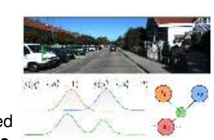
16:15–17:30 MoC1.6

Multimodal Semantic SLAM with Probabilistic Data Association

Kevin Doherty, Dehann Fourie, John Leonard
Computer Science and Artificial Intelligence Lab, Massachusetts Institute of Technology, USA

- Data association for semantic SLAM is ambiguous due to **perceptual aliasing** and **state uncertainty**
- We represent multiple object association hypotheses using **multimodal semantic factors** in a factor graph
- The resulting non-Gaussian problem is solved with **multimodal-iSAM** using **nonparametric belief propagation**
- Our solution is **more robust to association ambiguity** and **capable of representing non-Gaussian uncertainties**



Multimodal measurements arise from ambiguous data association, here modeled as *multimodal semantic factors*

Manipulation II - 1.3.05

Chair
Co-Chair

16:15–17:30	MoC1.1

Improving Incremental Planning Performance through Overlapping Replanning and Execution

Matthew Orton, Siyu Dai,
EECS, Massachusetts Institute of Technology, USA
Shawn Schaffert, Andreas Hofmann, and Brian Williams
EECS, Massachusetts Institute of Technology, USA

- A roadmap-based planner with trajectory optimization realizes superior performance to either component alone
- Incremental planning algorithms can be incorporated into this framework to account for changing environments
- Replanning while executing valid segments from prior plans shortens replanning time for these algorithms

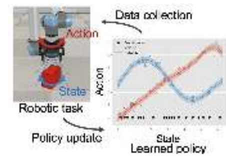
A cube is inserted into the path to force replanning

16:15–17:30	MoC1.2

Multimodal Policy Search using Overlapping Mixtures of Gaussian Process Prior

Hikaru Sasaki and Takamitsu Matsubara
Graduate School of Science and Technology, NAIST, Japan

- We propose a multimodal policy search reinforcement learning method based on Gaussian Processes (GPs).
- Variational Bayesian inference with overlapping mixtures of sparse GP prior is applied for policy improvement.
- We applied our method to two robotic tasks: 1) Object grasping and 2) Table-sweep.
- Our method can learn multimodal policies even with high dimensional observations.



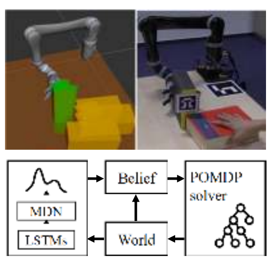
Multimodal policy search

16:15–17:30	MoC1.3

Online adaptation of uncertain models using neural network priors and partially observable planning

Akinobu Hayashi, Dirk Ruiken and Christian Goerick
Honda Research Institute Europe GmbH, Germany
Tadaaki Hasegawa
Honda R&D Co., Ltd. Center X, Japan

- Robust task solving despite unknown and uncertain models
- **Online POMDP planner with RNN** performs continuous model adaptation while solving the task
- Simulators configured from belief provide forward models
- Models with **discontinuities in the dynamics** are handled well
- Evaluation on various robotic pushing tasks with increasing complexity

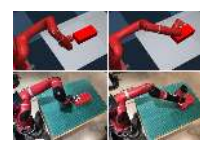


16:15–17:30	MoC1.4

Contact-Implicit Trajectory Optimization Based on a Variable Smooth Contact Model and Successive Convexification

Aykut Özgün Önol, Philip Long, and Taşkın Padır
Department of Electrical and Computer Engineering,
Northeastern University, USA

- A successive convexification-based approach is proposed to combine the benefits of shooting and direct optimization methods.
- The proposed method is tested for non-prehensile manipulation applications and compared to an iLQR-based version.
- Both methods can efficiently find physically-accurate motions with a trivial initial guess.
- The results show that the proposed approach outperforms the iLQR-based version.



Initial and final snapshots from planned and executed motions

16:15–17:30	MoC1.5

Automated Abstraction of Manipulation Domains For Cost-Based Reactive Synthesis

Keliang He, Lydia E. Kavraki and Moshe Y. Vardi
Department of Computer Science, Rice University, USA
Morteza Lahijanian
Dept. Aerospace Engineering Sceinces, University of Colorado Boulder, USA

- Automated process for discretizing manipulation domains with human interferences into finite abstractions
- All robot actions are efficiently validated, ensuring correctness of reactive synthesis
- Two methods for computing cost of robot actions that trade off runtime and proximity
- Efficacy demonstrated on UR5 performing pick-and-place tasks in the presence of human

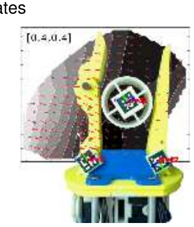
UR5 building an arch under human interference

16:15–17:30	MoC1.6

Energy Gradient-Based Graphs for Planning Within-Hand Caging Manipulation

Walter G. Bircher, Andrew S. Morgan,
Kaiyu Hang, and Aaron M. Dollar
Department of Mechanical Engineering and Materials Science,
Yale University, United States

- We describe a simple energy-based caging manipulation model
- The gradients of the energy model are computed, producing vector fields
- We use the vector fields to construct a graph, representing how objects move between points in the workspace
- Shortest paths to goal nodes are planned and executed on a physical system, producing simple translation manipulation



The red arrows show the possible motions that can be applied to an object

Micro/Nano Robots III - 1.3.06

Chair
Co-Chair

16:15–17:30	MoC1.1

A new robot skating on water surface intimating water striders based on flexible driving mechanism

Jihong Yan, Kai Yang, Yi Yang, Jie Zhao and Gangfeng Liu
State Key laboratory of Robotics and Systems, Harbin Institute of Technology,China
Shufeng Tang
School of mechanical engineering, Inner Mongolia university of technology , China

- Based on water strider's flexible driving mechanism, a robot skating on water surface is designed.
- The flexible driving effect is analyzed based on microelement cantilever method.
- Experiments show that the maximum skating speed of the robot is 36.2% higher than the robot with rigid legs.
- The Weber number reveals that flexible driving robot is quite analogous to biological water striders.

The miniature water-walking designed to study the flexible driving mechanism

16:15–17:30	MoC1.2

Performance Metrics for a Robotic Actuation System using Static and Mobile Electromagnets

Ruipeng CHEN, David FOLIO and Antoine FERREIRA
PRISME, INSA Centre Val de Loire, France

- This paper proposes a novel robotized EMA system for minimally invasive ophthalmic surgery.
- The performance of the robotic EMA system extending the static configurations has been investigated.
- The results demonstrate that the designed platform increases the versatility of the EMA system.

The photograph of the proof-of-concept

16:15–17:30	MoC1.3

Yaw Torque Authority for a Flapping-Wing Micro-Aerial Vehicle

Rebecca Steinmeyer, Nak-seung P. Hyun,
E. Farrell Helbling, and Robert J. Wood
John A. Paulson School of Engineering and Applied Sciences,
Harvard University, USA

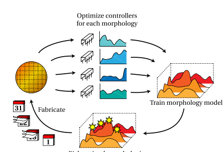
- The Harvard RoboBee filters yaw torque signals at typical flight conditions
- We expand the control space into an "iso-lift" regime to mitigate torque filtering
- We demonstrate controllable yaw torque at flight-worthy conditions suitable for aggressive maneuvers
- We implement the "iso-lift" method to achieve heading control

16:15–17:30	MoC1.4

Data-efficient Learning of Morphology and Controller for a Microrobot

T. Liao, G. Wang, B. Yang, R. Lee, K. Pister, S. Levine
EECS, UC Berkeley, CA, USA
R. Calandra
Facebook AI Research, Menlo Park, CA, USA

- How do you design morphologies and controllers when morphology evaluation is more expensive than controller evaluation?
- Using a hierarchical Bayesian optimization process, we design morphologies in batches and tune controllers automatically
- In simulation: 360% reduction in production cycles over standard Bayesian optimization, from 21 months to 4

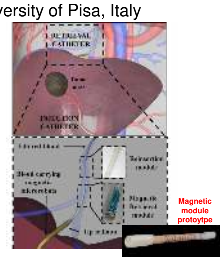


16:15–17:30	MoC1.5

Retrieval of magnetic medical microrobots from the bloodstream

Veronica Iacovacci, Leonardo Ricotti and Arianna Menciassi
The BioRobotics Institute, Scuola Superiore Sant'Anna, Italy
Giovanni Signore and Edoardo Sinibaldi
Istituto Italiano di Tecnologia, Italy
Fabio Vistoli
Division of Transplantations Surgery, University of Pisa, Italy

- A catheter appointed for magnetic microrobots retrieval within body fluids can foster their clinical translation
- Model-based design enabled the retrieval of different size micro-nano-particles in different working scenarios (i.e. different blood flows)
- Capture efficiency in realistic bloodstreams can reach 94% for 500 nm magnetic particles



16:15–17:30	MoC1.6

Reconsidering Six-degree-of-freedom Magnetic Actuation Across Scales

Colton R. Thornley, Lan N. Pham, and Jake J. Abbott
Department of Mechanical Engineering, University of Utah, USA

- We reconsider a magnetic actuation method that uses a three-magnet object in which one magnet is used for traditional 5-DOF actuation and two auxiliary magnets achieve the sixth (torque) DOF via a force couple.
- There is an optimal arrangement of the magnetic object.
- Adding the sixth DOF comes at the cost of a 61% reduction in the original 5-DOF.
- The sixth DOF scales poorly as manipulation distance is increased or as size is reduced.

An equivalent two-magnet object, being actuated by an OctoMag system.

Humanoid Robots III - 1.3.07

Chair
Co-Chair

16:15–17:30	MoC1.1

Experiments with Human-inspired Behaviors in a Humanoid Robot: Quasi-static Balancing using Toe-off Motion and Stretched Knees

Bernd Henze[1], Máximo A. Roa[1], Alexander Werner[2],
Alexander Dietrich[1], Christian Ott[1], Alin Albu-Schäffer[13]
[1] Institute of Robotics and Mechatronics, German Aerospace Center (DLR)
[2] University of Waterloo, Canada
[3] Technical University of Munich, Germany

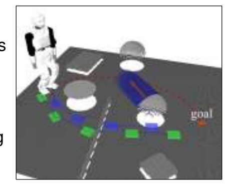
- Application of control framework for hierarchical whole-body balancing
- Adaptation to balancing with stretched knees
- Experimental evaluation of power consumption as a function of the knee flexion
- Increase of the kinematic workspace during stair climbing via toe-off motions

16:15–17:30	MoC1.2

Prediction Maps for Real-Time 3D Footstep Planning in Dynamic Environments

Philipp Karkowski and Maren Bennewitz
Humanoid Robots Lab, University of Bonn, Germany

- Generate a height map from depth data and segment it into planar and non-planar regions
- Track objects over multiple frames and predict their motion with a parabolic model
- Precompute a set of *prediction maps* that can be used for foresighted footstep planning
- A whole mapping cycle to generate up to 20 prediction maps takes only 10 ms for the shown example



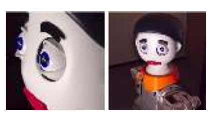
Predicting the motion of dynamic objects allows for foresighted footstep planning

16:15–17:30	MoC1.3

See and Be Seen – Rapid and Likeable High-Definition Camera-Eye for Anthropomorphic Robots

Simon Schulz and Sebastian Meyer zu Borgsen and Sven Wachsmuth
CITEC / CLF, Bielefeld University, Germany

- Robotic Camera-Eye with integrated eyelids and a high resolution camera for humanoid robot heads
- Human-like velocities, accelerations, and range of motion
- Comic style design with no mechanic parts visible to the user
- Specifically crafted to be seamlessly integrated into the overall appearance of a humanoid robot



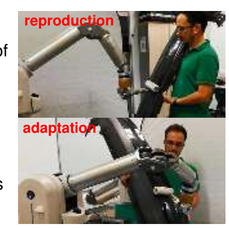
The proposed prototype integrated into the humanoid robot head Floka

16:15–17:30	MoC1.4

Generalized Orientation Learning in Robot Task Space

Yanlong Huang, Fares J. Abu-Dakka, João Silvério and Darwin G. Caldwell
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

- A **non-parametric solution** of learning orientation is proposed, which is capable of
(i) learning multiple quaternion trajectories;
(ii) adapting orientations towards arbitrary desired points that consist of quaternions and angular velocities;
(iii) alleviating the explicit definition of basis functions.



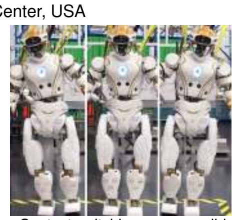
Robot Painting Task

16:15–17:30	MoC1.5

Thermal Recovery of Multi-Limbed Robots with Electric Actuators

Steven Jens Jorgensen[1,2], James Holley[2],
Frank Mathis[2], Joshua S. Mehling[2], and Luis Sentis[1]
[1] The University of Texas at Austin, USA
[2] NASA Johnson Space Center, USA

- Future thermal states are predicted using an effort-based, data-driven model.
- A contact-consistent gradient descent is used to find which robot configurations will minimize future thermal states.
- From a set of valid configurations, contact switching strategies are utilized to thermally recover actuators as fast as possible.



Contact switching among valid contact configurations enable fast actuator thermal recovery

16:15–17:30	MoC1.6

Humanoid Robot HRP-5P: an Electrically Actuated Humanoid Robot with High Power and Wide Range Joints

Kenji Kaneko, Hiroshi Kaminaga,
Takeshi Sakaguchi, Shuuji Kajita, Mitsuharu Morisawa,
Iori Kumagai, and Fumio Kanehiro
AIST, Japan

- Development of humanoid robot HRP-5P (Humanoid Robotics Platform – 5 Prototype), capable of heavy labor
- R&D platform for practical use of humanoid robots at sites assembling large structures
- High power body with a great number of degrees of freedom and a wide movable range for joints can handle large, heavy objects

Humanoid Robot HRP-5P

Localization III - 1.3.08

Chair
Co-Chair

16:15–17:30 MoC1.1

ATLAS FaST: Fast and Simple Scheduled TDOA for Reliable Ultra-Wideband Localization

Janis Tiemann, Lucas Koring and Christian Wietfeld
TU Dortmund University, Dortmund, Germany
Yehya Elmasry
Northwestern University, Evanston, IL, USA

- Provides infrastructure-based scalable, accurate, energy-efficient and real-time capable wireless localization
- FaST is a Time-Division Multiple Access (TDMA) scheme for infrastructure-based Real-Time Locating Systems (RTLS)
- This work is accompanied by an open-source ROS package and example dataset for the RTLS

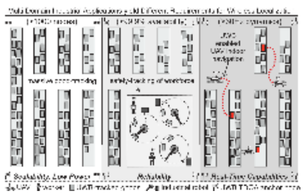


Illustration of ATLAS FaST Application Scenarios

16:15–17:30 MoC1.2

HD Map Change Detection with a Boosted Particle Filter

David Pannen and Martin Liebner
BMW Group, Germany
Wolfram Burgard
Department of Computer Science, University of Freiburg, Germany

- Particle Filter localization based on GNSS, odometry, lane marking and road edge observations
- Calculation of different metrics and classification with simple threshold, smoothing and hysteresis classifiers
- Training of an AdaBoost classifier using the simple classifier results as input
- Evaluation of classification results per trace and per bin along a route of interest

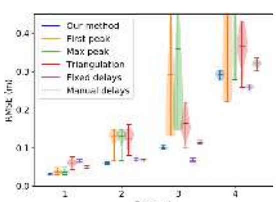
Classification results at a construction site entry

16:15–17:30 MoC1.3

Non-parametric Error Modeling for Ultra-wideband Localization Networks

Acshi Haggenmiller, Maximilian Krogius, and Edwin Olson
Computer Science and Engineering Department, University of Michigan, USA

- UWB suffers from multipath effects in non-line-of-sight (NLOS) conditions
- Internal antenna delay parameter needs to be calibrated
- Instead of rejecting multipath measurements, we estimate the full probability density
- Our graph realization achieves RMSE from 3 to 30 cm for an 8 node network



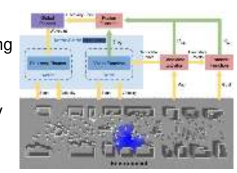
Performance of our method in increasingly difficult (NLOS) data sets

16:15–17:30 MoC1.4

Getting Robots Unfrozen and Unlost in Dense Pedestrian Crowds

Tingxiang Fan*, Xinjing Cheng*, Ruigang Yang
Robotics and Auto-Driving Lab, Baidu Research, China
Jia Pan, Pinxin Long, Wenxi Liu and Dinesh Manocha
University of Hong Kong, Metoak Technology, Fuzhou University, China
University of Maryland, College Park, USA

- Address the challenge of robot navigation in dense crowds without getting frozen or getting lost
- Formulate a novel framework to handle the lost and the freezing problem simultaneously
- Propose a reinforcement learning-based recovery algorithm that enables the robot to regain the localization



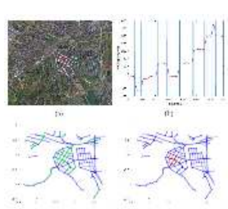
Actor-Critic based localization recovery behavior

16:15–17:30 MoC1.5

Proprioceptive Localization Assisted by Magnetoreception: A Minimalist Intermittent Heading-based Approach

Hsin-Min Cheng, Dezhen Song, Aaron Angert and Binbin Li
CSE Department, Texas A&M University, USA
Jingang Yi
Mechanical and Aerospace Engineering, Rutgers University, USA

- We reported a localization method that does not rely on external landmarks for a robot/vehicle traveling in urban area
- We tracked the sensory and map uncertainties and modeled them in the process to formulate a sequential Bayesian estimation problem framework.
- We employed information entropy to model map characteristics to identify typical heading and information entropy requirements for localization

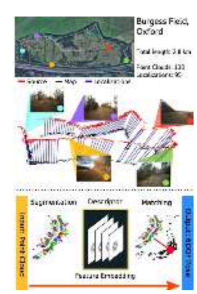


16:15–17:30 MoC1.6

Learning the See the Wood for the Trees: Deep Laser Localization on a CPU

Georgi Tinchev, Adrian Penate-Sanchez and Maurice Fallon
Oxford Robotics Institute, University of Oxford, UK

- Novel descriptor directly on raw point clouds
- Matching the state of the art in accuracy
- Enables real time performance on a CPU
- Tested extensively on urban and natural data



Service Robot - 1.3.09

Chair
Co-Chair

16:15–17:30 MoC1.1

Self-Supervised Incremental Learning for Sound Source Localization in Complex Indoor Environment

Hangxin Liu[1*], Zeyu Zhang[1*], Yixin Zhu[1,2], Song-Chun Zhu[1,2]
[*]Equal Contribution
[1]Statistics Department, UCLA
[2]International Center for AI and Robot Autonomy (CARA)

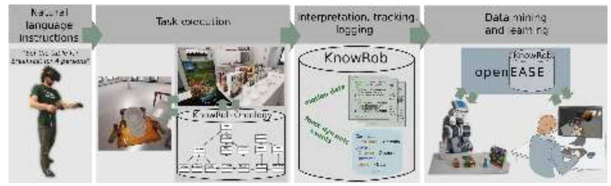
- An incremental learning scheme for sound source localization in the indoor setting with multiple rooms that allows the system to accumulate the training data on-the-fly.
- A self-supervision method that combines with the robot's active exploration.
- An auto-encoder for acoustic implicit feature extraction.

The algorithm ranks the priority of the rooms to be explored, and labels the data

16:15–17:30 MoC1.2

Automated Models of Human Everyday Activity based on Game and Virtual Reality Technology

Andrei Haidu and Michael Beetz
{ahaidu, beetz}@cs.uni-bremen.de

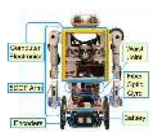


16:15–17:30 MoC1.3

Development of a Strain Gauge Based Disturbance Estimation and Compensation Technique for a Wheeled Inverted Pendulum Robot

Luis Canete and Takayuki Takahashi
Symbiotic Systems Science, Fukushima University, Japan

- Presents the work regarding strain gauge based disturbance estimation and compensation for the Inverted Pendulum Type Assistant Robot (I-PENTAR) .
- The model of the system with consideration to the strain gauge sensors is developed.
- The strain gauge sensor signals are used to improve the proposed unified controller.
- Actual tests were performed to show the effectiveness proposed sensor and control combination



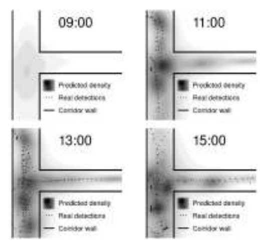
Inverted PENdulum Type Assitant Robot (I-PENTAR)

16:15–17:30 MoC1.4

Spatio-temporal representation for long-term anticipation of human presence in service robotics

Tomáš Vintr[1], Zhi Yan[2], Tom Duckett[3], Tomáš Krajník[1]
[1]Department of Computer Science, CTU-FEE, Czechia
[2]EPAN Research Group, UTBM, France
[3]L-CAS, UoL, United Kingdom

- Novel representation of time applicable to continuous and discrete world models
- Allows to predict future state of the environment
- Improves efficiency of long-term mobile robot operation
- Long-term predictions of people presence

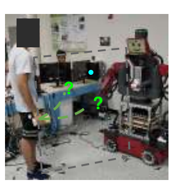


16:15–17:30 MoC1.5

Object Transfer Point (OTP) Estimation for Fluent Human-Robot Handovers

Heramb Nemlekar, Dharini Dutia and Zhi Li
Robotics Engineering, Worcester Polytechnic Institute, USA

- **Aim:** Robot response in handovers should be as fast, natural and fluent as a human's.
- **Background:** Human *givers* choose OTP before observing any *receiver* arm motion.
- **Method:** We learn a model to predict **Static OTP** based on position and physical features of a human *giver*.
- Static OTP (blue) is updated with **Dynamic OTP** (green) predicted based on *giver's* arm motion and grasp affordance of object.
- **Results:** (1) 19% improved initial prediction
 (2) Response time 3.1 secs, and
 (3) Prediction generalized across workspace.



Figurative depiction of Static OTP (blue) which will be updated with Dynamic OTP (green) depending on the motion of human giver's arm

16:15–17:30 MoC1.6

Controlling Aerobot: Development of A Motion Planner for an Actively Articulated Wheeled Humanoid Robot

Moyin Otubela, Michael Cullinan and Conor McGinn
Mechanical and Manufacturing Engineering, Trinity College Dublin, Ireland

- This paper presented a motion planner for a wheeled humanoid robot, Aerobot.
- A method for transitioning between its distinct modes is described.
- Sequential quadratic programming was used to generate feasible motion plans via the zero moment point.
- Crevice crossing and aspect ratio adjustment were demonstrated successfully.

Figure: Aerobot

Medical Robotics IV - 1.3.10

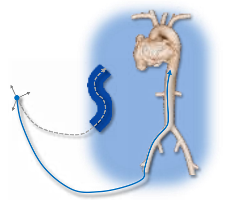
Chair
Co-Chair

16:15–17:30 MoC1.1

User Centric Device Registration for Streamlined Workflows in Surgical Navigation Systems

Paul Thienphrapa, Alvin Chen, and Douglas Stanton
Philips Research North America, Cambridge, MA, USA
Prasad Vagdargi
LCSR, Johns Hopkins University, USA

- *Purpose* – **Improve clinical workflows**, simplify setup, register on-the-fly
- *Concept* – **Simple gesture** to register surgical devices to navigation systems
- *Method* – **Continuous path** used to register (vs. discrete point fiducials)



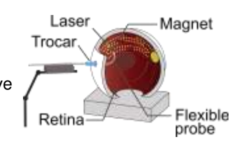
Clinician gestures device through fixture for fast registration

16:15–17:30 MoC1.2

A Magnetically Steered Endolaser Probe for Automated Panretinal Photocoagulation

Samuel L. Charreyron*, Edoardo Gabbi, Quentin Boehler*, Matthias Becker** and Bradley J. Nelson*
* Multi-Scale Robotics Lab, ETH Zurich, Switzerland
** Stadtspital Triemli Zurich, Switzerland

- Panretinal Photocoagulation (PRP) is performed to treat diabetic retinopathy, a leading cause of blindness
- A magnetically steered flexible endolaser probe is proposed to automatize this repetitive procedure
- Fully automatic PRP is performed in an eye phantom using our probe
- A clinical-level accuracy and faster speeds than human surgeons are achieved



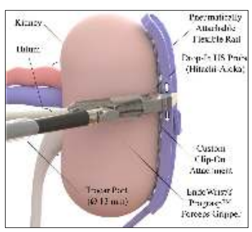
16:15–17:30 MoC1.3

Pneumatically Attachable Flexible Rails for Track-Guided Ultrasound Scanning in Robotic-Assisted Partial Nephrectomy — A Preliminary Design Study

Agostino Stilli, Emmanouil Dimitrakakis, Claudia D'Ettorre
Department of Computer Science, University College London, UK
Maxine Tran
Department of Surgical Biotechnology, University College London, UK
Danail Stoyanov
Department of Computer Science, University College London, UK

A novel approach for the navigation of drop-in ultrasound probes and for organ repositioning during RAPN procedures is presented:

- Pneumatically Attachable Flexible (PAF) rails that enable swift, effortless and accurate track-guided scanning of the kidney are introduced for the first time.
- The proposed system attaches on the side surface with the use of a series of bio-inspired vacuum suckers.

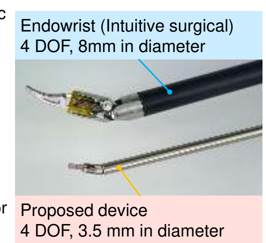


16:15–17:30 MoC1.4

Compliant four degree-of-freedom manipulator with locally deformable elastic elements for minimally invasive surgery

Jumpei Arata[1,2], Yosuke Fujisawa[1], Ryu Nakadate[1], Kazuo Kiguchi[1], Kanako Harada[2], Mamoru Mitsuishi[2] and Makoto Hashizume[3]
[1]Kyushu University, [2]The University of Tokyo, [3]Kitakyushu Chuo Hospital, Japan

- The proposed mechanism allows the elastic element to deform locally, thus minimizing its bending radius while the low number of mechanical parts greatly contributes to its compactness.
- This paper describes the design strategy, optimization method using FEA, prototype implementation, and evaluations.
- The evaluations reveal high accuracy and repeat accuracy, which are key elements for robotic instruments in minimally invasive surgery.

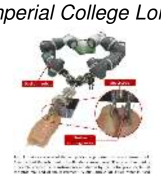


16:15–17:30 MoC1.5

Designing, Prototyping and Testing a Flexible Suturing Robot for Transanal Endoscopic Micro-Surgery

Yang Hu, Wei Li, Lin Zhang, and Guang-Zhong Yang
The Hamlyn Centre for Robotic Surgery, Imperial College London

- The mechanical design of the suturing instrument, including needle driving and locking mechanism as well as the two-sectional flexible joint.
- Kinematic control the flexible instrument.
- Suturing experiments, including running stitch with various orientations and knot tying.



16:15–17:30 MoC1.6

A Mechanics-Based Model for 3-D Steering of Programmable Bevel-Tip Needles

Thomas Watts and Riccardo Secoli
Ferdinando Rodriguez y Baena
Department Mechanical Engineering, Imperial College London, UK

- We present a model for the steering of programmable bevel-tip needles using a multi-beam approach based on Euler-Bernoulli beam theory
- Finite Element simulations for known loads are used to validate the multi-beam deflection model
- A set of experiments validate the modelling of the needle via a parameter optimization to produce a best-fit steering model

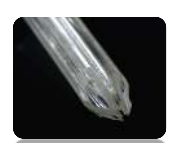


Figure showing the medical grade 2.5 mm outer diameter multi-segment needle

Telerobotics & Teleoperation III - 1.3.11

Chair
Co-Chair

16:15–17:30	MoC1.1

Safe teleoperation of a laparoscope holder with dynamic precision but low stiffness.

Jesus Mago, Mario Aricò, Jimmy Da Silva and Guillaume Morel
ISIR-Agathe, Sorbonne Université, CNRS, INSERM, France

- Robotic camera holders are of great interest in laparoscopic surgery as they increase surgeon's autonomy and image stability.
- To cope with unknown friction at the trocar, state-of-the-art robotic holders utilize high stiffness controllers that can harm the patient.
- We present a low-gain and yet precise control law for a robotic laparoscope holder.
- Our approach reduces tracking error by more than 50% in comparison to equal-gain standard PID.

16:15–17:30	MoC1.2

Real-time Teleoperation of Flexible Beveled-tip Needle Insertion using Haptic Force Feedback and 3D Ultrasound Guidance

Jason Chevrie, Alexandre Krupa and Marie Babel
Univ Rennes, Inria, CNRS, IRISA, INSA, France

- **Real-time semi-automated** and **teleoperated** needle steering using **6 degrees of freedom** base manipulation via a set of user-controlled or automated **task functions**
- **Intuitive control** of the needle tip 3D trajectory by the user directly in **ultrasound images**
- Comparison of **different haptic feedback** laws to provide guidance to the user

Teleoperated needle insertion setup

16:15–17:30	MoC1.3

End-User Robot Programming Using Mixed Reality

Samir Gadre*, Eric Rosen*, Gary Chien*, Elizabeth Phillips*^, Stefanie Tellex*, George Konidaris*
Computer Science, Brown University, USA
Behavioral Sciences and Leadership, US Air force Academy, USA

- We present a Mixed Reality (MR) Interface to for end users to program robots
- We ran a user study that compares the (MR) interface to a 2D interface
- We found the MR interface outperformed the 2D interface

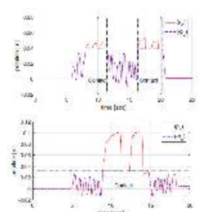
Our MR interface

16:15–17:30	MoC1.4

Control of Delayed Bilateral Teleoperation System for Robotic Tele-Echography

Jang Ho Cho, Joonho Seo, Hyuk Jin Lee, Kiyoung Kim, Hyun Soo Woo
Korea Institute of Machinery & Materials, South Korea
Maxim Kristalny
Faculty of Mechanical Engineering, Technion-IIT, Israel

- **Control design** of 6DOF bilateral teleoperation system for **tele-echography** under **time delays**
- Identical kinematic structure of master/slave devices (Stewart-Gough mechanisms)
- **Characterization of achievable teleoperator** admittance in analytic form under time delays
- Demonstration of **1 and 6 DOF experiments** of bilateral teleoperations under time delays



16:15–17:30	MoC1.5

A Unified Framework for the Teleoperation of Surgical Robots in Constrained Workspaces

Murilo M. Marinho[1], Bruno V. Adorno[2], Kanako Harada[1], Kyoichi Deie[3], Anton Deguet[4], Peter Kazanzides[4], Russel H. Taylor[4], and Mamoru Mitsuishi[1]
[1]The University of Tokyo, [2]Federal University of Minas Gerais, [3]The University of Tokyo Hospital, [4]Johns Hopkins University

- Motivated by surgeries in deep and narrow regions a teleoperation framework is proposed.
- The framework consists of balancing teleoperation-related terms while guaranteeing collision-free motion using all of the slave robots' degrees-of-freedom.
- Cartesian impedance is used on the master-side.
- The framework is evaluated in experiments with two robotic systems, the dVRK and a novel redundant robotic system, showing that smooth teleoperation can be achieved without collisions.

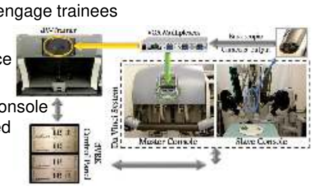
Master-slave robotic system teleoperation

16:15–17:30	MoC1.6

Multimodal Sensorimotor Integration for Expert-in-the-Loop Telerobotic Surgical Training

Mahya Shahbazi[1], Seyed Farokh Atashzar[2], Christopher Ward[3,5], Heidar Ali Talebi[4], Rajni V. Patel[3,5]
[1]Johns Hopkins University, USA; [2]Imperial College London, UK; [3]University of Western Ontario, Canada; [4]Amirkabir University of Technology, Iran; [5]Canadian Surgical Technologies & Advanced Robotics (CSTAR)

- A novel framework to enable hand-over-hand haptic cueing for robot-assisted surgical training
- Adaptive expertise-oriented training paradigm in real-time based on a Fuzzy Interface System to actively engage trainees
- Stability analysis of the closed-loop system in the absence and presence of tool-tissue interaction forces
- Experimental validation on a dual-console platform consisting of a dVRK-based da Vinci surgical system and the dV-Trainer (Mimic Technologies)



Grippers, Hand, and Grasping - 1.3.12

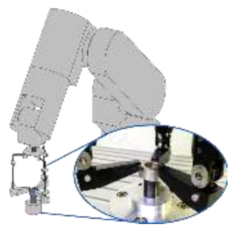
Chair
Co-Chair

16:15–17:30	MoC1.1

High-Speed Ring Insertion by Dynamic Observable Contact Hand

Yukihisa Karako and Shinji Kawakami
Technology and Intellectual Property H.Q., OMRON Corporation, Japan
Kensuke Koyama, Makoto Shimojo, Taku Senoo, and Masatoshi Ishikawa
The Department of Creative Informatics, University of Tokyo, Japan

- This study propose a dynamic observable contact hand to ensure high-speed insertion
- We evaluate the performance of a robot system which attached the proposed hand
- We compare the time of ring insertion by the robot system with that by human
- The result (robot:2.42s , human:2.58s) indicates that the robot outperforms with a higher speed than human



16:15–17:30	MoC1.2

Learning To Grasp Under Uncertainty Using POMDPs

Neha P. Garg[1,2] David Hsu[1,2] Wee Sun Lee[1]
[1]SOC, National University Of Singapore, Singapore
[2]NGS, National University Of Singapore, Singapore

- A principled, general and fast approach for grasp execution under uncertainty
- Model grasp execution for a known set of objects as POMDP for **robustness**
- Learn a **fast** policy from POMDP execution traces using 2-layer RNN
- **Generalize** to similar objects in simulation and real world

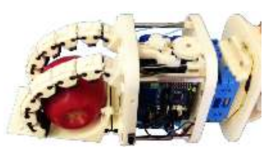
Known objects (top left) and test objects

16:15–17:30	MoC1.3

Soft Hands with Embodied Constraints: The Soft ScoopGripper

G. Salvietti[1,2], Z. Iqbal[1], M. Malvezzi[1,2], T. Eslami[1], D. Prattichizzo[1,2]
[1]Dept. of Information Engineering, University of Siena, Italy
[2] Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

- We present a modular under actuated soft hand in which we added a scoop as a feature of the palm, which simplify object grasping.
- The scoop allows to grasp objects in narrow spaces, augments the possible contact areas, allows to obtain more robust grasps, with lower forces
- Embedding a scoop may open to the study of a novel generation of soft-rigid grippers that brings the idea of environmental constraints exploitation inside the device

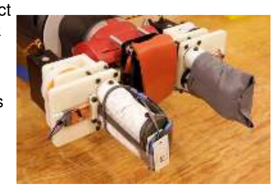


16:15–17:30	MoC1.4

A Simple Electric Soft Robotic Gripper with High-Deformation Haptic Feedback

Lillian Chin[1], Michelle C. Yuen[2,3], Jeffrey Lipton[1,4], Luis H. Trueba[1], Rebecca Kramer-Bottiglio[2], and Daniela Rus[1]
[1] Computer Science and Artificial Intelligence Lab, MIT, USA,
[2] School of Engineering & Applied Science, Yale University, USA,
[3] School of Mechanical Engineering, Purdue University, USA,
[4] Mechanical Engineering Department, University of Washington, USA

- A fully electric soft robotic gripper can detect object size and shape with tactile feedback
- The fingers are made of a pair of handed shearing auxetic cylinders
- Soft capacitive strain and pressure sensors give proprioceptive and haptic sensing
- The gripper detects size to within 33% of actual radius and stiffness with 78% accuracy

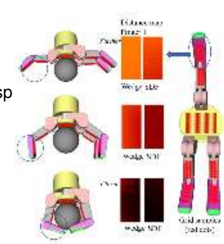


16:15–17:30	MoC1.5

Using Geometric Features to Represent Near-Contact Behavior in Robotic Grasping

Eadom Dessalene,
Computer Science, George Mason University, USA
Yi Hern Ong, John Morrow, Ravi Balasubramanian, Cindy Grimm
CoRIS, Oregon State University, USA

- This article proposes two novel geometric feature representations that aim to capture hand-object interaction.
- We approximate a predominant existing grasp metric with our feature representations.
- We train a binary classifier using our feature representations to predict real-world grasp success on a dataset of 588 grasps.



16:15–17:30	MoC1.6

A Hand Combining Two Simple Grippers to Pick up and Arrange Objects for Assembly

Kaidi Nie[1], Weiwei Wan[1,2], and Kensuke Harada[1,2]
[1] School of Engineering Science, Osaka University, Japan
[2] National Inst. of AIST, Japan

- A novel robotic hand designed for picking and arranging objects
- The hand combines two simple grippers - - an inner gripper for precise alignment, and an outer gripper for stable holding
- A low-cost solution for small screws and washers by taking advantages of the geometric constraints of fingers and gravity (non-prehensile manipulation)
- Demonstrated using robots and real-world tasks.

The proposed hand

Intelligent Manufacturing - 1.3.13

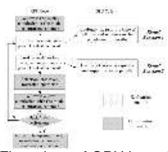
Chair
Co-Chair

16:15–17:30	MoC1.1

A GPU Based Parallel Genetic Algorithm for the Orientation Optimization Problem in 3D Printing

Zhishuai Li, Gang Xiong, Xipeng Zhang, Zhen Shen, Can Luo, Xiuqin Shang, Xisong Dong, Gui-Bin Bian, Xiao Wang and Fei-Yue Wang
Institute of Automation, Chinese Academy of Sciences, China.

- The model orientation problem is formulated as a single-objective optimization problem.
- The genetic algorithm (GA) is used to solve the optimization problem.
- The process of GA is parallelized and implemented on GPU.
- Our GPU based GA can speed up the process by about 50 time.


Flow chart of GPU based parallel GA

16:15–17:30	MoC1.2

Where Should We Place LiDARs on the Autonomous Vehicle?

Zuxin Liu
Instrumentation Science, Beihang University, China
Mansur Arief and Ding Zhao
Mechanical Engineering, Carnegie Mellon University, USA

- Investigate the optimal LiDAR configuration problem to achieve utility maximization
- Construct a min-max optimization problem using the perception area and non-detectable subspace
- Propose a bio-inspired measure – VSR – as an easy-to-solve cost function
- Use the Artificial Bee Colony algorithm as the optimizer

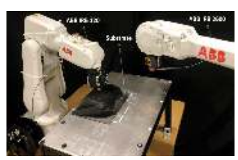

Optimal Configuration for 4 LiDARs

16:15–17:30	MoC1.3

A Robotic Cell for Multi-Resolution Additive Manufacturing

Prahar Bhatt, Ariyan Kabir, Rishi Malhan, Brual Shah, Aniruddha Shembekar, Yeo Jung Yoon, and Satyandra K. Gupta
University of Southern California, U.S.A.

- Multi-resolution robotic AM cell enables printing parts with short build times and good surface finish
- The robots can print on non-planar surfaces and orient fibers in the desired directions
- The paper presents computational foundations of part decomposition with multi-resolution layers and robot trajectory generation
- Parts with various sizes and complex shapes can be fabricated with multi-resolution printing

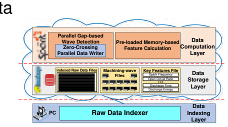

Multi-resolution 3D printing process by using two 6-DOF robotic manipulators

16:15–17:30	MoC1.4

A Novel Efficient Big Data Processing Scheme for Feature Extraction in Electrical Discharge Machining

Chao-Chun Chen[1], Min-Hsiung Hung[2*], Benny Suryajaya[1], Yu-Chuan Lin[1], Haw-Ching Yang[3], Hsien-Cheng Huang[1], and Fan-Tien Cheng[1]
[1]Institute of Manufacturing Information and Systems, National Cheng Kung University, Taiwan
[2*]Dept. of Computer Science and Information Engineering, Chinese Culture University, Taiwan
[3]Institute of Electrical Engineering, National Kaohsiung University of Sci. and Tech., Taiwan

- This paper proposes a novel efficient big data processing scheme for feature extraction in EDM, called BEDPS, based on Spark and HDFS.
- The BEDPS is much more efficient in machining wave detection and feature calculation and more scalable in the data size that can be processed than the existing system.
- The BEDPS is a promising feature extraction approach for conducting online virtual metrology (VM) of EDM.

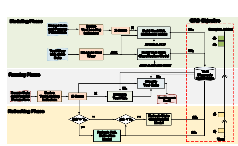

The system architecture of BEDPS

16:15–17:30	MoC1.5

A Gradual Refreshing Scheme for Improving Tool Utilization

Haw-Ching Yang
Institute of Electrical Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan, ROC
Tsung-Han Tsai, Hao Tieng and Fan-Tien Cheng
Institute of Manufacturing Information and Systems, National Cheng Kung University, Tainan, Taiwan, ROC

- Gradual Refreshing Scheme (GRS) for modeling, running, and refreshing tool diagnosis models.
- Sample extension method is presented for reducing modeling time and enhancing accuracy of tool-state classification.
- GRS adopts the SEM to generate dummy samples for building the state-classification model with few samples.

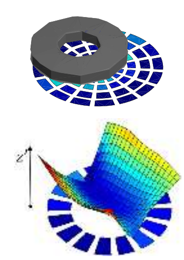


16:15–17:30	MoC1.6

Multimodal Bin Picking System with Compliant Tactile Sensor Arrays for Flexible Part Handling

Veit Müller and Norbert Elkmann
Robotic Systems, Fraunhofer IFF, Germany

- Flexible part handling using ***compliant tactile sensors*** on vacuum gripper and magnetic gripper
- ***Object monitoring*** for detection of part grasp, correct part placement etc.
- ***Grasp planning on partial object data*** on object fragments to handle transparent, polluted or blackened parts
- ***Object pose estimation*** of cylindrical parts



Prosthesis - 1.3.14

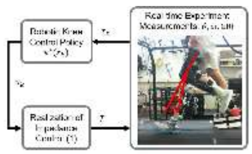
Chair
Co-Chair

16:15–17:30 MoC1.1

Offline Policy Iteration Based Reinforcement Learning Controller for Online Robotic Knee Prosthesis Parameter Tuning

Minhan Li, Yue Wen and He(Helen) Huang
Joint Biomedical Engineering Department, NC State University, University of North Carolina at Chapel Hill, USA
Xiang Gao and Jennie Si
Electrical, Computer and Energy Engineering Department, Arizona State University, USA

- Offline trained reinforcement learning controller was proposed to adjust knee prosthesis impedance parameters automatically.
- Online experiment was conducted on one able-bodied subject to test the performance of the controller.
- The proposed controller was able to reproduce near-normal knee kinematics with random initial parameters.



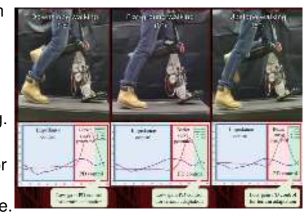
Framework of the reinforcement learning based knee prosthesis impedance control

16:15–17:30 MoC1.2

Consolidated control framework for a powered transfemoral prosthesis over sloped terrains

Woolim Hong[1], Victor Parades[2], Kenneth Chao[1], Shawanee Patrick[1] and Pilwon Hur[1]
[1]Department of Mechanical Engineering, Texas A&M University, USA
[2]LimaBionics, Peru

- Proper slope walking trajectories can be generated by using cubic Bezier polynomials.
- The optimal Bezier coefficients were obtained from an offline optimization compare to the human slope walking.
- A set of Bezier coefficients, let us achieve a unifying control scheme for the prosthetic slope walking without prior knowledge of slopes in real-time.



16:15–17:30 MoC1.3

A Lightweight, Efficient Fully-Powered Knee Prosthesis with Actively Variable Transmission

Minh Tran[1], Lukas Gabert[1], Marco Cempini[2] and Tommaso Lenzi[1]
[1]Dept. Mechanical Engineering, University of Utah, United States
[2]Neocis Inc., United States

- We introduce the first fully powered knee prosthesis that matches the weight of state-of-the-art passive
- A variable transmission enable the device to satisfy the speed and torque requirements for different ambulation activities with a small motor and a high electrical efficiency
- A preliminary validation is provided by an above-knee amputee subject ambulating on level-ground and stairs.

16:15–17:30 MoC1.4

Combining a Bio-Inspired Reflexive Neuromuscular Controller with a Trajectory Controller for Active Lower-Extremity Gait-Assistive Devices

Tycho Brug, Arvid Keemink, Gijs van Oort, Victor Sluiter, Edwin van Asseldonk and Herman van der Kooij
Biomechanical Engineering, University of Twente, The Netherlands
Nevio Luigi Tagliamonte, Matteo Arquilla, Iolanda Pisotta, Federica Tamburella, Marcella Masciullo, Romain Valette and Marco Molinari
Laboratory of Robotic Neurorehabilitation, Fondazione Santa Lucia, Italy

- A bio-inspired reflexive neuromuscular controller has been combined with trajectory controller using a tunnel approach.
- The controller removes uncertainty of the reflexive controller, while being less influenced by the repetitiveness of the trajectory controller
- The feasibility of the novel controller is shown by demonstrating gait with a impaired SCI subject.

16:15–17:30 MoC1.5

Modeling, Design and Test-Bench Validation of a Semi-Active Propulsive Ankle Prosthesis with a Clutched Series Elastic Actuator

Bryan Convens, Raphael Furnémont, Tom Verstraten, Pierre Cherelle, Dirk Lefeber and Bram Vanderborght
Depepartment of Mechanical Engineering, Vrije Universiteit Brussel, Belgium
Dianbiao Dong
School of Mechanical Engineering, Northwestern Polytechnical University, China

- Model drive-train dynamics to study electrical energy consumption
- Simulations and test-bench validations replicate non-pathological gait cycles at different walking speeds
- Resettable Overrunning Clutch offers natural gait/terrain adaptability and an electrical energy reduction of up to 22%

AMP-Foot 4+ Prototype

Soft Robots I - 1.3.15

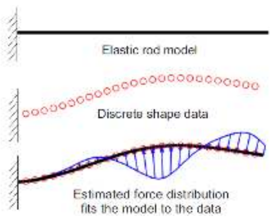
Chair
Co-Chair

16:15–17:30	MoC1.1

Estimating Loads Along Elastic Rods

Vincent A. Aloi and D. Caleb Rucker
Mechanical, Aerospace, and Biomedical Engineering
University of Tennessee, Knoxville, United States of America

- Given discrete shape data along an elastic rod, we estimate the distributed loading along the rod.
- Approach based on continuous Cosserat model and constrained optimization.
- A variety of loading conditions and validated experimentally, comparing two different functional representations of the loading.

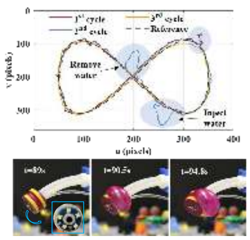


16:15–17:30	MoC1.2

Vision-based Online Learning Kinematic Control for Soft Robots using Local Gaussian Process Regression

Ge Fang, Xiaomei Wang, Kui Wang, Kit-Hang Lee, Justin Ho, Hing-Choi Fu, Denny Fu and Ka-Wai Kwok
Department of Mechanical Engineering
The University of Hong Kong, Hong Kong

- First attempt to address a learning-based visual servoing control for soft robots.
- Inverse kinematics directly approximated by local Gaussian process regression.
- Efficient update of the controller to compensate external disturbances.
- Experimental validations conducted to demonstrate the control performance on a hyper-elastic robot under varying load.

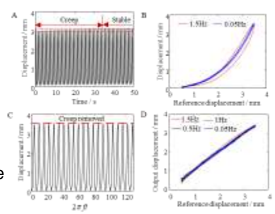


16:15–17:30	MoC1.3

Feedforward control of the rate-dependent viscoelastic hysteresis nonlinearity in dielectric elastomer actuators

Jiang Zou and Guoying Gu*
Soft Robotics and Biodesign Lab, Robotics Institute, school of Mechanical Engineering, Shanghai Jiao Tong University, China
State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, China

- The viscoelasticity of DEAs show both slow-time creep and rate-dependent hysteresis nonlinearities.
- A feedforward creep controller is firstly developed to remove the creep nonlinearity.
- An inverse hysteresis compensator is then established to compensate for the hysteresis nonlinearity.
- Tracking control of DEAs is achieved with a maximum tracking error of 6.18%.



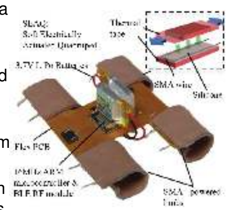
(A) Creep; (B) Hysteresis; (C) Creep control; (D) Hysteresis control.

16:15–17:30	MoC1.4

Soft Electrically Actuated Quadruped (SEAQ)

Xiaonan Huang, Kitty Kumar, Mohammad K. Jawed, Zisheng Ye and Carmel Majidi
Soft Machines Lab, Department of Mechanical Engineering, Carnegie Mellon University, USA

- **Untethered functionality**: SEAQ integrates a flex circuit board and shape memory alloy embedded elastomeric limbs
- **High speed**: SEAQ can walk at a peak speed of 32mm/s (0.56 body length per second)
- **Compliance**: SEAQ can navigate through confined space and be squeezed into a 37mm tube
- **Robust Maneuverability**: SEAQ can walk on incline, rocky and granular surface, and cross obstacles



16:15–17:30	MoC1.5

Expanding foam as the material for fabrication, prototyping and experimental assessment of low cost soft robots with embedded sensing

Luca Somm, David Hahn, Nitish Kumar, Stelian Coros
Computer Science Department, ETH Zurich, Switzerland

- **Foam-bodied soft robots** with integrated soft sensing, transmission and actuation.
- An **improved transmission system** for foam-bodied tendon-driven soft robots.
- Fabrication and prototyping techniques for **novel soft sensors**, which can be manufactured either as stand-alone devices, or more importantly, **integrated into our foam-bodied soft robot structures**.
- Organic foam robots of varying complexity from a **soft gripper to a soft "puppy".**

Foam-bodied soft robots

16:15–17:30	MoC1.6

Fast, Generic, and Reliable Control and Simulation of Soft Robots Using Model Order Reduction

Olivier Goury and Christian Duriez
DEFROST, Inria Lille – Nord Europe, France
CRIStAL UMR CNRS 9189, University of Lille, France

- A mechanical model of soft deformable robot is developed that is accurate, yet tractable in real-time for robotic applications
- It is based on a high resolution Finite Element Model (FEM) that is reduced to a low-dimensional surrogate model thanks to a model order reduction technique
- The result allows to control sophisticated soft robots in real-time with great accuracy.

Real Robot versus its reduced digital twin

Object Recognition II - 1.3.16

Chair
Co-Chair

16:15–17:30 MoC1.1

Oriented Point Sampling for Plane Detection in Unorganized Point Clouds

Bo Sun and Philippos Mordohai
Department of Computer Science, Stevens Institute of Technology, USA

- We propose the Oriented Point Sampling (OPS) algorithm which detects planes in unorganized point clouds
- OPS estimates the surface normal of a few points and performs one-point RANSAC
- We compare OPS with standard approach of sampling three unoriented points and regular RANSAC (modified FSPF)
- OPS is faster and more accurate than FSPF and 3D-KHT on the SUN RGB-D dataset

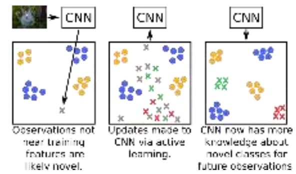
Left: input point cloud from the SUN RGB-D dataset. Right: OPS output.

16:15–17:30 MoC1.2

The Importance of Metric Learning for Robotic Vision: Open Set Recognition and Active Learning

Benjamin J. Meyer and Tom Drummond
ARC Centre of Excellence for Robotic Vision, Monash University, Australia

- State-of-the-art recognition systems are designed for static and closed worlds.
- Robotic problems are open set; the real-world distribution will differ from the training distribution.
- We present a deep metric learning approach to novelty detection and open set recognition.
- Further, our approach enables a robot to learn about observed novel classes via active learning.



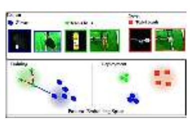
Overview of approach.

16:15–17:30 MoC1.3

Learning Discriminative Embeddings for Object Recognition *on-the-fly*

Miguel Lagunes-Fortiz
Bristol Robotics Laboratory, University of Bristol, UK
Dima Damen and Walterio Mayol-Cuevas
Computer Science Department, University of Bristol, UK

- Our network does not require re-training for learning new objects.
- Learns the concept of “object similarity” by mapping object's viewpoints close to each other if they belong to same class and farther apart otherwise.
- Learns a powerful visual representation by combining a metric learning and fully supervised losses.



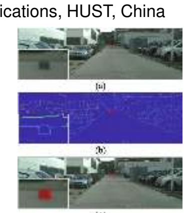
Our network produces discriminative embeddings of known and novel objects.

16:15–17:30 MoC1.4

A Novel Multi-layer Framework for Tiny Obstacle Discovery

Feng Xue, Anlong Ming and Menghan Zhou
School of Computer Science, BUPT, China
Yu Zhou
School of Electronic Information and Communications, HUST, China

- A set of novel obstacle-aware occlusion edge maps is constructed to characterize obstacles.
- An obstacle-aware regressor is proposed by combining appearance features and pseudo distance features.
- Our method improves the edge of obstacles, and gives the obstacles high score.
- Our method achieves remarkable performance on the Lost and Found dataset, outperforms the state-of-the-art algorithms.



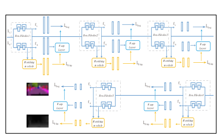
(a) is an image; (b) shows the occlusion edges; (c) shows the predicted obstacle which is marked in red.

16:15–17:30 MoC1.5

DSNet: Joint Learning for Scene Segmentation and Disparity Estimation

Wujing Zhan, Xinqi Ou, Yunyi Yang and Long Chen
School of Data and Computer Science,
Sun Yat-sen University, P.R.China

- Propose a unified multi-tasking architecture DSNet, for the simultaneous estimation of semantic and disparity information
- Design a matching module to connect the tasks of disparity estimation and scene parsing
- Put forward a training method to fulfill the two tasks in a single network



An overview of the structure of DSNet

16:15–17:30 MoC1.6

Spatial change detection using voxel classification by normal distributions transform

Ukyo Katsura, Kohei Matsumoto, Akihiro Kawamura, Ryo Kurazume
ISEE, Kyushu University, Japan
Tomohide Ishigami, Tsukasa Okada
Panasonic Inc., Japan

- Fast spatial change detection using a RGB-D camera and a precise 3D map is proposed.
- Normal distributions transform (NDT) is adopted to detect spatial changes.
- Real-time localization and spatial change detection experiments are conducted in indoor and outdoor environments.

Detected spatial changes

Aerial Systems: Perception III - 1.3.17

Chair
Co-Chair

16:15–17:30	MoC1.1

Set-based Inverse Kinematics Control of an Anthropomorphic Dual Arm Aerial Manipulator

E. Cataldi[1], F. Real[2], A.Suarez[2], P.A. Di Lillo[1], F. Pierri[3], G. Antonelli[1], F. Caccavale[3], G. Heredia[2], A. Ollero[2]
[1] University of Cassino and Southern Lazio, Cassino, Italy
[2] University of Sevilla, Sevilla, Spain
[3] University of Basilicata, Potenza, Italy

- Anthropomorphic Dual Arm Aerial Manipulator constituted by an hexarotor equipped with two lightweight 4-DOF manipulators.
- Two-layer architecture: the upper layer is an inverse kinematics control which exploits the Null-space based Behavioral control involving both *equality* and *set-based* tasks, while the bottom layer is a motion controller.

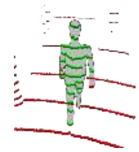

Experimental setup

16:15–17:30	MoC1.2

Detection and Tracking of Small Objects in Sparse 3D Laser Range Data

Jan Razlaw, Jan Quenzel, and Sven Behnke
Autonomous Intelligent Systems, University of Bonn, Germany

- Segment point groups of a specified width range using combination of median filters
- Detector utilizing segments, temporal information of tracker and inherent structure of data
- Real-time capability on a single CPU core
- Filtering the dynamic and mapping the static part of the world in the data

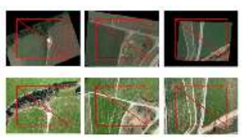

Segmented human in Velodyne VLP-16 scan

16:15–17:30	MoC1.3

GPS-Denied UAV Localization using Pre-existing Satellite Imagery

Hunter Goforth and Simon Lucey
The Robotics Institute, Carnegie Mellon University, USA

- Monocular vision replacement for GPS system in the event of noisy or unreliable signal
- CNNs used to overcome seasonal and perspective differences between UAV frames and satellite map
- Joint optimization of visual odometry and map alignment for improved accuracy
- Robustness to low-texture, rural environments


Alignment of satellite map (top) with UAV frames (bottom)

16:15–17:30	MoC1.4

Adaptive View Planning for Aerial 3D Reconstruction

Cheng Peng and Volkan Isler
College of Science and Engineering, University of Minnesota, USA

- Our novel trajectory planning algorithm naturally adapts to scene geometries and produce high quality reconstruction
- The algorithm selects a set of adaptive viewing planes for efficient view selections in 3D space
- Our planned trajectory provides a constant factor theoretical bound comparing to the optimal one

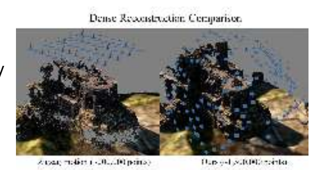


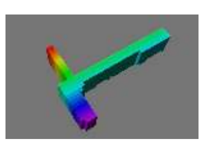
Fig: Our method produces significantly denser point clouds comparing to that of the baseline

16:15–17:30	MoC1.5

An Autonomous Loop-Closure Approach for Simultaneous Exploration and Mapping of Unknown Infrastructure using MAVs

David Vutetakis
Department of Computer Science, UNC Charlotte, USA
Jing Xiao
Department of Computer Science, Worcester Polytechnic Institute, USA

- Critical structure inspection requires precise 3D models built from sensor data
- This planning approach simultaneously fulfills objectives of exploration, coverage, and loop closure guidance
- Simulations demonstrate complete structure coverage producing twice as many loop closures than traditional NBV planner

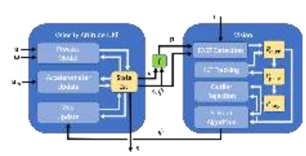


16:15–17:30	MoC1.6

Inertial Yaw-Independent Velocity and Attitude Estimation for High Speed Quadrotor Flight

James Svacha and Vijay Kumar
ESE and MEAM, University of Pennsylvania, USA
Giuseppe Loianno
ECE, New York University, USA

- IMU-based estimation for body-frame velocity, tilt, accelerometer biases, and model parameters
- Vision-based estimation of yaw
- IMU-based estimate is robust to unknown yaw
- UKF estimates the tilt on the 2-sphere and the yaw on the 1-sphere


overview of our estimation architecture

Aerial Systems: Perception IV - 1.3.18

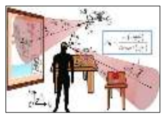
Chair
Co-Chair

16:15–17:30	MoC1.1

Unsupervised Learning of Assistive Camera Views by an Aerial Co-robot in Augmented Reality Multitasking Environments

William Bentz and Dimitra Panagou
Department of Aerospace Engineering, University of Michigan, USA
Sahib Dhanjal
Robotics Institute, University of Michigan, USA

- We track human head motion during multitasking to learn visual interest regions (VIR) online.
- A UAV monitors VIRs and streams live video to the human's augmented reality display.
- We conducted experimental trials on ten subjects.
- With the aid of the UAV, subject head motions and reaction times were improved.

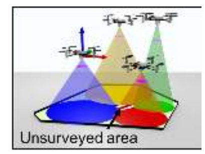


16:15–17:30	MoC1.2

Visual Coverage Control for Teams of Quadcopters via Control Barrier Functions

Riku Funada[1], María Santos[2], Junya Yamauchi[1], Takeshi Hatanaka[3], Masayuki Fujita[1] and Magnus Egerstedt[2]
[1] Department of Systems and Control Eng., Tokyo Tech., Japan
[2] School of Electrical and Computer Eng., Georgia Tech., USA
[3] Electronic and Information Eng., Osaka Univ., Japan

- How to conduct visual coverage ensuring no area is left unsurveyed among quadcopters' views?
- The cost function which favors coverage quality and penalizes overlapping coverage is designed.
- No appearance of unsurveyed area among views is guaranteed through control barrier function.
- The algorithm is evaluated through simulation.



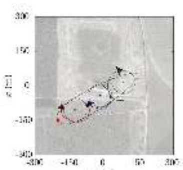
A team of quadcopters with downward facing camera monitors environment

16:15–17:30	MoC1.3

Field Deployment of a Plume Monitoring UAV Flock

Matthew Silic[1] and Kamran Mohseni[1,2]
[1]Mechanical and Aerospace Engineering, University of Florida, USA
[2]Electrical and Computer Engineering, University of Florida, USA

- We describe a plume monitoring platform consisting of a networked flock of unmanned aerial vehicles
- The UAVs work in parallel with an online simulation of the plume dispersion
- The UAVs and simulation interact through data assimilation and hotspot identification
- We validate the platform with a flight test where three UAVs trace a simulated plume



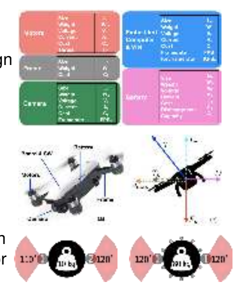
Flight test where three vehicles trace a simulated plume.

16:15–17:30	MoC1.4

Robot Co-design: Beyond the Monotone Case

Luca Carlone, MIT
Carlo Pinciroli, WPI

- We consider the problem of *computational* robot co-design with recursive constraints
- We propose a *binary optimization* formulation that generalizes over previous approaches
- We demo our approach on a drone design problem and on the design of a robot team for collective transport



16:15–17:30	MoC1.5

A Hybrid Approach of Learning and Model-Based Channel Prediction for Communication Relay UAVs in Dynamic Urban Environments

Pawel Ladosz and Wen-Hua Chen
AACME, Loughborough University, UK
Hyondong Oh
Ulsan National Institute of Science and Technology (UNIST), South Korea
Gan Zheng
Wolfson School of MEME, Loughborough University, UK

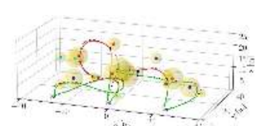
- **Problem:** Wireless communication during natural disasters is hard due to damaged infrastructure
- **Solution:** UAVs as temporary communication relay nodes in an urban environment
- **Methodology:** Optimise UAVs trajectory to maximise the communication performance
- **Contribution:** Parameters of the wireless signal strength model are estimated using machine learning approaches

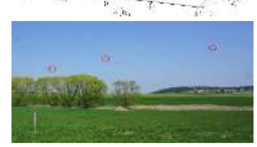
16:15–17:30	MoC1.6

Multi-Vehicle Close Enough Orienteering Problem with Bézier Curves for Multi-Rotor Aerial Vehicles

Jan Faigl and Petr Váňa and Robert Pěnička
Computational Robotics Laboratory
Artificial Intelligence Center, Faculty of Electrical Engineering
Czech Technical University in Prague, Czechia

- Data collection planning for a team of vehicles with limited travel budget
- Generalization of the Close Enough Orienteering Problem (CEOP) to motion constraints of multi-rotor vehicles
- Novel heuristic solution of the introduced CEOP with Bézier curves for a team of aerial vehicles
- Empirical evaluation and verification using multi-rotor aerial vehicles in the experimental field deployment





Motion Control of Manipulators - 1.3.19

Chair
Co-Chair

16:15–17:30	MoC1.1

Critically fast pick-and-place with suction cups

Hung Pham[1,2], Quang-Cuong Pham[1]
[1] Nanyang Technological University, Singapore
[2] Eureka Robotics, Singapore

- *Problem*: Plan the fastest possible motions for robotic pick-and-place with suction cups.
- Model and identify *suction grasp stability constraints* using polyhedral computation theory.
- Plan motions subject to constraints using TOPP-RA: a state-of-art path parameterization algorithm.

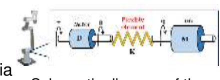
Robot moving critically fast

16:15–17:30	MoC1.2

Robust Link Position Tracking Control for Robot Manipulators with Series Elastic Actuators Using Time-delay Estimation

Sang Hyun Park, Kap-Ho Seo and Maolin Jin
Korea Institute of Robot and Convergence, Korea
Jinoh Lee
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

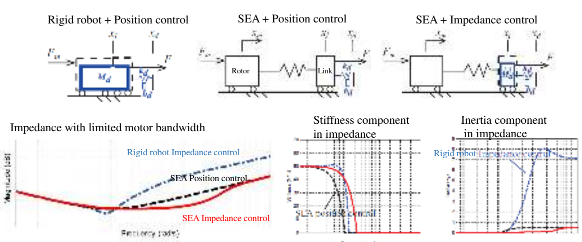
- A controller for a robot with series elastic actuators (SEAs) is developed.
- The control target is to achieve precise link position tracking coping with deflections.
- A time-delay estimation technique using inertia matrix model is adopted.
- The proposed controller is numerically validated by comparative simulations with an SEA-driven manipulator.



Schematic diagram of the joint with the SEA

16:15–17:30	MoC1.3

Benefit from SEA + Impedance control



At low frequencies,
designed stiffness is predominant, which can be arbitrarily set using control gains.
At high frequencies,
under the motor bandwidth limit, SEA+impedance control further decreases the impedance in comparison with SEA+position control.

16:15–17:30	MoC1.4

Robotic Cutting: Mechanics and Control of Knife Motion

Xiaoqian Mu, Yuechuan Xue, and Yan-Bin Jia
Computer Science, Iowa State University, United States

- Cutting as a sequence of three moves: *press*, *push*, and *slice* with separate control strategies.
- *Press*: position control to achieve steady cutting progress.
- *Push*: force control to establish knife-board contact.
- *Slice*: hybrid control to smoothly cut through the object and maintain certain contact force.

16:15–17:30	MoC1.5

A constrained control-planning strategy for redundant manipulators

Corina Barbalata and Matthew Johnson-Roberson
Naval Architecture and Marine Engineering, University of Michigan, US
Ram Vasudevan
Mechanical Engineering, University of Michigan, US

- A planning-control architecture using a robust initial estimation in a prioritized optimization framework subject to constraints.
- The method is advantageous for cases when robotic systems have to work in cluttered and dynamic environments.
- The strategy is validated with a 7 DOF Fetch manipulator and the results are comparable with state-of-the-art planning methods.

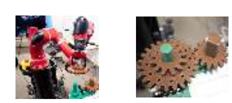
Algorithm performance analysis

16:15–17:30	MoC1.6

Reinforcement Learning on Variable Impedance Controller for High-Precision Robotic Assembly

Jianlan Luo, Eugen Solowjow, Chengtao Wen, Juan Aparicio
Alice Agogino, Aviv Tamar, Pieter Abbeel
UC Berkeley, USA
Siemens Corporate Research, USA
Technion, Israel

- Learning high-precision multi-stage robotic assembly task
- Reinforcement learning combined with operational space model for faster learning
- Generalization capability to environment variations



a) Robot learning for complex assemblies. b) Assembled gear.

Compliant Mechanisms - 1.3.20

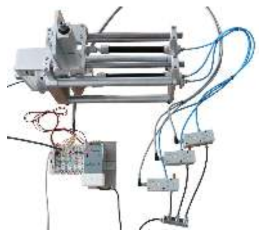
Chair
Co-Chair

16:15–17:30	MoC1.1

A Compliant and Precise Pneumatic Rotary Drive Using Pneumatic Artificial Muscles in a Swash Plate Design

Johannes T. Stoll and Kevin Schanz
Fraunhofer IPA, Stuttgart, Germany
Andreas Pott
Institute for Control Engineering (ISW), University of Stuttgart, Germany

- Stick-slip slip free, therefore enables precise positioning
- Back-drivable system features adjustable stiffness
- Capable of 360° continuous rotation
- Developed to be used in robotic applications, especially in human-robot collaboration


Laboratory test stand

16:15–17:30	MoC1.2

Passivity based Control of Antagonistic Tendon-Driven Mechanism

Junho Park[1], Geun Young Hong[1], Youngjin Choi[1], Dongliang Peng[2] and Qiang Lu[2]
[1]Department of Electrical Engineering, Hanyang University, South Korea
[2]School of Automation, Hangzhou Dianzi University, China

- A **passivity-based control** law for an **antagonistic tendon-driven mechanism** is proposed.
- The proposed control law is **simple to be implemented** for a complex tendon-driven mechanism
- The control law brings a **robustness** to the entire control system

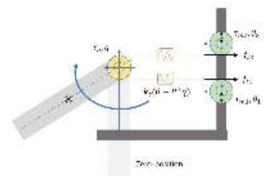


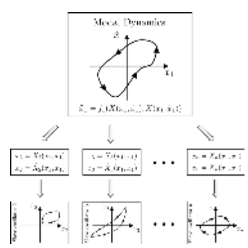
Fig. Schematic of the antagonistic tendon-driven mechanism

16:15–17:30	MoC1.3

Exact Modal Characterization of the Non Conservative Non Linear Radial Mass Spring System

Cosimo Della Santina
Centro E. Piaggio, University of Pisa, Italy
Antonio Bicchi
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy
Dominic Lakatos, and Alin Albu Schaeffer
Deutsches Zentrum fur Luft- und Raumfahrt (DLR), Germany

- Since the spread of robotic systems embedding in their mechanics purposefully designed elastic elements, the interest in characterizing and exploiting non-linear oscillatory behaviors has progressively grown. However, few works so far looked at the problem from the point of view of modal analysis.
- With the aim of making a step toward translating and extending this powerful tool to the robotic field, we present the complete modal characterization of a simple yet representative non-linear elastic robot: the 2D planar mass-spring-damper system.

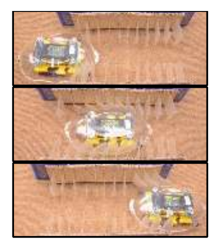


16:15–17:30	MoC1.4

Body Lift and Drag for a Legged Millirobot in Compliant Beam Environment

Can Koc, Cem Koc, Brian Su and Ronald S. Fearing
Dept. of Electrical Engineering and Computer Sciences, UC Berkeley, USA
Carlos S. Casarez
Mechanical Engineering Department, UC Berkeley, USA

- Legged millirobot with force sensing shell provides direct lift and drag measurements.
- Drag energy and specific resistance characterized in cluttered terrain with compliant beams.
- Shell shape provides negative lift which can improve traction, lower specific resistance of locomotion.

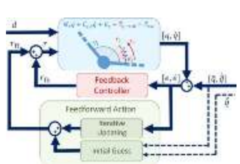

VelociRoACH with tactile shell traversing a channel with compliant beams.

16:15–17:30	MoC1.5

Decentralized Trajectory Tracking Control for Soft Robots Interacting with the Environment

Franco Angelini[1,2,3], Cosimo Della Santina[1,3], Manolo Garabini[1], Matteo Bianchi[1,3], Gian Maria Gasparri[1],Giorgio Grioli[2], Manuel G. Catalano[2], and Antonio Bicchi[1,2,3]
[1]Centro “E. Piaggio”, Pisa; [2]SoftBot, IIT, Genova; [3]DII, Università di Pisa (Italy)

- Trajectory tracking controller for articulated soft robots combining: a low-gain feedback, rough initial guess, feedforward action refined trough iterations
- The algorithm is independent from the robot kinematic structure, it preserves the robot soft behavior, and it is robust to external uncertainties
- The effectiveness of the method is tested on various experimental setups, i.e. serial and parallel structure, different degrees of interaction with the environment, different number of joints

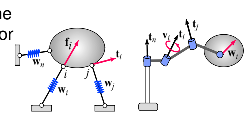


16:15–17:30	MoC1.6

Geometric Construction-Based Realization of Spatial Elastic Behaviors in Parallel and Serial Manipulators

Shuguang Huang and Joseph M. Schimmels
Department of Mechanical Engineering, Marquette University, USA

- Necessary and sufficient ***conditions*** for the realization of any spatial compliant behavior are identified.
- Conditions are ***interpreted*** in geometric terms for both fully serial and fully parallel mechanisms.
- Geometry based ***synthesis procedures*** for compliance realization with serial or parallel mechanisms are presented.


Geometric synthesis of compliance with parallel and serial mechanisms

Sensor Fusion I - 1.3.21

Chair
Co-Chair

16:15–17:30 MoC1.1

Tightly Coupled 3D Lidar Inertial Odometry and Mapping

Haoyang Ye, Yuying Chen and Ming Liu
ECE, The Hong Kong University of Science and Technology, Hong Kong

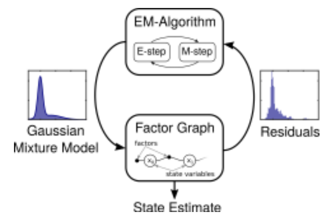
- Tightly-coupled lidar-IMU odometry algorithm (LIO) with high robustness to degraded lidar measurements and fast motion
- Rotational constrained refinement (LIO-mapping) further optimizing lidar poses and the generated point-cloud maps
- Extensive indoor and outdoor tests showing superior performance over the state of the art

16:15–17:30 MoC1.2

Expectation-Maximization for Adaptive Mixture Models in Graph Optimization

Tim Pfeifer and Peter Protzel
Dept. of Electrical Engineering and Information Technology
TU Chemnitz, Germany

- Sensor fusion often suffer from non-Gaussian errors
- We describe them as Gaussian mixture and adapt it online
- Extensive evaluation on several GNSS and localization datasets
- Code and data are online: https://mytuc.org/libRSF



16:15–17:30 MoC1.3

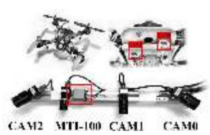
Multi-Camera Visual-Inertial Navigation with Online Intrinsic and Extrinsic Calibration

Kevin Eckenhoff, Patrick Geneva*,
Jesse Bloecker, and Guoquan Huang
Dept. Mechanical Engineering, University of Delaware, USA
*Dept. Computer and Information Sciences, University of Delaware, USA

- Propose a versatile MSCKF-based framework for VIO using *arbitrary* number of asynchronous cameras
- Limit computation by only estimating poses corresponding to one camera's images
- Linear interpolation on manifold to represent poses at other cameras' imaging times

this work we have used different multi-camera visual-inertial sensor platforms with non-ov

- Perform online calibration of both IMU-camera spatial/temporal extrinsincs and all camera intrinsics

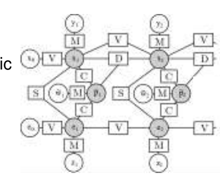


16:15–17:30 MoC1.4

Joint Inference of Kinematic and Force Trajectories with Visuo-Tactile Sensing

Sasha Lambert, Mustafa Mukadam, Bala Sundaralingam,
Nathan Ratliff, Byron Boots, Dieter Fox
Georgia Tech, University of Utah, University of Washington
NVIDIA, USA

- Sensor fusion and state estimation using Factor Graphs with Physics-based priors for Robot Manipulation tasks.
- Experiments are conducted on multiple robotic systems equipped with Tactile sensing capability, including a Syntouch Biotac.
- Vision-based tracking system (DART)
- Ablation studies are performed on various graphical model designs, with/without occlusion, indicating enhanced performance through joint inference over sensor modalities.

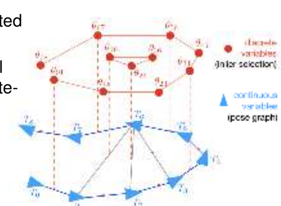


16:15–17:30 MoC1.5

Modeling Perceptual Aliasing in SLAM via Discrete-Continuous Graphical Models

Pierre-Yves Lajoie[1], Siyi Hu[2], Giovanni Beltrame[1], Luca Carlone[2]
[1]Department of Computer and Software Engineering,
École Polytechnique de Montréal, Canada
[2] Laboratory for Information & Decision Systems,
Massachusetts Institute of Technology, USA

- Perceptual aliasing causes highly-correlated outliers that lead to SLAM failure
- We propose a unified framework to model perceptual aliasing in SLAM using Discrete-Continuous Graphical Models (DC-GM)
- We propose a semidefinite relaxation for DC-GM that computes SLAM estimates with provable guarantees without relying on any initial guess
- We evaluate DC-GM against state-of-the-art methods including RRR, DCS, and Vertigo.



Discrete-Continuous Graphical Model for SLAM

16:15–17:30 MoC1.6

ConFusion: Sensor Fusion for Complex Robotic Systems using Nonlinear Optimization

Timothy Sandy, Lukas Stadelmann, Simon Kerscher
and Jonas Buchli
Agile & Dexterous Robotics Lab, ETH Zurich, Switzerland

- We present ConFusion, an open-source package for online sensor fusion for robotic applications.
- A generic set of update and process measurements are fused to generate estimates of user-defined robot states in a Moving Horizon Estimator.
- Performance is demonstrated on a mobile manipulator, fusing visual-inertial sensing at both the base and end-effector as well as wheel and arm odometry.

Our mobile manipulator demonstrator platform, IFmini

Model Learning for Control - 1.3.22

Chair
Co-Chair

16:15–17:30	MoC1.1

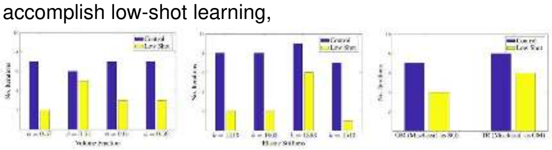
Every Hop is an Opportunity: Quickly Classifying and Adapting to Terrain During Targeted Hopping

Alex Chang[1], Christian Hubicki[2], Aaron Ames[3] and Patricio Vela[1]
[1]School of ECE, Georgia Institute of Technology, USA
[2]Dept. of ME, Florida A&M University-Florida State University, USA
[3]Dept. of Mech. and Civil Eng., California Institute of Technology, USA

- Collected robot trajectory data applied to train GP-based terrain classifier,

Prediction	Ground Truth		
	sg	*tramp*	*grs*
sg	96.9% (250)	0.7% (2)	2.6% (5)
tramp	0%	92.8% (271)	0%
grs	3.1% (8)	6.5% (19)	97.4% (187)

- Results inform an iterative control-learning procedure to accomplish low-shot learning,



16:15–17:30	MoC1.2

Semiparametrical GP Learning of Forward Dynamical Models for Navigating in a Circular Maze

Diego Romeres, Devesh Jha, William Yerazunis, Daniel Nikovski
MERL-Mitsubishi Electric Research Laboratories, Cambridge, USA
Alberto Dalla Libera
Department of Information Engineering, University of Padova, Italy

- Learning accurate models for physical systems is a known hard problem.
- We propose a semiparamteric GP to estimate the continuous forward dynamics of systems.
- The model is shown to be highly accurate for open loop rollouts and to control a physical system using iLQR.
- The study case is a Circular Maze, that we propose as a benchmark for RL and Robot Learning for its interesting properties and ease of reproducibility.

A circular maze is mounted in a in-house tip-tilt platform. The goal is to learn a control law to drive the ball to the center.

16:15–17:30	MoC1.3

Semantic Predictive Control for Interpretable and Efficient Policy Learning

Xinlei Pan*, John F. Canny, Fisher Yu
UC Berkeley, Berkeley, CA, USA
Xiangyu Chen*
Shanghai Jiao Tong University, Shanghai, China
Qizhi Cai
Nanjing University, Nanjing, China

- Predict future scenes as semantic segmentation and perform model predictive control to select actions
- Accelerate policy learning with high-level guidance prediction learned from self-imitation
- Semantic segmentation provides dense supervision for feature learning and can greatly improve policy learning efficiency

16:15–17:30	MoC1.4

Adaptive Variance for Changing Sparse-Reward Environments

Xingyu Lin[1], Pengsheng Guo[1], Carlos Florensa[2] and David Held[1]
[1]Robotics Institute, Carnegie Mellon University, USA
[2]University of California, Berkeley, USA

- A policy trained in a fixed environment often fails when environment changes due to a lack of sufficient exploration
- We propose a principled way to adapt the policy for better adaptation in changing sparse-reward environments
- Our method is provably optimal for Gaussian policies with sparse rewards in continuous bandit settings, and empirically works well also for challenging multi-step manipulation tasks

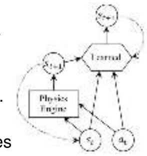
Manipulation tasks in changing, unknown environments

16:15–17:30	MoC1.5

Combining Physical Simulators and Object-Based Networks for Control

Anurag Ajay, Maria Bauza, Jiajun Wu, Nima Fazeli, Joshua B. Tenenbaum, Alberto Rodriguez, Leslie P. Kaelbling
Massachusetts Institute of Technology, USA

- It is hard to model contact dynamics analytically.
- We propose simulator-augmented interaction networks (SAIN), combining a physics engine with interaction networks for dynamics modeling.
- SAIN is more data-efficient, accurate, and generalizable than purely data-driven approaches and purely analytical approaches.
- SAIN performs better in complex control tasks.



Simulator Augmented Interaction Networks (SAIN)

16:15–17:30	MoC1.6

Using Data-Driven Domain Randomization to Transfer Robust Control Policies to Mobile Robots

Matthew Sheckells, Gowtham Garimella, Subhransu Mishra, and Marin Kobilarov
Laboratory for Computational Sensing and Robotics, Johns Hopkins University, USA

- Learn deep stochastic model of an agile UGV
- Train control policy in simulation and generate performance guarantees
- Show that policy trained on deep stochastic model outperforms policy trained on simple model with ad-hoc noise model
- Show empirically that guarantees transfer to the real vehicle

JHU UGV

Path Planning for Multi-Robot Systems II - 1.3.23

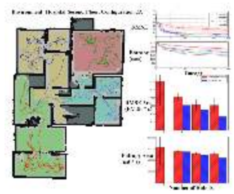
Chair
Co-Chair

16:15–17:30	MoC1.1

Coordinating multi-robot systems through environment partitioning for adaptive informative sampling

Nicholas Fung[1], John Rogers[1], Carlos Nieto[2], Henrik Christensen[2], Stephanie Kemna[3] and Gaurav Sukhatme[3]

- Goal: Enable team of robots to efficiently create a sensor model of the environment
- Robots seek to attain a high rate of expected information gain per cost (entropy reduction/distance traveled)
- Robots are coordinated by partitioning the environment according to expected traversal cost and assigning robots to separate partitions



Example of a partitioned environment and reduction in entropy over time

DEVCOM [1] UC San Diego JACOBS SCHOOL OF ENGINEERING [2] USC Viterbi [3]

16:15–17:30	MoC1.2

A Fleet of Miniature Cars for Experiments in Cooperative Driving

Nicholas Hyldmar, Yijun He and Amanda Prorok
Department of Computer Science and Technology
University of Cambridge, United Kingdom

- Unique experimental testbed with 16 miniature Ackermann-steering vehicles.
- The *Cambridge Minicar* has an open design and fills a price-range gap.
- Quantifiable traffic behavior through implementation of state-of-the-art driver models as well as cooperative driving strategies.
- Experimental highlight: cooperative driving increases throughput by up to 42%.

The fleet of Minicars on a U-shaped miniature highway.

16:15–17:30	MoC1.3

Multi-robot Informative Path Planning with Continuous Connectivity Constraints

Ayan Dutta, Anirban Ghosh and O. Patrick Kreidl
University of North Florida, USA

- This paper is the first to study the problem of information collection using a multi-robot system with continuous connectivity constraints.
- We leverage two graph theoretic concepts: 1) bipartite matching for collision-avoidance and maximizing information collection, and 2) minimal vertex separators for maintaining connectivity.
- Our proposed approach is guaranteed to be deadlock and livelock free.
- Video: https://bit.ly/2EgwLDq.

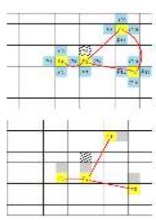


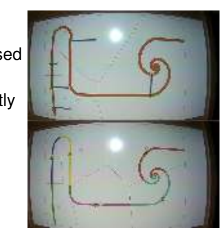
Fig.: An illustrative example.

16:15–17:30	MoC1.4

Sensor Coverage Control Using Robots Constrained to a Curve

Gennaro Notomista, María Santos
Seth Hutchinson, and Magnus Egerstedt
Institute for Robotics and Intelligent Machines,
Georgia Institute of Technology, USA

- An algorithm to perform coverage control in the case of robots constrained to move on curves (like wire-traversing robots) is proposed
- A convex relaxation of the formulated non-convex problem allows the robots to efficiently execute the developed algorithm in a decentralized fashion
- The algorithm is tested on a team of small-scale differential-drive robots on the Robotarium

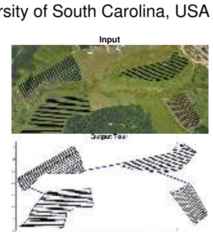


16:15–17:30	MoC1.5

Coverage of an Environment Using Energy-Constrained Unmanned Aerial Vehicles

Kevin Yu and Pratap Tokekar
Dept. of Electrical & Computer Engineering, Virginia Tech, USA
Jason M. O'Kane
Dept. of Computer Science & Engineering, University of South Carolina, USA

- Problem: Sensor coverage of a set of disjoint polygons using an energy-limited UAV
- Key Idea: Using a UGV as a mobile charging station that can rendezvous with the UAV at desired locations
- Objective: Minimize the total coverage time, including the time taken to land/take-off, recharge, and travel
- Solution: Algorithm that finds an optimal tour which dictates when, where, how and how much to recharge the UAV



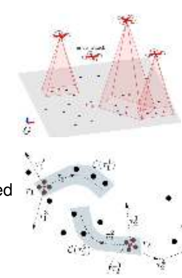
Black and Blue lines = UAV flight
Red and Pink lines = UAV recharging

16:15–17:30	MoC1.6

Resilient Active Target Tracking with Multiple Robots

Lifeng Zhou[1], Vasileios Tzoumas[2], George J. Pappas[3] and Pratap Tokekar[1]
[1]ECE, Virginia Tech, USA, [2] AeroAstro, MIT, USA, [3]ESE, UPenn, USA

- **Problem:** Deploy mobile robots to enable active multi-target tracking despite attacks to robots.
- **Sensing & Tracking:** Each robot has a tracking sensor, (e.g., a camera), and a set of candidate trajectories from which it must choose one. Each trajectory covers a number of targets.
- **Attack:** Targets can block the field-of-views of a worst-case subset of robots.
- **Objective:** Maximize the number of targets covered (submodular) subject to the worst-case attack.
- **Contribution:** Propose the first resilient algorithm with provable performance guarantees, and with running time quadric in the number of robots.



Depth Perception - 1.3.24

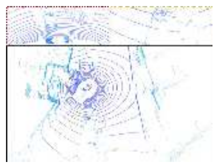
Chair
Co-Chair

16:15–17:30 MoC1.1

Point Cloud Compression for 3D LiDAR Sensor using Recurrent Neural Network with Residual Blocks

Chenxi Tu and Eijiro Takeuchi
Department of Intelligent System, Nagoya University, Japan
Alexander Carballo and Kazuya Takeda
Institutes of Innovation for Future Society, Nagoya University, Japan

- LiDAR packet data are converted into 2D matrix losslessly, then compressed by RNN
- Adding residual blocks in decoder improves performance significantly
- Compress point cloud from Velodyne HDL-32 sensor to 2 Mbps with 6 cm SNNRMSE
- Outperform JPEG based compression and octree compression



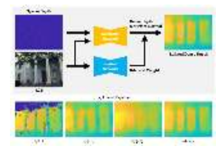
Decompression example at 2 Mbps

16:15–17:30 MoC1.2

Depth Completion with Deep Geometry and Context Guidance

Byeong-Uk Lee[1], Hae-Gon Jeon[2], Sunghoon Im[1] and In So Kweon[1]
[1]School of Electrical Engineering, KAIST, South Korea
[2]Robotics Institute, Carnegie Mellon University, USA

- We present an end-to-end convolutional neural network for depth completion.
- The geometry network generates an initial propagated depth map and surface normal.
- The context network extracts a local and a global feature of an image to compute a bilateral weight.
- The bilateral weight is multiplied to the initially propagated depth map for refined depth completion result.



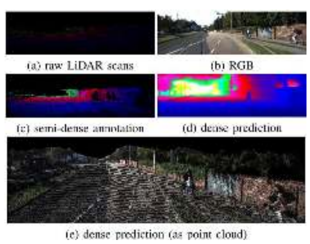
Overall pipeline and results comparisons to state-of-the-art methods.

16:15–17:30 MoC1.3

Self-Supervised Sparse-to-Dense: Self-Supervised Depth Completion from LiDAR and Monocular Camera

Fangchang Ma, Guilherme Venturelli Cavalheiro, Sertac Karaman
LIDS, MIT, USA

- A self-supervised training framework that requires only sequences of color and sparse depth images, without the need for dense depth labels
- A early-fusion deep regression network for depth completion, ranked 1st on the KITTI Benchmark



16:15–17:30 MoC1.4

In-hand Object Scanning via RGB-D Video Segmentation

Fan Wang and Kris Hauser
Department of Electrical and Computer Engineering
Duke University, USA

- 3D object scanning via in-hand manipulation using a hand-held RGB-D camera
- A novel semi-supervised video segmentation technique tailored for the hand-object segmentation task
- Our technique leads to improved tracking accuracy for rotating objects and better quality reconstructs
- An annotated RGB-D dataset containing 13 sequences of in-hand manipulation of objects

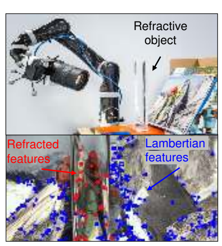
Fig 1: Some successfully reconstructed objects from a 200-item test set, scanned by a novice user of our system

16:15–17:30 MoC1.5

Distinguishing Refracted Features using Light Field Cameras with application to Structure from Motion

Dorian Tsai, Thierry Peynot and Peter Corke
Australian Centre for Robotic Vision, Queensland U. of Technology, Australia
Donald G. Dansereau
Australian Centre for Field Robotics, U. of Sydney, Australia

- Our method automatically distinguishes refracted and non-refracted image features in a single shot of a light field camera
- This enables successful Structure from Motion (SfM) in scenes with refractive objects, where traditional methods fail
- A critical step towards allowing robots to operate in the presence of refractive objects



We distinguish the refracted object, enabling SfM in challenging scenes

16:15–17:30 MoC1.6

:ts in Clutter through Inverse Physics Reasoning

Abdeslam Boularias
ınce, Rutgers University, USA

- a novel approach utilizing a physics engine to infer invi ene
- a Monte Carlo search method that returns a distributior
- integration of robot manipulators (pushing/poking), seg teri

Multi-Robot Systems III - 1.3.25

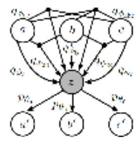
Chair
Co-Chair

16:15–17:30 MoC1.1

Multi-Modal Generative Models for Learning Epistemic Active Sensing

T. Korthals and D. Rudolph and M. Hesse and U. Rückert
Cognitronics & Sensor Systems, University Bielefeld, Germany
J. Leitner
Australian Centre for Robotic Vision, QUT, Australia

- Sensor information from various modalities (*a*,*b*,…) are used for unsupervised training of all encoder networks q_ϕ. using M²VAE
- M²VAE learns a coherent latent space *z* between all encoder networks
- The evidence lower bound (ELBO) of a subset (e.g. *a*) increases, iff an additional modality (e.g. *a* & *b*) adds new information
- This leads to an epistemic (ambiguity resolving) behavior by learning to maximize the ELBO using deep Q-Learning



Generative Model for learning a coherent latent space using our proposed multi-modal generative model (M²VAE)

16:15–17:30 MoC1.2

Decentralized Formation Coordination of Multiple Quadcopters under Communication Constraints

Pramod Abichandani and Kyle Levin
ECET, New Jersey Institute of Technology, USA
Donald Bucci
Lockheed Martin Advanced Technology Laboratory

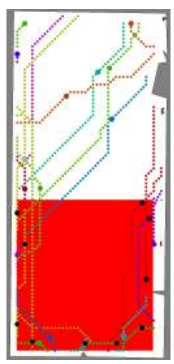
- Decentralized, outdoor formation coordination with multiple quadcopters formulated as a receding horizon, mixed-integer non-linear program (RH-MINLP)
- Framework is validated via Hardware-in-the-Loop (HITL) and outdoor flight test with up to 6 quadcopters
- Robust network performance for a round robin communication scheduling scheme

16:15–17:30 MoC1.3

Online Plan Repair in Multi-robot Coordination with Disturbances

Adem Coskun and Jason M. O'Kane
Department of Computer Science and Engineering
University of South Carolina, USA

- Many robots move together in a shared cluttered environment, according to a plan computed offline. This plan characterizes whether the path should travel "over" or "under" each coordination space obstacle.
- Robots experience random unexpected disturbances executing the plan. Disturbances may be non-uniform across the environment.
- We introduce online criteria for determining whether to modify the original plan, "flipping" a coordination space obstacle, in response to those observed disturbances.



16:15–17:30 MoC1.4

Trajectory Generation for Multiagent Transitions via Distributed Model Predictive Control

Carlos E. Luis and Angela P. Schoellig
Institute for Aerospace Studies, University of Toronto, Canada

- Problem: generate collision-free trajectories to drive N agents from an initial to a final configuration
- Distributed collision avoidance strategy: agents share predicted states to detect and avoid collisions, if required
- Significant reduction in computation time (>85%) compared to previous approaches
- Tested with a swarm of 25 quadrotors (Fig. 1), averaging ~1 second to compute

Fig. 1. A swarm of 25 quadrotors executing a transition using our method

16:15–17:30 MoC1.5

Persistent and Robust Execution of MAPF Schedules in Warehouses

Wolfgang Hönig and Nora Ayanian
Department of Computer Science, University of Southern California, USA
Scott Kiesel, Andrew Tinka, and Joseph W. Durham
Amazon Robotics, USA

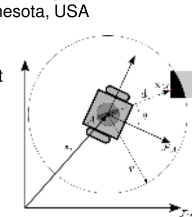
- Multi-Agent Path Finding (MAPF) has limiting assumptions:
  - Synchronous, perfect execution of plans, i.e., **MAPF is not robust**
  - Single-shot, i.e., **MAPF is not persistent**
- We present a MAPF **execution framework** to solve both issues using a novel data structure
- **Verification** in simulation and on robots

16:15–17:30 MoC1.6

Integrated Mapping and Planning for Very Large-Scale Robotic (VLSR) Systems

Julian Morelli and Pingping Zhu and Silvia Ferrari
Mechanical and Aerospace Engineering, Cornell University, USA
Bryce Doerr and Richard Linares
Department of Aerospace Engineering
and Mechanics, University of Minnesota, USA

- This paper presents path planning of a large system of hundreds of robots through an unknown, obstacle populated region of interest
- Using information-driven path planning, mapping of the environment can be done quickly and efficiently
- Obstacle avoidance is guaranteed by an information-driven probabilistic roadmap method.
- Communication protocol ensures quick and accurate data fusion between decentralized robots



Schematic of one of the many robots in our system

Multi-Robot Systems IV - 1.3.26

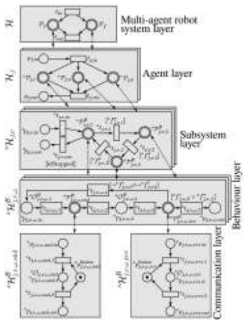
Chair
Co-Chair

16:15–17:30 MoC1.1

Methodology of Designing Multi-agent Robot Control Systems Utilising Hierarchical Petri Nets

Maksym Figat and Cezary Zieliński
Warsaw University of Technology, Poland

- Robot treated as a system composed of one or more embodied agents
- An embodied agent represented by a Hierarchical Petri Net (HPN)
- Layers represent: system, agents, subsystems, behaviours, inter-subsystem communication
- Developed tool for designing HPNs and enabling automatic generation of the robot controller code

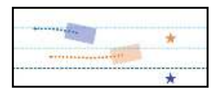


16:15–17:30 MoC1.2

Interaction-Aware Multi-Agent Reinforcement Learning for Mobile Agents with Individual Goals

Anahita Mohseni-Kabir
Robotics Institute, Carnegie Mellon University, USA
David Isele and Kikuo Fujimura
Honda Research Institute, USA

- In a multi-agent setting, the optimal policy of a single agent is largely dependent on the behavior of other agents.
- We introduce a curriculum learning method to address the problem of multi-agent reinforcement learning, focusing on decentralized learning in non-stationary domains for mobile robot navigation.
- We evaluated our approach on both an autonomous driving lane-change domain and a robot navigation domain.



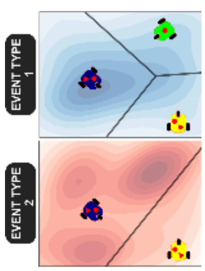
Double lane-change problem

16:15–17:30 MoC1.3

Coverage Control for Multiple Event Types with Heterogeneous Robots

Armin Sadeghi and Stephen L. Smith
Electrical and Computer Engineering, University of Waterloo, Canada

- New formulation of coverage for multiple event types using robots with heterogeneous suite of sensors
- Continuous-time descent algorithm converges to a locally optimal solution
- Extension to coverage of multiple event types in discrete environments
- Experimental results show improvement in the coverage compared to state-of-the-art



16:15–17:30 MoC1.4

Active Perception in Adversarial Scenarios using Maximum Entropy Deep Reinforcement Learning

Macheng Shen
Department of Mechanical Engineering, MIT, USA
Jonathan P. How
Department of Aeronautics and Astronautics, MIT, USA

- Problem: Active perception against adversarial agents
- Challenges: Partial Observability, Agent modeling uncertainty, Deceptive opponent
- Approaches: Belief space planning, Generative adversary modeling, and Maximum entropy reinforcement learning
- Contributions: A robust active perception method in adversarial scenarios that outperforms POMDP methods

Active perception in adversarial scenarios

16:15–17:30 MoC1.5

A Competitive Algorithm for Online Multi-Robot Exploration of a Translating Plume

Yoonchang Sung and Pratap Tokekar
Department of Electrical and Computer Engineering, Virginia Tech, USA

- We study the problem of exploring a translating plume with a team of aerial robots.
- The shape and the size of the plume are not known to the robots.
- We propose an online constant-competitive algorithm that generates a tour for each robot.
- We prove competitive ratios for both grid-shaped and arbitrarily-shaped plumes.

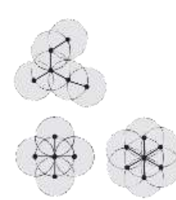
An aerial robot conducting plume exploration.

16:15–17:30 MoC1.6

A Comparison Between Decentralized Local and Global Methods for Connectivity Maintenance of Multi-Robot Networks

Koresh Khateri, Mahdi Pourgholi, and Mohsen Montazeri
Shahid Beheshti University, Tehran, Iran
Lorenzo Sabattini
University of Modena and Reggio Emilia, Reggio Emilia, Italy

- Connectivity preservation is fundamental, in networks of multiple mobile robots
- Local methods imply keeping each single link, as the system evolves, while global methods allow single links to be removed/added, as long as the overall graph remains connected
- Typically, global methods are considered more flexible
- We show the counterintuitive result that, in the presence of time delays, global methods are actually more restrictive than local ones



Award Session III

Chair *Jana Kosecka, George Mason University*
Co-Chair *Kazuhito Yokoi, National Inst. of AIST*

16:15–16:27	MoC2.1

Eagle Shoal: A new designed modular tactile sensing dexterous hand for domestic service robots

Tao Wang, Zhanxiao Geng, Bo Kang and Xiaochuan Luo
Intel Labs China, China

- This fully-actuated hand consists of 1 palm and 3 fingers, with embedded tactile sensors.
- Modular design makes it easy to assembly, palm and each finger have 2 DOFs.
- A series of experiments have been delivered to test new sensor unit and hand performance.
- This hand with low cost can help robotic manipulation research with visual and tactile data.

Eagle Shoal robot hand

16:27–16:39	MoC2.2

Classification of Household Materials via Spectroscopy

Zackory Erickson, Nathan Luskey, Sonia Chernova, and Charles C. Kemp
Georgia Institute of Technology, USA

- We demonstrate how robots can leverage spectral data to estimate the material of an object.
- Dataset of 10,000 spectral measurements collected from 50 different objects across five material categories.
- PR2 robot leveraged near-infrared spectroscopy to estimate the materials of everyday objects prior to manipulation.

16:39–16:51	MoC2.3

Multi-Robot Region-of-Interest Reconstruction with Dec-MCTS

Fouad Sukkar[1], Graeme Best[2], Chanyeol Yoo[1] and Robert Fitch[1]
[1]CAS, University of Technology Sydney, Australia
[2]CoRIS, Oregon State University, USA

- Targeted information gathering in high-dimensional action and state space
- Novel formulation that balances between discovering new regions of interest (ROIs) and high-quality reconstruction
- Decentralised multi-robot planning with coordinated plans and intermittent communication
- Significantly outperforms state-of-the-art volumetric information metrics

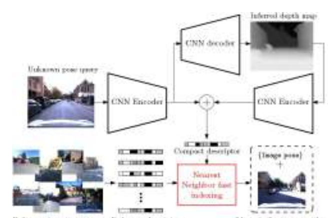
Two robot arms cooperatively searching for apples

16:51–17:03	MoC2.4

Learning Scene Geometry for Visual Localization in Challenging Conditions

Nathan Piasco[12] Désiré Sidibé[1], Valérie Gouet-Brunet[2] and Cédric Demonceaux[1]
[1] ImViA-VIBOT, Univ. Bourgogne Franche-Comté, France
[2] LaSTIG MATIS, IGN, ENSG, Univ. Paris-Est, France

- We introduce a new image descriptor for fast image indexing for the task of urban localization
- We rely on depth information that are not available at query time to train our descriptor
- Our system is especially efficient for cross-season and long-term localization



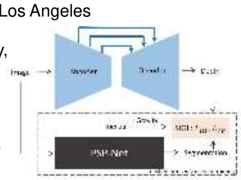
Our localization pipeline

17:03–17:15	MoC2.5

Geo-Supervised Visual Depth Prediction

Xiaohan Fei, Alex Wong, and Stefano Soatto
University of California Los Angeles

- The visual world is heavily affected by gravity, which can be easily inferred from ubiquitous and low-cost inertial sensors.
- We propose two gravity-induced regularizers for self-supervised visual depth prediction.
- We selectively apply our regularizers to image regions corresponding to semantic classes whose shape is biased by gravity.
- We apply our regularizers generically to *non-top performing* methods to outperform state-of-the-art.



System diagram. At training time, gravity extracted from inertials biases the depth prediction selectively based on semantic segmentation. At inference time, the network takes an RGB image as the only input and outputs an inverse depth map.

Industry Forum and IERA Program - Session III

Chair
Co-Chair

Welcome Reception with Exhibitors

Chair
Co-Chair

Plenary Session II

Chair *Jaydev P. Desai, Georgia Institute of Technology*
Co-Chair

08:30–09:30	TuPL.1*

Opportunities and Challenges for Autonomy in Micro Aerial Vehicles

Vijay Kumar, University of Pennsylvania

Keynote Session III

Chair *Jaydev P. Desai, Georgia Institute of Technology*
Co-Chair

09:45–10:30	TuKN1.1*

Embracing Failure

Matthew T. Mason, Carnegie Mellon University

Keynote Session IV

Chair *Gregory Dudek, McGill University*
Co-Chair

09:45–10:30	TuKN2.1*

Robotic Dresses and Emotional Interfaces

Anouk Wipprecht, Self-employed / Freelance / Hi-Tech Fashion Designer

PODS: Tuesday Session I

Chair

Co-Chair

Marine Robotics I - 2.1.01

Chair

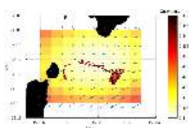
Co-Chair

11:00–12:15 TuAT1.1

Online Estimation of Ocean Current from Sparse GPS Data for Underwater Vehicles

K. M. B. Lee, C. Yoo, S. Huang and R. Fitch
Centre for Autonomous Systems, University of Technology Sydney, Australia
B. Hollings
Blue Ocean Monitoring Pty. Ltd., Australia
S. Anstee
Defence Science and Technology Group, Australia

- AUV position estimate drifts up to 2km due to lack of GPS.
- We use drift to estimate ocean current online.
- GP + incompressibility for better ocean model.
- Incompressible GP used for expectation-maximization (EM).
- Positive results with simulation and field data with Slocum G3 glider.
- Expected to 'close the loop' in underwater navigation.



Result with field data from Jervis Bay, Australia

11:00–12:15 TuAT1.2

Working towards Adaptive Sensing for Terrain-aided Navigation

Mingxi Zhou, GSO, University of Rhode Island, USA
Ralf Bachmayer, MARUM, University of Bremen, Germany
Brad DeYoung, Memorial University of Newfoundland, Canada

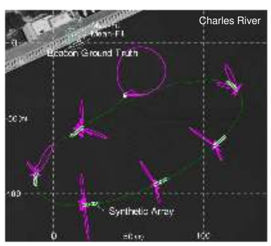
- Autonomous underwater vehicle
- Hybrid Slocum underwater glider
- Terrain-aided navigation
- Adaptive sensing strategy

11:00–12:15 TuAT1.3

Non-Gaussian SLAM utilizing Synthetic Aperture Sonar

Mei Yi Cheung, Pedro Teixeira, Henrik Schmidt, John Leonard
Dept. of Mechanical Engineering, MIT, USA
Dehann Fourie and Nicholas Rypkema
Dept. of Electrical Engineering, MIT, USA

- Non-Gaussian SLAM fuses raw acoustic waveforms with vehicle odometry to leverage Synthetic Aperture Sonar (SAS)
- SAS-Factor comprising inference over multiple vehicle poses and raw acoustic data
- Results presented from field experiments in the Charles River, Cambridge, MA

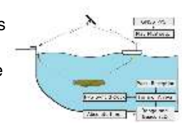


11:00–12:15 TuAT1.4

Easily Deployable Underwater Acoustic Navigation System for Multi-Vehicle Environmental Sampling Applications

Anwar Quraishi[1], Alexander Bahr[2], Felix Schill[2], Alcherio Martinoli[1]
[1]Distributed Intelligent Systems and Algorithms Laboratory (DISAL), EPFL, Switzerland
[2]Hydromea S.A., Lausanne, Switzerland

- We developed an acoustic navigation system consisting of two or more transmitting beacons deployed on the surface at known locations
- Clocks on underwater robots and beacons are synchronized using GNSS time information
- Robots measure one-way travel time to compute range to multiple beacons
- Range measurements are used to correct inertial navigation errors



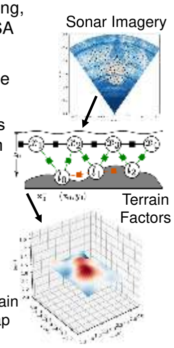
GNSS pulse per second (PPS) signal is used to compute range from one-way time of flight

11:00–12:15 TuAT1.5

Underwater Terrain Reconstruction from Forward-Looking Sonar Imagery

Jinkun Wang, Tixiao Shan and Brendan Englot
Department of Mechanical Engineering, Stevens Institute of Technology, USA

- We consider underwater vehicles using multibeam imaging sonar to map subsea terrain in 3D and localize in 6 DOF
- We propose the addition of **terrain factors** to a robot's factor graph, linking neighboring seafloor features with the goal of generating a smooth terrain map
- Subsea terrain is modeled as a Gaussian process random field on a Chow-Liu tree
- Additionally, optical flow is applied to sonar image sequences for improved tracking of salient point features
- Terrain reconstruction experiments performed with BlueROV2 and Oculus imaging sonar

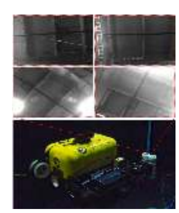


11:00–12:15 TuAT1.6

Through-water Stereo SLAM with Refraction Correction for AUV Localization

Sudharshan Suresh, Eric Westman, and Michael Kaess
Robotics Institute, Carnegie Mellon University, USA

- Accurate, drift-free pose estimates are vital for underwater inspection tasks in environments such as nuclear pools.
- We present a stereo SLAM framework for AUV localization using a ceiling feature map.
- We explicitly model water-air interface effects via a refraction correction module.
- Our method bounds vehicle drift as compared to dead-reckoning. This is shown in simulation and challenging real-world datasets.



Sample frames from stereo camera; the AUV in our test environment

Pose Estimation - 2.1.02

Chair
Co-Chair

11:00–12:15	TuAT1.1

Detect in RGB, Optimize in Edge: Accurate 6D Pose Estimation for Texture-less Industrial Parts

Haoruo Zhang and Qixin Cao
School of Mechanical Engineering, Shanghai Jiao Tong University, P.R. China

- A new pipeline of 6D pose estimation for texture-less industrial parts with only RGB input.
- Combined YOLOv3-tiny object detection network and edge-based pose initialization and optimization.
- The proposed method is verified by T-LESS dataset and robotic assembly task evaluation.

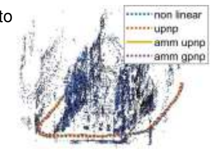
Dataset and Robotic Assembly Task Evaluation

11:00–12:15	TuAT1.2

POSEAMM: A Unified Framework for Solving Pose Problems using an Alternating Minimization Method

João Campos[1], João Cardoso[2], and Pedro Miraldo[3]
[1]Instituto Superior Técnico, Portugal
[2]Instituto Politecnico de Coimbra, Portugal
[3]Royal Institute of Technology, Stockholm, Sweden

- **Contribution:** A novel and generic framework to solve pose problem;
- **Approach:** Use an Alternating Minimization Methods to relax the non-linear constraints related with the rotation and translation parameters;
- **Solvers:** Steepest descent solvers to find the optimal pose (rotation and translation);
- **Results:** A solver which is faster than state-of-the-art methods and easy to use.



Pose retrieved by several algorithms using a noncentral system.

11:00–12:15	TuAT1.3

Learning Object Localization and 6D Pose Estimation from Simulation and Weakly Labeled Real Images

Jean-Philippe Mercier[1], Chaitanya Mitash[2], Philippe Giguère[1] and Abdeslam Boularias[2]
[1] Department of Computer Science & Software Engineering, Laval University, Canada
[2] Computer Science Department, Rutgers University, USA

- 6D Pose estimation pipeline using synthetic and a few weakly labeled real images
- A weakly supervised network, trained through domain adaptation, generates class specific heatmaps
- The Stochastic Congruent Sets (StoCS) method predicts the 6D pose using the heatmaps and depth images
- Our method achieves competitive results on YCB-Video and Occluded LineMOD datasets

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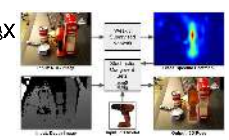


11:00–12:15	TuAT1.4

Stampede: A Discrete-Optimization Method for Solving Pathwise-Inverse Kinematics

Daniel Rakita, Bilge Mutlu, Michael Gleicher
Department of Computer Sciences, University of Wisconsin-Madison, USA
{rakita, bilge, gleicher}@cs.wisc.edu

- We present a discrete-optimization technique for finding feasible robot arm trajectories that pass through provided 6-DOF Cartesian-space end-effector paths with high accuracy
- Our method casts the robot motion translation problem as a discrete-space graph-search problem where the nodes in the graph are individually solved for using non-linear optimization
- We present techniques for sampling configuration space, such as diversity sampling and adaptive sampling, to construct the search-space in the graph

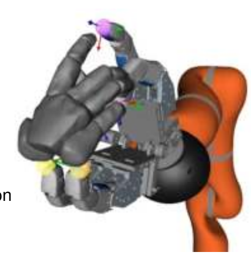
This figure shows a Sawyer robot tracing the word "ICRA" (the purple curve is ground truth, green curve is the robot's end effector path)

11:00–12:15	TuAT1.5

Reconstructing Human Hand Pose and Configuration using a Fixed-Base Exoskeleton

A. Pereira[1], G. Stillfried[1], T. Baker[1], A. Schmidt[1,2], A. Maier[1], B. Pleintinger[1], Z. Chen[1], T. Hulin[1], and N. Y. Lii
[1]German Aerospace Center (DLR), Germany
[2]TU Delft, Netherlands

- Real time reconstruction of human hand pose and finger joint angles on an exoskeleton
- Only contact points to exoskeleton used (no sensors on human)
- Exoskeleton (Exodex Adam) attached to human's fingers ***and*** the palm
- Nullspace optimisation to refine prediction
- Can be used for contact prediction in teleoperation/VR or intention recognition

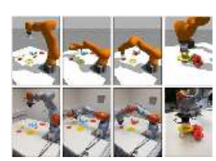


11:00–12:15	TuAT1.6

Learning Pose Estimation for High-Precision Robotic Assembly Using Simulated Depth Images

Yuval Litvak, Armin Biess and Aharon Bar-Hillel
Industrial Engineering and Management, Ben-Gurion University of the Negev Israel

- We present a high-accuracy two-stage pose estimation procedure based on CNN's trained on simulated depth images
- Depth images obtained in the real-world and in simulation were processed to bridge the simulation-reality gap
- Pick-and-place motions are calculated based on estimated poses from real images
- We obtain an average pose estimation error of 2.16 millimeters and 0.64 degree leading to 91% success rate for robotic assembly of randomly distributed parts



The KUKA LBR IIWA robot performs the Siemens Innovation Challenge in simulation and in reality

Visual Odometry I - 2.1.03

Chair
Co-Chair

11:00–12:15 TuAT1.1

Aided Inertial Navigation: Unified Feature Representation and Observability Analysis

Yulin Yang and Guoquan Huang
Dept. Mechanical Engineering, University of Delaware, USA

- We introduce two sets of unified representations (quaternion form and closest point form) for points, lines and planes.
- We proved that aided INS with combination of all the geometrical features in CP form has 4 unobservable directions: global position and yaw.
- We conducted extensive Monte-Carlo simulations to validate the proposed CP representation for aided INS with combinations of geometrical features.

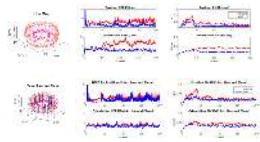


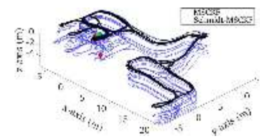
Figure: Monte-Carlo results of standard and ideal EKFs for visual-inertial SLAM.

11:00–12:15 TuAT1.2

A Linear-Complexity EKF for Visual-Inertial Navigation with Loop Closures

Patrick Geneva
Dept. of Computer and Information Sciences, University of Delaware, USA
Kevin Eckenhoff and Guoquan Huang
Dept. of Mechanical Engineering, University of Delaware, USA

- Propose a novel *O(n)* MSCKF algorithm for VINS with loop closures.
- Exploit Schmidt-KF for real-time consistent inclusion of old keyframes by only updating their cross-correlations.
- Leverage MSCKF nullspace-based marginalization, allowing for efficient processing measurements of keyframe-based loop-closures.



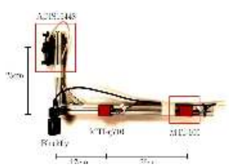
The proposed Schmidt-MSCKF accumulates only 0.04% error, as compared to 0.2% for the standard MSCKF, in a 1.5km multi-floor indoor test.

11:00–12:15 TuAT1.3

Sensor-Failure-Resilient Multi-IMU Visual-Inertial Navigation

Kevin Eckenhoff
Patrick Geneva* and Guoquan Huang
Dept. Mechanical Engineering, University of Delaware, USA
*Dept. Computer and Information Sciences, University of Delaware, USA

- Propose a resilient MSCKF-based VIO utilizing an *arbitrary* number of IMUs
- Jointly propagate the navigation state of each IMU while enforcing rigid-body hard constraints between them
- Perform online spatiotemporal calibration between all sensors
- Provide continuous estimation robust to *sensor failures* of individual IMUs



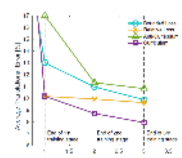
The 3-IMU visual-inertial sensor platform used for experimental valida

11:00–12:15 TuAT1.4

Learning Monocular Visual Odometry through Geometry-Aware Curriculum Learning

M. R. U. Saputra, Pedro P. B. de Gusmao, A. Markham, N. Trigoni
Department of Computer Science, University of Oxford, UK
S. Wang
School of Engineering and Physical Sciences, Heriot Watt University, UK

- We present the first curriculum learning strategy for VO problem
- Geometry-aware objective is proposed by optimizing relative and composite transformation over small windows
- We design CL-VO architecture which consists of cascade optical flow network and recurrent windowed composition layer
- Evaluation on 3 datasets shows superior performance of CL-VO over state-of-the-arts



The impact of CL algorithm

11:00–12:15 TuAT1.5

Visual-Odometric Localization and Mapping for Ground Vehicles Using SE(2)-XYZ Constraints

Fan Zheng and Yun-Hui Liu
Mechanical and Automation Engineering,
The Chinese University of Hong Kong, Hong Kong SAR

- Novel SE(2)-XYZ constraints proposed, incorporating image feature measurements and out-of-SE(2) perturbations
- Simpler and more robust than the stochastic constraints; more accurate than the deterministic SE(2) constraints
- More accurate and robust visual-odometric SLAM

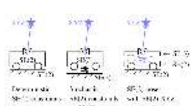


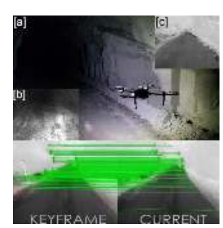
Illustration of SE(2)-XYZ constraints compared to previous models.

11:00–12:15 TuAT1.6

Keyframe-based Direct Thermal-Inertial Odometry

Shehryar Khattak, Christos Papachristos and Kostas Alexis
Department of Computer Science, University of Nevada, Reno, USA

- Keyframe-based Thermal-Inertial odometry estimation approach for operation in visually degraded environments is proposed.
- Sparse 14-bit radiometric information is utilized for frame alignment and landmark initialization.
- Sliding window Joint optimization of landmark re-projection errors and inertial measurement errors is performed.
- Tested in challenging visually degraded indoor settings as well as in dust filled underground mines.



Aerial robot navigating through an underground mine during an experiment.

Space Robotics I - 2.1.04

Chair
Co-Chair

11:00–12:15 TuAT1.1

On Parameter Estimation of Space Manipulator Systems with Flexible Joints Using the Energy Balance

Kostas Nanos and Evangelos Papadopoulos, *Fellow, IEEE*
School of Mechanical Engineering
National Technical University of Athens, Athens, Greece

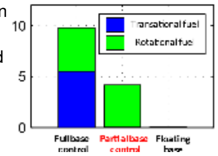
- Estimation of the full dynamics of a space manipulator system with *joint flexibilities*.
- Methods based on the *angular momentum conservation* cannot estimate joint flexibility parameters.
- A method, insensitive to sensor noise, based on the *energy balance* is developed.
- Allows use of advanced control strategies that benefit from the accurate knowledge of the system.

11:00–12:15 TuAT1.2

Coordinated control of spacecraft's attitude and end-effector for space robots

Alessandro M. Giordano[1,2], Christian Ott[1], and Alin Albu-Schäffer[1,2]
[1] German Aerospace Center (DLR), Germany
[2] Technical University of Munich (TUM), Germany

- Coordinated control with decoupled actuation structure for reduced thrusters use
- Partial base control: global CoM is controlled instead of base translation.
- Reduced fuel consumption
- Approach tested on hardware-in-the-loop facility based on 6DOF motion simulator (DLR OOS-Sim)



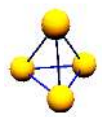
Fuel consumption for different coordinated control strategies

11:00–12:15 TuAT1.3

Central Pattern Generators Control of Momentum Driven Compliant Structures

Stephane Bonardi[1], John Romanishin[2], Daniela Rus[2], and Takashi Kubota[1]
[1] ISAS, JAXA, JAPAN; [2] DRL, CSAIL, MIT, USA

- Introduction of **Momentum Driven Structures** (MDS): inertially actuated units linked together by compliant elements for **rough environments exploration**.
- New bio-inspired **control method** for MDS based on Central Pattern Generator (CPG).
- Study in simulation of the **impact of compliance** distribution on locomotion performance.
- **Compliant structures outperform their rigid counterparts** in terms of distance traveled.



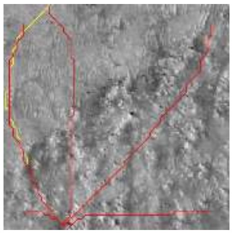
An example of MDS

11:00–12:15 TuAT1.4

Rover-IRL: Inverse Reinforcement Learning with Soft Value Iteration Networks for Planetary Rover Path Planning

Max Pflueger[1], Ali Agha[2], and Gaurav Sukhatme[1]
[1]University of Southern California, USA [2]Jet Propulsion Laboratory, USA

- We propose an inverse-RL formulation for learning a terrain reward function based on expert demonstrations.
- We use a modified *soft* value iteration network architecture to produce a differentiable planning algorithm.
- We show the importance of the *soft*-VIN architecture in producing useful gradients in this problem space
- The technique is evaluated for applications to rover path planning on Mars.



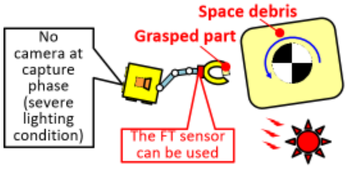
This example map shows the behavior of our learned policy (red) and the expert demo (yellow) where it deviated.

11:00–12:15 TuAT1.5

Contact-Event-Triggered Mode Estimation for Dynamic Rigid Body Impedance-Controlled Capture

Hiroki Kato, Daichi Hirano
Japan Aerospace Exploration Agency (JAXA)
Jun Ota
The University of Tokyo

- Real-time contact mode estimation *with only a force-torque sensor* for capturing a moving rigid body
- Contact-event-triggered particle filter (update when contact-event detected)
- Type of contact events: collision, sliding, with computationally light prediction model
- Experiment: 100% of success rate with the worst computation time of 8.3ms

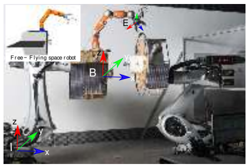


11:00–12:15 TuAT1.6

Multi-rate Tracking Control for a Space Robot on a Controlled Satellite: a Passivity-based Strategy

M. De Stefano[1,2], H. Mishra[1], R. Balachandran[1], R. Lampariello[1], C. Ott[1] and Cristian Secchi[2]
[1] German Aerospace Center (DLR), Germany
[2] University of Modena and Reggio Emilia (UNIMORE), Italy

- Tracking control for manipulator and actuated base with stability proofs.
- Stability issue due to different-rate of the controllers on the base and manipulator.
- Energy observer to measure the active energy.
- Passivity-based Control.
- Experimental validation.



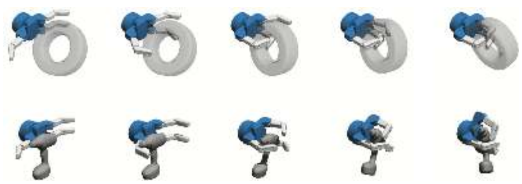
Deep Learning for Manipulation - 2.1.05

Chair
Co-Chair

11:00–12:15	TuAT1.1

Leveraging Contact Forces for Learning to Grasp

Hamza Merzić [1], Miroslav Bogdanović [2], Daniel Kappler [3], Ludovic Righetti [2, 4] and Jeannette Bohg [2, 5]
[1] DeepMind London (UK), [2] MPI-IS Tübingen (Ger), [3] Google X (USA), [4] NYU (USA), [5] Stanford University (USA)



Contact Feedback matters for Grasp Acquisition especially under noise and for objects of complex shapes.

We use model-free Reinforcement Learning to learn robust policies that generalize to new pre-grasps and show complex finger coordination.

11:00–12:15	TuAT1.2

Learning Latent Space Dynamics for Tactile Servoing

Giovanni Sutanto[1,2,3], Nathan Ratliff[1], Balakumar Sundaralingam[1,4], Yevgen Chebotar[1,3], Zhe Su[2,3], Ankur Handa[1] and Dieter Fox[1,5]
[1]NVIDIA, USA, [2]MPI-IS, Germany, [3]USC, USA, [4]UofUtah, USA, [5]UW, USA

- Learning-from-demonstration approach to acquire a dynamics model for tactile servoing.
- Using manifold learning to flatten the tactile skin surface representation.
- Minimizing both forward dynamics and inverse dynamics loss functions during training.
- The learned model is able to produce tactile servoing behavior to target contact points that requires rotational and translational motion.

Our robot executing the learned tactile servoing behavior

11:00–12:15	TuAT1.3

PointNetGPD: Detecting Grasp Configurations from Point Sets

Hongzhuo Liang[1†], Xiaojian Ma[2†], Shuang Li[1], Michael Görner[1], Song Tang[1], Bin Fang[2], Fuchun Sun[2*], Jianwei Zhang[1]

[1]Department of Informatics, Universität Hamburg, Germany
[2]Departmentof Computer Science and Technology, Tsinghua University, China

- We propose PointNetGPD, an end-to-end grasp evaluation model to localizing robot grasp configurations.
- We generate a large-scale grasp dataset with 350K real point cloud and grasps for training.
- Experiments on object grasping and clutter removal show a state-of-art performances.

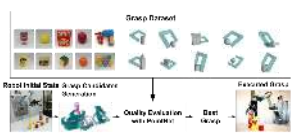


Fig: An illustration of our proposed PointNetGPD for detecting reliable grasp configuration from point sets.

11:00–12:15	TuAT1.4

Learning Deep Visuomotor Policies for Dexterous Hand Manipulation

Divye Jain[1], Andrew Li[1], Shivam Singhal[1], Aravind Rajeswaran[1], Vikash Kumar[2], Emanuel Todorov[1,3]

[1] University of Washington [2] Google Brain [3] Roboti LLC

- Dexterous hands and vision: versatile
- Hand-eye coordination: ubiquitous

Highlights

- Deep visuomotor policies for dexterous manipulation trained with visual imitation learning (~100 demos)
- Tactile sensing enables better policies for viewpoints with many occlusions

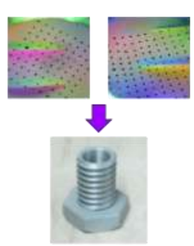
11:00–12:15	TuAT1.5

Learning to Identify Object Instances by Touch: Tactile Recognition via Multimodal Matching

Justin Lin[1], Roberto Calandra[2], Sergey Levine[1]
[1]Department of EECS, University of California, Berkeley, USA
[2]Facebook AI Research, Menlo Park CA, USA

Motivation:
- In certain settings, vision alone may not be enough to identify an object
- Can we determine the appearance of an object based on how it feels when grasped?

Approach:
- Using tactile sensors mounted on a robotic gripper, we associate raw tactile readings with object images
- Our model can recognize previously unseen objects from touch alone



Tactile readings are matched to object images

11:00–12:15	TuAT1.6

Dexterous Manipulation with Deep Reinforcement Learning: Efficient, General, and Low-Cost

Abhishek Gupta* [1], Henry Zhu* [1], Aravind Rajeswaran [2], Sergey Levine [1], Vikash Kumar [3]

[1] UC Berkeley [2] University of Washington [3] Google Brain, USA

- Dexterous complex behaviors learned in the real world using model-free RL in < 7 hours
- Introduces robust low-cost three-fingered hand
- Human demonstrations improve training by 2-5x

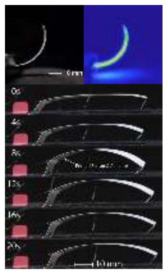
Product Design, Development and Prototyping - 2.1.06

Chair
Co-Chair

11:00–12:15	TuAT1.1

Inkjet Printable Actuators and Sensors for Soft-bodied Crawling Robots

Tung D. Ta, Takuya Umedachi, and Yoshihiro Kawahara
Department of Information and Communication Engineering
The University of Tokyo



- Thermal-based thin film bending actuators and sensors
- Using sintering-free silver ink to instantly print the actuator and sensor
- Bi-layer structure to generate bending actuation
- Measuring resistance change of the heater to determine bending angle
- Apply in printing paper caterpillar robots

11:00–12:15	TuAT1.2

Design and Evaluation of an Energy-Saving Drive for a Versatile Robotic Gripper

Job Neven, Mohamed Baioumy and Martijn Wisse
3ME, Delft University of Technology, The Netherlands
Wouter Wolfslag
School of Informatics, University of Edinburgh, United Kingdom

- A novel metric (Grip Performance Metric) to systematically evaluate drives on energy efficiency
- A novel Drive employing a Statically Balanced Force Amplifier (SBFA) and a non-backdriveable mechanism (NBDM)
- A reduction of **92%** in the actuation force and **86%** in energy for an example task.

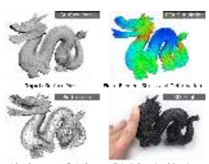
Prototype of the Robotic Energy-Efficient Drive connected to the Delft Hand 3 gripper

11:00–12:15	TuAT1.3

Generative Deformation: Procedural Perforation for Elastic Structures

Shane Transue and Min-Hyung Choi
Department of Comptuer Science and Engineering,
University of Colorado Denver,
Denver, Colorado, USA

- Aim: We combine generative modeling, dynamics, and elastic materials to target consumer-level 3D model printing
- Procedural perforation of volumetric meshes is used to modify elastic 3D model behaviors
- 1-to-1 pipeline between simulation geometry and printable surface models
- Provide an open-source tool for quickly perforating 3D volumetric models for changing elastic 3D print behaviors



Generative Deformation: Controlling Elasticity for Consumer-level 3D Printing

11:00–12:15	TuAT1.4

Robotics Education and Research at Scale: A Remotely Accessible Robotics Development Platform

Wolfgang Wiedmeyer, Michael Mende, Dennis Hartmann, Christoph Ledermann and Torsten Kröger
IAR-IPR, KIT, Germany
Rainer Bischoff
KUKA Robotics, Germany

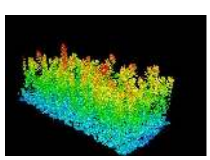
- Motivation: increasing the accessibility and availability of industrial lightweight robots for education and research
- Processing pipeline for fully automated execution of submitted experiments in parallel
- Focus on flexibility, safety and security
- Presentation of two initial use case examples and a long-term operation experiment

11:00–12:15	TuAT1.5

Automated Seedling Height Assessment for Tree Nurseries Using Point Cloud Processing

Thumeera R. Wanasinghe, Benjamin Robert Dowden, Oscar De Silva, and George K. I. Mann
Memorial University of Newfoundland, Canada
Cyril Lundrigan
Department of Fisheries and Land Resource, Government of NL, Canada

- This paper presents a prototype of an automated seedling height assessment system for tree nurseries.
- The system is implemented using in-line laser profilometer and 3D point-cloud processing algorithm is developed to measure the seedling heights with an overall system accuracy less than 5 mm.
- The field-test of the measurement system was conducted at Centre for Agriculture and Forestry Development, NL, Canada.

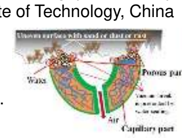


11:00–12:15	TuAT1.6

Adsorption Pad using Capillary Force for Uneven Surface

A. Ichikawa, S. Kajino, A. Takeyama, Y. Adachi, K. Totsuka, Y. Ikemoto, K. Ohara, T. Oomichi
Dept. of Mechatronics Engineering, Meijo University, Japan
T. Fukuda
Meijo University, Japan Nagoya University, Japan
Beijing Institute of Technology, China

- We propose a novel adsorption pad for wall climbing robot and irregular surface object using capillary force and water sealing.
- We call this adsorption pad as Super Wet Adsorption(SWA) pad. The SWA pad has a porous part and a capillary part.
- We apply this SWA pad for wall climbing robot and manipulation of foods.



SWA pad

Wall climbing robot with SWA pad

Food manipulation (Corn)

Humanoid Robots IV - 2.1.07

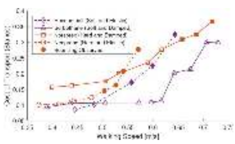
Chair
Co-Chair

11:00–12:15	TuAT1.1

Effects of Foot Stiffness and Damping on Walking Robot Performance

Ethan Schumann
Mechanical Engineering, University of Pittsburgh, United States
N. Smit-Anseeuw, P. Zaytsev, R. Gleason, K. Alex Shorter, and C. David Remy
Mechanical Engineering, University of Michigan, United States

- We considered four different foot designs with distinct stiffness and damping properties.
- We tested each design in drop experiments and walking on the bipedal robot RAMone.
- Feet with lower stiffness showed better energetic economy across all walking speeds.
- Feet with higher damping improved walking stability and energetic economy at high speeds.

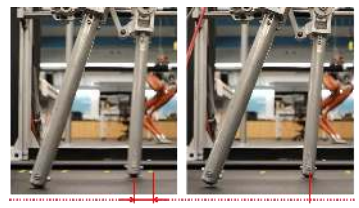


Stance leg contribution to overall cost of transport (CoT)

11:00–12:15	TuAT1.2

Dynamic Walking on Slippery Surfaces: Demonstrating Stable Bipedal Gaits with Planned Ground Slippage

Wen-Loong Ma, Yizhar Or and Aaron D. Ames



11:00–12:15	TuAT1.3

Torque and velocity controllers to perform jumps with a humanoid robot: theory and implementation on the iCub robot

Fabio Bergonti, Luca Fiori and Daniele Pucci
Dynamic interaction and control, Italian institute of Technology (IIT), Italy

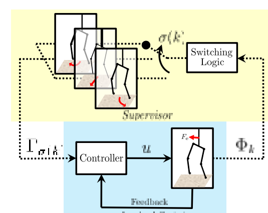
- Development of an algorithm to control jumps of humanoid robots
- Instantaneous optimization to compute inverse kinematic through quadratic programming.
- The movement is generated such that Centroidal angular momentum is set equal to zero to avoid robot rotation while is in air.
- CoM trajectories are generated offline.
- iCub could success jump of 4[cm] using the velocity controller.

11:00–12:15	TuAT1.4

Safe Adaptive Switching Among Dynamical Movement Primitives: Application to 3D Limit-Cycle Walkers

Sushant Veer and Ioannis Poulakakis
Department of Mechanical Engineering, University of Delaware, USA

- A **supervisory control** framework for **safe** switching among dynamical movement primitives **under external inputs/disturbances** is proposed
- Safety guarantees are provided via an explicit **average dwell-time bound** on the switching frequency
- The method is demonstrated in **adapting a dynamically walking** 3D biped to the intended trajectory of a leading co-worker for collaboration



11:00–12:15	TuAT1.5

Torque-Based Balancing for a Humanoid Robot Performing High-Force Interaction Tasks

Firas Abi-Farraj[1], Bernd Henze[2], Christian Ott[2], and Paolo Robuffo Giordano[1], and Máximo A. Roa[2]
[1]CNRS, Univ Rennes, Inria, IRISA, Rennes, France
[2]German Aerospace Center (DLR), Institute of Robotics and Mechatronics, Germany.

- Balancing a humanoid robot under **unknown high** perturbation **forces** during interaction tasks
- **Guaranteeing** the **feasibility** of the balancing forces by acting on the **Gravito-Inertial Wrench Cone** instead of the support area
- A **passivity-based** whole body framework
- Accounting for **any contact configuration** (hands or feet) and allowing for **online contact switching**

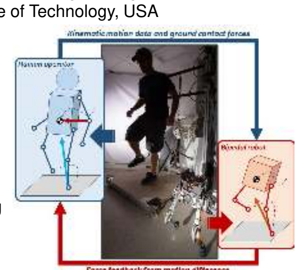
TORO pushing a table with a weight of 50 kg on top

11:00–12:15	TuAT1.6

Humanoid Dynamic Synchronization Through Whole-Body Bilateral Feedback Teleoperation

Joao Ramos and Sangbae Kim
Department of Mechanical Engineering,
Massachusetts Institute of Technology, USA

- We present a strategy that allows a human operator to control the locomotion of a bipedal robot via whole-body teleoperation.
- We explore the interplay between human Center of Mass and the contact forces to transmit to the robot the underlying balancing and stepping strategy.
- This initial study aims to grant legged robots motor capabilities comparable to humans.



Bilateral Teleoperation of a small-scale bipedal robot.

Human-Robot Interaction I - 2.1.08

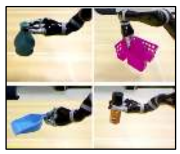
Chair
Co-Chair

11:00–12:15 TuAT1.1

Interactive Open-Ended Object, Affordance and Grasp Learning for Robotic Manipulation

S. Hamidreza Kasaei[1,2], Nima Shafii[1],
Luís Seabra Lopes[1], Ana Maria Tomé[1]
[1] IEETA / DETI, University of Aveiro, Portugal
[2] Department of AI, University of Groningen, the Netherlands

- An interactive open-ended learning approach to recognize multiple objects and their grasp affordances concurrently.
- The grasp affordance category and the grasp configuration are taught through verbal and kinesthetic teaching, respectively.
- An instance-based approach is used for affordance learning and recognition.
- A Bayesian approach is adopted for learning and recognition of object categories.


Four examples of affordance detection

11:00–12:15 TuAT1.2

A parallel low-impedance sensing approach for highly responsive human-robot interaction

Gabriel Boucher, Thierry Laliberté
Department of Mechanical Engineering, Université Laval, Canada
Clément Gosselin
Department of Mechanical Engineering, Université Laval, Canada

- Inspired by the macro-mini architecture but applied to a serial robot using light shells mounted around the links.
- Control of a serial robot using a low-impedance passive elastic mechanism, yielding low interaction forces and intuitive behavior.
- Design of a parallel elastic passive mechanism based on the Gough-Stewart architecture.

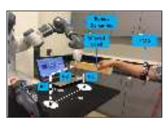

Collaborative robot with low-impedance sensing mechanism

11:00–12:15 TuAT1.3

Safe Human-Robot Cooperation in Task Performed on the Shared Load

Mohammad Anvaripour and Mehrdad Saif
ECE Department, University of Windsor, ON, Canada
Mahta Khoshnam and Carlo Menon
Mechatronic Systems Engineering, Simon Fraser University, BC, Canada

- Safe human-robot cooperation is achieved by applying human forearm FMG and robot dynamics.
- Human intention is predicted by effective FMG feature extraction and proposed structured RNN-based method.
- Robot reaction based on the dynamics and human applied force is developed for safe cooperation.
- The approach was evaluated in several collaboration scenarios.

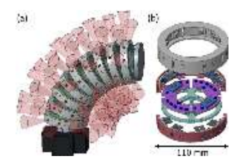

The experimental setup

11:00–12:15 TuAT1.4

A Multi-modal Sensor Array for Safe Human-Robot Interaction and Mapping

Colette Abah[1], Andrew L. Orekhov[1], Garrison Johnston[1],
Peng Yin[2], Howie Choset[2], Nabil Simaan[1]
[1] Department of Mechanical Engineering, Vanderbilt University, USA
[2] The Robotics Institute, Carnegie Mellon University, USA

- We propose to augment continuum robots with multi-modal sensing for *in-situ* human-robot collaboration in confined spaces.
- We present a sensing disk unit capable of contact detection and localization, force sensing, proximity sensing, and mapping.
- We demonstrate the use of multi-modal sensing for selecting admissible bracing regions, bracing, and detecting accidental contact.

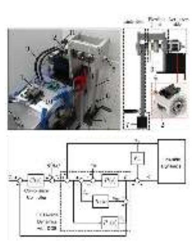

(a) Continuum segment augmented with multi-modal sensing. (b) Exploded view of sensing disk unit

11:00–12:15 TuAT1.5

Disturbance-Observer-Based Compliance Control of Electro-hydraulic Actuators with Backdrivability

Woongyong Lee* and Wan Kyun Chung*
*Mechanical Engineering, POSTECH, Republic of Korea

- Configurations of electro-hydrostatic actuator (EHA) and electro-hydraulic servo system (EHSS) could be inappropriate to provide desired impedance behaviors
- Electro-hydraulic torque actuator (EHTA) is configured by introducing backdrivable servovalves and torque sensors
- Stability-guaranteed disturbance-observer-based compliance control allows EHTA to asymptotically converge to the desired position

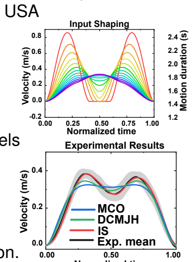

EHTA and control structure

11:00–12:15 TuAT1.6

Dynamic Primitives in Human Manipulation of Non-Rigid Objects

Hui Guang[1] and Salah Bazzi[2]
[1]Department of Mechanical Engineering, Tsinghua University, China
[2]Departments of Biology and ECE, Northeastern University, USA
Dagmar Sternad[3] and Neville Hogan[4]
[3]Departments of Biology and ECE, Northeastern University, USA
[4]Departments of ME and BCS, MIT, USA

- Hypothesis: Humans use dynamic primitives, submovements, to simplify physical interactions.
- Task: Move a virtual “cup of coffee” from a start to a target arriving with zero oscillations of the “coffee”.
- Comparison of 3 control models: 2 optimization models and Input Shaping (based on submovements).
- Result: Submovement-based controller fitted human data better.
- Discussion: Implementation of primitives-based controllers may simplify control of robotic manipulation.



Perception for Manipulation I - 2.1.09

Chair
Co-Chair

11:00–12:15	TuAT1.1

State Estimation in Contact-Rich Manipulation

F. Wirnshofer, P. S. Schmitt, P. Meister, G. v. Wichert
Siemens AG Corporate Technology, Germany
W. Burgard
Autonomous Intelligent Systems, University of Freiburg, Germany

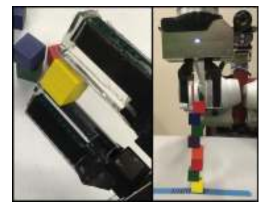
- We propose particle-based state estimator for contact-rich manipulation
- Applications include in-hand localization and non-prehensile manipulation.
- We allow for multiple manipulators and multiple or articulated objects.
- Online estimation of 6D pose and velocity at 200 Hz rate

11:00–12:15	TuAT1.2

Improved Proximity, Contact, and Force Sensing Via Optimization of Elastomer-Air Interface Geometry

Patrick E. Lancaster, Joshua R. Smith, Siddhartha S. Srinivasa
Paul G. Allen School of Computer Science and Engineering,
University of Washington, USA

- Sensor consists of optical time-of-flight modules covered in clear elastomer
- Use rounded elastomer-air interface to achieve better signal-to-noise ratio and continuous operation when switching between proximity and force regimes
- Measures distances up to 50mm and contact forces up to 10 netwons
- Open Source: https://bitbucket.org/opticalpcf



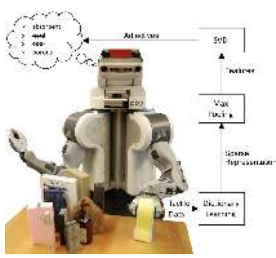
Left: Two fully-integrated sensors
Right: The robot uses the sensors to unstack blocks.

11:00–12:15	TuAT1.3

Improving Haptic Adjective Recognition with Unsupervised Feature Learning

Benjamin A. Richardson and Katherine J. Kuchenbecker
Haptic Intelligence, Max Planck Institute for Intelligent Systems, Germany

- Do learned features outperform hand-crafted features in haptic adjective recognition?
- We apply unsupervised dictionary learning to raw, multi-modal tactile data from the PHAC-2 dataset.
- Features are extracted and pooled over both space and time.
- This new feature set greatly increased the accuracy with which 19 unique haptic adjectives could be recognized.



11:00–12:15	TuAT1.4

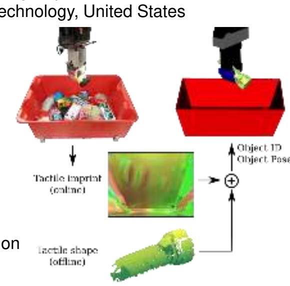
Tactile Mapping and Localization from High-Resolution Tactile Imprints

Maria Bauza, Oleguer Canal and Alberto Rodriguez
Mechanical Engineering Department,
Massachusetts Institute of Technology, United States

Shape reconstruction and object localization using tactile sensing

Approach:

1. Recovery of local shapes from contact
2. Reconstruction of the tactile shape of objects from tactile imprints
3. Accurate method for in-hand localization of previously reconstructed objects



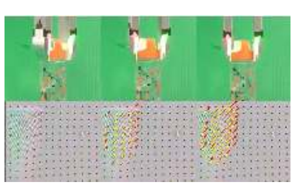
In-hand localization using tactile sensing

11:00–12:15	TuAT1.5

Maintaining Grasps within Slipping Bounds by Monitoring Incipient Slip

Siyuan Dong, Daolin Ma, Elliott Donlon and Alberto Rodriguez
Massachusetts Institute of Technology, USA

- Contribution: A real-time incipient slip detection algorithm with a vision-based tactile sensor GelSlim
- Feature: assuming rigid body motion, no prior knowledge (e.g. geometry, frictional coefficient) needed
- Demonstration: close-loop control in bottle cap screwing experiment



11:00–12:15	TuAT1.6

From Pixels to Percepts: Highly Robust Edge Perception and Contour Following using Deep Learning and an Optical Biomimetic Tactile Sensor

N. F. Lepora, A. Church, C. de Kerckhove & J. Lloyd
University of Bristol and Bristol Robotics Lab, U.K.
R. Hadsell
DeepMind, London, U.K.

- Optical tactile sensing act as a bridge between deep learning for vision and robot touch
- A deep CNN is applied to an optical biomimetic tactile sensor (the TacTip) that images internal pins resembling papillae within skin
- Reliable edge perception gives a policy for tactile servoing around object contours
- The benefit of a deep CNN is its capability to generalize well beyond its training data
- Hence, the performance is robust over irregular & compliant objects with tapping & sliding motion

Intelligent Transportation I - 2.1.10

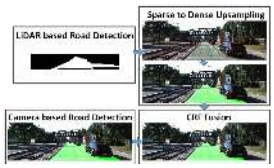
Chair
Co-Chair

11:00–12:15	TuAT1.1

Road Detection through CRF based LiDAR-Camera Fusion

Shuo Gu, Yigong Zhang, Jinhui Tang, Jian Yang and Hui Kong
School of Computer Science and Engineering, Nanjing University of Science and Technology, China

- Fast LiDAR based road detection at high frequency
- Simple but effective road detection result upsampling strategy
- Single CRF fuses the dense and binary detection equally



Flowchart

11:00–12:15	TuAT1.2

Semantic mapping extension for OpenStreetMap applied to indoor robot navigation

Lakshadeep Naik and Erwin Prassler
Department of Computer Science, Hochschule Bonn Rhein Sieg, Germany
Sebastian Blumenthal
Locomotec GmbH, Germany
Nico Huebel and Herman Bruyninckx
Robotics Research Group, KU Leuven, Belgium

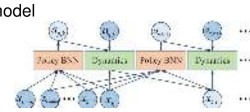
- A hierarchical & composable graph model used for creating semantic indoor maps
- Realised as an extension to OpenStreetMap
- Example application to navigation using virtual traffic lanes
- Compatibility to AMCL and other grid map based algorithms through map conversion

11:00–12:15	TuAT1.3

Adaptive Probabilistic Vehicle Trajectory Prediction Through Physically Feasible Bayesian RNN

Chen Tang, Jianyu Chen and Masayoshi Tomizuka
Department of Mechanical Engineering, UC Berkeley, USA

- Probabilistic trajectory prediction model consisted of policy BNN and dynamics model
- Optimized for long-term prediction with complicated trajectory distribution
- Encode kinematic constraints through embedded dynamics model
- Online adaptation towards predicted target through sequential Monte Carlo



11:00–12:15	TuAT1.4

Optimizing Vehicle Distributions and Fleet Sizes for Shared Mobility-on-Demand

Alex Wallar[1], Javier Alonso-Mora[2], and Daniela Rus[1]
[1]CSAIL, Massachusetts Institute of Technology, USA
[2]Department of Cognitive Robotics, Delft University of Technology, Netherlands

- Mobility-on-demand systems are revolutionizing urban transit with *ride-sharing*
- We present an algorithm to determine the size and distribution of a fleet of shared vehicles to provide a given level of service
- Fleet size can be reduced by 77% on average to service *all* taxi demand for one day in Manhattan using four passenger vehicles

11:00–12:15	TuAT1.5

Global Vision-Based Reconstruction of 3D Road Surfaces Using Adaptive Extended Kalman Filter

Diya Li and Tomonari Furukawa
The Department of Mechanical Engineering, Virginia Tech, USA

- A vision-based technique and a system developed for the global reconstruction of 3D road surfaces
- The probabilistic motion modeling determines the camera motion by road surface image match
- The proposed system overcomes the low-texture problem of road surface in global 3D reconstruction
- The efficacy of the proposed technique overs the EKF-based technique by 50% in accuracy

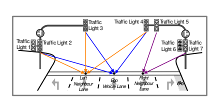
Figure: System Overview

11:00–12:15	TuAT1.6

Deep Metadata Fusion for Traffic Light to Lane Assignment

Tristan Langenberg
Research and Development, Mercedes-Benz Cars, Daimler AG, Germany
Timo Lüddecke and Florentin Wörgötter
Third Physical Institute, University Göttingen, Germany

- Our approach assigns all relevant traffic lights to their associated lanes.
- The deep metadata fusion approach connects image data and heterogeneous metadata inside a convolutional neural network.
- The results are compared to rule-based, only-metadata, and only-vision approaches as well as to a human subjective test.


Generic traffic light to lane assignment example.

Medical Robotics V - 2.1.11

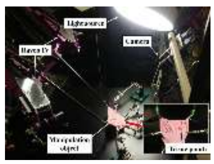
Chair
Co-Chair

11:00–12:15 TuAT1.1

Autonomous Tissue Manipulation via Surgical Robot Using Learning Based Model Predictive Control

Changyeob Shin, Peter Ferguson, Sahba Aghajani Pedram, Ji Ma and Jacob Rosen
Mechanical and Aerospace Engineering Department, UCLA, USA
Erik Dutson
Department of Surgery, UCLA, USA

- Tissue manipulation is necessary in many robotic surgery.
- Reinforcement learning and learning from demonstration algorithms for automated tissue manipulation are presented.
- Tissue manipulation simulation is designed and both algorithms are compared.
- Learning from demonstration algorithm is implemented to Raven IV surgical robot and showed successful experimental results.

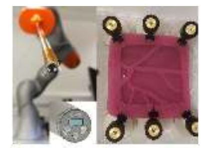


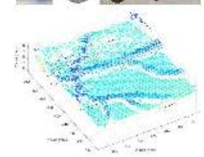
11:00–12:15 TuAT1.2

Robotic Control of a Multi-Modal Rigid Endoscope Combining Optical Imaging with All-Optical Ultrasound

George Dwyer, Richard J Colchester, Erwin J Alles, Efthymios Maneas, Sebastien Ourselin, Tom Vercauteren, Jan Deprest, Emmanuel Vander Poorten, Paolo De Coppi, Adrien E Desjardins and Danail Stoyanov

- Instrument (6.2mm diameter) integrating stereo camera, illumination, working channel and optical ultrasound
- Mounted on 7DOF robot manipulator constrained to a remote centre of motion
- Generates large scans on an acoustically realistic gelwax placenta (80mm x 80mm)



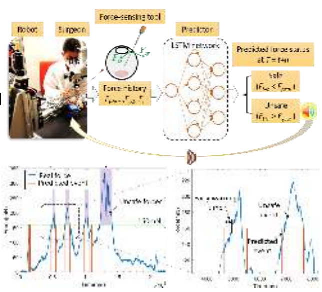


11:00–12:15 TuAT1.3

Enabling Technology for Safe Robot-Assisted Retinal Surgery: Early Warning for Unsafe Scleral Force

Changyan He, Niravkumar Patel,
Iulian Iordachita, Marin Kobilarov
LCSR, Johns Hopkins University, USA

- Retinal microsurgery is technically demanding, any unexpected manipulation could cause extreme tool-sclera contact force
- A recurrent neural network is trained to predict the force safety status up to 500 milliseconds in the future.
- The prediction is feed back to the surgeon via auditory substitution.
- A novel force sensing tool is used to measure the force, and an existing "steady hand" eye robot is utilized as the robot assistant.



11:00–12:15 TuAT1.4

Robotic bronchoscopy drive mode of the Auris Monarch platform

Chauncey Graetzel, Alexander Sheehy, David Noonan
Auris Health Inc., USA

- The Auris Monarch Platform is an FDA approved, commercially deployed, robotic bronchoscopy system.
- This paper presents how the physician drives the 10 DoF bronchoscope using a 3 DoF controller.
- The algorithms make the robotic bronchoscope instinctive and safe to drive for the physician, enabling more effective and earlier detection of lung cancer.

11:00–12:15 TuAT1.5

Using comanipulation with active force feedback to undistort stiffness perception in laparoscopy

François Schmitt[1], Josue Sulub[2], Ignacio Avellino[2], Jimmy Da Silva[2], Laurent Barbé[1], Olivier Piccin[1], Bernard Bayle[1] and Guillaume Morel[2]
[1]ICube, Université de Strasbourg/CNRS, France
[2]ISIR, Sorbonne Université/CNRS/INSERM, Paris, France

- Aim: compensating the fulcrum effect in collaborative robotized laparoscopy
- Feedback of the tool tip interaction force to the user
- Preliminary assessment of its impact on the user perception

General view of the experiment

Field Robotics II - 2.1.12

Chair
Co-Chair

11:00–12:15	TuAT1.1

VIKINGS : An autonomous Inspection Robot for the ARGOS Challenge

Pierre Merriaux, Romain Rossi, Rémi Boutteau, Vincent Vauchey, Lei Qin, Pailin Chanuc, Florent Rigaud, Benoit Decoux and Xavier Savatier
Normandie Univ, UNIROUEN, ESIGELEC, IRSEEM, France
Florent Roger
SOMINEX, France

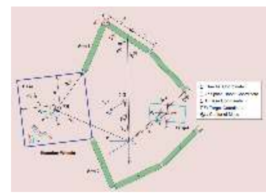
- Autonomous or remote-controlled operation with various assistance mode
- Visual inspection of pressure gauges, Thermal inspection of pipes and vessels, Gas leak detection
- High mobility : overcome obstacles, climb stairs up to 45°, autonomous path finding
- ATEX Ex II 2 G using Ex-d protection

11:00–12:15	TuAT1.2

Coordinated Control of a Dual-Arm Space Robot

Lingling Shi[1], Hiranya Jayakoby[2], Jayantha Katupitiya[2] and XinJin[1]
1 School of Mechanical Engineering, Beijing Institute of Technology, China
2 School of Mechanical and Manufacturing Engineering, University of New South Wales, Australia

- Robust controllers are developed for coordinated motion control of the spacecraft and the manipulators
- Adaptive variable structure controller (AVSC) provides high control accuracy and reduces energy consumption
- AVSC delivers good robustness when system uncertainties are considered
- AVSC can be extended to floating-base systems such as an unmanned aerial vehicle or underwater robotic system



11:00–12:15	TuAT1.3

Radiological Monitoring of Nuclear Facilities Using the (CARMA) Robot

B. Bird, A. Griffiths, H. Martin, E. Codres, A. Stancu, B. Lennox and S. Watson
School of Electrical and Electronic Engineering, University of Manchester, UK
X. Poteau
Sellafield Ltd., UK

- The CARMA robot has been used for autonomous radiological monitoring at Sellafield Ltd., UK
- Generates a geometric and radiological map of an environment
- Autonomous behavior is designed to minimize the risk of spreading contamination

The CARMA Robot

11:00–12:15	TuAT1.4

Robot Foraging: Autonomous Sample Return in a Large Outdoor Environment

Yu Gu, Jared Strader, Nicholas Ohi, Scott Harper, Kyle Lassak, Chizhao Yang, Lisa Kogan, Boyi Hu, Matthew Gramlich, Rahul Kavi, Jason Gross
West Virginia University, USA

- Robotic foraging is a rich and potentially fruitful research field
- The design of an autonomous foraging robot, named Cataglyphis, is presented in this paper
- It can autonomously find, retrieve, and return samples in a large outdoor environment
- The overall autonomy architecture and lesson learned can benefit the design of other robot applications

Cataglyphis Rover Approaching a Sample During the 2016 NASA SRR Challenge

11:00–12:15	TuAT1.5

Pictobot : A Cooperative Painting Robot for Interior Finishing of Industrial Developments

Ehsan Asadi and Li Bingbing
Transforma Robotics Pte Ltd, Singapore
I-Ming Chen
MAE, Nanyang Technological University (NTU), Sinagpore

- Intelligent painting system via in-situ 3D scanning and spray-gun motion planning
- Adaptation to the uncertainties of construction environment and as-built structure
- Human-Pictobot system works collaboratively,
- The worker's judgment and perception become the upper robot planner
- The robot autonomously plan and adjusts the spray gun path and the painting plans from various deployed positions

Pictobot at actual industrial developments

11:00–12:15	TuAT1.6

Teleoperated In-Situ Repair of an Aeroengine

David Alatorre, Amir Rabani, Adam Nagy, Xin Dong, Dragos Axinte
Mechanical, Materials & Manufacturing Eng. University of Nottingham, UK
Bilal Nasser, James Kell
On-Wing & Future Technology, Rolls-Royce PLC, UK

- A novel robot capable of repairing aeroengine compressors (boreblending) is presented
- A high-latency internet-based remote control protocol and strategy are presented
- A skilled operator uses a high-level interface with multiple control and oversight consoles
- A self-diagnosing, fail safe, low-level computer receives data packets and calculates the robot's movements

Boreblending robot end effector and compressor blade

Soft Robots II - 2.1.13

Chair
Co-Chair

11:00–12:15 TuAT1.1

Stiffness-Tuneable Limb Segment with Flexible Spine for Malleable Robots

Angus Benedict Clark and Nicolas Rojas
Dyson School of Design Engineering, Imperial College London, UK

- We introduce the concept of *malleable robots*: Reconfigurable serial arms of lower mobility with variable workspace
- Development of a multi-material spine-inspired flexible structure for variable stiffness robot links of large diameter
- Minimised central diameter deformation under bending is shown, resulting in a higher resisting force

11:00–12:15 TuAT1.2

A Reconfigurable Variable Stiffness Manipulator by a Sliding Layer Mechanism

Dickson Chun Fung Li, Zerui Wang, Bo Ouyang, and Yun-Hui Liu
T Stone Robotics Institute and Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Shatin, Hong Kong, China

- A manipulator that can achieve a variable stiffness and shift the stiffening regions is proposed
- It consists of two mechanisms: the honeycomb jamming mechanism and the sliding layer mechanism
- The variable stiffness mechanism is achieved by jamming between a honeycomb core and jamming layers
- The sliding layer mechanism reconfigures the robot via sliding the jamming layer strips

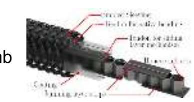


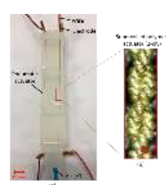
Illustration of the proposed mechanism

11:00–12:15 TuAT1.3

A Novel Variable Stiffness Actuator Based on Pneumatic Actuation and Supercoiled Polymer Artificial Muscles

Yang Yang, Zicheng Kan, Yazhan Zhang, Yu Alexander Tse, and Michael Yu Wang
Department of Mechanical and Aerospace Engineering, Hong Kong University of Science and Technology, Hong Kong, China

- First study to apply SCP actuator for stiffness tuning of soft robots;
- Novel design of variable stiffness actuator with antagonistic arrangement of pneumatic actuator and SCP actuator;
- Potential application in soft manipulators and locomotion robots with variable stiffness functions.



Proposed novel variable stiffness soft actuator

11:00–12:15 TuAT1.4

Design and Analysis of Pneumatic 2-DoF Soft Haptic Devices for Shear Display

Smita Kanjanapas[1], Cara M. Nunez[1,2], Sophia R. Williams[3] Allison M. Okamura[1] and Ming Luo[1]
[1] Mechanical Engineering, [2] Bioengineering, [3] Electrical Engineering
Stanford University, USA

- Multiple Degrees of Freedom (DoF) with a single contact point
- With normal force of 1 N: shear force between 0.2 N and 1 N and lateral displacement from 1 to 5 mm
- Compared soft housing and rigid housing
- 86% accuracy in four directional identification user study

11:00–12:15 TuAT1.5

Pre-charged Pneumatic Soft Gripper with Close Loop Control

Yunquan Li, Yonghua Chen and Yingtian Li
Mechanical Engineering, The University of Hong Kong, Hong Kong

- A controllable soft gripper based on pre-charged pneumatic (PCP) soft actuators
- The bending angle and bending speed of soft actuators are controlled by servomotors through tendons
- Close loop force and position control with feedback data from force and proximity sensors
- Vibration dynamic properties are experimentally studied

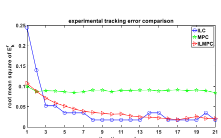
Soft Gripper Prototype

11:00–12:15 TuAT1.6

A Novel Iterative Learning Model Predictive Control Method for Soft Bending Actuators

Zhi Qiang Tang, Ho Lam Heung, Kai Yu Tong
Department of Biomedical Engineering,
The Chinese University of Hong Kong, Hong Kong, China
Zheng Li
Department of Surgery,
The Chinese University of Hong Kong, Hong Kong, China

- An iterative learning model predictive control method (ILMPC) is proposed for soft bending actuators;
- Proposed ILMPC improvs model accuracy gradually and outputs a satisfactory model after learning process;
- Proposed ILMPC outperforms MPC in tracking accuracy and excels ILC in reducing iterations.



Tracking performance comparison among MPC,ILC and ILMPC

Haptics & Interfaces I - 2.1.14

Chair
Co-Chair

11:00–12:15	TuAT1.1

ICRA 2019 Digest Template Design and Experimental Validation of a 2DOF Sidestick using Hyper-Redundant MR Actuators

Marc-André Bégin
Mechanical Engineering, Université de Sherbrooke, Canada
Marc Denninger and Jean-Sébastien Plante
Exonetik, Canada

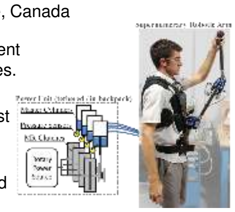
- **Problem:** Active joysticks for aerospace applications require high reliability, force density and quality force feedback
- **Solution:** Alternative actuation strategy combining redundant MR actuators with a cable transmission
- **Results:** Light, compact, jam-free design with duplex fault tolerance, high force density and good force resolution

11:00–12:15	TuAT1.2

A Lightweight Force-Controllable Wearable Arm Based on Magnetorheological-Hydrostatic Actuators

Catherine Véronneau, Jeff Denis, Louis-Philippe Lebel, Marc Denninger*, Jean-Sébastien Plante, Alexandre Girard
Dept. of mechanical engineering, Universite de Sherbrooke, Canada
* Exonetik Inc., Sherbrooke, Canada

- Supernumerary Robotic Limbs (SRLs) are recent wearable robots augmenting human capabilities.
- Existing SRLs lack mechanical transparency required for tasks where interaction forces must be controlled.
- Magnetorheological (MR) clutches coupled to hydrostatic transmissions actuate the proposed lightweight force-controllable SRL.
- Experiments demonstrate high force-bandwidth (>25 Hz) and good ability to control forces even if human add unpredictable disturbances.



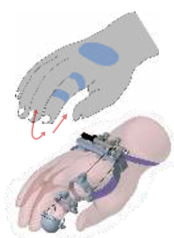
Proposed MR-Hydrostatic Supernumerary Robotic Arm

11:00–12:15	TuAT1.3

Effects of Different Hand-Grounding Locations on Haptic Performance With a Wearable Kinesthetic Haptic Device

Sajid Nisar[1,2], Melisa Orta Martinez[1], Takahiro Endo[2], Fumitoshi Matsuno[2] and Allison M. Okamura[1]
Department of Mechanical Engineering, Stanford University, USA
Department of Mechanical Engineering & Science, Kyoto University, Japan

- This research investigated the **effects of different hand-grounding locations** on user **haptic performance and experience**
- A modular wearable **hand-grounded haptic device** was realized to provide **kinesthetic feedback** in **two directions** with **three different grounding locations**
- User studies showed that the **choice of a grounding-location has profound impact** on user haptic performance and experience

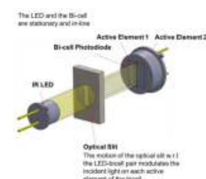


11:00–12:15	TuAT1.4

Optical Force Sensing In Minimally Invasive Robotic Surgery

Amir Hossein Hadi Hosseinabadi, Mohammad Honarvar, and Septimiu E. Salcudean
Electrical and Computer Engineering, University of British Columbia, Canada

- An optical slit is clamped onto the instrument shaft, in-line with an infrared LED-bicell pair.
- Deflection of the shaft moves the slit with respect to the LED-bicell pair
- Slit displacement modulates the light incident on each active element of the bicell.
- No modifications to the instrument, adaptable to different instruments, high-resolution, high-dynamic range, no hysteresis



Force Sensing Principle Using Bicells

11:00–12:15	TuAT1.5

Mechanical Framework Design with Experimental Verification of a Wearable Exoskeleton Chair

Bin Han, Zihao Du, Tiantian Huang and Xuedong Chen*
Huazhong University of Science and Technology, China
Tao Zhang and Zhiyuan Li
Tsinghua University, China.
Ou Bai
Florida International University, USA.

- A special multi-link support structure was proposed.
- A human-chair model is developed as the basis for a wearable chair design.
- The stress analysis was implemented within the whole part of the device.
- An electromyography (EMG) test platform was developed.

HUST-EC: A wearable exoskeleton chair designed in this study

11:00–12:15	TuAT1.6

Fluidic Elastomer Actuators (FEA) for Haptic Interactions in Virtual Reality

Jose Barreiros, Houston Claure, Bryan Peele, Malte Jung, and Robert Shepherd
Engineering, Cornell University, Ithaca, NY, USA
Omer Shapira, Josef Spjut, David Luebke
NVIDIA Corporation, Santa Clara, CA, USA.

- Development of a 12 DOF fluidically pressurized soft actuator for persistent and kinesthetic haptic sensations.
- We describe the design and manufacturing of an FEA based haptic sleeve for the HTC Vive Controller, as well as this hardware integration with SteamVR and NVIDIAs VR Funhouse.
- We characterized the mechanical performance of the sleeve, and performed a user study to assess how people interpret the motion from different classes of stimulus.

The Omnipulse device

SLAM - Session IV - 2.1.15

Chair
Co-Chair

11:00–12:15 TuAT1.1

KO-Fusion: Dense Visual SLAM with Tightly-Coupled Kinematic and Odometric Tracking

Charlie Houseago, Michael Bloesch, Stefan Leutenegger
Department of Computing, Imperial College London, United Kingdom

- A dense SLAM system with tightly-coupled pose predictions from onboard kinematics and odometry.
- Improved tracking and robustness on challenging trajectories.
- Runs in real-time on GPU on any robotic system capable of providing 6DOF pose estimates
- Supports loop closures and corrects for odometric drift

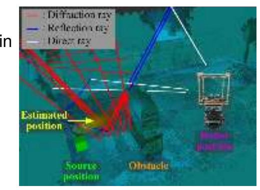

Map Example

11:00–12:15 TuAT1.2

Diffraction-Aware Sound Source Localization for a Non-Line-of-Sight Source

Inkyu An[1], Doheon Lee[1], Jung-woo Choi[2], and Sung-eui Yoon[1]
School of Computing[1] or School of Electrical Engineering[2], KAIST, South Korea
Dinesh Manocha
Dept. of CS & ECE, Univ. of Maryland, USA

- Present a novel sound localization algorithm for a ***non-line-of-sight*** source in real time
- Combine a ray tracing based sound propagation algorithm with the **Uniform Theory of Diffraction (UTD)** model
- Observe **37%** to **130%** improvement in accuracy (average error **0.7m**) by considering **diffraction effects** over a state-of-the-art method



Estimating source position considering diffraction rays

11:00–12:15 TuAT1.3

DeepFusion: Real-Time Dense 3D Reconstruction for Monocular SLAM using Single-View Depth and Gradient Predictions

Tristan Laidlow, Jan Czarnowski and Stefan Leutenegger
Dyson Robotics Laboratory, Imperial College London, UK

- DeepFusion is a 3D reconstruction system that produces fully dense, scaled depth maps.
- DeepFusion produces dense reconstructions in real-time on a GPU.
- Semi-dense depth estimates and CNN-based depth and gradient predictions are fused probabilistically.
- The system is evaluated on both synthetic and real-world datasets.

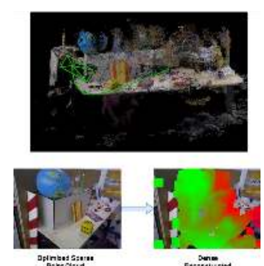

A projected keyframe created by DeepFusion

11:00–12:15 TuAT1.4

Sparse2Dense: From direct sparse odometry to dense 3D reconstruction

Jiexiong Tang, John Folkesson and Patric Jensfelt
Robotics, Perception and Learning Division,
Robotics, Perception and Learning Lab, Sweden

- We proposed a new deep learning based dense monocular SLAM;
- We used single view learned depth estimation as prior for monocular visual odometry;
- We re-constructed the dense 3D model via a sparse to dense mapping using learned surface normals.

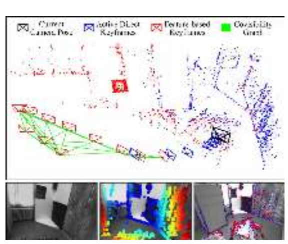


11:00–12:15 TuAT1.5

Loosely-Coupled Semi-Direct Monocular SLAM

Seong Hun Lee and Javier Civera
SLAMLab (I3A), University of Zaragoza, Spain

- We loosely couple direct odometry and feature-based SLAM to combine their complementary strengths.
- Locally, a direct method is used to track the camera pose.
- Globally, a feature-based method is used to close loops and build a reusable map.
- Our system outperforms DSO and ORB-SLAM in terms of overall accuracy and robustness.



Mapping - 2.1.16

Chair

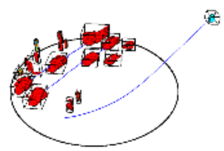
Co-Chair

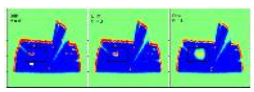
11:00–12:15	TuAT1.1

Dynamic Hilbert Maps: Real-time Occupancy Predictions in Changing Environments

Vitor Guizilini[1,2], Ransalu Senanayake[1], Fabio Ramos[1,3]
[1]School of Computer Science, The University of Sydney, Australia
[2]Toyota Research Institute, Los Altos, CA
[3]NVIDIA, USA

- Continuous occupancy mapping using unstructured pointcloud information
- Motion is encoded directly in the map, by iteratively learning dynamic models for different objects in the environment
- The accumulated map can be used to predict future occupancy probabilities for any query point
- Large-scale (1000 m^2) 3D occupancy predictions at 10 Hz



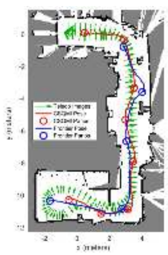


11:00–12:15	TuAT1.2

Evaluating the Effectiveness of Perspective Aware Planning with Panoramas

Daniel Mox and M. Ani Hsieh
MEAM, University of Pennsylvania, USA
Anthony Cowley and CJ Taylor
CIS, University of Pennsylvania, USA

- Information based exploration strategy tailored for the generation of high resolution 3D maps from RGBD panoramas
- CSQMI objective function operating on an angle enhanced occupancy grid with reduced search space using image morphology
- Experimentally compared against teleoperation and near frontier exploration in object recognition task

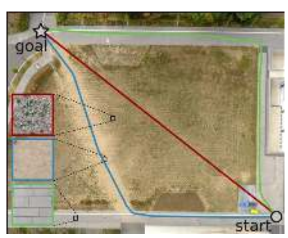


11:00–12:15	TuAT1.3

Actively Improving Robot Navigation on Different Terrains using Gaussian Process Mixture Models

Lorenzo Nardi and Cyrill Stachniss
University of Bonn, Germany

- **Improving** navigation **over time** by reducing the impact of the detrimental factors (e.g. vibrations)
- **Continuous learning** of a model of such factors from robot's online **observations**
- No explicit terrain classifier
- **Planning** uses this model to trade off **exploration** and **exploitation**
- Leads **quickly** the robot to navigate through low-cost paths

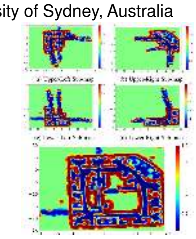


11:00–12:15	TuAT1.4

Continuous Occupancy Map Fusion with Fast Bayesian Hilbert Maps

Weiming Zhi, Lionel Ott, Ransalu Senanayake
School of Computer Science, The University of Sydney, Australia
Fabio Ramos
School of Computer Science, The University of Sydney, Australia
NVIDIA, USA

- Introduce a fast variant of Bayesian Hilbert Maps – a continuous mapping method that does not assume discretised grid cells
- Present a method to merge Fast Bayesian Hilbert Maps in a multi-agent scenario



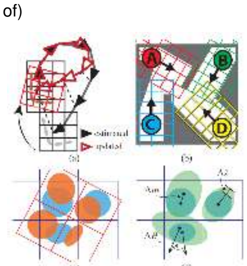
Merger of continuous sub-maps to one

11:00–12:15	TuAT1.5

Regeneration of Normal Distributions Transform for Target Lattice Based on Fusion of Truncated Gaussian Components

Hyunki Hong, H. W. Yu, and B. H. Lee
Department of Electrical and Computer Engineering, Seoul National University, Korea (Republic of)

- Normal distributions transform (NDT) is a Gaussian mixture spatial representation which is generated by regular cells.
- Due to the discretization, the simple fusion of NDTs may lead to the distortion.
- We propose a regeneration method which subdivides a Gaussian component (GC) into truncated GCs and fuses the truncated GCs in the same target cell.
- We evaluated the representation and the computational performance. Also, we showed the application of map fusion.



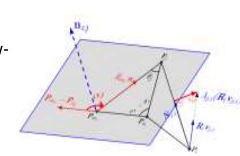
Simple fusion of NDTs.

11:00–12:15	TuAT1.6

Robust Global Structure from Motion Pipeline with Parallax on Manifold Bundle Adjustment and Initialization

Liyang Liu, Teng Zhang, Brenton Leighton, Liang Zhao, Shoudong Huang and Gamini Dissanayake
Centre for Autonomous Systems, University of Technology Sydney, Australia

- Global Structure from Motion pipeline friendly to urban scenes : friendliness to low-parallax features and collinear motions.
- BA stage: **P**arallax on-**M**anifold feature paramtrization based **B**undle **A**djustment (PMBA), full-rank optimization tolerant of low-parallax features
- Initialization stage: compatible to PMBA, friendly to collinear motion, robust to outlier, simple in calculation.



SfM using parallax-feature based Bundle Adjustment and Initialization

Aerial Systems: Mechanisms I - 2.1.17

Chair
Co-Chair

11:00–12:15	TuAT1.1

Fault-tolerant Flight Control of a VTOL Tailsitter UAV

Silvan Fuhrer, Sebastian Verling, Thomas Stastny, Roland Siegwart
Autonomous Systems Lab, ETH Zurich, Switzerland

- Tailsitter VTOL aircraft have an inherently low fault-tolerance to actuator failures
- We propose light-weight adaptions to the nominal controller to handle failures
- The fault-tolerant controller is implemented and tested on a small UAV
- It can handle elevon failures in both hover and cruise flight, and motor failures in cruise flight

11:00–12:15	TuAT1.2

Modeling and Control of a Passively-Coupled Tilt-Rotor Vertical Takeoff and Landing Aircraft

Romain Chiappinelli[1], Mitchell Cohen[2], Martin Doff-Sotta[2], Meyer Nahon[2], James Richard Forbes[2], and Jacob Apkarian[1]
[1]Coriolis Games Corporation, Toronto
[2]Department of Mechanical Engineering, McGill University, Canada

- The aircraft consists of a quadrotor frame attached to a fixed-wing aircraft by an unactuated hinged mechanism
- The coupled dynamics are modeled as a constrained multi-body system
- A simple P-PID controller is able to transition smoothly from hover to forward flight

The vogi platform

11:00–12:15	TuAT1.3

Power-Minimizing Control of a Variable-Pitch Propulsion System for Versatile UAVs

Travis Henderson and Nikolaos Papanikolopoulos
Comp. Sci. & Eng., Univ. of Minnesota, United States

- Properly controlled variable-pitch propellers have the potential to exceed fixed-geometry-propeller efficiency.
- A variable-pitch propeller controller is proposed for reducing power consumption in any flight state.
- The online, sensor-based control framework is validated with both table-top and aerial tests.
- Results show that this variable-pitch controller significantly improves performance across the board.

Aerial testbed used for flight tests

11:00–12:15	TuAT1.4

Rapid Inertial Reorientation of an Aerial Insect-sized Robot Using a Piezo-actuated Tail

Avinash Singh and Sawyer B. Fuller
Mechanical Engineering, University of Washington, USA
Thomas Libby
Electrical and Computer Engineering, University of Washington, USA

- Inertial Reorientation (IR) is defined as control of body orientation by inertial forces, e.g. via a swinging tail
- IR enables orientation control independent of external forces and can increase robustness
- We present an insect-sized, piezo-driven IR robot with a prefiltered feedforward controller
- We achieved high performance relative to wing-based control: angular acceleration over 150,000 deg/sec^2

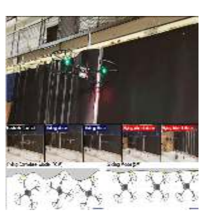
Honeybee-sized flying robot equipped with a piezo-actuated tail

11:00–12:15	TuAT1.5

Contact-based Navigation Path Planning for Aerial Robots

Nikhil Khedekar[1], Frank Mascarich[2], Christos Papachristos[2], Tung Dang[2], and Kostas Alexis[2]
[1]Department of Computer Science, BITS Pilani Goa Campus, India
[2]Department of Computer Science, University of Nevada, Reno, USA

- Approach for in-contact navigation for aerial robots on surfaces that can be highly anomalous
- Flying-Cartwheel-Mode and Sliding-Mode introduced for traversing anomalous and smooth surfaces respectively
- Planner proposed for finding cost-optimal paths including a traversability metric for selecting flight mode
- Planning and path execution demonstrated in real experiments and simulation



11:00–12:15	TuAT1.6

Cargo Transportation Strategy using T^3-Multirotor UAV

Seung Jae Lee[1], Dongjae Lee[1], and H. Jin Kim[1]
[1]Department of Mechanical and Aerospace Engineering, Seoul National University, Republic of Korea

- Improves the design of the T^3 (Tilting Thruster Type) full-DOF multirotor platform.
- Proposes a controller that provides a uniform flight performance for a variety of cargoes attached to the fuselage part.
- Demonstrates an improved transport capability of a high-moment-of-inertia cargo through the comparison of flight stability between a general multirotor and T^3-Multirotor.

Layout of T^3 Multirotor Ver. 2

General Multirotor T^3-Multirotor

Aerial Systems: Applications III - 2.1.18

Chair
Co-Chair

11:00–12:15 TuAT1.1

Experimental Learning of a Lift-Maximizing Central Pattern Generator for a Flapping Robotic Wing

Yagiz Efe Bayiz, Shih-Jung Hsu, Aaron Aguiles, Yano Shade-Alexander and Bo Cheng
Mechanical Engineering, The Pennsylvania State University

- A policy gradient algorithm is used to maximize the lift generation of a robotic wing.
- The wing motion is generated through a CPG and 3DoF motion with asymmetry is enabled.
- The learned wing kinematics used the full range of wing motion with low flapping frequency.
- Two locally optimal strategies are identified with similar cycle-averaged lift.

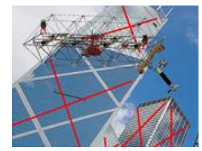

Robotic Wing Set-up

11:00–12:15 TuAT1.2

Toward Lateral Aerial Grasping & Manipulation Using Scalable Suction

Chad Kessens, (Matt Horowitz), James Dotterweich, Harris Edge
Army Research Laboratory (Engility Corporation), USA
Chao Liu, Mark Yim
GRASP Laboratory, University of Pennsylvania, USA

- Lateral force exerted by an aerial system is usually limited to a small thrust component.
- We introduce a scalable suction-based gripper to gain access to environmental forces for increasing lateral force exertion.
- A Spiral Zipper arm provides lightweight manipulation ability and standoff for attaching.
- An 8-rotor propulsion core with vectored thrust decouples attitude to increase workspace.
- Initial component experiments and demonstrations are presented.


Aerial platform with suction-based gripper for performing lateral work.

11:00–12:15 TuAT1.3

Light-Weight Whiskers for Contact, Pre-Contact and Fluid Velocity Sensing

William Deer and Pauline Pounds
ITEE, The University of Queensland, Australia

- Potted MEMS barometers give sensitive measurement, amplified by contact whiskers
- Whiskers are mde from drawn ABS fillaments
- Mass-manufacturable as an array of elements
- Vibrissae can detect as little as 300 uN of force at the tips
- Sensitive enough to detect the bow wave of air from an approaching hand 20 mm away.


Whisker sensor array

11:00–12:15 TuAT1.4

There's No Place Like Home: Visual Teach and Repeat for Emergency Return of Multirotor UAVs During GPS Failure

Michael Warren, Melissa Greeff, Bhavit Patel, Angela P. Schoellig and Timothy D. Barfoot
University of Toronto Institute for Aerospace Studies (UTIAS), Canada
Jack Collier
Suffield Research Centre, Defence Research & Development Canada, Canada

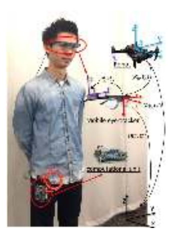
- Presentation of Visual Teach & Repeat on a large multirotor UAV for emergency return in large-scale, outdoor scenarios
- Enhanced localisation performance using gimbaled camera to attenuate dynamic motion
- Path-following controller for multirotor UAVs
- Comprehensive analysis of performance for large positional offsets and speeds up to 15 m/s
- Demonstration of closed-loop control in several large-scale outdoor tests, with over 1 km of autonomous flight in analogue test site

11:00–12:15 TuAT1.5

Human Gaze-Driven Spatial Tasking of an Autonomous MAV

Liangzhe Yuan[1], Christopher Reardon[2], Garrett Warnell[2], and Giuseppe Loianno[3]
[1]University of Pennsylvania, USA
[2]U.S. Army Research Laboratory, USA
[3]New York University, Tandon School of Engineering, USA

- The first work using human-gaze to directly maneuver a MAV in 3D space.
- A technique decoupling gaze direction from head attitude.
- A novel object-detection-based approach to localizing a MAV in the human sensor frame.



11:00–12:15 TuAT1.6

Optimal Trajectory Generation for Quadrotor Teach-and-Repeat

Fei Gao, Luqi Wang, Kaixuan Wang, William Wu, Boyu Zhou, Luxin Han and Shaojie Shen
ECE Department, Hong Kong University of Science and Technology, Hong Kong, China

- Propose a novel motion planning framework for quadrotor teach-and-repeat applications.
- Convert an arbitrary jerky human-piloted trajectory to a topologically equivalent one.
- Optimize the trajectory in both spatial and temporal aspects.
- Generate a topologically equivalent trajectory.
- Guarantee the safety, smoothness, and kinodynamic feasibility of the trajectory.
- Present autonomous indoor/outdoor flights.


Autonomous aggressive flight in the repeating.

Automation Technology - 2.1.19

Chair
Co-Chair

11:00–12:15	TuAT1.1

Design and Implementation of Computer Vision based In-Row Weeding System

Xiaolong Wu and Stephanie Aravecchia
ECE, Georgia Institute of Technology, United States
Cedric Pradalier
UMI2958 GeorgiaTech-CNRS, France

- A novel self-sustained weed control system using state-of-art weed/crop detection
- A 3D multi-object tracking framework using non-overlapping camera system
- Systematical comparison of intra- and inter-camera tracking approaches using direct and indirect principle
- Extensive evaluation in real-world sugar beets field

Figure. Mechanical and chemical weeding

11:00–12:15	TuAT1.2

LSTM-based Network for Human Gait Stability Prediction in an Intelligent Robotic Rollator

Georgia Chalvatzaki, Petros Koutras, Jack Hadfield, Xanthi S. Papageorgiou, Costas S. Tzafestas and Petros Maragos
School of Electrical and Computer Engineering,
National Technical University of Athens, Greece

- **RGB-D pose** detection and CoM tracking
- Human **gait state** estimation from **laser** data
- **Features**: CoM, legs positions and gait phase
- **Encoder-Decoder** sequence-to-sequence model predicts **gait stability** from features at each time instant
- LSTM-based gait stability network could be integrated into a general **user-adaptive control** architecture as a **fall-risk alarm**

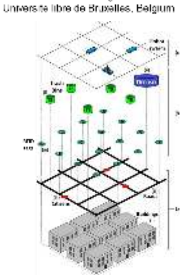
Elderly patient walking supported by a robotic rollator. Predicted states for Gait Stability may be Safe or Fall Risk.

11:00–12:15	TuAT1.3

Urban Swarms: A new approach for autonomous waste management

Luca Alfeo, <u>**Eduardo Castello**</u>, Yago Lizarribar, Arnaud Grignard, Luis Alonso, Dylan Sleeper, Kent Larson and Alex Pentland
MIT Media Lab, MIT, USA
Mario Cimino and Gigliola Vaglini, University of Pisa, Italy
Bruno Lepri, Bruno Kessler Foundation, Italy
Marco Dorigo, Université libre de Bruxelles, Belgium

- Modern **cities** are facing new challenges like **waste management**, which has become a pressing issue that **requires new solutions**.
- This paper proposes **a swarm robotic system** that can **handle** the **urban waste management**. New methods are designed, tested and analyzed.
- **Our approach** improves by 71% (AUT) and 99% (FTB) the management of urban public waste which **outperforms current solutions**.



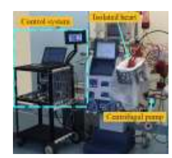
Multilayer model of a "smart city"

11:00–12:15	TuAT1.4

Automated Aortic Pressure Regulation in ex vivo Heart Perfusion

Liming Xin[1], Weiran Yao[1, 4], Yan Peng[3], Naiming Qi[4], Mitesh Badiwala[2], and Yu Sun[1]
[1.] Department of Mechanical and Industrial Engineering, University of Toronto, Canada
[2.] Faculty of Medicine, University of Toronto, Canada
[3.] School of Mechatronic Engineering and Automation, Shanghai University, China
[4.] School of Astronautics, Harbin Institute of Technology, China

- An automated *ex vivo* heart perfusion system was was developed for AoP regulation and maintained the heart's physiological aerobic metabolism
- A mathematical model of EVHP was first built based on the electrical analog method to predict the cardiac parameter changes
- A model-based adaptive control method was designed to adapt to cardiac changes and achieve AoP regulation rapidly and smoothly



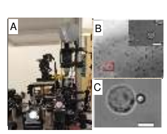
Automated aortic pressure control system for *ex vivo* heart perfusion

11:00–12:15	TuAT1.5

ICRA 2019 Digest Template Robotic Microscope for T Cell Receptor Acuity

L.L.S. Ong[1],H. Zhu[1], D. Banik[1], Z. Guan[1], Y. Feng[4], E.L. Reinherz [2,3], M.J. Lang[1,4,5], H.H. Asada[1,6]
[1]BioSyM, SMART, Singapore, [2]Dana-Faber Cancer Institute, [3]Harvard Medical School, [4]Chemical & Biomolecular Eng & [5]Molecular Physiology & Biophysics Eng, Vanderbilt University, [6]Mech Eng, MIT, USA

- During immune surveillance, some T cells can selectively identify and destroy tumor cells by recognizing pMHCs on cancer cells.
- We present a robotic microscope which presents micro-meter beads coated with pMHCs to T cells and generates piconewton-level forces required to detect T cell acuity.
- Our system integrates optical tweezers, precision nano-micro stages and episcopic/diascopic illumination schemes at two magnifications.



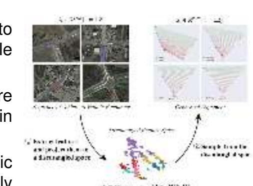
(A) Hardware, (B) Captured images at 20X and 100X, (C) Trapped bead and T cell.

11:00–12:15	TuAT1.6

A Multi-Vehicle Trajectories Generator to Simulate Vehicle-to-Vehicle Encountering Scenarios

Wenhao Ding
Electronic Engineering, Tsinghua University, China
Wenshuo Wang and Ding Zhao
Mechanical Engineering, Carnegie Mellon University, US

- Introducing the deep generative model to describe features of multi-vehicle trajectories through latent codes.
- Generating encounter trajectories that are consistent with the real traffic data in terms of spatio-temporal characteristics.
- Proposing a new disentanglement metric that is capable to comprehensively analyze deep generative models.



Procedure of multi-vehicle trajectories generator.

Force and Tactile Sensing I - 2.1.20

Chair
Co-Chair

11:00–12:15 TuAT1.1

Deep n-Shot Transfer Learning for Tactile Material Classification with a Flexible Pressure-Sensitive Skin

Berthold Bäuml and Andreea Tulbure
Institute of Robotics and Mechatronics, DLR, Germany

- Transfer learning important in robotics to reduce number of training samples needed
- Task: tactile material classification with pressure sensitive skin on robot's finger
- First time shown that deep end-to-end transfer learning works on real robotic setup
- Comparison of state of the deep transfer learning methods adapted to our TactNet-II
- 75% accuracy for 6-way 1-shot learning and 90% for 10-shot learning. Up to 15 time reduction in samples needed

Tactile material classifiaction by sweeping a finger over an object's surface.

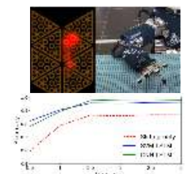
11:00–12:15 TuAT1.2

Towards Effective Tactile Identification of Textures using a Hybrid Touch Approach

Tasbolat Taunyazov[1,2], Hui Fang Koh[3], Caixia Cai[2]
Yan Wu[2] and Harold Soh[1]
School of Computing, National University Singapore, Singapore,
A*STAR Institute for Infocomm Research, Singapore
Mechanical Engineering, Nanyang Technological University, Singapore

Main contributions of paper:

- Texture classification is improved with both sliding and touch movement data.
- A texture classification framework with three different models compromising statistical machine learning and connectionist approaches
- A tactile dataset collected using the iCub humanoid robot on 23 textures (total of 2,852 samples)

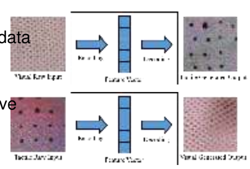


11:00–12:15 TuAT1.3

"Touching to See" and "Seeing to Feel": Robotic Cross-modal Sensory Data Generation for Visual-Tactile Perception

Jet-Tsyn Lee, Danushka Bollegala and Shan Luo
Department of Computer Science, University of Liverpool, United Kingdom

- We propose a novel cross-modal sensory data generation framework for visual and tactile perception;
- Pseudo visual images or tactile outputs have been generated from data of the other modality;
- It has potential to expand datasets for classification tasks, generate sensory outputs that are not easy to access, and also advance integrated visual-tactile perception.



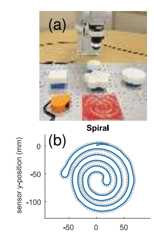
Cross-modal sensory data generation for visual-tactile perception

11:00–12:15 TuAT1.4

Shear-invariant Sliding Contact Perception with a Soft Tactile Sensor

Kirsty Aquilina, David A. W. Barton and Nathan F. Lepora
Bristol Robotics Laboratory and the Department of Engineering Mathematics, University of Bristol, UK

- **Main Contribution:** Features found in discrete contact data can also be extracted from sliding contact data using principal component analysis.
- **Experiment:** Discrete contact tap data used for training and sliding contact data used for testing.
- **Result 1:** Predictions of sensor orientation using offline sliding test set.
- **Result 2:** Successfully performed sliding contact contour following of 6 unknown shapes.
- **Conclusion:** We expect the proposed shear-invariant method to apply to more challenging tasks due to its generalisation capabilities.



(a) Robot setup and (b) sliding contact contour following result.

11:00–12:15 TuAT1.5

Soft tactile sensing: retrieving force, torque and contact point information from deformable surfaces

Simone Ciotti[*+], Teng Sun[ƚ], Edoardo Battaglia[+],
Antonio Bicchi[*+‡], Hongbin Liu[ƚ] and Matteo Bianchi[+‡]
*Soft Robotics for Human Cooperation and Rehabilitation, IIT, Genova, Italy
+Research Center E. Piaggio, University of Pisa, Pisa, Italy
ƚHaMMeR Lab, King's College London, London, UK
‡Department of Information Engineering, University of Pisa, Pisa, Italy

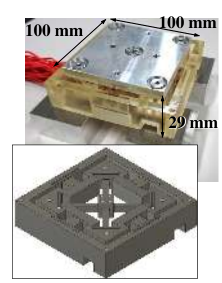
- Extension of Intrinsic Tactile Sensing to deformable surfaces, implemented in a ROS-based toolbox
- Contact centroid estimation through two methods: (i) closed-form and (ii) iterative approach
- Performance evaluated on two different stiffness silicone specimens probed from different directions
- The combination of two methods showed convergence under 1ms, attaining errors lower than 1mm

11:00–12:15 TuAT1.6

Miniaturization of multistage high dynamic range six-axis force sensor composed of resin material

Daisuke Okumura*, Sho Sakaino*,** and Toshiaki Tsuji*
*Dept. Electrical and Electronic Systems, Saitama University, Japan
** JST PRESTO

- A miniaturized structure for multistage high dynamic range force sensor is designed.
- Accuracy is higher than conventional sensors in low load region, even with inexpensive and lightweight resin material.
- Although creep and stress relaxation degrade accuracy, these effects could be reduced by 80 percent with a correction filter.



Social HRI II - 2.1.21

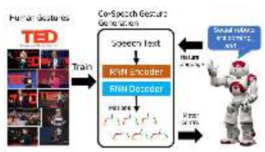
Chair
Co-Chair

11:00–12:15	TuAT1.1

Robots Learn Social Skills: End-to-End Learning of Co-Speech Gesture Generation for Humanoid Robots

Youngwoo Yoon, Woo-Ri Ko, Minsu Jang, Jaeyeon Lee, Jaehong Kim
HMI Research Group, ETRI, Republic of Korea
Geehyuk Lee
HCI Lab, KAIST, Republic of Korea

- Learning-based **co-speech gesture generation** method
- The end-to-end neural network model consists of an **encoder** for speech text understanding and a **decoder** to generate a sequence of gestures
- The network is trained from **52 h of TED talks**



11:00–12:15	TuAT1.2

The Doctor will See You Now: Could a Robot Be a medical Receptionist?

CJ Sutherland, BK Ahn, JY Lim, BA MacDonald, and HS Ahn
Department of Electrical, Software and Computer Engineering, University of Auckland, New Zealand
B Brown, DL Johanson, E Broadbent
Department of Psychological Medicine, University of Auckland, New Zealand

- Developed a robotic system to interact with patients in a medical clinic
- Investigated people's reactions via a Wizard-of-Oz study (40 participants)
- Results indicate the participants thought the EveR robot was friendly and could be a receptionist
- Could only do simple tasks, would still need a human for more complex interactions


EveR-4 Robot

11:00–12:15	TuAT1.3

Designing a Personality-Driven Robot for a Human-Robot Interaction Scenario

Hadi Beik Mohammadi*, Nikoletta Xirakia*, Fares Abawi, Irina Barykina, Krishnan Chandran, Gitanjali Nair, Cuong Nguyen, Daniel Speck, Tayfun Alpay, Sascha Griffiths, Stefan Heinrich, Erik Strahl, Cornelius Weber, Stefan Wermter
Department of Informatics, University of Hamburg, Germany

- **We present:** an autonomous AI system designed for an HRI study, set around a dice game scenario.
- **We answer:** does a robot with a socially engaged personality lead to a higher acceptance than a competitive personality?
- **We evaluate:** 3 questionnaires and CNN analyzing participants' face expressions
- **We conclude:** designing the robot with a socially engaged personality contributes to a higher acceptance within an HRI scenario.


Our robot NICO plays a dice game with a human.

11:00–12:15	TuAT1.4

How Shall I Drive? Interaction Modeling and Motion Planning towards Empathetic and Socially-Graceful Driving

Yi Ren, Steven Elliot, Yiwei Wang, Yezhou Yang and Wenlong Zhang
Fulton Schools of Engineering, Arizona State University, USA

- Empathetic intent inference: Incorporating other's lack of knowledge of self intent
- Motion planning incorporating inference uncertainty
- Socially-graceful planning: Balance self-goal & favored motion by others
- Less aggressive than proactive motions; creates negotiation with human drivers

11:00–12:15	TuAT1.5

It Would Make Me Happy if You Used My Guess: Comparing Robot Persuasive Strategies in Social Human-Robot Interaction

Shane Saunderson and Goldie Nejat
Autonomous Systems and Biomechatronics Laboratory, Deptartment of Mechanical and Industrial Engineering, University of Toronto, Canada

- Novel HRI study investigating the use of persuasive strategies by social robots to influence participant estimates in a jelly bean guessing game
- Ten multimodal strategies using compliance-gaining behavior were developed and implemented on two competing social robots
- The emotional-affective strategy had the highest persuasive influence, highlighting the importance of emotion processing in persuasion with robots
- Other strategies (Cooperative & Liking/Polite) showed conflicted results as they seemed to instill trust in participants, but not confidence in the suggested guess


The two NAO robots used in the jelly bean guessing game

11:00–12:15	TuAT1.6

Enabling Robots to Infer how End-Users Teach and Learn through Human-Robot Interaction

Dylan P. Losey and Marcia K. O'Malley
Department of Mechanical Engineering, Rice University, USA

- Today's robots assume that all humans teach or learn in the same way
- But we recognize that different users interact in different ways, so one size does not fit all
- Here we describe robots that maintain a distribution over how humans interact
- Using Bayesian inference, the robot infers each individual end-user's interaction strategy


Robot reasoning about human learning strategy

Object Recognition & Segmentation I - 2.1.22

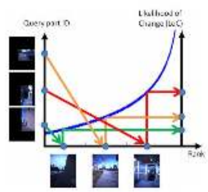
Chair
Co-Chair

11:00–12:15	TuAT1.1

Detection-by-Localization: Maintenance-Free Change Object Detector

Kanji Tanaka
Department of Engineering, University of Fukui, Japan

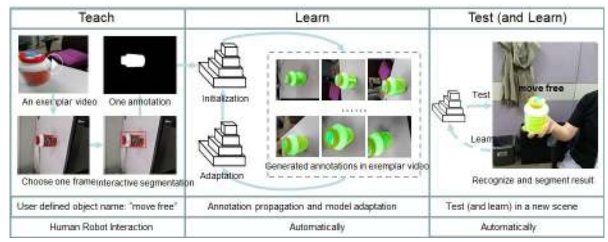
- A new detection-by-localization method for object-level change detection using a ranking-based self-localization model
- Change detection with very small extra cost by reusing self-localization capability
- No additional storage or detector engine (but only existing map database and localization engine) is required
- The degration of map quality (i.e., need of map update) in terms of self-localization performance can be directly detected.



11:00–12:15	TuAT1.2

Object Recognition and Segmentation by One Shot Learning with Human Robot Interaction

Ping Guo, Lidan Zhang, Lu Cao, Yingzhe Shen, Haibing Ren, and Yimin Zhang
Intel Labs China

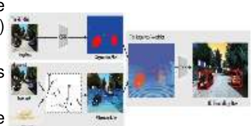


11:00–12:15	TuAT1.3

SEG-VoxelNet for 3D Vehicle Detection from RGB and LiDAR Data

Jian Dou(1), Jianru Xue (1), and Jianwu Fang(1,2)
1. Institute of Artificial Intelligence and Robotics, Xian Jiaotong University, Xi'an, P.R. China.
2. School of Electronic and Control Engineering, Chang'an University, Xi'an, , P.R. China.

- SEG-VoxelNet is composed of an image semantic segmentation network (SEG-Net) and an improved-VoxelNet.
- The novel fusion framework effectively fuses point cloud data with image semantic feature.
- The method achieved 86.32% mAP at the moderate levels on KITTI 3D vehicle detection benchmark.



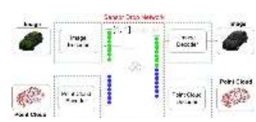
An overview of the SEG-VoxelNet architecture

11:00–12:15	TuAT1.4

Object Classification Based on Unsupervised Learned Multi-Modal Features For Overcoming Sensor Failures

Julia Nitsch[1,2] , Juan Nieto[2] , Roland Siegwart[2] , Max Schmidt[1] and Cesar Cadena[2]
[1]Ibeo Automotive Systems GmbH, [2]Autonomous Systems Lab, ETH Zurich

- We present an unsupervised multi-modal feature extraction from image and 3d-point cloud data.
- A supervised classification is proposed using multi-modal features with overcoming gradual or total sensor failure.
- We demonstrate the classifier on various noise patterns not present during training time.



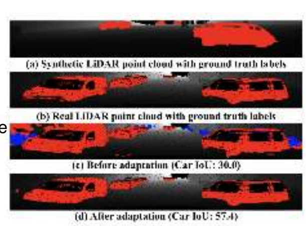
Architecture for unsupervised feature learning

11:00–12:15	TuAT1.5

SqueezeSegV2: Improved Model Structure and Unsupervised Domain Adaptation for Road-Object Segmentation from a LiDAR Point Cloud

Bichen Wu, Xuanyu Zhou, Sicheng Zhao, Xiangyu Yue, Kurt Keutzer
Berkeley AI Research, UC Berkeley
bichen@berkeley.edu

- LiDAR point cloud contains a lot of noises
- We improve the model structure of SqueezeSeg to reduce the noise sensitivity and improve accuracy
- To leverage simulated data to train the model, we propose a domain adaptation pipeline to transfer the model from simulated data to the real world data

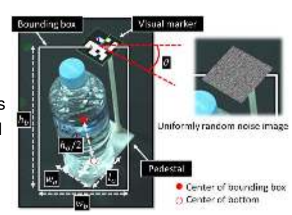


11:00–12:15	TuAT1.6

Fully Automated Annotation with Noise-Masked Visual Markers for Deep Learning-Based Object Detection

Takuya Kiyokawa, Keita Tomochika, Jun Takamatsu and Tsukasa Ogasawara
Division of Information Science, Nara Institute of Science and Technology, Japan

- Use visual markers to automatically annotate objects in training images
- Propose a noise masking method to avoid learning the markers as features
- Proposed vision system outperformed a system using manual annotation while reducing the annotation time



Setup of objects used in our automatic annotation

Localization and Estimation - 2.1.23

Chair
Co-Chair

11:00–12:15 TuAT1.1

RoPose-Real: Real World Dataset Acquisition for Data-Driven Industrial Robot Arm Pose Estimation

Thomas Gulde, Dennis Ludl, Johann Andrejtschik, Salma Thalji and Cristóbal Curio
Computer Science Department, Reutlingen University, Germany

- *RoPose-Real* applies our prior simulation based *RoPose* system to the real world
- We propose an extrinsic calibration tool based on manual labeling of robot joints to produce real world datasets
- Our CNN-based estimation architecture for robot joints is successfully applied to new acquired real world datasets

Estimated 2D poses

11:00–12:15 TuAT1.2

A Framework for Self-Training Perceptual Agents in Simulated Photorealistic Environments

Patrick Mania and Michael Beetz
Collaborative Research Centre Everyday Activities Science and Engineering (EASE), University of Bremen, Germany

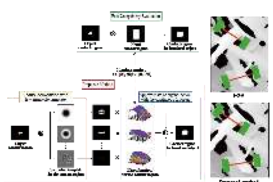
- Use game engine technology to recreate highly realistic environments for learning
- Virtual environments are described in a Scenario Description Language and instantiated in a game engine
- New Scenarios can be generated by probabilistic models with a Semantic Scenario Sampler
- Experiments showed that models trained with game engine vision data performs well on real robot

11:00–12:15 TuAT1.3

Fast and Precise Detection of Object Grasping Positions with Eigenvalue Templates

Kosuke Mano[1,2], Takahiro Hasegawa[1], Takayoshi Yamashita[1], Hironobu Fujiyoshi[1], and Yukiyasu Domae[2]
Machine Perception and Robotics Group, Chubu University, Japan
Automation Research Team, AIST, Japan

- **Fast and precise** grasping position detection in **bin picking robot system**
- Express hand templates compactly by using the singular value decomposition
- Higher detection accuracy by approximation in eigenfunction with the continuous function
- 61% reduction in processing time with parallel hand



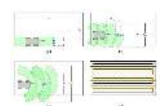
Propose method and detection results

11:00–12:15 TuAT1.4

Improved Coverage Path Planning Using a Virtual Sensor Footprint: a Case Study on Demining

Sedat Dogru and Lino Marques
Institute of Systems and Robotics,
Department of Electrical and Computer Engineering,
University of Coimbra,
3030-290 Coimbra, Portugal

- Coverage Path Planning performance depends both on the path created and the footprint of the sensor.
- Sensor footprint can be increased using more sensors, or sweeping with the single sensor as the platform moves.
- Effect of varying the footprint using different methods to the time spent and energy consumed is analyzed.



11:00–12:15 TuAT1.5

Model-Based Estimation of the Gravity-Loaded Shape and Scene Depth for a Slim 3-Actuator Continuum Robot with Monocular Visual Feedback

Yuyang Chen and Shu'an Zhang,
UM-SJTU Joint Institute, Shanghai Jiao Tong University, China
Lingyun Zeng, Xiangyang Zhu and Kai Xu*
School of Mechanical Engineering, Shanghai Jiao Tong University, China

- Model-based shape estimation for a slim continuum robot under gravity was investigated;
- The robot's shape is determined by the gravity and its three actuators;
- One camera with two UKFs was used to estimate the robot's shape and the feature depth;
- Acceptable accuracy for shape and depth estimation was obtained.

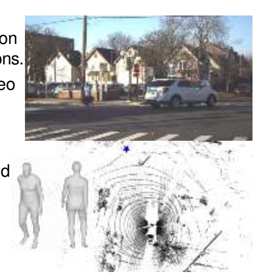
Shape estimation of continuum robot under gravity

11:00–12:15 TuAT1.6

PedX: Benchmark Dataset for Metric 3D Pose Estimation of Pedestrians in Complex Urban Intersections

Wonhui Kim, Manikandasriram Srinivasan Ramanagopal, Charles Barto, Ming-Yuan Yu, Karl Rosaen, Nick Goumas, Ram Vasudevan and Matthew Johnson-Roberson
University of Michigan, United States

- PedX is a large-scale multi-modal collection of pedestrians at complex urban intersections.
- The dataset provides high-resolution stereo images and LiDAR data sequences with 2D/3D labels.
- A 3D model fitting algorithm harnesses constraints across different modaltities and novel shape and temporal priors.
- PedX is available online: https://pedx.io.



Under-actuated Robots - 2.1.24

Chair
Co-Chair

11:00–12:15	TuAT1.1

Design of a Modular Continuum Robot Segment for use in a General Purpose Manipulator

Nicholas P. Castledine, Jordan H. Boyle and Jongrae Kim
School of Mechanical Engineering, University of Leeds, UK

- 3D printed, one piece design with flexible central core and rigid vertebra.
- Novel interlocking vertebra restrict torsional movement while allowing two bending degrees of freedom.
- Actuated by two antagonistic tendon pairs, each driven by a single geared DC motor.
- Modular system embeds motors in the base of each segment, with hollow central bore.

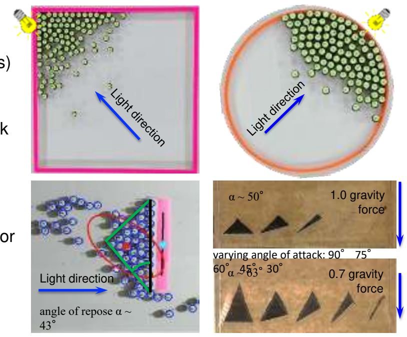
11:00–12:15	TuAT1.2

Reshaping Particle Configurations by Collisions with Rigid Objects

Shiva Shahrokhi, Haoran Zhao, Aaron Becker
Computer and Electrical Engineering, University of Houston, TX USA

Given many particles controlled by a global field (all get same control inputs)

- angle of repose used to reshape particles by controlling angle of attack and magnitude of the driving force.
- derive full set of stable, achievable mean and variance configurations for a *square* and a *circular* workspace.



11:00–12:15	TuAT1.3

Velocity Constrained Trajectory Generation for a Collinear Mecanum Wheeled Robot

Matthew T. Watson and Daniel T. Gladwin
Dept. of Electrical and Electronic Engineering, The University of Sheffield, UK
Tony J. Prescott
Dept. of Computer Science, The University of Sheffield, UK
Sebastian O. Conran
Consequential Robotics Ltd., UK

- The derivation of a differentially flat model of a novel omnidirectional wheel configuration known as a Collinear Mecanum Drive.
- The derivation of an optimal velocity constrained polynomial trajectory generator, utilizing sum-of-squares programming.
- The real-time generation and tracking of complex trajectories on an experimental Collinear Mecanum Drive prototype.

11:00–12:15	TuAT1.4

Vibration Control for Manipulators on a Translationally Flexible Base

Fabian Beck, Gianluca Garofalo, and Christian Ott
Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Germany

- The vibration control problem is studied on the basis of a fundamental oscillatory system.
- The proposed approach utilizes coordinate transformations to reduce n-link manipulators to the fundamental oscillatory system.
- A proof of stability for n-link manipulators on 3-DoF translationally flexible base is provided.
- The performance of proposed approach is compared to Inertial Vibration Damping control.

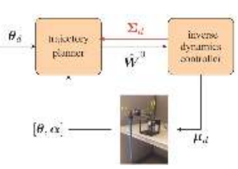
Medical robot MIRO modeled with translationally flexible base

11:00–12:15	TuAT1.5

Gaussian Processes Model-Based Control of Underactuated Balance Robots

Kuo Chen and Jingang Yi
Dept. of Mechanical and Aerospace Engineering, Rutgers University, USA
Dezhen Song
Dept. of Computer Science and Engineering, Texas A&M University. USA

- Developed a Gaussian process (GP)-based learning model for underactuated balance robotic systems
- Built an external/internal convertible (EIC) form using the learned robotic model
- Model predictive control and feedback linearization were used for simultaneously tracking and balancing tasks
- Experimental test and demonstration by using a Furuta pendulum setup



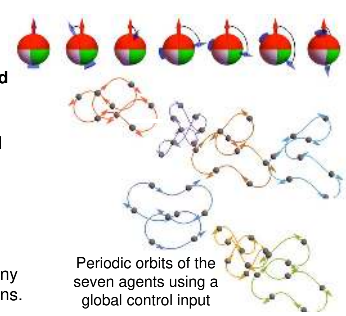
GP-based learning control flow structure for underactuated balance robots

11:00–12:15	TuAT1.6

3D Position Control for a Multi-Agent System of Self-Propelled Agents Steered by a Shared, Global Control Input

Li Huang, Julien Leclerc, and Aaron T. Becker
Electrical and Computer Engineering, University of Houston, USA

- Strategies for 3D multi-agent position control using a **shared control input** and **self-propelled** agents.
- Only control inputs allowed are rotation commands that rotate all agents by the **same rotation matrix**.
- In 3D up to three agents may be steered to arbitrary positions.
- With perturbations, the shared control is capable of bringing many agents ($n > 4$) to arbitrary locations.



Periodic orbits of the seven agents using a global control input

Human-Robot Interaction II - 2.1.25

Chair
Co-Chair

11:00–12:15	TuAT1.1

Working with Walt: How a Cobot Was Developed and Inserted on an Auto Assembly Line

Ilias El Makrini, Bram Vanderborght
Robotics and Multibody Mechanics, Vrije Universiteit Brussel, Belgium
Shirley A. Elprama, Charlotte Jewell, An Jacobs
imec – SMIT – Vrije Universiteit Brussel, Brussels, Belgium
Jan Van den Bergh
Expertise Centre for Digital Media, Flanders Make – tUL – UHasselt, Belgium

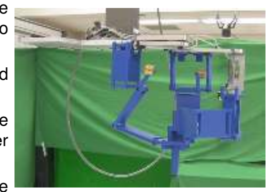
- Claxon project: investigation of human-robot interaction (HRI) in a real industrial context
- Realization of proof-of-concepts for multimodal HRI
- Implementation of a cobot in the car manufacturing plant of Audi Brussels
- Social experiments were carried with factory workers to study the social acceptance of cobots as well as the interactions between the human and the robot.

11:00–12:15	TuAT1.2

Intuitive Physical Human-Robot Interaction Using a Passive Parallel Mechanism

Nicolas Badeau, Clément Gosselin, Simon Foucault
Laboratoire de Robotique, Université Laval, Canada
Muhammad E. Abdallah
General Motors R&D, USA

- A novel mini Low-Impedance Passive mechanism is proposed to control a macro High-Impedance Active Gantry System.
- The mini mechanism is statically balanced in order to return to its neutral position.
- The mini-macro combination yields a large bandwidth and payload capability, together with precision and flexibility.
- Experimental results demonstrate the intuitiveness of such an architecture compared to admittance control.



11:00–12:15	TuAT1.3

SMErobotics: Smart Robots for Flexible Manufacturing

A. Perzylo, M. Rickert, B. Kahl, N. Somani, C. Lehmann, A. Kuss, S. Profanter, A. B. Beck, M. Haage, M. R. Hansen, M. T. Nibe, M. A. Roa, O. Sörnmo, S. G. Robertz, U. Thomas, G. Veiga, E. A. Topp, I. Kessler, M. Danzer

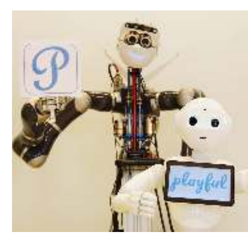
- Identification of challenges for industrial robot uptake in manufacturing SMEs through studies among CEOs
- Development and integration of technologies to address identified challenges, e.g., knowledge integration, uncertainty-aware robot skills, assembly planning, and learning and adaption strategies
- Evaluations on eight real-world demonstrators from the application domains of welding, mechanical assembly, and woodworking

11:00–12:15	TuAT1.4

The Playful Software Platform
Reactive Programming for Orchestrating Robotic Behavior

Vincent Berenz
Max Planck Institute for Intelligent Systems
Stefan Schaal
Max Planck Institute for Intelligent Systems
and CLMC lab at the University of Southern California

- Social robots need to interact in a reactive way
- Playful allows to compose dynamic behaviors using a basic set of primitives
- The language is simple (5 keyword) yet results in coordinated higher level sensory motor coupling
- Videos and downloads: http://playful.is.tuebingen.mpg.de



11:00–12:15	TuAT1.5

Better Teaming Through Visual Cues:
How Projecting Imagery in a Workspace Can Improve Human-Robot Collaboration

Ramsundar Ganesan, Heather Ross, Yash Rathore and Heni Ben Amor
CIDSE, Arizona State University, USA

- Human-robot interaction with mixed-reality
- Visual cues are projected into space
- Context-aware projections using tracking
- Communication via novel, visual language
- Projection significantly improves fluency, rapport and safety during collaborative manufacturing tasks.

Visual cues are projected to the human user

11:00–12:15	TuAT1.6

A Lower-Back Robotic Exoskeleton: Industrial Handling Augmentation Used to Provide Spinal Support

Ting Zhang
Robotics and Microsystems Center, Soochow University, China
He (Helen) Huang
Department of Biomedical Engineering, North Carolina State University, USA

- Development of a a high-power, passively mechanical and software-controlled actively compliant lower-back augmentation exoskeleton with four degrees of freedom that can assist in industrial material handling tasks.
- Each actuation unit includes a modular and compact SEA with clutch. It provides mechanical compliance at the interface between the exoskeleton and the user to ensure user safety.

Lower-back robotic exoskeleton

Multi-Robot Systems V - 2.1.26

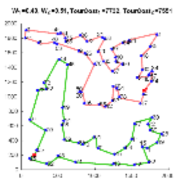
Chair
Co-Chair

11:00–12:15	TuAT1.1

A Heuristic for Task Allocation and Routing of Heterogeneous Robots while Minimizing Maximum Travel Cost

Jungyun Bae, Jungho Lee and Woojin Chung
Department of Mechanical Engineering, Korea University, Republic of Korea

- The proposed heuristic solves a min-max Traveling Salesman Problem for two structurally heterogeneous mobile robots.
- The mathematical formulations of Linear Program relaxation and its dual problem are presented.
- A primal-dual technique has been applied for task allocation.
- The implementation result shows the heuristic produces good approximate solutions within a short computation time.



Routes generated by the proposed heuristic for an instance with 80 targets

11:00–12:15	TuAT1.2

Solving Methods for Multi-Robot Missions Planning with Energy Capacity Consideration

Muhammad Khakim Habibi, Christophe Grand, Charles Lesire, Cédric Pralet
ONERA/DTIS, Université de Toulouse, F-31055 Toulouse, France

- An MRTA problem considering vehicles' capabilities and energy is formalized.
- The Branch-&-Cut Algorithm, the Multiphase heuristic and the Two-Phase Iterative Heuristic are implemented to solve the problem.
- The Two-Phase Iterative Heuristic outperforms the others in terms of the quality of the solutions and the CPU time.

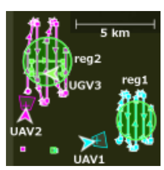
A solution obtained by the Two-Phase iterative heuristic in a few seconds

11:00–12:15	TuAT1.3

Salty – A Domain Specific Language for GR(1) Specifications and Designs

Trevor Elliott
Groq, Inc., USA
Mohammed Alshiekh and Ufuk Topcu
Aerospace Engineering, University of Texas at Austin, USA
Laura R. Humphrey
Aerospace Systems Directorate, Air Force Research Laboratory, USA
Lee Pike
Unaffiliated, USA

- DSL that makes GR(1) specifications easier to write and debug
- Translates designs synthesized from GR(1) specifications to software implementations
- Demonstrated on application with simulated unmanned air vehicles

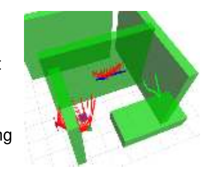


11:00–12:15	TuAT1.4

Persistent Multi-Robot Mapping in an Uncertain Environment

Derek Mitchell and Nathan Michael
Robotics Institute, Carnegie Mellon University, USA

- Energy-constrained robots are deployed to constantly observe an uncertain environment
- Environment model constantly degrades contributions of old measurements
- Plans are persistently extended using a sliding window horizon to compensate
- Result is a system able to steadily improve model accuracy with an energy-constrained team



Robots exploring a simulated environment

11:00–12:15	TuAT1.5

A Fog Robotics Approach for Deep Robot Learning: Application to Object Recognition and Grasp Planning in Surface Decluttering

Ajay K. Tanwani, Nitesh Mor, John Kubiatowicz, Joseph E. Gonzalez, Ken Goldberg
University of California, Berkeley

- Fog Robotics for deep robot learning balances storage, compute and networking resources between Cloud and Edge
- Surface decluttering with domain invariant object recognition and grasp planning by sim-to-real transfer for a mobile robot
- Deploying models on Edge reduces the inference time by 4x
- Toyota HSR grasps 185 objects from 213 grasp attempts

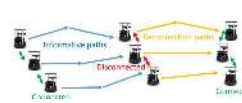
Surface Decluttering with Fog Robotics

11:00–12:15	TuAT1.6

Multirobot Reconnection on Graphs: Problem, Complexity, and Algorithms

Jacopo Banfi, Francesco Amigoni
Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Italy
Nicola Basilico
Dipartimento di Informatica, Università degli Studi di Milano, Italy

- We consider the problem of computing minimum-cost joint reconnection paths in a multirobot information-gathering mission
- We provide a graph-based formalization of the problem
- We prove its NP-hardness and hardness of approximation
- We present and experimentally evaluate exact and heuristic algorithms



The planning scheme considered in this paper

Award Session IV

Chair *Oliver Brock, Technische Universität Berlin*
Co-Chair *Yiannis Aloimonos, University of Maryland*

11:00–11:12 TuAT2.1

Efficient Symbolic Reactive Synthesis for Finite-Horizon Tasks

Keliang He, Andrew Wells, Lydia E. Kavraki, Moshe Y. Vardi
Department of Computer Science, Rice University, USA

- Reactive synthesis to generate execution strategy for robots performing finite-horizon tasks under human interference
- Use binary decision diagrams for compact representation of the synthesis problem
- Reduce runtime and memory usage of the synthesis algorithm
- Case study of a pick-and-place domain exhibit orders-of-magnitude speed-ups over existing approaches

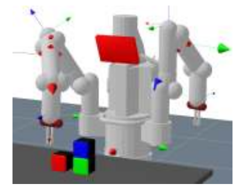
UR5 completing an arch using synthesized policy under human interference

11:12–11:24 TuAT2.2

Task and Motion Planning under Partial Observability: An Optimization-Based Approach

Camille Phiquepal and Marc Toussaint
Machine Learning & Robotic Lab, University of Stuttgart, Germany

- Optimization of Task and Motion Planning policies in a **POMDP** setting
- Policies are trees allowing the robot to react to different observations
- Motions are computed by solving a global optimization problem (trajectory-tree optimization)

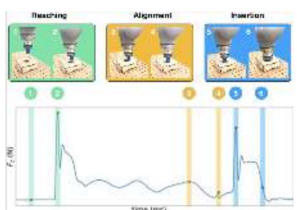


11:24–11:36 TuAT2.3

Making Sense of Vision and Touch :
Self-Supervised Learning of Multimodal Representations for Contact-Rich Tasks

Michelle A. Lee[1*], Yuke Zhu[1*], Krishnan Srinivasan[1], Parth Shah[1], Silvio Savarese[1], Li Fei-Fei[1], Animesh Garg[1,2] and Jeannette Bohg[1]
[1]Computer Science, Stanford University (USA) [2]Nvidia Research (USA)

- **Vision and touch** are complementary and concurrent in contact-rich manipulation.
- We learn a **fused representation** through **self-supervision.**
- This representation is the input to a **learned manipulation policy**.
- The policies are learned on a **real robot**.



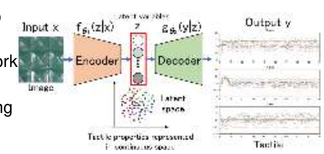
Images and force feedback for a peg insertion task

11:36–11:48 TuAT2.4

Deep Visuo-Tactile Learning: Estimation of Tactile Properties from Images

Kuniyuki Takahashi and Jethro Tan
Preferred Networks, Inc., Japan

- Estimation of the degree of tactile properties from images, called deep visuo-tactile learning
- A traditional encoder-decoder network with latent variables
- Continuous latent space representing tactile properties with degrees for various materials



11:48–12:00 TuAT2.5

Variational End-to-End Navigation and Localization

Alexander Amini[1], Guy Rosman[2], Sertac Karaman[3], Daniela Rus[1]
[1] Computer Science and Artificial Intelligence (CSAIL), MIT
[2] Toyota Research Institute (TRI)
[3] Laboratory for Information Decision Systems (LIDS), MIT

Objective:
- Learn control directly from raw sensor data, without any hand-engineered models or rules

New Results:
- Point-to-point navigational control using noisy GPS data
- Ability to reason about localization in the world using only raw visual perception

Impact: Enables deployment of end-to-end driving systems

Learning control (bottom) from raw perception (top)

Government Forum - Session I

Chair
Co-Chair

Lunch and Learn Keynote

Chair
Co-Chair

Lunch Break

Chair
Co-Chair

PODS: Tuesday Session II

Chair

Co-Chair

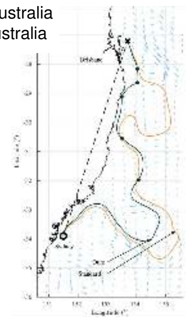
Marine Robotics II - 2.2.01

Chair
Co-Chair

13:30–14:45	TuBT1.1

Streamlines for Motion Planning in Underwater Currents

K. Y. Cadmus To[1], Ki Myung Brian Lee[1], Chanyeol Yoo[1], Stuart Anstee[2] and Robert Fitch[1]
[1] University of Technology Sydney, Australia
[2] DSTG, Department of Defence, Australia



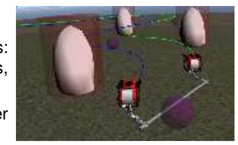
- Vehicle's constant velocity superimposed as uniform flow field onto underlying current
- Streamlines of resulting flow field used to examine reachability
- Velocity search to get from one point to another reduced to 1D from 2D
- With PRM*, efficient plans formed from Sydney to Brisbane (17 days instead of 22.8)

13:30–14:45	TuBT1.2

A Distributed Predictive Control Approach for Cooperative Manipulation of Multiple Underwater Vehicle Manipulator Systems

Shahab Heshmati-alamdari, George C. Karras and Kostas J. Kyriakopoulos
Control Systems Lab, Department of Mechanical Engineering, National Technical University of Athens, Greece

- Constrained workspace with static obstacles.
- Avoiding constraints and limitations such as: kinematic and representation singularities, joint limits and control input saturations.
- Imposes no restrictions on the underwater communication bandwidth
- The feedback relies on each UVMS's locally measurements and no explicit data is exchanged online among the robots
- Load sharing among the UVMSs according to their specific payload capabilities.



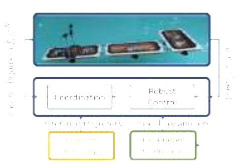
a cooperative control scheme for a team of UVMSs in a constrained workspace involving static obstacles

13:30–14:45	TuBT1.3

Coordinated Control of a Reconfigurable Multi-Vessel Platform: Robust Control Approach

Shinkyu Park[1,2], Erkan Kayacan[1,2], Carlo Ratti[1], and Daniela Rus[2]
[1]Senseable City Laboratory, Massachusetts Institute of Technology, USA
[2]CSAIL, Massachusetts Institute of Technology, USA

- We address the problem of designing a feedback control loop for a multi-vessel platform.
- We propose a coordinated robust control scheme that attains robust stability in the presence of disturbances.
- Through experiments, we validate that the control scheme achieves accurate trajectory tracking performance and bounded tracking-error-to-disturbance ratio.



Coordinated Robust Controller for a Multi-vessel platform

13:30–14:45	TuBT1.4

Ambient light based depth control of underwater robotic unit aMussel

Goran Vasiljevic, Barbara Arbanas, Stjepan Bogdan
Laboratory for Robotics and Intelligent Control Systems, University of Zagreb, Croatia

- **Depth control** of one degree of freedom (1DOF) underwater robotic platform aMussel, based on the measurements from pressure and ambient light sensors
- In a case of pressure sensor breakdown, a backup solution is to **communicate reference** of the ambient light from functioning aMussels using **acoustic communication**
- Tested in simulation and experiments in the pool

Heterogeneous multi-robot system of subCULTron project

13:30–14:45	TuBT1.5

A Unified Closed-Loop Motion Planning Approach for an I-AUV in Cluttered Environment with Localization Uncertainty

Huan Yu, Wenjie Lu and Dikai Liu
Centre for Autonomous Systems, University of Technology Sydney, Australia

- Proposed a unified I-AUV motion planning approach
- Fast I-AUV initial trajectories search method based on RRT-connect and NSS controller
- LQG and Information filter based control policy search for localization uncertainty minimization
- 9-DOF I-AUV motion planning simulations in cluttered scenarios

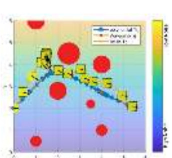


Figure 1. I-AUV trajectory

Marine Robotics III - 2.2.02

Chair
Co-Chair

13:30–14:45	TuBT1.1

A bio-robotic remora disc with attachment and detachment capabilities for reversible underwater hitchhiking

Siqi Wang[1], Lei Li[1], Yufeng Chen[2], Yueping Wang[1], Wenguang Sun[1], Junfei Xiao[1], Dylan Wainwright[3], Tianmiao Wang[1], Robert J. Wood[2], and Li Wen[1*]

[1] School of Mechanical Engineering and Automation, Beihang University, China.
[2] John A. Paulson School of Engineering and Applied Sciences and the Wyss Institute for Biologically Inspired Engineering, Harvard University, USA
[3]Museum of Comparative Zoology, Harvard University, USA.

- We found that remoras detach by curling up the anterior lip of their suction discs
- We fabricated a multi-material biomimetic disc that is capable of both attachment and detachment
- Preloads and angles of lamellae have important effects on attachment and detachment
- We demonstrated the underwater hitchhiking behavior of the biomimetic disc using an integrated ROV

13:30–14:45	TuBT1.2

Robot Communication Via Motion: Closing the Underwater Human-Robot Interaction Loop

Michael Fulton, Chelsey Edge and Junaed Satter
Computer Science, University of Minnesota, USA

- Proposed a system of “body language” for an AUV to be able to communicate with a diver.
- Developed a set of fifteen kinemes (motions with meaning) in an Unreal Engine simulation.
- Tested these kinemes against a system of colored LEDs in a 24-person pilot study.
- Study consisted of three groups which were given differing levels of education.
- Significant advantages of kinemes measured in communication accuracy at all education levels.

Unreal Engine simulation of the Aqua AUV

13:30–14:45	TuBT1.3

Three-Dimensionally Maneuverable Robotic Fish Enabled by Servo Motor and Water Electrolyser

Wenyu Zuo, Alicia Keow, and Zheng Chen
Mechanical Engineering, University of Houston, USA

- Novel design to achieve vertical maneuvering by applying IPMC electrolyser.
- Concise dynamic model describes the two-dimension and vertical motion.
- Comprehensive experiments exhibit the fish’s performance and validate the model.

3D Maneuverable Robotic Fish

13:30–14:45	TuBT1.4

A Multimodal Aerial Underwater Vehicle with Extended Endurance and Capabilities

Di Lu, Chengke Xiong, Zheng Zeng, and Lian Lian
SO, SJTU, China
SKLOE, SJTU, China

- A hybrid vehicle capable of level flight, hover, and underwater glide is proposed.
- A full dynamic model synthesizing the aero dynamics and underwater dynamics is obtained.
- Direct expressions of the critical design parameters of the vehicle are provided elaborately.
- Multimodal performance and multi-domain locomotion of the proposed vehicle are verified numerically and experimentally.

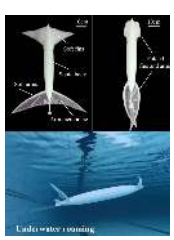
NEZHA, a proof-of-concept prototype of the multimodal hybrid aerial underwater vehicle

13:30–14:45	TuBT1.5

Design and Experiments of a Squid-like Aquatic-aerial Vehicle with Soft Morphing Fins and Arms

Taogang Hou, Xingbang Yang, Haohong Su, Buhui Jiang
Mechanical Engineering,
Beihang Uni., China

- Bionic squid-like aerial-aquatic vehicle that can shuttle between water and air.
- Novel soft morphing fins and arms help to better realize multi-locomotion by morphology trade-off.
- Soft fins and arms in spread state can provide 10 N more lift force in air.
- Soft fins and arms in folding state can reduce up to 3 N drag force underwater.



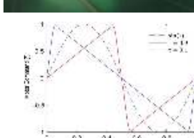
Squid-like robot with soft Morphing Fins and Arms

13:30–14:45	TuBT1.6

Nonlinear Orientation Controller for a Compliant Robotic Fish Based on Asymmetric Actuation

Christian Meurer and Maarja Kruusmaa
Department of Computer Systems, Tallinn University of Technology, Estonia
Ashutosh Simha and Ülle Kotta
Department of Software Science, Tallinn University of Technology, Estonia

- Orientation control of compliant underactuated robotic fish is challenging
- We propose a novel approach based on **asymmetric tail actuation** and a **nonlinear PD controller**
- Proposed control scheme is validated through field trials with the FILOSE robot
- Results show significant improvements compared to the standard approach



Visual Odometry II - 2.2.03

Chair
Co-Chair

13:30–14:45	TuBT1.1

Project AutoVision: Localization and 3D Scene Perception for an Autonomous Vehicle with a Multi-Camera System

Lionel Heng[1], Benjamin Choi[1], Zhaopeng Cui[2], Marcel Geppert[2], Sixing Hu[3], Benson Kuan[1], Peidong Liu[2], Rang Nguyen[3], Ye Chuan Yeo[1], Andreas Geiger[4], Gim Hee Lee[3], Marc Pollefeys[2,5], and Torsten Sattler[6]

[1]DSO National Laboratories, [2]ETH Zurich, [3]National University of Singapore, [4]MPI-IS and University of Tübingen, [5]Microsoft Switzerland, [6]Chalmers University of Technology

- Our paper describes calibration, localization and 3D scene perception for a self-driving vehicle with a multi-fisheye-camera system.
- GNSS-less localization leverages either a 3D sparse map or satellite imagery.
- Depth images are obtained via plane-sweeping stereo and fused into a TSDF volume from which a 3D map is obtained.
- Dynamic object detection is used to prevent trails of artefacts left behind by moving objects in the 3D map.

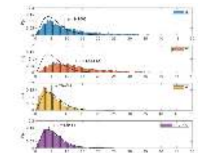
The sensor suite on the AutoVision vehicle platform.

13:30–14:45	TuBT1.2

Improving the Robustness of Visual-Inertial Extended Kalman Filtering

James Jackson, Tim McLain
Mechanical Engineering, Brigham Young University, USA
Jerel Nielsen, Randal Beard
ElectricalEngineering, Brigham Young University, USA

- We took state-of-the-art VI-EKF Filtering and added:
- Linear drag dynamics
- Partial Update
- Keyframe Reset
- Results in increased robustness



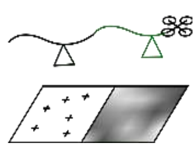
RMSE of monte carlo simulation

13:30–14:45	TuBT1.3

Towards Fully Dense Direct Filter-Based Monocular Visual-Inertial Odometry

Alexander Hardt-Stremayr and Stephan Weiss
Smart Systems Technologies, University of Klagenfurt, Austria

- Visual-Inertial Odometry in low-gradient environment
- EKF-based tightly coupled simultaneous single-step depth and 6DoF pose estimation
- Complexity reduction, speedup for near-realtime functionality



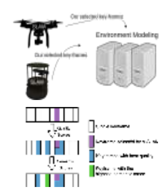
Visual-Inertial Odometry feasible in feature-less areas

13:30–14:45	TuBT1.4

Enhancing V-SLAM Keyframe Selection with an Efficient ConvNet for Semantic Analysis

I. Alonso, L. Riazuelo and Ana C. Murillo
DIIS – I3A, University of Zaragoza

- We propose a **novel VSLAM keyframe selection** evaluated in challenging drone imagery.
- It includes **relevant semantic information** for posterior recognition tasks.
- It **does not penalize VSLAM** place recognition or time restrictions.
- A key ingredient is our novel CNN **MiniNet** for quick image filtering on CPU.



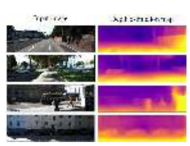
Semantic based keyframe selection

13:30–14:45	TuBT1.5

Unsupervised Learning of Monocular Depth and Ego-Motion Using Multiple Masks

Guangming Wang, Hesheng Wang, Yiling Liu and Weidong Chen
Department of Automation, Shanghai Jiao Tong University, China

- The pixel mismatch problem in the process of image reconstruction is considered.
- The overlap mask and blank mask are designed to solve most of the pixel mismatch.
- Repeated masking is proposed to solve the pixel mismatch problem further.
- The improvement of depth and ego-motion is demonstrated on KITTI dataset.



Unsupervised depth estimation examples

13:30–14:45	TuBT1.6

Experimental Comparison of Visual-Aided Odometry Methods for Rail Vehicles

Florian Tschopp[1], Thomas Schneider[1], Andrew W. Palmer[2], Navid Nourani-Vatani[2], Cesar Cadena[1], Roland Siegwart[1], and Juan Nieto[1]
[1]Autonomous Systems Lab, ETH Zürich, Switzerland
[1]Siemens Mobility, Germany

- Current rail localization is based on infrastructure-side Balises (beacons).
- Precise and reliable pose estimation using redundant sensors can boost infrastructure usage efficiency.
- Stereo visual-inertial motion estimation has a great potential to provide precise motion estimation.
- Challenging scenarios can result from high speeds, visual aliasing and challenging lighting conditions.

Figure 1: Custom sensor setup for evaluating visual-aided odometry for rail applications.

Space Robotics II - 2.2.04

Chair
Co-Chair

13:30–14:45	TuBT1.1

Characterizing the Effects of Reduced Gravity on Rover Wheel-Soil Interactions

Parna Niksirat, Krzysztof Skonieczny, and Amir Nassiraei
Department of Electrical and Computer Engineering,
Concordia University, Canada

- Rover-soil visualization technique produced rich datasets of reduced gravity wheel-terrain interaction (Martian-g, Lunar-g, and Earth-g)
- Results have implications regarding using reduced-mass rover on Earth to assess full-mass rover in reduced-gravity
- With wheel normal load held equal between experiments, higher soil mobilization observed as gravity decreases
- Deterioration in soil strength at lower gravities undermines rover mobility by reducing the net traction

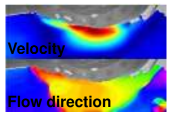


Fig1. Visualization of soil flow velocity magnitude and direction

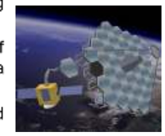
13:30–14:45	TuBT1.2

Adaptive H_∞ Controller for Precise Manoeuvring of a Space Robot

Asma Seddaoui and Chakravarthini M. Saaj
Department of Electrical and Electronic Engineering, University of Surrey, Guildford, United Kingdom
Steve Eckersley
Surrey Satellite Technology Limited, Guildford, United Kingdom

- The Controlled-Floating Space Robot (CFSR), that dovetails the merits of free-flying and free-floating space robots, is presented in this paper
- Small and precise close-proximity manoeuvres of CFSR are required during an assembly mission of a space modular telescope as illustrated in the figure
- A controller capable of producing a small and precise control effort is necessary for such missions

Novelty: Development of a new adaptive H_∞ controller to overcome the limitations of the conventional H_∞ controller



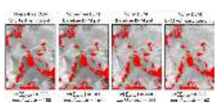
Telescope assembly using CFSR

13:30–14:45	TuBT1.3

Belief Space Planning for Reducing Terrain Relative Localization Uncertainty in Noisy Elevation Maps

Eugene Fang and William “Red” Whittaker
Robotics Institute, Carnegie Mellon University, USA
Michael Furlong
NASA Ames Research Center, USA

- Terrain relative navigation is limited by the presence of terrain features and quality of orbital data
- This work presents the application of belief space planning for terrain relative navigation
- Additionally, this work introduces a novel method for increasing route robustness to noisy elevation maps



13:30–14:45	TuBT1.4

Soil Displacement Terramechanics for Wheel-Based Trenching with a Planetary Rover

Catherine Pavlov and Aaron M. Johnson
Mechanical Engineering, Carnegie Mellon University, USA

- The wheels of planetary exploration rovers can be used to modify terrain
- By spinning a wheel while driving in soft soil, a rover can generate varied trench geometries
- This paper outlines and demonstrates a closed-form model used to predict the shape of such a trench
- The model is then used to draw conclusions on how to trench without getting stuck

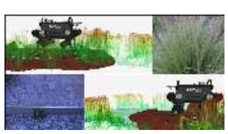
A trench dug by a rover wheel, with profile traced in red

13:30–14:45	TuBT1.5

Support Surface Estimation for Legged Robots

Timon Homberger[1], Lorenz Wellhausen[1], Péter Fankhauser[2], Marco Hutter[1]
[1] Robotics Systems Lab, ETH Zürich, Switzerland; [2] ANYbotics AG, Zürich, Switzerland;

- Enhanced robot navigation in environments with obstructed visibility of the ground
- Gaussian Process Regression to generate surface estimate from discrete haptic measurements
- Fusion of proprioceptive terrain measurements with exteroceptive elevation map data
- Adaptive weighting of proprioceptive and exteroceptive information



Support surface estimation for navigation with the ANYmal quadruped

13:30–14:45	TuBT1.6

Experimental Evaluation of Teleoperation Interfaces for Cutting of Satellite Insulation

Will Pryor[*,1], Balazs P. Vagvolgyi[*,1], William J. Gallagher[2], Anton Deguet[1], Simon Leonard[1], Louis L. Whitcomb[1], and Peter Kazanzides[1]
[*] These authors contributed equally to the work.
[1] Johns Hopkins University, Baltimore, MD, USA
[2] SAIC (NASA Goddard Space Flight Center), Lanham, MD, USA

- Teleoperation to cut satellite insulation on orbit is challenging due to limited visibility and time delay
- Experiments performed with NASA robot operators to evaluate three teleoperation interfaces:
  - Conventional visualization and control (KB+CAM)
  - Augmented Virtuality with conventional control (KB+AV)
  - Augmented Virtuality with direct teleoperation using da Vinci master console (dV+AV)
- Results indicate that KB+AV is best option
  - Easier and less frustrating (NASA TLX survey)
  - 99.7% successful cut compared to 95.3% (KB+CAM) and 91.2% (dV+AV)

Augmented Virtuality visualization showing projected tool camera image, guidance indicators, and user interface icons

Deep Visual Learning I - 2.2.05

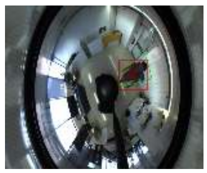
Chair
Co-Chair

13:30–14:45	TuBT1.1

OmniDRL: Robust Pedestrian Detection using Deep Reinforcement Learning on Omnidirectional Cameras

G. Dias Pais[1], Jacinto C. Nascimento[1], and Pedro Miraldo[2]
[1]ISR, Instituto Superior Técnico, Portugal
[2]KTH Royal Institute of Technology, Sweden

- ***Goal:*** Pedestrian Detection using an omnidirectional camera system;
- ***New Dataset:*** 921 Omnidirectional Images, labeled with the omnidirectional setting;
- ***Proposed Method:*** The use of a Deep RL agent, in a world environment, extracting the pedestrian's 3D position. The bounding boxes consider the underlying distortion;
- ***Results:*** Surpasses the perspective approaches on distorted images.

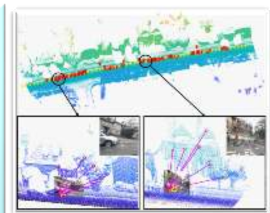


13:30–14:45	TuBT1.2

2D3D-MatchNet: Learning to Match Keypoints Across 2D Image and 3D Point Cloud

Mengdan Feng, Sixing Hu, Marcelo Ang and Gim Hee Lee
Department of Mechanical Engineering, National University of Singapore, Singapore
Department of Computer Science, National University of Singapore, Singapore

- Problem: Existing visual localization methods match images and PCL through pre-stored SIFT features.
- Motivation: How to match 2D images and 3D PCL directly for localization?
- Proposed method: Learn the similarity between 2D images and 3D PCL through triplet network directly.
- Results: Localization with average translation and rotation errors of 1.41m and 6.40 degree



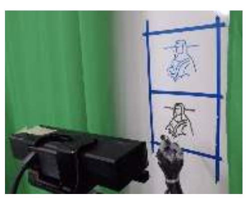
A visualization of the localization results

13:30–14:45	TuBT1.3

Teaching Robots To Draw

Atsunobu Kotani and Stefanie Tellex
Department of Computer Science, Brown University, USA

- Given an image of handwritten characters as input, our model infers a drawing policy
- We trained our network to write from a dataset of demonstrations
- Our model can reproduce any stroke-based drawing



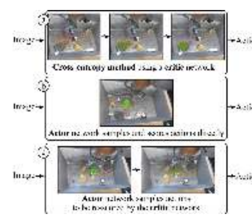
Robot drawing Mona Lisa
(Top: original, Bottom: reproduced)

13:30–14:45	TuBT1.4

Learning Probabilistic Multi-Modal Actor Models for Vision-Based Robotic Grasping

Mengyuan Yan
Electrical Engineering, Stanford University, USA
Adrian Li, Mrinal Kalakrishnan, Peter Pastor
X, the moonshot factory, USA

- A neural density model that directly generates distributions of promising robot actions.
- Flexible mixture of normalizing flow model, capable of modeling multi-modal action distribution.
- No sample-evaluate-rank process.
- Fast inference in higher dimensional action space.

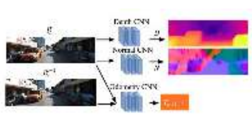


13:30–14:45	TuBT1.5

Self-supervised Learning for Single View Depth and Surface Normal Estimation

Huangying Zhan, Chamara Saroj Weerasekera, Ravi Garg, Ian Reid
School of Computer Science, University of Adelaide, Australia
Australian Centre for Robotic Vision

- Self-supervised framework for learning single-view depths & surface normals with depth-normal consistency
- Better regularization on depth using depth-normal consistency over smooth depth prior
- Depth and normal consistency over time
- State-of-the-art surface normal prediction on KITTI benchmark



Test-time setup:
1) Single-view depth and surface normal network
2) Two-view relative pose network

13:30–14:45	TuBT1.6

Learning to Drive from Simulation without Real World Labels

Alex Bewley, Jessica Rigley, Yuxuan Liu
Jeffrey Hawke, Richard Shen, Vinh-Dieu Lam and, Alex Kendall
Wayve, Cambridge, UK

- The first example of an end-to-end driving policy transferred from a simulation with control labels to an unlabelled real-world domain.
- Able to learn manoeuvres in states beyond the common driving distribution of real-world imitation learning.
- Closed-loop driving evaluated on over 3km of rural driving without intervention and further demonstrated with successful driving in a real urban environment.

Biological Cell Manipulation - 2.2.06

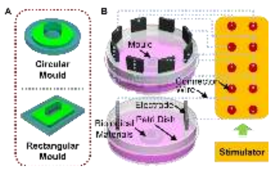
Chair
Co-Chair

13:30–14:45	TuBT1.1

Fabrication and Characterization of Muscle Rings Using Circular Mould and Rotary Electrical Stimulation for Bio-Syncretic Robots

Chuang Zhang, Jialin Shi, Wenxue Wang*, Yuechao Wang, and Lianqing Liu*
State Key Laboratory of Robotics, Shenyang Institute of Automation, China.
Ning Xi
University of Hong Kong Pokfulam, Hong Kong.

- Circular mould was proposed for culture of C2C12 tissues for bio-syncretic robots;
- Rotary electrical stimulation was proposed to build high-quality muscle rings;
- Contractility of muscle rings have been studied under different pulses, for the control of bio-syncretic robots.



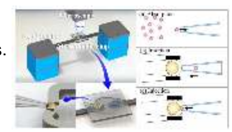
Equipment for culture and electrical stimulation of muscle rings.

13:30–14:45	TuBT1.2

Cell Injection Microrobot Development and Evaluation in Microfluidic Chip

Feng Lin, Dixiao Chen, Zhou Qiang, Song Bin, ZhangWei
School of Mechanical Engineering & Automation, Beihang University, China
Beijing Advanced Innovation Center for Biomedical Engineering, Beihang University, China

- Microrobots within a microfluidic chip aimed for cell surgery.
- Microrobots actuated by permanent magnets.
- The microrobot provides three degrees of freedom and generates micronewton forces.
- The microrobot can be used for injection of cell nucleus with a nozzle.

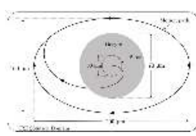

Microrobot system and process to inject cell nucleus into recipient cell

13:30–14:45	TuBT1.3

Orienting Oocytes using Vibrations for In-Vitro Fertilization Procedures

Daniel Meyer, Hossein V. Alizadeh, Martin Luis Perez Colon, Lisa Su and David B. Camarillo
Bioengineering/Mechanical Engineering, Stanford University, USA
Barry Behr
Reproductive Endocrinology and Infertility, Stanford University, USA

- Current method of oocyte manipulation is time consuming and inconsistent
- We use vibrations applied to the pipette holder to rotate oocytes around the pipette tip
- Oocytes are rotated until the polar body can be detected in plane using computer vision
- We present simulation and experimental results to validate the system

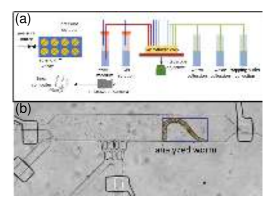

Schematic of a multi-physics simulation model

13:30–14:45	TuBT1.4

Vision-Based Automated Sorting of *C. Elegans* on a Microfluidic Device

Xianke Dong, Pengfei Song, and Xinyu Liu
Dept. of Mechanical and Industrial Eng., University of Toronto, Canada

- A vision-based microfluidic system for automated, high-speed sorting of the nematode worm *C. elegans*
- A microfluidic device with computer-controlled micro-values for sequential loading, trapping, imaging, and sorting of single worms
- Image processing algorithms for real-time worm size measurement and sorting state monitoring
- A sorting speed of 10.4 worms/min (5.8 s/worm) with an operation success rate of 90.3% (n = 319)



(a) Worm sorting system setup.
(b) Snapshot of real-time worm size measurement.

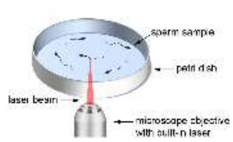
13:30–14:45	TuBT1.5

Automated Laser Ablation of Motile Sperm for Immobilization

Zhuoran Zhang, Changsheng Dai, Xian Wang, Changhai Ru, Khaled Abdalla, Sahar Jahangiri, Clifford Librach, Keith Jarvi, and Yu Sun

Dept. of Mechanical & Industrial Engineering, University of Toronto, Canada
CReATe Fertility Center, Canada

- Visual servo control with a feedforward compensator for accurate sperm positioning.
- 100% success rate achieved via tuning laser energy (n=900 sperm).
- Five times faster than manual operation.
- No damage to sperm DNA, safe for clinical robotic cell surgery applications.

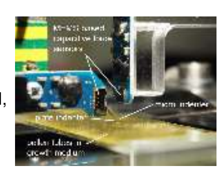


13:30–14:45	TuBT1.6

A Microrobotic System for Simultaneous Measurement of Turgor Pressure and Cell-Wall Elasticity of Individual Growing Plant Cells

Jan T. Burri, Nino F. Läubli and Bradley J. Nelson
Department of Mechanical and Process Engineering, ETH Zürich, Switzerland
Hannes Vogler, Gautam Munglani, Ueli Grossniklaus
Department of Plant and Microbial Biology, University of Zürich, Switzerland

- Plant cell growth requires a precise interplay between turgor pressure and cell-wall elasticity.
- The biomechanics vastly differ from cell to cell, so cells have to be individually characterized.
- The presented microrobotic dual-indentation system separately measures turgor pressure and cell-wall elasticity.
- The system combines cell compression and micro-indentation to non-invasively probe individual growing cells.


The microrobotic dual-indentation system

Human Detection and Tracking - 2.2.07

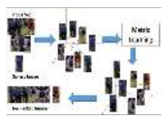
Chair
Co-Chair

13:30–14:45 TuBT1.1

Asymmetric Local Metric Learning with PSD Constraint for Person Re-identification

Zhijie Wen and MingYang Sun and Shihui Ying and Yaxin Peng
Department of Mathematics, Shanghai University, China
Ying Li
School of Computer Engineering and Sciences, Shanghai University, China

- Local metric learning method to solve the Person Re-identification problem
- Sparse learning methods to learn a set of anchor points
- Use local metrics to define a proximal operator to solve the solution



Metric learning for person re-identification

13:30–14:45 TuBT1.2

A Fast and Robust 3D Person Detector and Posture Estimator for Mobile Robotic Applications

Benjamin Lewandowski, Jonathan Liebner, Tim Wengefeld, Steffen Müller and Horst-Michael Gross
Neuroinformatics and Cognitive Robotic Lab, Ilmenau University of Technology, Germany

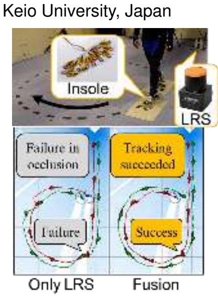
- Person detection in 3D point clouds in a supermarket environment on a mobile robot
- Detections up to ten meters and above on standard consumer CPU
- Posture estimation allows differentiation between standing and squatting
- Comparison to other detectors

13:30–14:45 TuBT1.3

Kinetic Gait Analysis System Based on Multisensor Fusion of Laser Range Sensor and Instrumented Insoles

Ryo Eguchi and Ayanori Yorozu
Graduate School of Sience and Technology, Keio University, Japan
Masaki Takahashi
Department of System Design Engineering, Keio University, Japan

- This system fuses a laser range sensor (LRS) and insoles with 15 force sensing resistors.
- The LRS detects leg positions and the insoles identifies their states (stance / swing phases).
- The system tracks legs using the Kalman filtering and data association with phase-based model switching.
- The proposed fusion algorithm enhanced tracking performance during walking along circles including overlaps and occlusions.

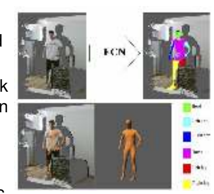


13:30–14:45 TuBT1.4

Part Segmentation for Highly Accurate Deformable Tracking in Occlusions via Fully Convolutional Neural Networks

Weilin Wan, Aaron Walsman and Dieter Fox
Paul G. Allen School, University of Washington, USA

- We propose a method based on fully convolutional neural networks to filter observed point clouds and track objects in occlusions.
- We develop an optimized Fast-FCN network architecture which allows us maintain interactive frame rates.
- We show that this model can be trained with a limited number of examples and almost no manual labelling by using an existing geometric tracker and data augmentation.

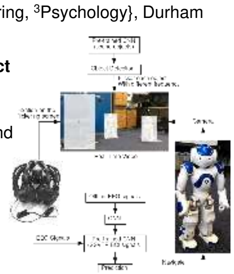


13:30–14:45 TuBT1.5

Using Variable Natural Environment BCI Stimuli for Real-time Humanoid Robot Navigation

Nik Khadijah Nik Aznan[1,2], Jason Connolly[3], Noura Al Moubayed[1], and Toby Breckon[1,2]
Department of {[1]Computer Science, [2]Engineering, [3]Psychology}, Durham University, UK

- **Variable position and size stimuli** using **object detection pixel region** within the live video stream from a **humanoid robot**.
- **CNN architecture** for scene object detection and dry-EEG bio-signal decoding**.**
- **Offline dry-EEG enabled SSVEP** BCI signal decoding achieving **mean accuracy of 84%**.
- **Real-time BCI teleoperation** of a humanoid robot with a **mean accuracy of 85%** and **ITR of 15.2 bits per minute** (bpm).



http://bit.ly/variableSSVEP

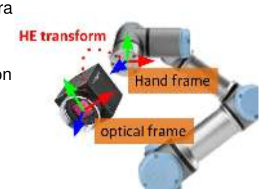
Durham University

13:30–14:45 TuBT1.6

General Hand-Eye Calibration Based on Reprojection Error Minimization

Kenji Koide and Emanuele Menegatti
Department of Information Engineering, University of Padova, Italy

- General hand-eye calibration technique, which can be applied to different camera models, is proposed.
- The technique estimates the hand-eye transformation such that the reprojection error is minimized.
- The pose graph optimization-based implementation realizes robust and efficient estimation.
- It has been validated on real systems equipped with RGB and X-ray cameras.



Visual Localization II - 2.2.08

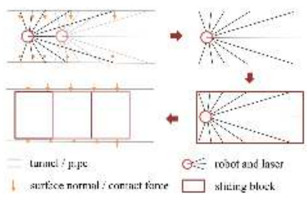
Chair
Co-Chair

13:30–14:45	TuBT1.1

Estimating the Localizability in Tunnel-like Environments using LiDAR and UWB

Weikun Zhen and Sebastian Scherer
Robotics Institute, Carnegie Mellon University, USA

- We propose a mathematical model to estimate ***localizability*** in tunnel-like environments
- The model naturally has an analogy to the ***frictionless force-closure***.
- Ultra-Wideband (***UWB***) ranging radio and ***LiDAR*** are used for localizability analysis.
- A probabilistic sensor fusion method is presented to achieve robust localization in real tunnels.



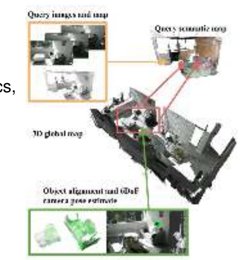
An analogy between navigation and a sliding block, indicating virtual wrenches

13:30–14:45	TuBT1.2

Global Localization with Object-Level Semantics and Topology

Yu Liu, Yvan Petillot, David Lane and Sen Wang
Edinburgh Centre for Robotics, Heriot-Watt University, UK

- A novel object-level localization pipeline for indoor environments
- Creatively integrates dense object semantics, 3D topology, scene matching and point alignment algorithms
- Robust place recognition under extreme illumination changes and incomplete query observations
- 6-DoF localization with centimeter-level precision

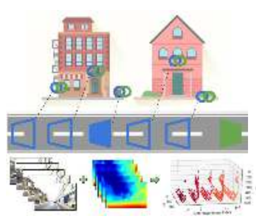


13:30–14:45	TuBT1.3

Look No Deeper: Recognizing Places from Opposing Viewpoints under Varying Scene Appearance using Single-View Depth Estimation

Sourav Garg[1], Madhu Babu V[2], Thanuja Dharmasiri[3], Stephen Hausler[1], Niko Sünderhauf[1], Swagat Kumar[2], Tom Drummond[3], Michael Milford[1]
[1]ACRV, QUT, Australia [2]TCS, Bangalore, India [3]Monash University, Australia

- Depth- and temporal-aware visual place recognition for *opposing viewpoints.*
- *Sequence-to-single* frame matching.
- Reference keypoint sequence (blue), capturing only *close-range* keypoints, is matched against all the keypoints from a *single* query image (green).
- Enables parametric control of visual information to avoid perceptual aliasing, especially for the day-night and autumn-winter comparisons.



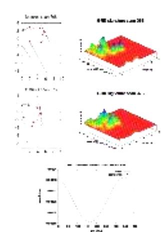
An on-demand local topometric representation of the reference image sequence

13:30–14:45	TuBT1.4

ICRA 2019
Geometric Relation Distribution for Place Recognition

Dario Lodi Rizzini, Francesco Galasso and Stefano Caselli
Dipartimento di Ingegneria e Architettura, University of Parma, Italy

- Novel signature for place recognition and loop closure with landmark maps
- *Geometric Relation Distribution* (GRD) represented by orthogonal function basis
- Rotation and translation invariant metric to compare GRD
- Effective place recognition assessed on benchmark datasets

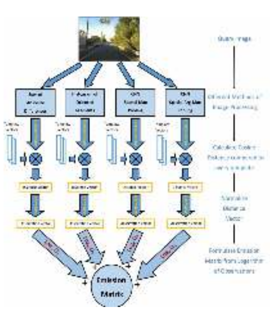


13:30–14:45	TuBT1.5

Multi-Process Fusion: Visual Place Recognition Using Multiple Image Processing Methods

Stephen Hausler, Adam Jacobson and Michael Milford
Queensland University of Technology, Australia

- We propose a method for combining multiple methods of image processing over a sequence of past images.
- A Hidden Markov Model and a dynamic sequence length are used to achieve reliable place recognition.
- We validate our algorithm on four datasets and compare our localization performance to NetVLAD and SeqSLAM.



13:30–14:45	TuBT1.6

Effective Visual Place Recognition Using Multi-Sequence Maps

Olga Vysotska and Cyrill Stachniss
Photogrammetry Department, University Of Bonn, Germany

- Sequence based **visual place recognition** approach that matches **multiple** image sequences.
- **Partially overlapping** image sequence trajectories with view-point, seasonal, and weather condition changes.
- Localization against **publicly available maps**, Google Street View.

Perception for Manipulation II - 2.2.09

Chair
Co-Chair

13:30–14:45	TuBT1.1

Exploiting Trademark Databases for Robotic Object Fetching

Joshua Song
School of ITEE, The University of Queensland, Australia
Hanna Kurniawati
Research School of CS, Australian National University, Australia

- Trademark databases contain large-scale data (Logos and their goods and services category)
- **RDSL** generates synthetic images using trademark databases, simple computer graphics techniques, and domain randomization
- CNN logo detectors trained with **only** RDSL generated images show promise for object fetching

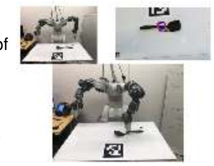
Robot fetches food for the user by identifying the Pringles logo

13:30–14:45	TuBT1.2

Object Detection Approach for Robot Grasp Detection

Hakan Karaoguz and Patric Jensfelt
EECS Division of Robotics Perception and Learning, KTH Royal Institute of Technology, Sweden

- We use an object detection based approach for detecting the optimal grasping locations of objects
- The approach is evaluated both on a benchmark dataset and a real robot
- Our approach performs on-par with the state of the art with a simpler neural network architecture and requires much smaller training data



Robot executing a grasp using the object detection approach

13:30–14:45	TuBT1.3

MetaGrasp: Data Efficient Grasping by Affordance Interpreter Network

Junhao Cai[1], Zhanpeng Zhang[2], Hui Cheng[1] and Jingcheng Su[1]
[1]Sun Yat-sen University, [2]SenseTime Group Limited

- A new data collecting system guided by the antipodal grasp rule in virtual environment.
- Without randomization and adaptation, model trained with only synthesized data performs well on real environments.
- The approach can generalize to different grasp scenarios.

The proposed grasp system pipeline.

13:30–14:45	TuBT1.4

Toward Fingertip Non-Contact Material Recognition and Near-Distance Ranging for Robotic Grasping

Cheng Fang, Di Wang, Dezhen Song and Jun Zou
Electrical & Computer Engineering and Computer Science & Engineering Departments, Texas A&M University, USA

- Feasibility study of non-contact acoustic and optical bi-modal distance & material sensor
- Pulse-echo ultrasound and optoacoustics for non-contact materials recognition
- Pulse-echo ultrasound ranging with maximum 0.23 mm axial deviation and 0.57 mm lateral resolution
- Feasible for robotic grasping based on primary experimental results

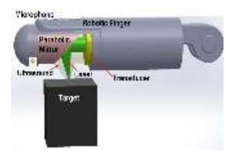


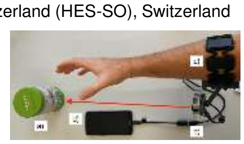
Figure. A diagram of bi-modal acoustic and optical distance & material sensor added to robotic finger.

13:30–14:45	TuBT1.5

Video-based Prediction of Hand-grasp Preshaping with Application to Prosthesis Control

Luke T Taverne[1,2], Matteo Cognolato[2,3], Tobias Bützer[2], Roger Gassert[2], Otmar Hilliges[1]
[1]Computer Science, ETH Zurich, Switzerland
[2]Health Sciences and Technology, ETH Zurich, Switzerland
[3]University of Applied Sciences Western Switzerland (HES-SO), Switzerland

- System designed to help prosthetic/orthotic devices automatically choose a grasp type for arbitrary object.
- Designed to require no additional motions or cognitive effort from the user, other than reaching for the object.
- Applies a deep recurrent model to RGB-D video data to generate a prediction at each frame.



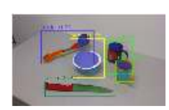
System schematic. As the user reaches for the desired object (a), the forearm-mounted RGB-D video camera (b) and Myo armband (c) stream data to a smartphone application (d).

13:30–14:45	TuBT1.6

Learning Affordance Segmentation for Real-world Robotic Manipulation via Synthetic Images

Fu-Jen Chu, Ruinian Xu and Patricio A. Vela
Institute for Robotics and Intelligent Machines, Georgia Institute of Technology, USA

- Proposed framework predicts affordances of object parts for robotic manipulation.
- The framework learns from annotated synthetic data and adapts to real-world domain without supervision.
- Domain invariant region proposals and task-level adaptation components are proposed.
- Real-world manipulations demonstrate the same performance as supervised methods.



Affordance detection with object priors learned from synthetic data unsupervisedly.

Human-Robot Interaction III - 2.2.10

Chair
Co-Chair

13:30–14:45 TuBT1.1

Reactive Walking Based on Upper-Body Manipulability: An application to Intention Detection and Reaction

Pouya Mohammadi and Jochen J. Steil
IRP, Technische Universität Braunschweig, Germany
Enrico Mingo Hoffman, Luca Muratore and Nikos G. Tsagarakis
Istituto Italiano di Tecnologia, Genova, Italy

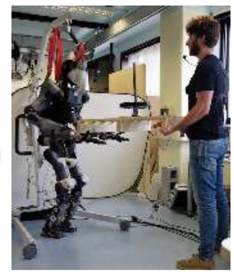
- The problem of hand-in-hand locomotion between human and humanoid is considered
- Human intentions are detected using a manipulability based measure
- Robot makes suitable step in reaction to human motions/intentions
- Method is evaluated on state of the art humanoid platform COMAN+

13:30–14:45 TuBT1.2

A Self-Modulated Impedance Multimodal Interaction Framework for Human-Robot Collaboration

Luca Muratore[1,2], Arturo Laurenzi[1], and Nikos G. Tsagarakis[1]
[1] *Advanced Robotics Department (ADVR), Istituto Italiano di Tecnologia, IT.*
[2] *School of Electrical and Electronic Engineering, University of Manchester, UK*

- A novel intrinsically adaptable multimodal (force, motion and verbal) interaction framework for human-robot collaboration (HRC)
- It leverages on an online self-tuning stiffness regulation principle
- It provides adaptation to interaction/payload forces and reject disturbances arising by unexpected interaction loads
- Validation in a high weight (10 Kg) carrying human-robot collaboration task using the humanoid COMAN+.



13:30–14:45 TuBT1.3

SMT-Based Control and Feedback for Social Navigation

Thais Campos, Adam Pacheck, Guy Hoffman, and Hadas Kress-Gazit
Mechanical and Aerospace Engineering, Cornell University, USA

- Synthesize online robot control that satisfies safety guarantees during robot-human social navigation
- Automatically generate human understandable feedback if constraints cannot be satisfied
- Demonstrate and compare with state-of-the-art in multiple simulated environments

13:30–14:45 TuBT1.4

Safe and Efficient High Dimensional Motion Planning in Space-Time with Time Parameterized Prediction

Shen Li and Julie A. Shah
Computer Science and Artificial Intelligence Intelligence Laboratory, Massachusetts Institute of Technology, USA

- Efficient geometric motion planner for dynamic obstacle avoidance.
- Configuration space reduction via path sampling and shortcutting.
- Time domain reduction via safe intervals.
- Lazy evaluation of the feasibility of graph nodes.
- Optimal search for a trajectory with minimal execution time within a short planning budget.

Waiting for the human to move out of the way is more efficient than a lengthy detour around.

13:30–14:45 TuBT1.5

Fast Online Segmentation of Activities from Partial Trajectories

Tariq Iqbal[1], Shen Li[1], Christopher Fourie[1], Bradley Hayes[2], and Julie A. Shah[1]
[1]Massachusetts Institute of Technology, USA
[2]University of Colorado Boulder, USA

- We present FOSAPT, an online activity segmentation algorithm capable of accurately identifying and labeling activity segments by processing just a part of the full activity trajectory.
- FOSAPT runs efficiently by modeling the activity transitions as an HMM and by using a particle filtering approach along with a concurrent search process to refine activity segments.
- FOSAPT demonstrates improved segmentation accuracy and can perform online only by processing a part of the full activity trajectory.

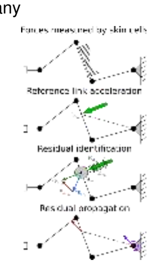
A collaborative robot providing parts to a worker at the appropriate time

13:30–14:45 TuBT1.6

Tactile-Based Whole-Body Compliance With Force Propagation for Mobile Manipulators

Quentin Leboutet, Emmanuel Dean-Leon, Florian Bergner and Gordon Cheng
Institute for Cognitive Systems, Technical University of Munich, Germany

- We propose a tactile-based method, for whole-body compliance implementation on mobile robots.
- The external forces applied to the robot are measured using a multimodal artificial skin.
- We formulate the compliance control law as a set of quadratic optimization problems (QP).
- The proposed method is easily tunable and robust to null-space interactions.



Medical Robotics VI - 2.2.11

Chair
Co-Chair

13:30–14:45	TuBT1.1

Laparoscopy instrument tracking for single view camera and skill assessment

Benjamin Gautier , Harun Tugal , Mustafa Suphi Erden
Heriot-Watt University, United Kingdom
Benji Tang , Ghulam Nabi
Cuschieri Skills Center, University of Dundee, United Kingdom

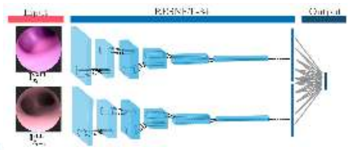
- 3D tracking of instruments in single camera videos of a standard laparoscopy training box
- Novel performance criteria to assess skill level with the extracted tool trajectories
- Verification with professional laparoscopy surgeons and novice subjects
- Significant step towards a low cost, automated, and widely applicable laparoscopy training and assessment

Laparoscopy instrument tracking with markers and single camera

13:30–14:45	TuBT1.2

OffsetNet: Deep Learning for Localization in the Lung using Rendered Images

Jake Sganga[1], David Eng[2], Chauncey Graetzel[3], and David B. Camarillo[1]
1. Bioengineering, Stanford University, USA
2. Computer Science, Stanford University, USA
3. Auris Health, Inc., USA



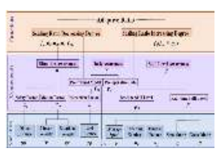
- 1[st] Deep learning method for localizing a bronchoscope in the lung
- Trained networks in simulation using domain randomization and generative adversarial network (GAN)

13:30–14:45	TuBT1.3

A Self-Adaptive Motion Scaling Framework for Surgical Robot Remote Control

Dandan Zhang, Bo Xiao, Baoru Huang, Lin Zhang, Jindong Liu, Guang-Zhong Yang
Hamlyn Centre, Imperial College London, UK

- Situation awareness can be regarded as an online pattern recognition of different operational situation
- User-specific factors can be addressed by skill level assessment
- Task-specific factors are incorporated into the framework to ensure generalizability of the system
- User studies are conducted on the da Vinci Research Kit (dVRK)



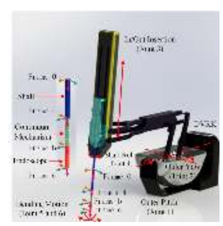
Self-Adaptive Motion Scaling Framework

13:30–14:45	TuBT1.4

Flexible Endoscope for Minimally Invasive Surgery with Enhanced Safety

Ma Xin, Song Chengzhi, Chiu Philip Waiyan, Li Zheng
Department of Surgiry, Chinese University of Hong Kong, Hong Kong.

- Developed a 6-DOF automatic flexible endoscope based on the tendon-driven continuum mechanism (TCM) and integrated it with the DVRK.
- Developed the kinematic model of the 6-DOF automatic flexible endoscope and achieved instruments tracking with visual servoing control.
- Developed the optimal control of the 6-DOF flexible endoscope with minimal motion.



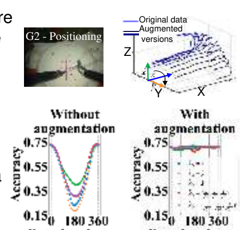
6-DOF flexible endoscope

13:30–14:45	TuBT1.5

Using Augmentation to Improve the Robustness to Rotation of Deep Learning Segmentation in Robotic-Assisted Surgical Data

Danit Itzkovich[1], Yarden Sharon[1], Anthony Jarc[2], Yael Refaely[3], and Ilana Nisky[1]
[1]Biomedical Engineering Department, Ben-Gurion University of the Negev Israel
[2]Medical Research, Intuitive Surgical Inc., Norcross, GA, USA
[3]Thoracic Surgery Unit, Soroka Medical Center, Israel

- Recurrent neural network for surgical gesture segmentation using kinematic data from the JIGSAWS dataset
- The structure of the dataset leads to poor generalization to rotation
- Surgical data is typically characterized by movements in arbitrary directions
- We propose and demonstrate a simple data augmentation algorithm to improve robustness to rotation



Rehabilitation Robotics II - 2.2.12

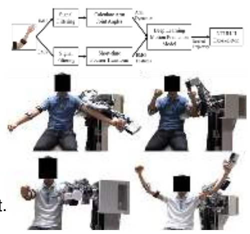
Chair
Co-Chair

13:30–14:45	TuBT1.1

Deep Learning based Motion Prediction for Exoskeleton Robot Control in Upper Limb Rehabilitation

Jia-Liang Ren[1], Ya-Hui Chien[1], En-Yu Chia[1],
Li-Chen Fu[1] and Jin-Shin Lai[2]
[1]Department of Electrical Engineering, National Taiwan University, Taiwan
[2]Department of Physical Medicine and Rehabilitation, National Taiwan University and National Taiwan University Hospital, Taiwan

- Following the subject's motion is needed for robot in robot-assisted stroke therapy.
- The delay of motion can be reduced by prediction of the desired trajectory.
- The proposed deep learning model using biosignal and kinematic data can predict human motion accurately.
- The results show higher motion synchronization between human and robot.



13:30–14:45	TuBT1.2

Adaptive Gait Planning for Walking Assistance Lower Limb Exoskeletons in Slope Scenarios

Chaobin Zou, Rui Huang, Hong Cheng and Qiming Chen
School of Automation and Engineering, UESTC, Chengdu, China
Jing Qiu
School of Mechanical and Electrical Engineering, UESTC, Chengdu, China

- Regard crutches as an external force exerted to the human-exoskeleton system;
- Model the human-exoskeleton system as a 2D Linear Inverted Pendulum Model;
- An adaptive gait planning approach based on Capture Point and DMPs in slope scenarios has been proposed;
- The approach was implemented and tested in a walking assistance exoskeleton named AIDER.

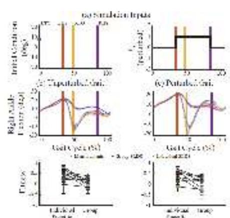
The subject is walking on a slope with AIDER

13:30–14:45	TuBT1.3

A Data-Driven Model of Individual-Specific Effects of FES on Human Gait Dynamics

Luke Drnach[1], Jessica L. Allen[2], Irfan Essa[1], and Lena H. Ting[1,3]
[1]Georgia Institute of Technology, USA
[2]West Virginia University, USA
[3]Emory University, USA

- Switched linear dynamical systems (SLDS) can **generate joint angle trajectories** from initial pose and gait phase information
- Input terms **model individual-specific perturbation responses** to functional electrical stimulation (FES) of muscles
- SLDS may be useful for modeling human dynamics for robot-assisted gait rehabilitation



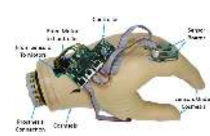
Joint angle trajectory predictions using individual-specific vs group SLDS models

13:30–14:45	TuBT1.4

The (Sensorized) Hand is Quicker than the Eye: Restoring Grasping Speed with Tactile Reflexes

Jeremy A. Fishel, Blaine Matulevich and Kelsey Muller
SynTouch, USA
Gary Berke
Berke Prosthetics, USA

- A myoelectric prosthesis was modified with tactile sensing and an inhibitory reflex
- Fragile grasping speed was evaluated in four unilateral amputees
- Modified prosthesis was found to significantly improve speed, approaching that of each subject's sound-side hand
- Tactile sensing was also found to be more useful than vision in fragile grasping



Prosthetic Hand with Tactile Sensors and Reflexes

13:30–14:45	TuBT1.5

Development of A Soft Power Suit for Lower Back Assistance

Zhejun Yao[1], Christine Linnenberg[2],
Robert Weidner[1,2] and Jens Wulfsberg[1]
[1]Department of Mechanical Engineering, Helmut Schmidt University, Germany
[2]Department of Mechatronics, University of Innsbruck, Austria

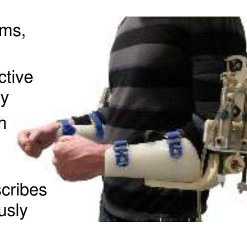
- Active tensile force to support forward bending and straightening of the back
- Passive stabilization to correct poor bending posture
- Fabric structure with biomimetic design and twisted string actuator
- Reducing the muscle activation required for both static bending and dynamic lifting

13:30–14:45	TuBT1.6

Toward Controllable Hydraulic Coupling of Joints in a Wearable Robot

Emma Treadway[1], Zhenyu Gan[1], C. David Remy[1,2]
and R. Brent Gillespie[1]
1. Mechanical Engineering, University of Michigan, USA
2. Institute for Nonlinear Mechanics, University of Stuttgart, Germany

- Routing power across a patient's body enables self-assist rehabilitation paradigms, coupling motions to impose constraints
- Hydraulic transmissions provide an attractive method for routing power across the body
- Controllable constraints are imposed with variable transmission ratios, realizing "hydraulic cobots"
- Our mathematical control framework describes switched (digital hydraulic) and continuously variable transmissions



Soft Robots III - 2.2.13

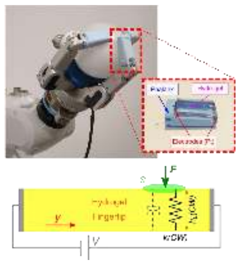
Chair
Co-Chair

13:30–14:45	TuBT1.1

A new soft fingertip based on electroactive hydrogels

A. López-Díaz, R. Fernández, A.S. Vázquez
ETSI Industriales, Universidad de Castilla-La Mancha, Spain
A. Martín-Pacheco, A.M. Rodríguez, M.A. Herrero, E. Vázquez
IRICA, Universidad de Castilla-La Mancha, Spain

- Soft hydrogel-based fingertip capable of changing its stiffness and volume under electric fields.
- Simple and easy to fabricate: photopolymerization (UV light) and 3D printable.
- Useful for both precision and power grasp applications.
- A model of the hydrogel actuation is proposed together with its experimental verification.

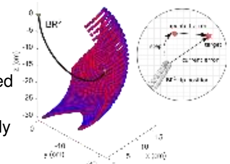


13:30–14:45	TuBT1.2

Open Loop Position Control of Soft Continuum Arm Using Deep Reinforcement Learning

Sreeshankar S, Naveen Uppalapati, Girish Krishnan
Industrial and Systems Engineering, UIUC, USA
Girish Chowdhary
Agricultural and Biological Engineering, UIUC, USA

- Model-free control of novel spatial soft manipulator for path tracking
- Control based on Deep-Q learning performed in simulation
- Control policy shown to generalize effectively for cases with external disturbances
- Controller efficacy demonstrated using prototype with tip in loaded and unloaded configurations



BR^2 learning scheme. Inset: MDP formulation of the control problem

13:30–14:45	TuBT1.3

Fast Motion Planning for High-DOF Robot Systems Using Hierarchical System Identification

Zherong Pan
Computer Science, University of North Carolina, USA
Dinesh Manocha
Computer Science, University of Maryland, USA

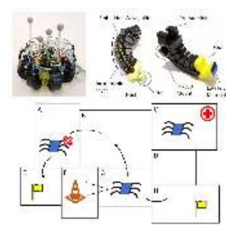
- Optimization-based motion planning for 1000-DOF robots under dynamics constraints
- Find motion plans efficiently using system identification
- System identification based on hierarchical grid-based data structure
- Guaranteed system identification accuracy

13:30–14:45	TuBT1.4

Resilient Task Planning and Execution for Reactive Soft Robots

Scott Hamill, John Whitehead, Peter Ferenz, Robert F. Shepherd, and Hadas Kress-Gazit
Mechanical and Aerospace Engineering, Cornell University, USA

- Multigait behavior allows walking soft robots to react to actuator failure.
- Embedded sensing in soft materials allows actuator degradation to be detected.
- In this work, formal synthesis is used to synthesize controllers that are resilient to actuator failure.
- Resulting controllers are demonstrated on a physical, soft robot.



13:30–14:45	TuBT1.5

Dynamic morphological computation through damping design of soft material robots: application to under-actuated grippers

Antonio Di Lallo[1,2], Manuel Catalano[3], Manolo Garabini[1], Giorgio Grioli[3], Marco Gabiccini[1,2] and Antonio Bicchi[1,3]
[1]Centro di Ricerca E. Piaggio e DII, Univ. di Pisa, Pisa, Italy
[2]Dipartimento di Ingegneria Civile e Industriale, Univ. di Pisa, Pisa, Italy
[3]Fondazione Istituto Italiano di Tecnologia, Genoa, Italy

- A damping-based design method of soft material robots is investigated in order to enable an under-actuated control strategy.
- The approach relies on cavities filled with granular material and viscous oil.
- Simulations and experiments are carried out to validate the method.
- An application example involving a two-fingered soft gripper is presented.

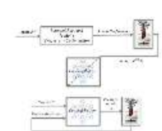
A two-fingered gripper exhibits different behaviors depending on the actuation rate from a single pneumatic line.

13:30–14:45	TuBT1.6

Model-Based Reinforcement Learning for Closed-Loop Dynamic Control of Soft Robotic Manipulators

Thomas George Thuruthel, Egidio Falotico, and Cecilia Laschi
The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa
Federico Renda
Mechanical Engineering and the Center for Autonomous Robotics Systems, Khalifa University of Science and Technology, United Arab Emirates

- This paper presents an approach for closed-loop dynamic control of soft robots using model-based reinforcement learning.
- A learned forward model with trajectory optimization is used to generate appropriate samples for direct policy learning.
- The approach is tested on a pneumatically actuated soft robot for dynamic reaching tasks with added loads.



Procedure for obtaining the closed-loop control policy

Haptics & Interfaces II - 2.2.14

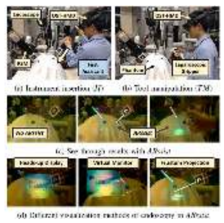
Chair
Co-Chair

13:30–14:45	TuBT1.1

Augmented Reality Assisted Instrument Insertion and Tool Manipulation for the First Assistant in Robotic Surgery

Long Qian, Anton Deguet and Peter Kazanzides
Department of Computer Science, Johns Hopkins University, USA
Zerui Wang and Yun-Hui Liu
T Stone Robotics Institute, Chinese University of Hong Kong, HKSAR, China

- ARssist: an AR application on HoloLens to help the first assistant (FA) in robotic surgery
- Evaluate ARssist for two frequent tasks of FA: Instrument Insertion and Tool Manipulation
- Pilot study with 3 surgeons, User study with 20 inexperienced users
- With ARssist in user study, 34.57% shorter navigation time, 41.74% more consistent operation, 40.04% smaller path deviation, 72.25% shorter manipulation time is achieved.

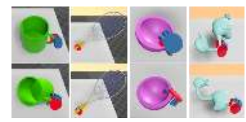


13:30–14:45	TuBT1.2

High-Fidelity Grasping in Virtual Reality using a Glove-based System

Hangxin Liu[1*], Zhenliang Zhang[1,2*], Xu Xie[1], Yixin Zhu[1], Yue Liu[2], Yongtian Wang[2], Song-Chun Zhu[1]
[*]Equal Contribution
[1]Statistics Department, UCLA
[2]School of Optics and Photonics, Beijing Institute of Technology
[3]International Center for AI and Robot Autonomy (CARA)

- 15 IMUs for hand pose sensing, Vive Tracker for hand positioning, and 6 vibration motors for haptic feedback.
- Caging-based stable grasp using collision geometry
- Data Logging system for recording detailed manipulative data (trajectories, grasping points)



Grasping various objects in VR

13:30–14:45	TuBT1.3

On the role of wearable haptics for force feedback in teleimpedance control for dual-arm robotic teleoperation

Janelle P. Clark and Marcia K. O'Malley
Mechanical Engineering, Rice University, U.S.A.
Gianluca Lentini, Federica Barontini, and Matteo Bianchi
Dipartimento di Ingegneria dell'Informazione, Università di Pisa, Italia
Gianluca Lentini, Federica Barontini, and Manuel G. Catalano
Istituto Italiano di Tecnologia, Italia

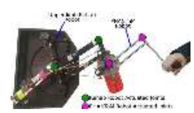
- Wearable haptic feedback can provide force information without compromising stability
- Normal and tangential forces of a box grasp are conveyed with the CUFF haptic device
- The addition of feedback increases the number of successful box placements
- The addition of feedback increases contact forces

13:30–14:45	TuBT1.4

Application of a Redundant Haptic Interface in Enhancing Soft-Tissue Stiffness Discrimination

Ali Torabi Electrical and Computer Eng., University of Alberta, Canada
Mohsen Khadem School of Informatics, University of Edinburgh, UK
Kourosh Zareinia Mechanical Eng., Ryerson University, Canada
Garnette Sutherland Faculty of Medicine, University of Calgary, Canada.
Mahdi Tavakoli Electrical and Computer Eng., University of Alberta, Canada

- The intrinsic benefits of employing a redundant haptic interface (RHI), namely, big workspace, reduced apparent inertia, and increased manipulability, are introduced.
- The RHI redundancy can further reduce its apparent inertia and manipulability via manipulating its extra DoF.
- A psychophysical experiment demonstrates that the redundancy in the RHI helps to enhance tissue stiffness discrimination ability of the user.



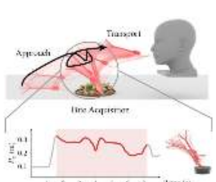
Augmentation of two HIs to develop a redundant HI for task performance enhancement.

13:30–14:45	TuBT1.5

Towards Robotic Feeding: Role of Haptics in Fork-based Food Manipulation

Tapomayukh Bhattacharjee, Gilwoo Lee, Hanjun Song, and Siddhartha S. Srinivasa
Computer Science and Engineering, University of Washington, USA

- 12.3 million people in the US needed assistance with ADLs or IADLs in 2010
- Eating is an ADL; but an intricate manipulation task for a robot
- Our contributions are a rich dataset, analysis of food manipulation strategies, an intuitive taxonomy, and a haptic analysis
- Our results show the importance of adapting manipulation control policies to the compliance of food items



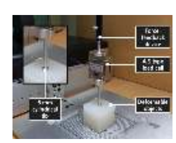
A sample feeding trial with multiple bite-acquisition attempts

13:30–14:45	TuBT1.6

Data-Driven Haptic Modeling of Normal Interactions on Viscoelastic Deformable Objects Using a Random Forest

Amit Bhardwaj, Hojun Cha and Seungmoon Choi
Computer Science Engineering, Pohang University of Science and Technology (POSTECH), South Korea

- Data-driven haptic rendering: an alternative to conventional physics-based rendering
- The paper proposes a new-data-driven approach based on random forest for haptic modeling of deformable objects
- Results show that the proposed approach requires five times less training data than the standard approach in the literature to provide the similar accuracy



Experimental setup for data acquisition

SLAM - Session V - 2.2.15

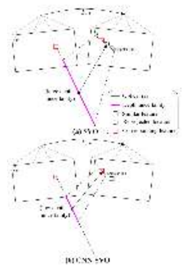
Chair
Co-Chair

13:30–14:45	TuBT1.1

CNN-SVO: Improving the Mapping in Semi-Direct Visual Odometry Using Single-Image Depth Prediction

Shing Yan Loo, Ali Jahani Amiri and Hong Zhang
Department of Computing Science, University of Alberta, Canada
Syamsiah Mashohor and Sai Hong Tang
Faculty of Engineering, Universiti Putra Malaysia, Malaysia

- Improve the mapping in SVO by initializing the map points with CNN depth estimation
- Effective feature matching between two frames
- Faster convergence of map points
- Increased robustness and camera tracking accuracy

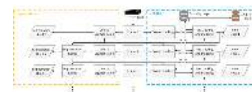


13:30–14:45	TuBT1.2

A Unified Framework for Mutual Improvement of SLAM and Semantic Segmentation

Kai Wang, Yimin Lin, Luowei Wang, Liming Han, Minjie Hua, Xiang Wang, Shiguo Lian and Bill Huang
CloudMinds Technologies Inc., China

- We present an online framework for improving vSLAM and segmentation performances simultaneously
- Segment moving and movable objects to enhance vSLAM precisions
- Refine segmentation result with 3D pose information
- Experiments on various datasets proved the improvement on both tasks



Workflow of our framework

13:30–14:45	TuBT1.3

MID-Fusion: Octree-based Object-Level Multi-Instance Dynamic SLAM

Binbin Xu, Wenbin Li, Dimos Tzoumanikas, Michael Bloesch, Andrew Davison, Stefan Leutenegger
Department of Computing, Imperial College London, United Kingdom

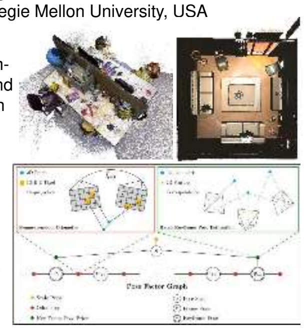
- First RGB-D multi-instance dynamic SLAM system using a volumetric representation
- A robust tracking method weighted via measurement uncertainty and being re-parametrised for object tracking
- A probabilistic fusion of semantic distribution and foreground object probability into octree-based object models
- Integrated segmentation using geometric, photometric, and semantic information

13:30–14:45	TuBT1.4

Surfel-Based Dense RGB-D Reconstruction with Global and Local Consistency

Yi Yang, Wei Dong, and Michael Kaess
Robotics Institute, Carnegie Mellon University, USA

- Our novel approach integrates SLAM odometry and structure-from-motion (SfM) to achieve globally and locally consistent 3D reconstruction
- Keyframe poses from offline SfM pipeline provide global accuracy
- SLAM odometry between frames with high local accuracy
- More accurate 3D reconstruction comparing to SLAM systems
- Significant speedup with respect to SfM-MVS pipelines

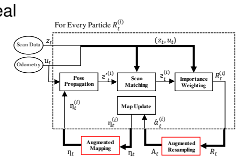


13:30–14:45	TuBT1.5

A-SLAM: Human in-the-loop Augmented SLAM

Abbas Sidaoui and Mohammad Kassem Zein and Imad H. Elhajj and Daniel Asmar
Vision and Robotics Lab, American University of Beirut, Lebanon

- Developed and implemented an intuitive Augmented SLAM system that works in real time.
- The system allows users to correct pose and map errors of a robot running SLAM.
- Built an AR application that works on HoloLens
- Proposed method eliminates post-processing of maps and help in achieving high quality occupancy grid maps.



13:30–14:45	TuBT1.6

Iteratively Reweighted Midpoint Method for Fast Multiple View Triangulation

Yang Kui, Zhao Yan and Deng Nianmao
Beihang University, China
Fang Wei
Beijing University of Posts and Telecommunications, China

- The classic midpoint method for triangulation is extremely fast, but is inaccurate due to its biased cost formulation.
- A weight is assigned to each measurement to rebalance the costs.
- A novel iterative method is proposed to minimize the weighted cost formulation.
- The proposed iterations has a quadratic convergence rate and can be formulated as an approximation to the classic Newton's method.
- The iteratively reweighted midpoint method we proposed is faster than the state-of-the-art without degrading the accuracy of the results.
- The proposed triangulation method can be used for future SLAM or SfM systems.

Humanoid Robots V - 2.2.16

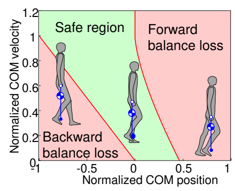
Chair
Co-Chair

13:30–14:45	TuBT1.1

Balance Map Analysis as a Measure of Walking Balance Based on Pendulum-like Leg Movements

Takahiro Kagawa
Dept. of Mechancial Engineering, Aichi Institute of Technology, Japan

- Balance map visualizes states in balance loss during walking based on pendulum-like movements of the stance and swing legs.
- The balance loss regions are represented on the state space of the body COM when the COM of the swing leg is under hip joint.
- The risk of fall can be evaluated by a margin of the current state from the boundary lines.
- Computer simulations of perturbed walking indicate effectiveness of the balance map.



13:30–14:45	TuBT1.2

Non-parametric Imitation Learning of Robot Motor Skills

Yanlong Huang, Leonel Rozo, João Silvério and Darwin G. Caldwell
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

- A novel **kernelized skill learning** approach is proposed, allowing robots to (i) learn probabilistic properties of multiple demonstrations; (ii) learn demonstrations associated with high-dimensional inputs; (iii) modulate trajectories when new task constraints arise on the fly.

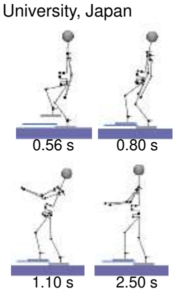
Collaborative Hand Task

13:30–14:45	TuBT1.3

Dynamic Stepping on Unknown Obstacles With Upper-Body Compliance and Angular Momentum Damping From the Reaction Null-Space

Yuki Hidaka, Kajun Nishizawa and Dragomir N. Nenchev
Graduate School of Engineering, Tokyo City University, Japan

- Foot contact destabilization after a collision with an obstacle is avoided by injecting angular momentum damping.
- The damping is derived from within the Reaction Null-Space and results in arm rotation.
- During the stepping motion, the angular excursion of the trunk is made compliant.
- The robustness is verified with dynamic stepping simulations on various obstacles.

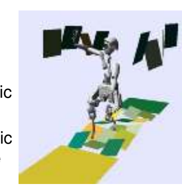


13:30–14:45	TuBT1.4

Efficient Humanoid Contact Planning using Learned Centroidal Dynamics Prediction

Yu-Chi Lin and Dmitry Berenson
Robotics Institute, University of Michigan, U.S.A.
Brahayam Ponton
Max Planck Institute for Intelligent Systems, Germany
Ludovic Righetti
Tandon School of Engineering, New York University, U.S.A.

- Conventional contact planner for multi-contact motion assumes quasi-static balance to reduce the computation challenge, but drops potential solutions requiring dynamic motion.
- We trained neural network to predict the dynamic evolution of the robot centroidal momenta.
- The contact planner is informed with the dynamic prediction as a cost function to quickly generate dynamically robust contact sequences.



13:30–14:45	TuBT1.5

Sparse Optimization of Contact Forces for Balancing Control of Multi-legged Humanoids

Matteo Parigi Polverini, Enrico Mingo Hoffman, Arturo Laurenzi, and Nikos G. Tsagarakis
Advanced Robotics Department (ADVR), Istituto Italiano di Tecnologia (IIT), Genova, Italy

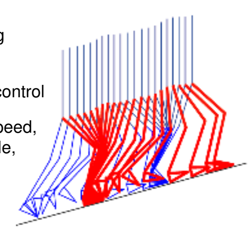
- This work employs the concept of *end-effector redundancy* for the balancing control problem in a torque-controlled multi-legged humanoid;
- Two *sparse* formulations of the force distribution problem are presented and extensively discussed;
- The minimum number of supporting legs is consequently employed for balancing;
- Validation performed on a simulated model of the CENTAURO robot.

13:30–14:45	TuBT1.6

Scalable closed-form trajectories for periodic and non-periodic human-like walking

Salman Faraji and Auke Ijspeert
Biorobotics Laboratory, EPFL, Switzerland

- Physics simulated by the 3LP linear walking model
- Stable gaits achieved with foot-placement control
- Scalable with respect to body properties, speed, cadence, step height, step width, torso angle, slope angle and external forces



- GUI and source codes available at: https://biorob.epfl.ch/research/humanoid/walkman

Aerial Systems: Mechanisms II - 2.2.17

Chair
Co-Chair

13:30–14:45	TuBT1.1

Flying STAR, a Hybrid Crawling and Flying Sprawl Tuned Robot

Nir Meiri and David Zarrouk
Mechanical Engineering, Ben-Gurion University, Israel

- This paper presents a novel sprawl tuned running and flying hybrid robot.
- The design of the robot which uses the same motors for flying and running is described.
- Experiments were performed with the robot both in running and flying modes.
- Thrust forces and energy consumption during flying and crawling were measured.

13:30–14:45	TuBT1.2

Autonomous Cooperative Flight of Rigidly Attached Quadcopters

Diego González Morín, José Araujo, Soma Tayamon and Lars A. A. Andersson
Ericsson Research, Ericsson, Sweden

- Novel method for online parameter estimation and automatic control of a system of rigidly attached quadcopters.
- Estimation relies solely on the individual Inertial Measurement Units (IMU) information.
- Q-Learning based algorithm for control architecture gains calculation.
- Fully automatized process in which both the estimation and gains adaptation is done via simple and short experiments.

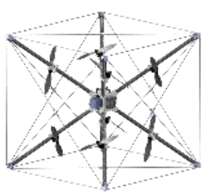
Crazyflies setup used in the experimentation.

13:30–14:45	TuBT1.3

Energy Optimal Control Allocation in a Redundantly Actuated Omnidirectional UAV

Eric Dyer, Shahin Sirouspour, and Mohammad Jafarinasab
Electrical and Computer Engineering, McMaster University, Canada

- Presentation of a novel actuation model and control allocation strategy for a redundantly-actuated multi-rotor unmanned aerial vehicle
- A new inverse actuator model is proposed to account for airflow interactions between propellers
- Actuation redundancy is resolved by solving a convex constrained optimization problem
- Real-time solution to the problem yields the most power efficient set of actuator thrusts within their limits



13:30–14:45	TuBT1.4

Development of SAM: cable-Suspended Aerial Manipulator

Yuri S. Sarkisov, Min Jun Kim, Christian Ott, and Konstantin Kondak
Institute of Robotics and Mechatronics, DLR, Germany
Davide Bicego and Antonio Franchi
LAAS-CNRS, France
Dzmitry Tsetserukou
Space CREI, Skoltech, Russia

- A cable-Suspended Aerial Manipulator (SAM) for the safe aerial manipulation in the complex environment is developed
- The SAM is equipped with 7-DoF robotic manipulator and has two different actuation systems: propulsion units and winches
- Mechanical design, working principle, architecture, control strategy, and the first experimental results were presented

13:30–14:45	TuBT1.5

The Phoenix Drone: An Open-Source Dual-Rotor Tail-Sitter Platform for Research and Education

Yilun Wu, Xintong Du, Rikky Duivenvoorden, and Jonathan Kelly
Institute for Aerospace Studies, University of Toronto, Canada

- A complete package of design documents, BOM, simulation tools, onboard firmware – everything you need to build and fly a tail-sitter from scratch!
- 650g, 64cm wingspan, 20 mins endurance
- Dynamic model acquired from static 6-DOF force/torque sensor. Cascaded PID feedback motion control with model inverse.
- Centimeter-level hovering accuracy, precise trajectory tracking.
- Package available at: https://github.com/utiasSTARS/PhoenixDrone

The Phoenix drone in flight

13:30–14:45	TuBT1.6

Fast and Efficient Aerial Climbing of Vertical Surfaces Using Fixed-Wing UAVs

Dino Mehanovic, David Rancourt and Alexis Lussier Desbiens
Department of Mechanical Engineering, Université de Sherbrooke, Canada

- **S-MAD** is a microspine-based perching UAV performing **thrust-assisted wall climbing**.
- Aircraft models are used to predict S-MAD's performance in various aerial climb regimes.
- Short and long vertical autonomous **climb maneuvers are demonstrated**.
- Results show that S-MAD compares favorably with existing climbers, having a **specific resistance of 19** at a **max. climb speed of 2 m/s**.

Autonomous thrust-assisted climbing of an outdoor brick wall

Flexible Robots - 2.2.19

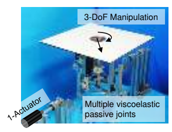
Chair
Co-Chair

13:30–14:45 TuBT1.1

1-Actuator 3-DoF Manipulation Using an Underactuated Mechanism with Multiple Nonparallel and Viscoelastic Passive Joints

Taisuke Kurita and Mitsuru Higashimori
Department of Mechanical Engineering, Osaka University, Japan

- A nonprehensile manipulation scheme that controls a 3-DoF motion of a part is proposed.
- The manipulator employs only one actuator and multiple nonparallel and viscoelastic passive joints.
- The orbital shape and direction of the plate end effector vary for the sinusoidal input.
- Eight primitives with CCW and CW plate motions are designed for the 3-DoF manipulation.



Prototype robot

13:30–14:45 TuBT1.2

Spline Based Curve Path Following of Underactuated Snake Robots

Weixin Yang, Gang Wang, and Haiyan Shao
Electrical & Biomedical Engineering, University of Nevada, Reno, USA
Yantao Shen
Electrical & Biomedical Engineering, University of Nevada, Reno, USA

- This paper investigates the curve path following problem for a class of snake robots.
- The cubic spline interpolation path-planning method is employed.
- An improved integral time-varying line-of-sight guidance algorithm is used.
- A backstepping controller is proved theoretically and is validated experimentally as well.


Snapshot of Curve Path Following of the Snake Robot

13:30–14:45 TuBT1.3

High-Bandwidth Control of Twisted String Actuators

Simeon Nedelchev, Igor Gaponov and Jee-Hwan Ryu
School of Mechanical Engineering, Korea University of Technology and Education, South Korea

- Paper proposes adaptive control methodology to improve tracking accuracy and bandwidth of TSA position controllers
- Tracking error is invariant to parameter changes and reference trajectory
- Proposed control method yields 300% greater tracking accuracy and decreased delay by a factor of 10 over conventional controllers

Photo of experimental setup.

13:30–14:45 TuBT1.4

TREE: A Variable Topology, Branching Continuum Robot

Michael C. Lastinger, Siddharth Verma, Apoorva D. Kapadia, and Ian D. Walker
ECE Department, Clemson University, U.S.A.

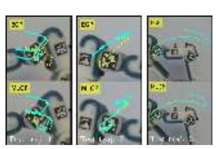
- Novel design: hybrid concentric-tube/tendon actuated trunk core featuring 2 pairs of branches
- Aimed at inspection and cleaning operations in hard-to-reach environments
- Branches are fully retractable, allowing robot to actively change its topology
- Evaluated workspace envelope, load capacities; demonstrated cleaning, inspection capabilities in simulated glove box environments

13:30–14:45 TuBT1.5

Learning a State Transition Model of an Underactuated Adaptive Hand

Avishai Sintov, Andrew Kimmel, Kostas Bekris and Abdeslam Boularias
Computer Science, Rutgers University, USA
Andrew Morgan and Aaron Dollar
Mechanical Engineering, Yale University, USA

- Learning a stochastic transition model for precise manipulation with a low-cost, underactuated adaptive hand.
- The grasped object position and actuators load sufficiently express the state.
- Model can generalize to objects of varying sizes.
- Use Manifold learning for local GP regression.

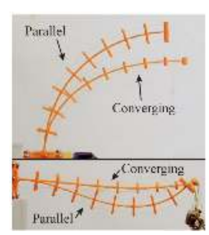


13:30–14:45 TuBT1.6

Continuum Robot Stiffness under External Loads and Prescribed Tendon Displacements

Kaitlin Oliver-Butler, John Till, and Caleb Rucker
Dept. of Mechanical, Aerospace, and Biomedical Engineering, University of Tennessee, Knoxville, USA

- Analytical models for tendon robot stiffness and deflection under external loads
- 3D, numerical statics model that includes prescribed tendon displacements and slack
- Robots with converging tendon paths can be up to 4 times stiffer than with parallel paths.
- Tendon stiffness and routing are highlighted as important factors in robot design.



Overlaid images of robots with parallel & converging tendon paths.

Force and Tactile Sensing II - 2.2.20

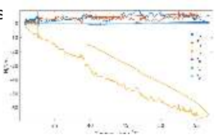
Chair
Co-Chair

13:30–14:45 TuBT1.1

Model Based *in Situ* Calibration with Temperature Compensation of 6 Axis Force Torque Sensors

Francisco Andrade, Gabriele Nava, Silvio Traversaro, Francesco Nori and Daniele Pucci
iCub Facility, Istituto Italiano di Tecnologia, Italy

- Is well known that sensors using strain gauges have a potential dependency on temperature.
- Experiments using the iCub and custom F/T sensors show that the temperature drift is relevant.
- An *in situ* calibration method with temperature compensation for six axis Force Torque sensors is proposed.



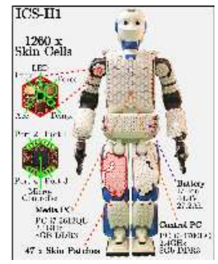
Change in F/T measurements due to temperature.

13:30–14:45 TuBT1.2

Whole-Body Active Compliance Control for Humanoid Robots with Robot Skin

Emmanuel Dean-Leon, J. Rogelio Guadarrama-Olvera, Florian Bergner, and Gordon Cheng
Institute for Cognitive Systems,
Department of Electrical and Computer Engineering, Technical University of Munich, Germany.

- Integration of multi-modal tactile information with different control approaches in a hierarchical task execution to produce dynamic robot behaviors suitable for HRI.
- Modular skin control that uses event-driven systems to support large-scale robot skin.
- Deployment in a hyper-redundant full-size humanoid robot with 30 DOF and 1260 skin cells distributed in the whole robot body.

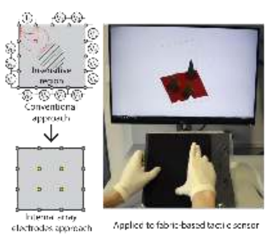


13:30–14:45 TuBT1.3

Internal Array Electrodes Improve the Spatial Resolution of Soft Tactile Sensors Based on Electrical Resistance Tomography

Hyosang Lee[1†], Kyungseo Park[2†],
Jung Kim[2], and Katherine J. Kuchenbecker[1]
[1]Haptic Intelligence, Max Planck Institute for Intelligent Systems, Germany
[2]Mechanical Engineering, KAIST, South Korea
† These authors contributed equally.

- We created a fabric-based tactile sensor to give robots whole-body tactile sensing
- Electrical resistance tomography (ERT) simplifies the fabrication and increases the robustness of our large, soft tactile sensor
- Internal array electrodes improve the sensor's spatial resolution

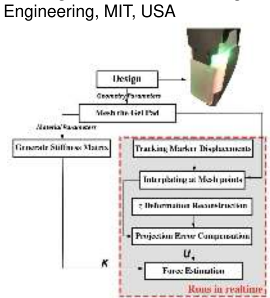


13:30–14:45 TuBT1.4

Dense Tactile Force Estimation using GelSlim and inverse FEM

Daolin Ma*, Elliott Donlon*, Siyuan Dong and Alberto Rodriguez
Department of Mechanical Engineering, MIT, USA

- We propose inverse FEM to reconstruct dense tactile force using GelSlim sensor.
- New hardware design makes GelSlim more rugged and parametrically adjustable.
- Experimental evaluation is performed by comparing with F/T sensor.
- The algorithm can run in realtime.

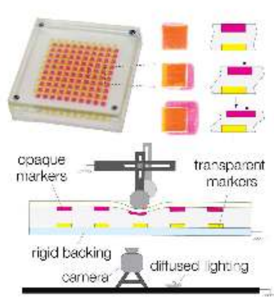


13:30–14:45 TuBT1.5

Sensing the frictional state of a Robotic Skin via Subtractive color

Xi Lin and Michaël Wiertlewski
Institut des Sciences du Mouvement, CNRS, Aix-Marseille Université, France

- Soft sensor to measure 3d interaction
- Color changes encode the normal displacement
- Precision: 2% of the original size of marker.
- Stress field involving friction can be resolved



13:30–14:45 TuBT1.6

A Sense of Touch for the Shadow Modular Grasper

Nicholas Pestell, Luke Cramphorn, Fotios Papodopoulos and Nathan F. Lepora
Department of Engineering Mathematics, University of Bristol, UK

- **Main Contribution:** Integration of established tactile sensor (TacTip) with multi-fingered industrial hand, and development of novel approach to real-time grasp stabilisation.
- **Experiment:** *i)* Off-line perception of contact orientation *ii)* Real-time adjustment of grasp based on on-line orientation prediction.
- **Results 1:** Accurate off-line predictions using 2nd order polynomial model.
- **Results 2:** Successful grasps on 3 real-world objects and useful re-adjustment using designed control procedure.

Tactile Modular Grasper.

Deep Visual Learning II - 2.2.21

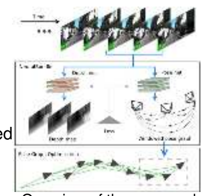
Chair
Co-Chair

13:30–14:45	TuBT1.1

Pose Graph Optimization for Unsupervised Monocular Visual Odometry

Yang Li[1], Yoshitaka Ushiku[1] and Tatsuya Harada[1,2]
[1] The University of Tokyo, Japan
[2] RIKEN

- We present a VO system which combines an unsupervised monocular VO with graph optimization backend.
- In frontend, a neural network based VO generate a windowed pose graph.
- In backend, pose graph optimization is applied to ensure global consistency
- Our system show favorable overall trajectory accuracy than established SLAM systems.



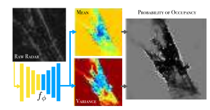
Overview of the proposed VO system

13:30–14:45	TuBT1.2

Probably Unknown: Deep Inverse Sensor Modelling Radar

Rob Weston, Sarah Cen, Paul Newman and Ingmar Posner
Oxford Robotics Institute, University of Oxford, UK

- Radar is a promising alternative to lidar and vision but is difficult to interpret
- Convert noisy radar sensor scans to occupancy grids using a deep neural network
- Self supervise the network using occupancy labels generated in Lidar
- Account for scene context and heteroscedastic noise to identify occupied, free and occluded space

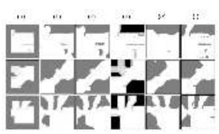


13:30–14:45	TuBT1.3

Uncertainty-Aware Occupancy Map Prediction Using Generative Networks for Robot Navigation

Kapil Katyal, Katie Popek and Phil Burlina
Johns Hopkins University Applied Physics Lab, USA
Chris Paxton, Greg Hager
Dept. of Comp. Sci., Johns Hopkins University, USA

- Efficient exploration through unknown environments remains a challenging problem for robotic systems
- Humans routinely make predictions beyond line of sight and generate multiple predictions
- We investigate using U-Net style autoencoder to predict occupied spaces beyond line of sight
- We generate multiple hypotheses as a heuristic for information theoretic robot exploration



Prediction of Occupied Spaces

13:30–14:45	TuBT1.4

Empty Cities: Image Inpainting for a Dynamic-Object-Invariant Space

Berta Bescos and José Neira
RoPeRT, University of Zaragoza, Spain
Roland Siegwart and Cesar Cadena
ASL, ETH Zurich, Switzerland

- End-to-end deep learning framework to turn images that show dynamic content, such as cars or pedestrians, into realistic static frames.
- Applications such as augmented reality, vision-based robot localization purposes, creation of high-detail road maps, privacy measure to replace faces and license plates blurring for street-view imagery, among others.
- Pilot experiments showing the benefits of our proposal for vision-based place recognition.

13:30–14:45	TuBT1.5

Autonomous Exploration, Reconstruction, and Surveillance Aided by Deep Learning

Louis Ly and Yen-Hsi Richard Tsai
Oden Institute for Computational Engineering and Sciences
The University of Texas at Austin, USA

- How to place a minimal set of sensors to achieve complete visibility coverage for surveillance or exploration of an environment?
- We propose a greedy algorithm which maximizes information gain at each step.
- CNN parametrizes geometric priors to efficiently approximate gain function based on measurements from previous vantage points.
- Simple volumetric representation of arbitrary geometries in 2D and 3D.

Snapshot of 3D Exploration Simulation

13:30–14:45	TuBT1.6

GANVO: Unsupervised Deep Monocular Visual Odometry and Depth Estimation with Generative Adversarial Networks

Yasin Almalioglu, Muhamad Risqi U. Saputra, Pedro P. B. de Gusmão, Andrew Markham, and Niki Trigoni
Computer Science Department, The University of Oxford, UK

Object Recognition & Segmentation II - 2.2.22

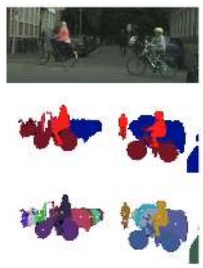
Chair
Co-Chair

13:30–14:45	TuBT1.1

Fast Instance and Semantic Segmentation Exploiting Local Connectivity, Metric Learning, and One-Shot Detection for Robotics

Andres Milioto and Leonard Mandtler and Cyrill Stachniss
University of Bonn

- **Semantic** and **instance segmentation** for **robotics**
- Fast for **online operation** in robot hardware
- Joint approach with **shared convolutional encoder** for instances and semantics
- **Metric learning** based approach
- Exploits **local connectivity** and **one-shot object detection** for fast clustering of instance embeddings

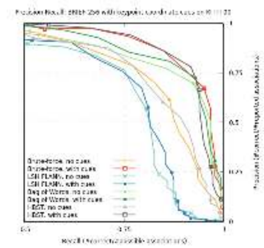


13:30–14:45	TuBT1.2

Adding Cues to Binary Feature Descriptors for Visual Place Recognition

Dominik Schlegel and Giorgio Grisetti
Department of Computer, Control, and Management Engineering,
Sapienza University of Rome, Italy

- Straightforward technique for embedding multi-dimensional cue information in binary descriptors
- Improves accuracy while requiring only minimal changes to the similarity search method
- Hamming metric compatible codes are obtained by quantizing and mapping continues values to bits



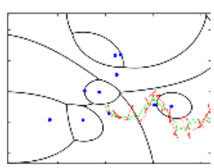
Cue performance evaluation on KITTI.

13:30–14:45	TuBT1.3

Recursive Bayesian Classification for Perception of Evolving Targets using a Gaussian Toroid Prediction Model

J. Josiah Steckenrider and Tomonari Furukawa
Mechanical Engineering, Virginia Tech, USA

- A recursive Bayesian framework is proposed to estimate evolving targets in a feature space
- Stochastic prediction is addressed by implementation of a Gaussian toroid model
- Multi-Gaussian belief fusion is used to increase certainty, and targets are classified probabilistically
- The proposed technique outperforms other naïve approaches, especially under high observational uncertainty



Directionally biased target evolution in 2-D feature space over decision boundaries

13:30–14:45	TuBT1.4

Large-Scale Object Mining for Object Discovery from Unlabeled Video

Aljoša Ošep* and Paul Voigtlaender* and Jonathon Luiten and Stefan Breuers and Bastian Leibe
Computer Vision Group, RWTH Aachen University, Germany

We propose an approach for automatic discovery of novel and rare object categories from large video corpora. We start by mining generic object tracks and extract novel object categories using unknown object tracks.

13:30–14:45	TuBT1.5

Goal-oriented Object Importance Estimation in On-road Driving Videos

Mingfei Gao[1], Ashish Tawari[2] and Sujitha Martin[2]
[1]University of Maryland, College Park, MD, USA
[2]Honda Research Institute, Mountain View, CA, USA

- The problem of object importance estimation (OIE) is formulated to study driver's attention mechanism
- Object importance depends on its visual dynamics and the ego vehicle's planned path
- A novel framework is proposed that incorporates visual and goal representations to conduct OIE
- The proposed model is validated on real-word driving scenarios at traffic intersections

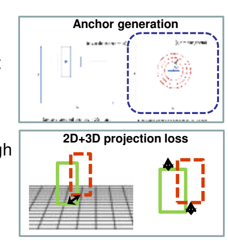
Scenario of OIE given the dynamic status of the road users and the driving goal

13:30–14:45	TuBT1.6

Priming Deep Pedestrian Detection with Geometric Context

Ishani Chakraborty, Microsoft Cloud & AI
Gang Hua, Wormpex AI

- One of the main reasons for poor recall in crowded scenes is inter-person occlusion.
- We propose to incorporate geometric context in a standard two-stage object detector to make it robust to occlusions.
- Geometry is factored in through early fusion, during region proposal generation and through late fusion, during loss computation.
- Our proposed extensions of R-FCN and Faster-RCNN improves pedestrian detection by 5% over baseline models.



Motion and Path Planning II - 2.2.23

Chair
Co-Chair

13:30–14:45	TuBT1.1

The Robust Canadian Traveler Problem Applied to Robot Routing

Hengwei Guo and Timothy D. Barfoot
Institute for Aerospace Studies, University of Toronto, Canada

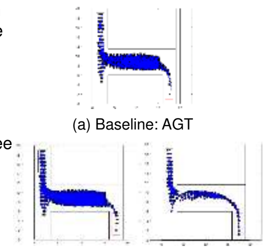
- The Robust Canadian Traveler Problem (RCTP) seeks policy with small mean and small variability.
- An optimal (offline) algorithm and an approximate (online) algorithm are proposed to solve the RCTP.
- RCTP policies have lower worst-case costs and faster convergence rates than classic CTP counterparts.

13:30–14:45	TuBT1.2

Improved A-Search Guided Tree Construction for Kinodynamic Planning

Yebin Wang
Mitsubishi Electric Research Laboratories, USA

- Two proposed algorithms concentrate on node expansion and selection to improve computation efficiency.
- I-AGT algorithm biases node expansion through prioritizing control actions and reduce tree complexity
- BAGT algorithm exploits bi-directional tree to better estimate heuristics during node selection for efficiency
- Simulation shows effectiveness of both algorithms for most of cases



(a) Baseline: AGT

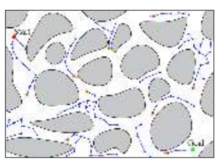
(b) I-AGT (c) BAGT

13:30–14:45	TuBT1.3

Balancing Global Exploration and Local-connectivity Exploitation with RRdT*

Tin Lai[1], Fabio Ramos[1,2] and Gilad Francis[1]
[1]School of Computer Science, The University of Sydney, Australia
[2]NVIDIA, USA

- Rapidly-exploring Random disjointed-Trees (RRdT*): an incremental multi-query sampling-based planner.
- Exploring C-space by building disjointed-trees with an MCMC Random Walker.
- Adaptive global and local sampling (trading-off exploration/exploitation) - formulated as a Multi-Armed Bandit problem.
- RRdT* achieves sample efficiency and robustly outperforms state-of-the-art in highly complex environment.



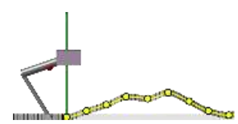
RRdT* exploiting multiple local-connectivity along narrow passages

13:30–14:45	TuBT1.4

Locomotion Planning through a Hybrid Bayesian Trajectory Optimization

Tim Seyde, Jan Carius, Ruben Grandia, Farbod Farshidian, Marco Hutter
Robotic Systems Lab, ETH Zurich, Switzerland

- Locomotion planning for legged systems requires suitable contact schedules
- Optimizing over both contacts and system trajectories can pose convergence issues
- We propose a bi-level optimization that decouples contact schedule selection from trajectory optimization
- A Gaussian process model learns contact schedule selection to constrain a motion planning nonlinear program



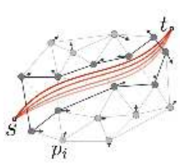
Single-legged hopping robot on rough terrain

13:30–14:45	TuBT1.5

Dynamic Channel: A Planning Framework for Crowd Navigation

Chao Cao
Robotics Institute, Carnegie Mellon University, USA
Peter Trautman and Soshi Iba
Honda Research Institute, USA

- Dynamic channels combines global optimality and a heuristic for efficient management of agent dynamics.
- Abstracts the environment using Delaunay Triangulation.
- Performance and efficiency are validated with thousands of real world pedestrian datasets.
- Our approach outperforms state of the art methods for task completion while remaining real-time computable.



A "dynamic channel" (bold line segments) and the corresponding homotopy class of paths (red curves) bounded within.

13:30–14:45	TuBT1.6

Composition of Local Potential Functions with Reflection

Adam Stager, Herbert G. Tanner
Mechanical Engineering, University of Delaware, USA

- Collisions can be useful if they are included in planning
- Robots made to store and release impact energy benefit by reflecting
- Planning to reflect can lead to faster convergence
- Reflection surfaces are identified in a sequence of locally convergent cells

Equipped with a protective, collision-energy restoring ring; Omnipuck awaits launch in a 3D printed jig before each experiment.

Industrial Robotics - 2.2.24

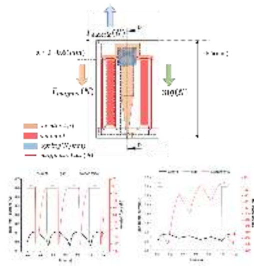
Chair
Co-Chair

13:30–14:45	TuBT1.1

Analyzing Electromagnetic Actuator based on Force Analysis

Jaewon Ahn and Dongwon Yun
Department of Robotics, University of Daegu Gyeongbuk Institute of Science & Technology, South Korea

- We modeled linear electromagnetic actuator system for better understanding on the operation of the actuator, by analyzing the system with mechanical, electrical and magnetic system.
- After the modeling, we examined our modeled system with simulation tool, Simulink. And compared the results with an experimental results.
- Using the simulation, we changed parameter values to check its performance. We found out that the parameters can have a complex effect on not only exerted force but also performance frequency of the actuator.



Simulation Results with Coil turn number of 3500(left) and 5500(right)

13:30–14:45	TuBT1.2

A Novel Robotic System for Finishing of Freeform Surfaces

Yalun Wen, Jie Hu and Prabhakar Pagilla
Mechanical Engineering, Texas A&M University, United States of America

- Workpiece surface geometry and local normal profile generation with a simple proximity sensor
- Trajectory generation from the scanned data
- Simultaneous normal force and position control based on workpiece local normal vectors
- System integration with ROS and experimental validation

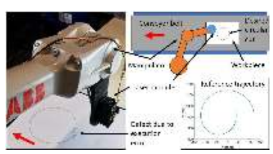
Fig. 1 Robotic surface finishing system

13:30–14:45	TuBT1.3

Context-Dependent Compensation Scheme to Reduce Trajectory Execution Errors for Industrial Manipulators

Prahar Bhatt, Pradeep Rajendran, and Satyandra Gupta
Aerospace and Mechanical Engineering, University of Southern California, USA
Keith McKay
Hexagon Manufacturing Intelligence, USA

- Industrial manipulators have high repeatability but low accuracy and exhibit considerable trajectory time tracking errors
- Compensation scheme presented in this paper uses a small portion of the input trajectory to train a sequence of neural networks
- The generated compensated trajectory has high accuracy and low time tracking errors



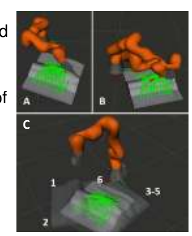
The actual setup, setup schematic, and the reference trajectory for the physical demonstration of execution error in articulated robots

13:30–14:45	TuBT1.4

Identifying Feasible Workpiece Placement with Respect to Redundant Manipulator for Complex Manufacturing Tasks

Rishi Malhan, Ariyan Kabir, Brual Shah, and Satyandra K. Gupta
Center For Advanced Manufacturing, University of Southern California, USA

- Many manufacturing tasks use manipulators to follow complex continuous paths under force and velocity constraints
- Workspace of a manipulator is limited and therefore we need to find a feasible placement of the workpiece in the robot workspace to successfully execute the task
- Formulating and solving this problem as a non-linear optimization problem is computationally challenging
- We demonstrate that using a precomputed capability map and successively applying constraints can be used to find feasible workpiece placement



A: Orientation is violated.
B: Path is not continuous.
C: Iterations of the algorithm to find a solution

13:30–14:45	TuBT1.5

Geometric Search-Based Inverse Kinematics of 7-DoF Manipulator with Multiple Joint Offsets

Anirban Sinha and Nilanjan Chakraborty
Department of Mechanical Engineering, Stony Brook University
Stony Brook, New York, USA

- A two-parameter search-based algorithm to compute multiple inverse kinematics (IK) solutions for 7 DoF manipulators that exploits the geometric structure of the manipulator.
- Proposed IK-solver is guaranteed to find all solutions (within a numerical tolerance) for robots with joint offsets at shoulder, elbow, and wrist joint while respecting joint limit constraints. No existing IK solvers can provide such guarantees.
- We apply this IK solver for redundancy resolution where the objective is to find a solution with minimum end effector positioning error due to actuation/control errors.

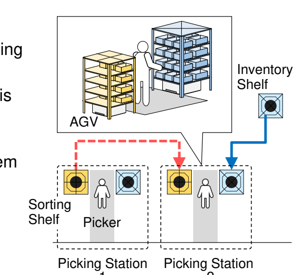
7-DoF redundant manipulator with offsets at shoulder, elbow and wrist joints

13:30–14:45	TuBT1.6

New Automated Guided Vehicle System Using Real-time Holonic Scheduling for Warehouse Picking

Hiroshi Yoshitake and Ryota Kamoshida
Research & Development Group, Hitachi Ltd., Japan
Yoshikazu Nagashima
Machinery Systems Division, Hitachi Ltd., Japan

- New AGV picking system in which inventory shelves and incomplete sorting shelves are transported.
- Real-time holonic scheduling method is applied to resolve shelf transportation scheduling problems.
- Simulation results show the new system is efficiently operated :
  - in large working area.
  - with high-mixed and low-volume picking orders.



Intelligent Transportation II - 2.2.25

Chair

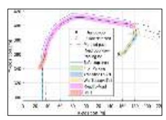
Co-Chair

13:30–14:45	TuBT1.1

Design and Formal Verification of a Safe Stop Supervisor for an Automated Vehicle

Jonas Krook and Martin Fabian
Electrical Engineering, Chalmers, Sweden
Lars Svensson and Yuchao Li and Lei Feng
Department Name, Royal Institute of Technology, Sweden

- In the presence of failures, an automated vehicle needs a backup plan that brings it to a safe state
- A supervisor governs mode switching between planners and safe states
- The supervisor is safety critical, and its correctness is of great importance
- Here, formal verification of the supervisor ensures correctness, and experiments validate the total system



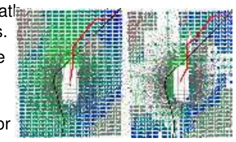
A birds eye view of an automated drive

13:30–14:45	TuBT1.2

Optimization-Based Terrain Analysis and Path Planning in Unstructured Environments

Ueli Graf, Roland Siegwart, and Reanud Dubé
Autonomous Systems Lab, ETH Zurich, Switzerland
Paulo Borges and Emili Hernández
Robotics and Autonomous Systems Group, CSIRO's Data61, Australia

- Real-time optimization-based approach to path planning in off-road and rough environments.
- Employs an irregular, hierarchical, graph-like environment model generated by recursive space division.
- A unique underlying data structure is used for both terrain modeling and path planning.
- Hierarchical environment model enables search-based local path planning for on-the-fly obstacle avoidance.

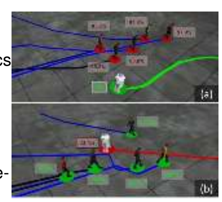


13:30–14:45	TuBT1.3

Pedestrian Dominance Modeling for Socially-Aware Robot Navigation

Tanmay Randhavane, Aniket Bera, Austin Wang, Kurt Gray
UNC Chapel Hill, USA
Emily Kubin
Tilburg University, Netherlands
Dinesh Manocha
UMD College Park, USA

- We model the dominance of pedestrians (PDM) using a perception study.
- Robot identifies the dominance characteristics of pedestrians based on their trajectories using PDM.
- Robot exhibits complementary behaviors to facilitate socially-aware navigation.
- We also present an application to dominance-based navigation of autonomous vehicles among pedestrians.



13:30–14:45	TuBT1.4

Dynamic Traffic Scene Classification with Space-Time Coherence

Athmanarayanan Lakshmi Narayanan and Isht Dwivedi
Honda Research Institute , USA
Behzad Dariush
Honda Research Institute , USA

- Includes 80 hrs of diverse high quality driving video data clips collected in the San Francisco Bay area with temporal annotations for road places, road types, weather, and road surface conditions.
- Algorithms to support Traffic Scene Classification under space-time variations in viewpoint is introduced
- Experimental results on how extracted features serve as strong priors and help with tactical driver behavior understanding.

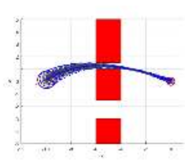
Temporal video annotations at multiple levels, including Places, Environments, Weather, and Road Surface.

13:30–14:45	TuBT1.5

Optimal Stochastic Vehicle Path Planning Using Covariance Steering

Kazuhide Okamoto and Panagiotis Tsiotras
School of Aerospace Engineering,
Georgia Institute of Technology, USA

- This work addresses the problem of vehicle path planning in the presence of obstacles and uncertainties, a fundamental robotics problem.
- Many path planning algorithms have dealt with only deterministic environments or with only *open-loop* uncertainty, which typically increases with time due to exogenous disturbances.
- We utilize the recently developed optimal covariance steering theory to compute less conservative nominal paths.



Optimal path computed using covariance steering.

13:30–14:45	TuBT1.6

Towards the Design of Robotic Drivers for Full-Scale Self-Driving Racing Cars

Danilo Caporale - Alessandro Settimi – Federico Massa
Francesco Amerotti – Andrea Corti – Adriano Fagiolini
Massimo Guiggiani – Antonio Bicchi – Lucia Pallottino
Research Centre E. Piaggio - Università di Pisa, Italy
Università degli Studi di Palermo, Italy

- Planning and control software stack for electric self-driving racing vehicles
- Hardware: NVIDIA PX2 and Speedgoat
- Offline Trajectory Optimization
- Real-Time Nonlinear Model Predictive Control
- LIDAR-based Mapping and Localization (Google's Cartographer)
- Experimental validation on Roborace's DevBot

Aerial Systems: Applications IV - 2.2.18

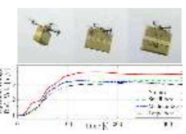
Chair
Co-Chair

13:30–14:45	TuBT1.1

Model-free Online Motion Adaptation for Optimal Range and Endurance of Multicopters

Andrea Tagliabue
Dept. Mech.and Civil Eng., California Institute of Technology, CA
Xiangyu Wu, Mark W. Mueller
Dept. Mech. Eng., University of California, Berkeley, CA

- We propose a method to find the velocities for **maximum range** or **endurance** for a multicopter.
- Our approach uses **Extremum Seeking control** and is **online** and **adaptive**.
- We **experimentally** show convergence to the optimal **endurance and range** velocities.
- We show **adaptation** to **unknown disturbances,** and that hovering is not the optimal loitering strategy



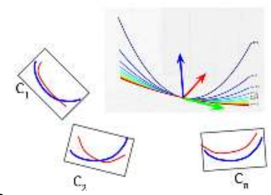
Finding the velocity for maximum range for unknown aerodynamic disturbances such as payloads

13:30–14:45	TuBT1.2

Multi-view Reconstruction of Wires using a Catenary Model

Ratnesh Madaan, Michael Kaess, and Sebastian Scherer
Robotics Institute, Carnegie Mellon University, USA

- Perform wire segmentation in images using CNN
- Minimize reprojection error to recover optimal catenary model
- Use distance transform of binary wire segmentations as loss function to obviate need of pixel correspondences



13:30–14:45	TuBT1.3

Real-Time Optimal Planning and Model Predictive Control of a Multi-Rotor with a Suspended Load

Clark Youngdong Son, Dohyun Jang, Hoseong Seo, H. Jin Kim
Mechanical and Aerospace Eng, Seoul National Univ, South Korea
HyeonBeom Lee
Electronics Eng, Kyungpook National Univ, South Korea

- Transformation of nonconvex constraints into convex ones using convexification
- Differential flatness to consider feasibility with linear equations
- Convex optimization to generate collision-free trajectories in real-time
- Model predictive control for generation of optimal control input in trajectory tracking

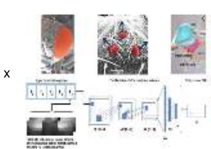
(a) Obstacle avoidance
(b) Load transportation

13:30–14:45	TuBT1.4

Bioinspired Direct Visual Estimation of Attitude Rates with Very Low Resolution Images using Deep Networks

M. Mérida-Floriano, F. Caballero, D. Acedo and L. Merino
Service Robotics Laboratory, Universidad Pablo de Olavide, Seville, Spain
D. García-Morales and F. Casares
Department of Gene Regulation and Morphogenesis, CABD, CSIC and Universidad Pablo de Olavide, Seville, Spain

- A bioinspired visual system sensor to estimate angular rates in unmanned aerial vehicles (UAV) using Neural Networks is presented.
- Emulating *Drosophila*'s ocellar system, we recover angular rates from three very low resolution images (10 x 8 pixels). The system recovers angular rates in both outdoor and indoor scenarios with changing light conditions. Our method does not need prior knowledge.
- We present a complete dataset with real and synthetic data in both indoor and outdoor scenarios. The dataset and the code has been released: https://github.com/robotics-upo/OCELLIMAV-Project
- We benchmark our learning-based method against a classical geometric method and a state of the art approach based on ocelli.



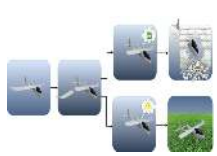
(Up) *Drosophila*'s ocellar system. (Down) Network architecture.

13:30–14:45	TuBT1.5

Automatic Real-time Anomaly Detection for Autonomous Aerial Vehicles

Azarakhsh Keipour, Mohammadreza Mousaei, and Sebastian Scherer
Robotics Institute, Carnegie Mellon University, USA

- A real-time approach to detect anomalies in the behavior of an aircraft
- Models the relationship between input-output pairs and uses the model to detect anomalies
- Easy-to-deploy method that works with any aircraft model and detects many types of faults
- A fault detection dataset from real data with ground truth is provided for autonomous aircraft with 8 types of faults



Not having knowledge about a fault can be a threat to the safety of an aircraft

13:30–14:45	TuBT1.6

Mid-air conflict avoidance and recovery: an acceleration-based approach for unmanned aircraft

Dasun Gunasinghe, Kiaran K. Lawson, Reuben Strydom and Mandyam Srinivasan
Queensland Brain Institute, The University of Queensland, Australia
Edwin Davis
School of Information Technology and Electrical Engineering, The University of Queensland, Australia

- We describe an acceleration-based technique for increasing the minimum separation between two aircraft.
- The theory predicts the separation that is achieved by any prescribed acceleration, while accounting for each aircraft's dynamical constraints.
- A method is also developed by which each aircraft can recover safely to its original velocity.
- Both maneuvers are validated in a virtual as well as a real, indoor environment using two Quadcopter platforms.

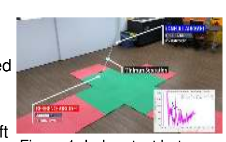


Figure 1: Indoor test between conflict & reference aircraft

Award Session V

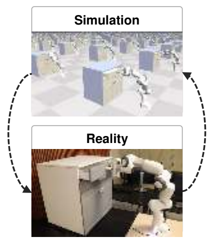
Chair *Vijay Kumar, University of Pennsylvania*
Co-Chair *Jing Xiao, Worcester Polytechnic Institute (WPI) computer science*

13:30–13:42	TuBT2.1

Closing the Sim-to-Real Loop: Adapting Simulation Randomization with Real World Experience

Yevgen Chebotar[1,2], Ankur Handa[1], Viktor Makoviychuk[1], Miles Macklin[1,3], Jan Issac[1], Nathan Ratliff[1], Dieter Fox[1,4]
[1]NVIDIA, USA [2]University of Southern California, USA
[3]University of Copenhagen, Denmark [4]University of Washington, USA

- Train policies entirely in simulation with randomized parameters
- Iteratively update simulation parameter distribution using a few real world trials
- Improve policy transfer by matching policy behavior in simulation and reality

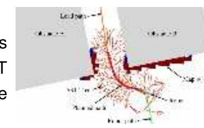


13:42–13:54	TuBT2.2

Online Multilayered Motion Planning with Dynamic Constraints for Autonomous Underwater Vehicles

Eduard Vidal, Narcís Palomeras and Marc Carreras
Underwater Robotics Research Center (CIRS), University of Girona, Spain
Mark Moll, Juan David Hernández and Lydia E. Kavraki
Kavraki Lab, Rice University, United States

- We present an efficient **motion planning** framework for autonomous underwater vehicles
- **Multilayered** design, combining RRT* and SST
- A **geometric lead path** is computed to **bias** the sampling of a motion **planner that accounts for the vehicle dynamics**
- Tested in simulation and in **sea experiments** using the Sparus II AUV



Example scenario. Sampling around the lead path, without mixing uniform sampling

13:54–14:06	TuBT2.3

Drift-free Roll and Pitch Estimation for High-acceleration Hopping

Justin K. Yim, Eric K. Wang, Ronald S. Fearing
Electrical Engineering and Computer Sciences, Univ. of California - Berkeley, United States

- Monopedal hopping robot Salto-1P estimates attitude and velocity from onboard sensing
- Roll and pitch estimates recover from disturbances using SLIP Hopping Orientation and Velocity Estimator (SHOVE)
- Over **300** consecutive fully autonomous, untethered hops spanning over 3 minutes

Salto-1P operates outdoors under human guidance

14:06–14:18	TuBT2.4

Robust Learning of Tactile Force Estimation through Robot Interaction

B. Sundaralingam[1,2], A. S. Lambert[1,3], A. Handa[1], B. Boots[1,3], T. Hermans[2], S. Birchfield[1], N. Ratliff[1], D. Fox[1,4]
1=NVIDIA, 2=Univ. of Utah, 3=Georgia Tech., 4= Univ. of Washington

- Collected Ground truth force from 3 different sources, over 140k samples.
- Novel inference method to estimate force from planar pushing as system of particles.
- 3D voxel grid encoding of tactile signals and novel loss scaling force to surface normal.
- Validation on object lifting & placement experiments.

14:18–14:30	TuBT2.5

Shallow-Depth Insertion: Peg in Shallow Hole Through Robotic In-Hand Manipulation

Chung Hee Kim and Jungwon Seo
Department of Electronic and Computer/Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology, Hong Kong

- Novel robotic manipulation technique for assembling thin peg-like objects into respective shallow holes
- Features dexterous manipulation actions that combine into a complete insertion operation
- Quasistatic stability attained through force-closure grasps
- Applicable to a variety of scenarios: dry cell/phone battery insertion, lego block assembly etc.

Shallow-depth insertion demonstrated through phone battery insertion.

14:30–14:42	TuBT2.6

Pre-Grasp Sliding Manipulation of Thin Objects Using Soft, Compliant, or Underactuated Hands

Kaiyu Hang, Andrew S. Morgan, and Aaron M. Dollar
Department of Mechanical Engineering and Material Science
Yale University, USA

- Our system integrates motion and grasp planning
- Our planner does not require start and goal configurations to be specified *a priori*
- We plan directly in the configuration space, and ensures a grasp solution after sliding
- We show that underactuated hands can greatly improve the efficiency

Government Forum - Session II

Chair
Co-Chair

PODS: Tuesday Session III

Chair

Co-Chair

Marine Robotics IV - 2.3.01

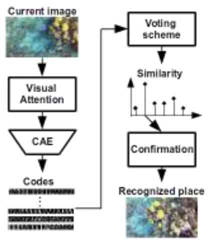
Chair
Co-Chair

15:15–16:30	TuCT1.1

Learning ad-hoc Compact Representations from Salient Landmarks for Visual Place Recognition in Underwater Environments

Alejandro Maldonado-Ramírez and L. Abril Torres-Méndez
Robotics and Advanced Manufacturing Group, CINVESTAV Saltillo, Mexico

- A convolutional autoencoder (CAE) is proposed to generate descriptors of regions detected by a visual attention algorithm.
- The learned descriptors are used in a voting scheme to find similarity between the last image in a sequence and the rest of them.
- By using that similarity, it is possible to recognize previously visited places.
- The approach has been tested on videos from real-life explorations in coral reefs.



15:15–16:30	TuCT1.2

Finding Divers with SCUBANet

Robert Codd-Downey and Michael Jenkin
Electrical Engineering and Computer Science, York University, Canada

- SCUBANet is a new underwater dataset focused around the recognition of underwater divers.
- Shows results from three different object detection neural networks after retraining on SCUBANet.

15:15–16:30	TuCT1.3

Robotic Detection of Marine Litter Using Deep Visual Detection Models

Michael Fulton, Jungseok Hong,
Md. Jahidul Islam, Junaed Satter
Computer Science, University of Minnesota, USA

- Developed a dataset consisting of real-world observations of trash, based on data from the JAMSTEC E-Library of Deep-sea Images.
- Evaluated the performance of four convolution neural network architectures for object detection on this dataset: YOLOv2, Tiny-YOLO, Faster-RCNN, and SSD.
- Evaluated these networks on three different hardware platforms: GPU (NVIDIA 1080, embedded GPU (NVIDIA TX2), and CPU (Intel i3-6100U)

An example YOLOv2 detection result

15:15–16:30	TuCT1.4

A Dual-Bladder Buoyancy System for a Cephalopod-Inspired AUV

Nick Sholl[1] and Kamran Mohseni[1,2]
[1]Department of Mechanical and Aerospace Engineering
[2]Department of Electrical and Computer Engineering
University of Florida, USA

- A nonlinear backstepping depth and pitch controller for autonomous underwater vehicles is presented.
- A Lyapunov stability analysis shows the system is asymptotically stable.
- Simulations of the CephaloBot AUV validate the results of the stability analysis.
- The controller is further validated with a one degree of freedom experiment.

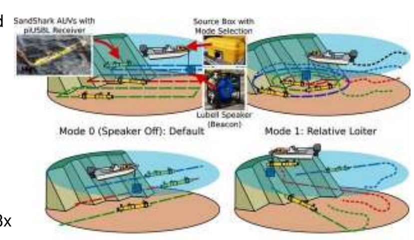
Single degree of freedom test cylinder (top) and CephaloBot AUV (bottom).

15:15–16:30	TuCT1.5

Relative Autonomy and Navigation for Command and Control of Low-Cost Autonomous Underwater Vehicles

Erin M. Fischell[1], Nicholas R. Rypkema[1][2] and Henrik Schmidt[2]
[1] Woods Hole Oceanographic Institution, Woods Hole, MA, USA
[2] Massachusetts Institute of Technology, Cambridge, MA, USA

- Multi-AUV command and control via time-sync beacon.
- Beacon-relative navigation and behavior.
- Group-wide cuing based on beacon waveform.
- Demonstrated with 3x SandShark AUVs.

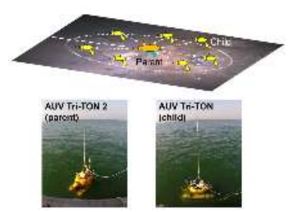


15:15–16:30	TuCT1.6

Accurate and Efficient Seafloor Observations with Multiple Autonomous Underwater Vehicles: Theory and Experiments in a Hydrothermal Vent Field

Takumi Matsuda, Toshihiro Maki, and Takashi Sakamaki
Institute of Industrial Science, The University of Tokyo, Japan

- We proposed multiple AUV navigation acoustically based on a single high-performance AUV (parent AUV).
- All AUVs can realize accurate self-localization thanks to relative positioning with the parent AUV.
- Sea experiments in a hydrothermal vent filed with 2 AUVs were conducted.
- Post-processing state estimation using sensor data from the experiments verified performance of the method.



Multiple AUV navigation acoustically based on a single high-performance AUV and sea experiments in a hydrothermal vent field.

Autonomous Vehicles I - 2.3.02

Chair
Co-Chair

15:15–16:30 TuCT1.1

Uncertainty-Aware Path Planning for Navigation on Road Networks Using Augmented MDPs

Lorenzo Nardi and Cyrill Stachniss
University of Bonn, Germany

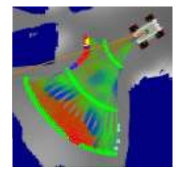
- **Planning** on road networks under **uncertainty** in the robot's position and action execution
- **Efficient** formulation that incorporates uncertainty without solving a full POMDP
- Action selection trades-off **safety** and **travel time**
- Policy **reduces** the number of **mistakes** that the robot makes during navigation with large position uncertainty

15:15–16:30 TuCT1.2

Real-time Model Based Path Planning for Wheeled Vehicles

Julian Jordan and Andreas Zell
Computer Science Department, University of Tübingen, Germany

- A real-time path planning method for wheeled vehicles on elevation maps is proposed
- It uses a detailed vehicle model to evaluate several safety criteria in real-time
- These safety criteria are used as additional heuristic values for a hybrid A* planner
- Evaluation in simulated and real world environments shows its reliability even in complex environments

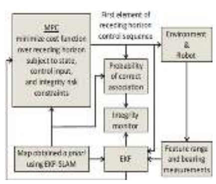


15:15–16:30 TuCT1.3

Integrity Risk-Based Model Predictive Control for Mobile Robots

Osama A. Hafez, Guillermo D. Arana, and Matthew Spenko
Mechanical and Aerospace Dept., Illinois Institute of Technology, USA

- This paper investigates the use of integrity risk metric in a model predictive control framework.
- Integrity risk is measure of localization safety that accounts for undetected faults.
- This work accounts for data association faults to guarantee localization safety over the receding horizon.
- The proposed controller generates a safe trajectory that minimizes a predefined cost function over receding horizon.



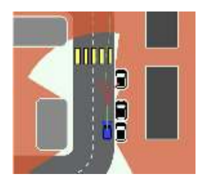
The proposed model predictive control architecture

15:15–16:30 TuCT1.4

What lies in the shadows? Safe and computation-aware motion planning for autonomous vehicles using intent-aware dynamic shadow regions

Yannik Nager, Andrea Censi and Emilio Frazzoli
Institute for Dynamic Systems and Control, ETH Zürich, Switzerland

- A method to reason about hypothetical agents existing beyond an autonomous vehicles' field of view is introduced
- It is incorporated into the planning process to generate passively-safe trajectories with respect to unseen agents.
- Furthermore, the method can be utilized to inform an autonomous vehicle about critical sensing directions

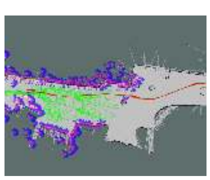


15:15–16:30 TuCT1.5

Dynamic Risk Density for Autonomous Navigation in Cluttered Environments without Object Detection

Alyssa Pierson[1], Cristian-Ioan Vasile[1,2], Anshula Gandhi[1], Wilko Schwarting[1], Sertac Karaman[2], and Daniela Rus[1]
[1]Computer Science and Artificial Intelligence Lab (CSAIL), MIT, USA
[2]Laboratory of Information and Decision Systems, MIT, USA

- Navigate congestion without object detection
- Use **dynamic risk density** to skew occupancy of environment by velocity field
- Autonomous wheelchair navigates cluttered hallway avoiding all pedestrians



15:15–16:30 TuCT1.6

Deep Local Trajectory Replanning and Control for Robot Navigation

Ashwini Pokle[1], Roberto Martín-Martín[1], Patrick Goebel[1], Vincent Chow[1], Hans M. Ewald[1], Junwei Yang[1], Zhenkai Wang[1], Amir Sadeghian[1], Dorsa Sadigh[1], Silvio Savarese[1], Marynel Vázquez[2]
Department of Computer Science, [1]Stanford University, [2]Yale University, USA

- Social navigation system adaptive to dynamic environments
- Hierarchical 3 level structure: classical motion planner + reactive replanner + velocity controller
- Replanner and velocity controller are neural networks trained to imitate human behavior

Figure 1. The robot can navigate to the goal while adapting to unmapped dynamic conditions using our method

Assembly - 2.3.03

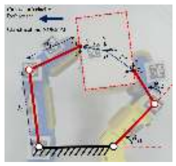
Chair
Co-Chair

15:15–16:30	TuCT1.1

Learning from Transferrable Mechanics Models: Generalizable Online Mode Detection in Underactuated Dexterous Manipulation

Andrew S. Morgan, Walter G. Bircher,
Berk Calli, and Aaron M. Dollar
Department of Mechanical Engineering and Materials Science,
Yale University, USA

- Learning manipulation is often gripper specific and does not generalize over different models
- By identifying and learning from geometrical representations of the system, learning can be transferred
- We test our approach with 3 different physical models of an underactuated hand
- Results show that mode prediction (normal, stuck, dropped, sliding) can be transferred through geometric features



Visually-extracted mechanical features

15:15–16:30	TuCT1.2

CARA system Architecture - A Click and Assemble Robotic Assembly System

Hatem Fakhurldeen, Farid Dailami and Anthony G. Pipe
Bristol Robotics Laboratory, United Kingdom

- The only input is an assembly file uploaded by the user through a web.
- It performs all the necessary planning before executing the assembly
- a real industrial product with tight tolerances was assembled from its CAD file only
- It combines all of the required components from previous advances in robotic assembly.

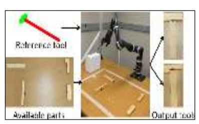
The system performing a torque limiter assembly using only CAD files.

15:15–16:30	TuCT1.3

Tool Macgyvering: Tool Construction Using Geometric Reasoning

Lakshmi Nair, Jonathan Balloch
and Sonia Chernova
Robot Autonomy and Interactive Learning Lab (RAIL),
Georgia Institute of Technology, USA

- **Motivation:** Improve robot adaptability by enabling them to construct tools when required tools are unavailable
- We formalized the tool construction problem to highlight different levels of problem complexity
- We introduced a geometric reasoning framework for tool construction from parts available in the environment
- Our framework successfully and efficiently constructed different tools from available parts



Robot takes available parts to output possible tool constructions

15:15–16:30	TuCT1.4

A Framework for Robot Manipulation: Skill Formalism, Meta Learning and Adaptive Control

Lars Johannsmeier and Sami Haddadin
Munich School of Robotics and Machine Intelligence, Technical University
Munich, Germany
Malkin Gerchow
Institute of Geoecology, Technical University Braunschweig, Germany

- Complexity of real-world manipulation problems is reduced by leveraging system knowledge.
- Adaptive impedance control is integrated with manipulation modelling.
- A difficult, contact-rich peg-in-hole problem with tolerances <0.1 mm is learned.
- State-of-the-art optimizers are compared.

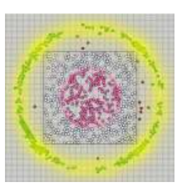
Figure caption is optional, use Arial 18pt

15:15–16:30	TuCT1.5

Open-Loop Collective Assembly Using a Light Field to Power and Control a Mini-Robot Swarm

Adam Bignell, Lily Li and Richard Vaughan
School of Computing Science, Simon Fraser University, Canada

- A population of simple mobile robots works to push blocks into polygonal shapes
- By dilating and contracting a light field we both power the robots and coordinate their activity to construct the shape
- We design dynamic light fields that robustly result in assembled shapes including nonconvex polygons
- A simple algorithm generates the light field patterns and is played open-loop



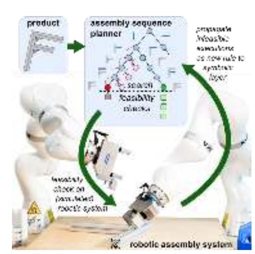
The 2D construction task during execution

15:15–16:30	TuCT1.6

Iteratively Refined Feasibility Checks in Robotic Assembly Sequnce Planning

Ismael Rodriguez, Korbinian Nottensteiner, Daniel Leidner,
Michael Kaßecker, Freek Stulp and Alin Albu-Schäffer
Robotics and Mechatronics, German Aerospace Center (DLR), Germany

- Feasibility checks of an assembly plan are performed in different complexity levels .
- The levels vary from considering only the product up to the whole robotic assembly system.
- Errors in these checks are propagated as symbolic rules to prune the search tree.
- We demonstrate the need for high-fidelity simulations on a two-armed robotic system.



Deep Perception - 2.3.04

Chair
Co-Chair

15:15–16:30	TuCT1.1

A Variational Observation Model of 3D Object for Probabilistic Semantic SLAM

Hyeonwoo Yu and Beomhee Lee
Electrical and Computer Engineering, Seoul National University, Republic of Korea

- We present a Bayesian object observation model for complete probabilistic semantic SLAM.
- We approximate the observation model of a 3D object with a tractable distribution.
- We also estimate the variational likelihood from the 2D image of the object to exploit its observed single view.

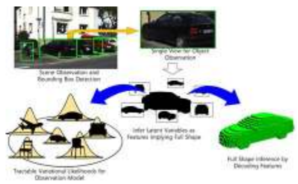


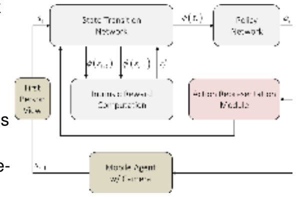
Fig. 1. In order to approximate the object observation model, we train the variational auto-encoder to achieve the object generative model.

15:15–16:30	TuCT1.2

Learning Action Representations for Self-supervised Visual Exploration

Changjae Oh and Andrea Cavallaro
Centre for Intelligent Sensing, Queen Mary University of London, UK

- A self-supervised **prediction network** that predict the (future) state from a state-action pair
- **Action representation module** that boosts the representation power
- Joint regression and triplet ranking loss for learning effectively visual features
- Faster training convergence than state-of-the-art with only +0.5% parameters

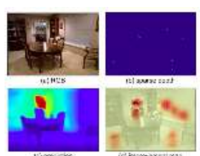


15:15–16:30	TuCT1.3

Plug-and-Play: Improve Depth Prediction via Sparse Data Propagation

Tsun-Hsuan Wang, Fu-En Wang, Juan-Ting Lin, Yi-Hsuan Tsai, Wei-Chen Chiu, Min Sun
National Tsing Hua University, Taiwan
National Chiao Tung University, Taiwan
NEC Labs America

- Given an (a) RGB image and a depth estimation / completion model, our PnP module **propagates information from (b) sparse points** and generates (c) improved depth prediction **without any re-training**. We show the (d) improvement denoted in red region.
- **Easily integrable** to all differentiable depth prediction approaches and simply **performed during inference**.
- Project page: https://zswang666.github.io/PnP-Depth-Project-Page/

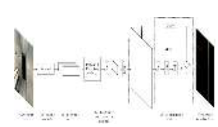


15:15–16:30	TuCT1.4

DFNet: Semantic Segmentation on Panoramic Images with Dynamic Loss Weights and Residual Fusion Block

Wei Jiang, Yan Wu*, Linting Guan, Junqiao Zhao
Computer Science and Technology, Tongji University, China

- Semantic segmentation of lane markings and parking slots on panoramic images
- Dynamic loss weights with threshold to overcome the negtive effect of imblance dataset
- Residual fusion block to refine the segmentation area



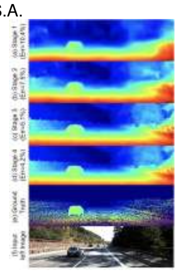
Overview of DFNet.

15:15–16:30	TuCT1.5

Anytime Stereo Image Depth Estimation on Mobile Devices

Yan Wang[1], Zihang Lai[2], Gao Huang[1], Brian H. Wang[3], Laurens van der Maaten[4], Mark Campbell[3], Kilian Q. Weinberger[1]
1. Computer Science, Cornell University, U.S.A.
2. Computer Science, University of Oxford, U.K.
3. Mechanical Engineering, Cornell University, U.S.A.
4. Facebook AI Research, U.S.A.

- Our model, AnyNet, estimates stereo depth while **dynamically trading off between speed and accuracy**.
- AnyNet rapidly performs an initial estimation, then refines it if more computation time is allotted. (See figure)
- On the KITTI dataset, outperformed other methods by 10 percentage points accuracy at > 30 FPS.

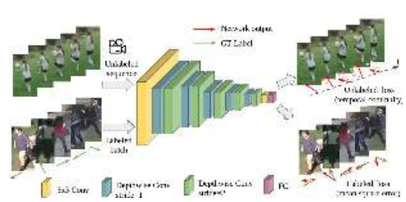


15:15–16:30	TuCT1.6

Improved Generalization of Heading Direction Estimation for Aerial Filming Using Semi-supervised Regression

air lab

1. We propose a novel semi-supervised approach that uses temporal continuity in sequential data for heading direction estimation problem;
2. We compare our method with baseline approaches, showing that we significantly reduce the amount of labeled data required to train a robust model;
3. We experimentally verify the robustness of our proposed method, while running on an onboard computer of a drone, following an actor.



Carnegie Mellon University
The Robotics Institute

YAMAHA

Path Planning I - 2.3.05

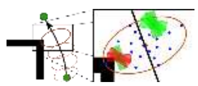
Chair
Co-Chair

15:15–16:30	TuCT1.1

Graduated Fidelity Lattices for Motion Planning under Uncertainty

Adrián González-Sieira, Manuel Mucientes and Alberto Bugarín
Research Centre in IT (CiTIUS), Univ. of Santiago de Compostela, Spain

- Obtention of safe and optimal paths in terms of traversal time.
- Reliable estimation of the probability of collision using the robot real shape.
- Graduated fidelity lattice which adapts to the obstacles in the map.
- Efficient multi-resolution, low dimensional heuristic.



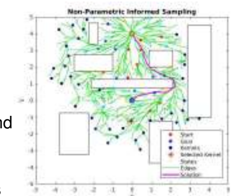
Estimation of the probability of collision using the robot real shape

15:15–16:30	TuCT1.2

Non-Parametric Informed Exploration for Sampling-Based Motion Planning

Sagar Suhas Joshi and Panagiotis Tsiotras
Institute for Robotics and Intelligent Machines
Georgia Institute of Technology, USA

- Efficient exploration is crucial for speedy convergence of sampling-based planning
- Informed Sampling method focuses search based on the current best solution
- Proposed Non-Parametric (NP) Informed sampling initializes a set of kernel vertices and generates new samples in their vicinity
- Heuristics and past obstacle collision data is used to prioritize search and reduce samples in obstacle space.



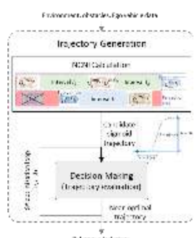
Color of the kernel Vertices signify their priority

15:15–16:30	TuCT1.3

Simulated Annealing-optimized Trajectory Planning within Non-Collision Nominal Intervals for Highway Autonomous Driving

Laurène Claussmann[1,2], Marc Revilloud[2] and Sébastien Glaser[3]
[1]Dpt. Autonomous Vehicles, Institut VEDECOM, France
[2]LIVIC, IFSTTAR, France
[3]CARRS-Q, Queensland University of Technology, Australia

- All-in-one architecture for decision making and trajectory generation
- Characterization of a set of Non-Collision Nominal Intervals (NCNI) under a velocity-space representation
- Optimizing the sigmoid trajectory parameters within the NCNI using a Simulated Annealing (SA) algorithm
- Real-time optimization for any kind of multi-criteria cost functions

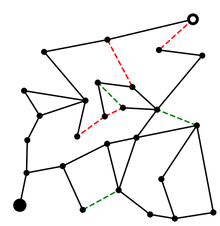


15:15–16:30	TuCT1.4

On the Impact of Uncertainty for Path Planning

Jérôme Guzzi, R. Omar Chavez-Garcia,
Luca M. Gambardella, Alessandro Giusti
IDSIA, USI-SUPSI, Switzerland

- Path planning on graphs with edges whose traversal probability is estimated by an imperfect classifier.
- Exact and heuristics policies solve the Canadian Traveller Problem.
- Large simulation campaign on synthetic and real-world maps to study the impact of uncertainty on the solutions.

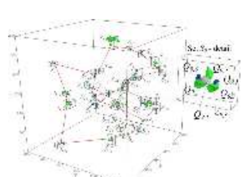


15:15–16:30	TuCT1.5

Fast Heuristics for the 3D Multi-Goal Path Planning based on the Generalized Traveling Salesman Problem with Neighborhoods

Jan Faigl and Petr Váňa and Jindřiška Deckerová
Computational Robotics Laboratory
Artificial Intelligence Center, Faculty of Electrical Engineering
Czech Technical University in Prague, Czechia

- Generalized Traveling Salesman Problem with Neighborhoods (GTSPN) with convex 3D regions (ellipsoids, polyhedra, hybrid)
- Efficient methods based on the decoupled approach and unsupervised learning of the **Growing Self-Organizing Array** (GSOA)
- Improving post-processing optimization
- Solutions of evaluated instances found up to **two orders of magnitude faster** than existing approaches



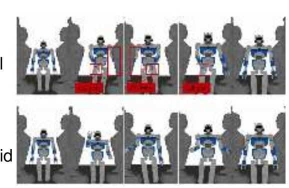
An instance of GTSPN and its solution found by the proposed method

15:15–16:30	TuCT1.6

Continuous Signed Distance Computation for Polygonal Robots in 3D

Youngeun Lee[1], Abderrahmane Kheddar[2], and Young J. Kim[1]
[1]Computer Science and Engineering, Ewha Womans University, Korea
[2]CNRS-AIST Joint Robotics Laboratory, Japan
[2]CNRS-University of Montpellier, France

- **Adaptive subdivision** (AS) to evaluate both positive and negative distance functions for moving general polygonal models in 3D
- Applicable to **optimization-based motion planning** for HRP-2 humanoid robot
- Guarantees **error-bounded results** in terms of the distance calculation



Motion Planning Benchmark
Top: without adaptive subdivision
Bottom: with adaptive subdivision

Visual Localization I - 2.3.06

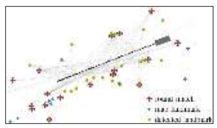
Chair
Co-Chair

15:15–16:30	TuCT1.1

Localization with Sliding Window Factor Graphs on Third-Party Maps for Automated Driving

Daniel Wilbers[1,2] and Christian Merfels[1,2] and Cyrill Stachniss[2]
[1]Volkswagen Group Research, Germany
[2]Institute of Geodesy and Geoinformation, University of Bonn, Germany

- We address the problem of urban vehicle localization on third-party landmark maps
- The approach relies on low-cost GNSS, odometry, and pole-like landmarks detected in lidar data
- We exploit the sliding window formulation to revise map associations
- Overall our graph-based optimization approach is fast enough for automated driving and outperforms particle filters



15:15–16:30	TuCT1.2

Night-to-Day Image Translation for Retrieval-based Localization

Asha Anoosheh[1], Radu Timofte[1], Luc Van Gool[1]
Torsten Sattler[3], Marc Pollefeys[2,4]
[1]D-ITET, ETH Zürich, Switzerland; [2]D-INFK, ETH Zürich, Switzerland; [3]Chalmers University of Technology; [4]Microsoft, Switzerland

- Our specialized **ToDayGAN** model converts night images to daytime, before querying existing day images
- Over ***250% improvement*** in localization benchmarks against other state-of-the-art methods
- Requires ***very few training images*** (and no correspondences) to fit any custom environment
- *Code & models: https://github.com/AAnoosheh/ToDayGAN*

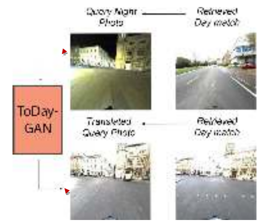


Image retrieval using nighttime image vs. converted daytime image

15:15–16:30	TuCT1.3

Accurate and Efficient Self-Localization on Roads using Basic Geometric Primitives

Julius Kümmerle, Marc Sons, Fabian Poggenhans, Tilman Kühner
FZI Research Center for Information Technology, Germany
Martin Lauer and Christoph Stiller
Institute of Measurement and Control Systems, Karlsruhe Institute of Technology (KIT), Germany.

- Highly accurate localization for next generation series cars
- Localization based on geometric primitives
- Compact map with less than 8kB/km
- Mean position error <10cm and mean yaw angle error <0.25° at 50Hz.

15:15–16:30	TuCT1.4

Efficient 2D-3D Matching for Multi-Camera Visual Localization

Marcel Geppert[1], Peidong Liu[1], Zhaopeng Cui[1], Marc Pollefeys[1,2], Torsten Sattler[3]
[1]ETH Zurich, [2]Microsoft Switzerland, [3]Chalmers University of Technology

- Running feature matching and pose estimation in parallel reduces the feature matching effort for localization.
- We tailor the prioritization function for feature matching to the multi-camera setup.
- Efficient geometric filtering can reduce the matching effort if a pose prior is available.
- We fuse large-scale visual localization and Visual Odometry for drift-less realtime pose estimation.

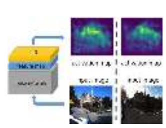
Established correspondences after matching a small subset of all image features

15:15–16:30	TuCT1.5

Localizing Discriminative Visual Landmarks for Place Recognition

Zhe Xin, Yinghao Cai, Tao Lu, Xiaoxia Xing, Jixiang Zhang, Yiping Yang, Yanqing Wang
Institute of Automation, Chinese Academy of Sciences, Beijing, China
Shaojun Cai
UISEE Technologies Beijing Co., Ltd

- Dealing with the problem of appearance-based place recognition
- Extract the robust image representation that is resilient against environmental changes
- Localizing discriminative visual landmarks that positively contribute to the similarity measurement
- Combining with ORB-SLAM to highlight the strength of the learned feature extractor



Landmark localization network

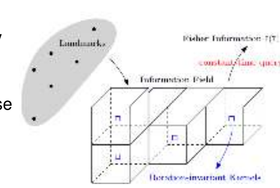
15:15–16:30	TuCT1.6

Beyond Point Clouds: Fisher Information Field for Active Visual Localization

Zichao Zhang and Davide Scaramuzza
Dep. of Informatics, University of Zurich
Dep. of Neuroinformatics, University of Zurich and ETH Zurich

- We propose an efficient volumetric map for active visual localization.
- The visual information from **an arbitrary number of landmarks** is compactly summarized in a 3D voxel grid.
- The Fisher information of any 6 DoF pose can be calculated **in constant time**, regardless of the number of landmarks.
- Our method is open source and can be readily used for different planning tasks.

https://github.com/uzh-rpg/rpg_information_field



Deep Learning for Navigation III - 2.3.07

Chair
Co-Chair

15:15–16:30	TuCT1.1

Deep Reinforcement Learning of Navigation in a Complex and Crowded Environment with a Limited Field of View

Jinyoung Choi, Kyungsik Park, Minsu Kim and Sangok Seok
NAVER LABS

- Deep reinforcement learning of navigation in a complex and crowded environment with a limited FOV
- Novel LSTM-LMC network architecture for more accurate learning of environment dynamics and state-action value
- Environment randomization for robust performance in real world
- Performance improved in both simulation and real world.

15:15–16:30	TuCT1.2

Sim-to-Real Transfer Learning using Robustified Controllers in Complex Dynamics Robot Tasks

Jeroen Vanbaar, Alan Sullivan, Radu Cordorel , Devesh Jha, Diego Romeres, and Daniel Nikovski
MERL-Mitsubishi Electric Research Laboratories, Cambridge, USA

- Training tasks in simulation and transfer to real robot is highly desirable.
- Train *robustified* policies in simulation, by randomizing appearance, physics and system setup parameters during RL.
- We demonstrate our method for a task involving complex dynamics.
- We show that robustified policies need fewer time steps for transfer compared to non-robustified policies.

A maze game is mounted on a robotic arm, and the goal is to move the marble to the center by tilting the maze game.

15:15–16:30	TuCT1.3

Generalization through Simulation: Integrating Simulated and Real Data into Deep Reinforcement Learning for Vision-Based Autonomous Flight

Katie Kang*, Suneel Belkhale*, Gregory Kahn*, Pieter Abbeel, Sergey Levine
Berkeley AI Research (BAIR), UC Berkeley, USA

- Goal: enable vision-based navigation for nano aerial vehicles using deep reinforcement learning
- However, learning-based methods require data, which can be very costly to gather
- Generalization through simulation: leverage simulation to learn generalizable visual features, and real data for dynamics
- Outperforms other sim-to-real approaches for collision avoidance with Crazyflie quadrotor

15:15–16:30	TuCT1.4

Crowd-aware Robot Navigation with Attention-based Deep Reinforcement Learning

Changan Chen, Yuejiang Liu, Sven Kreiss and Alexandre Alahi
VITA, EFPL, Switzerland

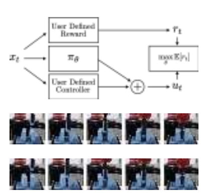
- Jointly model Human-Robot as well as Human-Human Interactions
- Aggregate interactions with a self-attention mechanism to learn the representation of crowd dynamics
- Demonstrated the effectiveness of our model in both simulation and real world experiments

15:15–16:30	TuCT1.5

Residual Reinforcement Learning for Robot Control

Tobias Johannink*[1], Shikhar Bahl*[2], Ashvin Nair*[2], Jianlan Luo[12], Avinash Kumar[1], Matthias Loskyll[1], Juan Aparicio Ojea[1], Eugen Solowjow[1], Sergey Levine[2]
[1]Siemens Corporation, [2]University of California, Berkeley

- Many control problems in manufacturing include contacts and friction; difficult to capture with first-order physical modeling.
- Reinforcement learning (RL) methods are capable of learning continuous robot controllers from interactions with the environment, even for problems that include friction and contacts.
- **Residual RL**: solve difficult control problems in the real world by decomposing them into a part that is solved efficiently by conventional feedback control methods, and the residual which is solved with RL.



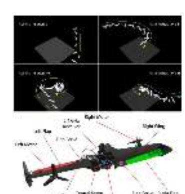
Top: residual RL method.
Bottom: rollouts from learned block insertion policy

15:15–16:30	TuCT1.6

A Reinforcement Learning Approach for Control of a Nature-Inspired Aerial Vehicle

Danial Sufiyan, Luke Thura Soe Win, Kyi Hla Win, Gim Song Soh, and Shaohui Foong
Engineering Product Development, Singapore University of Technology and Design, Singapore

- A reinforcement learning approach for the development of a position controller for a nature-inspired aerial vehicle was explored
- Deep Deterministic Policy Gradients (DDPG) with Ape-X Distributed Prioritized Experience Replay was used to train a neural network control policy with a simulated model of the UAV
- Multiple position control tests were conducted with the neural network controller on a physical prototype (shown on the right)



Training visualization (top) and physical prototype (bottom)

Formal Methods - 2.3.08

Chair

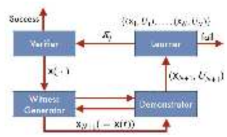
Co-Chair

15:15–16:30	TuCT1.1

Formal Policy Learning from Demonstration for Reachability Properties

Hadi Ravanbakhsh and Sanjit A. Seshia
EECS Department, University of California Berkeley, USA
Sriram Sankaranarayanan
CS Department, University of Colorado Boulder, USA

- Iterative learning from demonstration data
- Components:
  - Learner uses a linear model
  - Adversarial verifier actively looks for counter-examples, generating useful data
  - Demonstrator provides a set of possible actions
- Fast convergence of the learning process



Overview of the Formal Learning Framework

15:15–16:30	TuCT1.2

Formalized Task Characterization for Human-Robot Autonomy Allocation

Michael Young, Christopher Miller, Youyi Bi, Wei Chen
Mechanical Engineering, Northwestern University, USA
Brenna D. Argall
Computer Science and Mechanical Engineering, Northwestern University, USA

- Utilizing formal methods, we characterize task difficulty for tasks performed by human-robot teams.
- Our experimental results show that rotational task features contribute most to difficulty for robotic manipulation.
- We use shared-control to alleviate the effect of these features on difficulty and performance.
- We find that our shared-control improves performance and reduces difficulty when these features are present.

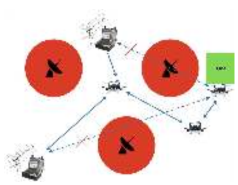
Kinova Arm and Experiment Environment

15:15–16:30	TuCT1.3

DoS-Resilient Multi-Robot Temporal Logic Motion Planning

Xiaowu Sun, Rohitkrishna Nambiar, Matthew Melhorn, and Yasser Shoukry
Electrical and Computer Engineering, University of Maryland, College Park
Pierluigi Nuzzo
Electrical and Computer Engineering, University of Southern California

- **Problem:** multi-robot motion planning from Linear Temporal Logic specifications in the presence of Denial-of-Service (DoS) attacks.
- **Solution:** A novel Satisfiability Modulo Convex programming (SMC) encoding that captures the mission, resilience against DoS, and differential constraints.
- **Results:** A provably correct and efficient SMC-based algorithm for DoS-resilient motion planning.



15:15–16:30	TuCT1.4

Task-Based Design of Ad-hoc Modular Manipulators

Thais Campos* and Hadas Kress-Gazit
Mechanical and Aerospace Engineering, Cornell University, USA
Jeevana Priya Inala* and Armando Solar-Lezama
CSAIL, Massachusetts Institute of Technology, USA

- A framework for synthesizing provably-correct task-based design and control for modular manipulators
- For partially infeasible tasks, our approach identifies a feasible subtask and generate a solution
- Our approach proposes multiple solutions to achieve the whole task when a single one cannot
- Our approach outperforms state-of-the-art algorithms in highly constrained environments

15:15–16:30	TuCT1.5

Point-Based Policy Synthesis for POMDPs with Boolean and Quantitative Objectives

Yue Wang, Swarat Chaudhuri, Lydia Kavraki
Department of Computer Science, Rice University, USA

- Studies POMDPs with boolean and quantitative objectives for both correctness and optimality
- Extends policy synthesis for POMDPs with only boolean objectives with policy iteration
- Results demonstrate that PBPS produces good approximate policies that achieve given safe-reachability objectives

Range and Reconstruction - 2.3.09

Chair

Co-Chair

15:15–16:30	TuCT1.1

SweepNet: Wide-baseline Omnidirectional Depth Estimation

Changhee Won, Jongbin Ryu, Jongwoo Lim*
Department of Computer Science, Hanyang University, Korea

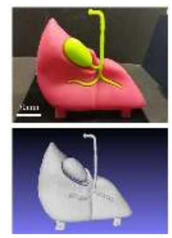
- The article address omnidirectional depth estimation using multiple wide field of view fisheye cameras.
- The proposed network, SweepNet computes the matching cost from the spherical images pair using global contexts in the sphere sweeping.
- The realistic synthetic urban datasets are rendered for training and testing the deep neural network.

15:15–16:30	TuCT1.2

3D Surface Reconstruction Using A Two-Step Stereo Matching Method Assisted with Five Projected Patterns

Congying Sui[1], Hejing He[1], Congyi Lyu[2], Zerui Wang[1] and Yun-Hui Liu[1]
[1]T Stone Robotics Institute and Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Hong Kong
[2] Smarteye Tech, Shenzhen, China

- Novel framework based on active stereo matching for fast and accurate 3D reconstruction.
- Two-step matching (coarse-precise matching) to enhance the efficiency and accuracy
- Only five phase-shifting patterns are projected to realize high encoding accuracy and robustness to noises.
- Correspondence refinement method is proposed to further enhances the precision.

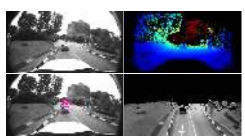


15:15–16:30	TuCT1.3

Real-Time Dense Mapping for Self-Driving Vehicles using Fisheye Cameras

Zhaopeng Cui[1], Lionel Heng[2], Ye Chuan Yeo[2], Andreas Geiger[3], Marc Pollefeys[1,4], and Torsten Sattler[5]
[1]Department of Computer Science, ETH Zurich, [2]DSO National Laboratories,
[3]MPI-IS and University of Tübingen, [4]Microsoft Switzerland, [5]Chalmers University of Technology

- Our paper describes a real-time dense geometric mapping algorithm for large-scale environments purely using fisheye cameras.
- A new multi-scale strategy is proposed for fisheye depth map estimation to maintain both depth map accuracy and efficiency.
- Multiple depth filtering and local map pruning techniques are utilized to handle noises.
- A fast object detection framework is used to remove potentially dynamic objects.



The 3D map is recovered in real-time from multiple fisheye images with fast depth estimation and object detection.

15:15–16:30	TuCT1.4

Tightly-Coupled Aided Inertial Navigation with Point and Plane Features

Yulin Yang, Patrick Geneva*, Xingxing Zuo**, Kevin Eckenhoff, Yong Liu** and Guoquan Huang
Dept. Mechanical Engineering, University of Delaware, USA
*Dept. Computer and Information Science, University Of Delaware, USA
**Institute of Cyber-System and Control, Zhejiang University, China

- Leveraging point and plane features, a tightly-coupled inertial navigation estimator applicable to a camera and a generic depth sensor is designed.
- An effective plane feature initialization for Kalman filter-based SLAM is introduced.
- Point-on-plane constraints are exploited to enhance the estimation accuracy.
- Both Monte-Carlo simulations and real-world experiments are performed to verify the estimator.

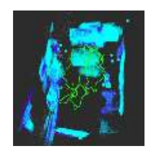


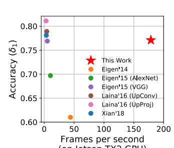
Figure: Real-world experiments of the proposed estimator with Intel ZR300 (RGBD).

15:15–16:30	TuCT1.5

FastDepth: Fast Monocular Depth Estimation on Embedded Systems

Diana Wofk*, Fangchang Ma*, Tien-Ju Yang, Sertac Karaman, Vivienne Sze
Massachusetts Institute of Technology, USA

- We present FastDepth, a deep neural network that performs **high accuracy, high throughput** monocular depth estimation.
- We use a lightweight network architecture with a **low-latency encoder and decoder.**
- We apply **network pruning** to further simplify the entire encoder-decoder network.
- We perform **hardware-specific compilation** to increase inference speed on a target embedded platform.



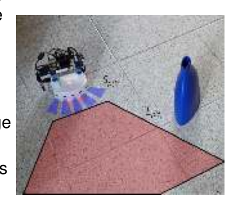
Our work is an order of magnitude faster while maintaining accuracy.

15:15–16:30	TuCT1.6

Learning Long-Range Perception Using Self-Supervision from Short-Range Sensors and Odometry

Mirko Nava, Jérôme Guzzi, R. Omar Chavez-Garcia, Luca M. Gambardella and Alessandro Giusti
Dalle Molle Institute for Artificial Intelligence, USI-SUPSI, Lugano (Switzerland)

- Long-range sensors produce a large amount of data that is hard to interpret, while short-range sensors are easy to interpret but are limited in range
- We propose a self-supervised approach to predict the future outputs of short-range sensors given the current outputs of long-range sensors
- We instantiate the approach on different robots and settings to evaluate the performance and robustness of predictions in unseen scenarios



Human-Robot Interaction IV - 2.3.10

Chair
Co-Chair

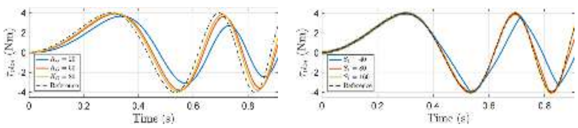
15:15–16:30	TuCT1.1

Sliding Mode disturbance observer

State of the Art	Proposed Approach
Classical Residual	Super twisting sliding mode control approach
Linear observer dynamics	Nonlinear observer dynamics
Asymptotic convergence for constant external forces	Finite time convergence for a broad class of signals

$$r = K_O\left(p - \int_0^t (\tau + C^\top \dot{q} - g + r)\,ds - p(0)\right)$$

$$\dot{\hat{p}} = \tau + C^\top \dot{q} - g - T|\tilde{p}|^{\frac{1}{2}}\,\mathrm{sgn}(\tilde{p}) + \sigma\,,\quad \dot{\sigma} = -S\,\mathrm{sgn}(\tilde{p})\,,$$

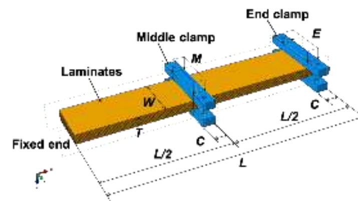


15:15–16:30	TuCT1.2

Discrete Layer Jamming for Safe Co-Robots

Yitong Zhou, Leon M. Headings, and Marcelo J. Dapino
Department of Mechanical and Aerospace Engineering
The Ohio State University, USA

- We propose a tunable stiffness mechanism for co-robot links based on discrete layer jamming
- Each link is made of multiple thin layers of ABS and mechanical clamps
- Bending stiffness increases with clamp pressure
- Near 17 times bending stiffness change is achieved (0.023 to 0.407 N/mm)



Concept of a discrete layer jamming link

15:15–16:30	TuCT1.3

Admittance Control for Human-Robot Interaction Using an Industrial Robot Equipped with a F/T Sensor

Eleonora Mariotti, Emanuele Magrini, and Alessandro De Luca
DIAG, Sapienza University of Rome, Italy

- physical Human-Robot Interaction (pHRI) for industrial robots with closed control architecture and a F/T sensor mounted at the end-effector
- no information on robot dynamics and low-level controllers, no joint torque sensors, users can only specify velocity/position reference inputs
- high-pass/low-pass filtering of motor currents
- features whole-body collision detection, distinguishing accidental/intentional contacts, and admittance control for collaborative tasks

Simultaneous pHRI at the end-effector and robot body level

15:15–16:30	TuCT1.4

Effect of Mechanical Resistance on Cognitive Conflict in Physical Human-Robot Collaboration

Stefano Aldini, Marc Carmichael and Dikai Liu
Centre for Autonomous Systems, University of Technology Sydney, Australia
Ashlesha Akella, Avinash Singh, Yu-Kai Wang and Chin-Teng Lin
Centre for Artificial Intelligence, University of Technology Sydney, Australia

- EEG data are used to estimate the cognitive conflict during physical human-robot collaboration (pHRC) through the measurement of prediction error negativity (PEN).
- Experiments demonstrate how mechanical resistance during pHRC can affect PEN.
- Results can lead to an adaptive control that enhance the intuitiveness of the interaction with a human co-worker.

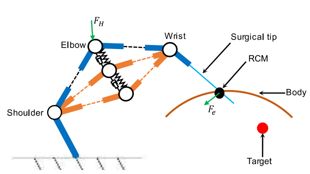
Participant running the experiment while his brain activity is recorded.

15:15–16:30	TuCT1.5

Improved Human-Robot Collaborative Control of Redundant Robot for Teleoperated Minimally Invasive Surgery

Hang Su, Giancarlo Ferrigno and Elena De Momi
Department of Electronics, Information and Bioengineering, Politecnico di Milano, Italy
Chenguang Yang
Bristol Robotics Laboratory, University of the West of England, UK

- Compliant null-space behavior
- Human-robot interaction,
- Remote center of motion
- Hierarchical control framework



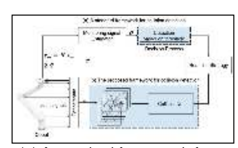
Improved Human-Robot Collaborative Control

15:15–16:30	TuCT1.6

Collision Detection for Industrial Collaborative Robots: A Deep Learning Approach

Young Jin Heo, Woongyong Lee, and Jonghoon Park
CILab, Neuromeka, South Korea
Dayeon Kim, Hyoungkyun Kim, and Wan Kyung Chung
Mechanical Engineering, POSTECH, South Korea

- Conventional collision detection method based on momentum-based observer has trade-off between **sensitivity to collision** and **robustness to false alarm**
- CollisionNet pipeline that applies convolutional neural network is proposed to achieve more sensitive and faster response to human-robot collision without detection failure
- The performances are quantitatively evaluated by many experiments



(a) A standard framework for collision detection, (b) The proposed CollisionNet for collision detection

Novel Applications II - 2.3.11

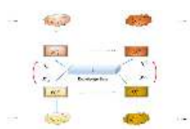
Chair
Co-Chair

15:15–16:30	TuCT1.1

Lifelong Learning for Heterogeneous Multi-Modal Tasks

Huaping Liu, Fuchun Sun, Bin Fang
Department of Computer Science and Technology,
Tsinghua University, China

- A multi-modal lifelong learning framework which deals with the consecutive multi-modal learning tasks.
- An efficient algorithm to jointly update the
- feature representation and the knowledge base, under the multi-modal lifelong learning framework.
- Experimental results show that exploiting the intrinsic relation between tasks and modalities is beneficial to improve the recognition performance.

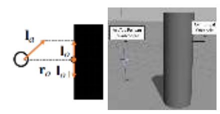


15:15–16:30	TuCT1.2

Magnetic-field-inspired Navigation for Quadcopter Robot in Unknown Environments

Ahmad Ataka and Hak-Keung Lam
Department of Informatics, King's College London, United Kingdom
Kaspar Althoefer
Faculty of Science and Engineering, Queen Mary University of London, United Kingdom

- We propose a reactive magnetic-field-inspired navigation for under-actuated quadcopter robot in unknown environments consisting of arbitrary-shaped convex obstacles.
- It is able to reactively generate motion commands relying only on a local sensory information without prior knowledge of the obstacles' shape or location and without getting trapped in local minima configurations.



Magnetic-field-inspired algorithm for Quadcopter navigation

15:15–16:30	TuCT1.3

Human-Care Rounds Robot with Contactless Breathing Measurement

Ryo Saegusa and Duc Minh Duong
Kanagawa Institute of Technology, Japan
Hirokazu Ito
Toyohashi University of Technology, Japa

- A contactless breathing measurement system is proposed.
- The system is implemented on the human-care rounds robot “Lucia.”
- The proposed system was experimentally evaluated in a nursing facility.
- The presence of breathing was detected within the accuracy of 90% or more.
- The ability of anomaly detection in breathing was suggested.

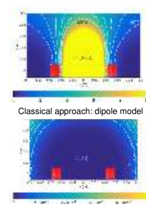
Contactless Breathing Measurement

15:15–16:30	TuCT1.4

An Improved Control-Oriented Modeling of the Magnetic Field

Maxime Etiévant, Aude Bolopion, Nicolas Andreff
AS2M department, FEMTO-ST Institute, UBFC – CNRS, France
Stéphane Régnier
INTERACTION department, ISIR, Sorbonne Université – CNRS, France

- The growing interest of magnetically actuated microrobots necessitates precise and fast to compute magnetic field models
- We propose an original analytical model based on elliptic integral functions
- We evaluate our model compared to classical approaches: finite element and dipole approximation
- Our approach proves to be an excellent trade-off between computation time and accuracy



Comparison of the magnetic field magnitude error w.r.t finite element results

15:15–16:30	TuCT1.5

Efficient Micro Waveguide Coupling based on Microrobotic Positioning

Panbing Wang, Denfeng Li, Haojian Lu, Yuanyuan Yang, Shihui Shen, and Yajing Shen
Department of Biomedical Engineering, City University of Hong Kong, Hong Kong SAR, China

- Development of the micro positioning system for automatic microwaveguide coupling in fabrication of optical devices.
- Machine vision method to recognize the position of the fiber in the alignment process.
- Build of the fuzzy controller for the path planning of the positioner to realize microwaveg-uide coupling.

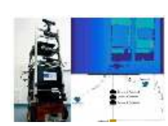
The micro positioning system for the automatic microwaveguide coupling.

15:15–16:30	TuCT1.6

An Empirical Evaluation of Ten Depth Cameras for Indoor Environments

Markus Suchi, Georg Halmetschlager-Funek and Markus Vincze
Automation and Control Institute, TU Wien, Austria
Martin Kampel
Computer Vision Lab, TU Wien, Austria

- Evaluation of 10 depth sensors using 3 different technologies
- 5 different experiments
- Metrics: Precision, Bias
- Multiple distances, different materials, varying lighting conditions, influence of additional sensors



Depth sensor test setup

Medical Robotics VII - 2.3.12

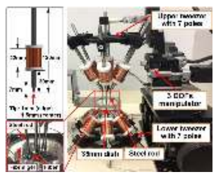
Chair
Co-Chair

15:15–16:30	TuCT1.1

Assembly of Multilayered Hepatic Lobule-like Vascular Network by using Heptapole Magnetic Tweezer

Eunhye Kim[1], Masaru Takeuchi[2], Taro Kozuka[1], Takuto Nomura[1], Akiyuki Hasegawa[1], Akihiko Ichikawa[1], Qiang Huang[3], and Toshio Fukuda[1,3]
[1]Dept. of Mechatronics Engineering, Meijo University, Japan
[2]Dept. of Micro-Nano Systems Engineering, Nogoya University, Japan
[3]Intelligent Robotics Institute, Beijing Institute of Technology, China

- Design a magnetic tweezer with seven poles based on 3D simulation data
- Construct multi-layered vascular network in 3D cellular structure by using heptapole magnetic tweezer
- Verify the efficiency of the channel by analyzing the cell viability according to the distance from the channel

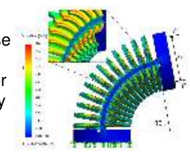


15:15–16:30	TuCT1.2

Design and Fabrication of a 3D Printed Metallic Flexible Joint for Snake-Like Surgical Robot

Yang Hu, Lin Zhang, Wei Li and Guang-Zhong Yang
The Hamlyn Centre for Robotic Surgery, Imperial College London

- The proposed design has less stress concentration and longer fatigue life because stress can be more uniformly distributed for bending a helical structure. The channels for routing the tendons can be easily created by using the 3D printing technique.
- The proposed design is a monolithic compliant structure, which requires less manufacturing and assembling effort.

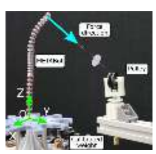

FEA of the proposed flexible joint mechanism

15:15–16:30	TuCT1.3

Comparison of Modeling Approaches for a TACR with Three Extensible Segments

M. T. Chikhaoui
Univ. Grenoble Alpes, CNRS, Grenoble INP, TIMC-IMAG, France
S. Lilge, S. Kleinschmidt, and J. Burgner-Kahrs
Laboratory for Continuum Robotics, Leibniz Universitaet Hannover, Germany

- Unified framework for Cosserat rod (CR) and beam mechanics (BM) model comparison in loaded and free-space experimental cases.
- Performance metrics: 3D shape difference, segments' end distance, and update rate.
- Model accuracy decreases from robot base to tip and with complex tendon actuations.
- CR is slightly more accurate than BM, yet exhibits significantly lower computation rate.


A tendon actuated continuum robot (TACR) under external load.

15:15–16:30	TuCT1.4

Motion Control of Cable-Driven Continuum Catheter Robot through Contacts

Zhongkai Zhang[1], Jeremie Dequidt[1], Junghwan Back[2], Hongbin Liu[2], Christian Duriez[1]
1. DEFROST Team, INRIA & University of Lille, France
2. HaMMeR Lab, King's College London, UK

- Model catheter robot with contacts using Finite Element Method;
- Decoupled motion control allows to control insertion and bending independently;
- Decoupled motion control can avoid the Jacobian matrix rotation without considering the contact;
- A simplified optimization method to compute the quadratic programming (QP) problem with a linear complementarity problem (LCP).

15:15–16:30	TuCT1.5

Sizing the aortic annulus with a robotised, commercially available soft balloon catheter: in vitro study on idealised phantoms

A. Palombi, G.M. Bosi, S. Homer-Vanniasinkam, G. Burriesci, **H.A. Wurdemann**
University College London, United Kingdom
S. Di Giuseppe, E. De Momi, Politecnico di Milano, Italy

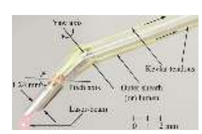
- **New, intra-operative approach** to determine the diameter of the aortic annulus **exploiting intra-balloon pressure and volume data**, acquired from a robotised valvuloplasty balloon catheter.
- Sizing algorithm allowing to precisely estimate the annular diameter relies on a characterised analytical model of the balloon free inflation and an iterative method based on linear regression.

15:15–16:30	TuCT1.6

Miniature Robotic Tubes with Rotational Tip-Joints as a Medical Delivery Platform

Rohith Karthikeyan, Shivanand Pattanshetti and Seok Chang Ryu
Department of Mechanical Engineering, Texas A&M University, USA

- Laser-machined hinges minimize tool-size, improve positioning accuracy, and enable the compact articulation of surgical instruments.
- An intuitively simple model can demonstrably and adequately describe tool behavior unlike flexure joints.
- Such hinged instruments are sufficiently robust, and capable of delivering material, devices/ drugs during in vivo operation.


Instrumented prototype: 2-DOF robotic arm w/optical fiber in working channel

Soft Robots IV - 2.3.13

Chair

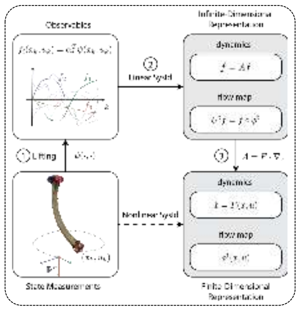
Co-Chair

15:15–16:30	TuCT1.1

Nonlinear System Identification of Soft Robot Dynamics Using Koopman Operator Theory

Daniel Bruder, C. David Remy, and Ram Vasudevan
Mechanical Engineering, University of Michigan, USA

- Soft robots are nonlinear dynamical systems that are difficult to model.
- Nonlinear system identification has limited convergence guarantees.
- Koopman operator theory enables linear system identification of nonlinear systems like soft robots.
- Using this theory, a model of a soft robot arm is identified via linear regression and shown to outperform several other data-driven models.



15:15–16:30	TuCT1.2

Data Driven Inverse Kinematics of Soft Robots using Local Models

Fredrik Holsten, Sune Darkner and Kenny Erleben
Department of Computer Science, University of Copenhagen, Denmark
Morten Pol Engell-Nørregård
Alexandra Institute, Denmark

- How can we learn to control robots made of highly compliant materials?
- We have built a physical environment for shape extraction of robots using RGB-D cameras.
- A mapping from desired shape to corresponding configuration is learned from the data.
- The benefits of using multiple local models opposed to one global model is investigated.

The Learning Cube, used for data acquisition

15:15–16:30	TuCT1.3

Modal Dynamics and Analysis of a Vertical Stretch-Retractable Continuum Manipulator with Large Deflection

Hao Wang*, Guohua Gao, Qixiao Xia, Xuping Zhang*
College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, China
Department of Engineering , Aarhus University, Denmark

Research in this paper

- Analyzing the Modal characteristics
- Building the Large deflection Modal dynamics
- Validating the response of the dynamics model

Ongoing research

- Extending the modelling method to the dynamics of the other DOFs
- Controlling the shape of the continuum manipulator by employing the modal dynamics modelling method

15:15–16:30	TuCT1.4

ChainQueen: A Real-Time Differentiable Physical Simulator for Soft Robotics

Yuanming Hu[1], Jiancheng Liu[2]*, Andrew Spielberg[1]*, Joshua B. Tenenbaum[1], William T. Freeman[1], Jiajun Wu[1], Daniela Rus[1], Wojciech Matusik[1]
[1]MIT CSAIL, USA [2]Tsinghua University, IIIS, China *joint second authors

- Differentiable Moving Least Squares Material Point Method (MLS-MPM) for **gradient-based** optimization applications.
- Easy-to-use **Python** interface with TensorFlow support.
- **Real-time** performance on GPUs: 300 FPS for 64K particles.
- Applications in inference, control and codesign for soft robotics.

Bottom to top: learning to walk in only 58 gradient descent iterations using our differentiable simulator.

15:15–16:30	TuCT1.5

A Validated Physical Model For Real-Time Simulation of Soft Robotic Snakes

Renato Gasoto and Miles Macklin and Xuan Liu and Yinan Sun
Kenny Erleben and Jie Fu and Cagdas Onal
Worcester Polytechnic Institute, USA and University of Copenhagen, Denmark

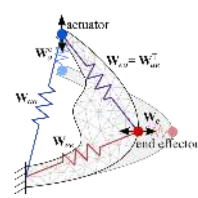
- A dynamical model to simulate 1D pneumatic actuators in real time
- Soft bodies are modeled as Tetrahedral FEMs; actuation is defined as particle constraints
- Mixture of soft and rigid bodies, and friction contacts are simulated and compared to real soft-robot snake
- Computation for one snake runs under 12ms per frame, and scales linearly

15:15–16:30	TuCT1.6

Stiffness Control of Deformable Robots Using Finite Element Modeling

Margaret Koehler and Allison M. Okamura
Mechanical Engineering, Stanford University, USA
Christian Duriez
DEFROST, Inria, France

- Stiffness projection between actuator and end-effector for an arbitrary deformable device using FEM
- Estimation of end-effector force and position using only actuator information for backdrivable deformable robots
- Demonstration of a novel deformable robot/haptic device which uses the stiffness projection



Legged Robots I - 2.3.14

Chair
Co-Chair

15:15–16:30	TuCT1.1

SpaceBok: A Dynamic Legged Robot for Space Exploration

Philip Arm, Radek Zenkl, Patrick Barton, Lars Beglinger, Alex Dietsche, Luca Ferrazzini, Elias Hampp, Jan Hinder, Camille Huber, David Schaufelberger, Felix Schmitt-Koopmann, Benjamin Sun, Boris Stolz, Hendrik Kolvenbach and Marco Hutter
Robotic Systems Lab, ETH Zurich, Switzerland

- SpaceBok, a quadruped robot designed to explore **dynamic locomotion for space exploration**
- The system design includes **parallel leg kinematics** and a **custom designed drivetrain**
- Robust locomotion is obtained using static and dynamic gaits with up to **1m/s on Earth**
- Simulation suggests that the robot moves with **increasing efficiency in lower-than-earth gravities**

15:15–16:30	TuCT1.2

Mini Cheetah: A Platform for Pushing the Limits of Dynamic Quadruped Control

Benjamin Katz and Sangbae Kim
Dept. of Mechanical Engineering, MIT, United States
Jared Di Carlo
Dept. of Electrical Engineering and Computer Science, MIT, United States

- Small 9kg high performance quadruped robot
- Inexpensive and extremely mechanically robust,
- Runs up to 2.45 m/s using less than ½ torque and speed
- Backflips with offline optimization

15:15–16:30	TuCT1.3

Optimal Leg Sequencing for a Hexapod Subject to External Forces and Slopes

Georgios Rekleitis, Menelaos Vidakis and Evangelos Papadopoulos
School of Mechanical Engineering
National Technical University of Athens, Greece

- Optimal **Leg Sequence Selection Algorithm**, maximizing hexapod robot stability
- Can employ *any stability criterion*. Can take into account top heaviness and external disturbances/conditions
- Provides **optimally stable leg sequence**, if one exists; else chooses stabler gait and continues searching
- **On-line applicable leg sequence algorithm** due to *intelligent search heuristics*

15:15–16:30	TuCT1.4

Stanford Doggo: An Open-Source, Quasi-Direct-Drive Quadruped

Nathan Kau, Aaron Shultz, Natalie Ferrante, and Patrick Slade
Mechanical Engineering, Stanford University, United States

- Quasi-direct-drive design enables dynamic locomotion
- Meets or exceeds state-of-the-art legged robots in common performance metrics
- Recorded a vertical jumping agility 22% higher than previous record
- Open-source, and costs less than US$3000 to fabricate and assemble

15:15–16:30	TuCT1.5

Workspace CPG with Body Pose Control for Stable, Directed Vision during Omnidirectional Locomotion

Samuel Shaw
Computer Science Department, Tufts University, USA
Guillaume Sartoretti, Jake Olkin, William Paivine, Howie Choset
The Robotics Institute, Carnegie Mellon University, USA

- Leverages locomotive degrees-of-freedom to control the pose of a vision system rigidly mounted to the robot's body
- Workspace Central Pattern Generator naturally smooths transitions between high-level commands (pose/velocity changes)
- Simultaneous, independent omnidirectional locomotion and body pose control
- Experimental validation on a hexapod robot in a series of indoor and outdoor trials

Robot locomotes up incline onto flat plain while maintaining gaze on the AprilTag to localize itself.

15:15–16:30	TuCT1.6

Frequency-Aware Model Predictive Control

Ruben Grandia, Farbod Farshidian, and Marco Hutter
Robotic Systems Lab, ETH Zurich, Switzerland
Alexey Dosovitskiy, and René Ranftl
Intel Labs, Munich, Germany

- Frequency-shaped cost functions are combined with model predictive control.
- Robust solutions achieved under unmodeled terrain compliance and actuator bandwidth limitations.
- Hardware experiments performed with ANYmal, a torque controlled legged robot.

ANYmal on compliant terrain

SLAM - Session VI - 2.3.15

Chair
Co-Chair

15:15–16:30	TuCT1.1

Robotic Forceps without Position Sensors using Visual SLAM

Takuya Iwai, Takahiro Kanno, Tetsuro Miyazaki, Toshihiro Kawase, and Kenji Kawashima
Institute of Biomaterials and Bioengineering, Tokyo Medical and Dental University, Japan

- We developed a 2 DOF robotic forceps without position sensors.
- A monocular camera attached to the driving unit moves synchronously with the forceps tip.
- A visual SLAM estimates the camera pose. The 2 DOF angles are obtained from the pose.

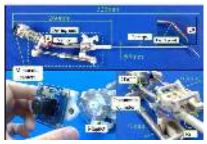


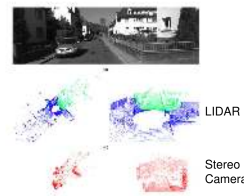
Fig. Developed robotic forceps

15:15–16:30	TuCT1.2

3D Keypoint Repeatability for Heterogeneous Multi-Robot SLAM

Elizabeth R. Boroson and Nora Ayanian
Department of Computer Science
University of Southern California, United States

- Loop closure in multi-robot SLAM between robots with heterogeneous sensors is challenging
- Traditional matching approaches use 2D features in imagery to find loop closures but this is not available for depth sensors such as LIDAR
- **We evaluate 3D keypoints for repeatability between heterogeneous sensors to find one that detects good points for matching**



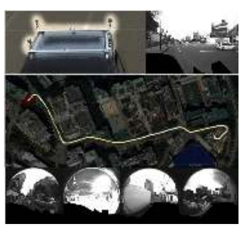
Point clouds of scene shown created from LIDAR and stereo camera

15:15–16:30	TuCT1.3

ROVO: Robust Omnidirectional Visual Odometry for Wide-baseline Wide-FOV Camera Systems

Hochang Seok, Jongwoo Lim*
Department of Computer Science, Hanyang University, Korea

- In this paper we propose a robust visual odometry system for a wide-baseline camera rig with wide field-of-view (FOV) fisheye lenses, which provides full omnidirectional stereo observations of the environment.
- For more robust and accurate ego-motion estimation we adds three components to the standard VO pipeline, 1) the hybrid projection model for improved feature matching, 2) multi-view p3p ransac algorithm for pose estimation, and 3) online update of rig extrinsic parameters.
- The proposed system is extensively evaluated with synthetic datasets with ground-truth and real sequences of highly dynamic environment, and its superior performance is demonstrated

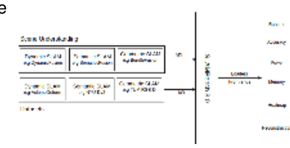


15:15–16:30	TuCT1.4

SLAMBench 3.0: Systematic Automated Reproducible Evaluation of SLAM Systems for Robot Vision Challenges and Scene Understanding

Mihai Bujanca[†], Paul Gafton[†], Sajad Saeedi[*], Andy Nisbet[†], Bruno Bodin[‡], Michael F.P. O'Boyle[‡], Andrew J. Davison[*], Paul H.J. Kelly[*], Graham Riley[†], Barry Lennox[†], Mikel Lujan[†], Steve Furber[†]
University of Manchester[†],University of Edinburgh[‡], Imperial College London[*]

- Building on top of SLAMBench 2.0, we extend the framework to encompass non-traditional SLAM
- Added 6 new metrics, 4 new datasets and 5 new algorithms
- Incorporates semantic and dynamic SLAM, as well as monocular depth estimation
- Open-source, provides tools for easy evaluation of new SLAM systems



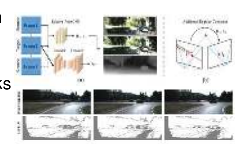
SLAMBench 3.0 workflow

15:15–16:30	TuCT1.5

Beyond Photometric Loss for Self-Supervised Ego-Motion Estimation

Tianwei Shen, Zixin Luo, Lei Zhou, Hanyu Deng, Long Quan
Computer Science & Engineering, HKUST, Hong Kong SAR (China)
Tian Fang
Altizure Inc, Hong Kong SAR (China)

- We propose an end-to-end motion estimation method for visual odometry
- Indirect components (geometric quantities) is implicitly embedded into deep neural networks with a direct (photometric loss) flavor.
- A simple threshold mask strategy is used to handle occlusions and reflections.
- Quantitative results on KITTI and Cityscapes datasets demonstrate the state-of-the-art performance for pose estimation.



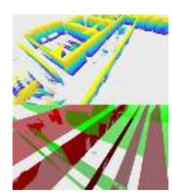
The architecture and threshold mask for the proposed method.

15:15–16:30	TuCT1.6

Simultaneous Localization and Layout Model Selection in Manhattan Worlds

Armon Shariati, Bernd Pfrommer, and Camillo J. Taylor
Computer and Information Science, University of Pennsylvania, USA

- Decouples rotation and translation by estimating the Manhattan frame at each timestep
- Detects and tracks layout planes : infinite axis-aligned surfaces along which walls, floors, and ceilings reside
- Recovers drift-corrected trajectory and simplest layout model simultaneously using convex optimization
- Performs automatic loop closure and data association



Point Cloud Reconstruction (top) and Planar Layout Model (bottom)

Localization IV - 2.3.16

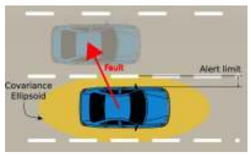
Chair
Co-Chair

15:15–16:30	TuCT1.1

Efficient Integrity Monitoring for KF-based Localization

Guillermo D. Arana and Matthew Spenko
Mechanical and Aerospace Dept., Illinois Institute of Technology, USA
Mathieu Joerger
Aerospace and Mechanical Dept., University of Arizona, USA

- Localization safety is quantified by monitoring integrity, a well-known aviation performance metric
- Integrity risk is defined as the probability of undetected faults resulting in a localization failure
- This method efficiently monitors localization integrity for robots with limited computing power



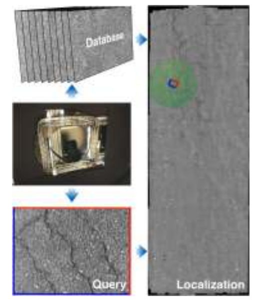
A fault affects the estimate but not the covariance envelope

15:15–16:30	TuCT1.2

High-Precision Localization Using Ground Texture

Linguang Zhang, Adam Finkelstein and Szymon Rusinkiewicz
Computer Science Department, Princeton University, USA

- Millimeter-level global localization based on unique features in ground textures: carpet, asphalt, concrete, wood, tiles and granite tiles.
- Downward-facing camera with controlled illumination.
- High-resolution maps built offline.
- Online descriptor retrieval followed by voting to eliminate false matches and estimate precise position.
- Demonstrated applications: repeatable mobile robot positioning in- and outdoors; footprint recording.

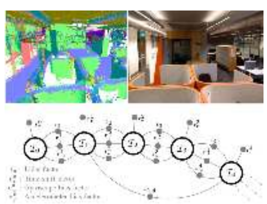


15:15–16:30	TuCT1.3

IN2LAMA: INertial Lidar Localisation And MApping

Cedric Le Gentil, Teresa A. Vidal-Calleja and Shoudong Huang
Centre for Autonomous Systems, University of Technology Sydney, Australia

- Lidar-inertial tight integration
- On-manifold probabilistic framework for localisation and mapping
- Upsampled Preintegrated Measurements (UPMs) to correct motion distortion
- Seamless interaction between front-end and back-end



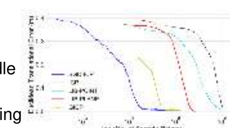
IN2LAMA: 3D map and factor graph

15:15–16:30	TuCT1.4

Speeding Up Iterative Closest Point Using Stochastic Gradient Descent

Fahira Afzal Maken, Fabio Ramos and Lionel Ott
School of Computer Science, The University of Sydney, Australia
Fabio Ramos
NVIDIA, USA

- Stochastic gradient descent (SGD) to solve the optimisation problem posed by ICP
- Improved speed and data efficiency to handle large scale point clouds
- Less sensitive to parameters when processing different data sources.



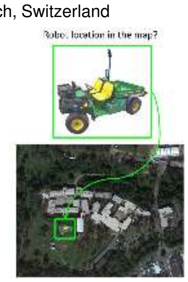
Data Efficient SGD-ICP

15:15–16:30	TuCT1.5

Local Descriptor for Robust Place Recognition using LiDAR Intensity

Jiadong Guo, Paulo Borges and Chanoh Park
Robotics and Autonomous Systems Group, CSIRO, Australia
Abel Gawel
Autonomous Systems Lab, ETH Zurich, Switzerland

- The goal is to find the initial pose of a robot in a pre-stored map.
- We combine Lidar range with Lidar intensity to achieve efficient results
- In contrast to previous works which used global descriptors, our local description solution presents better place discrimination.
- Results in a large site with multiple characteristics (built areas, roads, forests, etc) illustrate the applicability of the method.

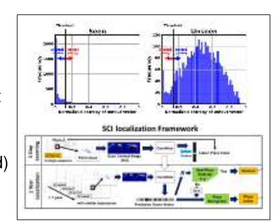


15:15–16:30	TuCT1.6

1-Day Learning, 1-Year Localization: Long-term LiDAR Localization using Scan Context Image

Giseop Kim and Ayoung Kim
Department of Civil and
Environmental Engineering, KAIST, South Korea
Byungjae Park
Intelligent Robot System Research Group, ETRI, South Korea

- Classification-based localization
- Entropy-based unseen place detection
- Robust to long-term changes (e.g., building demolition or severe viewpoint changes)
- Outperformed existing retrieval-based methods (e.g., M2DP and PointNetvlad)



Aerial Systems: Mechanisms III - 2.3.17

Chair
Co-Chair

15:15–16:30 TuCT1.1

Energy Tank-Based Wrench/Impedance Control of a Fully-Actuated Hexarotor: A Geometric Port-Hamiltonian Approach

Ramy Rashad, Johan B. C. Engelen
Robotics and Mechatronics , Twente University, Netherlands
Stefano Stramigioli
Twente University, Netherlands & ITMO University, Russia

- We present an energy tank-based wrench/impedance controller of a fully-actuated hexarotor UAV.
- The modeling, analysis, and control is achieved in the geometric port-Hamiltonian framework.
- The proposed approach is validated in simulation and experiments.

15:15–16:30 TuCT1.2

Integral Backstepping Position Control for Quadrotors in Tunnel-like Confined Environments

Chi Hei Vong, Kris Ryan and Hoam Chung
Department of Mechanical and Aerospace Engineering, Monash University, Australia

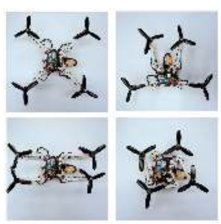
- Small tunnels create challenges for quadrotors due to difficulties in localisaiton and aerodynamic disturbances
- A semi-autonomous quadrotor using a Hough Scan Matching based localisation is proposed
- An integral backstepping controller is introduced for position tracking
- Experiments' results show good position tracking performance of the proposed system

15:15–16:30 TuCT1.3

The Foldable Drone: A Morphing Quadrotor that can Squeeze and Fly

D. Falanga*, K. Kleber*, S. Mintchev †, D. Floreano†, D. Scaramuzza*
*University of Zurich and ETH Zurich, Switzerland
† Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland

- A morphing quadrotor that can **change its shape and size** to adapt to different tasks.
- Composed of a main frame and four independently rotating arms.
- An **adaptive controller** aware of the morphology guarantees stable flight at all times.
- Can traverse gaps smaller than its size by folding, transport objects and inspect structures from very close.

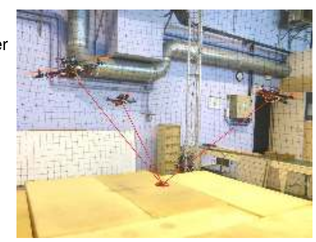


15:15–16:30 TuCT1.4

Control and Configuration Planning Of Aerial Cable-Towed Systems

Julian Erskine[1], Abdelhamid Chriette[1], and Stéphane Caro[2]
[1]École Centrale de Nantes, France
[2]Centre National de la Recherche Scientifique, France

- Design and validation of back-stepping computed torque controller
- Design of a customized prototype using open-source materials
- Validation of task space wrench analysis for varied payloads and configurations
- Analysis of the system limits and failure points in wrench-infeasible configurations



15:15–16:30 TuCT1.5

Adaptive Control of Aerobatic Quadrotor Maneuvers in the Presence of Propeller-Aerodynamic-Coefficient and Torque-Latency Time-Variations

Ying Chen and Néstor O. Pérez-Arancibia
Department of Aerospace and Mechanical Engineering, University of Southern California, USA

- Study the effects of the time-varying aerodynamic coefficients and torque latency on the aerobatic quadrotor maneuvers.
- Propose an adaptive control strategy to compensate for the negative effects of both phenomena.
- Consistent performance improvements are demonstrated in the experiments of three different aerobatic maneuvers.

15:15–16:30 TuCT1.6

Tele-MAGMaS: an Aerial-Ground Co-Manipulator System

Nicolas Staub[1], Mostafa Mohammadi[2], Davide Bicego[1], Quentin Delamare[3], Hyunsoo Yang[6], Domenico Prattichizzo[2], Paolo Robuffo Giordano[3], Dongjun Lee[4] and Antonio Franchi[1]
[1] CNRS, LAAS-CNRS, Université de Toulouse, France
[2] Dep. of Information Engineering and Mathematics, University of Siena, Italy
[3] CNRS, Univ Rennes, Inria, IRISA, France
[4] Dep. of Mechanical and Aerospace Engineering, SNU, South Korea

- ***Cooperative manipulation*** of long objects by ***aerial*** and ***ground*** robots, ***human*** in the loop
- ***OTHEx***: the ***aerial companion*** paradigm
- Different levels of system autonomy: ***fully autonomous***, ***tele-operated***, ***shared-control***
- Experimental Validation at ***2017 KUKA Innovation Award***

Aerial Systems: Perception V - 2.3.18

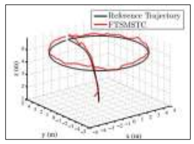
Chair
Co-Chair

15:15–16:30	TuCT1.1

ICRA 2019 Digest Template FTSMSTC For Position and Altitude Tracking of the Quadrotor

Vibhu Kumar Tripathi and Archit Krishna Kamath
Department of Electrical Engineering, IIT Kanpur, India
Nishchal K. Verma and Laxmidhar Behera
Department of Electrical Engineering, IIT Kanpur, India

- Nonlinear fast terminal sliding manifold is proposed for fast and finite time convergence of tracking error
- The super twisting reaching law is proposed to attenuate the chattering phenomena
- Analytical expression for the convergence time is derived and stability is investigated using Lyapunov's theory
- The controller has been experimentally validated using the DJI Matrice M100



3D Trajectory Of The Quadrotor

15:15–16:30	TuCT1.2

Multirotor Dynamics Based Online Scale Estimation for Monocular SLAM

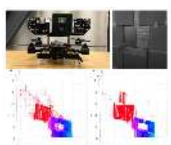
Mohit Ludhiyani, Tata consultancy services
Vishvendra Rustagi, TCS Innovations Lab
Ranjan Dasgupta, TCS Research
Arnab Sinha, TCS Innovation Lab Kolkata

15:15–16:30	TuCT1.3

Real Time Dense Depth Estimation by Fusing Stereo with Sparse Depth Measurements

Shreyas S. Shivakumar, Kartik Mohta, Bernd Pfrommer
GRASP Laboratory, University of Pennsylvania, USA
Vijay Kumar and Camillo J. Taylor
GRASP Laboratory, University of Pennsylvania, USA

- Integrate sparse accurate depth measurements into a dense stereo depth estimation framework
- Combines traditional stereo range fusion and depth interpolation techniques
- Evaluated on KITTI (LiDAR), Middlebury and qualitatively on our PMDTec dataset (ToF)
- Significant improvement in performance is seen across all datasets.



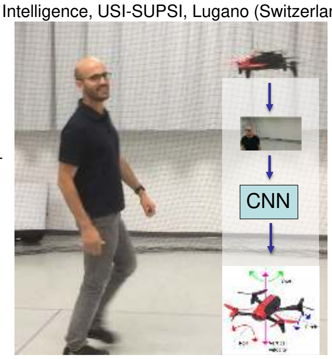
L-R: Stereo and ToF Platform, Example Scene, Before and After Fusion

15:15–16:30	TuCT1.4

Vision-based Control of a Quadrotor in User Proximity: Mediated vs End-to-End Learning Approaches

Dario Mantegazza, Jérôme Guzzi,
Luca M. Gambardella and Alessandro Giusti
Dalle Molle Institute for Artificial Intelligence, USI-SUPSI, Lugano (Switzerland)

- Task: vision-based control a quadrotor to hover in front of a freely moving user.
- We compare two paradigms: mediated (learns a high-level state from the input) vs end-to-end (skips high-level state estimation).
- Results: despite their fundamental difference, both approaches yield equivalent performance on this task.



15:15–16:30	TuCT1.5

Parity-Based Diagnosis in UAVs: Detectability and Robustness Analyses

Georgios Zogopoulos-Papaliakos, Michalis Logothetis and Kostas J. Kyriakopoulos
Department of Mechanical Engineering, NTU Athens, Greece

- Parity-based residual generation is a renowned tool for Fault Detection and Identification in large systems.
- However, for non-linear systems, the robustness and sensitivity to faults properties cannot be found analytically.
- We propose a methodology based on Particle Swarm Optimization to approach these metrics.
- We demonstrate our approach on real data collected with our UAV fixed-wing testbed.

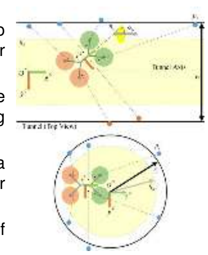
Sensor fault: A detached Angle-of-Sideslip vane

15:15–16:30	TuCT1.6

Design Optimisation of Sparse Sensing Array for Extended Aerial Robot Navigation in Deep Hazardous Tunnel

C. H. Tan, D. S. b. Shaiful, W. J. Ang, S. K. H. Win and S. Foong
Engineering Product Development Pillar,
Singapore University of Technology and Design, Singapore

- An optimisation scheme is conceived to design an array of range-based sensors for accurate localisation in shafts and tunnels.
- A genetic algorithm is employed to explore the large continuous search space, incorporating physical constraints on the robot.
- The optimised design is implemented on a UAV and experimentally tested in both indoor mock-up and field environment.
- The UAV achieved over 35 mins of autonomous flight



Human-Centered Robotics - 2.3.19

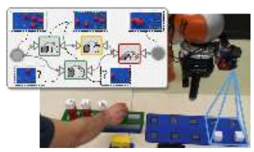
Chair
Co-Chair

15:15–16:30	TuCT1.1

Exploiting a Human-Aware World Model for Dynamic Task Allocation in Flexible Human-Robot Teams

Dominik Riedelbauch and Dominik Henrich
University of Bayreuth, Germany

- Flexible human-robot teaming without prior fixed task allocation
- Human-aware world model encoding trust in stored objects detected in partial workspace observations
- Integrated selection of actions from a task model and perception planning based on the world model



- Evaluation of system behavior using a simulation framework for partially randomized, simplified human models

15:15–16:30	TuCT1.2

Group Surfing: A Pedestrian-Based Approach to Sidewalk Robot Navigation

Yuqing Du, Nicholas J. Hetherington, Chu Lip Oon, Wesley P. Chan, Camilo Perez Quintero, and H.F. Van der Loos
CARIS Lab, University of British Columbia, Canada
Elizabeth Croft
Monash University, Australia

- Robots need to navigate spaces shared with humans
- Our approach uses imitation of pedestrians to navigate in a safe and socially compliant manner
- This was demonstrated in simulation and a real world situation

Navigation in real and simulated environments using group surfing.

15:15–16:30	TuCT1.3

Dentronics: Review, First Concepts and Pilot Study of a New Application in Dentistry

Jasmin Grischke and Lukas Eich
Robokind – Robotics for Mankind Foundation, Germany
Lars Johannsmeier and Sami Haddadin
Munich School of Robotics and Machine Intelligence, Technical University Munich, Germany

- Novel concept of dentronics is presented, robot assistants in the domain of dentistry.
- Fundamental design principles for dentronics are provided.
- An interaction framework as a basic component is developed and tested in a user-study.

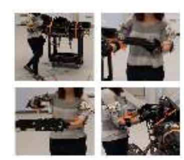
Dentronics concept

15:15–16:30	TuCT1.4

The Roles of Motion Capture and sEMG+inertial Wearables in Detecting Fine vs. Gross Motion

Alyssa Kubota[1], **Tariq Iqbal**[2], **Julie A. Shah**[2], **Laurel D. Riek**[1]
[1]Computer Science and Engineering, UC San Diego
[2]Aeronautics and Astronautics, Massachusetts Institute of Technology

- Robots may benefit from multi-modal systems that can recognize gross and fine motion independently
- We compare motion capture vs. wearable sensors for recognizing gross and fine motion
- We found motion capture better supports gross motion recognition, while wearable sensors better support fine
- We also introduce the MIT-UCSD Human Motion Dataset, comprised of sEMG/Vicon capture of manufacturing activities



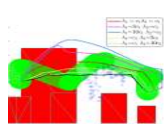
Gross motor activities of an automotive assembly task from the MIT-UCSD Human Motion Dataset

15:15–16:30	TuCT1.5

Optimal Proactive Path Planning for Collaborative Robots in Industrial Contexts

Andrea Casalino, Davide Bazzi, Andrea Maria Zanchettin and Paolo Rocco
D.E.I.B, Politecnico di Milano, Italy

- Many prior works addressing human-robot safe coexistance adopted reactive approaches.
- This work proposes proactive paths, computed in order to dodge in advance a human mate.
- Probabilistic point clouds model the space occupied by the human.
- The path of the robot is modified according to the repulsive field induced by a cloud.



Proactive paths induced by a single probability cloud

15:15–16:30	TuCT1.6

Everybody Needs Somebody Sometimes: Validation of Adaptive Recovery in Robotic Space Operations

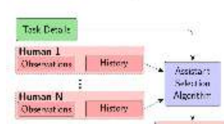
S. McGuire[1], P.M. Furlong[2], T. Fong[2], C. Heckman[1], D. Szafir[1], S. Julier[3], N. Ahmed[1]
[1]University of Colorado at Boulder, USA
[2]NASA Ames Research Center, USA
[3]University College London, U.K.

Problem: Existing task failure recovery methods use predefined roles for human operators

Hypothesis: Real-time assessment of potential assistance by human operators will improve recovery performance

Approach: Passive sensing to determine context and multi-arm bandits for selection

Results: Human studies show statistically significant improvement in failure recovery effectiveness



Sensor Fusion II - 2.3.20

Chair

Co-Chair

15:15–16:30	TuCT1.1

Build your own hybrid thermal/EO camera for autonomous vehicle

Yigong Zhang, Yicheng Gao, Shuo Gu, Yubin Guo, Minghao Liu, Zezhou Sun, Zhixing Hou, Hang Yang, Ying Wang, Jian Yang, Hui Kong
School of CSE, Nanjing Univ. of Sci. & Tech., China.
Jean Ponce
INRIA/Ecole Normale Superieure, France

- A redesign of the structure layout of the thermal and EO (Electro-Optical or visible-light) cameras.
- Obtaining a pixel-wise spatial registration of the thermal and RGB frames.
- Extending one single hybrid camera to a hybrid camera array, obtaining wide-view spatially aligned thermal, RGB and disparity images simultaneously.

15:15–16:30	TuCT1.2

Redundant Perception and State Estimation for Reliable Autonomous Racing

Nikhil Gosala, Andreas Bühler, Manish Prajapat, Claas Ehmke, Mehak Gupta, Ramya Sivanesan, Abel Gawel, Mark Pfeiffer, Mathias Bürki, Inkyu Sa, Renaud Dubé, Roland Siegwart
ETH Zürich, Switzerland

- A fully redundant perception system to estimate the color and position of landmarks using LiDAR and cameras independently.
- An EKF-based slip aware velocity estimation with probabilistic failure detection.
- A particle filter based SLAM algorithm for fusing multi-modal landmark observations.
- Extensive evaluation of the algorithms on the award winning race car «gotthard driverless».

«gotthard driverless»

15:15–16:30	TuCT1.3

UWB/LiDAR Fusion For Cooperative Range-Only SLAM

Yang Song, Mingyang Guan, Wee Peng Tay, Choi Look Law and Changyun Wen
School of Electrical and Electronic Engineering, Nanyang Technological Univeristy, Singapore

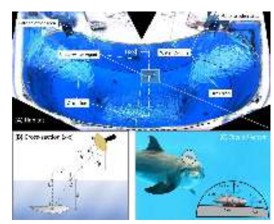
- Fusion of UWB and LiDAR for 2D SLAM
- No knowledge about the locations, status (moving or stationary) and numbers of UWB beacons.
- The robot can move fast without accumulating errors in LiDAR mapping.
- The map can be built in feature-less environment.

15:15–16:30	TuCT1.4

Localization and Tracking of Uncontrollable Underwater Agents: Particle Filter Based Fusion of On-Body IMUs and Stationary Cameras

Ding Zhang, Joaquin Gabaldon, Kira Barton
Matthew Johnson-Roberson, K. Alex Shorter
University of Michigan, Ann Arbor, USA
Lisa Lauderdale, Lance J. Miller
Chicago Zoological Society, USA

- Multiple uncontrollable agents with highly non-linear dynamics
- Pose a tracking problem from a localization perspective
- Robustly maintains identity and position of similar looking agents during tracking
- Accommodates long term inter-agent and environmental occlusions

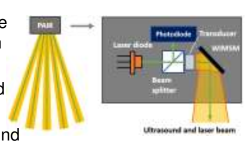


15:15–16:30	TuCT1.5

Steering Co-Centered and Co-Directional Optical and Acoustic Beams with a Water-immersible MEMS Scanning Mirror for Underwater Ranging and Communication

Xiaoyu Duan, Dezhen Song and Jun Zou
ECE and CSE Departments, TAMU, USA

- A compact optical-acoustic frontend module for underwater ranging and communication
- Utilizing ultrasound's wide dispersion for aligning narrow laser beams for high-speed signal transception.
- Co-steering co-centered laser and ultrasound beam using a water-immersible MEMS scanning mirror with feedback control.
- Laser and ultrasound beams remaining aligned within 2.1° under envelope of pan and tilt rotations.



Schematic design of the optical-acoustic frontend module for underwater ranging and communication

15:15–16:30	TuCT1.6

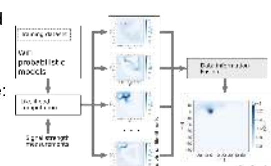
Data Information Fusion from Multiple Access Points for WiFi-based Self-localization

Renato Miyagusuku, Atsushi Yamashita and Hajime Asama
The University of Tokyo, Japan

- Precise, yet not overconfident, likelihood functions are essential for localization.
- For WiFi-localization, the challenges are:

❑The large number of sources

❑Homogeneity of sources



- Several information fusion algorithms that can cope with these issues are presented

Visual Servoing - 2.3.21

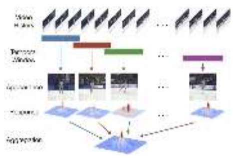
Chair
Co-Chair

15:15–16:30 TuCT1.1

A Simple Tracker with Reminiscences

Christopher Xie[1], Zaid Harchaoui[2], Emily Fox[1,2]
[1]Paul G. Allen School of Computer Science and Engineering,
[2]Department of Statistics,
University of Washington, USA

- Ensemble method of base trackers trained on different temporal windows of the video history
- Tracker can be trained using generic gradient-based convex optimization
- Robust to short-term and long-term changes in visual appearance
- On par with or outperforms state-of-the-art trackers on standard benchmarks



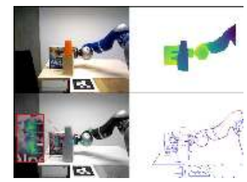
Visual description of tracker

15:15–16:30 TuCT1.2

Learning-driven Coarse-to-Fine Articulated Robot Tracking

Christian Rauch(1), Vladimir Ivan(1), Timothy Hospedales(1), Jamie Shotton(2), Maurice Fallon(3)
(1) University of Edinburgh, (2) Microsoft, (3) University of Oxford

- **Purely visual** tracking of robotic manipulator during grasping tasks
- Initialisation of optimiser using a prior robot state distribution
- **Combined objective** that uses stable sparse keypoints and dense fine edges
- Enables tracking of an **occluded manipulator** without proprioception



Top: RGB and depth image of grasping action
Bottom: detected keypoints (l) and estimated state (r).

15:15–16:30 TuCT1.3

Diagonally-Decoupled Direct Visual Servoing

Geraldo Silveira
Robotics and Computer Vision group, CTI, Brazil
Luiz Mirisola
Division of Computer Science (IEC), ITA, Brazil

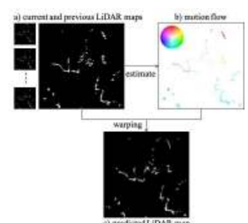
- New general intensity-based nonmetric (direct) visual servoing technique
- Pure decoupled control error dynamics with the aid of a new nonlinear observer
- Lyapunov-based stability analysis and theoretical proof of decoupling properties
- Experimental comparisons with existing techniques confirm its improved performances

15:15–16:30 TuCT1.4

LiDAR Map Prediction via Estimating Motion Flow with GRU

Yafei Song[12], Yonghong Tian[1], Gang Wang[2] and Mingyang Li[2]
[1] School of EECS, Peking University, China
[2] AI Labs, Alibaba Group, China

- A recurrent neural network LiDAR-FlowNet to estimate the motion flow between LiDAR maps.
- A self-supervised strategy along with Gaussian filter to train the LiDAR-FlowNet effectively.
- With the estimated motion flow, we can effect-tively predict the dynamic LiDAR map.



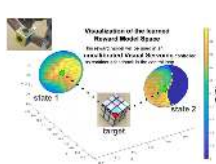
This paper predicts LiDAR map via estimating the motion flow using GRU.

15:15–16:30 TuCT1.5

Robot eye-hand coordination learning by watching human demonstrations: a task function approximation approach

Jun Jin, Laura Petrich, Masood Dehghan, Zichen Zhang, and Martin Jagersand
Department of Computing Science, University of Alberta, Canada

- We propose a method learning a task function from raw videos of human demos.
- The learned task function is then used in an traditional visual servoing controller (UVS).
- The UVS controller enables online training on real robot with a minimal 4-7 seconds.
- The UVS controller makes the policy independent of a specific robot platform.
- Experiments show generalization ability under different task/environment variances.



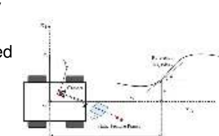
Our task function is represented using a reward model

15:15–16:30 TuCT1.6

Vision-Based Dynamic Control of Car-Like Mobile Robots

Shunbo Zhou, Zhe Liu, Chuanzhe Suo, Hongchao Zhao, and Yun-Hui Liu
T Stone Robotics Institute, The Chinese University of HK, China
Hesheng Wang
Department of Automation, Shanghai Jiao Tong University, China

- A CLMR dynamic control framework that fully considers dynamic effects of the robot
- Longitudinal and lateral velocities are provided by a newly designed visual estimator without any linearization or approximation
- Convergence of the estimator and stability of the controller are theoretically proved
- The performance is validated by full-scale experiments on an autonomous tractor



Intelligent Transportation III - 2.3.22

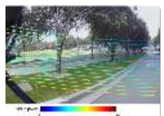
Chair
Co-Chair

15:15–16:30	TuCT1.1

Uncertainty Estimation for Projecting Lidar Points onto Camera Images for Moving Platforms

Charika De Alvis, Mao Shan, Stewart Worrall, and Eduardo Nebot
Australian Centre for Field Robotics, The University of Sydney, Australia

- The combination of the camera and lidar sensors enables precise range information associated with visual image data
- This work proposes a framework to predict the uncertainty of lidar measurements to image frame projection for moving platforms
- The uncertainty of the motion correction along with errors in the extrinsic and intrinsic calibration are considered for overall uncertainty estimation
- Results are demonstrated with real-world data



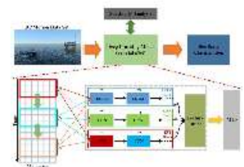
Laser points projected onto the image (30 km/h) (uncertainty based color)

15:15–16:30	TuCT1.2

Modeling and Analysis of Motion Data from DP Vessels for Sea State Estimation

Xu Cheng[1,2], Guoyuan Li[2], Robert Skulstad[2], Shengyong Chen[1], Hans Petter Hildre[2] and Houxiang Zhang[2]
[1]School of Computer Science and Technology, Tianjin University of Technology, China
[2]Department of Ocean Operations and Civil Engineering, Norwegian University of Science and Technology, Norway

- An end-to-end DL network (SeaStateNet) is designed, combining LSTM, CNN, FFT with feature fusion is proposed for sea state estimation.
- The proposed model is evaluated on the publicly benchmark datasets, and ship motion dataset from a commercial simulator.
- The real-time testings demonstrate the practicality of the proposed model.



Proposed framework for sea state estimation

15:15–16:30	TuCT1.3

Visual Localization at Intersections with Digital Maps

Augusto Luis Ballardini, Daniele Cattaneo and Domenico Giorgio Sorrenti
Dept. Informatica, Sistemistica e Comunicazione,
Università degli Studi di Milano - Bicocca, Milano, Italy

- We propose a vision-based algorithm to localize the vehicle as approaching intersection areas
- An improved sensing pipeline, exploiting Deep Neural Networks for both semantic segmentation and 3D reconstruction
- A GPU-Accelerated map-matching procedure allows evaluating a huge hypotheses number
- Performances were evaluated using KITTI urban sequences

Localizing the vehicle by aligning 2D occupancy grids and cartography

15:15–16:30	TuCT1.4

Interaction-aware Multi-agent Tracking and Probabilistic Behavior Prediction via Adversarial Learning

Jiachen Li*, Hengbo Ma* and Masayoshi Tomizuka
Mechanical Engineering, UC Berkeley, USA

- A generic framework of adversarial learning is utilized for probabilistic prediction of multi-agent behaviors.
- An empirical study to find out the relationship between the regularization coefficient of consensus optimization and training performance on GAN.
- The proposed prediction framework can be utilized as an implicit proposal distribution in Bayesian state estimation to enhance tracking performance.
- The proposed approach is applied to multi-vehicle trajectory prediction.

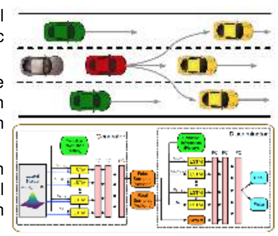


Fig. A real-world scenario and the proposed prediction framework.

15:15–16:30	TuCT1.5

Model Predictive Control of Ride-sharing Autonomous Mobility-on-Demand Systems

Matthew Tsao, Dejan Milojevic, Marco Pavone
Stanford University, United States
Claudio Ruch, Emilio Frazzoli
ETH Zurich, Switzerland

- We present an algorithm for controlling fleets of vehicles for mobility on demand service.
- The algorithm supports ride-sharing where a vehicle can carry multiple passengers at a time.
- A centralized algorithm allows for coordination of the fleet at a global level.
- We validate and compare our approach to the state-of-the-art in the MATSim environment.

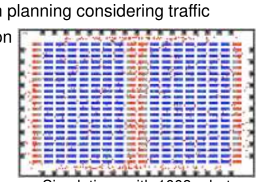
Visualization of ridehailing system in MATSim

15:15–16:30	TuCT1.6

A Hierarchical Framework for Coordinating Large-Scale Robot Networks

Zhe Liu, Shunbo Zhou, Haoang Li and Yun-Hui Liu
The Chinese University of Hong Kong, China
Hesheng Wang and Yi Shen
Shanghai Jiao Tong University, China

- Life-long planning and coordination problems of large-scale robot networks for logistic applications.
- Hierarchical framework: centralized path planning considering traffic flow equilibrium and decentralized motion coordination considering uncertainties.
- Simulation validations with more than one thousand robots and large motion uncertainties.
- Laboratory experiment validations.



Simulations with 1008 robots

Performance Evaluation and Benchmarking - 2.3.23

Chair
Co-Chair

15:15–16:30	TuCT1.1

EasyLabel: A Semi-Automatic Pixel-wise Object Annotation Tool for Creating Robotic RGB-D Datasets

Markus Suchi, Timothy Patten and Markus Vincze
Automation and Control Institute, TU Wien, Austria
David Fischinger
Aeolus Robotics, Inc., Austria

- Create object labels for point clouds by incrementally building up a scene
- Controlled approach → systematic evaluation!
- Object Clutter Indoor Dataset (OCID) 96 scenes, 2346 labeled point clouds, increasing amount of cluttered objects
- Evaluation of 4 object segmentation methods:

→ better performance by geometric based approaches

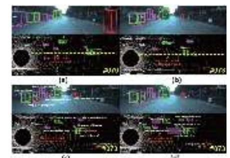
From recorded point clouds to labeled object datasets

15:15–16:30	TuCT1.2

BLVD: Building A Large-scale 5D Semantics Benchmark for Autonomous Driving

Jianru Xue (1), Jianwu Fang(1,2), Tao Li(1), Bohua Zhang(1), Pu Zhang(1), Zhen Ye(1) and Jian Dou(1)
1. Institute of Artificial Intelligence and Robotics, Xian Jiaotong University, Xi'an, P.R. China.
2. Shool of School of Electronic and Control Engineering, Chang'an University, Xi'an, China.

- Unlike previous detection benchmarks, BLVD provide a platform for deeper traffic scene understanding.
- We totally yield 249,129 3D annotations, which contains:
- 4, 902 independent individuals for tracking with the length of overall 214, 922 points,
- 6,004 valid fragments for 5D interactive event recognition, and
- 4,900 individuals for 5D intention prediction.



The task flow of BLVD with 5D semantic annotations: (a) 3D detection, (b) 4D tracking, (c) 5D interactive event recognition and (d) 5D intention prediction.

15:15–16:30	TuCT1.3

Robotic Pick-and-Place Systems in an Industrial Groce

ι[1], P. Sotiropoulos[1], M. A. Roa[2],
ıd G. Deacon[1]
n, Ocado Technology, UK
s, German Aerospace Center, Germany

- We present a benchmarking framework for the evaluation of robotic pick-and-
- The framework design contains surrogate objects, ironm
- The framework is applied to evaluate the performa ystems
- More information:

Experimental set-up for benchmarking

15:15–16:30	TuCT1.4

Characterizing Visual Localization and Mapping Datasets

Sajad Saeedi[1], Eduardo Carvalho[1], Wenbin Li[1,2], Dimos Tzoumanikas[1]
Stefan Leutenegger[1], Paul HJ Kelly[1], Andrew J Davison[1]
[1]Department of Computing, Imperial College London, UK
[2]Department of Computer Science, University of Bath, UK

- In this paper, a novel statistical metric is presented that characterizes the inherent tracking difficulty presented by different trajectories and environments.
- The metric does not rely on any SLAM or motion estimation algorithm.
- 16 new datasets each with real-world trajectories, synthetic RGB, Depth, Optic Flow, and inertial measurements are presented.
- The trajectories include VR, MAV, ground robot, walking, and running motions.

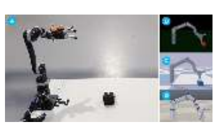
A sample image from the dataset

15:15–16:30	TuCT1.5

Quantifying the Reality Gap in Robotic Manipulation

Jack Collins[1,2], David Howard[2] and Jűrgen Leitner[1,3]
[1]Queensland University of Technology, Australia
[2]Commonwealth Scientific and Industrial Research Organisation, Australia
[3]Australian Centre for Robotic Vision, Australia

- The "Reality Gap" prevents simulated solutions from transferring to real robots.
- We quantify the accuracy of various contemporary simulators compared to a real world ground truth.
- Our ground truth is recorded using an accurate motion capture system.
- We highlight the relative strengths and weaknesses of tested simulators.



Real-World and simulated environments with the Kinova arm and cube (https://youtu.be/-33xXbd_JPI)

15:15–16:30	TuCT1.6

Are We Ready for Autonomous Drone Racing? The UZH-FPV Drone Racing Dataset

Jeffrey Delmerico, Titus Cieslewski, Henri Rebecq, Matthias Faessler, and Davide Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland

- **Aggressive flight dataset** inspired by FPV drone racing
- Challenging for visual inertial odometry due to **large apparent motion**
- 27+ Sequences, 10+ km flight distance, with **images, IMU, events, and ground truth**

Dataset and more information available at: **http://rpg.ifi.uzh.ch/uzh-fpv**

Optimization and Optimal Control - 2.3.24

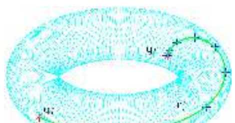
Chair
Co-Chair

15:15–16:30	TuCT1.1

Practical guide to solve the minimum-effort problem with geometric algorithms and B-Splines

Alvaro Paz and Gustavo Arechavaleta
Robotics and Advanced Manufacturing Group, Centro de Investigación y de Estudios Avanzados del IPN, Saltillo, México.

- Direct collocation method using geometric algorithms and the analytical differentiation of the robot inverse dynamics.
- Trajectory optimization algorithm where the configurational vector is parameterized by means of B-Splines.
- Important implementation issues for basis functions, geometric algorithms, and their differentiation.

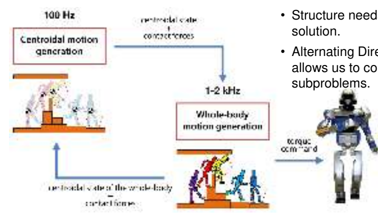


Trajectory optimization process over the configurational space.

15:15–16:30	TuCT1.2

Dynamics Consensus between Centroidal and Whole-Body Models for Locomotion of Legged Robots

Rohan Budhiraja[1], Justin Carpentier[1,2] and Nicolas Mansard[1]
[1]LAAS-CNRS [2]INRIA Paris



- The locomotion problems can be broken into the Centroidal and the Whole-Body subproblems.
- Structure needs to be maintained to provide a coherent solution.
- Alternating Direction Method of Multipliers (ADMM) allows us to converge to a consensus for the two subproblems.

15:15–16:30	TuCT1.3

Adaptive Bingham Distribution Based Filter for SE(3) Estimation

Feiran Li, Gustavo Alfonso Garcia Ricardez, Jun Takamatsu and Tsukasa Ogasawara
Information Science, Nara Institute of Science & Technology, Japan

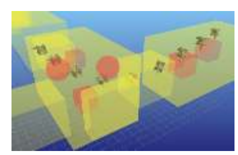
- Bingham distribution is theoretically superior than the Gaussian one in representing uncertainty of rotation group.
- We equip the Bingham filter with adaptive parameter-tuning ability and give analysis from isotropic condition to general counterparts.
- Our method achieves fully automatic tuning and can keep almost the same accuracy with the fine-tuned prototype.

15:15–16:30	TuCT1.4

GuSTO: Guaranteed Sequential Trajectory Optimization via Sequential Convex Programming

Riccardo Bonalli, Abhishek Cauligi, Andrew Bylard, and Marco Pavone
Department of Aeronautics and Astronautics, Stanford University, USA

- Continuous-time scheme applied to broad class of nonlinear dynamical systems
- Guaranteed convergence of solutions to at least a stationary point
- Provides informative dual-solutions that can be used to significantly accelerate convergence using indirect methods
- Analysis provides practical guidelines such as proper handling of constraints
- Code at github.com/StanfordASL/GuSTO.jl



15:15–16:30	TuCT1.5

Efficient Computation of Feedback Control for Equality-Constrained LQR

Forrest Laine and Claire Tomlin
EECS, UC Berkeley, USA

- Introduce a novel method for solving equality-constrained LQR problems
- As efficient as solving KKT conditions
- Produces constraint-aware feedback control policies
- Makes no restricting assumptions on dimensions of constraints

$$x_i^*(x_i) = \arg\min_{u_i} cost_i(x_i,u_i) + cost\_to\_go_{i+1}(x_{i+1})$$
$$\text{s.t. } 0 = dynamics(x_{i+1}, x_i, u_i)$$
$$u_i \in \arg\min_{u} \left\| \begin{bmatrix} constraint_i(x_i,u) \\ constraint\_to\_go_{i+1}(x_{i+1}) \end{bmatrix} \right\|_2$$

Single step of dynamic programming

15:15–16:30	TuCT1.6

Avoidance of Convex and Concave Obstacles with Convergence ensured through Contraction

Lukas Huber and Aude Billard
LASA Laboratory, EPFL, Switzerland
Jean-Jacques Slotine
Nonlinear Systems Laboratory, MIT, USA

- Dynamic obstacle avoidance, taking inspiration from fluid dynamics
- Convex and *star-shaped* (concave) are avoided with full convergence
- Physical simulation of a wheel chair in a crowded environment shows avoidance of several obstacles
- Robotic arm collaborates with humans and avoids them during task execution in 3D

The robot avoids the human operator during the *pick-and-place* task.

Legged Robots II - 2.3.25

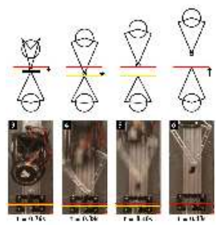
Chair
Co-Chair

15:15–16:30 TuCT1.1

Mitigating energy loss in a robot hopping on a physically emulated dissipative substrate

Sonia Roberts and Daniel E. Koditschek
Electrical and Systems Engineering, University of Pennsylvania, USA

- Built and characterized programmable **automated platform** emulating bulk behavior of **granular media**
- Single-leg hopper (1/4 **Minitaur**) with virtual leg spring jumps on platform
- Tested **active damping** controller, which dissipates energy into a virtual damper
- **Energetic cost** of jumping is consistently **reduced 20%** and up to 50% in specific cases

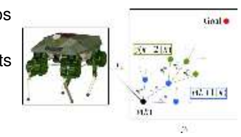


15:15–16:30 TuCT1.2

Energy Efficient Navigation for Running Legged Robots

Mario Y. Harper[1], John V. Nicholson[2], Emmanuel G. Collins, Jr.[3], Jason Pusey[4] and Jonathan E. Clark[2]
[1]Scientific Computing, FSU, USA; [2]Mechanical Engineering, FAMU-FSU, USA
[3]University of Louisville, USA; [4]Army Research Laboratory, USA

- Energy efficient navigation in some scenarios increases the operating time by 50%
- Legged robots with high energy requirements and limited payload will benefit greatly from this technology
- The SBMPO algorithm directly generates energy optimized motion trajectories while honoring natural running dynamics
- This method utilizes a neural network to learn motion properties of running



The sampling and traversal procedure is demonstrated on a simulated LLAMA platform

15:15–16:30 TuCT1.3

Force-controllable Quadruped Robot System with Capacitive-type Joint Torque Sensor

Yoon Haeng Lee, Young Hun Lee, Hyunyong Lee, Hansol Kang, Luong Tin Phan, Sungmoon Jin, Young Bum Kim, Dong-Yeop Seok, Seung Yeon Lee , Hyungpil Moon, Ja Choon Koo, and Hyouk Ryeol Choi
School of Mechanical Engineering, Sungkyunkwan University, South Korea

- To maintain the body balance in uneven terrains, force controllability of the quadruped robot is an important feature.
- To address this, we designed a quadruped robot which contains 12xActuator Modules, 2xcomputers, 12xcontrollers, and battery.
- Also, specially designed high-resolution Capacitive-type Joint Torque Sensors are embedded in each Actuator Modules.
- By this way, the robot achieved an accurate and wide range of force/torque controllability.

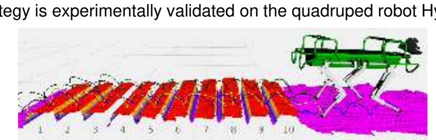
A force-controllable quadruped robot, AiDIN-VI

15:15–16:30 TuCT1.4

Fast and Continuous Foothold Adaptation for Dynamic Locomotion through CNNs

Octavio Villarreal[1], Victor Barasuol[1], Marco Camurri[1,4], Luca Franceschi[2], Michele Focchi[1], Massimiliano Pontil[2], Darwin G. Caldwell[3] and Claudio Semini[1]
[1]Dynamic Legged Systems lab, Istituto Italiano di Tecnologia, Italy
[2]Computational Statistics & Machine Learning, Istituto Italiano di Tecnologia, Italy
[3]Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy
[4]Oxford Robotics Institute, University of Oxford, UK

- An online foothold adaptation strategy based on visual feedback is presented
- Corrections are computed and executed continuously for dynamic locomotion
- A CNN is trained to compute the foothold adaptations based on vision
- The strategy is experimentally validated on the quadruped robot HyQ.



15:15–16:30 TuCT1.5

Keep Rollin' – Whole-Body Motion Control and Planning for Wheeled Quadrupedal Robots

Marko Bjelonic, C. Dario Bellicoso, Yvain de Viragh, Dhionis Sako, F. Dante Tresoldi, Fabian Jenelten and Marco Hutter
Robotic Systems Lab, ETH Zurich, Switzerland

- Tight integration of the additional DOF introduced by the **actuated wheels**
- **Combines the advantages** of legged and wheeled locomotion
- **Zero-Moment Point** based motion optimization continuously updates reference trajectories
- **Hierarchical whole-body controller** includes the nonholonomic rolling constraints

15:15–16:30 TuCT1.6

Computational Design of Robotic Devices From High-Level Motion Specifications

Sehoon Ha[1] Stelian Coros[2] Alexander Alspach[1] James Bern[2] Joohyung Kim[1] Katsu Yamane[1]
Disney Research, USA
ETH Zurich, Switzerland

- We present a novel computational approach to design the robotic devices from high-level motion specifications.
- By searching through arrangements of modular components, our method generates a functional, as-simple-as-possible robotic device.
- Our method can automatically generate a variety of robotic manipulators and legged robots.

Tetrabot, generated by our algorithm

Disney Research ETH zürich

Award Session VI

Chair *Michael Yu Wang, Hong Kong University of Science & Technology*
Co-Chair *Sanjiv Singh, Carnegie Mellon University*

15:15–15:27 TuCT2.1

Design and Control of a Passively Morphing Quadcopter

Nathan Bucki and Mark W. Mueller
Mechanical Engineering, University of California, Berkeley, United States

- Sprung hinges allow arms of quadcopter to fold downward when low thrusts are applied
- No additional actuation required
- Folding reduces largest dimension of vehicle by approximately 50%
- Existing quadcopter controllers can be used provided additional control input constraints are satisfied

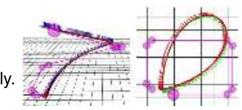
Flight through a small gap by folding and unfolding

15:27–15:39 TuCT2.2

Search-based 3D Planning and Trajectory Optimization for Safe Micro Aerial Vehicle Flight Under Sensor Visibility Constraints

Matthias Nieuwenhuisen
Cognitive Mobile Systems, Fraunhofer FKIE, Germany
Sven Behnke
Autonomous Intelligent Systems, University of Bonn, Germany

- Safe MAV flight in dynamic or partially known environments requires reliable obstacle perception with onboard sensors.
- Flight trajectories have to remain in the onboard obstacle sensor field of view locally.
- We take sensor visibility constraints into account for path planning and subsequent trajectory optimization.
- A tailored heuristic speeds up informed search-based planners.



Spiral trajectory for an altitude change remaining within the sensor FoV during ascent.

15:39–15:51 TuCT2.3

Fast and In Sync: Periodic Swarm Patterns for Quadrotors

Xintong Du, Carlos E. Luis,
Marijan Vukosavljev, and Angela P. Schoellig
Institute for Aerospace Studies, University of Toronto, Canada

- Performance design for a quadrotor swarm acting as an integrated and coordinated, fast moving unit
- Periodic motion pattern primitives embodying fast moving and deforming objects
- Trajectory planner facilitating smooth and safe transitions from one motion pattern to another
- Correction algorithm synchronizing the swarm to the desired rhythm based on the quadrotor's frequency response obtained from the experiments

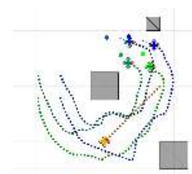
Twenty-five quadrotors performing a periodic wave motion in the vertical direction.

15:51–16:03 TuCT2.4

Distributed Multi-Robot Formation Splitting and Merging in Dynamic Environments

Hai Zhu, Jelle Juhl, Laura Ferranti and Javier Alonso-Mora
Cognitive Robotics, Delft University of Technology, Netherlands

- A distributed method for splitting and merging multi-robot formations
- Splitting and merging actions rely on the computation of an intersection graph and graph partition
- Limited communication range and visibility radius of the robots are considered
- Permanent and temporary communication and motion faults of the robots can be detected and recovered



A square-formation avoids obstacles by splitting/merging

Government Forum - Session III

Chair
Co-Chair

Young Professionals/RAS Technical Committees Networking Social

Chair
Co-Chair

Conference Banquet

Chair
Co-Chair

Plenary Session III

Chair *Gregory Dudek, McGill University*
Co-Chair

08:30–09:30	WePL.1*

A Future with Affordable Self-Driving Vehicles

Raquel Urtasun, University of Toronto

PODS: Wednesday Session I

Chair
Co-Chair

Marine Robotics V - 3.1.01

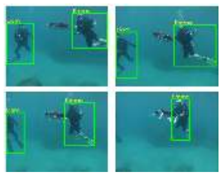
Chair
Co-Chair

09:40–10:55 WeAT1.1

Visual Diver Recognition for Underwater Human-Robot Collaboration

Youya Xia and Junaed Sattar
Department of Computer Science & Engineering,
University of Minnesota Twin Cities, USA

- Presents an approach to visually detect & identify divers and swimmers for AUVs
- Uses a mixture of deep- and feature-based learning to uniquely identify and discriminate between multiple divers
- Experimental results demonstrate efficiency and accuracy in diverse aquatic environments

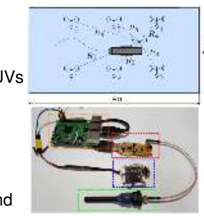


09:40–10:55 WeAT1.2

An Integrated Approach to Navigation and Control in Micro Underwater Robotics using RF Localization

D. A. Duecker, T. Johannink, E. Kreuzer, V. Rausch
Institute of Mechanics and Ocean Engineering, TU Hamburg, Germany
E. Solowjow
Siemens Corporate Technology, Berkeley, CA, USA

- Integration of a low-cost embedded Radio-Frequency-based Localization Module for µAUVs
- Design of a way-point tracking controller for confined environments
- Performance Benchmarks of the navigation and control system in two experimental scenarios.



Embedded RF Localization module

09:40–10:55 WeAT1.3

ICRA 2019 Digest Template
Online Utility-Optimal Trajectory Design for Time-Varying Ocean Environments

Mohan Krishna Nutalapati, Shruti Joshi and Ketan Rajawat
Electrical Engineering Dept., Indian Institute of Technology Kanpur, India

- Problem: Design online framework for energy efficient trajectory planning in time-varying ocean environments
- Formulation: A time-varying constrained convex optimization problem and solved using online gradient descent updates
- The proposed algorithm is referred as OTOGD and is shown to incur sublinear offline regret
- Numerical tests are carried out to show the efficacy of the proposed OTOGD algorithm

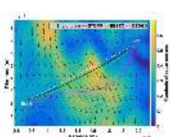


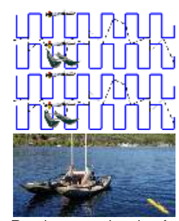
Figure 1: Trajectory Comparisons

09:40–10:55 WeAT1.4

Rendezvous Planning for Multiple AUVs with Mobile Charging Stations in Dynamic Currents

Bingxi Li and John Hoffman
Mechanical Engineering, Michigan Technological University, USA
Brian Page, Barzin Moridian, and Nina Mahmoudian
Mechanical Engineering, Purdue University, USA

- Persistent surveillance and mapping missions using multiple AUVs using mobile charging stations for energy replenishment.
- Energy minimization of mobile charging stations, given pre-defined trajectories for working AUV, considering dynamic currents and obstacles.
- Field experiments using two types of AUVs, an unmanned surface vessel, and a manned support vessel.



Rendezvous planning for recharging AUVs during area coverage mission using USVs.

09:40–10:55 WeAT1.5

Towards a Generic Diver-Following Algorithm: Balancing Robustness and Efficiency in Deep Visual Detection

Md Jahidul Islam, Michael Fulton and Junaed Sattar
Department of Computer Science, University of Minnesota- Twin Cities

- A set of deep diver detection models are evaluated in various real-world settings
- A CNN-based diver detection model is proposed for real-time diver-following applications
- The proposed model balances the robustness of performance and efficiency of the running time
- Performance validations in closed-water and open-water experiments are presented

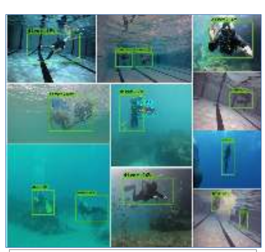


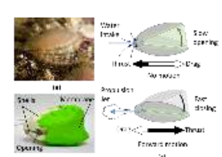
Fig: Detection of divers in various real-world scenarios

09:40–10:55 WeAT1.6

RoboScallop: A bivalve inspired swimming robot

Matthew A. Robertson, Filip Efremov, and Jamie Paik
Reconfigurable Robotics Lab, EPFL, Switzerland

- A robust underwater swimming robot design based on the morphology and functionality of bivalve animals, including scallops.
- Forward thrust generated by a simple, single-DoF crank mechanism, and configuration dependent asymmetric drag.
- Experimental measurement of prototype robot in free swimming speed up to 16 cm/s (2 BL/s) with measured propulsion thrust of 1 N.



Mapping and Reconstruction - 3.1.02

Chair

Co-Chair

09:40–10:55	WeAT1.1

Online Continuous Mapping using Gaussian Process Implicit Surfaces

Bhoram Lee, Clark Zhang, Zonghao Huang
GRASP Lab, University of Pennsylvania, USA
Daniel D. Lee
CornellTech, USA

- We suggest an online framework for mapping as continuous Signed Distance Function (SDF) using GPIS.
- The update works in a Bayesian scheme.
- Another GP regressor on measurements is introduced to infer surface points and normals continuously.
- Benefits of this method include direct access to SDF and its derivatives, probabilistic inference, and continuous expression of structure.

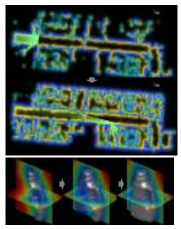


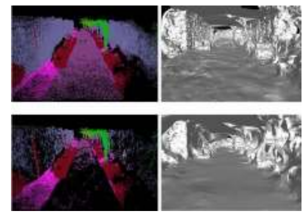
Figure: Examples on 2D and 3D Real Data

09:40–10:55	WeAT1.2

Dense 3D Visual Mapping via Semantic Simplification

Luca Morreale, Andrea Romanoni, Matteo Matteucci
DEIB, Politecnico di Milano, Italy

- Point Cloud Simplification based on 3D Point Semantics
- Reduce redundancy and outliers
- Decrease mesh size to less than half
- Increase efficiency of reconstruction pipeline



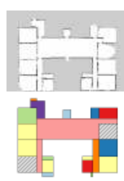
Original cloud on top, Simplified cloud below.

09:40–10:55	WeAT1.3

Predicting the Layout of Partially Observed Rooms from Grid Maps

Matteo Luperto
Dipartimento di Informatica, Università degli Studi di Milano, Italy
Valerio Arcerito, Francesco Amigoni
Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Italy

- The *layout* is an abstract geometrical representation of an indoor environment
- We propose a method that predicts the layout of an environment from a partial grid map
- Walls are used to segment the map into faces, which are then clustered in rooms
- Layout of partially observed rooms is predicted according to the structural features of the rest of the environment



A partial map and its predicted layout (predicted rooms are dashed)

09:40–10:55	WeAT1.4

Dense Surface Reconstruction from Monocular Vision and LiDAR

Zimo Li, Prakruti C. Gogia, and Michael Kaess
Robotics Institute, Carnegie Mellon University, USA

- Reconstruct dense 3D model for indoor scene using LiDAR and camera
- Recover surface from the combination of camera and LiDAR measurements with better accuracy and completeness
- Use a graph-cut algorithm on Delaunay tetrahedra to extract a surface mesh
- Demonstrate the proposed method in real world environments

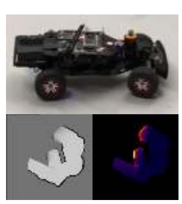
Fig 1. Reconstructed mesh with (top) and without texture (bottom)

09:40–10:55	WeAT1.5

FSMI: Fast computation of Shannon Mutual Information for information theoretic mapping

Zhengdong Zhang, Trevor Henderson, Vivienne Sze, Sertac Karaman
Massachusetts Institute of Technology, US

- Proposed FSMI algorithm to compute Shannon mutual information between perspective range measurements and the environment 1000x faster than the previous state-of-the-art
- Further acceleration via approximation of the Gaussian sensor noise model
- Proposed an even faster algorithm when the noise can be modeled by uniform distribution



A mini race car (top) explores a 2D environment (bottom left) based on the mutual information map (bottom right)

09:40–10:55	WeAT1.6

Real-time Scalable Dense Surfel Mapping

Kaixuan Wang, Fei Gao, and Shaojie Shen
ECE, HKUST, Hong Kong

- **Superpixels** extracted from both intensity and depth images are used to model the environment.
- Organize surfels accordingly to the pose graph of the sparse SLAM systems to achieve the **global consistency** in real-time.
- The proposed dense mapping system is implemented using **only CPU computation** and is **open source**.

Monocular Real-time reconstruction

Robots and Language - 3.1.03

Chair

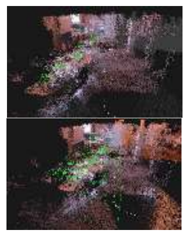
Co-Chair

09:40–10:55	WeAT1.1

Inferring Compact Representations for Efficient Natural Language Understanding of Robot Instructions

Siddharth Patki and Thomas M. Howard
University of Rochester, NY USA
Andrea F. Daniele and Matthew R. Walter
Toyota Technological Institute at Chicago, IL USA

- Proposed framework exploits language to infer minimal environment representations (top) for computationally efficient natural language understanding of robot instructions.
- Experimental results on two mobile robots demonstrate improvements in the efficiency of perception and inference over previous state-of-the-art methods that reason over exhaustive environment representations (bottom)



09:40–10:55	WeAT1.2

Improving Grounded Natural Language Understanding through Human-Robot Dialog

Jesse Thomason[1], Aishwarya Padmakumar[2], Jivko Sinapov[3], Nick Walker[1], Yuqian Zhang[2], Harel Yedidsion[2], Justin Hart[2], Peter Stone[2] and Raymond J. Mooney[2]
[1]Paul G. Allen School of Computer Science and Engineering, University of Washington, USA
[2]Department of Computer Science, University of Texas at Austin, USA
[3]Department of Computer Science, Tufts University, USA

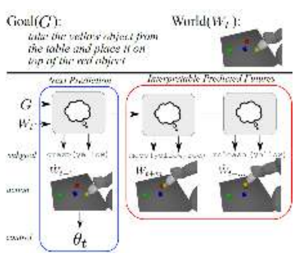
- Translate **natural language** commands to robot actions.
- Use **human-robot dialog** to learn better semantics + concepts.
- Multi-modal **language grounding** for words like *red*, *rattling*, and *heavy*.
- **Robot asks humans** questions about object properties and user intent.

09:40–10:55	WeAT1.3

Prospection: Interpretable Plans from Language by Visualizing the Future

Chris Paxton[1] Yonatan Bisk[2] Jesse Thomason[2]
Arunkumar Byravan[2] Dieter Fox[1,2]
[1] NVIDIA, Seattle, WA USA
[2] Paul G. Allen School of CSE, UWashington, Seattle, WA USA

- Actions have consequences: **DreamCells** allow robots to *predict* anticipated future sensory input
- Our architecture connects high-level goals, communicated in ***natural language***, with their execution all while building a multimodal latent embedding space.
- Finally, prospection opens a new previously unavailable avenue for ***interpretability*** in deep models.



09:40–10:55	WeAT1.4

Flight, Camera, Action! Using Natural Language and Mixed Reality to Control a Drone

Baichuan Huang, Deniz Bayazit, Daniel Ullman, Nakul Gopalan and Stefanie Tellex
Department of Computer Science, Brown University, USA

- Create Mixed Reality (MR) framework for commanding a drone.
- We ground natural language to reward specifications within a Markov Decision Process (MDP).
- Planning is then by the drone to complete the goal-oriented task.
- We performed a user study that shows our system is easier for user to control the drone than a web interface.

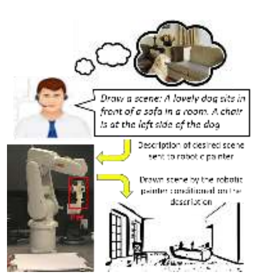
Take the picture of a location in the environment using a drone

09:40–10:55	WeAT1.5

An Interactive Scene Generation Using Natural Language

Yu Cheng, Yan Shi, Zhiyong Sun, Dezhi Feng, and Lixin Dong
Department of Electrical and Computer Engineering, Michigan State University, MI, USA

- A novel approach to generate complex and realistic scenes conditioned on NL descriptions
- Interactive framework allows to modify generated scenes to correct training errors or bias
- Use images retrieved from online image clouds to reduce manual labor and improve scene recognizability



09:40–10:55	WeAT1.6

Efficient Generation of Motion Plans from Attribute-Based Natural Language Instructions Using Dynamic Constraint Mapping

Jae Sung Park, Mohit Bansal
University of North Carolina at Chapel Hill, USA
Biao Jia, Dinesh Manocha
University of Maryland at College Park, USA
http://gamma.cs.unc.edu/SafeMP/NLP/

- Dynamic Grounding Graph (DGG) is developed for understanding natural language instructions.
- Attributes in instructions are handeled – speed, orientation, smoothness, repulsion, etc.
- Efficient training and inferencing on DGG generate parameterized constraints for optimization-based motion planner.
- Constraints are dynamically changed on abrupt natural language commands

Robot understands spoken natural language instructions

Path Planning II - 3.1.04

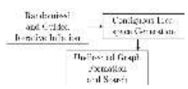
Chair
Co-Chair

09:40–10:55	WeAT1.1

Safe and Fast Path Planning in Cluttered Environment using Contiguous Free-space Partitioning

Arup Sadhu and Shubham Shukla and Titas Bera and Ranjan Dasgupta
Research & Innovation Labs, Tata Consultancy Services, Kolkata, India

- Efficiently generates an undirected graph of achievable waypoints for path planning.
- Undirected graph formation does not require to detect and avoid obstacles.
- Naturally, the proposed planning algorithm enjoys the inherited feature of not detecting and avoiding obstacles.



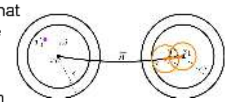
Modules of the proposed method

09:40–10:55	WeAT1.2

Probabilistic completeness of RRT for geometric and kinodynamic planning with forward propagation

Michal Kleinbort[1], Kiril Solovey[2], Zakary Littlefield[3], Kostas E. Bekris[3], and Dan Halperin[1]
[1] Computer Science, Tel-Aviv University, Israel, [2] Aeronautics and Astronautics, Stanford University, USA, [3] Computer Science, Rutgers University, USA

- We provide proofs for the probabilistic completeness (PC) of RRT in two settings, with a mild set of assumptions.
- In the purely geometric setting, we require that the solution path has a clearance δ from the obstacles.
- In the kinodynamic case with forward propagation of random controls and duration, we only consider in addition mild Lipschitz-continuity conditions.

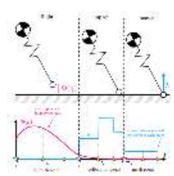


09:40–10:55	WeAT1.3

Contact-Implicit Trajectory Optimization using Orthogonal Collocation

Amir Patel and Stacey Shield
University of Cape Town, South Africa
Saif Kazi, Aaron Johnson and Lorenz Biegler
Carnegie Mellon University, USA

- Contact-implicit optimization can generate trajectories without a-priori knowledge of contact order
- Previous contact-implicit methods suffer from integration error
- We utilize orthogonal collocation and demonstrate an order of magnitude increase in optimal trajectories



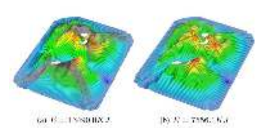
Conceptual representation of the method.

09:40–10:55	WeAT1.4

Energy-Efficient Coverage Path Planning for General Terrain Surfaces

Chenming Wu[1], Chengkai Dai[2], Xiaoxi Gong[3], Yong-Jin Liu[1], Jun Wang[3], Xianfeng David Gu[4] and Charlie C.L. Wang[5]
1. Tsinghua U., CN 2. TU Delft, NL 3. NUAA, CN
4. Stony Brook U., USA 5. CUHK, HKSAR

- An energy-efficient, Fermat-spiral-based coverage path planning algorithm for general terrain surfaces.
- The generation of geodesic Fermat spiral paths on 3D surface is based on the boundary-sourced geodesic distance field.
- Energy-efficient planning is achieved by incorporating the height-extremity into the computation of geodesic distance field.



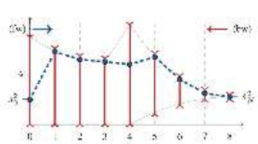
Less energy-consumption than geometry-only path planning

09:40–10:55	WeAT1.5

A New Approach to Time-Optimal Path Parameterization Based on Reachability Analysis

Hung Pham[1,2], Quang-Cuong Pham[1]
[1] Nanyang Technological University, Singapore
[2] Eureka Robotics, Singapore

- *Problem*: Compute the Time-Optimal Path Parameterization (TOPP) for a pre-definec geometric path.
- The proposed algorithm TOPP-RA is both highly efficient and computationally robust
- Open source implementation is available at [github.com/hungpham2511/toppra]



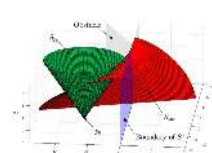
The proposed two-pass approach

09:40–10:55	WeAT1.6

On Optimal Pursuit Trajectories for Visibility-Based Target-Tracking Game

Rui Zou and Sourabh Bhattacharya
Department of Mechanical Engineering, Iowa State University, USA

- Concept of dominant strategy to derive the optimal control of the observer in the class of open-loop strategies.
- Motion primitives for optimal tracking are straight line (ST) and spiral-like curves (C) around the corner
- Optimal trajectory of the observer, and show that they belong to the class {ST,C-ST,ST-C-ST}.
- Cell decomposition of the workspace around the corner based on the nature of the optimal trajectory.



Space-time coordinates for players

Learning from Demonstration II - 3.1.05

Chair

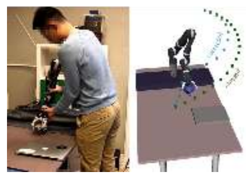
Co-Chair

09:40–10:55	WeAT1.1

Learning from Extrapolated Corrections

Jason Zhang and Anca Dragan
EECS, UC Berkeley, USA

- When teaching robots, users can provide *corrections* more easily than full *demonstrations.*
- Corrections require that the robot *extrapolate* to the rest of the trajectory.
- We generalize prior work by formulating extrapolation as online function approximation, where different inner products encode different assumptions about the user's intended trajectory.
- We study how the choice of an inner product affects learning performance.



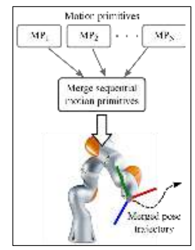
The user provides a correction to the green trajectory. The blue trajectory shows one possible interpretation of the correction.

09:40–10:55	WeAT1.2

Merging Position and Orientation Motion Primitives

Matteo Saveriano[1], Felix Franzel[2], and Dongheui Lee[1,2]
[1]Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Germany
[2]Human-Centered Assistive Robotics, Technical University of Munich, Munich

- Stability analysis of Orientation Dynamic Movement Primitives (DMP)
- Merging of multiple pose DMP to smoothly transit between sequential motions
- 3 merging approaches are developed and compared with simulations and experiments on a real robot
- Benefits and drawbacks of the 3 approaches are discussed

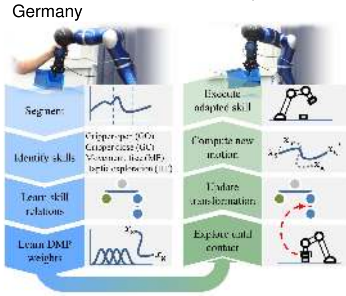


09:40–10:55	WeAT1.3

Learning Haptic Exploration Schemes for Adaptive Task Execution

Thomas Eiband[1], Matteo Saveriano[1] and Dongheui Lee[1,2]
[1] Institute of Robotics and Mechatronics, German Aerospace Center, Germany
[2] Chair of Human-centered Assistive Robotics, Technical University of Munich, Germany

- Fast programming of exploration schemes from few demonstrations
- Contact-based object localization and manipulation in partially structured environments
- Execution adapts to explored environment
- Evaluation in a 2D localization task



09:40–10:55	WeAT1.4

Learning Motion Trajectories from Phase Space Analysis of the Demonstration

Paul Gesel, Momotaz Begum, and Dain La Roche
Cognitive Assistive Robotics Laboratory, University of New Hampshire, USA

- The Phase Space Model (PSM) is a novel parametric low-level learning from demonstration framework
- Trajectories are encoded via a piecewise approximation with linear second order differential equations
- PSM inherently learns kinematic constraints, both position and velocity, from the demonstrated trajectory
- PSM is Robust to spatial temporal perturbation during execution

Experiment: the robot executes a sequential feeding assistant task with the PSM framework

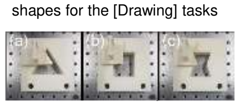
09:40–10:55	WeAT1.5

Relationship between the Order for Motor Skill Transfer and Motion Complexity in RL

Nam Jun Cho[1] ,Sang Hyoung Lee[2,†], Il Hong Suh[1,†], and Hong-Seok Kim[2]
[1]Department of Electronics and Computer Engineering, Hanyang Univ., Korea
[2]Smart Research Group, Korea Institute of Industrial Technology, Korea

- A method is proposed to generate an order for learning and transferring motor skills based on motion complexity, then evaluate the order to learn motor skills of a task and transfer them to another task as a form of RL.
- Two tasks [Drawing] and [Fitting] are performed using an actual robotic arm to evaluate these orders.
- We provide guidelines for using these orders in RL.

Illustrations of the different shapes for the [Drawing] tasks



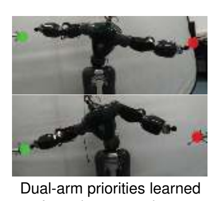
Illustrations of the different shapes for the [Fitting] tasks

09:40–10:55	WeAT1.6

Learning Task Priorities from Demonstrations

João Silvério[1], Sylvain Calinon[2], Leonel Rozo[1,3], Darwin Caldwell[1]
[1]Istituto Italiano di Tecnologia, Italy
[2]Idiap Research Institute, Switzerland
[3]Bosch Center for Artifical Intelligence, Germany

- Approach for extracting the prioritization of tasks from demonstrations
- Statistical analysis to extract invariant hierarchy patterns from a set of projections
- Task-Parameterized Gaussian Mixture Models (TP-GMM) extended to null space structures
- Learned priorities are reproduced using a *soft weighting of strict hierarchies*



Dual-arm priorities learned from demonstrations

Semantic Scene Understanding I - 3.1.06

Chair
Co-Chair

09:40–10:55 WeAT1.1

I Can See Clearly Now : Image Restoration via De-Raining

Horia Porav, Tom Bruls and Paul Newman
Oxford Robotics Institute, University of Oxford, UK

- We present a method for improving segmentation tasks on images affected by adherent rain drops and streaks.
- We introduce a novel stereo dataset recorded using a system that allows one lens to be affected by real water droplets while keeping the other lens clear.
- We train a denoising generator using this dataset and show that it is effective at removing the effect of real water droplets, in the context of image reconstruction and road marking segmentation.

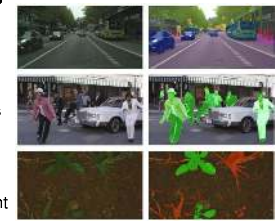
De-raining of real and computer generated rain

09:40–10:55 WeAT1.2

Bonnet: An Open-Source Training and Deployment Framework for Semantic Segmentation in Robotics using CNNs

Andres Milioto and Cyrill Stachniss
University of Bonn

- **Semantic segmentation** for **robotics**
- Available frameworks have a **steep learning curve** for **non-experts** in machine learning
- Our framework allows to **quickly** implement new **models** and **datasets** to approach new problems
- **Zero code** for basic usage
- Stable **C++ deployment** library and **ROS-compatible** interface for different hardware accelerators

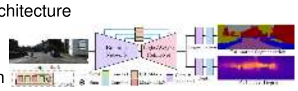


09:40–10:55 WeAT1.3

Real-Time Joint Semantic Segmentation and Depth Estimation Using Asymmetric Annotations

Vladimir Nekrasov, Chunhua Shen, Ian Reid
School of Computer Science, the University of Adelaide, Australia
Thanuja Dharmasiri, Andrew Spek, Tom Drummond
Monash University, Australia

- We propose an efficient multi-task architecture for dense per-pixel tasks
- Our network performs joint semantic segmentation and depth estimation in real-time on indoor and outdoor datasets
- By leveraging hard knowledge distillation, we acquire missing annotations for all presented modalities
- Our method can further be extended to handle more tasks and even be used in SemanticSLAM



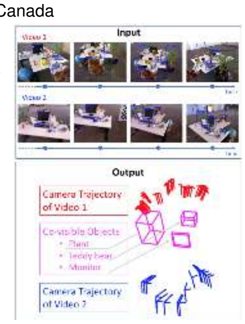
Network structure

09:40–10:55 WeAT1.4

Semantic Mapping for View-Invariant Relocalization

Jimmy Li, David Meger, and Gregory Dudek
School of Computer Science, Centre for Intelligent Machines, McGill University, Canada

- Visual SLAM that uses object landmarks to achieve relocalization under very large viewpoint changes (>125°)
- Existing methods (i.e. ASIFT) fail completely for view changes of > 70°, but we achieve 90% relocalization rate
- Geometrically-detailed semantic map relevant for manipulation and natural language understanding
- Figure: Two disjoint camera trajectories localized in a common reference frame via covisible objects

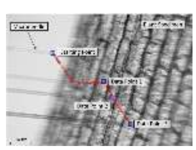


09:40–10:55 WeAT1.5

Automatic Targeting of Plant Cells via Cell Segmentation and Robust Scene-Adaptive Tracking

Ishara Paranawithana[1], Zhong Hoo Chau[1], Liangjing Yang[2], Zhong Chen[3], Kamal Youcef-Toumi[4] and U-Xuan Tan[1]
[1]Singapore University of Technology and Design, Singapore
[2]Zhejiang University/University of Illinois at Urbana-Champaign Institute, China
[3]National Institute of Education, Nanyang Technological University, Singapore
[4]Massachusetts Institute of Technology, USA

- Motivation: Develop an effective cell segmentation method for automatic targeting of plant cells.
- Problem: Cell segmentation and uninterrupted visual tracking is extremely challenging with multi-layered, non-homogeneous plant cell arrays.
- Solution: Automatic identification of plant cells using watershed segmentation with adaptive thresholding and tracking the microneedle with scene-adaptive tracking algorithm.
- Contribution: Improving the automatic vision- guided micromanipulation workflow for plant cell studies under visually challenging conditions.



Overlay of the microscopic images during automatic targeting of plant cells

SLAM - Session VII - 3.1.07

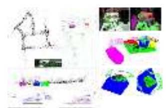
Chair
Co-Chair

09:40–10:55	WeAT1.1

Real-Time Monocular Object-Model Aware Sparse SLAM

Mehdi Hosseinzadeh, Kejie Li, Yasir Latif, and Ian Reid
Australian Centre for Robotic Vision, School of Computer Science
University of Adelaide, Australia

- Real-time *Semantic SLAM* system that integrates objects and planar structures directly in the *bundle adjustment*
- Marries deep-learned plane and object detections with geometric factor-graph based SLAM framework
- Incorporates 3D object model hallucination reconstructed by a CNN, on top of coarse object representations
- Accuracy improvement, evaluated extensively on public indoor and outdoor benchmarks



Generated Maps and Camera Trajectories

09:40–10:55	WeAT1.2

Probabilistic Projective Association and Semantic Guided Relocalization for Dense Reconstruction

Sheng Yang, Zheng-Fei Kuang, Yan-Pei Cao, and Shi-Min Hu
Department of Computer Science and Technology, Tsinghua University, China
Yu-Kun Lai
School of Computer Science & Informatics, Cardiff University, UK

- We propose a method that uses semantic information to improve the geometric quality of the 3D dense reconstruction.
- A probabilistic projective association for pixel correspondences, with the joint likelihood estimation considering geometric, semantic and photometric information.
- Incorporate semantic labels into the original Randomized Ferns for loop detection.

Semantic-Aided Dense Reconstruction

09:40–10:55	WeAT1.3

MRS-VPR: a multi-resolution sampling based global visual place recognition method

Peng Yin, Rangaprasad Arun Srivatsan, Yin Chen, Xueqian Li, Hongda Zhang, Lingyun Xu, Lu Li,
Zhengzhong Jia, Jianmin Ji, Yuqing He

- Based on the sequential matching-based place recognition method, we propose a multi-resolution sampling scheme to balance the matching accuracy and searching efficiency.
- We present a theoretical basis of our MRS-based method in the sequence matching. We also compare the improvement in performance of the MRS-VPR to the original SeqSLAM method.

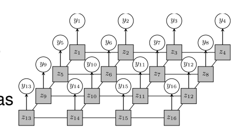
(a) The framework of Multi-resolution sampling based sequence matching.

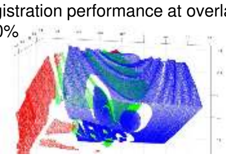
09:40–10:55	WeAT1.4

Robust low-overlap 3-D point cloud registration for outlier rejection

John Stechschulte and Christoffer Heckman
Computer Science, University of Colorado, Boulder, USA
Nisar Ahmed
Aerospace Engineering, University of Colorado, Boulder, USA

- Hidden Markov random field infers which points lie in the overlap of two point clouds
- Residuals modeled as mixture distribution
- Good registration performance at overlap as low as 30%





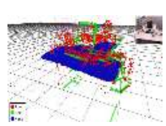
Above: probabilistic model. Left: red points (outliers) and green points (inliers) form one cloud, aligned to reference cloud in blue.

09:40–10:55	WeAT1.5

Unified Representation and Registration of Heterogeneous Sets of Geometric Primitives

Federico Nardi and Bartolomeo Della Corte and Giorgio Grisetti
Department of Computer, Control, and Management Engineering Antonio Ruberti, Sapienza University of Rome, Italy

- We propose a **unified representation** for hybrid scenes consisting of points, lines and planes.
- We derive both an **iterative** and a **direct** method to register heterogeneous scenes.
- We evaluated our approach on **synthetic**, **simulated** and **real-world** data.
- We release our implementation as open source C++ code: https://gitlab.com/srrg-software/srrg_sasha



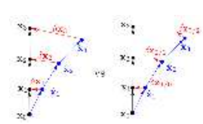
Example reconstruction obtained by our approach.

09:40–10:55	WeAT1.6

Direct Relative Edge Optimization, a Robust Alternative for Pose Graph Optimization

James Jackson, Brendon Forsgren, David Wheeler, Timothy McLain
Mechanical Engineering, Brigham Young University, USA
Kevin Brink
Air Force Research Laboratory, USA

- Re-parameterized pose graph optimization problem in terms of relative edges
- Derived method to optimize over loops with relative constraints
- Shows increased robustness to initialization error over pose-based methods.



AI-based Methods I - 3.1.08

Chair

Co-Chair

09:40–10:55	WeAT1.1

Generalized Controllers in POMDP Decision-Making

Kyle Hollins Wray and Shlomo Zilberstein
College of Information and Computer Sciences
University of Massachusetts Amherst, USA

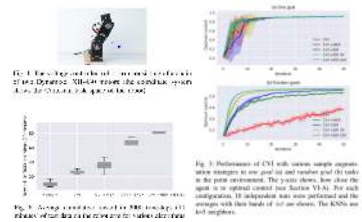
- Partially observable Markov decision process (POMDP): A *belief-based* planning model
- Approximate solutions: Based on belief points, finite state controllers (FSC), and compression
- Contribution: *Unification* of all three disparate approximate forms under one family of policy and value, the *controller family*
- Enables: Improved algorithm performance by integrating policy forms, and new controller-based POMDP decision-making for robots

Novel Belief-Infused FSC is in the controller family; blue are FSC nodes, and green are belief points

09:40–10:55	WeAT1.2

Continuous Value Iteration (CVI) Reinforcement Learning and Imaginary Experience Replay (IER) for learning multi-goal, continuous action and state space controllers

- Proposal
  - New Value Function Approximation RL algorithm for continuous state, action, goal spaces and multi-goal environments
  - New sample generation technique
- Results
  - Learns real robot torque controller quickly and efficiently
  - Beats DDPG baseline on point environment



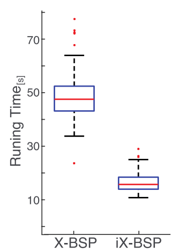
Andreas Gerken and Michael Spranger
Sony Computer Science Laboratories Inc.

09:40–10:55	WeAT1.3

IX-BSP: Belief Space Planning through Incremental Expectation

Elad I. Farhi
Technion Autonomous Systems Program (TASP), Technion, Israel
Vadim Indelman
Department of Aerospace Engineering, Technion, Israel

- Novel paradigm for Solving the basic intractable BSP problem, through incremental expectation
- Calculations in consecutive planning sessions are similar in nature and can be thus re-used
- Our approach for incremental expectation outperforms the standard approach in the sense of computation time
- Whilst preserving the advantages of expectation, and providing with the same estimation accuracy

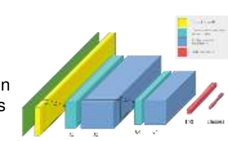


09:40–10:55	WeAT1.4

What am I touching? Learning to classify terrain via haptic sensing

Jakub Bednarek, Michał Bednarek and Krzysztof Walas
Institute of Control, Robotics and Information Engineering,
Poznan University of Technology, Poland
Lorenz Wellhausen and Marco Hutter
Robotics Systems Lab, ETH Zuerich, Switzerland

- Classification method based on raw readings from the sensor using recurrent neural networks
- Fully connected neural model for classification of the terrain type for different walking speeds and directions
- New clustering technique which allows the robot to not only recognise differences between terrain but also which leg is interacting with the terrain



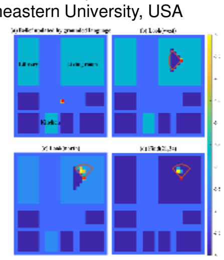
Convolutional neural network architecture with 1D convolution for signals classification in time domain .

09:40–10:55	WeAT1.5

Multi-Object Search using Object-Oriented POMDPs

Arthur Wandzel[1], Yoonseon Oh[1], Michael Fishman[1], Nishanth Kumar[1], Lawson L.S. Wong[2], and Stefanie Tellex[1]
[1]Department of Computer Science, Brown University, USA
[2]Khoury College of Computer Sciences, Northeastern University, USA

- Introduce Object-Oriented POMDPs (OO-POMDPs), which enable **object-based reasoning** under uncertainty.
- Structure afforded by OO-POMDPs support **efficient inference** on factored representation for **solving** a novel **multi-object search task**.
- Structure afforded by OO-POMDPs support **grounded language commands** that provide observational information on task onset.



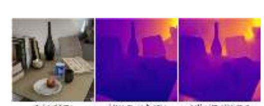
Sequence of agent actions for task under uncertainty.

09:40–10:55	WeAT1.6

Depth Generation Network: Estimating Real World Depth from Stereo and Depth Images

Zhipeng Dong and Yi Gao, Yunhui Yan
Mechanical Engineering and Automation, Northeastern University, China
Qinyuan Ren
Key Laboratory of Industrial Control Technology, Zhejiang University , China
Fei Chen
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

- Estimating dense depth map by exploiting the variational method and the deep-learning technique.
- Propose Depth Generation Network (DGN) based on the Dense Convolutional Network (DenseNet) architecture.
- Experimentally verified the feasibility of generalizing the model for real-world depth estimation.



Performance of DGN on Falling Things (FAT) dataset

Perception for Manipulation III - 3.1.09

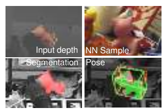
Chair
Co-Chair

09:40–10:55 WeAT1.1

Multi-Task Template Matching for Object Detection, Segmentation and Pose Estimation Using Depth Images

Kiru Park, Timothy Patten, Johann Prankl and Markus Vincze
V4R Laboratory, Automation and Control Institute, TU Wien, Austria

- MTTM matches templates of a new target object for pose estimation without additional training of the CNN and 3D models
- The descriptor is trained to find the nearest pose template of the given regions of interest (ROI)
- The feature map of the input scene is re-used to predict the segmentation masks and the pose



09:40–10:55 WeAT1.2

A Clustering Approach to Categorizing 7 Degree-of-Freedom Arm Motions during Activities of Daily Living

Yuri Gloumakov and Aaron M. Dollar
Mechanical Engineering and Materials Science, Yale University, USA
Adam J. Spiers
Max Planck Institute for Intelligent Systems, Germany

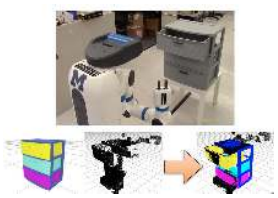
- Arm joint angle trajectories during ADLs are investigated and clustered using data driven approaches
- Joint angle trajectories primarily clustered based on task locations
- Torso motion played a role in making some locations appear more similar
- Proposed clustering methodology outperformed alternative strategies

09:40–10:55 WeAT1.3

Factored Pose Estimation of Articulated Objects using Efficient Nonparametric Belief Propagation

Karthik Desingh, Shiyang Lu, Anthony Opipari, Odest Chadwicke Jenkins
Department of Computer Science and Engineering, Robotics Institute, University of Michigan, Ann Arbor, USA

- Articulated objects factored into collections of rigid parts
- Problem formulated as Markov Random Field (MRF)
- Pull Message Passing algorithm for Nonparametric Belief Propagation (PMPNBP)
- Baseline comparisons with traditional particle filter approach



Articulated pose estimation of a cabinet using a point cloud observation

09:40–10:55 WeAT1.4

Domain Randomization for Active Pose Estimation

Xinyi Ren, Abhishek Gupta, Aviv Tamar, Pieter Abbeel
EECS, UC Berkeley, USA
Jianlan Luo, Eugen Solowjow, Juan Aparicio Ojea
Siemens Corp

- To improve pose estimation, incorporate **domain randomization** with **active perception**
- Train in a domain-randomized simulation to estimate pose from a sequence of images and tests in real-life
- Leveraging consistency among multiple images improves the estimation accuracy by > 2x

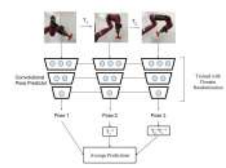


Figure: Inverse Transform Domain Randomization

09:40–10:55 WeAT1.5

GraspFusion: Realizing Complex Motion by Learning and Fusing Grasp Modalities with Instance Segmentation

Shun Hasegawa, Kentaro Wada, Shingo Kitagawa, Yuto Uchimi, Kei Okada and Masayuki Inaba
Graduate School of Information Science and Technology, The University of Tokyo, Japan

- For capable and stable object manipulation, our system fuses different grasp modalities (pinch and suction)
- Object-class-agnostic grasp modality segmentation is executed for each modality
- To avoid grasping multiple objects at once in grasp fusion, object-class-agnostic instance segmentation is conducted
- Grasp primitive template matching plans a grasping pose proper for the segmentation results

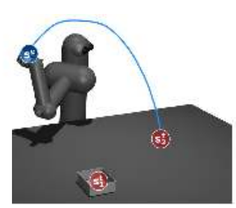
Instance-aware multi-modal grasp fusion

09:40–10:55 WeAT1.6

Factored Contextual Policy Search with Bayesian Optimization

Robert Pinsler[1] Peter Karkus[2] Andras Kupcsik[3,4]
[1] University of Cambridge, UK [2] National University of Singapore
David Hsu[2] Wee-Sun Lee[2]
[3] Idiap Research Institute, Switzerland [4] Bosch Center for AI, Germany

- Efficiently learning policies that generalize over different tasks (contexts) is difficult
- **We factor contexts into *target* and *environment* context; re-evaluate prior experience given new target**
- We apply factorization to contextual policy search with Bayesian optimization
- Achieves **faster learning** and **better generalization** in various robotic tasks



Object Recognition & Segmentation III - 3.1.10

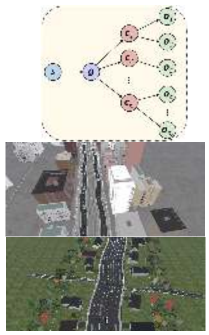
Chair
Co-Chair

09:40–10:55	WeAT1.1

Structured Domain Randomization: Bridging the Reality Gap by Context-Aware Synthetic Data

Aayush Prakash, Shaad Boochoon, Mark Brophy, David Acuna, Eric Cameracci, Gavriel State, Omer Shapira, Stan Birchfield
NVIDIA

- We propose a variant of Domain Randomization (DR) called Structured Domain Randomization (SDR)
- SDR exploits the underlying structure of the scenes to add context to DR.
- SDR achieves compelling results for 2D object detection on KITTI using networks trained on synthetic data only.
- Performance is also better than real data from another domain (BDD100k).
- Synthetic SDR data combined with real KITTI data outperforms real KITTI data alone.



09:40–10:55	WeAT1.2

Probabilistic Active Filtering for Object Search in Clutter

James Poon, Yunduan Cui, and Takamitsu Matsubara
Nara Institute of Science and Technology, Japan
Junichiro Ooga and Akihito Ogawa
Toshiba Corporation, Japan

- Aim to explore the object search problem in an information-theoretic manner
- Probabilistic models of state dynamics and observation function via Gaussian Processes
- Search for actions that maximize the mutual information between predicted state and observation
- Experiments in both simulated and real settings with an upper-body humanoid

09:40–10:55	WeAT1.3

Robust 3D Object Classification by Combining Point Pair Features and Graph Convolution

Jean-Baptiste Weibel, Timothy Patten and Markus Vincze
V4R, TU Wien, Austria

- 3D reconstruction differs from CAD models: occluded objects under random orientation
- Use features invariant to rotation around the global vertical axis (PPF with z-elevation)
- Pairs sampled in a graph structure and combined using graph convolution
- Better on real reconstructed objects (ScanNet, S3DIS), while competitive on CAD models

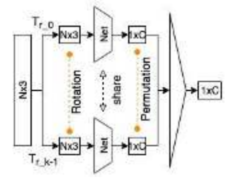
Real and artificial data differences

09:40–10:55	WeAT1.4

Discrete Rotation Equivariance for Point Cloud Recognition

Jiaxin Li and Yingcai Bi and Gim Hee Lee
School of Computing, National University of Singapore, Singapore

- A general method that can be applied to existing networks to achieve discrete SO(2)/SO(3) equivariance.
- Theoretical proof is provided for our proposed rotation equivariance.
- State-of-the-art performance is achieved on classifying ModelNet40/10, rotated MNIST.
- We analyze the necessary conditions of enhancing PointNet based networks with our method.



Architecture of our proposed method

09:40–10:55	WeAT1.5

MVX-Net: Multimodal VoxelNet for 3D Object Detection

Vishwanath A. Sindagi
ECE Department, Johns Hopkins University, USA
Yin Zhou and Oncel Tuzel
AI Research, Apple Inc., USA

- We present two early-fusion approaches to combine the RGB and point cloud modalities for 3D detection.
- Both methods are enhancements to the recently introduced VoxelNet architecture.
- These simple, effective architectures achieve state-of-the-art 3D detection results on the KITTI benchmark.

3D Detection using MVX-Net

09:40–10:55	WeAT1.6

Segmenting Unknown 3D Objects from Real Depth Images using Mask R-CNN Trained on Synthetic Point Clouds

Michael Danielczuk, Matthew Matl, Saurabh Gupta, Andrew Lee, Andrew Li, Jeffrey Mahler, Ken Goldberg
Electrical Engineering and Computer Science, UC Berkeley, USA

- We train SD Mask R-CNN on a synthetic training dataset of 50,000 depth images and 320,000 object masks to perform category-agnostic instance segmentation
- We evaluate the trained network on a set of real, high-resolution depth images of challenging, densely-cluttered bins containing objects with highly-varied geometry.
- SD Mask R-CNN outperforms point cloud clustering baselines by an absolute 15% in AP and 20% in AR on COCO benchmarks, similar to Mask R-CNN trained on a massive, hand-labeled RGB dataset
- Code, datasets, and supplementary material available at https://bit.ly/2letCuE

Manipulation III - 3.1.11

Chair
Co-Chair

09:40–10:55	WeAT1.1

The Task Motion Kit

Neil T. Dantam
Department of Computer Science, Colorado School of Mines, USA
Swarat Chaudhuri and Lydia E. Kavraki
Department of Computer Science, Rice Unversity, USA

- TMKit offers a general framework for integrated task and motion planning
- Efficient symbolic reasoning (Z3) and motion planning (OMPL)
- Extensible to new robots, scenarios, actions
- Open Source: http://tmkit.kavrakilab.org

Everyday tasks combine high-level action and geometric motion

09:40–10:55	WeAT1.2

A Soft Modular End Effector for Underwater Manipulation

Domenico Mura and Andrea Caiti
Centro di Ricerca “E. Piaggio” and DII, Univ. di Pisa, Pisa, Italy
Manuel Barbarossa, Giacomo Dinuzzi,
Giorgio Grioli and Manuel G. Catalano
Istituto Italiano di Tecnologia, Genoa, Italy

- Getting the same grasping capability of the *Pisa/IIT SoftHant* underwater
- Pressure tolerant system, tested in laboratory up to ≈ 500-m depth
- Fast coupling of different tools thanks to magnetic coupling and custom-made snap mechanism
- Field results at 10-m depth show good grasping performance in both dexterity and force tasks

The developed system grasping a coin underwater

09:40–10:55	WeAT1.3

Multimodal Aerial Locomotion: An Approach to Active Tool Handling

Han Wopereis, Wilbert van de Ridder, Tom Lankhorst, Lucian Klooster,
Evyatar Bukai, Johan Engelen and Stefano Stramigioli
Robotics and Mechatronics (RAM) Lab, University of Twente, The Netherlands
David Wuthier, George Nikolakopoulos
Control Engineering Group, Luleå University of Technology, Sweden
Matteo Fumagalli
RVMI Lab, Aalborg University Copenhagen, Denmark

- Many maintenance procedures require operating a tool on a precise location with significant contact force.
- A multimodal aerial locomotion approach can tackle this challenging task.
- The drone provides contact force, controlling its orientation relative to the end-effector.
- The end-effector exploits this contact force both for repositioning and for tool operation.

The aerial manipulator (2.5 kg) tilts 40º to provide significant contact force while the tool moves on the surface.

09:40–10:55	WeAT1.4

Tele-MAGMaS: an Aerial-Ground Co-Manipulator System

Nicolas Staub[1], Mostafa Mohammadi[2], Davide Bicego[1],
Quentin Delamare[3], Hyunsoo Yang[6], Domenico Prattichizzo[2],
Paolo Robuffo Giordano[3], Dongjun Lee[4] and Antonio Franchi[1]
[1] CNRS, LAAS-CNRS, Université de Toulouse, France
[2] Dep. of Information Engineering and Mathematics, University of Siena, Italy
[3] CNRS, Univ Rennes, Inria, IRISA, France
[4] Dep. of Mechanical and Aerospace Engineering, SNU, South Korea

- ***Cooperative manipulation*** of long objects by ***aerial*** and ***ground*** robots, ***human*** in the loop
- ***OTHEx***: the ***aerial companion*** paradigm
- Different levels of system autonomy: ***fully autonomous***, ***tele-operated***, ***shared-control***
- Experimental Validation at ***2017 KUKA Innovation Award***

09:40–10:55	WeAT1.5

A Smart Companion Robot for Heavy Payload Transport and Manipulation in Automotive Assembly

Yi Chen, Weitian Wang, Zoleikha Abdollahi, Zebin Wang,Venkat Krovi, and Yunyi Jia
Department of Automotive Engineering, Clemson University, USA
Joerg Schulte
BMW Manufacturing Co. LLC, Germany

- A Smart Companion Robot (SCR) is designed, developed and validated to collaborate with humans in automotive assembly.
- It can hold a heavy payload for humans and enable humans to use their motions and finger forces to transport and manipulate heavy parts in all six degrees of freedom.
- Human workers are assisted by the robot to effectively, flexibly and conveniently handle heavy parts in automotive assembly, which has great potential benefits in increasing the automotive assembly production efficiency and quality as well as improving ergonomics.

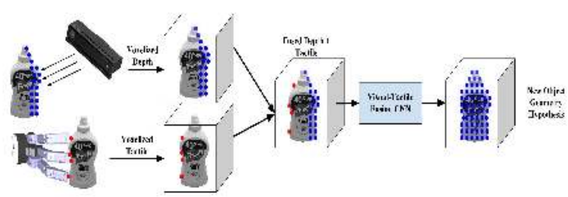
Smart companion robot for automotive assembly

09:40–10:55	WeAT1.6

Multi-Modal Geometric Learning for Grasping and Manipulation

David Watkins-Valls, Jacob Varley, and Peter Allen
Dept. of Computer Science, Columbia University, USA

- Framework for integrating multi-modal visual and tactile data to reason about object geometry and enable robotic grasping
- Uses CNN to perform 3D Shape Completion from a single depth image and sparse tactile exploration
- Completed meshes are then used for online grasp planning



Mechanism Design II - 3.1.12

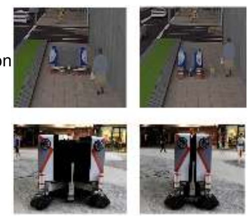
Chair
Co-Chair

09:40–10:55 WeAT1.1

Panthera: Design of a Reconfigurable Pavement Sweeping Robot

Abdullah A. Hayat, Rizuwana Parween, Mohan R. Elara, Karthikeyan Parsuraman, and Prathap S. Kandasamy
Singapore University of Design and Technology, Singapore

- The self-reconfigurable robot for pavement cleaning named *Panthera* is proposed.
- Reconfiguration is gained using the expansion and contraction of the body frame using a single lead screw shaft and linkages mechanism.
- *Panthera* reconfigures on the basis of pavement width and pedestrian density.
- In this work, the motivation for the design, system architecture, modeling, steering kinematics and reconfiguration gaits are presented.


Extended and retracted state of *Panthera*

09:40–10:55 WeAT1.2

Automatic Leg Regeneration for Robot Mobility Recovery

Liyu Wang and Ronald S. Fearing
Department of Electrical Engineering and Computer Sciences, University of California Berkeley, USA

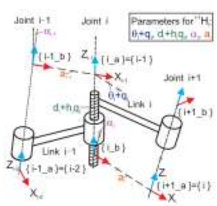
- A 10-motor 4-sensor robotic system for end-to-end and automatic leg regeneration
- On-the-fly fabrication integrated method for cooperative repair
- 30 mm regeneration granularity based on ribbon folding
- Mobility recovery of 90% forward speed, 19.7% peak power increase, & 9.3% reduction of cost of transport, compared to the intact

09:40–10:55 WeAT1.3

Geometric interpretation of the general POE model for a serial-link robot via conversion into D-H parameterization

Liao Wu
University of New South Wales, Sydney, Australia
Ross Crawford and Jonathan Roberts
Queensland University of Technology, Brisbane, Australia

- An AUTOMATIC algorithm to convert DH parameters to POE parameters, and vice versa.
- Explained the singularity in calibration with DH parameters.
- Found that the maximum number of identifiable parameters in a general POE model is 5h+4r+2t+n+6 where h, r, t, and n stand for the number of helical, revolute, prismatic, and general joints, respectively.



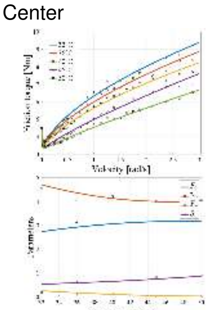
Helical joint

09:40–10:55 WeAT1.4

Dynamic friction model with thermal and load dependency: modeling, compensation, and external force estimation

Maged Iskandar and Sebastian Wolf
DLR - German Aerospace Center

- **Fully parametric** approach to express friction with temperature, velocity and load dependency.
- Three applications are demonstrated: **dynamic simulation**, **friction compensation** and **external torque estimation**.
- We show the effectiveness of applying an impedance control without a torque sensor by the integration of the proposed model.

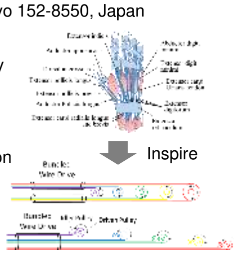


09:40–10:55 WeAT1.5

Bundled Wire Drive
Proposal and Feasibility Study of a Novel Tendon-Driven Mechanism Using Synthetic Fiber Ropes

Gen Endo, Youki Wakabayashi, Hiroyuki Nabae and Koichi Suzumori
Department of Mechanical Engineering, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8550, Japan

- This paper proposes a new wire-driven mechanism to relay many ropes very simply and compactly.
- Synthetic fiber ropes pass through in a joint while bundled.
- Investigate the influence of sliding on tension transmission efficiency and rope strength.
- The feasibility of this system was studied through hardware experiments and a horizontally extendable manipulator.

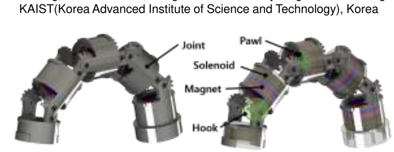


Basic concept of bundled wire drive

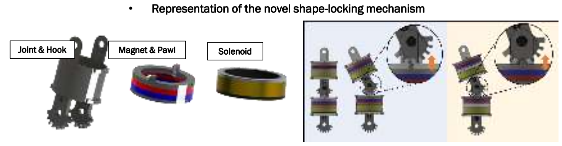
09:40–10:55 WeAT1.6

Shape-Locking Mechanism of Flexible Joint Using Mechanical Latch with Electromagnetic Force

Deok Gyoon Chung, Joonhwan Kim, DongHoon Baek, Joonyeong Kim[1] and Dong-Soo Kwon
KAIST(Korea Advanced Institute of Science and Technology), Korea



- Representation of the novel shape-locking mechanism



- Mechanism components
- Operation principle, locking-off (left), locking-on (right)

Soft Robots V - 3.1.13

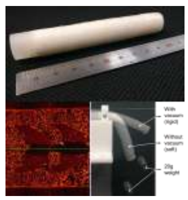
Chair
Co-Chair

09:40–10:55	WeAT1.1

Echinoderm Inspired Variable Stiffness Soft Actuator with Connected Ossicle Structure

Hwayeong Jeong and Jung Kim
Mechanical Engineering Department, Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea

- An **echinoderm** can actively modulate the structural stiffness of its body wall by as much as 10 times, using the material and structural features that make up its body.
- This paper presents a **stiffness modulation method** inspired by the **connected ossicle structures** of echinoderms.
- We applied proposed actuator to a **robotic gripper**, a typical device that interacts with unpredictable environments and needs variable stiffening ability.

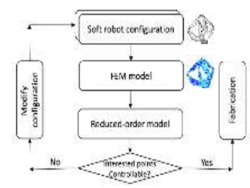


09:40–10:55	WeAT1.2

Controllability pre-verification of silicon soft robots based on finite-element method

Gang Zheng, Olivier Goury , Maxime Thieffry
Alexandre Kruszewski and Christian Duriez
Defrost team, Inria Lille, France

- Question: Given a configuration and certain points of interest, is it controllable?
- Modeling: Using finite-element method to deduce dynamical model;
- Checking: Using differential geometric method to deduce rank condition to check the controllability;
- Iteration: Modify the configuration until the points of interest are controllable.

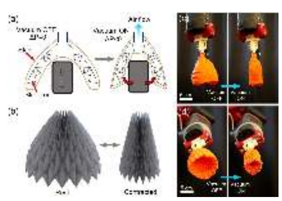


09:40–10:55	WeAT1.3

A Vacuum-driven Origami "Magic-ball" Soft Gripper

Shuguang Li, John J. Stampfli, Helen J. Xu,
Elian Malkin, and Daniela Rus
CSAIL, MIT, USA
Shuguang Li, Evelin Villegas Diaz, and Robert J. Wood
Wyss Institute/SEAS, Harvard University, USA

- A light-weight, vacuum-driven soft robotic gripper;
- It is made of an origami "magic-ball" and a flexible thin membrane;
- It can grasp delicate foods, heavy bottles, and other miscellaneous items.



Vacuum-driven Origami "Magic-ball" Soft Gripper

09:40–10:55	WeAT1.4

Azimuthal Shear Deformation of a Novel Soft Fiber-reinforced Rotary Pneumatic Actuator

Young Min Lee and Hyuk Jin Lee
Hyung Pil Moon and Hyouk Ryeol Choi and Ja Choon Koo
the School of Mechanical Engineering, Sunkyunkwan University, South Korea

- A novel soft fiber-reinforced rotary pneumatic actuator that causes azimuthal deformation by rotation
- The fiber set, a strain limiting element, is placed inside the elastomer
- The swollen hyper-elastic material interacting with the anisotropic distributed fiber set results in rotating motion

Figure caption is optional, use Arial 18pt

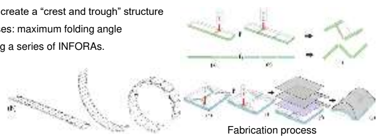
09:40–10:55	WeAT1.5

ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR MICRO-BIOROBOTICS

INFORA: A Novel Inflatable Origami-based Actuator

A. Leylavi Shoushtari, G. A. Naselli, A. Sadeghi and B. Mazzolai
Center for Micro-Biorobotics, Istituto Italiano di Tecnologia, Italy

- **INFORA:** pneumatic actuator built as a combination of inflatable membrane and origami
- **Fabrication process** based on laser cut to create a "crest and trough" structure
- **Mathematical modelling** for design purposes: maximum folding angle
- **A tendril –based gripper** is fabricated using a series of INFORAs.



Fabrication process

Coiling by applying pressure

09:40–10:55	WeAT1.6

Pellicular Morphing Surfaces for Soft Robots

Krishna Manaswi Digumarti[1]
Andrew T Conn[1,2] and Jonathan Rossiter[1,3]
[1] SoftLab, Bristol Robotics Laboratory, UK
[2] Department of Mechanical Engineering, University of Bristol, UK
[3] Department of Engineering Mathematics, University of Bristol, UK

- Bio-inspired morphing surfaces inspired by the microstructures in the pellicle of *Euglena*
- Sliding between polymeric strips leads to variation in shape
- Explored shapes arising due to various strains and constraints on sliding
- Demonstrate an active shape changing surface for soft robots

Top: Pellicle in *E. Gracilis* [J. Cell Science, w/ perm.]
Below: bioinspired pellicle

Legged Robots III - 3.1.14

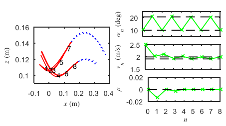
Chair
Co-Chair

09:40–10:55	WeAT1.1

Dynamic Period-two Gait Generation in a Hexapod Robot based on the Fixed-point Motion of a Reduced-order Model

Wei-Chun Lu and Pei-Chun Lin
Department of Mechanical Engineering, National Taiwan University, Taiwan

- This research explored the period-two dynamic running motion in a RHex-style robot.
- Based on reduced-order model, the distribution of the period-two fixed points was analyzed.
- Both simulation study and experimental evaluation of period-two gait are investigated.



The behavior of the model converges to a period-two fixed point

09:40–10:55	WeAT1.2

Realizing Learned Quadruped Locomotion Behaviors through Kinematic Motion Primitives

Abhik Singla, Shounak Bhattacharya, Dhaivat Dholakiya, Shalabh Bhatnagar, Ashitava Ghosal, Bharadwaj Amrutur and Shishir Kolathaya
Robert Bosch Centre for Cyber-Physical Systems, Indian Institute of Science (IISc), India

- Deep Reinforcement Learning was used to learn the walking behaviors in simulation.
- Realized a set of behaviors, namely trot, walk, gallop and bound via Kinematic Motion Primitives in our custom built quadruped robot, Stoch.

Figure 1. Stoch robot

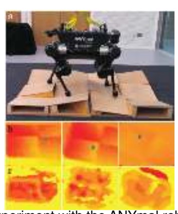
Figure 2. Walking tile of Stoch

09:40–10:55	WeAT1.3

Single-shot Foothold Selection and Constraint Evaluation for Quadruped Locomotion

Dominik Belter, Jakub Bednarek
Poznan University of Technology, Poland
Hsiu-Chin Lin, Guiyang Xin, Michael Mistry
University of Edinburgh, United Kingdom

- Goal: Foothold selection for quadruped robots walking over rough terrain
- Approach: train a CNN model that maps the elevation map to the quality of footholds
- Features:
  - CNN evaluates potential footholds and check constraints (collisions and kinematic) at the same time
  - Select a constraint consistent foothold in real-time



Experiment with the ANYmal robot on the rough terrain mockup (a): example terrain patches (b) and CNN output (c)

09:40–10:55	WeAT1.4

Optimized Jumping on the MIT Cheetah 3 Robot

Quan Nguyen, Matthew J. Powell, Benjamin Katz, Jared Di Carlo, and Sangbae Kim
Massachusetts Institute of Technology, Cambridge, MA 02139

- This paper presents a novel methodology for implementing optimized jumping behavior on quadruped robots.
- Enable the MIT Cheetah 3 robot to repeatably jump onto and jump down from a desk with the height of 30'' (0.76 m).
- The proposed approach includes efficient trajectory optimization, precise high-frequency tracking controller and robust forced-based landing controller for stabilizing the robot body position and orientation after impact.

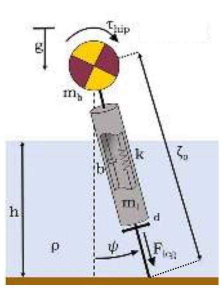
MIT Cheetah 3 jumps on a 30-inch desk

09:40–10:55	WeAT1.5

Lift Your Leg: Mechanics of Running Through Fluids

Ryan Alicea, Kyle Ladyko, and Jonathan Clark
Department of Mechanical Engineering, Florida State University, United States of America

- This work modified the SLIP model of running to capture fluid interaction mechanics
- Allows for adaptation of legged robots to more varied and natural terrain archetypes
- Retracting the leg throughout flight can have a profound effect on runner efficiency
- Gaits with negative touchdown angles can be favorable in certain conditions



09:40–10:55	WeAT1.6

CENTAURO: A Hybrid Locomotion and High Power Resilient Manipulation Platform

Navvab Kashiri, Lorenzo Baccelliere, Luca Muratore, Arturo Laurenzi, Zeyu Ren, Enrico Mingo Hoffman, Malgorzata Kamedula, Giuseppe Francesco Rigano, Jorn Malzahn, Stefano Cordasco, Paolo Guria, Alessio Margan, Nikos G. Tsagarakis
Humanoids and Human-centred Mechatronics, Istituto Italiano di Tecnologia, Italy

- Modular torque-controlled compliant actuation
- Human size and weight compatible
- Bi-manipulation and legged/wheeled mobility
- Resilience to harsh physical interactions
- Strength/power to manipulate heavy payloads

Robot Safety I - 3.1.15

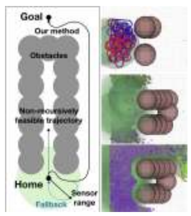
Chair
Co-Chair

09:40–10:55	WeAT1.1

Safely Probabilistically Complete Real-Time Planning and Exploration in Unknown Environments

David Fridovich-Keil*, Jaime F. Fisac*, and Claire J. Tomlin
EECS Department, UC Berkeley, USA

- Our framework avoids attractive but unsafe shortcuts in arbitrary *a priori* unknown static environments
- Strong reachability-based runtime safety guarantees
- Preserves ability to eventually reach goal state during exploration while maintaining safety

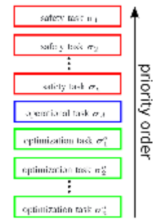


09:40–10:55	WeAT1.2

Handling robot constraints within a Set-Based Multi-Task Priority Inverse Kinematics Framework

Paolo Di Lillo, Stefano Chiaverini, Gianluca Antonelli
Dep. of Electrical and Information Engineering, University of Cassino, Italy

- In task priority frameworks the choice of the hierarchy determines the behavior of the system
- Higher priority tasks are related to safety, and their activation affects the lower-priority ones
- Proper optimization tasks can be inserted in order to minimize the activation of the safety tasks
- The result is that the operational tasks are better executed

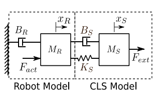


09:40–10:55	WeAT1.3

Compliant Limb Sensing and Control for Safe Human-Robot Interactions

Colin Miyata and Mojtaba Ahmadi
Mechanical and Aerospace Engineering, Carleton University, Canada

- Develops a control methodology for safety during human-robot interaction using compliant sensor shells
- Proposed method seeks to improve safety without requiring robot redesign
- Stability and performance are analyzed using a linear time-invariant single DoF robot model
- Experiments compare the proposed controller against an admittance control law during interaction



Linear time invariant model employed for analysis

09:40–10:55	WeAT1.4

Hybrid Nonsmooth Barrier Functions with Applications to Provably Safe and Composable Collision Avoidance

Paul Glotfelter, Ian Buckley, and Magnus Egerstedt
IRIM, Georgia Institute of Technology, USA

- Extends nonsmooth barrier functions to a class of hybrid systems
- Provides controller-synthesis results for these new hybrid objects
- Formulates a composable collision-avoidance framework using the theoretical contributions
- Deploys the resulting algorithm onto a LIDAR-equipped differential-drive robot

09:40–10:55	WeAT1.5

VUNet: Dynamic Scene View Synthesis for Traversability Estimation using an RGB Camera

Noriaki Hirose, Amir Sadeghian, Fei Xia, Roberto Martín-Martín, and Silvio Savarese
Computer Science, Stanford University, USA

- Scene view synthesis considering 1) camera pose change, and 2) motion of dynamic objects(pedestrians)
- Separate models SNet and DNet distangle 1) and 2).
- VUNet (SNet+DNet) can extend the traversability estimation of GONet.

http://svl.stanford.edu/projects/vunet/

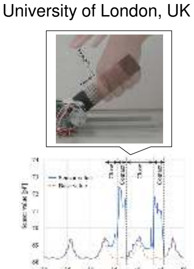
Dynamic Scene View Synthesis for Mobile Robots

09:40–10:55	WeAT1.6

Adaptive Update of Reference Capacitances in Conductive Fabric Based Robotic Skin

Takahiro Matsuno, Zhongkui Wang and Shinichi Hirai
Department of Robotics, Ritsumeikan University, Japan
Kaspar Althoefer
Faculty of Science and Engineering, Queen Mary University of London, UK

- This paper proposes a sensor using conductive fabric that can detect proximity and contact by measuring the capacitance between the sensor and the surrounding environment.
- In the proposed method, the reference capacitance is adaptively update to eliminate the influence of the environment.
- Proximity and contact can be successfully detected by the proposed sensor, independently of whether the robot arm is at rest or moving.



Proximity and contact sensor

Wheeled Robotics I - 3.1.16

Chair
Co-Chair

09:40–10:55 WeAT1.1

Ascento: A Two-Wheeled Jumping Robot

Victor Klemm*, Alessandro Morra*, Ciro Salzmann*, Florian Tschopp, Karen Bodie, Lionel Gulich, Nicola Küng, Dominik Mannhart, Corentin Pfister, Marcus Vierneisel, Florian Weber, Robin Deuber, and Roland Siegwart
*Contributed equally to this work
Autonomous Systems Lab, ETH Zurich, Switzerland

- *Ascento*, a bipedal two-wheeled robot design combining both wheels and legs is presented.
- Compact and lightweight design was achieved by 3D-printing and topology optimization.
- The system is capable of robust stabilization, jumping and controlled resting including fall recovery.
- System performance was successfully evaluated in realistic scenarios through three experiments.

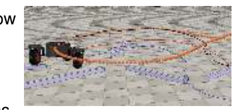
Figure 1. Current prototype of the *Ascento* robot

09:40–10:55 WeAT1.2

Path Following Controller for Differentially Driven Planar Robots with Limited Torques and Uncertain and Changing Dynamics

Ville Pitkänen, Veikko Halonen, Anssi Kemppainen and Juha Röning
Department of Computer Science and Engineering, University Of Oulu, Finland

- Conceptually simple path following controller.
- For differentially driven mobile robots with low force to mass ratio.
- Resistant against environmental forces and inaccurate inertia estimates.
- Internal prioritization of desired accelerations.

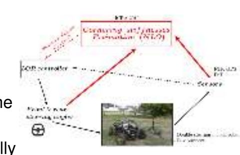


09:40–10:55 WeAT1.3

ICRA 2019 Digest Template Nonlinear Tire Cornering Stiffness Observer for a Double Steering Off-Road Mobile Robot

Mohamed Fnadi, Frédéric Plumet and Faïz Benamar
Sorbonne university, Institut des Systèmes Intelligents et de Robotique - ISIR, CNRS UMR 7222, F-75005 Paris - France

- Path tracking controllers for off-road mobile robots depend highly on tire/ground parameters estimation
- On-line estimation of the front and rear cornering stiffnesses is crucial to enhance the efficiency of the LQR controller
- The proposed nonlinear observer successfully improves the path tracking accuracy and lateral stability of the system



Nonlinear tire cornering stiffnesses approach

09:40–10:55 WeAT1.4

Hierarchical Optimization for Whole Body Control of Wheeled Inverted Pendulum Humanoids

Munzir Zafar, Seth Hutchinson and Evangelos A. Theodorou
Institute of Robotics and Intelligent Machines, Georgia Institute of Technology, USA

- A unified approach to control locomotion and manipulation of wheeled inverted pendulum humanoids
- Hierarchical framework with two levels: High-level controller and low-level controller
- High-level controller uses MPC to determine trajectory for center of mass and wheel locomotion
- Low-level uses a QP based multi-objective operational space control framework to control the full body

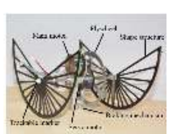
A wheeled inverted pendulum humanoid carrying a cup on a tray

09:40–10:55 WeAT1.5

Efficient and Stable Locomotion for Impulse-Actuated Robots Using Strictly Convex Foot Shapes

Fabio Giardina and Fumiya Iida
Department of Engineering, University of Cambirdge, UK

- We test locomotion efficiency and stability of an impulse-actuated hopping robot
- We identified the foot shape to be crucial for the obtained efficiency
- A 10-fold reduction in required impulse per distance travelled is observed in circular shapes as compared to a cube
- Robot experiments verify our theoretical results



The off-centred disc robot *Robbit*

Actuators - 3.1.17

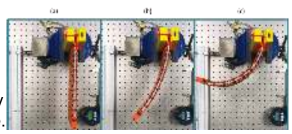
Chair
Co-Chair

09:40–10:55 WeAT1.1

An Actively Controlled Variable Stiffness Structure via Layer Jamming and Pneumatic Actuation

Collin Mikol and Hai-Jun Su
Dept. of Mechanical & Aerospace Engineering, The Ohio State University, USA

- Lightweight structure with pneumatic system for both shape morphing and stiffness variation in robotics applications.
- Pseudo-Rigid-Body Model accurately predicts morphed structure curvature.
- Maximum to minimum stiffness variation of 75.01 X using layer jamming.
- Minimum stiffness under 0.1 N/mm.



Actuated Structure at three various Pressures: (a) 0.4 Psig (b) 24.0 Psig (c) 33.0 Psig

09:40–10:55 WeAT1.2

A Floating-Piston Hydrostatic Linear Actuator and Remote-Direct-Drive 2-DOF Gripper

Eric Schwarm, Kevin Gravesmill, and John Peter Whitney
Mechanical and Industrial Engineering, Northeastern University, USA

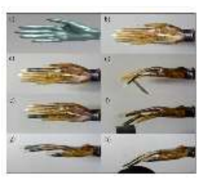
- Low-friction hydrostatic transmission using rolling diaphragms
- Floating-piston linear actuator weighs 55g with a force output of +/- 230N, fully backdrivable
- Symmetric four bar linkage gripper has a 120 degree range of motion and a maximum grip strength of 6.6Nm, high bandwidth force control and force sensing

09:40–10:55 WeAT1.3

3D Printed Ferrofluid Based Soft Actuators

Ela Sachyani Keneth[1], Alexander R. Epstein[2], Michal Soreni Harari[2], Ryan St. Pierre[3], Shlomo Magdassi[1] and Sarah Bergbreiter[3]
1. Institute of Chemistry and the Center for Nanoscience and Nanotechnology, The Hebrew University of Jerusalem, Israel
2. Department of Mechanical Engineering, University of Maryland, USA
3. Department of Mechanical Engineering, Carnegie Mellon University, USA

- Novel 3D printed soft actuator, where the flow of a ferrofluid affects actuator dynamics
- The effect of both 3D printed material and ferrofluid was studied to better understand the dynamics of the actuators
- Actuators mimicking a human hand and worm demonstrate complex motion of actuators



A soft, 3D printed hand with ferrofluid moving between the fingers for actuation

09:40–10:55 WeAT1.4

A Simple Tripod Mobile Robot Using Soft Membrane Vibration Actuators

DongWook Kim, Jae In Kim, Yong-Lae Park
Department of Mechanical and Aerospace Engineering
Seoul National University, Republic of Korea

- Design and fabrication of soft membrane vibration actuators for a simple tripod robot
- Stretchable membrane on an air chamber vibrates making robot move with increased internal air pressure of the chamber
- Motion control using Gaussian Process and phase difference
- Capable of carrying payload and following reference trajectories with vision feedback

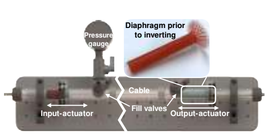
Design of the robot and following trajectories

09:40–10:55 WeAT1.5

Long-stroke rolling diaphragm actuators for haptic display of forces in teleoperation

Alexander Gruebele, Samuel Frishman, Mark R. Cutkosky
Mechanical Engineering, Stanford University, USA

- A new rolling diaphragm actuator accurately transmits forces in a teleoperated system
- The actuator uses an anisotropic laser-patterned fabric embedded in silicone for stiffness
- The design allows for large length-to-diameter ratios
- We present results for a system with 6cm stroke, and minimum force of 0.3 N to move



Diaphragm actuators and teleoperator

09:40–10:55 WeAT1.6

High-performance Continuous Hydraulic Motor for MR Safe Robotic Teleoperation

Z. Dong, Z. Guo, K.H. Lee, G. Fang, W. L. Tang and K.W. Kwok
Department of Mechanical Engineering, The University of Hong Kong
H.C. Chang
Department of Diagnostic Radiology, The University of Hong Kong
D.T.M. Chan
Department of Surgery, The Chinese University of Hong Kong

- Design of a hydraulic motor for high performance tele-operation of MRI guided robotic interventions;
- Dynamics modelling of the hydraulic actuation for design optimization;
- Three-cylinder design integrated into an MR safe robotic platform for cardiac catheterization;
- Experimental validations conducted to ensure dexterous robotic actuation.

Autonomous Agents - 3.1.18

Chair
Co-Chair

09:40–10:55	WeAT1.1

Learning Primitive Skills for Mobile Robots

Yifeng Zhu, Devin Schwab and Manuela Veloso
Carnegie Mellon University, United States

- This paper presents learning primitive skills for mobile robots using deep reinforcement learning.
- Use robot soccer “small size” domain as the testing domain.
- Demonstrate overall better performance of DRL compared with hand-coded policies.
- Demonstrate good performance of the trained policy from simulation on the real robot directly.

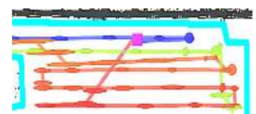
Trained go-to-ball skill using DDPG

09:40–10:55	WeAT1.2

Coverage Path Planning in Belief Space

Robert Schirmer[1,2] and Peter Biber[1]
(1) Robert Bosch GmbH, Germany
Cyrill Stachniss[2]
(2) University of Bonn, Institute of Geodesy and Geoinformation, Germany

- Our approach plans coverage paths taking uncertainty from movement and sensing into account.
- At planning time, we predict how the robot localizability evolves over the path using a localizability prior.
- We formulate the coverage problem as a Generalized TSP that considers both path length and localizability in the cost function.



Predicted robot localizability (ellipses) over a path

09:40–10:55	WeAT1.3

Continuous Control for High-Dimensional State Spaces: An Interactive Learning Approach

Rodrigo Pérez-Dattari[1], Carlos Celemin[2], Javier Ruiz-del-Solar[1] and Jens Kober[2]
[1]Electrical Engineering Department and AMTC, University of Chile, Chile
[2]Cognitive Robotics Department, TU Delft, The Netherlands

- Human corrective feedback during task execution for learning policies is analyzed
- Enhanced D-COACH is proposed, a framework for learning policies with high-dimensional state spaces
- State representation strategies are included to make deep neural networks converge faster
- Policies are learned on the order of tens of minutes in real robots

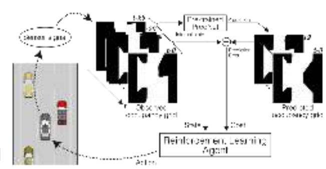
3DoF robot arm, pusher task.

09:40–10:55	WeAT1.4

A Predictive Reward Function for Human-like Driving based on a Transition Model of Surrounding Environment

Daiki Hayashi and Kazuya Takeda
Graduate School of Informatics, Nagoya University, Japan
Yunfei Xu and Takashi Bando
Silicon Valley Innovation Center, DENSO International America, USA

- We propose a reward function that evaluates the naturalness of driving
- The proposed function takes prediction into account
- We trained a reinforcement learning agent using the reward and confirmed the benefit of prediction



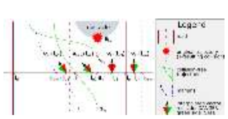
Overview of our proposed method

09:40–10:55	WeAT1.5

ADAPS: Autonomous Driving Via Principled Simulations

Weizi Li, David Wolinski, and Ming C. Lin
Dept. of Computer Science, UNC-Chapel Hill, USA
Dept. of Computer Science, Univ. of Maryland, College Park, USA

- ADAPS consists of two simulation platforms, **SimLearner** and **SimExpert**, and a control policy for autonomous driving.
- **SimLearner** is for testing learned policies, simulating accidents, and generating training data.
- **SimExpert** is for automatic analysis of accidents and safe trajectory planning.
- Both theoretical and experimental results are produced to show the benefits of ADAPS.



ADAPS in generating safe trajectories and training data.

09:40–10:55	WeAT1.6

Planning Coordinated Event Observation for Structured Narratives

Dylan Shell[1], Li Huang[2], Aaron Becker[2], Jason O'Kane[3]
[1] Computer Science and Engineering, Texas A&M University, TX USA
[2] Computer and Electrical Engineering, University of Houston, TX USA
[3] Computer Science and Engineering, University of South Carolina, SC USA

What if you asked your robots to *tell you a story*? Our paper begins to explore the question of how to direct robots to achieve such things autonomously.

•introduce method for specifying desired narrative structure as a **function**

•function specified in a compact, legible form ≈ **weighted finite automaton**

•planner uses simple predictions of future **events** to coordinate robots' efforts to capture most important events

Contact Modeling - 3.1.19

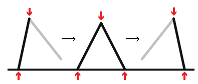
Chair
Co-Chair

09:40–10:55 WeAT1.1

Algorithmic Resolution of Multiple Impacts in Nonsmooth Mechanical Systems with Switching Constraints

Yangzhi Li[1], Haoyong Yu[2] and David J. Braun[1*]
[1] Dynamics and Control Lab, Singapore University of Technology and Design
[2] Biorobotics Lab, National University of Singapore

- Novel impact resolution algorithm which explicitly resolves the discrete dynamics at multiple simultaneous impacts.
- The algorithm avoids priori assumptions on the post impact active constraints and does not require iterative computation.
- The algorithm may be used to investigate the nonsmooth dynamics of robotic systems subject to switching constraints.



→ active constraints:
$$\Lambda^+ = -\left[A_{s^+} M^{-1} A_{s^+}^\top\right]^{-1} A_{s^+} v^- \succ 0$$

Λ^+: impulsive constraint forces
s^+: post-impact active constraints
v^-: pre-impact velocities
M: inertia matrix

09:40–10:55 WeAT1.2

Rigid Body Motion Prediction with Planar Non-Convex Contact Patch

Jiayin Xie and Nilanjan Chakraborty
Department of Mechanical Engineering, Stony Brook University, USA

- We present a principled method for motion prediction via dynamic simulation for rigid bodies in intermittent contact with each other where the contact can be non-point contact.
- Our method ensures seamless transition between contact modes, i.e., 1) non-convex patch contact vs multiple point contact vs convex patch contact vs single point contact. 2) contact vs non-contact.
- Our method guarantees that there is no undesirable penetration between the objects.

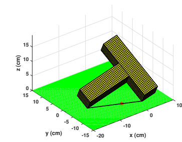


Figure : The T-shaped bar with contact changing between non-convex patch contact and multiple disconnected point contacts.

09:40–10:55 WeAT1.3

A Data-Driven Approach for Fast Simulation of Robot Locomotion on Granular Media

Yifan Zhu and Kris Hauser
Electrical and Computer Engineering, Duke University, USA
Laith Abdulmajeid
Mechanical Engineering, University of Wisconsin Madison, USA

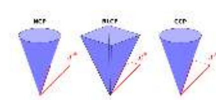
- A semi-empirical approach, which combines data and modeling for data efficiency
- A contact model between a robot foot and granular terrains is learned via experiments
- The model is then used in a contact force solver for rigid-body simulation
- The simulation is based on the Maximum Dissipation Principle

09:40–10:55 WeAT1.4

On the Similarities and Differences among Contact Models in Robot Simulation

Peter Horak
Charles Stark Draper Laboratory, USA
Jeff Trinkle
Computer Science, Rensselaer Polytechnic Institute, USA

- Robot contact dynamics are often modeled with rigid bodies and Coulomb friction
- Various formulations and relaxations obscure common structure between models
- We present 4 models in terms of a single solver method to compare them
- Simulation results from sliding, wedging, grasping, and stacking experiments illustrate consequences of model differences



Friction cone projections used by different models

09:40–10:55 WeAT1.5

Grasping Interface with Wet Adhesion and Patterned Morphology: Case of Thin Shell

Pho Van Nguyen and Van Anh Ho
School of Materials Science,
Japan Advanced Institute of Science and Technology (JAIST)

- Study the role of the **micropattern** with **wet adhesion** in grasping a **deformable thin shell**.
- Principle inspired by wet attachment of **tree-frog's toes**
- Proposed a model for **wet adhesion** between two **parallel curved surfaces**
- Showcased the **design** of a soft robotic hand which can **grip a contact lens**.

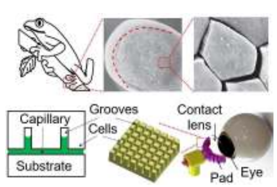


Figure 1. Wet adhesion mimicked tree-frog toes and application

Hybrid Logical/Dynamical Planning and Verification - 3.1.20

Chair

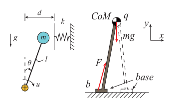
Co-Chair

09:40–10:55	WeAT1.1

Controller Synthesis for Discrete-time Hybrid Polynomial Systems via Occupation Measures

Weiqiao Han and Russ Tedrake
Computer Science and Artificial Intelligence Laboratory
Massachusetts Institute of Technology
USA

- Goal: Stabilizing a mechanical system by making and breaking multiple contacts with the environment.
- Model the system as a discrete-time hybrid polynomial system, which results from time-stepping dynamics.
- Design control policies based on the notion of occupation measures.
- Advantages: Do not need prespesified mode switch sequences, and the optimization problem is convex.



Systems used in this work

09:40–10:55	WeAT1.2

Optimal Path Planning for ω-regular Objectives with Abstraction-Refinement

Yoke Peng Leong
California Institute of Technology, USA
Pavithra Prabhakar
Department of Computer Science, Kansas State University, USA

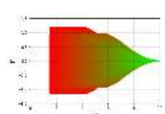
- Abstract a discrete-time “concrete” system into a finite weighted transition system using a finite partition of the state-space.
- Solve a two-player mean payoff parity game on the product of the abstract system and the Buchi automaton corresponding to the ω-regular objective, to obtain an optimal “abstract” controller that satisfies the ω-regular objective.
- The abstract controller is guaranteed to be implementable in the concrete discrete-time system, with a sub-optimal cost that upper bounds the optimal cost. The abstraction is refined with finer partitions to reduce the sub-optimality.
- A robot surveillance scenario is presented to illustrate the feasibility of the approach.

09:40–10:55	WeAT1.3

Sampling-based Polytopic Trees for Control of Piecewise Affine Systems

Sadra Sadraddini and Russ Tedrake
Computer Science and Artificial Intelligence Laboratory
Massachusetts Institute of Technology
USA

- Piecewise affine models characterize local multi-contact robot dynamics well
- Online planning and control through contact requires combinatorial optimization – too slow!
- We provide an alternative: find trajectories of polytopes offline. Polytopes map to each other using simple control laws.
- We grow and connect polytopic trajectories using sampling-based techniques backward from the goal region in the state-space. We obtain fast hybrid control laws.



Planar pushing alongside x-axis: a tree of polytopes grown backward from the goal at (10,0)

09:40–10:55	WeAT1.4

A Classification-based Approach for Approximate Reachability

Vicenç Rubies-Royo, David Fridovich-Keil, Sylvia Herbert and Claire J. Tomlin
Electrical Engineering & Computer Science, UC Berkeley, USA

•We present an approximate dynamic programming approach to perform scalable Hamilton-Jacobi (HJ) reachability
•We learn a controller as a sequence of simple binary classifiers
•We compare our approach to existing grid-based methodologies in HJ reachability
•We demonstrate our approach on several examples, including a physical quadrotor navigation task

Quadrotor navigating around obstacles (blue lantern) in a motion capture arena using our controller

09:40–10:55	WeAT1.5

Practical Resolution Methods for MDPs in Robotics, a Disassembly Planning Example

Alejandro Suárez-Hernández, Guillem Alenyà and Carme Torras
Institut de Robòtica I Informàtica Industrial, UPC, Spain

- Classical methods for MDP solving are impractical for large state spaces.
- Our on-line decision unit is based on determinization and selection of subtasks.
- Disassembly of electromechanical devices as target application.
- We are competitive with other on-line methods in a testbed of disassembly problems.

Disassembly of hard drives use case

Aerial Systems - 3.1.21

Chair
Co-Chair

09:40–10:55 WeAT1.1

Improving drone localisation around wind turbines using monocular model-based tracking

Oliver Moolan-Feroze and Andrew Calway
Department of Computer Science, University of Bristol, UK
Konstantinos Karachalios and Dimitrios N. Nikolaidis
Perceptual Robotics, UK

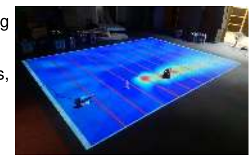
- Accurate drone localisation is important for safe and repeatable wind turbine inspection
- Using a CNN, we estimate a simplified wind turbine representation from RGB images
- The simplified representation is easily incorporated into a pose graph optimiser
- We show the improvement in localisation accuracy of our method using synthetic and real data

09:40–10:55 WeAT1.2

Experimental Assessment of Plume Mapping using Point Measurements from Unmanned Vehicles

Michael Hutchinson, Pawel Ladosz, Cunjia Liu and Wen-Hua Chen
Department of Aeronautical and Automotive Engineering
Loughborough University, UK

- Plume mapping algorithms are assessed in repeatable controlled experiments using a real dispersive source and sensor.
- The dataset, consisting of 54 experiments, is made available on GitHub.
- Algorithms include Gaussian Process regression, Neural networks and piecewise linear interpolation.
- Plume mapping is demonstrated in a realistic environment using a UAV.

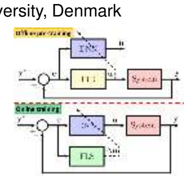

The controlled experiment setup and an example gas distribution map.

09:40–10:55 WeAT1.3

Online Deep Learning for Improved Trajectory Tracking of UAVs Using Expert Knowledge

Andriy Sarabakha
School of Mechanical and Aerospace Engineering,
Nanyang Technological University, Singapore
Erdal Kayacan
Department of Engineering, Aarhus University, Denmark

- This work presents an online learning control method for improved control of unmanned aerial vehicles.
- The proposed method does not require the exact model of the system to be controlled.
- The learning is divided into two phases: offline pre-training and online post-training.
- Thanks to the expert knowledge, the proposed framework learns in real-time.


Block diagrams of offline pre-training and online post-training.

09:40–10:55 WeAT1.4

Decentralized collaborative transport of fabrics using micro-UAVs

Ryan Cotsakis
University of British Columbia, Canada
David St-Onge and Giovanni Beltrame
Polytechnique Montreal, Canada

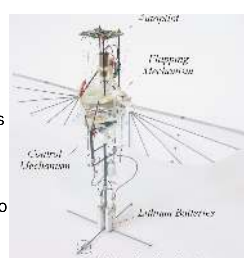
- Novel decentralized infrastructure for micro-UAVs leveraging the Buzz swarm-programming language and virtual machine
- Integration of a deformable linear object model in two decentralized collaborative transport algorithms: spring-damper and Lennard-Jones
- Comparison of the algorithms with series of experiments on a small indoor fleet

09:40–10:55 WeAT1.5

Precision Stationary Flight of a Robotic Hummingbird

Ali Roshanbin, Emanuele Garone and Andre Preumont
Department of Control Engineering and System Analysis,
Universite Libre de Bruxelles (ULB), Belgium

- The COLIBRI robot has demonstrated a precision hovering flight within a circle with a radius of one wingspan of the robot.
- The kinematic and dynamic behavior of the early version of COLIBRI flapping motion has been improved; leading to less parasitic torques, more efficient mechanism, and less sensor noise.
- A cascade control structure is implemented to remove the remaining parasitic torques associated with the developed wing drive system.

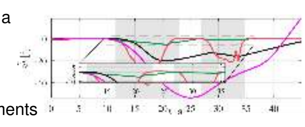

COLIBRI robot

09:40–10:55 WeAT1.6

Robust attitude estimation using an adaptive unscented Kalman filter

Antonio Chiella and Bruno Teixeira
Universidade Federal de Minas Gerais, Brazil
Guilherme Pereira
West Virginia University, USA

- Robust attitude estimation using a MARG sensor;
- Attitude parameterized with unit quaternion;
- Outlier rejection in the measurements using Hamper identifier;
- Covariance matching used to detect slow changes in measurements' uncertainty.



Performance of RAUKF confronted with open source and commercial solutions.

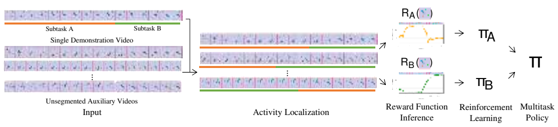
Learning from Demonstration III - 3.1.22

Chair
Co-Chair

09:40–10:55 WeAT1.1

One-Shot Learning of Multi-Step Tasks from Observation via Activity Localization in Auxiliary Video

Wonjoon Goo and Scott Niekum
Department of Computer Science, University of Texas at Austin, USA



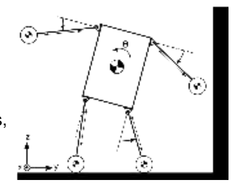
- Goal: given a single segmented demonstration video for a multi-step task, train a policy
- Approach: make use of auxiliary videos through activity localization for better generalization
- Challenges: target activity to localize is unknown beforehand
- Method: meta-learning (MAML, Reptile)

09:40–10:55 WeAT1.2

LVIS : Learning from Value Function Intervals for Contact-Aware Robot Controllers

Robin Deits, Twan Koolen, and Russ Tedrake
CSAIL, MIT, USA

- Learning policies from non-convex optimization (e.g. Guided Policy Search) is difficult.
- Instead, we solve mixed-integer optimizations, terminating them early to extract intervals containing the true cost-to-go.
- Those intervals let us train a neural net to mimic the value function of our robot model.
- We can descend the learned value function with MPC to create a policy that takes advantage of our offline optimization.



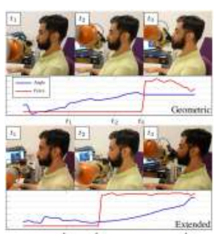
Planar humanoid robot model used to demonstrate LVIS.

09:40–10:55 WeAT1.3

Augmenting Action Model Learning by Non-Geometric Features

Iman Nematollahi, Daniel Kuhner, Tim Welschehold, Wolfram Burgard
Department of Computer Science, University of Freiburg, Germany

- A novel approach to integrate non-geometric features into action model learning
- Encode trajectories in a dynamical system using a Gaussian Mixture Model (GMM)
- Capture correlation between the geometric course of the motion and the additional features through means and covariances of GMM
- Evaluated on real-world robot experiments including a drinking, a handover and a pouring task

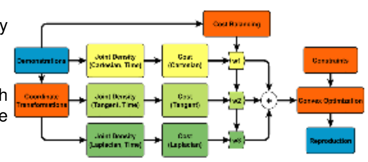


09:40–10:55 WeAT1.4

Skill Acquisition via Automated Multi-Coordinate Cost Balancing

Harish Ravichandar[a], S. Reza Ahmadzadeh[b], M. Asif Rana[a], Sonia Chernova[a]
[a]Georgia Tech, USA; [b]University of Massachusetts Lowell, USA

- A *task-independent* trajectory learning framework
- Encodes joint density with time *simultaneously* in multiple differential coordinates



- Defines a *blended cost function* that incentivizes conformance to the mean in each coordinate system while considering expected variance
- Learns optimal weights directly from the demonstrations to *balance the relative influence* of each coordinate system

09:40–10:55 WeAT1.5

Real-time Multisensory Affordance-based Control for Adaptive Object

Vivian Chu[1], Reymundo A. Gutierrez[2], Sonia Chernova[3], and Andrea L. Thomaz[4]
[1]Diligent Robotics, USA
[2]Computer Science, University of Texas at Austin, USA
[3]College of Computing, Georgia Institute of Technology, USA
[4]Electrical and Computer Engineering, University of Texas at Austin, USA

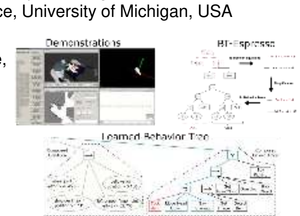
- RMAC: algorithm to allow robots to adaptively interact with objects using multisensory input (haptic, audio, visual)
- RMAC uses Hidden Markov Models (HMMs) to determine in real-time how much the robot should adapt
- Online and off-line experiments of robot opening drawers and turning on lamps

09:40–10:55 WeAT1.6

Learning Behavior Trees From Demonstration

Kevin French[1], Shiyu Wu[2], Tianyang Pan[1], Zheming Zhou[1], Odest Chadwicke Jenkins[2]
[1]Robotics Institute, University of Michigan, USA
[2]Department of Computer Science, University of Michigan, USA

- Behavior Trees transparent, reactive, modular, parallel policy for LfD
- Execute complex high level goal oriented task
- Learn state transitions from demonstration
- Simplify Behavior Trees for efficient execution



User demonstrates and robot executes dusting task

Learning from Demonstration IV- 3.1.23

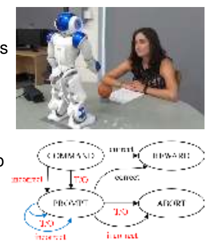
Chair
Co-Chair

09:40–10:55	WeAT1.1

Leveraging Temporal Reasoning for Policy Selection in Learning from Demonstration

Estuardo Carpio, Madison Clark-Turner
Paul Gesel and Momotaz Begum
Cognitive Assistive Robotics Laboratory, University of New Hampshire, USA

- We propose the Temporal Context Graph (TCG), a temporal reasoning model that learns the temporal structure of a task.
- TCG is capable of modeling tasks with repetitive atomic actions and non-sequential temporal relations.
- TCS leverages the current temporal context to address instances of perceptual aliasing.
- TCG helps to reduce action-space and improve policy selection in learning from demonstration.



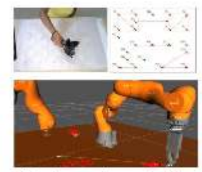
TCG learned from Demonstrated interaction

09:40–10:55	WeAT1.2

Specifying Dual-Arm Robot Planning Problems through Natural Language and Demonstration

Jan Kristof Behrens[1], Karla Stepanova[2], Ralph Lange[1], and Radoslav Skoviera[2]
[1] Robert Bosch GmbH, Corporate Research, Renningen, Germany
[2] CIIRC, Czech Technical University in Prague, Czech Republic

- Planning techniques necessary to utilize capabilities of modern dual-arm robots
- Simultaneous task allocation and motion scheduling (STAAMS) is tailored for industrial manipulation and assembly use-cases
- We propose multi-modal approach (natural language and demonstration) for specifying STAAMS planning problems efficiently
- Elaborate user-study shows significant benefits over textual specification



Single arm demonstration is planned and optimized for two manipulators

09:40–10:55	WeAT1.3

Learning To Serve: An Experimental Study for a New Learning From Demonstrations Framework

Okan Koç[1] and Jan Peters[1,2]
[1]MPI for Intelligent Systems, Tübingen, Germany
[2]FG Intelligente Autonome Systeme, TU Darmstadt, Germany

- Multiple table tennis serve demonstrations are recorded via kinesthetic teach-in.
- Previous approaches learn each joint motion independently: too many parameters for many DoF robots, difficult to apply RL afterwards.
- Learning instead sparse demonstration parameters using alternating optimization.
- Multi-task Elastic Net (inducing sparsity) is alternated with nonlinear optimization (adapting the features).

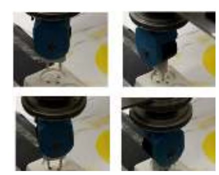
Barrett WAM learning to serve

09:40–10:55	WeAT1.4

Imitating Human Search Strategies for Assembly

Dennis Ehlers[1], Markku Suomalainen[1,2], Jens Lundell[1] and Ville Kyrki[1]
[1]Aalto University, Helsinki, Finland
[2]University of Oulu, Finland

- We present a method that allows a robot to learn search motions often required as exception strategies
- A human demonstration for searching is used to create an exploration distribution, from which the search trajectory is created
- Experiments on a real robot with 2-D and 3-D search tasks show the feasibility of the method



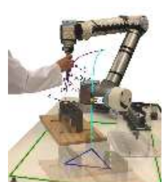
Example of searching in a plug-and-socket task

09:40–10:55	WeAT1.5

Combining Imitation Learning with Constraint-based Task Specification and Control

Cristian Vergara, Joris De Schutter and Erwin Aertbeliën
Department of Mechanical Engineering, KU Leuven, Belgium.

- Enables adaptation of complex tasks to new environments with a small number of demonstrations.
- Brings the capability to generalize trajectories towards non-demonstrated targets.
- Allows the ability to assist a human by generating variable impedance.
- Offers the possibility to integrate sensor inputs, and other aspects of robotic tasks.



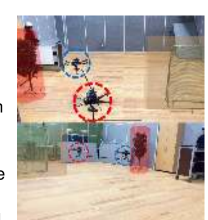
Variable impedance behavior when adding an extra demonstration.

09:40–10:55	WeAT1.6

Incorporating Safety into Parametric Dynamic Movement Primitives

H Kim[1], H Seo[1], S Choi[1], Claire J. Tomlin[2] and H. Jin Kim[1]
[1]Mechanical and Aerospace Eng, Seoul National Univ, South Korea
[2]Electrical Engineering and Computer Sciences, UC Berkeley, USA

- Demonstration-based learning techniques benefit from proper a separation of 'bad' demonstration data from 'good' ones.
- We propose a process to isolate bad demonstrations that generate unsafe motion in parameterized dynamic movement primitives (PDMPs).
- Safety criteria for a parameter in PDMPs are provided using optimization.
- Simulations and experiments are performed on cooperative aerial transportation.



Learning and Manipulation I - 3.1.24

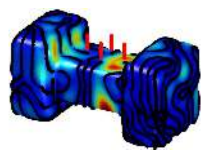
Chair
Co-Chair

09:40–10:55	WeAT1.1

Active Multi-Contact Continuous Tactile Exploration with Gaussian Process Differential Entropy

Danny Driess, Daniel Hennes, Marc Toussaint
Machine Learning & Robotics Lab
University of Stuttgart, Germany

- Formalization of continuous tactile exploration utilizing multiple contacts simultaneously within an information theoretic context
- Active tactile exploration by sliding over an unknown object to maintain the contact
- Compliant controller framework
- Generalization to non-convex objects
- Nonmyopic multi-step exploration planning

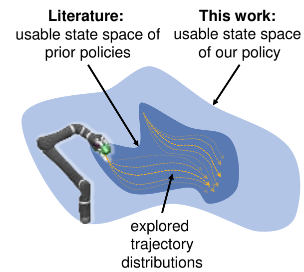


09:40–10:55	WeAT1.2

Learning Robust Manipulation Skills with Guided Policy Search via Generative Motor Reflexes

Philipp Ennen, Pia Bresenitz, Rene Vossen and Frank Hees
Cybernetics Lab IMA & IfU, RWTH Aachen, Germany

- New neural network based **policy representation** with improved robustness against unmodelled input state noise
- Policy is trained by **Guided Policy Search**
- Evaluation scenarios include simulated and **real-world peg-in-hole tasks** for a six axis torque controlled robot

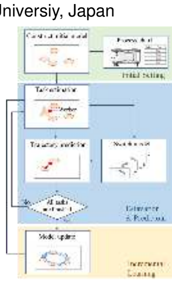


09:40–10:55	WeAT1.3

Incremental Learning of Spatial-Temporal Features in Human Motion Patterns with Mixture Model for Planning Motion of a Collaborative Robot in Assembly Lines

Akira Kanazawa, Jun Kinugawa, Kazuhiro Kosuge
Department of Robotics, Tohoku Universiy, Japan

- Worker's spatial and temporal features are modeled by the mixture model incrementally.
- We propose the incremental learning algorithm which make the mixture model more generalized.
- Experiments confirmed that the proposed system could predict worker's trajectories in human-robot collaborative workspace.

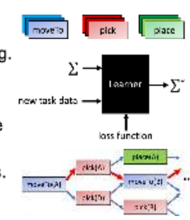


09:40–10:55	WeAT1.4

Learning Quickly to Plan Quickly Using Modular Meta-Learning

Rohan Chitnis, Leslie Kaelbling, Tomás Lozano-Pérez
Computer Science and Artificial Intelligence Laboratory, MIT, USA

- **Meta-learn** a library ∑ of specializers that parameterize actions in task and motion planning.
- **Learn quickly**: adapt ∑ for a new task with little data from that task.
- **Plan quickly**: plan with ∑ rather than exhaustive search over parameter values.
- Specializers are fully connected neural networks.

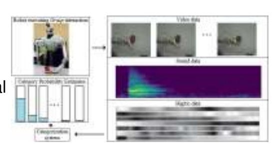


09:40–10:55	WeAT1.5

Deep Multi-Sensory Object Category Recognition Using Interactive Behavior

Gyan Tatiya and Jivko Sinapov
Department of Computer Science, Tufts University, USA

- **Object category recognition** is an important skill for a wide variety of robot tasks
- **Interacting** with objects gives non-visual information such as haptic & auditory properties of objects
- We propose a **Deep Multi-modal Network** that inputs video, audio & haptic signal
- Our approach outperforms the published baseline & achieves good prediction early on during interaction



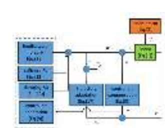
Overview of the proposed categorization pipeline

09:40–10:55	WeAT1.6

Force, Impedance, and Trajectory Learning for Contact Tooling and Haptic Identification

Y. Li, G. Ganesh, N. Jarrasse and E. Burdet
Department of Bioengineering, Imperial College London, UK
S. Haddadin and A. Albu-Schaeffer
Institute of Robotics and Mechatronics, German Aerospace Center, Germany

- We develop a robot controller that concurrently adapts feedforward force, impedance, and reference trajectory
- The robot's reference trajectory is adapted to maintain a desired interaction force
- Feedforward force and impedance adaptation compensates for the interaction with the environment



Block diagram of proposed controller

Learning and Manipulation II - 3.1.25

Chair

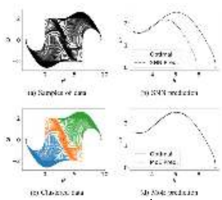
Co-Chair

09:40–10:55	WeAT1.1

Discontinuity-Sensitive Optimal Control Learning by Mixture of Experts

Gao Tang and Kris Hauser
ECE Department, Duke Univ., USA

- We predict optimal solutions for trajectory optimization problems
- Standard neural network has averaging issue at function discontinuity which is prevalent in parametric optimal control problems
- A Mixture of Experts (MoE) model has a classifier and several regressors where each regressor is tuned to a particular continuous regions
- Use novel training approach to train the model and achieves highly reliable trajectory predictions.

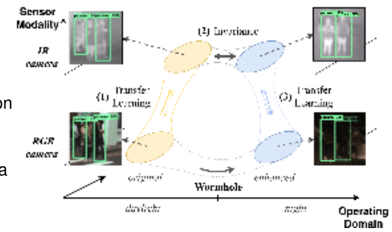


09:40–10:55	WeAT1.2

Wormhole Learning

Alessandro Zanardi, Julian Zilly, Andreas Aumiller, Andrea Censi and Emilio Frazzoli
Institute for Dynamic Systems and Control, ETHz, Switzerland

- Enables **automatic inheritance** of auxiliary sensors invariance.
- Showcase the instantiation of this principle with an **RGB** and **IR camera**.
- Theoretical description via **information theory** provides insights on how to maximize the **wormhole gain**.



Wormhole learning pipeline.

09:40–10:55	WeAT1.3

Sharing the Load: Human-Robot Team Lifting Using Muscle Activity

Joseph DelPreto and Daniela Rus
Distributed Robotics Lab, MIT, USA

- Integrated system using only two EMG signals to control a robot during collaborative lifting tasks
- Algorithm using biceps activity estimates hand height and creates a controller for explicitly commanding adjustments
- Neural network trained on prior users detects up/down gestures for finer control and larger workspaces
- Experimental evaluation with 10 subjects demonstrates lifting and assembly tasks with rigid and flexible objects

Two pipelines process EMG signals to estimate continuous height adjustments and detect up or down gestures.

09:40–10:55	WeAT1.4

Position control of medical cable-driven instruments by combining machine learning and kinematic analysis

Rafael Aleluia Porto, Florent Nageotte, Philippe Zanne and Michel de Mathelin
ICube, University of Strasbourg, France

- Hysteresis effects greatly impact the accuracy of conventional kinematic models in cable-driven systems.
- We propose a new Inverse Kinematic Model which can take into account hysteresis effects.
- The method relies on the off-line learning of the behavior of the instruments and basic knowledge of the kinematics.
- The accuracy is shown to be significantly improved with respect to other learning-based methods

2D trajectory performed with the proposed approach.
Red: Trajectory
Blue: Reference

09:40–10:55	WeAT1.5

Online Learning for Proactive Obstacle Avoidance with Powered Transfemoral Prostheses

Max Gordon
ECE Department, NCSU, United States
Nitish Thatte and Hartmut Geyer
Robotics Institute, Carnegie Mellon University, United States

- Obstacle avoidance is a problem for transfemoral amputees
- We developed an online learning system for powered prostheses to help avoid obstacles
- Our system detects trip avoidance intent and modifies the swing joint angle trajectories
- This allows the user to more successfully avoid obstacles.

Obstacle Avoidance In Progress

09:40–10:55	WeAT1.6

Passive Dynamic Object Locomotion by Rocking and Walking Manipulation

Abdullah Nazir
Department of Electronic and Computer Engineering, The Hong Kong University of Science and Technology, Hong Kong
Jungwon Seo
Departments of Mechanical and Aerospace/Electronic and Computer Engineering, The Hong Kong University of Science and Technology, Hong Kong

- Passive dynamic object locomotion to transport heavy objects
- Kinematics and dynamics of rocking motion and how individual rocking steps can be concatenated to give a sense of locomotion
- Demonstrate proof of concept with a UR10 arm and a model conic object

(a) Rocking and walking the 3m tall moai-replica with teams of people handling three ropes. Figure adapted with permission. (b) Our robotic rocking and walking technique

ICRA X: Robotic Art Forum - Session I

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PODS: Wednesday Session II

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Marine Robotics VI - 3.2.01

Chair
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11:30–12:45	WeBT1.1

Autonomous Latching System for Robotic Boats

Luis A. Mateos, Wei Wang, Banti Gheneti,
Fabio Duarte, Carlo Ratti and Daniela Rus
MIT - Massachusetts Institute of Technology,
77 Massachusetts Avenue, Cambridge, MA 02139, USA

- One of the attractive features specially applied in water environment is to dynamically link and join multiple boats into one unit
- Form floating infrastructure such as bridges, markets or concert stages
- Vision based robot controller with high accuracy to guide the robotic boats in wavy water environments
- Autonomously adapts and retries to latch if it failed to latch in the first attempt due to harsh environment (water current or high wind)

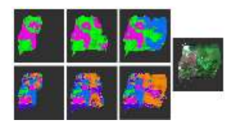
Autonomous robotic boats latched in train link configuration.

11:30–12:45	WeBT1.2

Streaming Scene Maps for Co-Robotic Exploration in Bandwidth Limited Environments

Yogesh Girdhar[1], Levi Cai[2], Stewart Jamieson[2], Nathan McGuire[3], Genevieve Flaspohler[2], Stefano Suman[1], Brian Claus[1]
WHOI[1], MIT[2], Northeastern[3], USA

- Want to interactively explore previously unmapped underwater environments with strong bandwidth constraints.
- Unsupervised scene understanding approach, HDP-ROST, enables realtime scene maps to be transmitted and updated efficiently.
- Hyperparameters enable tuning of bandwidth-resolution tradeoffs.
- Demonstrated using an AUV equipped with a stereo camera, and evaluated using a coral reef dataset.



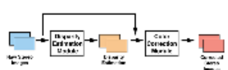
Example of temporal sequence of maps produced using HDP-ROST with two different params.

11:30–12:45	WeBT1.3

UWStereoNet: Unsupervised Learning for Depth Estimation and Color Correction of Underwater Stereo Imagery

Katherine A. Skinner and Elizabeth A. Olson
Robotics Institute, University of Michigan, USA
Junming Zhang
Electrical Engineering and Computer Science, University of Michigan, USA
Matthew Johnson-Roberson
Naval Architecture and Marine Engineering, University of Michigan, USA

- This work presents an unsupervised learning framework that takes in raw underwater stereo imagery and outputs dense depth maps and color-corrected imagery.
- Results are validated with real data gathered in underwater environments.



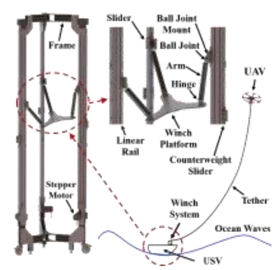
Overview of UWStereoNet

11:30–12:45	WeBT1.4

Design & Parameter Optimization of a 3-PSR Parallel Mechanism for Replicating Wave & Boat Motion

Kurt Talke, Dylan Drotman, Mauricio de'Oliveira, Thomas Bewley
MAE, University of California, San Diego, USA
Kurt Talke, Nick Stroumtsos
Unmanned Systems, Spawar Systems Center Pacific, USA

- 3-DOF (heave, roll, pitch) parallel mechanism developed for replicating wave and boat motion
- Forward kinematic lookup table developed relating platform pose to slider heights
- Parameter optimization (arm length, platform size, ball joint mounting angle) for largest roll-pitch workspace
- Prototype build and experimental validation



11:30–12:45	WeBT1.5

Autonomous Navigation for UUV's: Real-Time Experiments using Computer Vision

A. Manzanilla, S. Reyes, M. Garcia and R. Lozano
LAFMIA-UMI 3175, CINVESTAV-IPN, Mexico
D. Mercado
Research Center in Mathematics CIMAT-Zacatecas, Mexico

- Parallel Tracking and Mapping is employed to localize the vehicle using a single camera.
- Extended Kalman Filter is used to fuse the visual information with data from an IMU.
- PID controller with compensation of the restoring forces is proposed to accomplish trajectory tracking.
- Real-time experiments are presented to validate the navigation strategy, using a BlueROV2.

Fig. AUV in an autonomous mission using vision based localization.

11:30–12:45	WeBT1.6

A Framework for On-line Learning of Underwater Vehicles Dynamic Models

Bilal Wehbe, Marc Hildebrandt and Frank Kirchner
DFKI – Robotic Innovation Center, Bremen, Germany
and
University of Bremen, Bremen, Germany

- Learning the dynamics of robots from data can improve the control or navigation algorithms
- A framework for learning robot dynamics from online data is developed
- The framework is based on incremental support vector regression withstrategies for including and forgetting samples
- The framework is evaluated on real and simulated data.

The AUV Dagon with different configurations used as a test platform

Human Robot Communication - 3.2.02

Chair

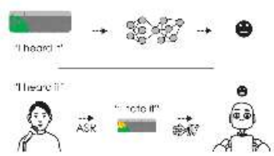
Co-Chair

11:30–12:45	WeBT1.1

Incorporating End-to-End Speech Recognition Models for Sentiment Analysis

Egor Lakomkin, Mohammad Zamani, Cornelius Weber, Sven Magg and Stefan Wermter
Knowledge Technology, Department of Informatics, University of Hamburg

- Existing approaches for sentiment analysis assume manually transcribed speech is present as input (not practical).
- Combining speech recognition with deep neural character-level language model achieves competitive performance without ground truth text.



11:30–12:45	WeBT1.2

Improved Optical Flow for Gesture-based Human-robot Interaction

Jen-Yen Chang, Antonio Tejero-de-Pablos, Tatsuya Harada
Graduate School of Information Science and Technology, The University of Tokyo, Japan.

- Proposed gesture-based HRI pipeline that uses novel optical flow estimation methods, improving speed-accuracy trade-off.
- Introduced four improvements: stronger feature extractors, attention to contours, mid-way features, and combined.
- Our methods provide a better understanding of motion and a finer representation of silhouettes.
- Generated a dataset, MIBURI, that contains gestures to command a home service robot.

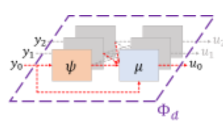
Overview of our pipeline

11:30–12:45	WeBT1.3

Decentralization of Multiagent Policies by Learning What to Communicate

James Paulos*, Steven Chen*, Daigo Shishika, and Vijay Kumar
GRASP Laboratory, University of Pennsylvania, USA, *(*) co-first authors*

- Decentralized policies are desirable, but difficult to hand-engineer due to communication constraints.
- We learn **decentralized** policies for a perimeter defense game directly from centralized policies.
- Key Idea: Find **communication policies** and **action policies** using supervised learning.
- Neural network activations learned during training becomes messages passed between agents during testing.



Distributed Policy Neural Network Architecture

11:30–12:45	WeBT1.4

Acquisition of Word-Object Associations from Human-Robot and Human-Human Dialogues

- **Instruction-based word learning (IBWL)**
  - Teaching through structured human-robot dialogues
  - under constrained perceptual and linguistic circumstances (e.g., "this object is a **knife**")
  - Fast
  - accurate
- **Cross-situational word learning (CSWL)**
  - Teaching through human-human and human-robot dialogues
  - Slow
  - Less reliable
  - under naturalistic perceptual and linguistic circumstances
- **Integration of IBWL and CSWL within the DIARC CRA**
  - Context disambiguation for CSWL
    - Filtering non-referential words based on POS tags provided by NLU
    - Filtering out word and objects learned through IBWL from input
  - Learning from a wider range of interactions including human-human and human-robot interactions

11:30–12:45	WeBT1.5

Robot Object Referencing through Situated Legible Projections

Thomas Weng[1], Leah Perlmutter[2], Stefanos Nikolaidis[3], Siddhartha Srinivasa[2], Maya Cakmak[2]
[1]Robotics Institute, Carnegie Mellon University, USA
[2]Computer Science and Engineering, University of Washington, USA
[3]Department of Computer Science, University of Southern California, USA

- **Goal:** Optimize the placement of a projected arrow for referencing an object.
- **Key Insight:** Maximize referential probability towards target object using *distance functions* (e.g. angle of arrow with object, proximity to object) while minimizing referential probability towards other objects.
- **Findings:** In two studies (online N=48 and in-person N=12), the system produces clear object references in crowded scenes.

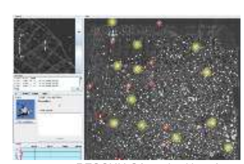
A robot projecting an arrow to reference a tabletop object.

11:30–12:45	WeBT1.6

Security-Aware Synthesis of Human-UAV Protocols

Mahmoud Elfar, Haibei Zhu, M.L. Cummings and Miroslav Pajic
Duke University, USA

- Problem: Can we synthesize **human-UAV** collaboration protocols to enhance their security against stealthy cyber attacks?
- **Delayed-Action Games** (DAGs) were developed to model the system.
- We developed **RESCHU-SA** testbed for human experiments to realize the model.
- **PRISM-games** model checker was used for protocol synthesis from the DAG model.
- **Human experiments** confirm that *human operators can enhance systems' security in highly-uncertain situations.*



RESCHU-SA testbed interface

Human geolocation strategies

Cooperative and Distributed Robot Systems I - 3.2.03

Chair
Co-Chair

11:30–12:45	WeBT1.1

Underwater Communication Using Full-Body Gestures and Optimal Variable-Length Prefix Codes

Karim Koreitem, Jimmy Li, Ian Karp, Travis Manderson, and Gregory Dudek
School of Computer Science, McGill University, Canada

- An inter-robot communication protocol based on full-body gestures consisting of sequences of poses
- Prefix-free encoding of pose sequences for unambiguous message interpretation
- Visual pose detection pipeline consisting of a convnet-based pose estimation network
- Experiments demonstrate successful gesture-based communication in real underwater settings

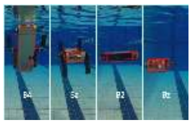


Figure: Sequence of poses comprising a message being communicated by the underwater robot

11:30–12:45	WeBT1.2

WISDOM: WIreless Sensing-assisted Distributed Online Mapping

Charuvahan Adhivarahan and Karthik Dantu
Department of Computer Science & Engineering, University at Buffalo, USA

- Merges 3D point clouds from multiple robots efficiently and accurately.
- Uses Wi-Fi data from multiple Access Points that are ubiquitous in indoor environments
- Executes a modified ICP algorithm to merge maps
- Can be integrated with any SLAM system that produces point cloud or grid maps

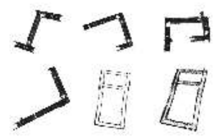


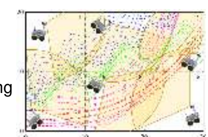
Fig: Maps from multiple robots merged using WISDOM

11:30–12:45	WeBT1.3

Learning Recursive Bayesian Nonparametric Modeling of Moving Targets via Mobile Decentralized Sensors

Chang Liu, Yucheng Chen, Jake Gemerek, Hengye Yang and Silvia Ferrari
Sibley School of Mechanical and Aerospace Engineering, Cornell University, USA

- Developed a recursive fusion approach for Dirichlet Process Gaussian Process (DPGP)
- Proposed an input-dependent, Wasserstein metric-based DP prior for measurement clustering
- Applied the proposed recursive DPGP to decentralized multi-target motion model estimation.
- Derived an analytical expression of information gain, which can be utilized for informative motion planning.

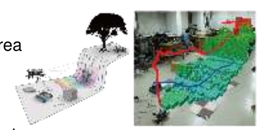

Target kinematics learning using multiple mobile sensors.

11:30–12:45	WeBT1.4

UAV/UGV Autonomous Cooperation: UAV assists UGV to climb a cliff by attaching a tether

Takahiro Miki, Petr Khrapchenkov, Koichi Hori
Aeronautics and Astronautics, University of Tokyo, Japan

- Cooperative system where UAV and UGV collaboratively navigate through unknown environment.
- UAV can attach a tether to inaccessible area for UGV.
- UGV can enhance its traversability by winding the attached tether.
- Autonomous framework for the mission and comparison of the tether attachment methods.
- The feasibility of the system was demonstrated through experiments.

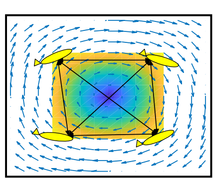

Proposed system and experimental result

11:30–12:45	WeBT1.5

Distributed Motion Tomography for Reconstruction of Flow Fields

Dongsik Chang and Jing Sun
Department of Naval Architecture and Marine Engineeing, University of Michigan, USA
Fumin Zhang
School of Electrical and Computer Engineering, Georgia Institute of Technology, USA

- For flow field mapping using a network of marine robots, distributed motion tomography is developed.
- Motion tomography formulates a nonlinear system of equations to infer a flow field from vehicle trajectories.
- A distributed method that solves the system of equations is developed to estimate a flow field.
- The convergence and consensus for the method is studied and the method is demonstrated through simulations.


Reconstruction of a flow field by distributed MT

11:30–12:45	WeBT1.6

Adaptive Sampling and Reduced Order Modeling of Dynamic Processes by Robot Teams

Tahiya Salam and M. Ani Hsieh
GRASP Laboratory, University of Pennsylvania, USA

- Adaptive sampling and tracking of dynamic process
- Robots collect sparse measurements, create reduced-order model, and estimate field values
- Decentralized strategy for leveraging dynamics of time-varying process to estimate field


Marine robots tracking dynamic process using decentralized algorithm

Cognitive HRI - 3.2.04

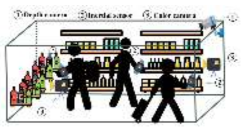
Chair
Co-Chair

11:30–12:45	WeBT1.1

Who Takes What: Using RGB-D Camera and Inertial Sensor for Unmanned Monitor

Hsin-Wei Kao, Ting-Yuan Ke, Kate Ching-Ju Lin and Yu-Chee Tseng
Computer Science, National Chiao Tung University, Taiwan

- We propose a framework to detect "Who takes what" (WTW) events
- WTW consists of two event detection algorithms: user-taking and object-taken
- We develop pair scoring functions to find correlation between user-taking and object-taken events and perform pairwise matching
- Our prototype evaluation shows robustness and stability in real environments



Architecture of WTW (Who Takes What)

11:30–12:45	WeBT1.2

Sound-Indicated Visual Object Detection for Robotic Exploration

Feng Wang, Di Guo, Huaping Liu, Junfeng Zhou, Fuchun Sun
Department of Computer Science and Technology,
Tsinghua University, China

- A novel robotic sound-indicated visual object detection framework.
- A two stream network which aligns the audio concepts and visual concepts.
- We evaluate our method and some promising application are demonstrated on robotic platforms

A robotic is exploring to find the object that sounds.

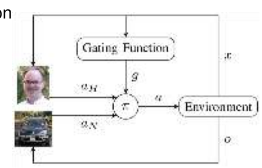
11:30–12:45	WeBT1.3

HG-DAgger: Interactive Imitation Learning with Human Experts

Michael Kelly, Chelsea Sidrane,
Katherine Driggs-Campbell, and Mykel J. Kochenderfer
Stanford University, USA

Human-Gated Dagger (HG-DAgger) is designed for safer and more effective imitation learning from human experts

- We demonstrate ***improved sample efficiency***, ***greater training stability***, and ***more human-like behavior***
- We introduce a data-driven approach for ***learning a safety threshold*** for our policy using Bayesian deep learning
- We demonstrate the effectiveness of our method on a ***real vehicle***



Train-time control loop for HG-DAgger

11:30–12:45	WeBT1.4

Proximity Human-Robot Interaction Using Pointing Gestures and a Wrist-Mounted IMU

Boris Gromov, Luca M. Gambardella, Alessandro Giusti
Dalle Molle Institute for Artificial Intelligence (IDSIA), SUPSI-USI, Switzerland
Gabriele Abbate
University of Milano-Bicocca (UNIMIB), Italy

- Intuitive interface for proximity interaction using pointing gestures sensed by off-the-shelf IMU
- User points and keeps following a moving robot to localize and identify it, and then guides it to a desired location
- Immediate visual feedback provided by robot's own motion allows the user to correct any inaccuracies

Guiding a drone with pointing gestures

11:30–12:45	WeBT1.5

Bayesian Active Learning for Collaborative Task Specification Using Equivalence Regions

Nils Wilde*, Dana Kulić*† and Stephen L. Smith*
*University of Waterloo, Canada, †Monash University, Australia

- Enable **non-expert users** to specify complex robot tasks by defining constraints
- Query users to **choose from alternative paths** to revise importance of constraints
- Quick and robust learning through greedy approach and **probabilistic user model**
- **Practical performance** in simulation with 20 iterations of user interaction

Improving material transport performance

Calibration and Identification - 3.2.05

Chair
Co-Chair

11:30–12:45	WeBT1.1

Lidar Measurement Bias Estimation via Return Waveform Modelling in a Context of 3D Mapping

Johann Laconte, Simon-Pierre Deschênes, Mathieu Labussière, François Pomerleau
Northern Robotics Laboratory, Université Laval, Canada

- This paper focuses on Lidar measurement bias and its effect on mapping.
- We provide a physical explanation of the bias which generalizes to multiple sensors
- Using an experimental setup, we measured the bias of the Sick LMS151, Velodyne HDL-32E, and Robosense RS-LiDAR-16 as a function of depth and incidence angle.
- We used our model to remove bias from the measurements, leading to more accurate maps

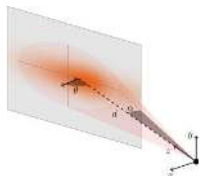


Illustration of a laser beam hitting an oriented surface

11:30–12:45	WeBT1.2

An Extrinsic Calibration Tool for Radar, Camera and Lidar

Joris Domhof, Julian F .P. Kooij and Dariu M. Gavrila
Cognitive Robotics, Delft University of Technology, The Netherlands

- Three extrinsic sensor calibration configurations to jointly calibrate radar, camera and lidar.
- Calibration target design that is detectable by lidar, camera and radar.
- An open-source extrinsic calibration tool with bindings to ROS.

11:30–12:45	WeBT1.3

Unified Motion-Based Calibration of Mobile Multi-Sensor Platforms with Time Delay Estimation

Bartolomeo Della Corte and Giorgio Grisetti
Department of Computer, Control, and Management Engineering
"Antonio Ruberti", Sapienza University of Rome, Italy
Henrik Andreasson and Todor Stoyanov
Center of Applied Autonomous
Sensor Systems (AASS), Örebro University, Sweden

The **Methodology** presented in this paper:

- Simultaneously estimates the platform kinematic parameters, the sensors extrinsics, and their time delays.
- Easily extendible to other class of parameters.
- Runs in a semi-active way, discarding less informative portions of trajectory.
- Is suitable to be used in failure detection pipelines through the continuous observation of the parameters evolution.

Dead reckoning map built on a trajectory of approximately 200 meters, after the calibration procedure.

11:30–12:45	WeBT1.4

Degenerate Motion Analysis for Aided INS with Online Spatial and Temporal Sensor Calibration

Yulin Yang, Patrick Geneva*, Kevin Eckenhoff and Guoquan Huang
Dept. Mechanical Engineering, University of Delaware, USA
*Dept. Computer and Information Science, University Of Delaware, USA

- Spatial/temporal calibration are observable for aided INS under general motion.
- Four degenerate motions causing online spatial/temporal calibration to fail are identified.
- These degenerate motions still hold even when global pose measurements are present.
- These degenerate motions are validated through extensive Monte-Carlo simulations and real-world experiments.

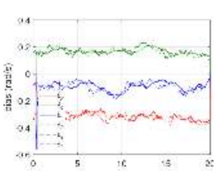
Figure: Observability of spatial and temporal calibration of aided INS with different motions

11:30–12:45	WeBT1.5

Compensation of measurement noise and bias in geometric attitude estimation

Yujendra Mitikiri
Mechanical and Aerospace Engineering, University of Florida, USA
Kamran Mohseni
Mechanical and Aerospace Engineering, University of Florida, USA

- We consider two main kinds of noise in IMU measurements: zero-mean Gaussian and slowly varying random walk with exponential autocorrelation
- We present optimal filtering for the first kind and estimation and compensation for the second kind
- Both solutions developed to account for the nonlinearity inherent to attitude kinematics and dynamics



Estimation of constant and slowly varying gyro bias

11:30–12:45	WeBT1.6

Geometric Calibration of Continuum Robots: Joint Space and Equilibrium Shape Deviations

Long Wang and Nabil Simaan
Department of Mechanical Engineering, Vanderbilt University, USA

- A novel kinematic calibration framework for continuum robots capturing shape deviation, torsional twist, and joint home offsets
- Kinematic error propagation formulated, calibration identification Jacobians derived
- Simulations of calibration sensitivity investigated, calibration experiments validated on a single port access surgery robot
- Real-time calibrated model implemented, and a 3D trajectory following test conducted.

Calibration experimental setup for continuum robots

Semantic Scene Understanding II - 3.2.06

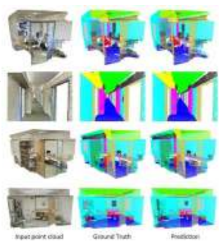
Chair
Co-Chair

11:30–12:45 WeBT1.1

Hierarchical Depthwise Graph Convolutional Neural Network for 3D Semantic Segmentation of Point Clouds

Zhidong Liang
Research Institute of Robotics, Shanghai Jiao Tong University, China
Ming Yang, Liuyuan Deng, Chunxiang Wang, Bing Wang
Department of Automation, Shanghai Jiao Tong University, China

- We propose a depthwise spatial graph convolution followed by 1 ✕ 1 convolution as the pointwise convolution. Based on this, we design the DGConv block which is effective for local feature extraction.
- We utilize the hierarchical structure combined with the DGConv block to extract local and global features hierarchically.
- Our proposed method achieves state-of-the-art performance on S3DIS and Paris-Lille-3D benchmark.

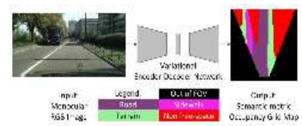


11:30–12:45 WeBT1.2

Monocular Semantic Occupancy Grid Mapping with Convolutional Variational Encoder-Decoder Networks

Chenyang Lu, René van de Molengraft, Gijs Dubbelman
Eindhoven University of Technology, The Netherlands

- End-to-end learning on monocular imagery to produce a semantic-metric occupancy grid map
- Intrinsically robust to pitch and roll perturbations
- Generalizes on unseen data from different cameras
- Trained from weak ground truth



System overview

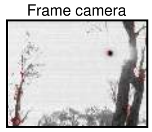
11:30–12:45 WeBT1.3

Asynchronous Spatial Image Convolutions for Event Cameras

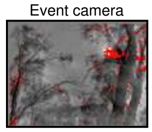
Cedric Scheerlinck, Nick Barnes and Robert Mahony
College of Engineering & Computer Science,
The Australian National University, Australia

- Event cameras output pixel-wise changes in brightness called 'events.'
- An event contains (x, y) pixel address, timestamp, and polarity indicating increase or decrease in brightness.
- Spatial convolution of one event influences the output image in a local neighbourhood.
- Asynchronous, event-by-event convolution enables sparse, low-latency processing, e.g. corner detection.

Frame camera



Event camera



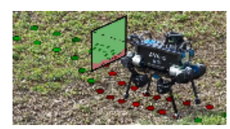
Corners: 'looking at the sun.'

11:30–12:45 WeBT1.4

Where Should I Walk? Predicting Terrain Properties From Images via Self-Supervised Learning

Lorenz Wellhausen[1], Alexey Dosovitskiy[2], René Ranftl[2], Krzysztof Walas[3], Cesar Cadena[4], Marco Hutter[1]
[1,4] Robotics Systems Lab[1], Autonomous Systems Lab[4], ETH Zürich, Switzerland;
[2] Intel Labs, Germany; [3] IARII, Poznan University of Technology, Poland

- Robot navigation in natural environment requires information about terrain properties
- Sensorized feet measure terrain interactions which are projected into camera images
- A convolutional network is trained to predict terrain properties from images
- Terrain property predictions are used as a cost measure for path planning with the ANYmal quadruped



Haptic Measurements are Projected into Images to obtain Label Data

11:30–12:45 WeBT1.5

Adapting Semantic Segmentation Models for Changes in Illumination and Camera Perspective

Wei Zhou, Alex Zyner, Stewart Worrall, and Eduardo Nebot
Australian Centre for Field Robotics, the University of Sydney, Australia

- Improve the robustness of semantic segmentation for new environments
- Use gamma correction and skew to simulate illumination and camera perspective changes
- Significant improvements on both real-time network (ENet) and high-performance network (PSPNet)
- Stitch multiple-view images to form a 180° semantic segmentation

180° Semantic Segmentation

SLAM - Session VIII - 3.2.07

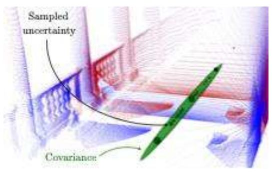
Chair
Co-Chair

11:30–12:45	WeBT1.1

CELLO-3D: Estimating the Covariance of ICP in the Real World

David Landry, François Pomerleau, Philippe Giguère
Northern Robotics Laboratory, Université Laval, Canada

- This paper focuses on the problem of estimating the covariance of ICP in real 3D environments.
- We provide an experimental explanation as to why current covariance estimation algorithms may perform poorly.
- We present a data-driven approach to estimating the uncertainty of 3D ICP that works with any error metric.



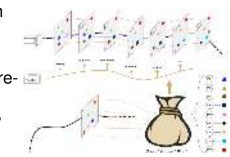
A reading point cloud (red) is being registered against a reference point cloud (blue) leading to uncertainty on the resulting transformation.

11:30–12:45	WeBT1.2

Probabilistic Appearance-Based Place Recognition through Bag of Tracked Words

Konstantinos A. Tsintotas, Loukas Bampis and Antonios Gasteratos
Production and Management Engineering,
Democritus University of Thrace, Greece

- A fully probabilistic visual place recognition with low computational complexity.
- Robust local keypoints tracking through Kanade-Lucas-Tomasi and a guided-feature-detection.
- Novel incremental "Bag of Tracked Words" generation assigned to the traversed map.

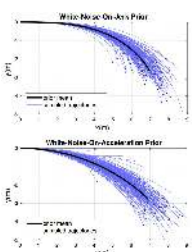


11:30–12:45	WeBT1.3

A White-Noise-On-Jerk Motion Prior for Continuous-Time Trajectory Estimation on *SE(3)*

Tim Y. Tang, David J. Yoon, and Timothy D. Barfoot
Autonomous Space Robotics Lab, University of Toronto, Canada

- Current formulations of Simultaneous Trajectory Estimation and Mapping (STEAM) assume a white-noise-on-acceleration (WNOA) motion prior
- A WNOA prior cannot sufficiently represent trajectories with non-zero acceleration, leading to a bias
- We derive a white-noise-on-jerk (WNOJ) motion prior, with the prior mean encouraging constant body-centric acceleration
- Validation on real-world datasets shows that the WNOJ prior leads to better solution accuracy



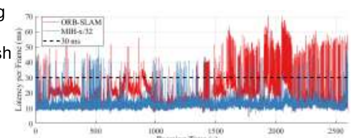
WNOJ Prior (top) vs. WNOA Prior (bottom)

11:30–12:45	WeBT1.4

Low-latency Visual SLAM with Appearance-Enhanced Local Map Building

Yipu Zhao, Wenkai Ye and Patricio A. Vela
ECE, Georgia Institute of Technology, Atlanta, Georgia

- This paper describes an appearance-based enhancement to conventional co-visibility local map building in VSLAM.
- Only the map features visually similar to the current measurements are potentially useful for data association and downstream state optimization.
- Mapped features are indexed and queried with Multi-index Hashing (MIH); further reduce the overhead of MIH with online hash table selection.
- Demonstrate significant latency reduction with performance preservation when integrated to ORB-SLAM.

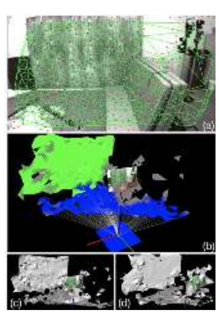


11:30–12:45	WeBT1.5

Incremental Visual-Inertial 3D Mesh Generation with Structural Regularities

Antoni Rosinol[1], Torsten Sattler[2], Marc Pollefeys[2], Luca Carlone[1]
[1]LIDS, MIT, USA [2]CVG, ETHZ, Switzerland

- 3D Mesh generated from Delaunay triangulation over image keypoints. Spans time-horizon of the fixed-lag optimization.
- Planar structural constraints extracted from 3D Mesh are encoded in a novel factor-graph formulation.
- Experimental results on Euroc dataset show improvements in:
  > Pose estimation: +20% accuracy when structural regularities are present.
  > Mesh generation: smoother 3D mesh.



AI-based Methods II - 3.2.08

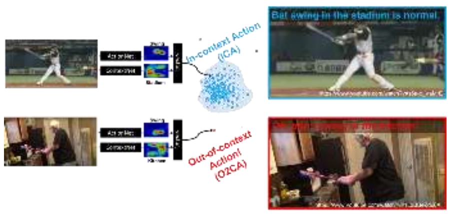
Chair
Co-Chair

11:30–12:45	WeBT1.1

Unsupervised Out-of-context Action Understanding

Hirokatsu Kataoka and Yutaka Satoh
AIST

- Out-of-context action (O2CA) is (un)supervised from both human action and context modalities statistically.
- To generate the necessary unsupervised labels, we comprehensively evaluate both responses from {action, context}-CNN.
- Analyzing the modalities of human action and context separately.



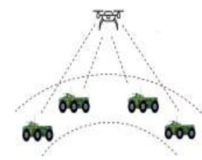
Example of out-of-context (O2CA). When considering an action such as a bat swing, a background stadium indicates an in-context action. However, a bat swing in a kitchen would be an O2CA

11:30–12:45	WeBT1.2

Air-to-Ground Surveillance Using Predictive Pursuit

Sourav Dutta and Chinwe Ekenna
Computer Science, University at Albany, SUNY, USA

- A new approach to target tracking problem.
- A probabilistic prediction model with a variant of Markov decision process in an air-to-ground robot surveillance scenario.
- Target localization by combining prediction of used planning algorithm by the target, and its application to predict future trajectories.
- High predictive accuracy based on final point of interception of the target.



11:30–12:45	WeBT1.3

Online Planning for Target Object Search in Clutter under Partial Observability

Yuchen Xiao, Sammie Katt, Andreas ten Pas, Shengjian Chen and Christopher Amato
Khoury College of Computer Sciences, Northeastern University, USA

- A **POMDP model** for **target object search** in an unstructured environment.
- **Parameterized Action POMCP** considers the effect of the robot's current belief on the action success.
- A **run-time initial belief generator** reasons about potential target locations.
- Experiments show that our method outperforms baselines by taking **fewer object movements**.

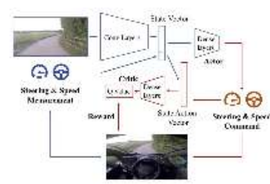
A mobile robot is tasked with finding **a hidden blue Lego block.**

11:30–12:45	WeBT1.4

Learning to Drive in a Day

Alex Kendall, Jeffrey Hawke, David Janz, Przemyslaw Mazur, Daniele Reda, John-Mark Allen, Vinh-Dieu Lam, Alex Bewley and Amar Shah
Wayve, Cambridge, UK

- First application of deep reinforcement learning to autonomous driving.
- We learn to lane follow from monocular image input using reward: distance travelled by the vehicle before safety driver intervention.
- We discuss the challenges and opportunities to scale reinforcement learning to autonomous driving.

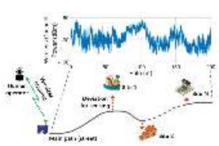


11:30–12:45	WeBT1.5

Human-Robot Collaborative Site Inspection under Resource Constraints

Hong Cai and Yasamin Mostofi
ECE Deptartment, University of California, Santa Barbara, USA

- Co-optimization of robot's motion, sensing, and communication to remote operator, considering *imperfect human performance* and *realistic wireless channel environments*
- Efficient Linear Program-based near-optimal algorithm for robot decision-making, with mathematically proven small optimality gap
- Comprehensive validation with *real human data* and *real wireless channel data* that confirms the significant advantage of using our proposed approach



To classify the targets at the sites, the robot decides for which sites it should move closer to sense better and for which sites it should query the remote human operator.

Simulation and Animation - 3.2.09

Chair
Co-Chair

11:30–12:45 WeBT1.1

Generating Adversarial Driving Scenarios in High-Fidelity Simulators

Yasasa Abeysirigoonawardena and Gregory Dudek
Center for Intelligent Machines, McGill University, Canada
Florian Shkurti
Department of Computer Science, University of Toronto, Canada

- Given a self-driving policy, how can we automatically find driving scenarios in which the policy fails (causes an accident) in simulation?
- We optimize the motion of pedestrians and other car trajectories that will lead the self-driving car closer to a crash.
- We use Bayesian Optimization for sample-efficient motion optimization and discovery of adversarial driving scenarios.
- The generated adversarial scenarios are used to request a demonstration from the user.

Adversarial scenario: before demonstration

After demonstration: self-driving car swerves

11:30–12:45 WeBT1.2

Data-Driven Contact Clustering for Robot Simulation

Myungsin Kim, Jaemin Yoon, Dongwon Son, and Dongjun Lee
Department of Mechanical & Aerospace Engineering and IAMD, Seoul National University, Republic of Korea

- We propose a novel **data-driven/learning-based contact clustering framework** with its accuracy established by experimental data
- Multilayer perceptron network and constraint-based optimization contact solver are utilized for the contact clustering
- Significant performance improvement over Bullet & ODE and meaningful accuracy improvement over Vortex were achieved

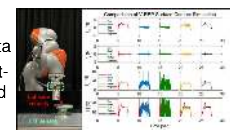


Figure: Experimental data is utilized for the accuracy of contact simulation

11:30–12:45 WeBT1.3

Pavilion: Bridging Photo-Realism and Robotics

Fan Jiang and Qi Hao
Dept. of CSE, Southern University of Science and Technology, China

- New simulator concept with Unreal Engine
- Ability to generate various sensor and corresponding ground-truth like LIDAR and optical flow
- Seamless integration of UE4 and ROS
- Ability to import SDF models

The simulator running LIDAR SLAM

11:30–12:45 WeBT1.4

A Real-Time Interactive Augmented Reality Depth Estimation Technique for Surgical Robotics

Megha Kalia and Tim Salcudean
Electrical and Computer Engineering, University of British Columbia, Canada
Nassir Navab
Chair of Computer Aided Medical Procedures, Technical University of Munich, Germany

- Proposed a Color Depth Encoding technique for robotics assisted surgery.
- Mapped distance to color to estimate depth of anomalies like tumor.
- Used a virtual tool for evaluation using forward kinematics data from da Vinci surgical robot.
- Evaluation showed significant improvement in depth judgment.

11:30–12:45 WeBT1.5

Force-based Heterogeneous Traffic Simulation for Autonomous Vehicle Testing

Qianwen Chao
Department of Computer Science, Xidian University, China
The Engineering Product Development, SUTD,Singapore

- Scalable framework based on the force-based concept to generate complex virtual urban traffic environments
- A unified model for various detailed behaviors of vehicles, unlike previous traffic simulation methods
- A viable solution for describing the interactions among different types of road users in simulation

Generated mixed traffic scenario by our approach

Object Recognition & Segmentation IV - 3.2.10

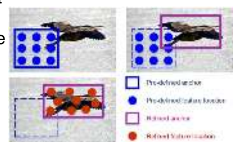
Chair
Co-Chair

11:30–12:45	WeBT1.1

Dual Refinement Network for Single-Shot Object Detection

Xingyu Chen, Xiyuan Yang, Shihan Kong, Zhengxing Wu, and Junzhi Yu
Institute of Automation, Chinese Academy of Sciences, China

- Drawing inspiration from the merits of two-stage methods, we propose an anchor-offset detection including an anchor refinement, feature a offset refinement, and a deformable detection head to further improve the performance of the single-stage detector.
- A multi-deformable head is designed to leverage both region-level features and contextual information for describing objects.
- The DRN sees 82.0% mAP vs. 55.2 FPS on VOC2007 test set and 69.4% mAP vs. 40.5 FPS on ImageNet VID validation set.



Detection modes of SSD, RefineDet, and DRN

11:30–12:45	WeBT1.2

Distant Vehicle Detection Using Radar And Vision

Simon Chadwick, Will Maddern and Paul Newman
Oxford Robotics Institute, University of Oxford, United Kingdom

- Fusion of radar and vision using SSD-style CNN improves detection of small vehicles
- Dataset including radar is automatically generated using cameras of different focal lengths and existing object detector
- Performance exceeds both detector used for labelling and vision only performance

Using radar makes it possible to detect distant and hard to see vehicles

11:30–12:45	WeBT1.3

Customizing Object Detectors for Indoor Robots

Saif Alabachi and Gita Sukthankar
University of Central Florida, Orlando, FL USA
Rahul Sukthankar
Google Research, Mountain View, CA USA

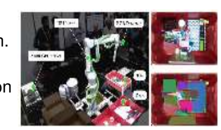
- System for rapidly creating customized object detectors using a quadcopter
- Introduce DUNet (Dense Upscaled Network) for learning detectors using limited data
- Outperforms state of the art on real time object detection for indoor robots
- Released DroSet dataset of indoor images collected with quadcopter

11:30–12:45	WeBT1.4

Semi Supervised Deep Quick Instance Detection and Segmentation

Ashish Kumar and L. Behera
Electrical Engineering, Indian Institute of Technlogy, Kanpur, India

- Semi Supervised ground truth generation.
- Occlusion aware synthetic clutter generation.
- A system which can generate data and train itself for instance detection and segmentation incrementally.
- A complex organization of many hardware, software and deep learning components altogether functioning harmonically.



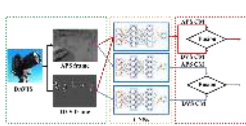
Overall system with instance detection and segmentation results

11:30–12:45	WeBT1.5

Mixed Frame-/Event-Driven Fast Pedestrian Detection

Zhuangyi Jiang, Pengfei Xia, Walter Stechele, Zhenshan Bing, Alois Knoll
Technical University of Munich, Germany
Kai Huang
School of Data and Computer Science, Sun Yat-sen University, China
Guang Chen
School of Automotive Studies, Tongji University, China

- First work on pedestrian detection by using DAVIS.
- Combine APS channel and DVS channel by fusing confidence maps derived from CNN.
- Achieve 72-93% average precision (3-18% higher) at 57 fps (2.28 times) than conventional frame-based camera.



mixed frame-/event-driven pedestrian detection

11:30–12:45	WeBT1.6

Real-Time Vehicle Detection from Short-range Aerial Image with Compressed MobileNet

Yuhang He[1], Ziyu Pan[1], Lingxi Li[2], Yunxiao Shan[1], Dongpu Cao[3] and Long Chen[1]
[1]School of Data and Computer Science, Sun Yat-sen Univ., China
[2]Depart. of Electrical and Computer Engineering, IUPUI, USA.
[3]Depart. of Mechanical and Mechatronics Engineering, Univ. of Waterloo, CA.

- Challenges: blocking, motion blurring, irrelevant interference, etc.
- We propose compressed MobileNet, which internally resists these challenges.
- We gain high detection/accuracy tradeoff, without introducing much extra FLOPs.
- Performance: GPU 110 FPS, CPU 31 FPS, Mobile Phone: 15 FPS.

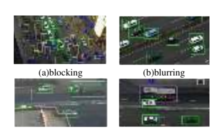


Fig. 1. Challenges in Vehicle Detection

Haptics and Manipulation - 3.2.11

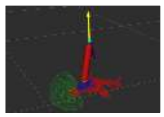
Chair
Co-Chair

11:30–12:45	WeBT1.1

Guaranteed Active Constraints Enforcement on Point Cloud-approximated Regions for Surgical Applications

Theodora Kastritsi [2], Dimitrios Papageorgiou [1,2], Iason Sarantopoulos [1,2], Sotiris Stavridis [1,2], Zoe Doulgeri [1,2] and George A. Rovithakis [1,2]
[1] Information Technologies Institute, Center of Research and Technology Hellas, Thessaloniki, Greece
[2] Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece

- A novel constraint enforcement controller guarantees that the robot tool will never touch a constraint surface provided by a point cloud.
- Utilizes Artificial Potential fields to produce repulsive wrenches on the tool in the vicinity of the constraints.
- Proof for closed loop passivity, boundedness of state and non violation of constraints is given.
- Experimental results for constraint enforcement on the whole tool are included.



forbidden region (vessels) can never be violated

11:30–12:45	WeBT1.2

Designing an accurate and customizable epidural anesthesia haptic simulator

Thibault Sénac ∗, Arnaud Lelevé ∗, Richard Moreau∗, Laurent Krahenbuhl ∗, Florent Sigwalt †, Christian Bauer †‡, Quentin Rouby ∗
∗ Laboratoire Ampère, INSA Lyon, ECL, France, † Département d'Anesthésie-Réanimation, Hôpital de la Croix Rousse, France, ‡ SAMSEI, UCBL, France

- A haptic simulator has been developed to help students learn the epidural anesthesia procedure
- The proposed simulator emulates both the needle insertion and the syringe behavior
- The simulator was tested involving experts anesthetists and novices to assess its realism
- The first results allow to draw some key aspects of a mastered epidural anesthesia

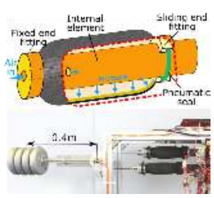
Simulator in use

11:30–12:45	WeBT1.3

Sleeve Pneumatic Artificial Muscles for Antagonistically Actuated Joints

Michael F. Cullinan, Conor McGinn and Kevin Kelly
Department of Mechanical and Manufacturing Engineering, Trinity College Dublin, Ireland

- A comparison of Sleeve Pneumatic Artificial Muscles (PAMs) and Traditional PAMS is conducted both theoretically and experimentally.
- Joint torque can be increased by more than 50% using sleeve PAMs, or joint rotation may be extended by 14%.
- The closed system stiffness (mass of air in the PAM held constant) is up to 3 times greater with sleeve PAMs
- A method to theoretically estimate energy usage is presented and the sleeve PAM is shown to be significantly more efficient.



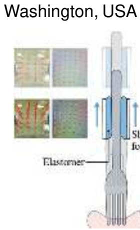
The sleeve PAM concept and testing apparatus

11:30–12:45	WeBT1.4

Sensing Shear Forces During Food Manipulation: Resolving the Trade-Off Between Range and Sensitivity

Hanjun Song, Tapomayukh Bhattacharjee, and Siddhartha S. Srinivasa
Computer Science & Engineering, University of Washington, USA

- We customized two low-cost shear sensing fingertip tactile sensors for feeding tasks.
- We investigated the trade-offs between sensing range and sensitivity when measuring shear forces with the tactile sensors for manipulating food items.
- We developed a control policy to regulate the sensitivity and the sensing range of these fingertip tactile sensors by adapting gripping forces.



Sensing shear force with fingertip tactile sensors

11:30–12:45	WeBT1.5

Benchmarking Resilience of Artificial Hands

F. Negrello[1], M. Garabini[2], G. Grioli[1], N. Tsagarakis[1], A. Bicchi[1,2], M.G. Catalano[1]
1 Istituto Italiano di Tecnologia, Italy
2 Centro di Ricerca E. Piaggio e Dipartimento di Ingegneria dell'Informazione, Università di Pisa, Italy.

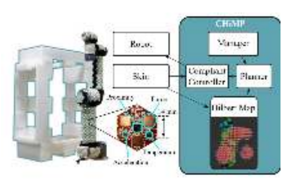
- Real world scenarios involve high physical interactions,
- We propose a novel method for benchmarking robotics hands based on Charpy and Izod tests.
- We validated the method through experimental tests on two soft robotic hands

11:30–12:45	WeBT1.6

CHiMP: A Contact based Hilbert Map Planner

Constantin Uhde, Emmanuel Dean-Leon and Gordon Cheng
Institute for Cognitive Systems,
Technical University of Munich, Germany

- Contact-based 3D path planning approach for manipulators using robot skin
- 3D extension of *Stochastic Functional Gradient Path Planner*
- Experimental platform with 6 DOF robot, covered in multi-modal robot skin.
- Compared against different state-of-the-art planners



Compliant Actuators I - 3.2.12

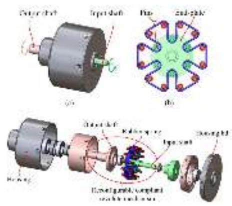
Chair
Co-Chair

11:30–12:45 WeBT1.1

A Novel Reconfigurable Revolute Joint with Adjustable Stiffness

Zhongyi Li and Shaoping Bai
Department of Materials and Production, Aalborg University, Denmark
Weihai Chen
Automation Science and Electrical Engineering, Beihang University, China

- An innovative design of revolute joint of adjustable stiffness with reconfigurability (JASR) is developed.
- The new joint features adjustable stiffness with various elastic behaviours based on the reconfiguration design.
- The joint enables innovative designs of robotic systems such as exoskeletons, service robots to interact naturally with environments.

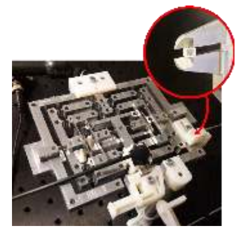


11:30–12:45 WeBT1.2

A novel force sensor with zero stiffness at contact transition based on optical line generation

J. Begey, M. Nierenberger, P. Pfeiffer, S. Lecler and P. Renaud
ICube, University of Strasbourg, CNRS, INSA Strasbourg, France

- Zero stiffness in initial position for enhanced contact with stiff structures
- 3D printed transparent optical component
- Optical line for off-axis behavior improvement
- Experimental evaluation with a proof of concept



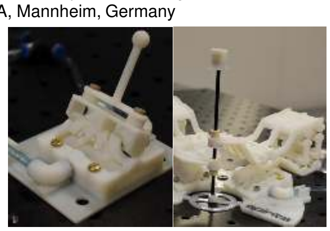
Evaluated proof of concept using a printed optical component

11:30–12:45 WeBT1.3

Hydraulically-actuated compliant revolute joint based on multimaterial additive manufacturing

A. Pfeil[1], M. Siegfarth[2], F. Geiskopf[1], T.P. Pusch[2], L. Barbé[1] and P. Renaud[1]
[1] ICUBE, INSA – CNRS - University of Strasbourg, France
[2] Fraunhofer IPA, Mannheim, Germany

- Multimaterial additive manufacturing for design of active compliant revolute joint
- Miniature hydraulic cylinders with new sealings for low friction
- Compliant joint with embedded rack-and-pinion mechanism
- Experimental evaluation and integration for hydraulically-actuated revolute joint suitable for medical robotic systems



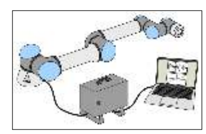
Hydraulic compliant revolute joint and integration in proof of concept of needle manipulation device

11:30–12:45 WeBT1.4

Model-Based On-line Estimation of Time-Varying Nonlinear Joint Stiffness on an e-Series Universal Robots Manipulator

Emil Madsen and Xuping Zhang
Department of Engineering, Aarhus University, Denmark
Oluf Skov Rosenlund and David Brandt
Universal Robots A/S, DK-5260 Odense S, Denmark

- The torsional stiffness of strain-wave transmissions change over time due to wear
- This paper experimentally demonstrates an RLS-based method for on-line stiffness estimation
- The method proves efficient by estimating the stiffness to an NRMSE of over 95 % in 10 seconds
- Applications include model-based feedforward & feedback control and predictive maintenance



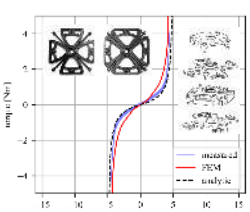
Experimental set-up: The laptop estimates the robot joint stiffness based on sampled data.

11:30–12:45 WeBT1.5

A Rolling Flexure Mechanism for Progressive Stiffness Actuators

Jörn Malzahn, Eamon Barrett and Nikos Tsagarakis
Humanoids & Human Centred Mechatronics Lab,
Istituto Italiano Di Tecnologia, Italy

- Nonlinear Series Elastic Actuation
- Pairing Impedance Rendering Accuracy with High Torque Bandwidth
- Simple Monolithic Spring Design with Low Hysteresis
- Theory, Numerical and Experimental Results with Two Prototypes



Soft Robots VI - 3.2.13

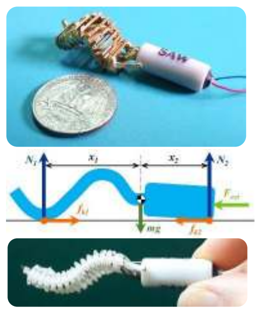
Chair
Co-Chair

11:30–12:45	WeBT1.1

Locomotion Dynamics of a Miniature Wave-Like Robot, Modeling and Experiments

Lee-Hee Drory and David Zarrouk
Mechanical Engineering, Ben Gurion University of the Negev, Israel

- This paper presents the design and analysis of a miniature minimally actuated wave robot.
- The analysis of the robot's locomotion on various surfaces and crawling environments is described.
- Multiple highly flexible tube-like shapes were developed.
- The robot's advancing conditions were formulated and validated through experiments.

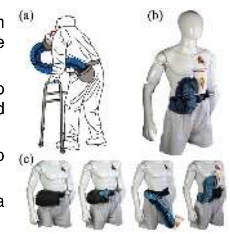


11:30–12:45	WeBT1.2

Fabric Soft Poly-Limbs for Physical Assistance of Daily Living Tasks

Pham H. Nguyen[1], Imran I. B. Mohd[1], Curtis Sparks[1], Francisco L. Arellano[1], Wenlong Zhang[1] and Panagiotis Polygerinos[1]
[1]Arizona State University, USA

- Design and Development of a continuum fabric-based Soft Poly-Limb (fSPL) for mobile manipulation assistance.
- Computational FEM models are used to optimize the design of the fabric-based components.
- The fSPL is capable of carrying loads up to 10.1x its body weight.
- The fSPL is fully collapsible and stowable in a soft waist belt.



11:30–12:45	WeBT1.3

Design of a Soft Ankle-Foot Orthosis Exosuit for Foot Drop Assistance

Carly M. Thalman, Joshua Hsu, and Panagiotis Polygerinos*
Ira A. Fulton Schools of Engineering, Arizona State University, USA
Laura Snyder
Barrow Neurological Institute, St. Joseph's Hospital, USA

- Soft AFO exosuit aides foot drop by assisting dorsiflexion and proprioception during walking.
- Sock-like AFO comprised of soft pneumatic actuators made from thermally bonded nylon.
- FEA model created to optimize design of the dorsiflexion actuator, capable of 197N pulling force.
- Embedded FSR sensors in AFO used to detect users gait, and portable logic control belt houses all hardware and pump.

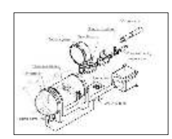
Soft AFO exosuit assists in both (1) dorsiflexion and (2) lateral/medial ankle support.

11:30–12:45	WeBT1.4

A Depth Camera-Based Soft Fingertip Device for Contact Region Estimation and Perception-Action Coupling

Isabella Huang, Ruzena Bajcsy
EECS, UC Berkeley, USA
Jingjun Liu
Department of Letters & Science , University of Wisconsin-Madison, USA

- We present a compliant fingertip-inspired robot that can accurately reconstruct 3D obstacle geometries upon contact
- It can also apply precise forces in real-time autonomously with our proposed force-deformation model
- We use a miniature depth-camera for high resolution deformation imaging
- Compliant materials and pneumatics ensure intrinsically safe interaction with the environment



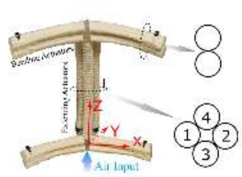
Design components

11:30–12:45	WeBT1.5

A Pipe-Climbing Soft Robot

Gaurav Singh, SreeKalyan Patiballa, Xiaotian Zhang and Girish Krishnan
Industrial and Enterprise Systems Engineering, University of Illinois Urbana-Champaign, USA

- Bio-inspired soft pneumatic robot for locomotion on the outside of a pipe
- Uses extending and bending fiber reinforced actuators (FREEs)
- Completely soft and can grasp pipes of varying dimensions
- Applicable towards inspection and maintenance of pipelines



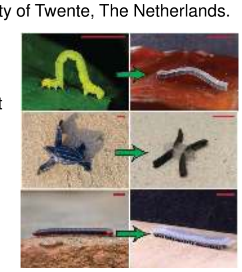
Design of the robot

11:30–12:45	WeBT1.6

ICRA 2019 Digest Template Bio-inspired Terrestrial Motion of Magnetic Soft Millirobots

Venkatasubramanian Kalpathy Venkiteswaran, Luis Fernando Pena Samaniego, Jakub Sikorski and Sarthak Misra
Dept. of Biomechanical Engineering, University of Twente, The Netherlands.

- Magnetic soft robots: contactless actuation, adaptability to environment
- Four biomimetic multi-limbed milli-scale soft robots are designed and actuated using magnetic fields
- Straight-line locomotion on hard surfaces demonstrated with good repeatability
- Benefits of multi-limbed motion on uneven surfaces also demonstrated



Legged Robots IV - 3.2.14

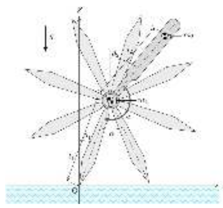
Chair
Co-Chair

11:30–12:45 WeBT1.1

Generation of Stealth Walking Gait on Low-friction Road Surface

Fumihiko Asano
School of Information Science,
Japan Advanced Institute of Science and Technology, Japan

- A realistic situation for stealth walking on the low-friction road surface is discussed.
- An eight-legged rimless wheel with an upper body is introduced for analysis.
- The desired time trajectory for non-slippery stance-leg motion is designed by using the linearized model.
- The required maximum static friction coefficients for the single-limb support and double-limb support phases are minimized simultaneously through optimization of the double-limb support motion.



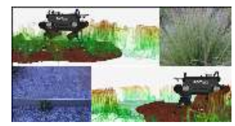
Underactuated rimless wheel that walks on low-friction road surface

11:30–12:45 WeBT1.2

Support Surface Estimation for Legged Robots

Timon Homberger[1], Lorenz Wellhausen[1], Péter Fankhauser[2], Marco Hutter[1]
[1] Robotics Systems Lab, ETH Zürich, Switzerland; [2] ANYbotics AG, Zürich, Switzerland;

- Enhanced robot navigation in environments with obstructed visibility of the ground
- Gaussian Process Regression to generate surface estimate from discrete haptic measurements
- Fusion of proprioceptive terrain measurements with exteroceptive elevation map data
- Adaptive weighting of proprioceptive and exteroceptive information



Support surface estimation for navigation with the ANYmal quadruped

11:30–12:45 WeBT1.3

ALMA - Articulated Locomotion and Manipulation for a Torque-Controllable Robot

C. Dario Bellicoso, Koen Krämer, Markus Stäuble, Dhionis Sako, Fabian Jenelten, Marko Bjelonic, Marco Hutter
Robotic Systems Lab, ETH Zurich, Switzerland

- ALMA: a motion planning and control framework for a quadrupedal robot equipped with a robotic manipulator
- The ZMP-based receding-horizon motion planner generates motions for the COM
- The hierarchical whole-body controller tracks the references and generates torques for the whole system
- Locomotion and manipulation coordination is shown by opening doors and collaborating with a human to deliver a payload

ALMA, a framework for coordinated locomotion and manipulation

11:30–12:45 WeBT1.4

Real-time Model Predictive Control for Versatile Dynamic Motions in Quadrupedal Robots

Yanran Ding, Abhishek Pandala, and Hae-Won Park
MechSE, University of Illinois at Urbana-Champaign, USA

- A Model Predictive Control (MPC) framework for controlling various dynamic movements of a quadrupedal robot
- This formulation linearizes rotation matrix without resorting to parameterization of the attitude.
- The capability of the MPC is verified by various experiments including pose control, balancing, trotting and bounding.
- The simulation result of an acrobatic motion is presented.

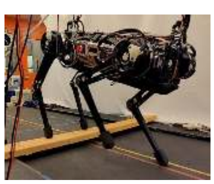
Quadrupedal Robot Bounding

11:30–12:45 WeBT1.5

Online Gait Transitions and Disturbance Recovery via the Feasible Impulse Set

Chiheb Boussema and Auke J. Ijspeert, EPFL
Matthew J. Powell, Gerardo Bledt and Sangbae Kim, MIT
Patrick M. Wensing, Univ. of Notre Dame

- Introduces the Feasible Impulse Set (FIS) to quantify notions of leg utility and agility
- Details application of the FIS to coordinate adaptive touchdown and non-time-based liftoff
- Presents experiments with MIT Cheetah 3
- Demonstrates non-time-based emergent gait transitions with unprescribed foot sequences, and gait adaptation to novel contexts, such as a partially moving walkway (right)
- Shows capture-point-like push recovery, selecting where, when, and with which leg to step



MIT Cheetah 3 on a partially moving walkway

11:30–12:45 WeBT1.6

Walking and Running with Passive Compliance: Lessons from Developing the ATRIAS Biped

Christian Hubicki
Mechanical Engineering, Florida State University, USA
Andy Abate, Patrick Clary, et al.
Agility Robotics, Albany OR, USA

- Robot built to embody spring-mass dynamics
- Blindly handles obstacles 30% of its leg length
- Top speed: 2.5 m/s (5.6 mph)
- Smoothly transitions between walking and running
- Total Cost of Transport: 1.3
- Only has 6 motors

ATRIAS Biped on Rough Terrain at the 2015 DARPA Robotics Challenge Expo

Robot Safety II - 3.2.15

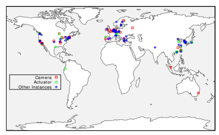
Chair
Co-Chair

11:30–12:45	WeBT1.1

Scanning the Internet for ROS: A View of Security in Robotics Research

Nicholas DeMarinis, Stefanie Tellex, Vasileios P. Kemerlis, George Konidaris, and Rodrigo Fonseca
Department of Computer Science, Brown University, USA

- Security is important in robotics; a compromised robot can leak information or cause physical harm
- We conducted Internet-wide scans for exposed ROS master nodes to identify potentially vulnerable robotic systems
- Our scans identified over 100 ROS instances in 22 countries, including robots, simulators, and other platforms
- With permission from its owner, we demonstrate an “attack” on one robot we identified

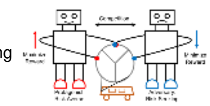

Approximate locations of ROS masters identified across all scans

11:30–12:45	WeBT1.2

Risk Averse Robust Adversarial Reinforcement Learning

Xinlei Pan, Daniel Seita, Yang Gao, John F. Canny
University of California, Berkeley, CA, USA

- Risk averseness comes from variance based risk modeling
- Robustness comes from training two competing agents together: protagonist and adversary.
- The protagonist agent is risk averse, the adversarial agent is risk seeking
- The use of the adversary helps the protagonist to effectively explore risky states

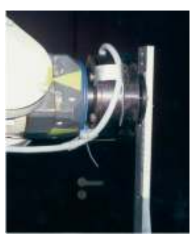

Risk averse robust adversarial reinforcement learning diagram

11:30–12:45	WeBT1.3

Bounded Collision Force by the Sobolev Norm

Kevin Haninger and Dragoljub Surdilovic
Robotics and Automation, Fraunhofer IPK, Germany

- Sobolev norm rigorously bounds collision force of complex robot models (joint and end-effector compliance, feedback control) in general environments (inertia or stiffness).
- Sob. norm found by H_2 norm on transformed system; controller which minimizes collision force via LQR.
- Norm validated with collision experiments with admittance-controlled robot, flexible-joint robot simulation
- Collision performance of moderate joint stiffnesses (1-10 kNm/rad) comparable to low joint stiffnesses when joint torque control used.


Norm validated on hardware and with simulation of flexible-joint robots

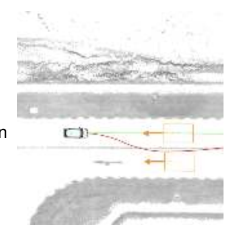
11:30–12:45	WeBT1.4

Liability, Ethics, and Culture-Aware Behavior Specification using Rulebooks

Andrea Censi, Konstantin Slutsky, Tichakorn Wongpiromsarn, Dmitry Yershov, Scott Pendleton, James Fu, Emilio Frazzoli

nuTonomy

- **The behavior of self-driving cars** depends on numerous factors: in addition to vague rules of the road, there are also rules related to liability, ethics, and local driving culture.
- We describe a formalism called “**Rulebooks**” that allows to define the behavior specification and in particular allows to describe **priorities** and deal with **conflicting rules**.



11:30–12:45	WeBT1.5

Early Failure Detection of Deep End-to-End Control Policy by Reinforcement Learning

Keuntaek Lee and Kamil Saigol
Electrical and Computer Engineering, Georgia Institute of Technology, USA
Evangelos A. Theodorou
Aerospace Engineering, Georgia Institute of Technology, USA

- We learn safe MPC using end-to-end imitation learning with Bayesian convolutional neural networks
- We use the Cross-Entropy RL to optimally select an uncertainty threshold
- The threshold is used for return of control from a learned model to MPC expert
- Our algorithm is robust to uncertainty from variations in system dynamics and partial state observability

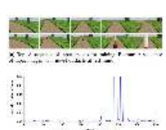


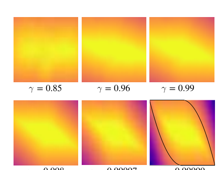
Fig: Increased output variance from the Bayesian CNN.

11:30–12:45	WeBT1.6

Bridging Hamilton-Jacobi Safety Analysis and Reinforcement Learning

Jaime F. Fisac*, Neil L. Lugovoy*, Vicenç Rubies-Royo, Shromona Ghosh and Claire J. Tomlin
Electrical Engineering & Computer Science, UC Berkeley, USA

•We present a new formulation for Hamilton-Jacobi (HJ) safety analysis compatible with reinforcement learning.
•Our HJ formulation yields a contraction Bellman operator compatible with well-known difference learning techniques.
•We validate our method’s correctness against analytic and numerical solutions.
•We demonstrate scalability on simulated systems of up to 18 dimensions.



Progression of neural network output of our *safety Q-learning* algorithm for a double-integrator system.

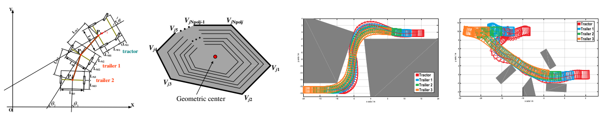
Wheeled Robotics II - 3.2.16

Chair
Co-Chair

11:30–12:45	WeBT1.1

Trajectory Planning for a Tractor with Multiple Trailers in Extremely Narrow Environments: A Unified Approach

Bai Li[a], Youmin Zhang[b], Tankut Acarman[c], Qi Kong[a], and Yue Zhang[d]
a. JD Inc.; b. Concordia University; c. Galatasaray University; d. Boston University



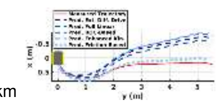
- Prevalent sampling-based or search-based planners suitable for rigid-body vehicles are not capable of handling the articulated vehicles;
- Based on an optimal control problem formulation, an adaptively homotopic warm-starting approach is proposed to facilitate the numerical solution process;
- For a tractor with 4 trailers in the tiny environments, our planner finds precise and optimal solutions that other existing planners cannot.

11:30–12:45	WeBT1.2

A Friction-Based Kinematic Model for Skid-Steer Wheeled Mobile Robots

Sadegh Rabiee and Joydeep Biswas
College of Information and Computer Sciences
University of Massachusetts Amherst, USA

- A physically interpretable kinematic model capable of slip prediction for skid-steer wheeled mobile robots (SSWMR).
- A public benchmark dataset of more than 6km worth of trajectories, well-suited for studying the kinematics and dynamics of SSWMRs.
- Improved accuracy in predicting the pose of the robot over a time horizon in the future compared to the state-of-the-art.

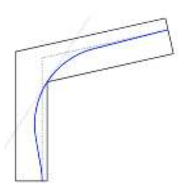


11:30–12:45	WeBT1.3

Turning a Corner with a Dubins Car

Alan Koval and Volkan Isler
College of Science and Enginnering, University of Minnesota, USA

- We determine classes of optimal paths for a Dubins car in a corner environment
- Our solution applies when feasible paths of type RSRSR, RSRSL, LSRSR or LSRSL exist
- We offer a procedure to compute the shortest path by parameterization of the solution set



An optimal Dubins path around a corner

11:30–12:45	WeBT1.4

Modeling and state estimation of a MBBR using a high yaw-rate dynamic model and an EKF

Eric Sihite, Daniel Yang and Thomas Bewley
Mechanical Engineering, University of California San Diego, USA

- Derivation of a high yaw-rate model for a Ball-Balancing Robot.
- The new model is used in an Extended Kalman Filter (EKF).
- EKF estimation accuracy is compared to the linear model Kalman Filter using motion capture.
- The controller with EKF has better accuracy and stability under high yaw rates.

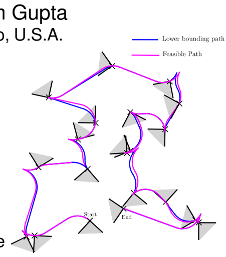
Micro Ball-Balancing Robot (MBBR)

11:30–12:45	WeBT1.5

Near-Optimal Path Planning for a Car-Like Robot Visiting a Set of Waypoints with Field of View Constraints

Sivakumar Rathinam and Yuntao Zhang
Mechanical Engineering, Texas A & M University, U.S.A.
Satyanarayana Manyam Gupta
Infoscitex Corporation, Ohio, U.S.A.

- This article considers two variants of a shortest path problem for a mobile robot visiting a set of waypoints.
- A general technique is provided to find tight lower and upper bounds to the optimum.
- The technique is applied to a car-like robot (Reeds-Shepp vehicle).
- Simulation results are provided to corroborate the quality of the solutions obtained by the proposed approach.



Solutions to the path planning problem

Motion Planning - 3.2.17

Chair
Co-Chair

11:30–12:45	WeBT1.1

Orientation-Aware Motion Planning in Complex Workspaces using Adaptive Harmonic Potential Fields

Panagiotis Vlantis, Constantinos Vrohidis,
Charalampos P. Bechlioulis, and Kostas J. Kyriakopoulos
Control Systems Lab, School of Mechanical Engineering,
National Technical University of Athens, Greece

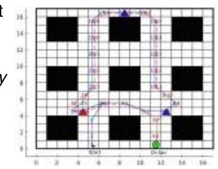
- Polygonal robot navigation in an arbitrary, multiply connected planar workspace
- Configuration space over- and under-approximations used for guiding feasible solution search
- Control scheme based on harmonic transformations and adaptive potential fields

11:30–12:45	WeBT1.2

Energy-Aware Temporal Logic Motion Planning for Mobile Robots

Tanmoy Kundu and Indranil Saha
Department of Computer Science and Engineering
Indian Institute of Technology Kanpur, India

- Robot motion plan such that it never goes out of charge while performing its task specified using temporal logic optimally
- Algorithm reduces the problem to *Satisfiability Modulo Theory* solving problem
- Output: Robot trajectory that visits charging station optimally, and recharger location
- Experimental results for various task specifications, different robot dynamics, and workspaces



Optimal trajectory of a quadcopter without (blue) and with (red) a visit to a charging station

11:30–12:45	WeBT1.3

Using Local Experiences For Global Motion Planning

Constantinos Chamzas, Anshumali Shrivastava
and Lydia E. Kavraki
Department of Computer Science, William Marsh Rice University, U.S.A.

- Framework that decomposes the workspace to local workspaces.
- Creates efficient local sampling distributions for each local workspace based on previous experiences.
- Synthesize a biased global sampling distribution from the local samplers.
- Achieve orders of magnitude better performance compared to uniform sampling and other methods.

Solving challenging planning queries using our proposed framework

11:30–12:45	WeBT1.4

DMP Based Trajectory Tracking for a Nonholonomic Mobile Robot with Automatic Goal Adaptation and Obstacle Avoidance

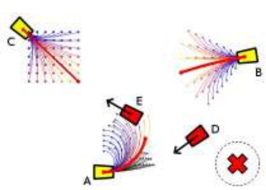
Radhe Shyam Sharma, IIT Kanpur
Santosh Shukla, IIT Kanpur
Hamad Karki, Petroleum Institute
Amit Shukla, The Petroleum Institute, Abu Dhabi
Laxmidhar Behera, IIT Kanpur
K. Venkatesh Subramanian, Indian Intitute of technology Kanpur

11:30–12:45	WeBT1.5

Predictive Collision Avoidance for the Dynamic Window Approach

Marcell Missura and Maren Bennewitz
Humanoid Robots Lab, University of Bonn, Germany

- Extends the Dynamic Window Approach with predictive collision detection capabilities
- Obstacles in the environment are modeled as moving polygons
- Significantly reduces the number of collisions
- Suitable for nonholonomic robots

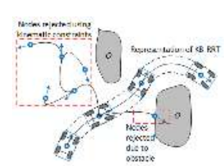


11:30–12:45	WeBT1.6

Kinematic Constraints Based Bi-directional RRT (KB-RRT) with Parameterized Trajectories for Robot Path Planning in Cluttered Environment

Dibyendu Ghosh, Ganeshram Nandakumar, Karthik Narayanan,
Vinayak Honkote and Sidharth Sharma
Intel Labs, Bangalore, India

- KB-RRT Restricts the number of nodes generated without compromising on the accuracy.
- Incorporates kinodynamic constraints for generating smooth trajectories of autonomous mobile robots.
- KB-RRT is tested in a highly cluttered environment on a vehicle model with severe kinematic constraints.
- Experimental results demonstrate that KB-RRT achieves three times (3X) better performance in convergence rate and memory utilization compared to Bi-RRT.



Representation of node selection using KB-RRT

Autonomous Vehicles II - 3.2.18

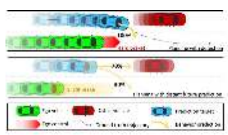
Chair
Co-Chair

11:30–12:45	WeBT1.1

Predicting Vehicle Behaviors Over An Extended Horizon Using Behavior Interaction Network

Wenchao Ding and Shaojie Shen
ECE, HKUST, Hong Kong, China
Jing Chen
DJI, China

- Extending the prediction horizon by modeling interaction among vehicles.
- A novel vehicle behavior interaction network (VBIN) structure for modeling interaction.
- Comprehensive experiments on a publicly available dataset showing superior performance.

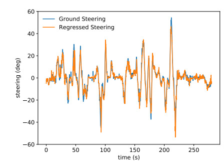


11:30–12:45	WeBT1.2

Multimodal Spatio-Temporal Information in End-to-End Networks for Automotive Steering Prediction

Mohamed Abouhussein, Joschka Bödecker
Chair of Neurorobotics, Freiburg University, Germany
Stefan H. Müller
BMW AG, Germany

- We study the end-to-end steering problem using visual input data from an onboard vehicle camera.
- We introduce a new metric to quantify smoothness of the steering
- We conclude that optical flow incorporation significantly improves the steering error and the use of recurrent networks enhances the smoothness.
- Our proposed recurrent multimodal model outperforms state-of-the-art results.



Ground vs regressed steering from our developed model

11:30–12:45	WeBT1.3

OVPC Mesh: 3D Free-space Representation for Local Ground Vehicle Navigation

Fabio Ruetz[1] , Emili Hernández[2], Mark Pfeiffer[1], Helen Oleynikova[1], Mark Cox[2], Thomas Lowe[2], Paulo Borges[1]
[1]Autonomous Systems Lab, ETH Zurich, Switzerland
[2]Robotics and Autonomous Systems, Data61, CSIRO, Brisbane, Australia

- General hidden point removal operator to generate a conservative free space representation from a raw 3D point cloud for navigation purposes.
- Traversability analysis on the 3D watertight mesh for rough terrain navigation.
- System evaluation on a UGV, using the traversability information for local planning purposes

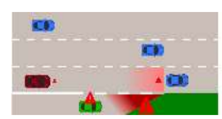
Ovpc Mesh (white) overlaid on a point cloud (colour)

11:30–12:45	WeBT1.4

Attention-based Lane Change Prediction

Oliver Scheel*, Naveen Shankar Nagaraja*, Loren Schwarz
BMW Group, Munich, Germany
Nassir Navab, Federico Tombari
Faculty of Computer Science, TU Munich, Germany

- Predict lane change maneuvers using LSTM network + attention
  - ⇒ Shift focus to important aspects of current scene
- Encouraging results + explanation of decision making by visualization of attention
- Introduce metrics which reflect driver comfort (Delay, Overlap, Frequency, Miss)



Sample image of how attention mechanism perceives a scene.

11:30–12:45	WeBT1.5

Safe Reinforcement Learning with Model Uncertainty Estimates

Björn Lütjens, Michael Everett and Jonathan How
Massachusetts Institute of Technology, USA

- **Status**: Many autonomous systems strongly rely on black box predictions from Deep Neural Networks (DNNs); even for safety-critical tasks
- **Problem**: DNNs can fail on far-from-distribution data without indication
- **Approach**: Use model uncertainty estimates in a Reinforcement Learning framework to detect novel scenarios and act more cautious in them

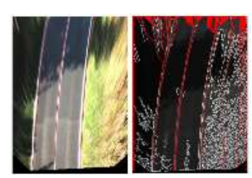
An autonomous vehicle observes a novel pedestrians and avoids him cautiously

11:30–12:45	WeBT1.6

Using DP Towards A Shortest Path Problem-Related Application

Jianhao Jiao, Rui Fan, Ming Liu
Department of ECE, HKUST, Hong Kong SAR, China.
Han Ma
Department of Mechanical Engineering, Tsinghua University, Beijing, China

- We introduce a graph model and define a specific shortest path problem (SPP).
- We analyze the properties of this graph and use DP to solve the SPP.
- We formulate lane detection as an SPP, and apply the algorithm to detect lanes.



Lanes (left) are detected using the graph model (right).

Manipulation IV - 3.2.19

Chair
Co-Chair

11:30–12:45 WeBT1.1

Improving dual-arm assembly by master-slave compliance

Markku Suomalainen[1,2], Sylvain Calinon[3], Emmanuel Pignat[3] and Ville Kyrki[1]
[1]Aalto University, Helsinki, Finland
[2]University of Oulu, Finland
[3]Idiap Research Institute, Martigny, Switzerland

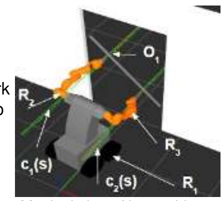
- We show how compliance for both master and slave manipulators can be efficiently learned from human demonstration using a single manipulator
- We present an analysis of the importance of choosing the Center of Compliance to mitigate pose errors
- We present experimental results showing the advantage of the proposed approach: larger region of convergence, faster execution and less joint motions

11:30–12:45 WeBT1.2

Generation of Synchronized Configuration Space Trajectories of Multi-Robot Systems

Ariyan M. Kabir, Alec Kanyuck, Rishi K. Malhan, Aniruddha V. Shembekar, Shantanu Thakar, Brual C. Shah, and Satyandra K. Gupta
University of Southern California, U.S.A.

- Many applications require complex motion synchronization among multiple robots
- This paper presents an optimization framework that uses successive refinement techniques to generate synchronous trajectories
- We have demonstrated the effectiveness and computational efficiency of the method on a wide range of test cases using up to 21-DOF robotic system



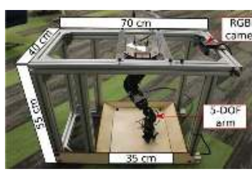
Manipulation of large objects with mobile manipulators require complex motion synchronization among the base and the arms.

11:30–12:45 WeBT1.3

REPLAB: A Reproducible Low-Cost Arm Benchmark For Robotic Learning

Brian Yang, Dinesh Jayaraman, Jesse Zhang, Sergey Levine
Berkeley Artificial Intelligence Research Laboratory, UC Berkeley

- Fully standardized hardware stack for visual robot learning Instructions at https://goo.gl/5F9dP4
- Plug-and-play software (>5 grasping approaches that run out-of-the-box from a Docker image).
- Public dataset of >50k random grasps.
- Platform for consistent, reproducible progress metrics for benchmarking robotic learning.
- Low barrier to entry (cost approx 2000 USD, size: 70x40x55cm)



11:30–12:45 WeBT1.4

Stable Bin Packing of Non-convex 3D Objects with a Robot Manipulator

Fan Wang and Kris Hauser
Department of Electrical and Computer Engineering
Duke University, USA

- A formulation of the packing problem tailored to automated robot packing in warehouses
- Propose a set of constraints with regards to stability and robot-feasibility
- A polynomial time constructive algorithm to implement a resolution-complete search under the proposed constraints
- Algorithm can efficiently pack arbitrary shaped, complex 3D objects

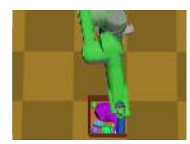


Fig 1: Testing open-loop execution feasibility of packing plans in a physics simulator, using high-quality object scannings

11:30–12:45 WeBT1.5

A Constraint Programming Approach to Simultaneous Task Allocation and Motion Scheduling for Industrial Dual-Arm Manipulation Tasks

Jan Kristof Behrens and Ralph Lange
Robert Bosch GmbH, Germany
Masoumeh Mansouri
Örebro University, Sweden

- Flexible manufacturing requires **automated planning** instead of manual teach-in
- In many use-cases task and motion planning can be reduced to **Simultaneous Task Allocation and Motion Scheduling (STAAMS)**
- **Ordered Visiting Constraints** are a novel and intuitive model to formulate STAAMS problems in a modular and portable manner
- Proposed solver easily scales to 200 objects

A typical assembly task executed by a dual-arm robot

11:30–12:45 WeBT1.6

Exploiting Symmetries in Reinforcement Learning of Bimanual Robotic Tasks

Adrià Colomé and Carme Torras
Institut de Robòtica i Informàtica Industrial (IRI), CSIC-UPC, Spain
Fabio Amadio
Departement of Information Engineering, Università di Padova, Italy

- Many robotic tasks present patterns of symmetry that are often known but ignored during learning.
- We can represent a bimanual task as the motion of one robot and its symmetric.
- The symmetry surfaces considered are planes, spheres and cylinders.
- This symmetrization allows a more efficient definition of bimanual robotic tasks and improves the learning.

Experiment: Towel folding

Medical Computer Vision - 3.2.20

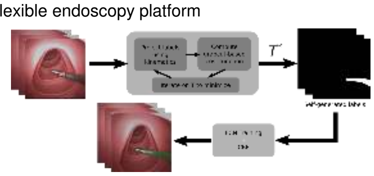
Chair
Co-Chair

11:30–12:45 WeBT1.1

Self-Supervised Surgical Tool Segmentation using Kinematic Information

Cristian da Costa Rocha, Nicolas Padoy, and Benoit Rosa
ICube, University of Strasbourg, CNRS, IHU Strasbourg, France

- SSTS: Self-Supervised Tool Segmentation method using inaccurate continuum robot kinematics
- No ground truth or manually labeled images required
- Approach validated on challenging *in vivo* conditions using a robotized flexible endoscopy platform

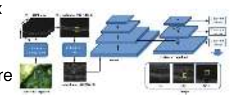


11:30–12:45 WeBT1.2

Needle Localization for Robot-assisted Subretinal Injection based on Deep Learning

Mingchuan Zhou, Xijia Wang, Jakob Weiss, Nassir Navab, and Alois Knoll
Department of Computer Science, TU München, Germany
Mathias Maier, Chris P. Lohmann, and M. Ali Nasseri
Klinikum rechts der Isar, TU München, Germany
Kai Huang
Sun Yat-Sen University, School of Data and Computer Science, China
Abouzar Eslami
Carl Zeiss Meditec AG. , Germany

- Subretinal injection is a delicate and complex microsurgery
- The needle localization method is developed with RetinaNet and needle geometrical feature
- The method is verified on the ex-vivo pig eye dataset with an confidence of 99.2%



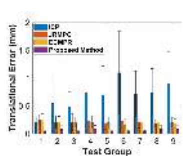
The framework of proposed method

11:30–12:45 WeBT1.3

Robust Generalized Point Set Registration using Inhomogeneous Hybrid Mixture Models via Expectation Maximization

Zhe Min and Max Q.-H. Meng
Robotics, Perception and Artificial Intelligence Lab
The Chinese University of Hong Kong, N.T., Hong Kong

- A robust point set registration method is proposed. Normal vectors that can be extracted from the point sets are used in the registration.
- Inhomogeneous hybrid mixture models are used to model the data point set.
- Matrix forms for the updated parameters are presented.
- Experimental results on the human femur bone data show that our algorithm outperforms the state-of-the-art registration methods.



The translational error values using the four registration methods with 300 inlier points intra-operatively.

11:30–12:45 WeBT1.4

Visual Guidance and Automatic Control for Robotic Personalized Stent Graft Manufacturing

Yu Guo, Miao Sun, Frank Po Wen Lo, Benny Lo
Hamlyn Centre, Imperial College London, UK

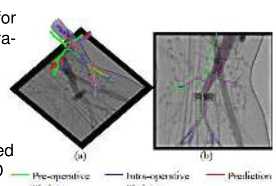
- This paper presents a method for the robotic treatment of Abdominal Aortic Aneurysms (AAA)
- An intelligent robotic platform is presented which enables reliable and efficient personalized stent graft manufacturing
- A novel automated visual-guidance system is proposed for tracking and guiding the sewing process
- A reinforcement learning based visual-servoing approach is proposed for autonomous control of the sewing process

11:30–12:45 WeBT1.5

Towards 3D Path Planning from a Single 2D Fluoroscopic Image for Robot Assisted Fenestrated Endovascular Aortic Repair

Jian-Qing Zheng, Xiao-Yun Zhou, Celia Riga & Guang-Zhong Yang
Imperial College London, UK

- A 3D skeleton instantiation framework for robotic path planning from a 2D intra-operative fluoroscopy
- Including shape segmentation, skeletonization, graph matching and skeleton deformation.
- A novel graph matching method proposed for efficient correspondence between 2D and 3D skeleton points
- Validation on the data of simulation, phantom and patient with high accuracy and time-efficiency



The demo of the instantiated skeletons in 3D (a) and 2D (b)

11:30–12:45 WeBT1.6

Context-Aware Depth and Pose Estimation for Bronchoscopic Navigation

Mali Shen*, Yun Gu*, Ning Liu and Guang-Zhong Yang
The Hamlyn Centre for Robotic Surgery,
Imperial College London, UK

- A depth estimation approach based on GAN that requires no paired bronchoscopic video and depth images.
- Conditions are incorporated into the network to deal with partial occlusion caused by image artifacts.
- Its resilience to image artifacts greatly improves the robustness of the navigation framework for clinical use.

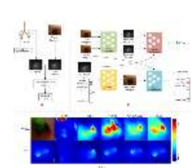


Figure. The workflow and validation results.

* indicates equal contribution

Active Perception - 3.2.21

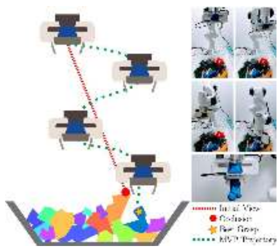
Chair
Co-Chair

11:30–12:45 WeBT1.1

Multi-View Picking: Next-best-view Reaching for Improved Grasping in Clutter

Douglas Morrison, Peter Corke and Jürgen Leitner
Australian Centre for Robotic Vision (ACRV),
Queensland University of Technology, Australia

- Multi-View Picking (MVP) Controller selects informative viewpoints while reaching for a grasp.
- Directly uses entropy in the grasp pose estimation to influence control.
- Up to 12% increase in grasp success compared to single-viewpoint method.
- Optimise between efficiency or grasp success rate by varying exploration cost.

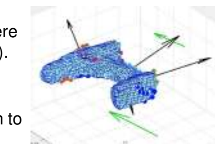


11:30–12:45 WeBT1.2

A Multi-Sensor Next-Best-View Framework for Geometric Model-Based Robotics Applications

Jinda Cui and Jeff Trinkle
Computer Science, Rensselaer Polytechnic Institute, USA
John T. Wen
ECSE, Rensselaer Polytechnic Institute, USA

- Our framework utilizes all available 3D sensors for geometric model generation (here a Kinect and a 2D Laser Profiler were used).
- Candidate sensing actions are generated actively from the geometric model at the current stage. And the best action is chosen to update the model.
- The whole process can be tuned to best accomplish different tasks including but not limited to 3D reconstruction and visual inspection tasks.



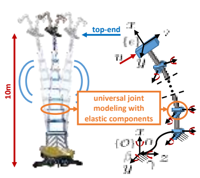
Candidate sensing actions

11:30–12:45 WeBT1.3

Model-Free Optimal Estimation and Sensor Placement Framework for Elastic Kinematic Chain

Joonmo Ahn, Jaemin Yoon, Jeongseob Lee, and Dongjun Lee
Department of Mechanical & Aerospace Engineering
Seoul National University, Republic of Korea

- Output (top-end motion) estimation necessary for vibration suppression control of telescopic mast
- Difficulties on identifying system parameters of high-DOF EKC and deploying sensors on every link
- Model-free output estimation of EKC utilizing only limited number of IMUs
- Sensor placement optimization to minimize estimation error covariance



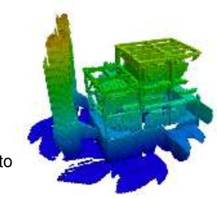
Telescopic mast and n-link three-dimensional EKC model

11:30–12:45 WeBT1.4

Efficient Autonomous Exploration Planning of Large Scale 3D-Environments

Magnus Selin, Mattias Tiger, Fredrik Heintz
IDA, Linköping University | LiU, Sweden
Daniel Duberg, Patric Jensfelt
RPL, Royal Institute of Technology | KTH, Sweden

- *Autonomous Exploration Planner* (AEP) can explore a generic 3D-Environment carefully without getting stuck in dead-ends.
- AEP combines NBV-planning and frontier exploration.
- AEP estimates *potential information* gain in nodes, with the sensor configuration taken into account.
- Estimated data points are cached for Gaussian process regression and to define frontiers.



Gazebo *Power Plant* scenario explored

11:30–12:45 WeBT1.5

Tree Search Techniques for Minimizing Detectability and Maximizing Visibility

Zhongshun Zhang, Yoonchang Sung, Lifeng Zhou, Pratap Tokekar
Electrical & Computer Engineering, Virginia Tech, USA
Joseph Lee, Jonathon M. Smereka
U.S.Army TARDEC, USA

- **Objective**: Planning a trajectory for an agent to carry out a scouting mission while avoiding being detected by an adversarial guard.
- **Problem Formulation**: Find the policy for the agent, which maximizes the visible region and minimizes the times of being detected.

$$\max_{\pi_s(t)} \min_{\pi_g(t)} \{R(\pi_s(t)) - \eta(\pi_s(t), \pi_g(t))P\}$$

- **Approach:** Considering it as a turn-based game between an agent and a target. We apply the **Minimax search tree** and the **Monte Carlo search tree.**
- We proposed **pruning** algorithms to save computation expenses and still guarantee optimality.

Reconnaissance missions: Maximizing the total reward collected while avoiding the grid cells from where the agent can be detected.

11:30–12:45 WeBT1.6

Autonomous exploration of complex underwater environments using a probabilistic NBV planner

Narcís Palomeras, Natalia Hurtós, Eduard Vidal and Marc Carreras
Computer Vision and Robotics Group, Universitat de Girona, Spain

- We have proposed a new methodology for exploring complex underwater structures using a probabilistic NBV planner.
- The method can be used by any hovering vehicle equipped with a scanning system and takes into account the main challenges imposed by the underwater medium.
- Four tests have been conducted to validate the proposed method.

Next-Best-View planner execution

Planning - 3.2.22

Chair

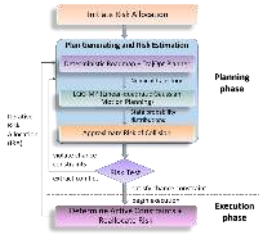
Co-Chair

11:30–12:45	WeBT1.1

Chance Constrained Motion Planning for High-Dimensional Robots

Siyu Dai, Shawn Schaffert, Ashkan Jasour, Andreas Hofmann and Brian Williams
CSAIL, MIT, USA

- Fast Plan Generator: Deterministic Chekov Planner
- Risk Reallocation: expediting the search for feasible solutions and extracting conflicts
- State Probability Distribution Estimation: Linear-quadratic Gaussian Motion Planning (LQG-MP)
- Waypoint Collision Risk Estimation: Quadrature-based Sampling Approach



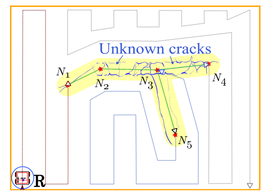
11:30–12:45	WeBT1.2

Complete and Near-Optimal Path Planning for Simultaneous Sensor-Based Inspection and Footprint Coverage in Robotic Crack Filling

Kaiyan Yu
Department of Mechanical Engineering, Binghamton University, USA
Chaoke Guo and Jingang Yi
Department of Mechanical and Aerospace Engineering, Rutgers University, USA

A simultaneous robotic footprint and sensor coverage planning scheme is proposed to

- minimize the total traveling distance of the robot,
- guarantee the complete sensor coverage of the whole inspection area, and
- achieve near-optimal footprint coverage of all the target regions.



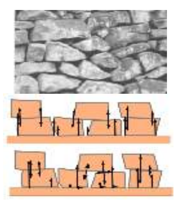
The planned path of robot **R** to inspect and fill all the unknown cracks in a structured environment.

11:30–12:45	WeBT1.3

Approximate Stability Analysis for Drystacked Structures

Yifang Liu, Maira Saboia, Vivek Thangavelu and Nils Napp
Department of Computer Science and Engineering, State University of New York at Buffalo, United States

- In disaster areas, robots that could build structures with found objects would be extremely useful.
- Evaluating stability is essential for automated construction.
- We propose a fast stability evaluation for drystacked structures based on *kern*.
- Proposed method improves existing heuristics-based planning.



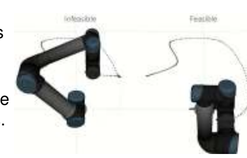
Real stone wall and feasible forces in simulation

11:30–12:45	WeBT1.4

User-Guided Offline Synthesis of Robot Arm Motion from 6-DoF Paths

Pragathi Praveena, Daniel Rakita, Bilge Mutlu, Michael Gleicher
Department of Computer Sciences, University of Wisconsin-Madison, USA

- Our approach aims to closely match position and orientation goals of a given path.
- The method relaxes these goals if there is danger of self-collisions / joint-space discontinuities / kinematic singularities.
- The method provides user control for more effective selection of acceptable solutions.
- Evaluation shows that smooth, feasible, accurate trajectories with user control over errors can be generated.



11:30–12:45	WeBT1.5

Visual Robot Task Planning

Chris Paxton, Yotam Barnoy, Kapil Katyal, and Gregory D. Hager
Department of Computer Science, Johns Hopkins University, USA

- We propose the problem of visual robot task planning, where we learn models that can predict different prospective futures and use them to determine the correct sequences of actions to take to arrive at a task-level goal.
- An algorithm based on Monte Carlo Tree Search allows us to explore these futures and arrive at alternate high-level action sequences.
- We show our planning approach in a block-stacking domain and show prediction results in a navigation and surgical robotics domain.

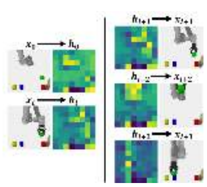


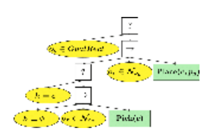
Fig. 1: Our approach allows us to predict the results of whole sequences of high-level actions for task planning.

11:30–12:45	WeBT1.6

Towards Blended Reactive Planning and Acting using Behavior Trees

Michele Colledanchise
iCub Facility, Istituto Italiano di Tecnologia, Italy
Diogo Almeida, Petter Ögren
Robotics, Perception and Learning, KTH, Sweden

- We show how a planning algorithm can be used to automatically create Behavior Trees.
- The proposed approach allow to blend acting and planning in a way that allows the robot to effectively plan and react to external disturbances.
- We illustrate our approach in two different robotics scenarios



Example of a BT automatically synthesized for a pick-and-place task

Vision-based Navigation - 3.2.23

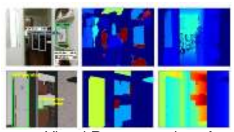
Chair
Co-Chair

11:30–12:45 WeBT1.1

Visual Representations for Semantic Target Driven Navigation

Arsalan Mousavian[1,3], Alexander Toshev[2], Marek Fiser[2], Jana Kosecka[1], Ayzaan Wahid[2], James Davidson[4]
[1]George Mason University, [2]Robotics at Google, [3]NVIDIA Research, [4]Third Wave Automation

- Goal: Learning to navigate toward semantic targets using high level visual representation.
- Visual Representation of Image: Object detection, semantic segmentation, and depth.
- Training supervision signal: how much progress each action make toward the goal.
- Training Data: combination of real and simulated data. Evaluation is done on unseen real environments.



Visual Representation of Real and Synthetic data

11:30–12:45 WeBT1.2

Deep Object-Centric Policies for Autonomous Driving

Dequan Wang[1], Coline Devin[1], Qi-Zhi Cai[2]
Fisher Yu[1], Trevor Darrell[1]
[1]EECS, UC Berkeley, USA
[2]CS, Nanjing University, China

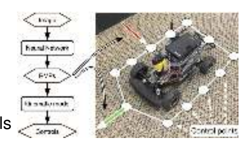
- Learning driving policies requires reasoning about instances such as cars and pedestrians.
- We present a taxonomy of object-centric models that combine discrete object representations with deep policy learning.
- We show results on both on-policy driving in the GTA simulator and off-policy behavioral cloning on a real world dashcam dataset.

11:30–12:45 WeBT1.3

Neural Autonomous Navigation with Riemannian Motion Policy

Xiangyun Meng
University of Washington, USA
Nathan Ratliff, Yu Xiang and Dieter Fox
NVIDIA and University of Washington, USA

- Image-based autonomous navigation leveraging RMP as the policy structure
- Explicit modeling of vehicle geometry and dynamics exhibits excellent obstacle avoidance behavior
- Better generalization than predicting controls or depth directly

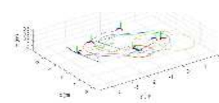


11:30–12:45 WeBT1.4

Oxford Multimotion Dataset: Multiple SE(3) Motions with Ground Truth

Kevin Judd and Jonathan Gammell
Oxford Robotics Institute, Oxford University, United Kingdom

- Almost two hours of multimotion data
- Data: Stereo, RGB-D, IMU, and Vicon
- Sensor motions: Static, Translational ($\mathbb{R}^3$), and Unconstrained ($SE(3)$)
- Varying number of moving bodies
- Increasingly difficult estimation challenges:
  - Simple rotations
  - Occlusions
  - Types of body motions



11:30–12:45 WeBT1.5

Safe Navigation with Human Instructions in Complex Scenes

Zhe Hu
City University of Hong Kong, Hong Kong
Jia Pan and Tingxiang Fan
University of Hong Kong, Hong Kong
Ruigang Yang
Baidu Research, China
Dinesh Manocha
University of Maryland, USA

- We present a robotic navigation algorithm with natural language interfaces
- We use the costmap motion planner as the bridge connecting the NLP module and the navigation command generator
- We use phrase classification network to classify phrases into 'goal', 'constraint' and 'uninformative phrase'
- For constraint grounding, we use mask-rcnn to match the visual regions and instruction words

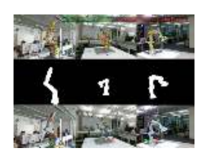
The scene of navigation with human instructions

11:30–12:45 WeBT1.6

Two-Stage TL for Robot Detection and 3D Joint Position Estimation in a Color Image using CNN

Justinas Mišeikis, Kyrre Glette, Ole Jakob Elle, Jim Torresen
Department of Informatics, University of Oslo, Norway
Inka Brijačak, Saeed Yahyanejad
Joanneum Research - Robotics, Klagenfurt am Wörthersee, Austria

- Multi-objective CNN for Robot body detection and 3D position estimation of joints in an uncalibrated 2D camera image
- Two-stage transfer learning approach to train new robot types to an existing CNN
- Automatic motion-capture based training data collection method
- Works with UR3, UR5, UR10, Kuka iiwa LBR and Franka Emika Panda robots



UR, Kuka and Franka Panda robot detection using TL based CNN

Medical Robotics VIII - 3.2.24

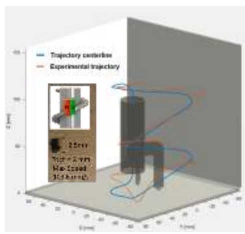
Chair
Co-Chair

11:30–12:45	WeBT1.1

Control of Rotating Millimeter-Scale Swimmers Through Obstacles

Julien Leclerc, Haoran Zhao, and Aaron T. Becker
Department of Electrical and Computer Enbgineering,
University of Houston, USA

- An algorithm able to control miniature rotating magnetic swimmers in 3D was designed
- Different swimmers designs were built and tested
- The swimmers can navigate inside a 15 mm diameter tube without touching the walls
- Miniature swimmers were able to reach velocities greater than 100 mm/s

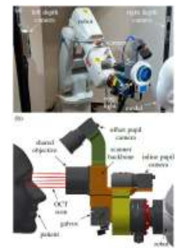


11:30–12:45	WeBT1.2

Automatic Optical Coherence Tomography Imaging of Stationary and Moving Eyes with a Robotically-Aligned Scanner

Mark Draelos, Pablo Ortiz, Ruobing Qian, Brenton Keller, PhD, Kris Hauser, PhD, Anthony Kuo, MD, and Joseph Izatt, PhD
Duke University, USA

- Clinical OCT systems are bulky, tabletop instruments that cannot evaluate bedbound, unconscious, or injured patients
- Compact handheld OCT probes are limited by operator skill and weight restrictions
- We propose a robotically-aligned OCT scanner capable of automatically imaging eyes without chinrest stabilization
- Our system demonstrates motion-stabilized OCT imaging of eyes undergoing physiologic movement

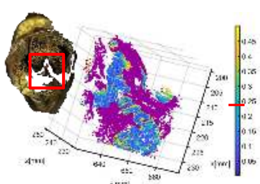


11:30–12:45	WeBT1.3

Dense-ArthroSLAM: dense intra-articular 3D reconstruction with robust localization prior

Andres Marmol, Artur Banach and Thierry Peynot
Australian Centre for Robotic Vision,
Queensland University of Technology, Australia

- Novel SLAM-based system estimating dense, accurate, at-scale intra-articular maps (0.5mm RMSE, 14.7cm^2).
- Demonstrated for knee arthroscopy in nine experiments performed in phantom and three cadavers.
- Significantly outperforms state-of-the-art feature-based and direct SLAM methods in reliability and accuracy.
- Key enabler of future robotic assistants in arthroscopy.



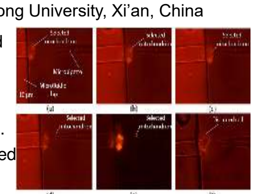
Estimated dense map of the knee area in the red square. Errors in mm.

11:30–12:45	WeBT1.4

3D Image Reconstruction of Biological Organelles with a Robot-aided Microscopy System for Intracellular

Wendi Gao, Adnan Shakoor and Dong Sun
Biomedical Engineering, City University of Hong Kong, Hong Kong SAR, China
Wendi Gao, Libo Zhao and Zhuangde Jiang
Mechanical Engineering, Xi'an Jiaotong University, Xi'an, China

- A novel robot-aided microscopy system and 3D reconstruction algorithm for intracellular surgery with 3D information
- A 3D reconstruction model of the specimen was realized after several image processes.
- Simulations and experiments were performed to verify the accuracy of the proposed algorithm.
- 3D reconstruction position feedback was applied to extract mitochondria via the microscope system.



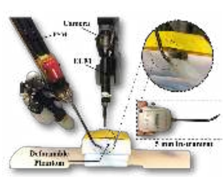
The mitochondrion extraction process. (a-e are by 3D information and f is by 2D information)

11:30–12:45	WeBT1.5

Autonomous Data-Driven Manipulation of Unknown Anisotropic Deformable Tissues Using Unmodelled Continuum Manipulators

Farshid Alambeigi, Rachel Hegeman, and Mehran Armand
Dep. of ME Engineering, Johns Hopkins University, USA
Zerui Wang, Yun-Hui Liu
Dep. of ME Engineering, The Chinese University of Hong Kong, Hong Kong

- Autonomous manipulation approach for tissues with anisotropic deformation behavior using a continuum manipulator.
- Online simultaneous learning of the deformation behavior of an unknown deformable tissue and unmodelled continuum manipulator.
- Evaluation experiments using the da Vinci Research Kit coupled with a 5 mm instrument with a snake-like wrist.



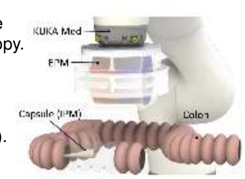
The 5 mm Intuitive Surgical Debakey forceps manipulating deformable phantom.

11:30–12:45	WeBT1.6

Magnetic Levitation for Soft-Tethered Capsule Colonoscopy Actuated with a Single Permanent Magnet: a Dynamic Control Approach

Giovanni Pittiglio[1], Lavinia Barducci[1], James W. Martin[1], Joseph C. Norton[1], Carlo A. Avizzano[2], Keith L. Obstein[3], and Pietro Valdastri[1]
[1]STORM Lab UK, University of Leeds, UK
[2]PERCRO, Scuola Superiore S. Anna, Italy
[3]STORM Lab, Vanderbilt University, USA

- Novel control approach to achieve free-space levitation for magnetically actuated colonoscopy.
- Based on a nonlinear dynamic backstepping approach.
- Reducing contact with the environment from 100% (standard approach) to 19% (levitation).
- Reduced contact aids exploration and risk of adverse events.



ICRA X: Robotic Art Forum - Session II

Chair
Co-Chair

Awards Luncheon

Chair
Co-Chair

Keynote Session V

Chair *Jaydev P. Desai, Georgia Institute of Technology*
Co-Chair

14:45–15:30	WeKN1.1*

Robotic Technologies and Targeted Therapy: Challenges and Opportunities

Arianna Menciassi, Scuola Superiore Sant'Anna - SSSA

Keynote Session VI

Chair *Gregory Dudek, McGill University*
Co-Chair

14:45–15:30	WeKN2.1*

Mocap As a Service

Yoshihiko Nakamura, University of Tokyo

PODS: Wednesday Session III

Chair

Co-Chair

Award Finalists I - 3.3.01

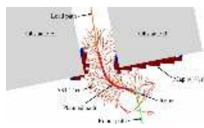
Chair
Co-Chair

16:00–17:15	WeCT1.1

Online Multilayered Motion Planning with Dynamic Constraints for Autonomous Underwater Vehicles

Eduard Vidal, Narcís Palomeras and Marc Carreras
Underwater Robotics Research Center (CIRS), University of Girona, Spain
Mark Moll, Juan David Hernández and Lydia E. Kavraki
Kavraki Lab, Rice University, United States

- We present an efficient **motion planning** framework for autonomous underwater vehicles
- **Multilayered** design, combining RRT* and SST
- A **geometric lead path** is computed to **bias** the sampling of a motion **planner that accounts for the vehicle dynamics**
- Tested in simulation and in **sea experiments** using the Sparus II AUV



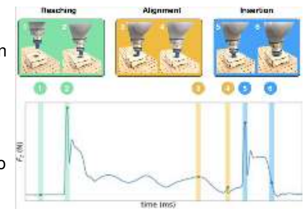
Example scenario. Sampling around the lead path, without mixing uniform sampling

16:00–17:15	WeCT1.2

Making Sense of Vision and Touch : Self-Supervised Learning of Multimodal Representations for Contact-Rich Tasks

Michelle A. Lee[1*], Yuke Zhu[1*], Krishnan Srinivasan[1], Parth Shah[1], Silvio Savarese[1], Li Fei-Fei[1], Animesh Garg[1,2] and Jeannette Bohg[1]
[1]Computer Science, Stanford University (USA) [2]Nvidia Research (USA)

- **Vision and touch** are complementary and concurrent in contact-rich manipulation.
- We learn a **fused representation** through **self-supervision.**
- This representation is the input to a **learned manipulation policy**.
- The policies are learned on a **real robot**.



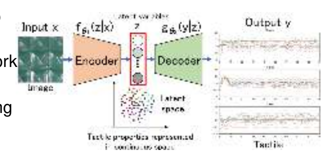
Images and force feedback for a peg insertion task

16:00–17:15	WeCT1.3

Deep Visuo-Tactile Learning: Estimation of Tactile Properties from Images

Kuniyuki Takahashi and Jethro Tan
Preferred Networks, Inc., Japan

- Estimation of the degree of tactile properties from images, called deep visuo-tactile learning
- A traditional encoder-decoder network with latent variables
- Continuous latent space representing tactile properties with degrees for various materials



16:00–17:15	WeCT1.4

Variational End-to-End Navigation and Localization

Alexander Amini[1], Guy Rosman[2], Sertac Karaman[3], Daniela Rus[1]
[1] Computer Science and Artificial Intelligence (CSAIL), MIT
[2] Toyota Research Institute (TRI)
[3] Laboratory for Information Decision Systems (LIDS), MIT

Objective:
- Learn control directly from raw sensor data, without any hand-engineered models or rules

New Results:
- Point-to-point navigational control using noisy GPS data
- Ability to reason about localization in the world using only raw visual perception

Impact: Enables deployment of end-to-end driving systems

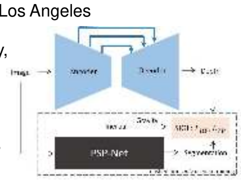
Learning control (bottom) from raw perception (top)

16:00–17:15	WeCT1.5

Geo-Supervised Visual Depth Prediction

Xiaohan Fei, Alex Wong, and Stefano Soatto
University of California Los Angeles

- The visual world is heavily affected by gravity, which can be easily inferred from ubiquitous and low-cost inertial sensors.
- We propose two gravity-induced regularizers for self-supervised visual depth prediction.
- We selectively apply our regularizers to image regions corresponding to semantic classes whose shape is biased by gravity.
- We apply our regularizers generically to *non-top performing* methods to outperform state-of-the-art.



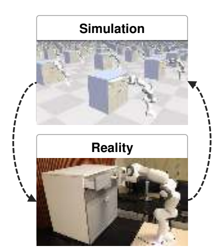
System diagram. At training time, gravity extracted from inertials biases the depth prediction selectively based on semantic segmentation. At inference time, the network takes an RGB image as the only input and outputs an inverse depth map.

16:00–17:15	WeCT1.6

Closing the Sim-to-Real Loop: Adapting Simulation Randomization with Real World Experience

Yevgen Chebotar[1,2], Ankur Handa[1], Viktor Makoviychuk[1], Miles Macklin[1,3], Jan Issac[1], Nathan Ratliff[1], Dieter Fox[1,4]
[1]NVIDIA, USA [2]University of Southern California, USA
[3]University of Copenhagen, Denmark [4]University of Washington, USA

- Train policies entirely in simulation with randomized parameters
- Iteratively update simulation parameter distribution using a few real world trials
- Improve policy transfer by matching policy behavior in simulation and reality



Award Finalists II - 3.3.02

Chair

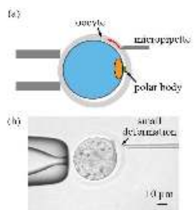
Co-Chair

16:00–17:15	WeCT1.1

Robotic Orientation Control of Deformable Cells

Changsheng Dai, Zhuoran Zhang, Yuchen Lu, Guanqiao Shan, Xian Wang, Qili Zhao, and Yu Sun
Advanced Micro and Nanosystems Laboratory, University of Toronto, Canada

- Deep neural networks for polar body detection with an accuracy of 97.6%
- Modeling and path planning to determine the micropipette path to rotate the oocyte with minimal cell deformation
- Compensation controller to accommodate the variations of cell mechanical properties
- Accuracy of 0.7° in oocyte orientation control with maximum oocyte deformation of 2.69 μm



16:00–17:15	WeCT1.2

Drift-free Roll and Pitch Estimation for High-acceleration Hopping

Justin K. Yim, Eric K. Wang, Ronald S. Fearing
Electrical Engineering and Computer Sciences, Univ. of California - Berkeley, United States

- Monopedal hopping robot Salto-1P estimates attitude and velocity from onboard sensing
- Roll and pitch estimates recover from disturbances using SLIP Hopping Orientation and Velocity Estimator (SHOVE)
- Over **300** consecutive fully autonomous, untethered hops spanning over 3 minutes


Salto-1P operates outdoors under human guidance

16:00–17:15	WeCT1.3

Efficient Symbolic Reactive Synthesis for Finite-Horizon Tasks

Keliang He, Andrew Wells, Lydia E. Kavraki, Moshe Y. Vardi
Department of Computer Science, Rice University, USA

- Reactive synthesis to generate execution strategy for robots performing finite-horizon tasks under human interference
- Use binary decision diagrams for compact representation of the synthesis problem
- Reduce runtime and memory usage of the synthesis algorithm
- Case study of a pick-and-place domain exhibit orders-of-magnitude speed-ups over existing approaches

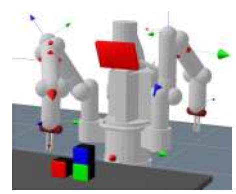

UR5 completing an arch using synthesized policy under human interference

16:00–17:15	WeCT1.4

Task and Motion Planning under Partial Observability: An Optimization-Based Approach

Camille Phiquepal and Marc Toussaint
Machine Learning & Robotic Lab, University of Stuttgart, Germany

- Optimization of Task and Motion Planning policies in a **POMDP** setting
- Policies are trees allowing the robot to react to different observations
- Motions are computed by solving a global optimization problem (trajectory-tree optimization)



16:00–17:15	WeCT1.5

Towards Robust Product Packing with a Minimalistic End-Effector

Rahul Shome, Wei N. Tang, Changkyu Song, Chaitanya Mitash, Chirs Kourtev, Jingjin Yu, Abdeslam Boularias, and Kostas E. Bekris
Computer Science Dept, Rutgers University, USA

- Complete hardware stack and software pipeline for developing and testing algorithmic solutions for robotic packing tasks.
- Explores the use of a minimalistic, suction-based, end-effector.
- Develops and evaluates corrective prehensile and non-prehensile manipulation primitives:
  - Toppling, robust placement via adaptive pushing, and corrective packing
- Experiments show that the primitives provide robustness to errors and failures


Initial scene

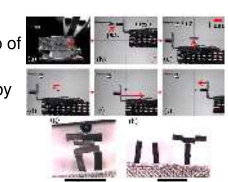

Final scene

16:00–17:15	WeCT1.6

Contactless Robotic Micromanipulation in Air Using a Magneto-acoustic System

Omid Youssefi and Eric Diller
Department of Mechanical and Industrial Engineering, University of Toronto, Canada

- Micromanipulion tasks at sizes smaller than 3mm are challenging due to increasing ratio of surface to volumetric forces.
- Microcomponents are positioned vertically by an encapsulating acoustic field (levitated).
- A magnetic field constrains the pose of the levitated component.
- Using vision feedback, the components are assembled without direct physical contact.
- Potential for fully automated microassembly is demonstrated.


Microassembly Demo

Award Finalists III - 3.3.03

Chair
Co-Chair

16:00–17:15	WeCT1.1

Pre-Grasp Sliding Manipulation of Thin Objects Using Soft, Compliant, or Underactuated Hands

Kaiyu Hang, Andrew S. Morgan, and Aaron M. Dollar
Department of Mechanical Engineering and Material Science
Yale University, USA

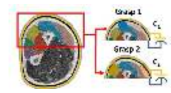
- Our system integrates motion and grasp planning
- Our planner does not require start and goal configurations to be specified *a priori*
- We plan directly in the configuration space, and ensures a grasp solution after sliding
- We show that underactuated hands can greatly improve the efficiency

16:00–17:15	WeCT1.2

Gesture Recognition via Flexible Capacitive Touch Electrodes

Louis Dankovich
Mechanical Engineering, University of Maryland College Park, United States
Sarah Bergbreiter
Mechanical Engineering, Carnegie Mellon University, United States

- Preliminary trial of Capacitive Touch (CT) sensing for wearable gesture recognition
- Novel wearable device using flexible CT electrode straps was prototyped
- Random Forest algorithm applied to data from 32 motions/gestures (including Cutkosky grasp taxonomy) achieved recognition rate of 95.6+/- 0.06%



(a) ΔC with different grasps

(b) Wearable armband with CT electrodes

16:00–17:15	WeCT1.3

Robust Learning of Tactile Force Estimation through Robot Interaction

B. Sundaralingam[1,2], A. S. Lambert[1,3], A. Handa[1], B. Boots[1,3], T. Hermans[2], S. Birchfield[1], N. Ratliff[1], D. Fox[1,4]
1=NVIDIA, 2=Univ. of Utah, 3=Georgia Tech., 4= Univ. of Washington

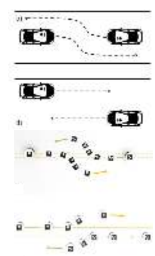
- Collected Ground truth force from 3 different sources, over 140k samples.
- Novel inference method to estimate force from planar pushing as system of particles.
- 3D voxel grid encoding of tactile signals and novel loss scaling force to surface normal.
- Validation on object lifting & placement experiments.

16:00–17:15	WeCT1.4

Deconfliction of Motion Paths with Traffic Inspired Rules in Robot–Robot and Human–Robot Interactions

Federico Celi and Lucia Pallottino
Research Centre E. Piaggio - Università di Pisa, Italy
Li Wang and Magnus Egerstedt
Georgia Institute of Technology, GA, USA

- Motion algorithms for autonomous vehicles are designed in compliance with traffic rules; however there are environments where rules are not as firm and they may be *broken* (e.g., parking lots)
- We consider mixed autonomous and human-driven vehicles where the rules of the road are less strict
- We ensure safety with Safety Barrier Certificates and disengage conflicting motions with traffic-like rules by perturbing the underlying problem formulation
- Results are verifies and tested on the Robotarium, a remotely accessible swarm robotics platform



16:00–17:15	WeCT1.5

The Role of Closed-Loop Hand Control in Handshaking Interactions

Francesco Vigni[1], Espen Knoop[2], Domenico Prattichizzo[1,3] and Monica Malvezzi[1,3]
[1] University of Siena, Italy; [2] Disney Research, Switzerland; [3] IIT, Italy

- We implement and evaluate 3 different handshaking hand controllers combining open- and closed-loop contributions.
- A user study shows that controllers change perceived handshake quality and robot personality traits.
- Adding a controller delay (mimicking human CNS reaction time) is beneficial for making interactions more human-like.

We study open- and closed-loop controllers for hand forces in human-robot handshakes

Award Finalists IV - 3.3.04

Chair
Co-Chair

16:00–17:15 WeCT1.1

Soft Robotic Glove with Integrated Sensing for Intuitive Grasping Assistance Post Spinal Cord Injury

Yu Meng Zhou, Diana Wagner, Kristin Nuckols, Roman Heimgartner, Carolina Correia, Megan Clarke, Dorothy Orzel, Ciarán O'Neill, Ryan Solinsky, Sabrina Paganoni, and Conor J. Walsh
Harvard SEAS & Wyss Institute, Harvard University, MA, USA

- We present a fully-integrated soft robotic glove for grasping assistance for individuals with SCI.
- The glove is controlled through a state machine controller with contact detection by textile-elastomer sensors.
- Through human subject testing, participants operated the glove independently and improved grasping on select metrics.

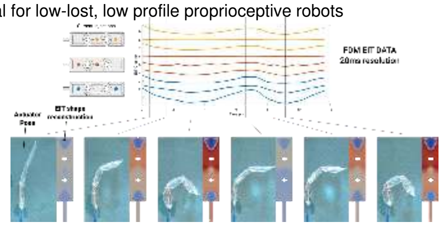
SCI participant wearing and operating the glove during human subject testing

16:00–17:15 WeCT1.2

Shape Sensing of Variable Stiffness Soft Robots using Electrical Impedance Tomography

James Avery, Mark Runciman, Ara Darzi and George P. Mylonas
HARMS Lab, NIHR Imperial BRC, Imperial College London, United Kingdom

- Soft hinged actuators with internal electrodes and conductive working fluid
- Impedance measurements obtained using Frequency Division Multiplexed Electrical Impedance Tomography (FDM EIT)
- FDM EIT can infer shape changes with 20 ms temporal resolution
- Potential for low-lost, low profile proprioceptive robots

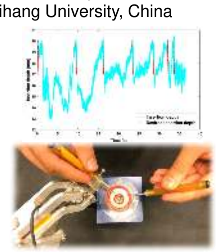


16:00–17:15 WeCT1.3

Adaptive Control of Sclera Force and Insertion Depth for Safe Robot-Assisted Retinal Surgery

Ali Ebrahimi[1] and Niravkumar Patel[1] and Changyan He[3]
Peter Gehlbach[2] and Marin Kobilarov[1] and Iulian Iordachita[1]
[1] Dept. of Mechanical Engineering, Johns Hopkins University, USA
[2] School of Medicine, Johns Hopkins University, USA
[3] Dept. of Mechanical Engineering, Beihang University, China

- This paper addresses the safety issues in robot-assisted eye surgery.
- An adaptive control method is investigated to keep the sclera force and insertion depth in safe ranges.
- The control method makes the sclera force and insertion depth to follow desired and safe trajectories.
- After implementing the method on the eye surgical robot, it is observed that it can guarantee surgery safety.

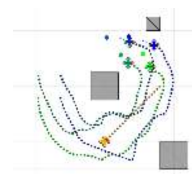

Implementation results for the insertion depth control on the robot

16:00–17:15 WeCT1.4

Distributed Multi-Robot Formation Splitting and Merging in Dynamic Environments

Hai Zhu, Jelle Juhl, Laura Ferranti and Javier Alonso-Mora
Cognitive Robotics, Delft University of Technology, Netherlands

- A distributed method for splitting and merging multi-robot formations
- Splitting and merging actions rely on the computation of an intersection graph and graph partition
- Limited communication range and visibility radius of the robots are considered
- Permanent and temporary communication and motion faults of the robots can be detected and recovered


A square-formation avoids obstacles by splitting/merging

16:00–17:15 WeCT1.5

Eagle Shoal: A new designed modular tactile sensing dexterous hand for domestic service robots

Tao Wang, Zhanxiao Geng, Bo Kang and Xiaochuan Luo
Intel Labs China, China

- This fully-actuated hand consists of 1 palm and 3 fingers, with embedded tactile sensors.
- Modular design makes it easy to assembly, palm and each finger have 2 DOFs.
- A series of experiments have been delivered to test new sensor unit and hand performance.
- This hand with low cost can help robotic manipulation research with visual and tactile data.


Eagle Shoal robot hand

Award Finalists V - 3.3.05

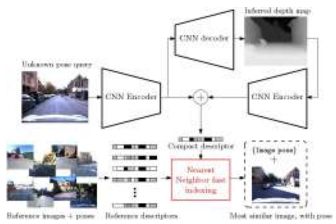
Chair
Co-Chair

16:00–17:15	WeCT1.1

Learning Scene Geometry for Visual Localization in Challenging Conditions

Nathan Piasco[1,2] Désiré Sidibé[1], Valérie Gouet-Brunet[2] and Cédric Demonceaux[1]
[1] ImViA-VIBOT, Univ. Bourgogne Franche-Comté, France
[2] LaSTIG MATIS, IGN, ENSG, Univ. Paris-Est, France

- We introduce a new image descriptor for fast image indexing for the task of urban localization
- We rely on depth information that are not available at query time to train our descriptor
- Our system is especially efficient for cross-season and long-term localization



Our localization pipeline

16:00–17:15	WeCT1.2

Multi-Robot Region-of-Interest Reconstruction with Dec-MCTS

Fouad Sukkar[1], Graeme Best[2], Chanyeol Yoo[1] and Robert Fitch[1]
[1]CAS, University of Technology Sydney, Australia
[2]CoRIS, Oregon State University, USA

- Targeted information gathering in high-dimensional action and state space
- Novel formulation that balances between discovering new regions of interest (ROIs) and high-quality reconstruction
- Decentralised multi-robot planning with coordinated plans and intermittent communication
- Significantly outperforms state-of-the-art volumetric information metrics

Two robot arms cooperatively searching for apples

16:00–17:15	WeCT1.3

Classification of Household Materials via Spectroscopy

Zackory Erickson, Nathan Luskey, Sonia Chernova, and Charles C. Kemp
Georgia Institute of Technology, USA

- We demonstrate how robots can leverage spectral data to estimate the material of an object.
- Dataset of 10,000 spectral measurements collected from 50 different objects across five material categories.
- PR2 robot leveraged near-infrared spectroscopy to estimate the materials of everyday objects prior to manipulation.

16:00–17:15	WeCT1.4

Design and Control of a Passively Morphing Quadcopter

Nathan Bucki and Mark W. Mueller
Mechanical Engineering, University of California, Berkeley, United States

- Sprung hinges allow arms of quadcopter to fold downward when low thrusts are applied
- No additional actuation required
- Folding reduces largest dimension of vehicle by approximately 50%
- Existing quadcopter controllers can be used provided additional control input constraints are satisfied

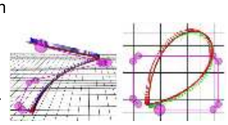
Flight through a small gap by folding and unfolding

16:00–17:15	WeCT1.5

Search-based 3D Planning and Trajectory Optimization for Safe Micro Aerial Vehicle Flight Under Sensor Visibility Constraints

Matthias Nieuwenhuisen
Cognitive Mobile Systems, Fraunhofer FKIE, Germany
Sven Behnke
Autonomous Intelligent Systems, University of Bonn, Germany

- Safe MAV flight in dynamic or partially known environments requires reliable obstacle perception with onboard sensors.
- Flight trajectories have to remain in the onboard obstacle sensor field of view locally.
- We take sensor visibility constraints into account for path planning and subsequent trajectory optimization.
- A tailored heuristic speeds up informed search-based planners.



Spiral trajectory for an altitude change remaining within the sensor FoV during ascent.

Award Finalists VI - 3.3.06

Chair
Co-Chair

16:00–17:15 WeCT1.1

LineRanger: Analysis and Field Testing of an Innovative Robot for Efficient Assessment of Bundled High-Voltage Powerlines

Pierre-Luc Richard, Nicolas Pouliot, François Morin, Marco Lepage, Philippe Hamelin, Marin Lagacé, Alex Sartor, Ghislain Lambert and Serge Montambault
Hydro-Québec's Research Institute, Canada

- New robotic rolling platform for high-voltage powerlines assessment
- Innovative mechanism allowing quick and easy obstacle crossing
- Mathematical analysis to ensure stability while rolling on cable bundles
- Prototype with cameras and sensors tested on a full scale mock up

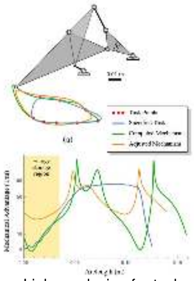

Prototype of the LineRanger

16:00–17:15 WeCT1.2

Adjustable Power Modulation for a Leg Mechanism Suitable for Running

Mark Plecnik, Katherine M. Fearing, and Ronald S. Fearing
Dept. of EECS, University of California, Berkeley USA

- Power modulation previously used for high vertical agility jumping robots
- Here, power modulation provides energy storage during part of leg cycle in running
- Leg mechanism is designed with adjustable power modulation, suitable for different gaits and terrain types
- 1 leg prototype demonstrates both high and low power modes


Linkage design for task with energy storage

16:00–17:15 WeCT1.3

Fast and In Sync: Periodic Swarm Patterns for Quadrotors

Xintong Du, Carlos E. Luis, Marijan Vukosavljev, and Angela P. Schoellig
Institute for Aerospace Studies, University of Toronto, Canada

- Performance design for a quadrotor swarm acting as an integrated and coordinated, fast moving unit
- Periodic motion pattern primitives embodying fast moving and deforming objects
- Trajectory planner facilitating smooth and safe transitions from one motion pattern to another
- Correction algorithm synchronizing the swarm to the desired rhythm based on the quadrotor's frequency response obtained from the experiments


Twenty-five quadrotors performing a periodic wave motion in the vertical direction.

16:00–17:15 WeCT1.4

Development and Experimental Validation of Aerial Vehicle with Passive Rotating Shell on Each Rotor

Carl John Salaan[1], Kenjiro Tadakuma[2], Yoshito Okada[1,2], Yusuke Sakai[2], Kazunori Ohno[1,3], and Satoshi Tadokoro[2]
[1]RIKEN Center for Advanced Intelligence Project, Japan
[2]Graduate School of Information Sciences, Tohoku Univ., Japan
[3]New Industry Creation Hatchery Center, Tohoku Univ., Japan

- A new idea is introduced in response to the limitations of aerial vehicle with a protective shell that can rotate passively.
- It is proposed to position two passive rotating hemispherical shells in each rotor.
- General concept, design and proof of concept are presented.
- Various experiments are conducted to demonstrate the advantages of the proposed flying robot.

16:00–17:15 WeCT1.5

Shallow-Depth Insertion: Peg in Shallow Hole Through Robotic In-Hand Manipulation

Chung Hee Kim and Jungwon Seo
Department of Electronic and Computer/Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology, Hong Kong

- Novel robotic manipulation technique for assembling thin peg-like objects into respective shallow holes
- Features dexterous manipulation actions that combine into a complete insertion operation
- Quasistatic stability attained through force-closure grasps
- Applicable to a variety of scenarios: dry cell/phone battery insertion, lego block assembly etc.


Shallow-depth insertion demonstrated through phone battery insertion.

Medical Robotics IX - 3.3.07

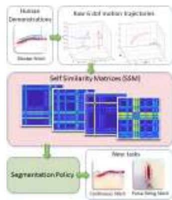
Chair
Co-Chair

16:00–17:15	WeCT1.1

Transfer Learning for Surgical Task Segmentation

Ya-Yen Tsai[1], Bidan Huang[2], Yao Guo[1] and Guang-Zhong Yang[1], Fellow, IEEE
[1]Hamlyn Centre, Imperial College London, UK
[2]Robotics X, Tencent, China

- A model free transfer learning approach to transfer learned segmentation policy to segment new surgical subtasks
- A novel feature selection method using SSM to extract segmentation-related features
- Advantages of frame invariant, robust to noise and capability of working with multiple Degree of Freedom (DoF) data.



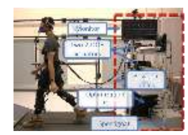
Pipeline of the proposed method

16:00–17:15	WeCT1.2

Bayesian Optimization of Soft Exosuits Using a Metabolic Estimator Stopping Process

Myunghee Kim[1,3*], Charles Liu[1*], Jinsoo Kim[1,2], Sangjun Lee[1,2], Adham Meguid[1], Conor J. Walsh[1,2], Scott Kuindersma[1]
SEAS, Harvard, USA[1]; Wyss, Harvard, USA[2]
MIE, University of Illinois at Chicago, USA[3]

- **Time-efficiency** is critical in **human-in-the-loop optimization** experiments to individualize assistance
- Algorithm for **trading off time spent on exploration and metabolic estimation** using estimator stopping process
- Preliminary (N=2) results from **human walking experiments** using single- and multi-joint soft exosuits



HIL hip and ankle control parameter optimization using a soft exosuit

16:00–17:15	WeCT1.3

Towards Semi-Autonomous and Soft-Robotics Enabled Upper-Limb Exoprosthetics: First Concepts and Robot-based Emulation Prototype

Johannes Kühn, Johannes Ringwald, Moritz Schappler, Lars Johannsmeier and Sami Haddadin
Munich School of Robotics and Machine Intelligence, Technical University Munich, Germany

- Formal introduction of upper-limb exoprosthetics with human embodied exoprosthesis dynamics model.
- Early robot-based prototype emulating several aspects of the future target system.
- Semi-autonomous kinesthetic coordinated prosthesis control strategy.
- First experimental evaluation of current exoprosthesis system

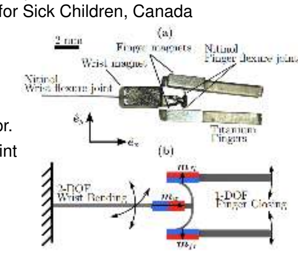
Bottle grasping with intermediate exoprosthesis prototype

16:00–17:15	WeCT1.4

Cable-Less, Magnetically-Driven Forceps for Minimally Invasive Surgery

Cameron Forbrigger[1], Andrew Lim[2,3], Onaizah Onaizah[1], Sajad Salmanipour[1], Thomas Looi[3], James Drake[3], Eric Diller[1]
[1] MIE and [2] IBBME, University of Toronto, Canada;
[2] CIGITI, Toronto Hospital for Sick Children, Canada

- A novel magnetic microgripper is presented.
- The gripper has the potential future application as a surgical end-effector.
- Its wireless, cable-less compliant-joint design allows high positional repeatability.
- Future work will focus on improving grip strength.



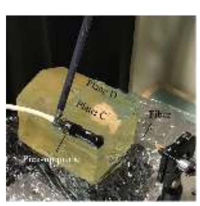
(a) Photograph of the gripper.
(b) Gripper schematic.

16:00–17:15	WeCT1.5

Towards Robot-assisted Photoacoustic Imaging: Implementation Using the dVRK and VFs

Hamid Moradi, Shuo Tang, and Septimiu E. Salcudean
Electrical and Computer Engineering, University of British Columbia, Canada

- The da Vinci robot is programmed to acquire trajectory for prostate photoacoustic imaging.
- Shared-control configuration with virtual fixture was designed to collect photoacoustic signals from an optimum volume.
- Pick-up transducer is controlled so that it stays parallel to the tomography axis.
- Pick-up transducer also stays normal to a virtual plane, normal to the tomography axis.



Collecting photoacoustic signals from a chicken breast phantom

16:00–17:15	WeCT1.6

A Miniature Suction-gripper with Passive and Active Microneedle Arrays to Manipulate Peripheral Nerves

Namseon Jang, Yong Seok Ihn, Jinwoo Jeong, Sungwook Yang, Sehyuk Yim, Sang-Rok Oh, Keehoon Kim, and Donghyun Hwang
Center for Intelligent and Interactive Robotics, Korea Institute of Science and Technology, Republic of Korea

- Development of the miniature gripper being capable of manipulating the peripheral nerves with the suction force
- Utilization of the wire-type SMA actuators as the active-microneedles for improving the gripping ability
- Performance verification based on practical in-vivo surgery with a tele-operated neurosurgery robot

Aerial Robotics - 3.3.08

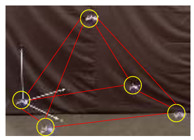
Chair
Co-Chair

16:00–17:15	WeCT1.1

Robust 3D Distributed Formation Control with Collision Avoidance and Application to Multirotor Aerial Vehicles

Kaveh Fathian[1], Sleiman Safaoui[2], Tyler H. Summers[3], and Nicholas Gans[4]
[1]AeroAstro, MIT, USA. [2]Elec. Eng., UT Dallas, USA. [3]Mech. Eng., UT Dallas, USA. [4]UTARI, UT Arlington, USA.

- We propose a semidefinite programming formulation to generate robust control gains given a desired formation
- The formation control law is fully distributed
- Each agents calculates its control using relative position measurements
- Collisions are resolved by rotating the control to a safe direction

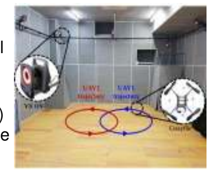

Five drones forming a square-base pyramid

16:00–17:15	WeCT1.2

Networked operation of a UAV using Gaussian process-based delay compensation and model predictive control

D Jang[1], J Yoo[2], C Y Son[1], H. Jin Kim[1] and K H. Johansson[3]
[1]Mechanical and Aerospace Eng, Seoul National Univ, South Korea
[2]Electrical, Electronic and Control Eng, Hankyong National Univ, South Korea
[3]Electrical Eng, KTH Royal Institute of Technology, Sweden

- The control of a UAV over longer distance with time-varying network delay and unknown UAV physical properties is addressed.
- We suggest a networked controller using model predictive control (MPC) for the multirotor systems.
- This paper employs the Gaussian process (GP) to learn the multirotor dynamics and improve the networked control performance.
- Simulations and experiments are performed for networked operation of UAVs.

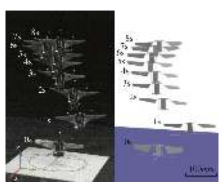


16:00–17:15	WeCT1.3

Flappy Hummingbird: An Open Source Dynamic Simulation of Flapping Wing Robots and Animals

Fan Fei, Zhan Tu, Yilun Yang, Jian Zhang and Xinyan Deng
School of Mechanical Engineering, Purdue University, US

- Realistic simulation environment compatible with OpenAI Gym
- Validated with real robot on force measurement, wing kinematics, open loop state transition
- Model-based and learning-based controller designed in simulation
- Successful sim-to-real transfer demonstrates the fidelity and usefulness of the simulation


Robot vs simulation in controlled flight test

16:00–17:15	WeCT1.4

A Truly-Redundant Aerial Manipulator System with Application to Push-and-Slide Inspection in Industrial Plants

M. **Tognon**[1], H. A. **Tello Chávez**[1], E. **Gasparin**[2], Q. **Sablé**[1], D. **Bicego**[1], A. **Mallet**[1], M. **Lany**[2], G. **Santi**[2], B. **Revaz**[2], J. **Cortés**[1], A. **Franchi**[1]
[1]LAAS-CNRS, Université de Toulouse, CNRS, Toulouse, France
[2]SENSIMA INSPECTION, Switzerland
Accepted for publication in the Robotics & Automation Letters

- *Design*: aerial robot with **8 fully-actuated DoFs** (6 Base + 2 Arm) capable of **physical interaction** on **curved surfaces**
- *Control*: PI + displaced D-term that accounts for **elasticity** and **vibrations**
- *Motion planning*: **kinodynamic**, **control-aware**, and **task-constrained**
- *Demo*: push-slide-sense for **EC inspection** of a **metallic pipe**

Vision and Control - 3.3.09

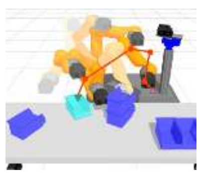
Chair
Co-Chair

16:00–17:15	WeCT1.1

Visual Repetition Sampling for Robot Manipulation Planning

En Yen Puang, Peter Lehner, Zoltan-Csaba Marton, Maximilian Durner, Rudolph Triebel, Alin Albu-Schäffer
Institute of Robotics and Mechatronics, German Aerospace Center, Germany

- Improve the sampling efficiency of sampling-based motion planner with a vision module
- Adaptively changing the biased sampling distributions according to queried scene
- Scene understanding is done using an Autoencoder trained in self-supervised manner
- Adaptation and randomization methods are used to achieve data-efficient sim2real

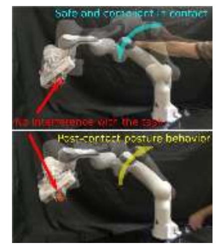


16:00–17:15	WeCT1.2

Contact-Driven Posture Behavior for Safe and Interactive Robot Operation

Mikael Jorda, Elena Galbally Herrero, Oussama Khatib
Computer Science, Stanford University, USA

- We propose an approach for robots to react to unexpected contacts on their links
- The robot reacts safely without disturbing the task
- The approach gives the possibility to control the contact behavior
- It does not require external sensors
- It does not require to find the contact location



16:00–17:15	WeCT1.3

SuperDepth: Self-supervised, Super-Resolved Monocular Depth Estimation

Sudeep Pillai and Rareș Ambruș and Adrien Gaidon
Toyota Research Institute (TRI), CA, USA

- We propose two key extensions to self-supervised monocular disparity estimation: **Sub-Pixel convolutions for Super-Resolution** and a **Differentiable Flip Augmentation layer**
- We train in a self-supervised setting on stereo image pairs and recover a scale-aware monocular depth estimation network
- We achieve state-of-the-art results on monocular depth and pose on the KITTI benchmark

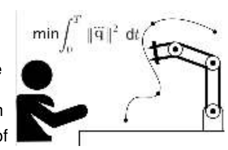
Estimated monocular depth

16:00–17:15	WeCT1.4

A Variational Approach to Minimum Jerk Trajectories for Psychological Safety in Collaborative Assembly Stations

Rafael A. Rojas, Manuel A. Ruiz Garcia
Erich Wehrle and Renato Vidoni
Faculty of Science and Technology, Free University of Bozen-Bolzano

- Variational formulation of minimum jerk trajectory problem passing through a sequence of waypoints to achieve psychological safety.
- Exploitation of the invariance properties of the extremals of the minimum jerk problem to achieve safe physical human-robot interaction
- Numerical and experimental implementation of smooth trajectories which are psychologically and physically safe.



16:00–17:15	WeCT1.5

The Mechanics and Control of Leaning to Lift Heavy Objects with a Dynamically Stable Mobile Robot

Fabian Sonnleitner,[1] Roberto Shu,[2] and Ralph Hollis[2]
[2]The Robotics Institute, Carnegie Mellon University, USA
[1]ITS, University of Applied Sciences Salzburg, Austria

- The results in this paper utilize the CMU Ballbot, a person size single spherical wheel dynamically stable mobile robot
- Using simple 2-DOF series elastic arms, the ballbot is able to lift payloads up to 15 kg by leaning to maintain balance
- Successful transfers were made of 10 kg payloads from the ballbot to a person and from a person to the ballbot
- The ballbot successfully picked, transferred, and placed 10 kg payloads from/to a tabletop

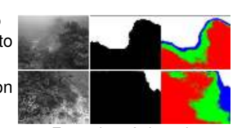
The ballbot lifting a 15 kg payload by leaning backward

16:00–17:15	WeCT1.6

Improving Underwater Obstacle Detection using Semantic Image Segmentation

Bilal Arain[^*], Chris McCool[^], Paul Rigby[*], Daniel Cagara[^*] and Matthew Dunbabin[^]
[^]Queensland University of Technology, Australia
[*]Australian Institute of Marine Science, Australia

- We propose combining feature-based stereo matching with learning-based segmentation to improve obstacle detection
- Consider binary (two class) obstacle detection as well as multi-class detection with range estimation
- Evaluated on field data from cluttered, visually degraded coral reef environments
- Experimental results show improved image-wide obstacle detection and rejection of transient/dynamic objects



Examples of obstacle detection from the binary (middle) and multi-class (right) classifiers on a coral reef

Mobile Robotics - 3.3.10

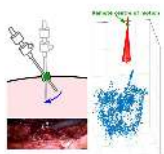
Chair
Co-Chair

16:00–17:15	WeCT1.1

RCM-SLAM: Visual Localisation and Mapping under Remote Centre of Motion Constraints

Francisco Vasconcelos, Evangelos Mazomenos, Danail Stoyanov
Wellcome Trust Interventional and Surgical Sciences Institute, UCL, UK
John Kelly
Division of Surgery and Interventional Science, UCL, UK

- In minimally invasive robotic surgery the motion of each instrument is constrained by a remote centre of motion (RCM).
- **Contribution:** incorporate the RCM constraints of a laparoscopic camera into a visual SLAM pipeline. This involves modifying both the closed form initialization algorithms (relative pose, absolute orientation) and the global refinement step (bundle adjustment).



16:00–17:15	WeCT1.2

Comparing Physical and Simulated Performance of a Deterministic and a Bio-inspired Stochastic Foraging Strategy for Robot Swarms

Qi Lu[1], Antonio D. Griego[1], G Matthew Fricke[1], and Melaine E. Moses[1,2]
[1]Department of Computer Science, University of New Mexico, USA
[2]Santa Fe Institute, Santa Fe, USA

- Evaluated the stochastic CPFA and deterministic DDSA swarm foraging algorithms.
- The DDSA outperforms the CPFA in Gazebo simulation.
- The CPFA marginally outperforms the DDSA in physical experiments.
- The stochasticity of outdoor environments degrades the deterministic algorithm, making it effectively random.

16:00–17:15	WeCT1.3

WheeLeR: Wheel-Leg Reconfigurable Mechanism with Passive Gears for Mobile Robot Applications

Chuanqi Zheng and Kiju Lee
Department of Mechanical and Aerospace Engineering, Case Western Reserve University, USA

- A new passive wheel-leg transformation mechanism based on a unique geared structure is presented.
- The wheel can transform between two modes, adapting to varying ground conditions.
- The number of legs, wheel size, and the gear ratio are customizable to achieve effective locomotion in a target environment.
- The wheels are able to climb over obstacles up to 2.4 times the height of wheel radius.

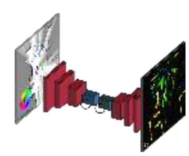
WheeLeR in the leg mode for climbing an obstacle

16:00–17:15	WeCT1.4

Long-Term Occupancy Grid Prediction Using Recurrent Neural Networks

Marcel Schreiber, Stefan Hoermann and Klaus Dietmayer
Institute of Measurement, Control and Microtechnology, Ulm University, Germany

- Predicting future occupancy grids of a complex downtown scenario, based on past dynamic grids
- Convolutional layers exploit context and enables to model interactions and multimodal predictions
- Recurrent network architecture enables sequential filtering of the inputs and prediction of occluded objects

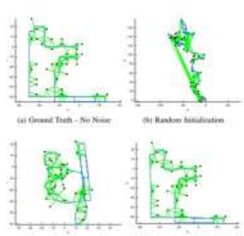


16:00–17:15	WeCT1.5

Guaranteed Globally Optimal Planar Pose Graph and Landmark SLAM via Sparse-Bounded Sums-of-Squares Programming

Joshua Mangelson, Jinsun Liu, Ryan Eustice, and Ram Vasudevan
Robotics Institute, University of Michigan, USA

- Formulation of Simultaneous Localization and Mapping (SLAM) as a polynomial optimization problem
- Solution via sparse bounded sum-of-squares (SOS) optimization
- Proof that under this formulation planar SLAM is SOS-convex
- Guaranteed globally optimal solution with no dependence on initialization or limits on measurement noise



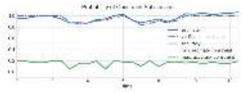
Control - 3.3.11

Chair
Co-Chair

16:00–17:15	WeCT1.1

Trust Regions for Safe Sampling-Based Model Predictive Control

Martin Koch
University of Stuttgart, Bosch Center for Artificial Intelligence, Germany
Markus Spies, Mathias Bürger
Bosch Center for Artificial Intelligence, Germany



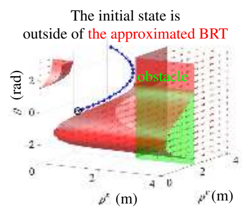
- Our goal is to **guarantee constraint satisfaction** in non-linear systems by using **sampling-based control**
- We **prove a bound** on the deviation from the sampling distribution which guarantees safety in the following form: *The probability of constraint violation is less than* γ. *The probability of having underestimated this probability by more than* c *is less than* δ.
- We present a case study in the navigation domain to demonstrate the applicability of the proposed approach

16:00–17:15	WeCT1.2

Removing Leaking Corners to Reduce Dimensionality in Hamilton-Jacobi Reachability

Donggun Lee*
Mechanical Engineering, UC Berkeley, USA
Mo Chen*
Computing Science, Simon Fraser University, Burnaby, BC, Canada
Claire Tomlin
Electrical Engineering & Computer Science, UC Berkeley, USA

- We present a coupled Hamilton-Jacobi formulation that guarantees safety and dimensionality reduction.
- The formulation provides an avoidance controls to the system.
- We demonstrate our method in vehicle's obstacle avoidance problems with a 5D car model.

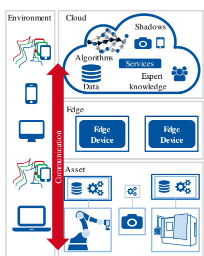


16:00–17:15	WeCT1.3

Control from the Cloud: Edge Computing, Services and Digital Shadow for Automation Technologies

Christian Brecher, Melanie Buchsbaum and Simon Storms
Laboratory for Machine Tools and Production Engineering (WZL) , RWTH Aachen University, Germany

- Combining Cloud and Edge Computing with distributed services and Digital Shadow
- Cloud and Edge Computing are used as infrastructure for a distributed automation process
- Services control the process and interact with the physical assets
- The Digital Shadow provide state information of each production asset



16:00–17:15	WeCT1.4

Robot self-calibration using multiple kinematic chains - a simulation study on the iCub humanoid robot

Karla Stepanova[1,2], Tomas Pajdla[2] and Matej Hoffmann[1]
[1]FEE, Czech Technical University in Prague, Czech Republic
[2]CIIRC, Czech Technical University in Prague, Czech Republic

- A simulated iCub humanoid robot - stereo camera system & end-effector contact emulation.
- Quantitative comparison - kinematic calibration by employing different combinations of intersecting kinematic chains.
- Adding "touch" to calibration is superior to only hand-eye calibration (in terms of both calibration results and observability).
- Parameters of all chains (here 86 DH parameters) calibrated simultaneously -> for 50 (100) poses end-effector error of around 2 (1) mm.

iCub upper body and schematic illustration of kinematic chains considered

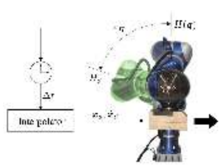
16:00–17:15	WeCT1.5

Improving the Minimization Performance of Auxiliary Null Space Tasks via Time Scaling of the Primary Task

Nico Mansfeld[1], Youssef Michel[2], Tobias Bruckmann[3] and Sami Haddadin[2]

[1] German Aerospace Center (DLR), Germany
[2] Technical University of Munich, Germany
[3] University of Duisburg-Essen, Germany

- Hierarchical null space control is typically defined in an instantaneous manner, the temporal fulfillment of tasks is not considered
- We investigate how main and auxiliary null space tasks can be synchronized via time scaling
- Experiments for one redundant DOF carried out with DLR/KUKA Lightweight Robot, simulations for hierarchical null space control in simulation

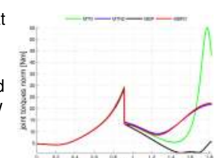


16:00–17:15	WeCT1.6

Stable Torque Optimization for Redundant Robots Using a Short Preview

Khaled Al Khudir, Gaute Halvorsen,
Leonardo Lanari, and Alessandro De Luca
Sapienza University of Rome, Italy

- Different joint torque optimization methods that address the known instability issue of instantaneous joint torque minimization
- Torque norm is minimized over the current and a future sample, using a short preview window
- A momentum-damping joint torque can be added as a dynamic null-space term
- Stable and consistent behaviors are obtained along short or long Cartesian trajectories



Comparison of different torque optimization solutions

Compliant Actuators II - 3.3.12

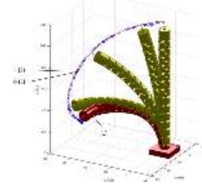
Chair
Co-Chair

16:00–17:15	WeCT1.1

Shape Memory Structures - Automated Design of Monolithic Soft Robot Structures with Pre-defined End Poses

Yannick S. Krieger, Simon Schiele, Samuel Detzel, Christian Dietz, and Tim C. Lueth
Institute of Micro Technology and Medical Device Technology (MiMed), Technical University of Munich, Germany

- Automated design process for monolithic flexure hinge structures with pre-defined end poses
- Task-specific design with direct interface to additive manufacturing technologies
- Frist design of system for potential applications using the automated design process

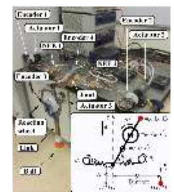

Monolithic soft robotic structure with minimum number of DoF for actuation

16:00–17:15	WeCT1.2

Energy-Aware Optimal Control of Variable Stiffness Actuated Robots

Altay Zhakatayev, Matteo Rubagotti and Huseyin Atakan Varol
Department of Robotics and Mechatronics, Nazarbayev University, Kazakhstan

- Definition and solution of different types of numerical optimal control problems for variable stiffness actuated robots.
- Constraints on power and energy explicitly accounted for, while minimizing energy consumption or maximizing performance.
- Validation on a ball-throwing case study, with simulation and experimental results.

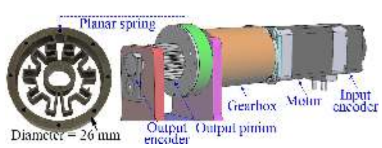


16:00–17:15	WeCT1.3

Design of a Miniature Series Elastic Actuator for Bilateral Teleoperations Requiring Accurate Torque Sensing and Control

Ying-Lung Yu and Chao-Chieh Lan
Department of Mechanical Engineering, National Cheng Kung University, Taiwan

- Existing rotary series elastic actuators (SEAs) are bulky and not suitable for multiple-degree-of-freedom haptics applications.



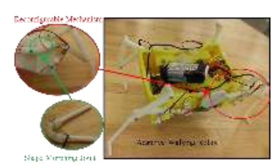
- By using a specifically designed planar spring, the size of the SEA can be minimized while the output torque and stiffness can still be accurately controlled.
- A master-slave robot system using the proposed SEA demonstrates that both stiff and soft remote environments can be virtually realized.

16:00–17:15	WeCT1.4

An Adaptive Walking Robot with Reconfigurable Mechanisms using Shape Morphing Joints

Jiefeng Sun and Jianguo Zhao
Department of Mechanical Engineering, Colorado State University, USA

- Reconfigurable robots that adapt to various environments and tasks without altering its hardware design.
- A reconfigurable mechanism can generate different configurations or trajectories.
- The strategy can be applied to any mechanism that has a four-bar loop.
- Three example trajectories are implemented on a walking robot.


An adaptive walking robot

16:00–17:15	WeCT1.5

A Novel Rotating Beam Link for Variable Stiffness Robotic Arms

Tyler Morrison, Chunhui Li and Hai-Jun Su
Dept. of Mechanical & Aerospace Engineering, The Ohio State University, USA
Xu Pei
Beihang University, China

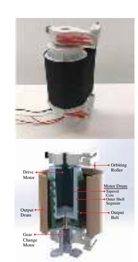
- Simple, compact design for varying stiffness to increase corobot safety when working with humans.
- Comprehensive analytical mechanics model accurately describes controllable stiffness behavior.
- Ratio of maximum to minimum lateral stiffness greater than 10x.
- Minimum stiffness under 0.2 N/mm.

16:00–17:15	WeCT1.6

Low-cost, Continuously Variable, Strain Wave Transmission Using Gecko-inspired Adhesives

Nicholas Naclerio, David Haggerty, Elliot Hawkes
Mechanical Engineering, University of California Santa Barbara, USA
Capella Kerst, Srinivasan Suresh, Sonali Singh, Mark Cutkosky
Mechanical Engineering, Stanford University, USA
Kenichi Ogawa, Susumu Miyazaki
Honda R&D Ltd., Japan

- High gear reduction transmission with continuously variable gear ratio.
- Smooth frictional contact instead of gear teeth enables continuous gear change.
- High frictional torque transfer via the capstan effect reduces the preload required to operate.
- Gecko-inspired dry adhesive used for high friction at low normal forces, without tackiness.



Soft Robots VII - 3.3.13

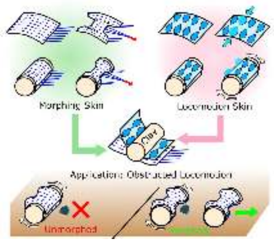
Chair
Co-Chair

16:00–17:15	WeCT1.1

Morphing Robots Using Robotic Skins That Sculpt Clay

Dylan S. Shah, Michelle C. Yuen, Liana G. Tilton, Ellen J. Yang and Rebecca Kramer-Bottiglio
Department of Mechanical Engineering and Materials Science, Yale University, USA

- Morphing robots change their shape to adapt to new task requirements or changing environments
- Here, we wrap active robotic skins around a sculptable host body (clay)
- We show a cable-driven morphing skin, and a pneumatically-actuated rolling locomotion skin
- Working in tandem, the robot is able to overcome obstacles in its path

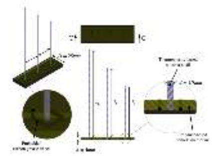


16:00–17:15	WeCT1.2

Mechanical Fourier Transform using an Array of Additively Manufactured Soft Whisker-like Sensors

Apoorv Vaish, Shien Yang Lee, and Pablo Valdivia y Alvarado
Engineering and Product Development, Singapore University of Technology and Design, Singapore

- A single-step additive manufacturing approach to fabricate an array of bio-inspired soft whisker-like sensors is presented.
- Each whisker is a damped oscillator tuned to a different resonant frequency.
- A 3 × 1 polymer based whisker-array is used to distinguish individual frequency components in mixed-frequency air signals, achieving a form of "mechanical Fourier transform".



Fully 3D printed soft whisker array

16:00–17:15	WeCT1.3

Multi-Task Sensorization of Soft Actuators Using Prior Knowledge

Vincent Wall and Oliver Brock
Robotics and Biology Laboratory, Technische Universität Berlin, Germany

- Soft actuators exhibit *specific deformations* for a given task.
- This can be used to *sensorize* the actuator with only *few sensors.*
- But different task might result in different deformations.
- Using *prior knowledge* about the tasks, we can measure deformations in *multiple tasks* while maintaining *existing sensor hardware*.

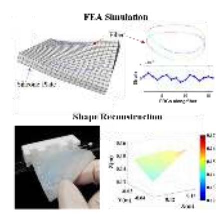
A sensorized PneuFlex actuator with 16 strain sensors

16:00–17:15	WeCT1.4

Real-time Surface Shape Sensing for Soft and Flexible Structures using Fiber Bragg Gratings

T.L.T Lun, K. Wang, J.D.L. Ho, K.H. Lee, K.Y. Sze, and K.W. Kwok
Department of Mechanical Engineering, The University of Hong Kong

- Single-core optical fiber with sparsely distributed FBGs was used to detect surface morphology in real-time.
- FEA to determine sensor design parameters with embedded FBGs.
- Machine learning-based modelling to enable more robust and reliable shape reconstruction without explicit knowledge of the FBG configuration.

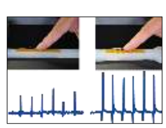


16:00–17:15	WeCT1.5

Wrinkled Soft Sensor with Variable Afferent Morphology

Qiukai Qi and Van Anh Ho
School of Materials Science, Japan Advanced Institute of Science and Technology, Japan
Shinichi Hirai
Department of Robotics, Ritsumeikan University, Japan

- The design was inspired by Water-induced wrinkle on human finger
- The sensor possesses variable sensibility to normal indention and tangential sliding stimuli
- This work was towards further development of active tactile sensing system
- Variable Afferent Network morphology (VANmorph) was proposed for the first time



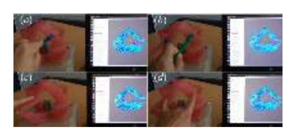
Sensor respond to finger sliding

16:00–17:15	WeCT1.6

Calibration and External Force Sensing for Soft Robots using an RGB-D Camera

Zhongkai Zhang, Antoine Petit, Jeremie Dequidt, Christian Duriez
INRIA & University of Lille, France

- Model the robot using Finite Element Method;
- Propose a method to calibrate both the sensor-robot coordinate system and the actuator inputs;
- Location detection of external forces based on the point cloud from an RGB-D camera;



- Marker-free external force sensing based on the registration between the point cloud and the FE model.

Legged Robots V - 3.3.14

Chair

Co-Chair

16:00–17:15 WeCT1.1

Self-Modifying Morphology Experiments with DyRET: Dynamic Robot for Embodied Testing

Tønnes F. Nygaard, Charles P. Martin,
Jim Torresen and Kyrre Glette
Department of Informatics, University of Oslo, Norway

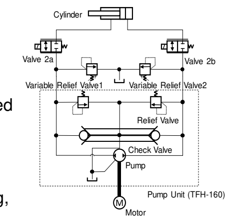
- We have developed a robot that can adapt its own morphology
- We test different leg lengths in several internal and external environments
- Our results show better performance with an adaptable robot body
- The robot is a certified open source hardware project, with Gazebo simulator integration

16:00–17:15 WeCT1.2

Experimental Validation of High-Efficiency Hydraulic Direct-Drive System for a Biped Humanoid Robot

Juri Shimizu, Takuya Otani, Hideki Mizukami and Atsuo Takanishi
Waseda University, Japan
Kenji Hashimoto
Meiji University, Japan

- We employ a hydraulic direct drive system based on flow-control
- The hydraulic direct-drive system is evaluated in an actual hydraulic system.
- The proposed system is compared with the valve-based control system.
- Velocity followability, excellent energy saving, and virtually perfect position tracking are achieved



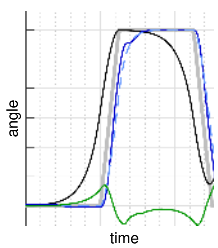
Bench Hydraulic Circuit for Hydraulic Direct-Drive System

16:00–17:15 WeCT1.3

Experimental Demonstration of High-Performance Robotic Balancing

Josephus J. M. Driessen, Antonios E. Gkikakis,
Roy Featherstone, B. Roodra P. Singh
Dept. Advanced Robotics, Istituto Italiano di Tecnologia, Italy

- *Aim:* experimentally demonstrating accurate and fast motion tracking while maintaining balance about unactuated support joint.
- *Experimental motion response* (—) matches well with *theoretical motion response* (– –) .
- Support joint *leans in anticipation* (—) of *commanded trajectory* (—), caused by pre-processing using an *acausal filter* (—).
- No steady state error due to the introduction of a *balance offset observer.*



16:00–17:15 WeCT1.4

OpenRoACH: A Durable Open-Source Hexapedal Platform with Onboard Robot Operating System (ROS)

Liyu Wang, Yuxiang Yang and Ronald S. Fearing
EECS, University of California Berkeley, USA
Gustavo Correa, Konstantinos Karydis
ECE, University of California Riverside, USA

- Scale-up principles for legged robots based on smart composite microstructure (SCM)
- Open mechanics, electronics, and software
- Feedback with gyroscopes, accelerometers, Beacon, colour vision, linescan, and cameras
- Multi-surface walking and running, 24-hour continuous burn-in test on a treadmill

16:00–17:15 WeCT1.5

Design of Anti-skid Foot with Passive Slip Detection Mechanism for Conditional Utilization of Heterogeneous Foot Pads

Jaejun Park, Do Hun Kong and Hae-Won Park
Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, USA

- Design of the anti-skid foot for legged robots utilizing a rubber pad and a spine mechanism
- The footpad is switched from the rubber pad to the spine mechanism when the foot slips.
- The spine mechanism is activated through the passive slip detection and lock & release mechanisms.
- A robot equipped with the foot jumped and attached to a 50° inclined concrete block.

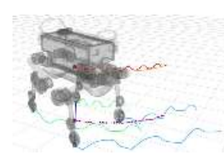
The anti-skid foot design inspired by the feet of Felidae

16:00–17:15 WeCT1.6

Trajectory Optimization for Hybrid Locomotion of Wheeled-Legged Quadrupedal Robots

Yvain de Viragh, Marko Bjelonic, C. Dario Bellicoso,
Fabian Jenelten and Marco Hutter
Robotic Systems Lab, ETH Zurich, Switzerland

- **Hybrid locomotion**: simultaneous walking, driving, and turning, even for full flight gaits
- **Linearized ZMP constraints**: novel linear formulation of ZMP balance criterion
- **Online optimization:** relies on quadratic programming and runs at 50 Hz
- **Rolling constraint**: wheel trajectories satisfy non-holonomic rolling constraint



ANYmal executing a hybrid, full flight trotting gait

Compliance - 3.3.15

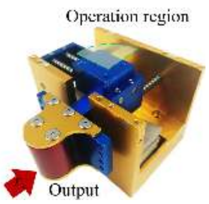
Chair
Co-Chair

16:00–17:15	WeCT1.1

Sensorless Force Control of Automated Grinding/Deburring Using an Adjustable Force Regulation Mechanism

Yu-Ling Kuo, Sheng-Yuan Huang, and Chao-Chieh Lan
Department of Mechanical Engineering,
National Cheng Kung University, Taiwan

- The use of sensors and control is costly and introduces extra complexity for grinding tools.
- A novel fore regulation mechanism (FRM) is presented to be installed on a grinding tool.
- Without using extra sensors and control, the FRM can passively produce adjustable normal contact force between the tooltip and workpiece of various geometry.
- The robot arm movement does not need to be used to regulate the contact force.



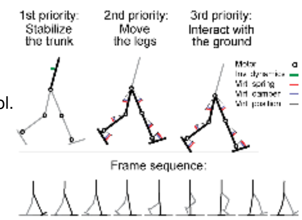
Force Regulation Mechanism Prototype

16:00–17:15	WeCT1.2

Constrained Feedback Control by Prioritized Multi-objective Optimization

Linfeng Li and David J. Braun
Dynamics and Control Lab
Singapore University of Technology and Design, Singapore

- We present a control formulation that does not necessarily require the dynamic model.
- The formulation extends previous prioritized operational space control.
- Approaches such as "simple impedance control" can be utilized with task prioritization and input saturation.



16:00–17:15	WeCT1.3

Exploitation of Environment Support Contacts for Manipulation Effort Reduction of a Robot Arm

Cheng Fang, Navvab Kashiri, Giuseppe F. Rigano, Arash Ajoudani and Nikos G. Tsagarakis
Advanced Robotics Department, Istituto Italiano di Tecnologia, Italy

- Environment is utilized for non-end-effector support contact(s) to reduce the joint efforts during manipulation tasks
- A three-level hierarchical compliance controller is designed to achieve aforementioned control goal
- The contact force at the elbow is adaptively optimized to minimize the joint effort
- Explicit contact force control is not required in the proposed control scheme

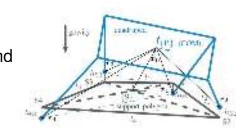
A robot arm utilizes environment support contact for manipulation

16:00–17:15	WeCT1.4

A Coordinate-based Approach for Static Balancing and Walking Control of Compliantly Actuated Legged Robots

D. Lakatos, Y. Federigi, T. Gumpert, B. Henze, M. Hermann, F. Loeffl, F. Schmidt, D. Seidel, and A. Albu-Schäffer
Institute of Robotics and Mechatronics,
German Aerospace Center (DLR), Germany

- Control is realized by commanding motor positions only
- Exploits bijective relation between motor and link position under static conditions
- Definition of task-coordinates for balancing and walking taking contact constraints into account
- Experimental validation on a compliantly actuated quadruped



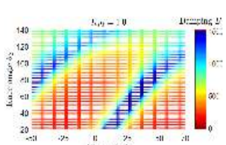
Static balancing coordinates

16:00–17:15	WeCT1.5

Joint kinematic configuration influence on the passivity of an impedance-controlled robotic leg

Felipe Higa, Gustavo Lahr, Glauco Caurin and Thiago Boaventura
São Carlos School of Engineering, University of São Paulo, Brazil

- Passivity can ensure stable robot-environment interactions
- For cascaded impedance controllers, the inner force control loop can greatly affect robot's performance and passivity
- We demonstrate the influence of leg joint kinematic configuration on achievable virtual stiffness and damping



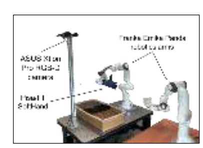
Maximum virtual damping that keeps the system passive throughout the leg's workspace

16:00–17:15	WeCT1.6

Towards Robot Interaction Autonomy: Explore, Identify, and Interact

Pietro Balatti and Arash Ajoudani
HRI² Lab, Istituto Italiano di Tecnologia, Italy
Dimitrios Kanoulas and Nikos G. Tsagarakis
HHCM Lab, Istituto Italiano di Tecnologia, Italy

- Novel **self-tuning impedance** controller that regulates robot quasi-static parameters, i.e., stiffness and damping, based on the robot sensory data and vision.
- Parameters tuning achieved **only in the direction(s) of interaction** or movement, by distinguishing **expected interactions** from **external disturbances**.
- Framework **evaluation** in an agricultural task.



Object Recognition & Segmentation V - 3.3.16

Chair
Co-Chair

16:00–17:15	WeCT1.1

Personalized Online Learning of Whole-Body Motion Classes Using Multiple Inertial Measurement Units

Viktor Losing*‡, Taizo Yoshikawa+, Martina Hasenjäger‡, Barbara Hammer* and Heiko Wersing‡
*Bielefeld University, Bielefeld, Germany
‡Honda Research Institute Europe GmbH, Offenbach, Germany
+Honda R&D Co. Ltd, R&D Center X, Japan

- Wearable assist devices for the support of human motions should adapt to their user's personal motion patterns in real-time.
- We compare personalized online machine learning models and average user models for online action classification based on IMU data.
- Only a few IMU sensors are necessary for accurate action classification.
- Personalized models are very efficient learners that yield better results with less data than average user models.

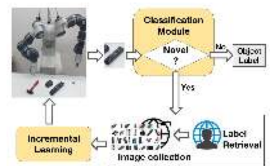
Example motion: Lift a box

16:00–17:15	WeCT1.2

Knowledge is Never Enough: Towards Web Aided Deep Open World Recognition

Massimiliano Mancini[1,2], Hakan Karaoguz[3], Elisa Ricci[2,4], Patric Jensfelt[3] and Barbara Caputo[5]
[1]Sapienza University of Rome, Italy - [2]Fondazione Bruno Kessler, Italy
[3]KTH Royal Institute of Technology, Sweden - [4]University of Trento, Italy
[5]Italian Institute of Technology, Italy

- Closed word assumption is unrealistic for visual recognition algorithms acting in the real world.
- We propose an Open World Recognition algorithm, discovering and adding new objects to a classifier.
- The algorithm is based on a deep architecture, trained end-to-end.
- We propose a simple way to include web-information within the pipeline, towards automatically tackling OWR.



16:00–17:15	WeCT1.3

Inferring Robot Morphology from Observation of Unscripted Movement

Neil Bell, Brian Seipp, Tim Oates, Cynthia Matuszek
Computer Science and Electrical Engineering
University of Maryland, Baltimore County, USA

* Determine a robot's kinematic model through passive observation of unscripted movement.
* Train Recurrent Neural Network (RNN) for temporally-robust morphology estimation from simulated ground truth.
* Mimicking Kinect2's depth sensor, simulation produces occluded pointclouds of semi-random robot movement.
* Two RNN approaches produce promising results worthy of further research.

From a pointcloud to an estimated morphology

16:00–17:15	WeCT1.4

The H3D Dataset for Full-Surround 3D Multi-Object Detection and Tracking in Crowded Urban Scenes

Abhishek Patil, Srikanth Malla, Haiming Gang and Yi-Ting Chen
Honda Research Institute USA

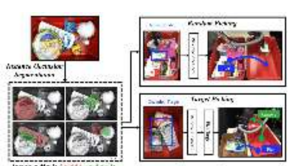
- The H3D is a full 360-degree LiDAR multi-object detection and tracking dataset
- It consists of 160 crowded and highly interactive traffic scenes
- Comprises of more than 1 million 3D bounding box labels
- Benchmarked on state-of-the art algorithms for 3D only detection and tracking algorithms

16:00–17:15	WeCT1.5

Joint Learning of Instance and Semantic Segmentation for Robotic Pick-and-Place with Heavy Occlusions in Clutter

Kentaro Wada, Kei Okada and Masayuki Inaba
University of Tokyo, JSK Laboratory, Japan

- Introduce semantic occlusion segmentation based on pixel-wise score regression.
- Joint learning of instance and semantic segmentation for occluded regions.
- Achieve different robotic pick-and-place tasks (target and random picking) with heavy occlusions of objects.



16:00–17:15	WeCT1.6

Weakly Supervised Recognition of Surgical Gestures

Beatrice van Amsterdam[1], Hirenkumar Nakawala[2], Elena De Momi[3], Danail Stoyanov[1]
[1]Wellcome/EPSRC Centre for Interventional and Surgical Sciences (WEISS), UCL, UK
[2]Department of Computer Science, Università di Verona, Italy
[3]Department of Biomedical Engineering, Politecnico di Milano, Italy

- Action recognition in robot-assisted minimally invasive surgery
- GMM clustering to segment surgical demonstrations into action units
- GMM initialization on few labelled expert demonstrations boosts recognition performance alongside better definition of action labels

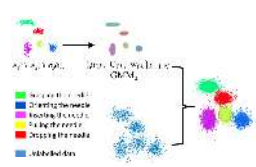


Fig. We use few labelled expert demonstrations **e**(t) for GMM initialization (GMM_0).

Autonomous Vehicles III - 3.3.17

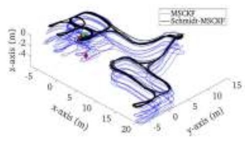
Chair
Co-Chair

16:00–17:15	WeCT1.1

Visual-Inertial Navigation: A Concise Review

Guoquan (Paul) Huang
Department of Mechanical Engineering, University of Delaware, USA

- We, for the first time, offer a concise but complete contemporary literature review on visual-inertial navigation systems (VINS)
- This review primarily focuses on: (i) state estimation, (ii) sensor calibration, and (iii) observability analysis
- We open discussions on the challenges remaining to tackle and the future possible research directions of VINS



Some of our recent VINS algorithms:
•**Closed-form preintegration (CPI):** [WAFR 2016, IJRR 2019]
•**Robocentric-VIO (R-VIO):** [IROS 2018, IJRR 2019]
•**Schmidt-MSCKF:** [ICRA 2019, CVPR 2019]
•**Multi-cam VIO:** [ICRA 2019]
•**Multi-IMU VIO:** [ICRA 2019]

16:00–17:15	WeCT1.2

Building a Winning Self-Driving Car in Six Months

Keenan Burnett, Andreas Schimpe, Mona Gridseth, Chengzhi Winston Liu, Qiyang Li, Zachary Kroeze, and Angela P. Schoellig

Institute for Aerospace Studies, University of Toronto, Canada

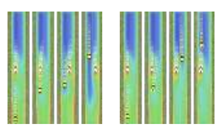
- A winning approach to the SAE AutoDrive Challenge.
- It is possible to develop a system with basic autonomy features in just six months relying on simple, robust algorithms.
- Visual localization without a prior map.
- We highlight the performance of our system on several closed-loop experiments.

16:00–17:15	WeCT1.3

Hierarchical Game-Theoretic Planning for Autonomous Vehicles

Jaime F. Fisac*[1], Eli Bronstein*[1], Elis Stefansson[2], Dorsa Sadigh[3], S. Shankar Sastry[1], and Anca Dragan[1]
[1]Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, United States
[2]Department of Mathematics, KTH Royal Institute of Technology, Sweden
[3]Computer Science Department, Stanford University, United States

- We propose a hierarchical decomposition to tractably plan through dynamic interactions:
- *Strategic level:* simplified physics model, full closed-loop feedback dynamic game (dynamic programming)
- *Tactical level:* high-fidelity physics, simplified interaction model (trajectory optimization)
- Use strategic value functions to inform trajectory predictions/plans at tactical level.



The strategic value function guides the autonomous vehicle (yellow) to approach the human (white) aiming to incentivize a lane change and otherwise overtake.

16:00–17:15	WeCT1.4

IceVisionSet: lossless video dataset collected on Russian winter roads with traffic sign annotations

Artem L. Pavlov, Pavel A. Karpyshev, and Dzmitry Tsetserukou
Space Center, Skolkovo Institute of Science and Technology
George V. Ovchinnikov, Ivan V. Oseledets,
Center for Computational and Data-Intensive Science and Engineering, Skolkovo Institute of Science and Technology

- In this work we present a comprehensive, lifelike dataset of traffic sign images collected on the Russian winter roads in varying conditions, which include different weather, camera exposure, illumination and moving speeds.
- The dataset was annotated in accordance with the Russian traffic code. Annotation results and images are published under open CC BY 4.0 license and can be downloaded from the project website: http://oscar.skoltech.ru/

Open Skoltech Car platform used for dataset collection

16:00–17:15	WeCT1.5

Integrated UWB-Vision Approach for Autonomous Docking of UAVs in GPS-denied Environments

Thien-Minh Nguyen, Thien Hoang Nguyen, Muqing Cao, Zhirong Qiu and Lihua Xie
School of EEE, Nanyang Technological University, Singapore

- Using UWB, UAV can relatively locate and approach a target without relying on any external positioning infrastructure, thus enabling potential applications in many GPS-less environments.
- Due to being omni-directional, UWB can also make up for temporary loss of vision due to limited FOV at the landing phase, thus improving the reliability of the approach.
- Approaching and Landing on a 1.5m x 1.5m large platform from 50m away has been successfully implemented on a UAV platform with great efficiency.

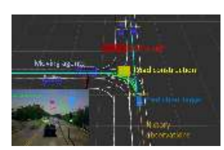
Autonomous approaching and landing on a moving target with UWB anchor nodes from 50 meters away.

16:00–17:15	WeCT1.6

Online Vehicle Trajectory Prediction using Policy Anticipation Network and Optimization-based Context Reasoning

Wenchao Ding and Shaojie Shen
ECE, HKUST, Hong Kong

- An online two-level trajectory prediction framework which incorporates the multimodal nature of future trajectories.
- A highly flexible optimization-based context reasoning process which encodes various contextual factors.
- Integration of the vehicle trajectory prediction framework and presentation of the results in various traffic configurations.



Neurorobotics - 3.3.18

Chair
Co-Chair

16:00–17:15 WeCT1.1

A Flexible Low-Cost Biologically Inspired Sonar Sensor Platform for Robotic Applications

Dennis Laurijssen, Robin Kerstens, Girmi Schouten, Walter Daems & Jan Steckel
Faculty of Applied Engineering, University of Antwerp, Belgium

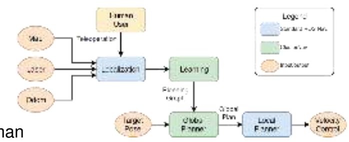
- Small, versatile and low-cost sonar sensor (size: 7.5 cm x 5.0 cm x 2.8 cm weight: 90 g).
- Bat pinnae introduce spatio-spectral cues between left and right microphone channels.
- Subsumption control architecture chooses from three behaviors based on the auditory information.

The proposed flexible sonar sensing platform with the replica of the common big-eared bat and its natural counterpart.

16:00–17:15 WeCT1.2

ClusterNav: Learning-Based Robust Navigation Operating in Cluttered Environments

Gonçalo S. Martins, Rui P. Rocha, Fernando J. Pais and Paulo Menezes
ISR-UC, University of Coimbra, Portugal



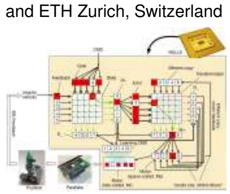
- Model-based navigation techniques fall short in achieving human-like behaviour while navigating cluttered environments
- ClusterNav learns from human demonstration, capturing trajectory features as a graph via clustering
- This representation is then used to generate new trajectories from known points, allowing the robot move in an acceptable manner
- The technique was tested in a real environment, comparing it with the model-based approach

16:00–17:15 WeCT1.3

Adaptive Motor Control and Learning in a Spiking Neural Network Realised on a Mixed-Signal Neuromorphic Processor

Sebastian Glatz, Julien N.P. Martel, Raphaela Kreiser, Ning Qiao, Yulia Sandamirskaya
Institute of Neuroinformatics, University of Zurich and ETH Zurich, Switzerland

- We present a simple feedback controller, fully realized in a spiking neural network on a mixed-signal analog/digital neuromorphic processor ROLLS
- When the controller converges, it triggers learning of a feedforward mapping from a task-level to motor command realized with on-chip plasticity on the neuromorphic processor
- We demonstrate performance of the hardware system in controlling a miniature robotic vehicle



Scheme of the spiking neural network controller on the neuromorphic processor ROLLS and the robotic setup

16:00–17:15 WeCT1.4

Adaptive Genomic Evolution of Neural Network Topologies (AGENT) for State→Action Mapping

Amir Behjat, Sharat Chidambaran, and Souma Chowdhury
Mechanical and Aerospace Engineering, University at Buffalo, USA

- AGENT is an approach to co-evolving the topology and weights of neural networks (NN).
- AGENT introduces diversity and fitness improvement controllers for an efficient and non-stagnating evolution process.
- When tested on Open-AI benchmark problems, AGENT's (state→action mapping) performance compares well with state-of-the-art RL.
- Model trained by AGENT for quadcopter collision avoidance demonstrates 96% success rate over unseen scenarios.

16:00–17:15 WeCT1.5

End to End Learning of a Multi-layered SNN Based on R-STDP for a Target Tracking Snake-like Robot

Zhenshan Bing, Zhuangyi Jiang, and Alois Knoll
Department of Informatics, Technical University of Munich, Germany
Caixia Cai
Institute for Infocomm Research (I2R), A*STAR, Singapore
Long Cheng, Kai Huang
School of Data and Computer Science, Sun Yat-sen University, China

- We propose a policy that propagates the reward back through all the layers of an SNN and acts as individual neural modulator.
- We offer a general workflow to implement an SNN controller based on our proposed learning rule, together with information encoding and decoding strategies.
- The results also reveals that compared with other SNN-based controllers with different topologies, our method has advantages in terms of tracking accuracy and stability.

Target tracking task for a snake-like robot.

Cooperative and Distributed Robot Systems II - 3.3.19

Chair
Co-Chair

16:00–17:15	WeCT1.1

Improving collective decision accuracy via time-varying cross-inhibition

Mohamed S. Talamali, Thomas Bose, James A. R. Marshall and Andreagiovanni Reina
Department of Computer Science, University of Sheffield, UK

- **Task:** Swarm of simplistic robots with noisy sensors must agree on the best-quality option
- **Solution:** Bio-inspired decision strategy which includes a mechanism to overcome robots' noise in quality estimates
- **Contribution:** Time-varying quality-dependent communication improves both decision speed and accuracy

16:00–17:15	WeCT1.2

A Motion Planning Scheme for Cooperative Loading using Heterogeneous Robotic Agents

Michalis Logothetis, Panagiotis Vlantis, Constantinos Vrohidis, George C. Karras, and Kostas J. Kyriakopoulos
Control Systems Lab, Dept. of Mechanical Engineering, National Technical University of Athens, Greece.

- A decentralized motion planning and control solution for the automated load exchange task between heterogeneous robotic agents.
- An algorithm based on PRMs is responsible for the optimal loading area calculation.
- The motion control of the mobile robot is realized by a harmonic-based scheme with guaranteed obstacle avoidance and convergence properties.

Cooperative Loading Scenario Snapshots

16:00–17:15	WeCT1.3

Voluntary Retreat for Decentralized Interference Reduction in Robot Swarms

Siddharth Mayya, Pietro Pierpaoli, and Magnus Egerstedt
School of Electrical and Computer Engineering, Georgia Institute of Technology, USA

- How much time does a robot spend avoiding other robots vs. performing the given task?
- Contribution: Decentralized algorithm to reduce overcrowding in robot swarms.
- Robots decide to leave the domain if swarm density becomes too high.
- Robots do not communicate and only use binary encounter information to make the decision to stay or leave.

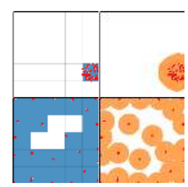
Experimental Verification on the Robotarium

16:00–17:15	WeCT1.4

Spatial Coverage Without Computation

Anıl Özdemir, Matthew D. Hall, and Roderich Groß
Automatic Control and Systems Engineering, The University of Sheffield, UK
Melvin Gauci
Wyss Institute, Harvard University, MA
Andreas Kolling
iRobot, Pasadena, CA

- A spatial coverage strategy for extremely simple robots (no memory, 1-bit sensor)
- The strategy outperforms multiple other solutions
- It can be used in different environments, and even for navigating a maze
- Experiments done with a swarm of 25 e-puck robots



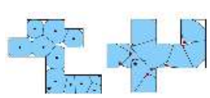
Initial and final scenes for cell coverage and area coverage performance measures

16:00–17:15	WeCT1.5

Decentralized Full Coverage of Unknown Areas by Multiple Robots with Limited Visibility Sensing

Junxun Zhong, Hui Cheng, and Liu He
School of Data and Computer Science, Sun Yat-sen university, China
Fan Ouyang
College of Engineering, South China Agricultural University, China

- This paper address the full coverage problem of unknown convex and concave 2D areas
- The areas are initially unknown to the multiple robots
- A novel continuous max-sum algorithm with gradient descent (CMGD) is proposed
- This method can be applied to omnidirectional/fan-shaped sensor models with various sensing ranges



Results of CMGD

16:00–17:15	WeCT1.6

Swarm Aggregation Without Communication and Global Positioning

Dhruv Shah and Leena Vachhani
Indian Institute of Technology Bombay, India

- Principled approach for swarm aggregation to a fixed target using a decentralized control-law and no inter-agent communication
- Provably stable aggregation using multiple Lyapunov function theory for switched systems
- Experiments on simulated and real robot systems to demonstrate aggregation and collision avoidance
- *Inter-agent communication is not a necessary factor in aggregation*: facilitates study on swarms having heterogenous communication capabilities

Machine Learning for Transportation - 3.3.20

Chair
Co-Chair

16:00–17:15	WeCT1.1

DeepSignals: Predicting Intent of Drivers through Visual Attributes

Davi Frossard[1,2], Eric Kee[1] and Raquel Urtasun[1,2]
Uber Advanced Technologies Group[1]
University of Toronto[2]

- Predicting the intention of drivers is an essential task for autonomous driving.
- Turn signals and emergency flashers communicate driver intentions, providing seconds of critical reaction time.
- We design a neural network to classify driver intent from image sequences.
- Evaluation on more than 1M show high per-frame accuracy in challenging scenarios.

Left turn (←) and occlusion (?) correctly classified in video sequence

16:00–17:15	WeCT1.2

Real-time Intent Prediction of Pedestrians for Autonomous Ground Vehicles via Spatio-Temporal DenseNet

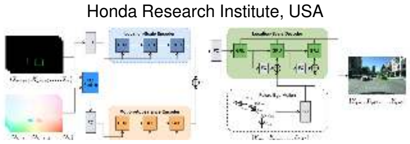
Khaled Saleh and Mo Hossny and Saeid Nahavandi
Institute for Intelligent Systems Research and Innovation (IISRI), Deakin University, Australia

- A real-time framework is proposed to track and predict the intended actions of pedestrians
- We have extended deep DenseNet architecture to model spatio-temporal image sequences for intended crossing actions
- Our framework has shown resilient and competitive results in comparison to other baseline approaches
- Overall, we achieved an average precision score of 84.76% with real-time performance at 20FPS.

16:00–17:15	WeCT1.3

Egocentric Vision-based Future Vehicle Localization for Intelligent Driving Assistance Systems

Yu Yao, Ella M. Atkins,
Robotics Institute, University of Michigan, USA
Mingze Xu, David J.
Department Name, University of , Country
Chiho Choi and CrandallBehzad Dariush
Honda Research Institute, USA



- We propose a multi-stream RNN encoder decoder for future vehicle localization (FVL) in egocentric view.
- We propose a new dataset (HEV-I) for the FVL related problems.
- We evaluated our method against the state-of-the-art method on HEV-I and KITTI datasets and achieves better performance with different metrics.

16:00–17:15	WeCT1.4

Uncertainty-Aware Driver Trajectory Prediction at Urban Intersections

Xin Huang[1,2] and Stephen McGill[2] and Brian Williams[1] and Luke Fletcher[2] and Guy Rosman[2]
[1]CSAIL, Massachusetts Institute of Technology, USA
[2]Toyota Research Institute, USA

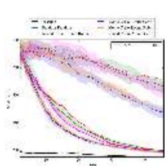
- We propose a DNN-based variational trajectory prediction framework with inputs from multiple sensor modalities.
- We use a second DNN to estimate prediction confidence scores over different horizons.
- We compare the variational predictor with a physics-based odometry predictor based on confidence estimates.
- Shown on the right, we choose the predictor with a better estimate to improve performance.

16:00–17:15	WeCT1.5

Go with the Flow: Exploration and Mapping of Pedestrian Flow Patterns from Partial Observations

Sergi Molina, Grzegorz Cielniak and Tom Duckett
Lincoln Centre for Autonomous Systems, University of Lincoln, United Kingdom

- Modelling and predicting pedestrian flow patterns in dynamic environments.
- Model built from partial observation both in the spatial and the temporal domain.
- Exploration policy based on the relative uncertainty of time-dependent Poisson processes.
- Results outperforming the uninformed exploration strategies.



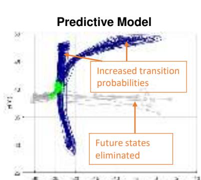
Model error over time across different exploration strategies combinations.

16:00–17:15	WeCT1.6

Pedestrian Motion Model Using Non-Parametric Trajectory Clustering and Discrete Transition Points

Yutao Han, Rina Tse, and Mark Campbell
Mechanical and Aerospace Engineering, Cornell University, United States

- A pedestrian motion model with low level trajectory patterns and high level discrete transitions
- Iterative clustering algorithm with Dirichlet Process Gaussian Process that splits trajectory patterns into sub-trajectories
- A formal approach to discover transition points and split sub-trajectory patterns using hypothesis testing
- A formal approach to discover anomalous sections of trajectories online using learned Gaussian Process models



Online predictive model with current trajectory and states, and predicted future states

Legged Robots VI - 3.3.21

Chair

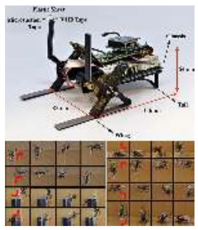
Co-Chair

16:00–17:15	WeCT1.1

Design and Analysis of A Miniature Two-Wheg Climbing Robot with Robust Internal and External Transitioning Capabilities

Darren C. Y. Koh*, Audelia G. Dharmawan*, Hassan H. Hariri#, Gim Song Soh, Shaohui Foong, Roland Bouffanais, Hong Yee Low, and Kristin L. Wood
Engineering Product Development, Singapore University of Technology and Design, Singapore
#Mechanical and Mechatronic Engineering, Rafik Hariri University, Lebanon

- Development of a two-wheg miniature climbing robot with a novel passive vertical tail component
- The robot can climb any slope angles, 4-way internal transitions, and 4-way external transitions
- The design decision leading to the extensive climbing capabilities was derived from an in-depth analysis of the robot
- The result of this study opens up the opportunity to miniaturize and develop a robust climbing robot requiring only two whegs



*Authors contributed equally to this work

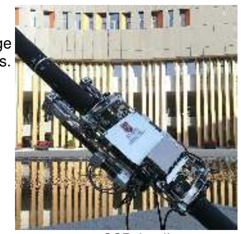
16:00–17:15	WeCT1.2

Design and Implementation of CCRobot-II: a Palm-based Cable Climbing Robot for Cable-stayed Bridge Inspection

Ning Ding and Zhenliang Zheng
Institute of Robotics and Intelligent Manufacturing,
The Chinese University of Hong Kong, Shenzhen(CUHKSZ), China

- A bio-inspired palm-based climbing robotic technology for cable inspection on the cable-stayed bridge is developed.
- CCRobot-II works effectively even if the bridge cable surface is attached with small obstacles.

Parameters	Values
Weight	25 kg
Maximal diameter	320 mm
Cable diameter for climbing	100 mm ~ 130 mm
Maximal climb-up speed	5.2 m/min
Maximal sliding distance	480 mm
Minimal Length	850 mm
Maximal Length(extension)	1100 mm
Maximal payload	30 kg
Maximal climbing angle	90°
Maximal height of obstacle	15 mm



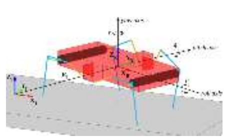
CCRobot-II

16:00–17:15	WeCT1.3

Dynamic Modeling and Gait Analysis for Miniature Robots in the Absence of Foot Placement Control

Mohammad Askari and Onur Ozcan
Department of Mechanical Engineering, Bilkent University, Turkey

- A comprehensive dynamic model of the miniature foldable robot, MinIAQ-II is presented.
- The model includes foldable leg kinematics, rigid body dynamics and ground reaction forces.
- The model is verified using slow speed walking experiments on flat terrain.
- Difference between intended gait and achieved gait in the absence of foot control is investigated.



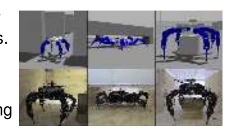
A schematic representation of the modeled miniature robot

16:00–17:15	WeCT1.4

Walking Posture Adaptation for Legged Robot Navigation in Confined Spaces

Russell Buchanan[1,2], Tirthankar Bandyopadhyay[1], Marko Bjelonic[2], Lorenz Wellhausen[2], Marco Hutter[2],Navinda Kottege[1]
[1]Robotics and Autonomous Systems Group, CSIRO, Australia
[2]Robotic Systems Lab, ETH Zürich

- Legged robots have the ability to adapt their walking posture to navigate confined spaces.
- However, this has not been exploited in most common multilegged platforms.
- This paper presents a deformable bounding box abstraction of the robot model, with accompanying mapping and planning strategies, that enable a legged robot to autonomously change its body shape to navigate confined spaces.



Three tasks attempted in simulation and on the real robot.

Robot Learning II - 3.3.22

Chair

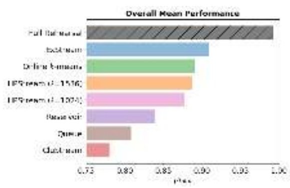
Co-Chair

16:00–17:15	WeCT1.1

Memory Efficient Experience Replay for Streaming Learning

Tyler L. Hayes, Nathan D. Cahill, and Christopher Kanan
Carlson Center for Imaging Science, Rochester Institute of Technology, USA

- Robots operate in changing environments and must quickly learn new things from data streams
- Neural Networks are susceptible to catastrophic forgetting in this streaming paradigm
- Rehearsal mitigates forgetting by mixing new data with previous data and updating the network
- Here, we introduce ExStream, a memory efficient rehearsal scheme, and compare it to alternatives

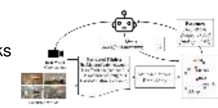


16:00–17:15	WeCT1.2

RoboCSE: Robot Common Sense Embedding

Angel Daruna, Weiyu Liu, Zsolt Kira, Sonia Chernova
Institute for Robotics and Intelligent Machines (IRIM)
Georgia Institute of Technology, Atlanta, United States

- Robot semantic reasoning requires computational frameworks that generalize, model uncertainty, and are memory-efficient
- We present a novel class of such frameworks for robotics, multi-relational embeddings
- We validate in a realistic home environment simulator reasoning about affordances, locations, and materials of objects
- RoboCSE outperforms baselines in multiple domains at prediction while consuming orders of magnitude less memory than BLNs



RoboCSE framework integrated on robot

16:00–17:15	WeCT1.3

Neural Lander: Stable Drone Landing Control using Learned Dynamics

Guanya Shi[1], Xichen Shi[1], Michael O'Connell[1], Rose Yu[2], Kamyar Azizzadenesheli[3], Animashree Anandkumar[1], Yisong Yue[1], Soon-Jo Chung[1]
[1]Caltech, [2]Northeastern University, [3]University of California, Irvine

- Use spectrally normalized DNNs with bounded Lipschitz constant to learn residual dynamics
- Design a robust feedback linearization controller using the learned DNNs with stability guarantee
- Leverage Lipschitz property of DNNs to circumvent non-affine-in-control
- Outperform baseline nonlinear tracking controller in landing and cross-table tracking tasks

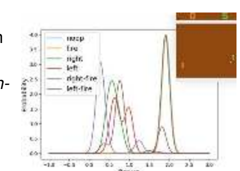
Neural Lander performance

16:00–17:15	WeCT1.4

Distributional Deep Reinforcement Learning with a Mixture of Gaussians

Yunho Choi, Kyungjae Lee, and Songhwai Oh
Department of Electrical and Computer Engineering, Seoul National University, Republic of Korea

- The proposed method models the distribution of the return with a mixture of Gaussians.
- For the distributional Bellman update, *Jensen-Tsallis distance (JTD)* loss is used.
- *JTD* can compute the distance between two mixtures of Gaussians in a closed form.
- Free from the projection step and cumbersome hyper-parameter tuning.



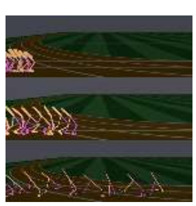
Learned value distribution during an episode of the game Pong.

16:00–17:15	WeCT1.5

Jointly Learning to Construct and Control Agents using Deep Reinforcement Learning

Charles Schaff
TTI-Chicago
David Yunis
U. Chicago
Ayan Chakrabarti
Washington U. in St. Louis
Matthew R. Walter
TTI-Chicago

- We explore the automatic design and control of agents to be successful at a given task.
- We introduce an efficient algorithm based on deep reinforcement learning.
- We test our algorithm in the context of legged locomotion, showing that it finds novel designs and walking gaits.



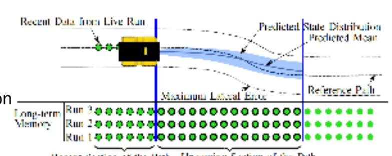
Evolution of design and walking gait.

16:00–17:15	WeCT1.6

Learn Fast, Forget Slow: Safe Predictive Learning Control for Systems with Unknown and Changing Dynamics Performing Repetitive Tasks

Christopher D. McKinnon and Angela P. Schoellig
UTIAS, University of Toronto, Canada

- Probabilistic model learning framework
- Based on local, weighted Bayesian linear regression
- Designed for stochastic model predictive control
- **Long-term learning** and fast adaptation



The proposed framework constructs a context-specific local model for the robot dynamics over the upcoming section of the path.

Medical Robotics X - 3.3.23

Chair
Co-Chair

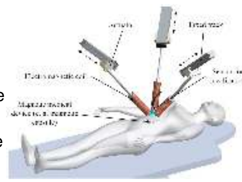
16:00–17:15 WeCT1.1

DeltaMag: An Electromagnetic Manipulation System with Parallel Mobile Coils

Lidong Yang[1], Xingzhou Du[1,2,3], Edwin Yu[1], Dongdong Jin[1,2] and Li Zhang[1,3,4]

[1]Department of Mechanical and Automation Engineering, The Chiness University of Hong Kong (CUHK)
[2]Department of Biomedical Engineering, CUHK
[3]Chow Yuk Ho Technology Centre for Innovative Medicine, CUHK
[4]CUHK T Stone Robotics Institute, CUHK

- New concept of Magnetic manipulation using parallel mobile electromagnetic coils;
- Manipulation of magnetic medical devices in a large workspace;
- Vision feedback and motor control for the closed-loop position control;
- Manipulation of mockups of magnetic capsule and magnetic catheter are demonstrated.



16:00–17:15 WeCT1.2

Surgical Instrument Segmentation for Endoscopic Vision with Data Fusion of CNN Prediction and Kinematic Pose

Fangbo Qin[1], Yangming Li[2], Yun-Hsuan Su[2], De Xu[1], Blake Hannarford[2]*

[1] Institute of Automation, Chinese Academy of Sciences, China
[2] Department of Electrical Engineering, University of Washington, USA
[3] Department of Electrical Computer and Telecommunications Engineering Technology, Rochester Institute of Technology, USA

- A novel instrument segmentation pipeline for endoscopic vision of *local surgeries*.
- *ToolNet-C* learns features from numerous unlabeled data, and learns segmentation from few labeled data.
- The 3D shape of instrument is projected onto image as silhouette mask with *kinematic pose*.
- *Particle filter* is used to fuse the data of ToolNet-C prediction and silhouette projection.

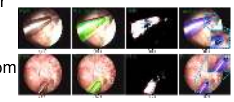


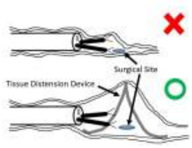
Fig. Surgical instrument segmentation results with data fusion

16:00–17:15 WeCT1.3

Pneumatically Actuated Deployable Tissue Distension Device for NOTES for Colon

Muneaki Miyasaka, Jiajun Liu, Lin Cao, and Soo Jay Phee
School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore

- Endoscopic vision and task space are occluded when colon tissue collapses
- Deployable and undeployable tissue distension device is developed to solve the issue
- The device fits in 4.5 mm endoscopic channel and is flexible to be delivered through tortuous pathway
- The device was tested in-vitro with a pig's colon and the functionality was validated

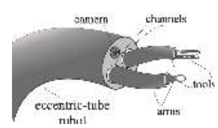


16:00–17:15 WeCT1.4

Steering a Multi-armed Robotic Sheath Using Eccentric Pre-curved Tubes

Jiaole Wang, Junhyoung Ha and Pierre E. Dupont
Department of Cardiovascular Surgery, Boston Children's Hospital, USA

- A continuum robotic sheath for use in single-port minimally invasive procedures such as neuro-endoscopy.
- The channels of the sheath are made from eccentrically arrayed pre-curved tubes.
- The channels act as delivery channels and driving elements simultaneously.
- Sheath shape is controlled by rotating the tubes forming the delivery channels.



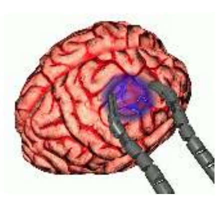
Conceptual design of a 2-channel eccentric-tube robot with two arms delivered through the channels.

16:00–17:15 WeCT1.5

Context-Aware Modelling for Augmented Reality Display Behaviour

Gauthier Gras, Guang-Zhong Yang
Imperial College London, United Kingdom

- Optimal augmented reality view selection based on user intention and scene context
- Multi Gaussian Process voter model using gaze tracking as an input
- Model uncertainty is fed back to the user to guide the training
- Results show context-aware augmented reality behaviour can significantly reduce inattention blindness and task time

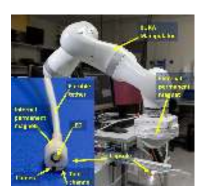


16:00–17:15 WeCT1.6

Explicit Model Predictive Control of a Magnetic Flexible Endoscope

B. Scaglioni[1], L. Previtera[2], J. Martin[1], J. Norton[1], K.L. Obstein[3], P. Valdastri[1]
1 STORM Lab UK, University of Leeds, UK
2 Universitá di Pisa, Italy,
3 STORM Lab USA, Nashville, USA

- Explicit model predictive control is adopted for navigating a magnetic flexible endoscope in a colon phantom
- A dynamic model of the capsule is developed and embedded in a MPC controller
- The linear MPC approach is coupled with a nonlinear optimization stage for the solution of the magnetic problem
- The approach is validated with experimental results



ICRA X: Robotic Art Forum - Session III

Chair

Co-Chair

Farewell Reception

Chair
Co-Chair

The Future of Aerial Robotics: Challenges and Opportunities - Session I

Chair
Co-Chair

08:30–10:00	ThAT1.1*

The Future of Aerial Robotics: Challenges and Opportunities

Anibal Ollero, University of Seville
Gianluca Antonelli, Univ. of Cassino and Southern Lazio
Giuseppe Loianno, New York University
Kostas Alexis, University of Nevada, Reno
Margarita Chli, ETH Zurich

Towards Real-World Deployment of Legged Robots - Session I

Chair
Co-Chair

08:30–10:00	ThAT2.1*

Towards Real-World Deployment of Legged Robots

Marko Bjelonic, ETH Zurich
Dimitrios Kanoulas, Istituto Italiano Di Tecnologia
Krzysztof, Tadeusz Walas, Poznan University of Technology
Marco Camurri, University of Oxford
Navinda Kottege, CSIRO
Eiichi Yoshida, National Inst. of AIST
Andrea Del Prete, Max Planck Institute for Intelligent Systems
C. Dario Bellicoso, ETH Zurich
Maurice Fallon, University of Oxford
Marco Hutter, ETH Zurich
Ioannis Havoutis, University of Oxford
Tirthankar Bandyopadhyay, CSIRO

Bringing perception-based manipulation to the real world: standardizing robot manipulation learning - Session I

Chair

Co-Chair

08:30–10:00	ThAT3.1*

Bringing perception-based manipulation to the real world: standardizing robot manipulation learning

Sami Haddadin, Technical University of Munich
Tamim Asfour, Karlsruhe Institute of Technology (KIT)
Patrick van der Smagt, Volkswagen Group
Wolfram Burgard, University of Freiburg
Dieter Fox, University of Washington
Aude Billard, EPFL
Gregory Hager, Johns Hopkins University
Oliver Brock, Technische Universität Berlin

High Accuracy Mobile Manipulation in Challenging Environments: Challenges in Systems, Control, and Perception - S

Chair

Co-Chair

08:30–10:00	ThAT4.1*

High Accuracy Mobile Manipulation in Challenging Environments: Challenges in Systems, Control, and Perception

Timothy Sandy, ETH Zürich
Abel Roman Gawel, Autonomous Systems Lab, ETH Zurich
Bharath Sankaran, University of Southern California
Stuart Maggs, Scaled Robotics
Juan Nieto, ETH Zürich

Taking Reproducible Research in Robotics to the Mainstream: Building on the IEEE RAM R-Articles - Session I

Chair
Co-Chair

08:30–10:00	ThAT5.1*

Taking Reproducible Research in Robotics to the Mainstream: Building on the IEEE RAM R-Articles

Fabio Paolo Bonsignorio, Heron Robots srl and The Biorobotics Insitute Scuola Superiore S. Anna
Signe Redfield, Naval Research Laboratory
Angel P. del Pobil, Jaume-I University

Robot Design and Customization: Opportunities at the Intersection of Computation and Digital Fabrication - Session I

Chair

Co-Chair

08:30–10:00	ThAT6.1*

Robot Design and Customization: Opportunities at the Intersection of Computation and Digital Fabrication

Cynthia Sung, University of Pennsylvania
Stelian Coros, Carnegie Mellon University
Robert MacCurdy, CU Boulder
Mark Yim, University of Pennsylvania

Second International Workshop on Lines, Planes and Manhattan models for 3-D Mapping (LPM 2019) - Session I

Chair

Co-Chair

08:30–10:00	ThAT7.1*

Second International Workshop on Lines, Planes and Manhattan models for 3-D Mapping (LPM 2019)

Andrew Calway, University of Bristol
Michael Kaess, Carnegie Mellon University
Srikumar Ramalingam, University of Utah

Opportunities and Challenges in Soft Robotics Across Length Scales - Session I

Chair
Co-Chair

08:30–10:00	ThAT8.1*

Opportunities and Challenges in Soft Robotics Across Length Scales

Hamidreza Marvi, Arizona State University
Guo Zhan Lum, Nanyang Technological University
Ian Walker, Clemson University

Open Challenges and State-of-the-Art in Control System Design and Technology Development for Surgical Robotic Sys

Chair

Co-Chair

08:30–10:00	ThAT9.1*

Open Challenges and State-of-the-Art in Control System Design and Technology Development for Surgical Robotic Systems

Mahdi Tavakoli, University of Alberta
Christos Bergeles, King's College London
K. W. Samuel Au, The Chinese University of Hong Kong
Mohsen Khadem, University of Edinburgh

Progress Toward Automated Micro-Bio-Nano Factories Through Robotic Manipulation - Session I

Chair
Co-Chair

08:30–10:00	ThAT10.1*

Progress Toward Automated Micro-Bio-Nano Factories Through Robotic Manipulation

Ashis Banerjee, University of Washington
Eric D. Diller, University of Toronto
Dan Popa, University of Louisville
Kaiyan Yu, Binghamton University

Human-Robot Teaming Beyond Human Operational Speeds - Session I

Chair
Co-Chair

08:30–10:00	ThAT11.1*

Human-Robot Teaming Beyond Human Operational Speeds

Henrik Iskov Christensen, UC San Diego
Nicholas Roy, Massachusetts Institute of Technology
Sonia Chernova, Georgia Institute of Technology
M. Ani Hsieh, University of Pennsylvania
Carlos Nieto-Granda, Georgia Institute of Technology
Stuart Young, Army Research Laboratory
David Baran, Army Research Laboratory
Ethan Stump, US Army Research Laboratory
Christopher M. Reardon, U.S. Army Research Laboratory

Human movement science for physical human-robot collaboration - Session I

Chair
Co-Chair

08:30–10:00	ThAT12.1*

Human movement science for physical human-robot collaboration

Pauline Maurice, INRIA Nancy Grand Est
Meghan Huber, Massachusetts Institute of Technology
Claudia Latella, Istituto Italiano di Tecnologia
Serena Ivaldi, INRIA
Neville Hogan, Massachusetts Institute of Technology

Rhetoric and Robotics. An exercise to shape the values of the discipline of robotics. - Session I

Chair

Co-Chair

08:30–10:00	ThAT13.1*

Rhetoric and Robotics. An exercise to shape the values of the discipline of robotics.

Jean-Paul Laumond, LAAS-CNRS
Emmanuelle Danblon, ULB
Gentiane Venture, Tokyo University of Agriculture and Technology
Céline Pieters, LAAS-CNRS, INSA Toulouse, France - ULB, Belgium

Optimal Planning and Control Fusing Offline and Online Algorithms - Session I

Chair
Co-Chair

08:30–10:00	ThAT14.1*

Optimal Planning and Control Fusing Offline and Online Algorithms

Manolo Garabini, Università di Pisa
Tobia Marcucci, Università di Pisa

ViTac: Integrating Vision and Touch for Multimodal and Cross-modal Perception - Session I

Chair
Co-Chair

08:30–10:00	ThAT15.1*

ViTac: Integrating Vision and Touch for Multimodal and Cross-modal Perception

Shan Luo, University of Liverpool
Nathan Lepora, University of Bristol
Uriel Martinez-Hernandez, University of Bath
Joao Bimbo, Istituto Italiano di Tecnologia
Huaping Liu, Dr.

Benchmarks for Robotic Manipulation - Session I

Chair

Co-Chair

08:30–10:00	ThAT16.1*

Benchmarks for Robotic Manipulation

Berk Calli, Worcester Polytechnic Institute
Aaron Dollar, Yale University
Yu Sun, University of South Florida
Maximo A. Roa, DLR - German Aerospace Center

Approaching Residency of Marine Robots for Deep-Sea Research - Session I

Chair
Co-Chair

08:30–10:00	ThAT17.1*

Approaching Residency of Marine Robots for Deep-Sea Research

Zhuoyuan Song, University of Hawaii at Manoa
Aaron Marburg, University of Washington
Mike Krieg, University of Florida
Kamran Mohseni, University of Florida at Gainesville

Sound Source Localization and Its Applications for Robots - Session I

Chair
Co-Chair

08:30–10:00	ThAT18.1*

Sound Source Localization and Its Applications for Robots

Sung-eui Yoon, KAIST
Dinesh Manocha, University of Maryland

The Future of Aerial Robotics: Challenges and Opportunities - Session II

Chair
Co-Chair

Towards Real-World Deployment of Legged Robots - Session II

Chair
Co-Chair

Bringing perception-based manipulation to the real world: standardizing robot manipulation learning - Session II

Chair
Co-Chair

High Accuracy Mobile Manipulation in Challenging Environments: Challenges in Systems, Control, and Perception - S

Chair

Co-Chair

Taking Reproducible Research in Robotics to the Mainstream: Building on the IEEE RAM R-Articles - Session II

Chair
Co-Chair

Robot Design and Customization: Opportunities at the Intersection of Computation and Digital Fabrication - Session I

Chair

Co-Chair

Second International Workshop on Lines, Planes and Manhattan models for 3-D Mapping (LPM 2019) - Session II

Chair

Co-Chair

Opportunities and Challenges in Soft Robotics Across Length Scales - Session II

Chair

Co-Chair

Open Challenges and State-of-the-Art in Control System Design and Technology Development for Surgical Robotic Sys

Chair

Co-Chair

Progress Toward Automated Micro-Bio-Nano Factories Through Robotic Manipulation - Session II

Chair

Co-Chair

Human-Robot Teaming Beyond Human Operational Speeds - Session II

Chair
Co-Chair

Human movement science for physical human-robot collaboration - Session II

Chair
Co-Chair

Rhetoric and Robotics. An exercise to shape the values of the discipline of robotics. - Session II

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The Future of Aerial Robotics: Challenges and Opportunities - Session III

Chair
Co-Chair

Towards Real-World Deployment of Legged Robots - Session III

Chair

Co-Chair

Bringing perception-based manipulation to the real world: standardizing robot manipulation learning - Session III

Chair

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Chair

Co-Chair

ViTac: Integrating Vision and Touch for Multimodal and Cross-modal Perception - Session III

Chair
Co-Chair

Robotic Technology for In-Space Assembly - Session I

Chair

Co-Chair

13:30–15:00	ThCT16.1*

Robotic Technology for In-Space Assembly

Craig Carignan, University of Maryland
Kazuya Yoshida, Tohoku University
Giacomo Marani, West Virginia University

Mobile Robot Assistants for the Elderly - Session I

Chair

Co-Chair

13:30–15:00	ThCT17.1*

Mobile Robot Assistants for the Elderly

Francois Michaud, Universite de Sherbrooke
Adriana Tapus, ENSTA-ParisTech
François Ferland, Université de Sherbrooke
Goldie Nejat, University of Toronto
Eva Barrett, NUI Galway
Dympna Casey, NUI Galway

MATLAB and Simulink for Robotics Research and Education - Session I

Chair
Co-Chair

13:30–15:00	ThCT18.1*

MATLAB and Simulink for Robotics Research and Education

Roberto Valenti, MathWorks
Peter Corke, Queensland University of Technology
Pulkit Kapur, MathWorks
Remo Pillat, University of Central Florida

The Future of Aerial Robotics: Challenges and Opportunities - Session IV

Chair

Co-Chair

Towards Real-World Deployment of Legged Robots - Session IV

Chair
Co-Chair

Bringing perception-based manipulation to the real world: standardizing robot manipulation learning - Session IV

Chair
Co-Chair

High Accuracy Mobile Manipulation in Challenging Environments: Challenges in Systems, Control, and Perception - S

Chair

Co-Chair

Taking Reproducible Research in Robotics to the Mainstream: Building on the IEEE RAM R-Articles - Session IV

Chair
Co-Chair

Robot Design and Customization: Opportunities at the Intersection of Computation and Digital Fabrication - Session I

Chair

Co-Chair

Second International Workshop on Lines, Planes and Manhattan models for 3-D Mapping (LPM 2019) - Session IV

Chair

Co-Chair

Opportunities and Challenges in Soft Robotics Across Length Scales - Session IV

Chair
Co-Chair

Open Challenges and State-of-the-Art in Control System Design and Technology Development for Surgical Robotic Sys

Chair

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Human-Robot Teaming Beyond Human Operational Speeds - Session IV

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Human movement science for physical human-robot collaboration - Session IV

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Chair
Co-Chair

Robotic Technology for In-Space Assembly - Session II

Chair
Co-Chair

Mobile Robot Assistants for the Elderly - Session II

Chair

Co-Chair

MATLAB and Simulink for Robotics Research and Education - Session II

Chair
Co-Chair

Physical human-robot interaction: a design focus - Session I

Chair

Co-Chair

08:30–10:00	FrAT1.1*

Physical human-robot interaction: a design focus

Clement Gosselin, Université Laval
Vincent Duchaine, Ecole de Technologie Superieure

Subterranean Autonomy: Open Challenges, Resilient Design, and Virtual Benchmarking - Session I

Chair
Co-Chair

08:30–10:00	FrAT2.1*

Subterranean Autonomy: Open Challenges, Resilient Design, and Virtual Benchmarking

Ethan Stump, US Army Research Laboratory
John G. Rogers III, US Army Research Laboratory
Nathan Koenig, Willow Garage
Gaurav Sukhatme, University of Southern California

Dataset Generation and Benchmarking of SLAM Algorithms for Robotics and VR/AR - Session I

Chair

Co-Chair

08:30–10:00	FrAT3.1*

Dataset Generation and Benchmarking of SLAM Algorithms for Robotics and VR/AR

Sajad Saeedi, Imperial College London
Bruno Bodin, The University of Edinburgh
Wenbin Li, Imperial College London
Luigi Nardi, Stanford

Learning Legged Locomotion - Session I

Chair
Co-Chair

08:30–10:00	FrAT4.1*

Learning Legged Locomotion

Ken Caluwaerts, Google
Atil Iscen, Google
Jie Tan, Google
Tingnan Zhang, Google
Karen Liu, Georgia Tech
Ludovic Righetti, New York University
Jonathan Hurst, Oregon State University

2nd International Workshop on Computational Models of Affordance in Robotics - Session I

Chair
Co-Chair

08:30–10:00	FrAT5.1*

2nd International Workshop on Computational Models of Affordance in Robotics

Philipp Zech, University of Innsbruck
Erwan Renaudo, University of Innsbruck
Peter Kaiser, Karlsruhe Institute of Technology (KIT)
Raja Chatila, ISIR

Debates on the Future of Robotics Research - Session I

Chair
Co-Chair

08:30–10:00	FrAT6.1*

Debates on the Future of Robotics Research

Lee Clement, University of Toronto
Valentin Peretroukhin, University of Toronto
Matthew Giamou, University of Toronto
Jonathan Kelly, University of Toronto

Next Generation Surgery: Seamless integration of Robotics, Machine Learning and Knowledge Representation within

Chair
Co-Chair

08:30–10:00	FrAT7.1*

Next Generation Surgery: Seamless integration of Robotics, Machine Learning and Knowledge Representation within the operating rooms

Federica Ferraguti, Università degli Studi di Modena e Reggio Emilia
George Mylonas, Imperial College London
Cristian Secchi, Univ. of Modena & Reggio Emilia
Alicia Casals, UniversitatPolitècnica de Catalunya, Barcelona Tech.
Marcello Bonfe, University of Ferrara
Riccardo Muradore, University of Verona

Long-Term Human Motion Prediction - Session I

Chair
Co-Chair

08:30–10:00	FrAT8.1*

Long-Term Human Motion Prediction

Luigi Palmieri, Robert Bosch GmbH
Kai Oliver Arras, Bosch Research
Jim Mainprice, Max Planck Institute
Marc Hanheide, University of Lincoln
Achim J. Lilienthal, Orebro University

Learning for Industry 4.0: feasibility and challenges - Session I

Chair
Co-Chair

08:30–10:00	FrAT9.1*

Learning for Industry 4.0: feasibility and challenges

Matteo Saveriano, German Aerospace Center (DLR)
Pietro Falco, ABB, Corporate Research
Sylvain Calinon, Idiap Research Institute

Underwater Robotics Perception - Session I

Chair
Co-Chair

08:30–10:00	FrAT10.1*

Underwater Robotics Perception

Arturo Gomez Chavez, Jacobs University Bremen gGmbH
Enrica Zereik, CNR - National Research Council
Francesco Maurelli, Jacobs University Bremen

Algorithms and Architectures for Learning in-the-Loop Systems in Autonomous Flight - Session I

Chair
Co-Chair

08:30–10:00	FrAT11.1*

Algorithms and Architectures for Learning in-the-Loop Systems in Autonomous Flight

Aleksandra Faust, Google Brain
Vijay Reddi, University of Texas at Austin
Angela P. Schoellig, University of Toronto
Sarah Tang, University of Pennsylvania

Advances and Challenges on the Development, Testing and Assessment of Internet of Robotic Things (IoRT): Experien

Chair

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08:30–10:00	FrAT12.1*

Advances and Challenges on the Development, Testing and Assessment of Internet of Robotic Things (IoRT): Experiences from Engineering and Human Science Research

Cheng Zhang, Waseda University
Jorge Solis, Karlstad University / Waseda University
Yukio Takeda, Tokyo Institute of Technology
Ahmed Mobyen, MÃ¤lardalen University
Yoshiaki Tanaka, Waseda University

Toward Online Optimal Control of Dynamic Robots: From Algorithmic Advances to Field Applications - Session I

Chair
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08:30–10:00	FrAT13.1*

Toward Online Optimal Control of Dynamic Robots: From Algorithmic Advances to Field Applications

Farbod Farshidian, ETH Zurich
Justin Carpentier, INRIA
Patrick M. Wensing, University of Notre Dame
Eiichi Yoshida, National Inst. of AIST

Autonomous RACECAR: 1/10-scale Autonomous Car Platform for Research and Education in Robotics - Session I

Chair
Co-Chair

08:30–10:00	FrAT14.1*

Autonomous RACECAR: 1/10-scale Autonomous Car Platform for Research and Education in Robotics

Andrew Fishberg, MIT
Trevor Henderson, Massachusetts Institute of Technology
Ken Gregson, MIT
Zachary Dodds, Harvey Mudd College
Don Krawciw, University of British Columbia
Christine Nicholls, FIRST Robotics British Columbia
Sertac Karaman, Massachusetts Institute of Technology

Soft Haptic Interaction: Modeling, Design and Application - Session I

Chair

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08:30–10:00	FrAT15.1*

Soft Haptic Interaction: Modeling, Design and Application

Hongbin Liu, King's College London
Matteo Bianchi, University of Pisa
Van Ho, Japan Advanced Institute of Science and Technology

Workshop on Continuous Management and Scheduling of multiple simultaneous prioritized Tasks for redundant Robo

Chair

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08:30–10:00	FrAT16.1*

Workshop on Continuous Management and Scheduling of multiple simultaneous prioritized Tasks for redundant Robots

Niels Dehio, Karlsruhe Institute of Technology
Abderrahmane Kheddar, CNRS-AIST JRL (Joint Robotics Laboratory), UMI3218/CRT
Alin Albu-Schäffer, DLR - German Aerospace Center

Topological Methods in Robot Planning - Session I

Chair

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08:30–10:00	FrAT17.1*

Topological Methods in Robot Planning

Subhrajit Bhattacharya, Lehigh University
Florian T. Pokorny, KTH Royal Institute of Technology
Vijay Kumar, University of Pennsylvania

Tutorial on Dynamical System-based Learning from Demonstration - Session I

Chair

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08:30–10:00	FrAT18.1*

Tutorial on Dynamical System-based Learning from Demonstration

Nadia Figueroa, École Polytechnique Fédérale de Lausanne
Seyed Sina Mirrazavi Salehian, EPFL
Lukas Huber, EPFL
Aude Billard, EPFL

Physical human-robot interaction: a design focus - Session II

Chair
Co-Chair

Subterranean Autonomy: Open Challenges, Resilient Design, and Virtual Benchmarking - Session II

Chair

Co-Chair

Dataset Generation and Benchmarking of SLAM Algorithms for Robotics and VR/AR - Session II

Chair

Co-Chair

Learning Legged Locomotion - Session II

Chair

Co-Chair

2nd International Workshop on Computational Models of Affordance in Robotics - Session II

Chair
Co-Chair

Debates on the Future of Robotics Research - Session II

Chair
Co-Chair

Next Generation Surgery: Seamless integration of Robotics, Machine Learning and Knowledge Representation within

Chair

Co-Chair

Long-Term Human Motion Prediction - Session II

Chair

Co-Chair

Learning for Industry 4.0: feasibility and challenges - Session II

Chair

Co-Chair

Underwater Robotics Perception - Session II

Chair

Co-Chair

Algorithms and Architectures for Learning in-the-Loop Systems in Autonomous Flight - Session II

Chair

Co-Chair

Advances and Challenges on the Development, Testing and Assessment of Internet of Robotic Things (IoRT): Experien

Chair

Co-Chair

Toward Online Optimal Control of Dynamic Robots: From Algorithmic Advances to Field Applications - Session II

Chair

Co-Chair

Autonomous RACECAR: 1/10-scale Autonomous Car Platform for Research and Education in Robotics - Session II

Chair
Co-Chair

Soft Haptic Interaction: Modeling, Design and Application - Session II

Chair

Co-Chair

Workshop on Continuous Management and Scheduling of multiple simultaneous prioritized Tasks for redundant Robo

Chair

Co-Chair

Topological Methods in Robot Planning - Session II

Chair

Co-Chair

Tutorial on Dynamical System-based Learning from Demonstration - Session II

Chair
Co-Chair

Physical human-robot interaction: a design focus - Session III

Chair
Co-Chair

Subterranean Autonomy: Open Challenges, Resilient Design, and Virtual Benchmarking - Session III

Chair
Co-Chair

Dataset Generation and Benchmarking of SLAM Algorithms for Robotics and VR/AR - Session III

Chair
Co-Chair

Learning Legged Locomotion - Session III

Chair
Co-Chair

2nd International Workshop on Computational Models of Affordance in Robotics - Session III

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Debates on the Future of Robotics Research - Session III

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Next Generation Surgery: Seamless integration of Robotics, Machine Learning and Knowledge Representation within

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Long-Term Human Motion Prediction - Session III

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Learning for Industry 4.0: feasibility and challenges - Session III

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Co-Chair

Underwater Robotics Perception - Session III

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Co-Chair

Algorithms and Architectures for Learning in-the-Loop Systems in Autonomous Flight - Session III

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Advances and Challenges on the Development, Testing and Assessment of Internet of Robotic Things (IoRT): Experien

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Toward Online Optimal Control of Dynamic Robots: From Algorithmic Advances to Field Applications - Session III

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Autonomous RACECAR: 1/10-scale Autonomous Car Platform for Research and Education in Robotics - Session III

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Soft Haptic Interaction: Modeling, Design and Application - Session III

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Resilient Robot Teams: Composing, Acting, and Learning - Session I

Chair
Co-Chair

13:30–15:00	FrCT16.1*

Resilient Robot Teams: Composing, Acting, and Learning

Amanda Prorok, University of Cambridge
Brian Sadler, Army Research Laboratory
Gaurav Sukhatme, University of Southern California
Vijay Kumar, University of Pennsylvania

Half-Day Workshop: Tensegrity Robotics Workshop - Session I

Chair
Co-Chair

13:30–15:00	FrCT17.1*

Half-Day Workshop: Tensegrity Robotics Workshop

John Rieffel, Union College
Dario Floreano, Ecole Polytechnique Federal, Lausanne
Massimo Vespignani, USRA / NASA ARC-TI
Valter Boehm, OTH Regensburg

Bias-sensitizing robot behaviours: A quest for AvoidinG hArmful bIas aNd diScriminaTion by robots (AGAINST-19) -

Chair
Co-Chair

13:30–15:00	FrCT18.1*

Bias-sensitizing robot behaviours: A quest for AvoidinG hArmful bIas aNd diScriminaTion by robots (AGAINST-19)

Masoumeh Mansouri, Örebro University
Martim Brandao, University of Oxford
Alessandro Saffiotti, Orebro University

Physical human-robot interaction: a design focus - Session IV

Chair
Co-Chair

Subterranean Autonomy: Open Challenges, Resilient Design, and Virtual Benchmarking - Session IV

Chair

Co-Chair

Dataset Generation and Benchmarking of SLAM Algorithms for Robotics and VR/AR - Session IV

Chair
Co-Chair

Learning Legged Locomotion - Session IV

Chair
Co-Chair

2nd International Workshop on Computational Models of Affordance in Robotics - Session IV

Chair
Co-Chair

Debates on the Future of Robotics Research - Session IV

Chair
Co-Chair

Next Generation Surgery: Seamless integration of Robotics, Machine Learning and Knowledge Representation within

Chair

Co-Chair

Long-Term Human Motion Prediction - Session IV

Chair
Co-Chair

Learning for Industry 4.0: feasibility and challenges - Session IV

Chair

Co-Chair

Underwater Robotics Perception - Session IV

Chair
Co-Chair

Algorithms and Architectures for Learning in-the-Loop Systems in Autonomous Flight - Session IV

Chair

Co-Chair

Advances and Challenges on the Development, Testing and Assessment of Internet of Robotic Things (IoRT): Experien

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Autonomous RACECAR: 1/10-scale Autonomous Car Platform for Research and Education in Robotics - Session IV

Chair
Co-Chair

Soft Haptic Interaction: Modeling, Design and Application - Session IV

Chair

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Resilient Robot Teams: Composing, Acting, and Learning - Session II

Chair
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Half-Day Workshop: Tensegrity Robotics Workshop - Session II

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Bias-sensitizing robot behaviours: A quest for AvoidinG hArmful bIas aNd diScriminaTion by robots (AGAINST-19) -

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Co-Chair