ICRA2017

May 29 – June 3, 2017 • Singapore

PROGRAM Day 2

Wednesday, 31 May

May 29-June 3, 2017 • Singapore

IEEE International Conference on Robotics and Automation

IEEE

IEEE Robotics & Automation Society

Kinematics and Dynamics

Chair *Hiromi Mochiyama, University of Tsukuba*
Co-Chair *Yukio Takeda, Tokyo Institute of Technology*

09:30–09:35 WeA1.1

Inverse Kinematics with Strict Nonholonomic Constraints on Mobile Manipulator

KangKyu Lee, Jaesung Oh, Okkee Sim and Hyoin Bae
Department of Mechanical Engineering, KAIST, Republic of Korea
Jun-Ho Oh
Department of Mechanical Engineering, KAIST, Republic of Korea

- It is possible to violate the nonholonomic constraint on mobility by distorting the Jacobian
- Application of strict nonholonomic constraints can address the issue of Jacobian distortion
- A proposition to correct for slip error in order to increase the speed of convergence. The avoiding velocity vectors are then adjusted to account for this error

09:35–09:40 WeA1.2

On Orientation Control of Functional Redundant Robots

Leon Žlajpah
Dept. of Automation, Biocybernetics and Robotics
Jožef Stefan Institute, Slovenia

- We present an approach for the orientation related functional redundancy resolution, which is based on the task space rotation.
- A time-variant task frame is defined, where the functional redundancy is represented as one or more rows of the Jacobian matrix.
- In the proposed control algorithms the non-controlled rotations are excluded from the task space and are used for the self-motion.

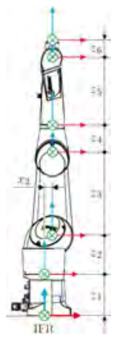
Two-arm KUKA LWR robot system performing „buzz wire“ task

09:40–09:45 WeA1.3

Recursive Second-Order Inverse Dynamics for Serial Manipulators

Andreas Mueller
Institute of Robotics, Johannes Kepler University
Linz, Austria

- *Higher-order derivatives of inverse dynamics* solutions needed for flatness-based control of serial elastic manipulators and optimal control
- Lie group recursive O(n) algorithms for inverse dynamics are compact and coordinate invariant
- Here two Lie group O(n) algorithms are presented for *first* and *second* derivatives
- The first in terms of body-fixed and the second one in terms of hybrid representation of twists.
- Kinematics in terms of intrinsic geometric parameters instead of DH-parameters



Geom. parameters for example

09:45–09:50 WeA1.4

Multi-Arm Snake-Like Robot

Yannick S. Krieger, Daniel B. Roppenecker, Ismail Kuru and Tim C. Lueth
Institute of micro technology and medical device technology (MiMed) of the Technische Universität München, Munich, Germany

- Selective laser sintered manipulator system for gastroscopic interventions with a purely mechanical control concept.
- Monolithical snake-like overtube structure for standard endoscopes with two manipulator arms (each 4 DoF).
- Evaluation of the system in a lab experiment and further clinical evaluation in a clinical trial.

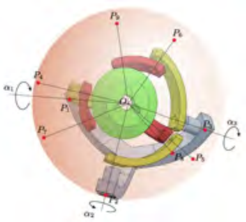
Manipulator system with a purely mechanical control concept

09:50–09:55 WeA1.5

Position Analysis of Spherical Linkages via Angle-Bound Smoothing

Josep M. Porta and Federico Thomas
Institut de Robòtica i Informàtica Industrial, CSIC-UPC, Spain

- This paper generalizes bound-smoothing to deal with points on a sphere.
- The angular distance between points on a sphere are lengths of arcs of great circles.
- The proposed method is based on constraints involving sets of four points derived from Gram determinants.
- The position analysis of two spherical mechanisms is presented to validate the approach.



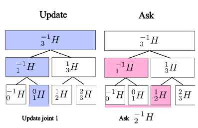
The position of points on a sphere determines the forward kinematics of a spherical manipulator.

09:55–10:00 WeA1.6

O(log n) Algorithm for Forward Kinematics under Asynchronous Sensory Input

Ryo Wakatabe*,**, Yasuo Kuniyoshi** and Gordon Cheng*
* The Institute for Cognitive Systems, The Technical Univ. of Munich, Germany
** Department of Mechano-Informatics, The Univ. of Tokyo, Japan

- Conventional FK assumes synchrony of all sensory information, which is disadvantage when high DoF.
- Preferable for hardware systems, less processors idleness and real-time computation of hyper-redundant robots
- Real-time algorithm.
- Computation time with over 50000 links takes less than 35 us for 1 query.



An example of how AFK works.

Kinematics and Dynamics

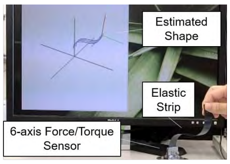
Chair *Hiromi Mochiyama, University of Tsukuba*
Co-Chair *Yukio Takeda, Tokyo Institute of Technology*

10:00–10:05	WeA1.7

Real-time Shape Estimation of Kirchhoff Elastic Rod Based on Force/Torque Sensor

Ryo Takano and Hiromi Mochiyama
University of Tsukuba, Japan
Naoyuki Takesue
Tokyo Metropolitan University, Japan

- A real-time spatial shape estimation method for an elastic rod is proposed with using a single six-axis force/torque sensor placed near one end of elastic rod.
- The proposed method is based on a discretized Kirchhoff elastic rod model and the real-time computation can be achieved stably because its computational time is linear in the partition number for the discretization.
- Experimental results show the validity of the proposed method.



An actual 'S'-shape of an elastic strip is calculated based on the force/torque sensor information in real-time and drawn on a display.

10:05–10:10	WeA1.8

Parallel Dynamics Computation using Prefix Sum Operations

Yajue Yang[1], Yuanqing Wu[2] and Jia Pan[1]
1 Department of Mechanical and Biomedical Engineering, City University of Hong Kong, China
2 Department of Industrial Engineering, University of Bologna, Italy

- A new parallel framework for fast computation of dynamics of articulated robots is proposed.
- The parallel prefix sum algorithm is applied for parallelizing linear recurrences within the dynamics computation.
- Several parallel and sequential-parallel hybrid dynamics algorithms are implemented.
- The experiments performances are compared and analyzed.

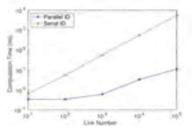


Fig. 1: Computation time comparison between serial and parallel inverse dynamics implementations

Mapping 1

Chair *José Neira, Universidad de Zaragoza*
Co-Chair *Fabio Ramos, University of Sydney*

09:30–09:35	WeA2.1

Dense Monocular Reconstruction using Surface Normals

Chamara Saroj Weerasekera, Yasir Latif, Ravi Garg, Ian Reid
School of Computer Science, University of Adelaide, Australia

- We propose a surface normal-based inverse-depth regularizer for efficient dense monocular mapping
- Surface normals are predicted from a deep CNN, capturing high and low level image information
- The proposed regularizer helps determine a more accurate solution to a multi-view photometric cost
- Demonstrates better performance than standard inverse-depth smoothness regularization in a variety of indoor scenes

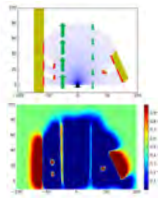
Dense reconstruction of an office desk obtained using the normal-based prior

09:35–09:40	WeA2.2

Learning Highly Dynamic Environments with Stochastic Variational Inference

Ransalu Senanayake and Fabio Ramos
The University of Sydney, Australia
Simon O'Callaghan
Data61/CSIRO, Australia

- Learning the **long-term occupancy** of an environment is important for safer and reliable path planning.
- The proposed method can build such long-term occupancy maps in **dynamic environments** using a stream of laser data.
- We make use of "Big Data Gaussian Process" models for building **continuous occupancy maps** by considering spatiotemporal relationships.
- The model learns all key parameters itself and hence the accuracy does not rely on heuristic parameter choices.
- It does not require any underlying motion model or object trackers.



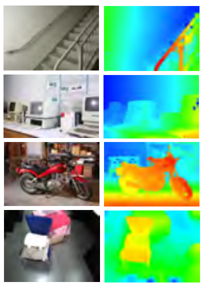
Top: the world
Bottom: Occupancy map built over time

09:40–09:45	WeA2.3

Robust Stereo Matching with Surface Normal Prediction

Shuangli Zhang[1], Weijian Xie[1], Guofeng Zhang[1], Hujun Bao[1], Michael Kaess[2]
[1]State Key Lab of CAD&CG, Zhejiang University, China
[2]Robotics Institute, Carnegie Mellon University, USA

- Significantly improve stereo matching in textureless, occluded and reflective regions by combining the predicted surface normal with deep learning.
- Propose a reliable disparity confidence estimation method by combining LRD-based and plane-fitting based confidence measurements.
- Detect and fuse edges with multiple cues to locate discontinuity boundaries.
- Convert surface normal to disparity by solving a sparse linear system incorporating both normal and depth constraints.



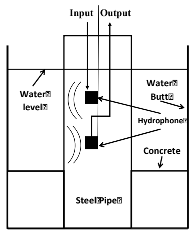
Left image Disparity map

09:45–09:50	WeA2.4

Robot mapping and localisation in metal water pipes using hydrophone induced vibration and map alignment by dynamic time warping

Ke Ma, Michele M. Schirru, Ali Hassan Zahraee, Rob Dwyer-Joyce, Joby Boxall, Tony J. Dodd, Richard Collins and Sean R. Anderson
University of Sheffield, United Kingdom

- The aim is to develop mapping and localization for metal water pipes.
- But… water pipes are relatively featureless and lack landmarks for navigation.
- Our novel approach is to excite pipe vibration using a hydrophone to create a map.
- We align multiple maps using dynamic time warping and localize by EKF or particle filter.

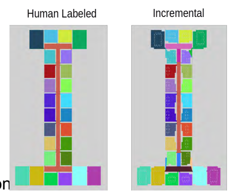


09:50–09:55	WeA2.5

Incremental Contour-Based Topological Segmentation for Robot Exploration

L. Fermin-Leon, J. Neira and J. A. Castellanos
DIIS, University of Zaragoza, Spain

- Alternative approach: Contour-Based Segmentation using Dual Decomposition.
- Tuning of a single parameter.
- Incremental version reuses the last segmentation to produce faster and equally accurate results.
- Tests demonstrate that the incremental version outperforms the state of the art.



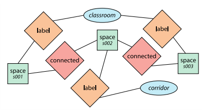
Example

09:55–10:00	WeA2.6

Semantic Classification by Reasoning on the Whole Structure of Buildings using Statistical Relational Learning Techniques

Matteo Luperto, Alessandro Riva, and Francesco Amigoni
Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Italy

- Semantic classification of places is usually based on *local* features
- We propose a **statistical relational learning** approach to reason on the *global* structure of buildings
- We use the **kLog** framework to perform semantic classification tasks
- Experiments include place (room) classification, building classification, and simulated environment classification tasks



Graphicalized Entity/Relation representation of a simple environment

Mapping 1

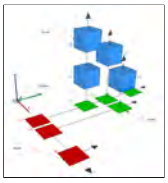
Chair *José Neira, Universidad de Zaragoza*
Co-Chair *Fabio Ramos, University of Sydney*

10:00–10:05	WeA2.7

SkiMap: An Efficient Mapping Framework for Robot Navigation

Daniele De Gregorio, Luigi Di Stefano
DISI, University of Bologna, Italy

- Novel mapping framework for **Robot Navigation** with multi-level querying system: 2D, 2.5D and 3D
- Suitable for large scale environments and for any kind of integrable data (RGB, Occupancy, SDF)
- Based on SkipList data structure to ensure O(log n) for random voxel access
- Radius Search is an intrinsic feature of the architecture that outperforms Octree



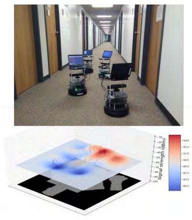
3D View of Data Structure

10:05–10:10	WeA2.8

Multirobot Online Construction of Communication Maps

Jacopo Banfi[1], Alberto Quattrini Li[2], Nicola Basilico[3], Ioannis Rekleitis[2], Francesco Amigoni[1]
[1]DEIB, Politecnico di Milano, Italy
[2]Dept. of Computer Science and Engineering, University of South Carolina, USA
[3]Dept. of Computer Science, University of Milan, Italy

- Knowledge about possibility of establishing wireless communication links between arbitrary pairs of locations, a.k.a. *communication map*, is fundamental for reliable multirobot systems
- Problem: efficiently building a communication map of an environment
- Our solution: model communication maps with Gaussian Processes and use leader-follower strategies for deciding where to sample



Turtlebots building communication maps

Session WeA3 | Rm. 4311/4312 | Wednesday, May 31, 2017, 09:30–10:45

Visual Learning

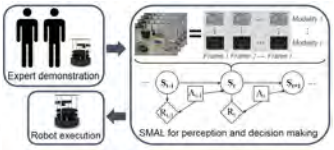
Chair *Hao Zhang, Colorado School of Mines*
Co-Chair *Tamim Asfour, Karlsruhe Institute of Technology (KIT)*

09:30–09:35 WeA3.1

Sequence-based Multimodal Apprenticeship Learning For Robot Perception and Decision Making

Fei Han[1] and Xue Yang[1] and Yu Zhang[2] and Hao Zhang[1]
1. Computer Science Dept., Colorado School of Mines, USA
2. Computer Science and Engineering Dept., Arizona State University, USA

- Integration of real-time multisensory robot perception and decision making to learn tasks from humans in challenging environments
- A novel representation of world states in reinforcement learning modeling
- Capability to address perceptual aliasing by simultaneously fusing temporal information and multimodal data



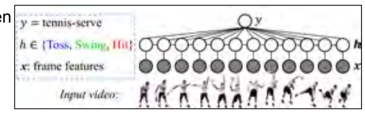
Overview of the SMAL method to achieve robot apprenticeship learning

09:35–09:40 WeA3.2

Minimum Uncertainty Latent Variable Models for Robot Recognition of Sequential Human Activities

Fei Han[1] and Christopher Reardon[2] and Lynne E. Parker[3] and Hao Zhang[1]
1. Computer Science Department, Colorado School of Mines, USA
2. US Army Research Laboratory, USA
3. EECS Department, University of Tennessee, USA

- A new approach for sequential human activity recognition based on Minimum Uncertainty Hidden Conditional Random Fields
- A novel regularization capturing the uncertainty in latent underlying temporal patterns
- Theoretical proof that the formulated objective function has a closed form



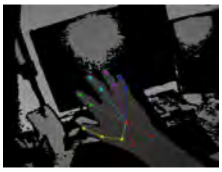
An example of utilizing HCRFs to model a sequential "tennis-serve" activity

09:40–09:45 WeA3.3

Learning a Deep Network with Spherical Part Model for 3D Hand Pose Estimation

Tzu-Yang Chen, Pai-Wen Ting, Min-Yu Wu, Li-Chen Fu
Department of Computer Science and Information Engineering, National Taiwan University, Taiwan

- Present a novel 3D hand pose estimation system based on depth images
- Propose a deep convolutional neural network framework that integrates hand detection and pose estimation
- Design a Spherical part model (SPM) as physical constraints to improve the training model
- Demonstrate outstanding results of our experiments in three challenging datasets



09:45–09:50 WeA3.4

Visual Stability Prediction for Robotic Manipulation

Wenbin Li[1], Ales Leonardis[2], Mario Fritz[1]
Max Planck Institute for Informatics, Germany[1]
School of Computer Science, University of Birmingham, UK[2]

- End-to-end learning of intuitive physics for stability prediction.
- Accompanied human subject study showing our model achieves comparable or even better results.
- Investigate the discriminative image regions from the model for intuitive interpretation.
- Integrate visual stability prediction into manipulation.

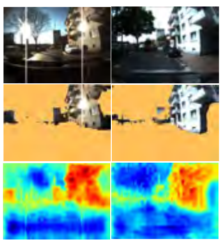
Pipeline of our approach.

09:50–09:55 WeA3.5

Semantics-aware Visual Localization under Challenging Perceptual Conditions

Tayyab Naseer, Gabriel Oliveira, Thomas Brox and Wolfram Burgard
Computer Science Department, University of Freiburg, Germany

- A novel approach to learn a discriminative and robust scene description.
- Semantically labeled dataset capturing extreme perceptual and structural dynamics.
- Learn salient image regions based on the geometrically stable image semantics.
- Leverage the robust semantic-aware scene description for visual robot localization.
- Outperforms off-the-shelf features from deep convolutional neural networks.



09:55–10:00 WeA3.6

Simultaneous Feature and Body-Part Learning for Real-Time Robot Awareness of Human Behaviors

Fei Han[1] and Xue Yang[1] and Christopher Reardon[2] and Yu Zhang[3] and Hao Zhang[1]
1. Computer Science Dept., Colorado School of Mines, USA
2. US Army Research Laboratory, USA
3. Computer Science and Engineering Dept., Arizona State University, USA

- A novel approach for real-time robot awareness of human behaviors
- A new optimization formulation with simultaneous learning of discriminative human body parts and skeletal features
- An optimization algorithm to solve the robot learning problem with theoretical convergence capability


Simultaneous learning of discriminative human body parts and skeletal features

Visual Learning

Chair *Hao Zhang, Colorado School of Mines*
Co-Chair *Tamim Asfour, Karlsruhe Institute of Technology (KIT)*

10:00–10:05	WeA3.7

Visual Closed-Loop Control for Pouring Liquids

Connor Schenck and Dieter Fox
Department of Computer Science & Engineering
University of Washington, USA

- In this paper we show how a robot can pour precise amounts of liquid using closed-loop visual feedback.
- First, the robot detects the liquid using a fully-convolutional recurrent neural network.
- Next, the robot uses this to estimate the volume of liquid in the target container.
- Finally, the robot feeds the difference between this estimate and the target volume to a PID controller.

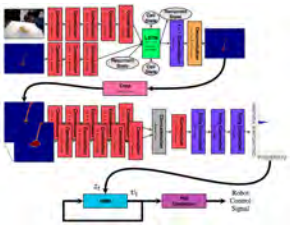


Diagram of raw images to liquid detections, to volume estimate, to control signal

10:05–10:10	WeA3.8

Unsupervised Linking of Visual Features to Textual Descriptions in Long Manipulation Activities

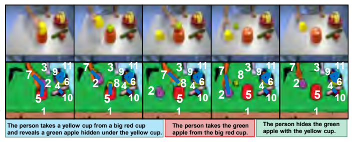
E. E. Aksoy[1], E. Ovchinnikova[1], A. Orhan[1], Y. Yang[2] and T. Asfour[1]
[1]H2T, Karlsruhe Institute of Technology, Germany
[2]CIDSE, Arizona State University, AZ, USA.

- We present a novel unsupervised framework, which links visual features and symbolic textual descriptions of manipulation activity videos. The proposed framework allows robots:

(1) to autonomously parse, classify, and label sequentially and/or concurrently performed atomic manipulations

(2) to simultaneously categorize and identify manipulated objects without using any standard feature-based recognition methods,

(3) to generate textual descriptions for long activities.



Sensor and Robtoic Networks

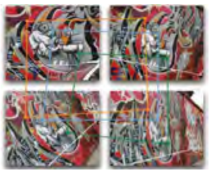
Chair *Michael Beetz, University of Bremen*
Co-Chair *Fumitoshi Matsuno, Kyoto University*

09:30–09:35	WeA4.1

Distributed Consistent Data Association via Permutation Synchronization

S. Leonardos, X. Zhou and K. Daniilidis
Department of Computer and Information Science, University of Pennsylavnia, USA.

- Given noisy pairwise associations, find permutations so that
  $$\tilde{\Pi}_{ij} = \Pi_i \Pi_j^T, \qquad \forall\, (i,j) \in \mathcal{E}$$
- Analogous to rotation synchronization problem from relative measurements.
- Proposed solution: distributed averaging on the set of doubly stochastic matrices:
  $$\Pi_i(t+1) = \frac{1}{|\mathcal{N}_i|+1}\Big(\Pi_i(t) + \sum_{j\in\mathcal{N}_i} \tilde{\Pi}_{ij}\Pi_j(t)\Big)$$

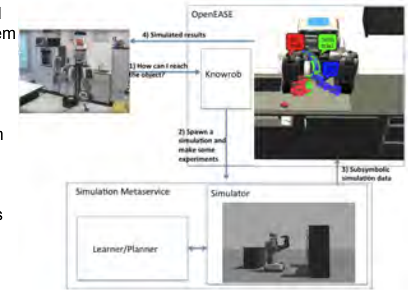


09:35–09:40	WeA4.2

A Cloud Service for Robotic Mental Simulations

Asil Kaan Bozcuoğlu and Michael Beetz
Institute for Artificial Intelligence, Bremen, Germany

- In this work, we extend openEASE cloud system to be capable of acting as a remote mental simulation service.
- People and robots can define a problem within a semantically-annotated map with Prolog queries.
- Then, openEASE runs the selected learning algorithm and returns results

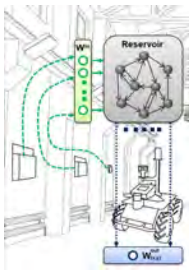


09:40–09:45	WeA4.3

Mobile Robots for Learning Spatio-temporal Interpolation Models in Sensor Networks – The Echo State Map Approach

Erik Schaffernicht, Victor Hernandez B., and Achim J. Lilienthal
AASS Research Centre, Örebro University, Sweden

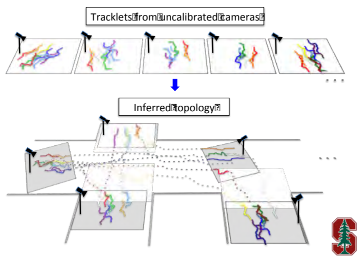
- Calibration and interpolation in sensor networks with the help of robot measurements
- *Echo State Networks* for temporal interpolation and *Gaussian Processes* spatial interpolation
- Novel combination of Echo State Networks and Gaussian Processes to create *Echo State Maps*
- Evaluation in simulation and for occupational health monitoring in an industrial environment



09:45–09:50	WeA4.4

Unsupervised Camera localization in Crowded spaces

Alexandre Alahi, Judson Wilson, Li Fei-Fei, Silvio Savarese
Stanford University



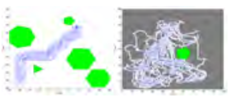
Stanford University

09:50–09:55	WeA4.5

Automated Sequencing of Swarm Behaviors for Supervisory Control of Robotic Swarms

Sasanka Nagavalli*, Nilanjan Chakraborty†, Katia Sycara*
*Robotics Institute, Carnegie Mellon University, USA
†Mechanical Engineering, Stony Brook University, USA

- Given a library of swarm behaviors and a performance criterion encoding the task at hand, what is the optimal sequence of swarm behaviors to accomplish the desired task?
- Formalization of swarm behavior sequencing problem
- Algorithm for finding the best swarm behavior sequence for given decision time points with optimality (or bounded suboptimality) and completeness guarantees
- Simulation results for (1) swarm navigation and (2) dynamic area coverage applications

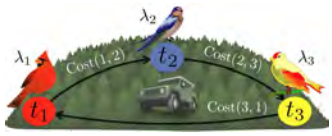


Swarm robot trajectories resulting from execution of chosen behavior sequences for navigation (left) and area coverage (right) applications

09:55–10:00	WeA4.6

Persistent Surveillance of Events with Unknown, Time-varying Statistics

Cenk Baykal, Guy Rosman, Sebastian Claici, and Daniela Rus
CSAIL, Massachusetts Institute of Technology, USA



- Algorithm for monitoring stochastic events with time-varying rates
- Bridges the Multi-Armed Bandit problem and persistent surveillance
- Long-run average optimal policies under temporal variation constraints
- Simulation results in real-world inspired persistent surveillance scenarios

Sensor and Robtoic Networks

Chair *Michael Beetz, University of Bremen*
Co-Chair *Fumitoshi Matsuno, Kyoto University*

10:00–10:05	WeA4.7

Decentralized Navigation for Heterogeneous Swarm Robots with Limited Field of View

Ryuma Maeda, Takahiro Endo and Fumitoshi Matsuno
Department of Mechanical Engineering and Science,
Kyoto University, Japan

- A connectivity-maintenance method for a heterogeneous swarm.
- A single leader navigates the other followers without communication.
- Each robot has a different sensing range, limited field of view, and physical limitations.
- The proposed method is fully decentralized, which provides scalability.

10:05–10:10	WeA4.8

Distributed Voronoi Neighbor Identification from Inter-Robot Distances

Matthew Elwin, Randy Freeman, and Kevin Lynch
Northwestern University, USA

- A large group of robots has range-only measurements to other robots
- Robots identify their Voronoi neighbors without localization
- Improves efficiency of distributed algorithms relevant to large multi-robot systems
- Distances estimated with XBee Received Signal Strength Indicator (RSSI)

Aerial Robot 1

Chair *Woosoon Yim, University of Nevada, Las Vegas*
Co-Chair *Stefano Stramigioli, University of Twente*

09:30–09:35	WeA5.1

Application of Substantial and Sustained Force to Vertical Surfaces using a Quadrotor

Han Wopereis, Jim Hoekstra,
Tjark Post, Geert Folkertsma, Stefano Stramigioli
RAM, University of Twente, The Netherlands
Matteo Fumagalli
RVMI, Aalborg University Copenhagen, Denmark

- This work presents a control algorithm capable of controlling a quadrotor in high-force interaction.
- The controller is based on LQR-optimized state feedback, coupling roll and yaw control.
- Experiments demonstrate sustained interaction forces exceeding the quadrotor's weight.


The quadrotor applying substantial force.

09:35–09:40	WeA5.2

Three Dimensional Moving Path Following for Fixed-Wing Unmanned Aerial Vehicles

Tiago Oliveira
Portuguese Air Force Academy, Portugal
A. Pedro Aguiar
Faculty of Engineering, University of Porto, Portugal
Pedro Encarnação
Católica Lisbon School of Business & Economics, Portugal

- MPF allows an autonomous vehicle to follow a path that is moving w.r.t. an inertial frame;
- Lyapunov-based control law using a quaternion formulation;
- Flight test results:
  - Autonomous landing on a (emulated) moving vessel;
  - Tracking a 3D moving lemniscate path.


ANTEX-X02 UAV

09:40–09:45	WeA5.3

Modeling and Control of a Saucer Type Coandă Effect UAV

Jameson Lee and Woosoon Yim
Mechanical Engineering, University of Nevada, Las Vegas, USA
Seung Hwan Song, Hyun Wook Shon, and Hyouk Ryeol Choi
Mechanical Engineering, Sungkyunkwan University, Republic of Korea

- A dynamic model and controller for a prototype Coandă effect drone was developed.
- Experimental validation of model parameters was performed to improve the controller and model simulation performance.
- A custom flight stack was developed using the ArduPilot firmware to affect the derived servo mapping.
- Initial flight tests were performed on the prototype using the experimental flight stack


Initial Flight Test of the S-Coandă Drone with the Developed Controller

09:45–09:50	WeA5.4

Implementation of a Parametrized Infinite-Horizon MPC Scheme with Stability Guarantees

M. Muehlebach, C. Sferrazza, and R. D'Andrea
Institute for Dynamic Systems and Control, ETH Zurich, Switzerland

- Parametrized Infinite-Horizon Model Predictive Control Scheme
- Retain Infinite Prediction Horizon by using Basis Functions -> Inherent Closed-Loop Stability
- Experimental Evaluation on an 8kg-UAV that uses Thrust Vectoring for Stabilization

09:50–09:55	WeA5.5

A global controller for flying wing tailsitter vehicles

Robin Ritz and Raffaello D'Andrea
Institute for Dynamic Systems and Control, ETH Zurich, Switzerland

- We present a global controller for tracking nominal trajectories with a flying wing tailsitter vehicle
- An outer control loop computes a desired attitude keeping the vehicle in coordinated flight
- An inner control loop tracks the desired attitude using a lookup table with precomputed optimal trajectories
- The proposed controller can be implemented on a typical microcontroller and the performance is demonstrated in various experiments


The IDSC Tailsitter. This vehicle is used for experimental validation of the proposed controller.

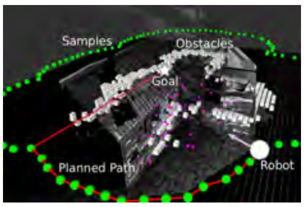
09:55–10:00	WeA5.6

Short-term UAV Path-Planning with Monocular-Inertial SLAM in the Loop

Ignacio Alzugaray, Lucas Teixeira and Margarita Chli
Vision for Robotics Lab, ETH Zurich, Switzerland

A novel path-planning pipeline with monocular-inertial SLAM in the loop of finding a path.

- Designed for robotic platforms with high-mobility & limited onboard computational capacity, such as small aircraft.
- Allows structured exploration to a goal destination without requiring a map of the scene known *a priori.*
- Avoids newly appearing obstacles on the fly via quick re-planning.



Façade Inspection: the Planned Path to reach the Goal is constantly updated to avoid the obstacles perceived on the fly

Aerial Robot 1

Chair *Woosoon Yim, University of Nevada, Las Vegas*
Co-Chair *Stefano Stramigioli, University of Twente*

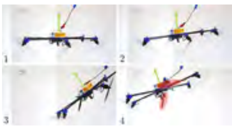
10:00–10:05	WeA5.7

Control of Statically Hoverable Multi-Rotor Aerial Vehicles and Application to Rotor-Failure Robustness for Hexarotors

Giulia Michieletto[1,2] , Markus Ryll[1] and Antonio Franchi[1]

[1] LAAS-CNRS, Université de Toulouse, CNRS, France.
[2] Dep. of Information Engineering, University of Padova, Italy.

- **Algebraic conditions** to ensure **static hover** (zero linear and angular momenta) for any multi-rotor platform with generically oriented rotors
- **Cascaded controller** based on a **preferential direction** in the null-space of the control moment matrix
- analysis on the **hoverability capabilities** of hexarotor platforms when a **rotor fails**



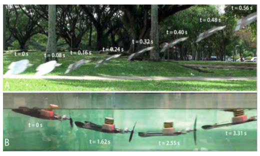
A tilted-propeller hexarotor recovering from a failure thanks to the analysis and the controller proposed in the paper.

10:05–10:10	WeA5.8

ICRA 2017 Digest Template
Efficient Aerial-Aquatic Locomotion with a Single Propulsion System

Yu Herng Tan Rob Siddall and Mirko Kovac
Department of Aeronautics, Imperial College London, UK

- Aerial-aquatic propulsion is challenging because of the dramatically different properties of air and water.
- While small aerial propellers can operate efficiently underwater, a single motor cannot drive the propeller efficiently in both media
- We have designed a two speed epicyclic gearbox which maximises efficiency in air and water.
- The robot can change gear simply by reversing motor direction, and no additional actuation is required.



A miniature robot propelling itself efficiently in air and water/

Cognitive Robotics

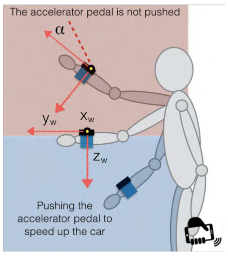
Chair *Minoru Asada, Osaka University*
Co-Chair *Fulvio Mastrogiovanni, University of Genoa*

09:30–09:35	WeA6.1

Gesture-based Robot Control: Design Challenges and Evaluation with Humans

Enrique Coronado, Jessica Villalobos,
Barbara Bruno and Fulvio Mastrogiovanni
Department of Informatics, Bioengineering, Robotics and Systems Engineering,
University of Genoa, Italy

- We introduce a control framework for mobile robots relying on *human gestures* and discuss the related design principles.
- Gestures are modelled using 6D inertial information of the person's wrist.
- We tested the framework on the Husqvarna Research Platform robot, with 27 volunteers.
- The developed software is available online.

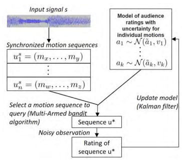


09:35–09:40	WeA6.2

Learning Individual Motion Preferences From Audience Feedback of Motion Sequences

Junyun Tay[1,2] and Manuela Veloso[1]
[1]Department of Mechanical Engineering, Carnegie Mellon University, USA
I-Ming Chen[2]
[2]School of Mechanical and Aerospace Engineering,
Nanyang Technological University, Singapore

- Goal: Select the most preferred motion sequence for the robot to animate an input signal
- Audience's feedback comprises the ratings of the motions and motions' ratings are unknown initially
- Observation of audience feedback at the end of the motion sequence queried is noisy
- MAK selects sequences to query and learns the motions' ratings to determine most preferred sequence



Overview of Approach – **M**ulti-**A**rmed bandit and **K**alman filter (MAK)

09:40–09:45	WeA6.3

Semantic Web-Mining and Deep Vision for Lifelong Object Discovery

Jay Young and Lars Kunze and Nick Hawes
Intelligent Robotics Lab, University Of Birmingham, UK
Valerio Basile
INRIA, WIMMICS, France
Barbara Caputo
University de Roma, Sapienza, Italy

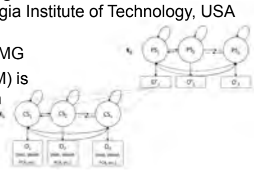
- A novel approach for predicting the semantic identity of unknown, everyday objects based on web-mining using distributional semantics and Deep Vision.
- Utilised as part of a fully autonomous lifelong object discovery pipeline for mobile robots, and deployed long-term in an active workplace.
- Allows the robot to constrain the meaning of objects it discovers using both spatial-semantic context and visual features.

09:45–09:50	WeA6.4

Predicting Task Intent From Surface Electromyography Using Layered Hidden Markov Models

Yosef Razin
School of Aerospace Engineering, Georgia Institute of Technology, USA
Kevin Pluckter and Jun Ueda
School of Mechanical Engineering, Georgia Institute of Technology, USA
Karen Feigh
School of Aerospace Engineering, Georgia Institute of Technology, USA

- First successful application of HMM-based learning to physiological data, *e.g.* arm sEMG
- Our Layered Hidden Markov Model (LHMM) is a modular bi-layer system for classification and prediction
- LHMM outperformed six other common classifiers, achieving an F1 of .735
- With the highest performing features, LHMM reached 82% intent prediction accuracy over the next second



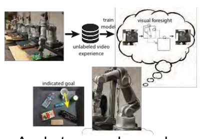
Layered Hidden Markov Model for Intent Prediction

09:50–09:55	WeA6.5

Deep Visual Foresight for Planning Robot Motion

Chelsea Finn and Sergey Levine
Google Brain, Mountain View, CA, USA
Dept. of Computer Science, UC Berkeley, CA, USA

- Combine a learned action-conditioned predictive model of images (i.e. a visual imagination) with model-predictive control to plan to push objects
- Entirely self-supervised approach, requiring minimal human involvement



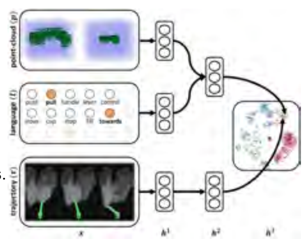
A robot uses a learned predictive model of images to push objects.

09:55–10:00	WeA6.6

Deep Multimodal Embedding: Manipulating Novel Objects with Point-clouds, Language and Trajectories

Jaeyong Sung*[§] Ian Lenz* Ashutosh Saxena[‡]
*Cornell University
[§]Stanford University
[‡]Brain of Things, Inc.

- Learns a semantically meaningful embedding space of point-clouds, language and trajectories.
- A novel approach to manipulation via shared multi-modal embedding with deep neural networks.
- An algorithm for unsupervised pre-training of multi-modal features.
- Tested on Robobarista dataset and on a PR2 robot.



Cognitive Robotics

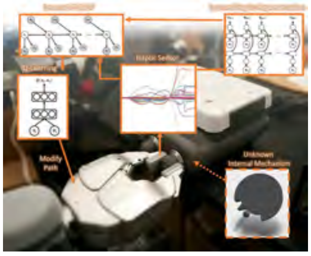
Chair *Minoru Asada, Osaka University*
Co-Chair *Fulvio Mastrogiovanni, University of Genoa*

10:00–10:05	WeA6.7

Learning to Represent Haptic Feedback for Partially-Observable Tasks

Jaeyong Sung[1,2] J. Kenneth Salisbury[1] Ashutosh Saxena[3]
[1] Stanford University
[2] Cornell University
[3] Brain of Things, Inc.

- We introduce an algorithm which learns a task relevant representation of haptic feedback
- A framework for modifying a nominal manipulation plan for interactions that involve haptic feedback
- The model, parametrized by deep recurrent neural networks, utilizes variational Bayes methods

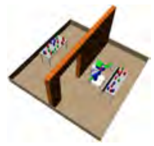


10:05–10:10	WeA6.8

Learning to guide task and motion planning using score-space representation

Beomjoon Kim and Leslie Pack Kaelbling and Tomas Lozano-Perez
Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, USA

- We propose an algorithm that speeds up planning by learning from past experience
- Predict constraints on the search space in order to afford good generalization while reducing computation time
- Representing a planning problem with scores of previously attempted plans gives direct information about similarity among constraints and problem instances



An instance of a planning problem where the robot needs to pick-and-place the black object from one table to another in the other room

Grippers and Other End-Effectors

Chair *Wei Lin, SIMTech, A*STAR*
Co-Chair *Shinichi Hirai, Ritsumeikan Univ.*

09:30–09:35	WeA7.1

Design of a Novel Variable Stiffness Gripper Using Permanent Magnets

Amirhossein H. Memar and Ehsan T. Esfahani
Mechanical and Aerospace Engineering Department, University at Buffalo, USA
Nicholas Mastronarde
Electrical Engineering Department, University at Buffalo, USA

- A robot gripper with compliantly actuated fingers to improve safety in manipulation
- Use of repulsive magnets in antagonistic configuration as nonlinear springs
- Estimation of external forces without the need for force sensor at each finger
- Experimentally validated the gripper's functionality during stiff collisions

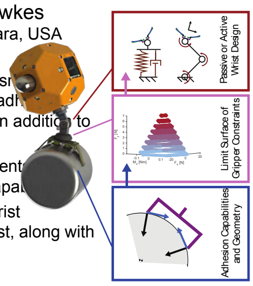

Variable Stiffness Gripper

09:35–09:40	WeA7.2

Force and Moment Constraints of a Curved Surface Gripper and Wrist for Assistive Free Flyers

Matthew A. Estrada, Hao Jiang, Bessie Noll,
Marco Pavone, Mark R. Cutkosky
Stanford University, USA
Elliot W. Hawkes
UC Santa Barbara, USA

- Design considerations of wrist mechanisr flying robots equip with gecko inspired adh Wrist allows a robot to apply moments in additi to forces.
- Establish limitations on the forces/moment wrist can impart, subject to adhesion capa
- Present analysis for tuning a passive wrist mechanism, or controlling an active wrist, along with experiments and simulation.



09:40–09:45	WeA7.3

Design of Parallel-Jaw Gripper Tip Surfaces for Robust Grasping

Menglong Guo, David V. Gealy, Jacky Liang, Jeffrey Mahler, Aimee Goncalves, Stephen McKinley, Juan Aparicio Ojea, Ken Goldberg
UC Berkeley AUTOLAB and Siemens, Berkeley CA, USA

- 37 gripper jaw surface designs were created using 3D printed casting molds and silicon rubber.
- 1377 physical grasp trials using a 4-axis robot (with automated reset).
- Most effective surface design compared in 320 trials with ABB robot against: std. gripper surface, std. gripper wrapped with tape, and gecko-inspired gripper surface.

09:45–09:50	WeA7.4

Vision-Based Model Predictive Control for Within-Hand Precision Manipulation with Underactuated Grippers

Berk Calli and Aaron M. Dollar
Department of Mechanical Engineering and Material Science, Yale University, U.S.A.

- Precision manipulation with underactuated hands is challenging due to difficulties in modeling the process.
- Conventional visual servoing methods provide a degree of robustness to modeling uncertainties.
- However, if inaccuracies are large, significant performance degradation is observed.
- To attain high performance even with rough models, we propose a novel Model Predictive Control-based visual servoing method.

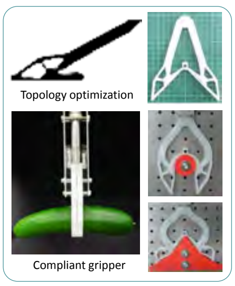

Vision-based within-hand precision manipulation with Model T42 hand.

09:50–09:55	WeA7.5

Optimal Design of a Soft Robotic Gripper with High Mechanical Advantage for Grasping Irregular Objects

Chih-Hsing Liu, and Chen-Hua Chiu
Department of Mechanical Engineering, National Cheng Kung University, Taiwan

- An optimal design procedure (including topology optimization and size optimization) has been presented to synthesize compliant mechanisms with high mechanical advantage.
- The proposed topology optimization method can consider both mechanical advantage and geometric advantage of the analyzed compliant mechanism with multiple output ports.
- Experimental results (including mechanical advantage test, geometric advantage test, adaptability test, and grasping test) show the developed gripper is with higher payload, faster response, better adaptability and stability in overall among the three analysis cases.

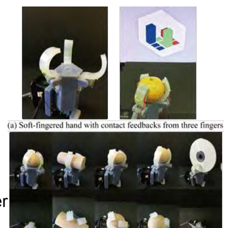


09:55–10:00	WeA7.6

Design and Analysis of a Soft-Fingered Hand with Contact Feedback

Van Ho
JAIST, Japan
Shinichi Hirai
Department of Robotics, Ritsumeikan Univ., Japan

- This paper presents a novel approach to the fabrication of a soft robotic hand with contact feedback for grasping delicate objects.
- Each finger has a multilayered structure, consisting of a main structure and sensing elements. The main structure includes a softer layer much thicker than a stiffer layer.
- The gripping energy of the fingers is generated from the elastic energy of the pre-stretched softer layers, and controlled by simple tendon strings pulled/released by a single actuation


(a) Soft-fingered hand with contact feedbacks from three fingers
(b) Grasp ability of the proposed hand on various objects

Grippers and Other End-Effectors

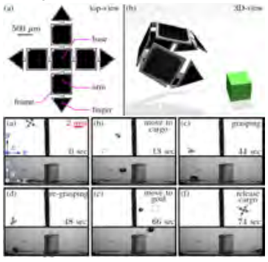
Chair *Wei Lin, SIMTech, A*STAR*
Co-Chair *Shinichi Hirai, Ritsumeikan Univ.*

10:00–10:05	WeA7.7

Reliable Grasping of Three-Dimensional Untethered Mobile Magnetic Microgripper for Autonomous Pick-and-Place

Jiachen Zhang[a], Onaizah Onaizah[a], Kevin Middleton[b], Lidan You[a,b], and Eric Diller[a]
[a] Department of Mechanical & Industrial Engineering, Univ. of Toronto, Canada
[b] Institute of Biomaterials & Biomedical Engineering, Univ. of Toronto, Canada

- The first example of reliable autonomous 3D micrograsping and cargo delivery with different cargo shapes
- The microgripper is controlled by a global magnetic field with simple controllers and limited feedback
- The microgripper can grasps repeatedly and each attempt takes less than 1 second
- The microgripper is biocompatible and does not harm cells in contact



10:05–10:10	WeA7.8

Variable-grasping-mode underactuated soft gripper with environmental contact-based operation

Toshihiro Nishimura, Kaori Mizushima, Yosuke Suzuki, Tokuo Tsuji and Tetsuyou Watanabe
Natural science and Technology, Kanazawa University, Japan

- Development of the robotic gripper with soft surface and underactuated joints.
- With one actuator, three grasping mode, i.e., parallel gripper, pinching and enveloping, are realized by utilizing contact with an environment, such as a supporting surface.
- The range of graspable objects is wide and included soft, rigid, deformable, fragile, small, large, thin and heavy objects
- The grasping test for various 68 items was conduced to validate the gripper's capability.

Physical Human-Robot Interaction

Chair *Alin Albu-Schäffer, DLR - German Aerospace Center*
Co-Chair *Jun Kinugawa, Tohoku University*

09:30–09:35	WeA8.1

A Framework For Robot-Assisted Doffing of Personal Protective Equipment

Antonio Umali[1] and Dmitry Berenson[2]
[1]Computer Science Department, Worcester Polytechnic Institute, USA
[2]EECS Department, University of Michigan, USA

- Health workers treating Ebola are at high risk of infection during the doffing of Personal Protective Equipment (PPE)
- We introduce a semi-autonomous robot doffing assistant to reduce risk and human effort
- We segment the doffing procedure into a sequence of human and robot actions. The robot only assists when necessary, the human performs the more intricate parts.
- Robot motions are planned autonomously using new cost functions with TrajOpt.
- Experiments on five doffing tasks suggest that safety can be improved in some tasks while effort can be reduced in all five.

Baxter helping to doff an apron

09:35–09:40	WeA8.2

A System for Learning Continuous Human-Robot Interactions from Human-Human Demonstrations

David Vogt[1], Simon Stepputtis[2], Steve Grehl[1],
Bernhard Jung[1], Heni Ben Amor[2]
[1] Faculty of Mathematics and Informatics, TU Bergakademie Freiberg, Germany
[2] School of Computing, Informatics, Decision Systems Engineering, Arizona State University, Tempe, USA

- From two-person task demonstration an Interaction Model is extracted
- During runtime the model is employed in a human-robot setting
- The model allows spatio-temporal adaptation of demonstrated tasks
- Two complex, sequential assembly tasks show the effectiveness of the approach

In a collaborative Lego assembly task, the robotic assistant continuously coordinates its behavior with the human co-worker.

09:40–09:45	WeA8.3

A Study of Bidirectionally Telepresent Tele-action During Robot-mediated Handover

Jianqiao Li and Kris Hauser
Electrical and Computer Engineering Department, Duke University, USA
Zhi Li
Department of Mechanical Engineering, Worcester Polytechnic Institute, USA

- How does communication affect physical interaction between a human and human-controlled robot?
- Concept: Bidirectionally Telepresent Teleaction
- User study: telepresence improves intimacy and workload in object handover
- *Did not actually* improve performance, but subjects *perceived* improved performance

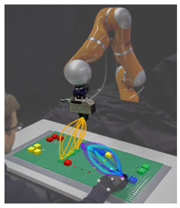
Object handover experiment

09:45–09:50	WeA8.4

A Game-Theoretic Approach for Adaptive Action Selection in Close Proximity Human-Robot-Collaboration

V. Gabler, T. Stahl, G. Huber, O. Oguz, and D. Wollherr
Technical University of Munich

- ***Problem:*** Adaptive action-selection in close proximity Human-Robot-Collaboration(HRC).
- ***Approach:*** Define HRC as an iterative game with personal and interactive costs to reflect mutual influence.
- ***Experimental Evaluation:*** Dyadic joint pick-and-place scenario in close proximity
- ***Result/Contribution:*** Online application of an autonomous decision framework based on game theory incorporating mutual influences amongst the agents involved.



Exemplary joint pick-and-place HRC-scenario

09:50–09:55	WeA8.5

An EMG-Driven Assistive Hand Exoskeleton for Spinal Cord Injury Patients: Maestro

Youngmok Yun, Paria Esmatloo, Alfredo Serrato,
Priyanshu Agarwal and Ashish D. Deshpande
Dept. of Mechanical Engineering, The University of Texas at Austin, USA
Sarah Dancausse
Dept. of Mechanical Engineering, ENISE, France
Curtis A. Merring
Brain & Spine Recovery Center, Seton Brain & Spine Institute, USA

- We developed an **EMG-driven assistive hand exoskeleton for SCI** patients.
- SCI patients with the exoskeleton **grasped various objects** required in daily activities.
- **Sollerman hand function test** results show the **improved hand functions** of SCI patients.

Hand Assistive Exo

09:55–10:00	WeA8.6

Admittance Control Parameter Adaptation for Physical Human-Robot Interaction

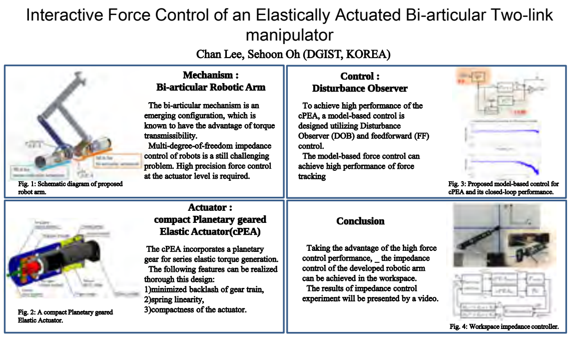
Chiara Talignani Landi, Federica Ferraguti,
Lorenzo Sabattini, Cristian Secchi, Cesare Fantuzzi
DISMI, University of Modena and Reggio Emilia, Italy

- In physical Human-Robot Interaction, instability occurs when the operator stiffens his/her arm
- We propose a heuristic for detecting the deviation from the "nominal behavior"
- Adjustment of the admittance parameters while guaranteeing the passivity of the system, exploiting energy tanks
- Experiments validated on a KUKA LWR 4+

Physical Human-Robot Interaction

Chair *Alin Albu-Schäffer, DLR - German Aerospace Center*
Co-Chair *Jun Kinugawa, Tohoku University*

10:00–10:05	WeA8.7



10:05–10:10	WeA8.8

Dance Teaching by a Robot: Combining Cognitive and pHRI for Supporting the Skill Learning Process

Diego F. Paez G., Jun Kinugawa, and Kazuhiro Kosuge
Robotics Department, Tohoku University, Japan

Breno A. Yamamoto
University of Uberlandia , Brazil

Hiroko Kamide
Nagoya Univeristy, Japan

- Design of a robot teacher with the role of guiding a human partner in a dance scenario.
- A novel cumulative performance score system that modifies the robot's behavior during interactions with each student.
- A *progressive teaching* methodology for adapting low-level control to the student's state during the learning process.

Session WeA9 Rm. 4811/4812 Wednesday, May 31, 2017, 09:30–10:45

TRO Session - Actuation, Locomotion, Grasping

Chair *Patrick Wensing, Massachusetts Institute of Technology*
Co-Chair *Pey Yuen Tao, SIMTech*

09:30–09:45	WeA9.1

Proprioceptive Actuator Design in the MIT Cheetah: Impact Mitigation and High-Bandwidth Physical Interaction for Dynamic Legged Robots

Patrick M. Wensing, Albert Wang, Sangok Seok, David Otten, Jeffrey Lang, and Sangbae Kim
Massachusetts Institute of Technology, USA

- Introduces an actuator paradigm to handle impact and manage physical interaction
- Presents central principles through modal analysis of a simple leg model and dimensional analysis of DC motor geometry
- Introduces the impact mitigation factor (IMF) to quantify backdrivability at impact
- Includes results from bounding experiments with the MIT Cheetah II robot, highlighting force tracking in highly-dynamic regimes

Proprioceptive actuators provide impact mitigation for dynamic locomotion

09:45–10:00	WeA9.2

Energy Efficient Monopod Running with Large Payload Based on Open Loop Parallel Elastic Actuation

Fabian Guenther
ETH Zurich, Switzerland
Fumiya Iida
University of Cambridge, United Kingdom

- Simulation and experimental analyses of a monopod running robot CARGO
- World record of energy efficiency in hopping robot locomotion (Total Cost of Transport 0.10 at Velocity 0.19m/s with a total body mass of 183kg)
- Open-loop locomotion stability over variations of carrying payload from 0 to 150kg

Energy Efficient Monopod Robot *CARGO*

10:00–10:15	WeA9.3

Stabilizing Series-Elastic Point-Foot Bipeds Using Whole-Body Operational Space Control

Donghyun Kim, Ye Zhao, Gray Thomas, Benito R. Fernandez, Luis Sentis
Mechanical Engieering, University of Texas at Austin, US

- Planning algorithms for achieving unsupported dynamic balancing on our point-foot biped
- Force feedback control of the internal forces to regulate contact interactions with the complex environment.
- Experimental validation the efficacy of our new Whole-Body Operational Space Control and planning strategies via balancing over a disjointed terrain and attaining dynamic balance without a mechanical support

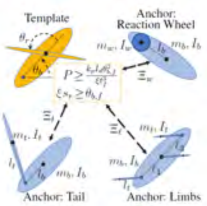
Point foot biped robot, Hume

10:15–10:30	WeA9.4

Comparative Design, Scaling, and Control of Appendages for Inertial Reorientation

Thomas Libby[1], Aaron M. Johnson[2], Evan Chang-Siu[3], Robert J. Full[1] and Daniel E. Koditschek[4]
[1]Univ. of California at Berkeley; [2]Carnegie Mellon University; [3]California State University Maritime Academy; [4]University of Pennsylvania; USA

- Inertial Reorientation: agility via orientation control
- Simple model (template): links design to tasks
- Detailed models (anchors): real morphology
- "*Morphological Reduction*:"
  - collapses dimension from anchor to template
  - facilitates design
  - enables comparison of diverse bodies
- Thanks to NSF:
  - CiBER-IGERT Award DGE-0903711
  - CABiR Award CDI-II 1028237



10:30–10:45	WeA9.5

Hierarchical Fingertip Space: A Unified Framework for Grasp Planning and In-Hand Grasp Adaptation

K. Hang[1], M. Li[2], J. A. Stork[1], Y. Bekiroglu[1], F. T. Pokorny[1], A. Billard[2] and D. Kragic[1]
[1]RPL/CAS, KTH Royal Institute of Technology, Sweden
[2]LASA, École Polytechnique Fédérale de Lausanne, Switzerland

- Formulates a **unified optimization framework** based on a **hierarchical representation** of contact candidates
- Optimizes grasp **stability, hand reachability,** and **adaptability**
- Integrates **grasp optimization, control,** and **stability estimation**
- Allows **fingertip grasp synthesis, grasp adaptation,** and **finger gaiting** on arbitrary shapes

Medical Robots and Systems 4

Chair *Atsuo Takanishi, Waseda University*
Co-Chair *Robert James Webster III, Vanderbilt University*

09:30–09:35 WeA10.1

An Intervening Ethical Governor for a robot mediator in patient-caregiver relationship: Implementation and Evaluation

Jaeeun Shim, Ronald Arkin, and Michael Pettinatti
Mobile Robot Laboratory, Georgia Institute of Technology, USA

- An intervening ethical governor (IEG) enables a robot mediator to ethically intervene in a situation where patients or caregivers cross accepted ethical boundaries

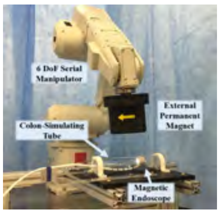
- Developed and implemented four intervention rules
  - Angry, Quiet/withdrawn, Stay-in-the-room, Safety-first rules
- Evaluated the IEG model by conducting a qualitative study (interviews) with the target population - adults 60 years of age or older

09:35–09:40 WeA10.2

Autonomous Retroflexion of a Magnetic Flexible Endoscope

Piotr Slawinski, Addisu Taddese and Kyle Musto
Mechanical Engineering, Vanderbilt University, USA
Keith Obstein
Vanderbilt University Medical Center, USA
Pietro Valdastri
School of Electronic and Electrical Engineering, University of Leeds, UK

- We have developed an algorithm that optimizes an applied magnetic wrench to achieve retroflexion
- The nature of the dipole field dictates how much torque can be applied about a device's particular axis
- This is the first demonstration of an autonomous maneuver in magnetically actuated colonoscopy

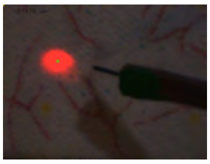


09:40–09:45 WeA10.3

Toward Monocular Camera-Guided Retinal Vein Cannulation with an Actively Stabilized Handheld Robot

S. Mukherjee, S. Yang, R. A. MacLachlan, L. A. Lobes, Jr., J. N. Martel, C. N. Riviere
The Robotics Institute, Carnegie Mellon University, USA

- Monocular camera-based surface reconstruction and homography matrix estimation, using surgical laser scanning.
- Targets defined in image coordinates are projected on to robot's global coordinate system. Motion scaling for precise cannula positioning around the target.
- Experiments demonstrate more accurate surface reconstruction and more precise approach to the vessels.



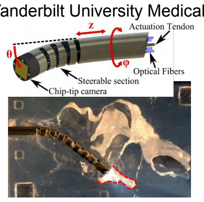
Tool, laser, and eye phantom

09:45–09:50 WeA10.4

Through the Eustachian Tube and Beyond: A New Miniature Robotic Endoscope to See into the Middle Ear

L. Fichera[1], N.P. Dillon[1], D. Zhang[2], I.S. Godage[1], M. A. Siebold[2], B.I. Hartley[3], J.H. Noble[2], P.T. Russell III[4], R.F. Labadie[4], R.J. Webster[1]
[1]Dept. of Mechanical Engineering and [2] Dept. of Electrical Engineering and Computer Science, Vanderbilt University, United States
[3]Dept. of Radiology and [4]Dept. of Otolaryngology, Vanderbilt University Medical Center, United States

- We present a novel miniature steerable endoscope for minimally-invasive surveillance of the Middle Ear (diameter: 1.80 mm)
- Kinematic requirements for the device are derived based on medical images
- The device is deployed in a 3D plastic phantom
- Results show that the device provides > 74% visibility coverage of the *sinus tympani* (see figure) compared to only 6.9% using a straight, non-articulated endoscope



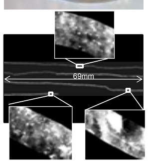
Endoscope insertion in the Middle Ear. The dashed line indicates the location of the *sinus tympani*.

09:50–09:55 WeA10.5

A Balloon Endomicroscopy Scanning Device for Diagnosing Barrett's Oesophagus

Siyang Zuo, Michael Hughes, and Guang-Zhong Yang
Hamlyn Centre for Robotic Surgery, Imperial College London, UK

- A new robotic catheter for controlled, large area scanning and mosaicing of the oesophagus
- Encapsulated in an inflatable balloon
- Suitable for deployment through an endoscope working channel
- *Ex vivo* swine oesophagus tissue results are demonstrated, illustrating a viable scanning approach for oesophagus endomicroscopy



Mosaic images

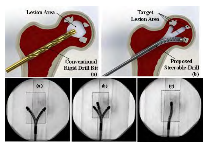
Combined with endoscope

09:55–10:00 WeA10.6

A Curved-Drilling Approach in Core Decompression of the Femoral Head Osteonecrosis Using a Continuum Manipulator

Farshid Alambeigi, Shahriar Sefati, Ryan J. Murphy, Iulian Iordachita, Russel H. Taylor, Harpal Khanuja, and Mehran Armand
Laboratory for Computational Sensing and Robotics,Johns Hopkins University
Yu Wang
School of Biological Science and Medical Engineering, Beihang University
Cong Gao
Department of Electronic Engineering, Tsinghua University

- Design and fabrication of a novel steerable drill using a continuum dexterous manipulator.
- Quantitative performance and efficiency evaluation of the tool in robot-assisted treatment of core decompression of osteonecrosis.
- Verification experiments for S-shape and multiple-branch drilling performed on both simulated and human cadaveric bones.



Medical Robots and Systems 4

Chair *Atsuo Takanishi, Waseda University*
Co-Chair *Robert James Webster III, Vanderbilt University*

10:00–10:05	WeA10.7

A Single-Port Robotic System for Transanal Micro-Surgery – Design and Validation

Jianzhong Shang, Konrad Leibrandt, Petros Giataganas, Valentina Vitiello, Carlo Seneci, Piyamate Wisanuvej, Jindong Liu, Gauthier Gras, James Clark, Ara Darzi and Guang-Zhong Yang
The Hamlyn Centre, Imperial College London, UK

- This paper introduces a single-port robotic platform for Transanal Endoscopic Micro-Surgery
- The system is based on master-slave robotically controlled tele-manipulation
- Design considerations of the robotic system are introduced
- Results from benchtop tests, *ex-vivo* animal tissue evaluation and *in-vivo* studies are presented

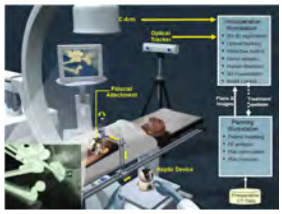
Full thickness dissection on bovine tissue using the micro-IGES surgical robot

10:05–10:10	WeA10.8

Development and Evaluation of Concurrent Control for Osteolytic Lesion Treatment

Paul Wilkening, Farshid Alambeigi, Russell H. Taylor, and Mehran Armand
Laboratory for Computational Sensing and Robotics, Johns Hopkins University, USA
Ryan J. Murphy and Mehran Armand
Research and Exploratory Development Department, JHU Applied Physics Laboratory, USA

- Osteolysis treatment surgery requires a high degree of dexterity within a confined area to clear lesion material
- Our system concurrently controls a robotic arm and a continuum dexterous manipulator within the hip implant
- This system guides the manipulator while enforcing safety barriers to prevent collisions with the implant
- The controller reliably followed a goal path with a mean error of 0.42 mm



Proposed robotic system for osteolysis treatment

BIGSS JHU Laboratory for Computational Sensing and Robotics

Automation

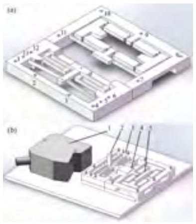
Chair *Ron Lumia, University of New Mexico*
Co-Chair *Rolf Johansson, Lund University*

09:30–09:35 WeA11.1

Design of a Flexure-Based Micro-Motion Stage With Constant Output Force

Piyu Wang and Qingsong Xu
Department of Electromechanical Engineering
University of Macau, Macau, China

- A new flexure-based precision positioning micro-motion stage with constant output force is designed and analyzed
- The zero-stiffness mechanism is realized by combining a bistable mechanism and a positive-stiffness mechanism
- Analytical modeling and finite element analysis simulation are conducted
- A prototype is fabricated using 3D printing for experimental verification

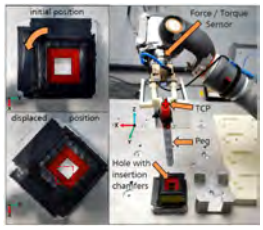


09:35–09:40 WeA11.2

Iteratively Learned and Temporally Scaled Force Control with Application to Robotic Assembly in Unstructured Environments

Johannes Bös, Arne Wahrburg, and Kim D. Listmann
ABB Corporate Research Germany

- Iterative Learning Control (ILC) applied to robotic assembly
- Compliance introduced by admittance control, reference trajectories modified by ILC
- Simultaneous increase of speed of operation and reduction of contact forces during assembly
- Experimental validation on 7 DoF manipulator (ABB YuMi)

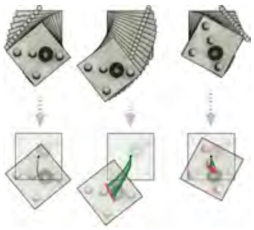


09:40–09:45 WeA11.3

A Probabilistic Data-Driven Model for Planar Pushing

Maria Bauza and Alberto Rodriguez
Mechanical Engineering Department,
Massachusetts Institute of Technology, United States

- Data-driven approach to predict the most likely outcome of a push and its variance.
- The learned model outperforms analytical models with less than 100 samples.
- Results are validated against a collected dataset of repeated pushes.
- The model captures the stability of different pushes and their variability.



09:45–09:50 WeA11.4

A Distributed Approach to Automated Manufacturing Systems with Complex Structures using Petri Nets

Yan Yang and HeSuan Hu
School of Electro-mechanical Engineering, Xidian University
Xi'an, Shaanxi, P. R. China
Yang Liu
School of Computer Science and Engineering, Nanyang Technological University, Republic of Singapore

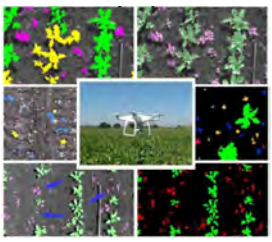
- First, this paper presents an innovative solution for distributed supervisor based on AMSs with flexible routes and assembly operations, thus allowing an extension to a broader class of AMSs;
- Second, instead of collecting and distributing the global information from all nodes to different control points, our method allows implementing global goals through local observation, control, and execution upon processes;
- Third, in case some resources are failed, our method can easily adapt to such contingencies through on-line updating current resource information so that the available information on the resources can be incorporated in our method's logic.

09:50–09:55 WeA11.5

UAV-Based Crop and Weed Classification for Smart Farming

Philipp Lottes[1], Raghav Khanna[2], Johannes Pfeipfer[2], Roland Siegwart [2] and Cyrill Stachniss[1]
[1] University of Bonn, Germany, [2] ETHZ, Switzerland

- **UAV**-based **field monitoring** using also an out-of-the-box Phantom 4
- **Multiclass detection** of sugar beets and typical weed types using a **regular RGB** and **RGB+NIR** data
- **Tested** on fields in different countries
- Classification **accuracies: 86-96%**



09:55–10:00 WeA11.6

NimbRo Picking: Versatile Part Handling for Warehouse Automation

Max Schwarz, Anton Milan*, Christian Lenz, Aura Muñoz, Arul Selvam Periyasamy, Michael Schreiber, Sebastian Schüller and Sven Behnke
Autonomous Intelligent Systems, University of Bonn, Germany
* ACVT, University of Adelaide, Australia

- System for the Amazon Picking Challenge 2016: Second and third place
- Two deep-learning approaches for object detection and semantic segmentation
- Model registration and heuristic grasp selection
- Parametrized motion primitives using a custom inverse kinematics solver

Automation

Chair *Ron Lumia, University of New Mexico*
Co-Chair *Rolf Johansson, Lund University*

10:00–10:05	WeA11.7

Planning and Executing Optimal Non-Entangling Paths for Tethered Underwater Vehicles

Seth McCammon and Geoffrey A. Hollinger
School of Mechanical, Industrial, and Manufacturing Engineering
Oregon State University

- Formulate Non-Entangling extension to the Travelling Salesman Problem (NE-TSP)
- Compute optimal solution to NE-TSP with Mixed Integer Programming on a homotopy augmented graph
- MIP method outperforms greedy and heuristic methods in simulated trials
- Simulated results validated in pool test and wharf inspection with Seabotix vLVB300 AUV

Non-entangling path for tethered vehicle

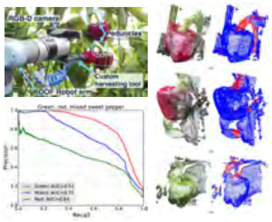
10:05–10:10	WeA11.8

Peduncle Detection of Sweet Pepper for Autonomous Crop Harvesting - Combined Colour and 3D Information

Inkyu Sa[1], Chris Lehnert[2], Andrew English[2], Chris McCool[2], Feras Dayoub[2], Ben Upcroft[2], and Tristan Perez[2]
[1] Autonomous Systems Lab., ETH Zürich, Switzerland
[2] Science and Engineering Faculty, Queensland University of Technology, Australia

- Motivation: Cutting the peduncle cleanly is one of the most difficult stages of the harvesting process and important for the crop quality.
- Approach: Fusing colour and 3D geometry information of sweet peppers acquired from an RGB-D sensor with a supervised-learning framework.
- Results: Quantitative and qualitative evaluations are performed with field-grown sweet pepper dataset and achieved average 0.71 AUC [3] for red, mixed-, green crops.
- Releasing annotated 3D sweet peppers and peduncle image dataset.

[3] the Area-Under-the-Curve



Experimental setup (top-left), quantitative (bottom-left), and qualitative (right) results for red-green sweet peppers' peduncle detection (marked in red from the right figure).

Compliance

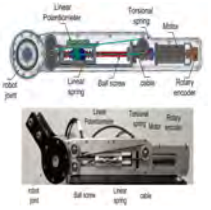
Chair *Kensuke Harada, Osaka University*
Co-Chair *Christian Ott, German Aerospace Center (DLR)*

11:05–11:10	WeB1.1

A Sliding Mode Controller Design for the Robust Position Control Problem of Series Elastic Actuators

Emre Sariyildiz and Haoyong Yu
Biomedical Engineering, National University of Singapore, Singapore
Huiming Wang
Automation, Chongqing University of Posts and Telecommunications, China

- Robust position controller design for Series Elastic Actuators (SEAs)
- A novel Sliding Mode Controller design using disturbance estimation
- Improving robustness and suppressing chattering using second order Disturbance Observer (DOb)
- Cancelling collocated and non-collocated disturbances



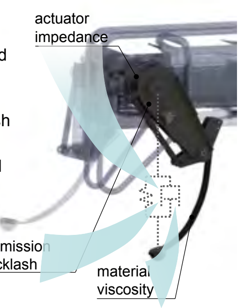
Novel Series Elastic Actuator

11:10–11:15	WeB1.2

Realizing Natural Springy Motion of Robotic Leg by Cancelling the Undesired Damping Factors

Jungsoo Cho and Kyoungchul Kong
Mechanical Engineering Department, Sogang University, Korea

- Realization of the SLIP model for running of legged robots is challenged by the undesired practical damping factors
- The damping factors include mechanical impedance of actuators, friction and backlash in power transmission mechanism, etc.
- The proposed control method presents ideal springy motion of a robotic leg by cancelling resistive forces resulted from the damping factors

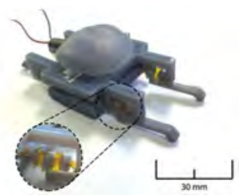


11:15–11:20	WeB1.3

3DFlex: A rapid prototyping approach for multi-material compliant mechanisms in millirobots

Ryan St. Pierre, Noah Paul, and Sarah Bergbreiter
Department of Mechanical Engineering and Institute for Systems Research, University of Maryland, College Park, MD USA

- The rigid components are 3D printed, and flexures are inserted into the rigid components, creating the final mechanism.
- The assembled mechanisms are robust, requiring over 1 N of force to delaminate, and surviving 150,000 cycles of bending without failure
- A 6 g walking quadrupedal millirobot is presented as a case study for the design and manufacturing methodology.



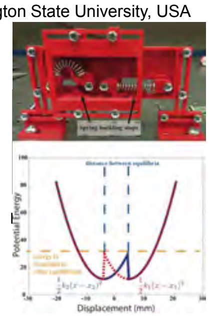
A 30 mm long, 6 g millirobot made with 3D printed rigid components and Kapton flexures

11:20–11:25	WeB1.4

Compliant, Bi-stable Mechanisms with Multiple Stiffnesses through Controlled Spring Buckling

Brian LaFerriere, Carson Schlect, and John Swensen
School of Mechanical and Materials Eng., Washington State University, USA

- Design and modeling of bi-stable mechanism with multiple stiffnesses.
- Bi-stability generated through precise control compression spring buckling.
- Mathematical model presented to provide ability optimize the potential energy profile.
- Design, fabrication, and analysis of prototype mechanism is demonstrated.

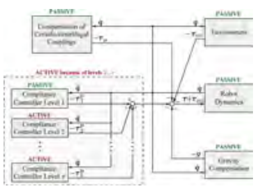


11:25–11:30	WeB1.5

Passive Hierarchical Impedance Control via Energy Tanks

A. Dietrich[1], X. Wu[2], K. Bussmann[1], C. Ott[1], A. Albu-Schäffer[1,2], and S. Stramigioli[3]
[1] Institute of Robotics and Mechatronics, DLR, Germany
[2] Department of Informatics, TUM, Germany
[3] University of Twente, the Netherlands

- **Proof of passivity** for hierarchical multi-objective control of redundant robots
- Two approaches based on virtual energy tanks (local & global tanks)
- Comparison with the classical, null-space-based approach and discussion
- Simulations and experiments on DLR's humanoid robot Justin



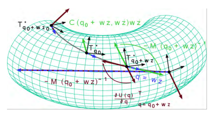
Source of activity in the classical approach

11:30–11:35	WeB1.6

Eigenmodes of Nonlinear Dynamics: Definition, Existence, and Embodiment into Legged Robots with Elastic Elements

Dominic Lakatos[1], Werner Friedl[1], and Alin Albu-Schäffer[1,2]
[1]Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Germany
[2]Department of Informatics, Technical University Munich, Germany

- Concept: invariant, linear 1-D submanifolds of the configuration space of multibody systems with joint elasticities called eigenmodes of nonlinear dynamics
- Method: embodiment of task related eigenmodes in the dynamics of compliantly actuated robotic systems by mechanical design
- Example: three-segment pantograph leg with embodied SLIP dynamics by selection of realizable design parameters



Geometrical representation of eigenmode dynamics on torus manifold

Compliance

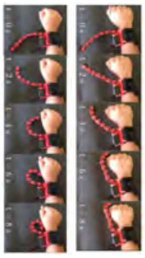
Chair *Kensuke Harada, Osaka University*
Co-Chair *Christian Ott, German Aerospace Center (DLR)*

11:35–11:40	WeB1.7

On the Role of Stiffness Design for Fingertip Trajectories of Underactuated Modular Soft Hands

I. Hussain[2], G. Salvietti[1,2], M. Malvezzi[1,2], D. Prattichizzo[1,2]
[1] Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy
[2] Department of Information Engineering and Mathematics, University of Siena, Italy

- In this work, we propose a method to compute the stiffness of flexible joints and its realization in order to let the fingertips track a certain predefined trajectory.
- The stiffness computation is obtained leveraging on the the mechanics of tendon-driven hands and on compliant systems, while for its implementation beam theory has been exploited.
- We validate the proposed framework both in simulation and with experiments using a wearable robot for grasping compensation in patients with a paretic hand.

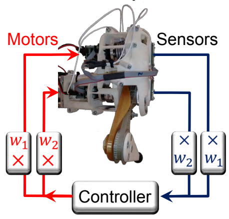


11:40–11:45	WeB1.8

Legged Elastic Multibody Systems: Adjusting Limit Cycles to Close-to-Optimal Energy Efficiency

Philipp Stratmann[1,2], Dominic Lakatos[2], Mehmet C. Özparpucu[2], Alin Albu-Schäffer[1,2]
[1]Department of Informatics, TU Munich, Germany
[2]Institute of Robotics and Mechatronics, DLR, Germany

- Passive compliant elements used for energy-efficient movement.
- Leg with multiple bodies subject to nonlinear dynamics and damping.
- Optimal control of hybrid dynamical system, experiments with Monte Carlo parameter screening, video.
- Linear coordinate transformation induces close-to-optimal movement and allows adjustment to changing resonance conditions



Linear Coordinate Transformation

Session WeB2 Rm. 4111 Wednesday, May 31, 2017, 11:05–12:20

Mapping 2

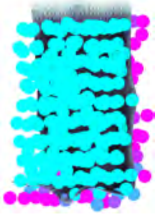
Chair *Martin Magnusson, Örebro University*
Co-Chair *Jaime Valls Miro, University of Technology Sydney*

11:05–11:10	WeB2.1

AtomMap: A Probabilistic Amorphous 3D Map Representation for Robotics and Surface Reconstruction

David Fridovich-Keil, Erik Nelson, and Avideh Zakhor
Electrical Engineering and Computer Sciences, UC Berkeley, USA

- Novel occupancy map representation, with optional signed distance field
- More accurate than grid methods near surfaces
- Represent space as identical, non-overlapping spheres
- Utilize approximate surface normals for improved accuracy

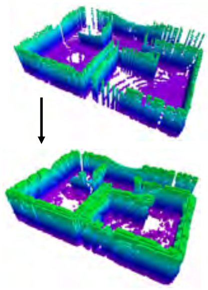


11:10–11:15	WeB2.2

Bayesian Generalized Kernel Inference for Occupancy Map Prediction

Kevin Doherty, Jinkun Wang and Brendan Englot
Stevens Institute of Technology, USA

- A novel supervised learning formulation of occupancy mapping is proposed that leverages Bayesian nonparametric inference, a sparse kernel, and efficient data structures
- Predictive and accurate 3D, real-time viable mapping is achieved over sparse range data
- Reverts to a specified prior when there is insufficient training data to reliably predict occupancy
- Exact recursive updates allow stable long-term performance under repeated observation of the same portions of the map, in contrast with other methods



11:15–11:20	WeB2.3

Deliberative Object Pose Estimation in Clutter

Venkatraman Narayanan and Maxim Likhachev
The Robotics Institute, Carnegie Mellon University, USA

•Identification and pose estimation of 3D object instances from depth data is a fundamental perception task: e.g., Amazon Picking Challenge

•Generative methods such as PERCH were introduced recently to address limitations of discriminative methods (sensitivity to occlusions and training-data)

•While PERCH casts multi-object localization as an efficient optimization over hypothesized scenes, it assumes that scenes contain only "known" objects

•We extend PERCH to be applicable in scenes containing extraneous unmodeled clutter as well as for providing pose uncertainty estimates, thereby increasing its practical applicability

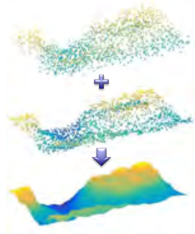
Multiple pose predictions with uncertainty estimates

11:20–11:25	WeB2.4

Coupling Conditionally Independent Submaps for Large-Scale 2.5D Mapping with Gaussian Markov Random Fields

Liye Sun , Teresa Vidal-Calleja, and Jaime Valls Miro
Centre for Autonomous Systems, University of Technology Sydney, Australia

- A generic submapping method for fusing multi-modal uncertain data in a correlated way.
- Computation gain by combining
  - Gaussian Markov Random Fields,
  - Fusion in information form, and
  - Conditional Independence.
- Novel information propagation that allows linear time recovery of the optimal global map.



11:25–11:30	WeB2.5

Automatic Room Segmentation from Unstructured 3D Data of Indoor Environments

Rareș Ambruș
KTH Royal Institute of Technology, Sweden
Sebastian Claici
CSAIL, MIT, USA
Axel Wendt
Bosch Research and Techology Center, USA

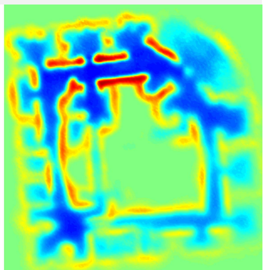
- We present an automatic method for reconstructing 2D floor plans.
- Our approach emphasizes accurate and robust primitive detection, and ease of use.
- We provide detailed qualitative and quantitative experimental results.

11:30–11:35	WeB2.6

Warped Gaussian Processes Occupancy Mapping with Uncertain Inputs

Maani Ghaffari Jadidi, Jaime Valls Miro, and Gamini Dissanayake
University of Technology Sydney, Australia

- We account for the complication of the robot's perception noise using Warped Gaussian Processes (WGPs) in the occupancy mapping problem.
- This approach allows for non-Gaussian noise in the observation space and captures the possible nonlinearity in that space better than standard GPs.



Mapping 2

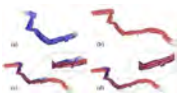
Chair *Martin Magnusson, Örebro University*
Co-Chair *Jaime Valls Miro, University of Technology Sydney*

11:35–11:40	WeB2.7

3D Map Merging on Pose Graphs

Taigo Maria Bonanni, Bartolomeo Della Corte, and Giorgio Grisetti
Dept. Computer, Control, and Management Eng., Sapienza Univ. of Rome, Italy

- Traditional map merging approaches are based on single rigid transformations
- If input maps are noisy, distortions are propagated in the merged output
- Our approach uses piece-wise deformations and graph optimization to reduce noise and artifacts
- First map merging approach for 3D maps, also capable of dealing with noisy input



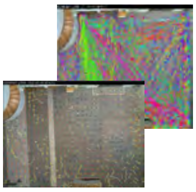
a) and b) are two input maps. c) is the distorted outpu

11:40–11:45	WeB2.8

Enabling Flow Awareness for Mobile Robots in Partially Observable Environments

Tomasz Piotr Kucner, Martin Magnusson, Erik Schaffernicht, Victor Hernandez Bennetts, and Achim J. Lilienthal
AASS Research Centre, Örebro University, Sweden

- Probabilistic multi-modal flow modelling with ***Circular-Linear Flow Field map (CliFF-map).***
- Method for building ***dense maps*** based on ***sparsely distributed*** measurement locations of ***pedestrian flow and air flow.***
- Representation applicable in ***Human-Robot Interaction*** and ***Mobile Robot Olfaction.***



People velocity measurements and resulting map of people flow

Visual Localization

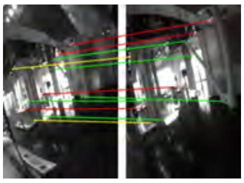
Chair *Giorgio Metta, Istituto Italiano di Tecnologia (IIT)*
Co-Chair *Edwin Olson, University of Michigan*

11:05–11:10	WeB3.1

Efficient Descriptor Learning for Large Scale Localization

Antonio Loquercio[1], Marcin Dymczyk[1], Bernhard Zeisl[2], Simon Lynen[2], Igor Gilitschenski[1], Roland Siegwart[1]
[1]Autonomous System Laboratory, ETH Zurich, Switzerland
[2]Google Inc., Zurich, Switzerland

- A novel **learning strategy** trains efficient projections of visual descriptors: **matching** becomes **fast** and highly **robust**.
- A low latency **linear projection** increases the retrieval of **input descriptors** while decreasing memory and computational costs.
- With **context information**, we substantially increase the discriminability of **low level features** as edges, corners or blobs.



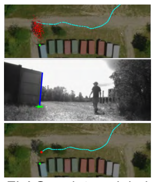
Difficult descriptor matches under strong **viewpoint changes**.

11:10–11:15	WeB3.2

Feature-based Localization between Air and Ground

Xipeng Wang, Steve Vozar and Edwin Olson
Computer Science & Engineering, University of Michigan, USA

- FLAG allows ground robot to perform global positioning by recognizing landmarks in an aerial image.
- FLAG has comparable performance to LIDAR-based scan-matching localization in indoor and outdoor environment.
- FLAG could be used as a replacement or augmentation for GPS.



FLAG updates global position by matching large vertical features from the ground to features in an aerial image

11:15–11:20	WeB3.3

Action Recognition: From Static Datasets to Moving Robots

F. Rezazadegan, S. Shirazi, B.Upcroft, M. Milford
Department of Electrical Engineering and Computer science, Queensland University of Technology, Australia

- A DCNN algorithm for moving robots to recognize human actions in non-informative backgrounds
- Generating action region proposals extracting one human action in unconstrained videos regardless of camera motion
- Demonstrating the outperformance compared to the state-of-the-art in two benchmarks and two new datasets
- Validating action recognition method in an abnormal behavior detection scenario to improve workplace safety

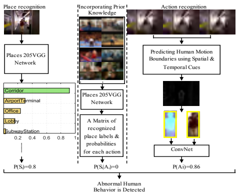


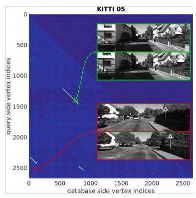
Figure1. Overview of our approach for unbiased human action recognition on a sample of the Guiabot robot dataset

11:20–11:25	WeB3.4

Visual Place Recognition with Probabilistic Voting

Mathias Gehrig, Elena Stumm, Timo Hinzmann and Roland Siegwart
Autonomous Systems Lab, ETH Zürich, Switzerland

- Place recognition based on nearest neighbor descriptor voting instead of BoW.
- Detect revisited places using probabilistic scoring of vote count per image.
- State-of-the-art results for feature based localization running at > 20 Hz on Laptop CPU.

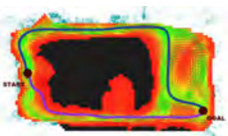


11:25–11:30	WeB3.5

Map Quality Evaluation for Visual Localization

Hamza Merzić, Elena Stumm, Marcin Dymczyk, Roland Siegwart, and Igor Gilitschenski
Autonomous Systems Lab, ETH Zurich, Switzerland

- Efficient algorithm for evaluating map quality
- A way of visualizing map quality
- Evaluations performed on both indoor and outdoor environments through the use of ground and flying agents
- A demonstration of the algorithm applied to generating belief for path planning under uncertainty



Path planning under uncertainty using map quality as the belief measure

11:30–11:35	WeB3.6

Incremental Robot Learning of New Objects with Fixed Update Time

Raffaello Camoriano[*,a,b,c], Giulia Pasquale[*,a,b,c], Carlo Ciliberto[b], Lorenzo Natale[a], Lorenzo Rosasco[b,c] and Giorgio Metta[a]

[a] iCub Facility / [b] LCSL, Istituto Italiano di Tecnologia, Italy
[c] DIBRIS, Università degli Studi di Genova, Italy

- Motivated by visual recognition in lifelong robot learning, we propose a novel incremental classification algorithm
- New classes can be learned without retraining from scratch or storing past data
- Unbalanced class proportions, occurring when learning new objects, are efficiently rebalanced, significantly increasing accuracy
- Empirical evaluations on several benchmark datasets are presented

iCub learning a new object

Visual Localization

Chair *Giorgio Metta, Istituto Italiano di Tecnologia (IIT)*
Co-Chair *Edwin Olson, University of Michigan*

11:35–11:40 WeB3.7

Temporal Persistence Modeling for Object Search

Russell Toris
Worcester Polytechnic Institute, USA
Sonia Chernova
Georgia Institute of Technology, USA

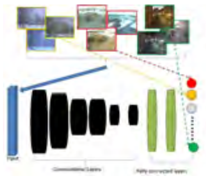
- This work addresses object search for domains in which object permanence cannot be assumed.
- We formalize object search as a failure analysis problem and contribute a probabilistic temporal persistence modeling algorithm.
- Results are reported in two domains, large scale GPS person tracking, and multi-object tracking on a mobile robot operating over a 2-week period.

11:40–11:45 WeB3.8

Deep Learning Features at Scale for Visual Place Recognition

Zetao Chen
ETH Zurich, Switzerland
Adam Jacobson, Niko Sünderhauf, Ben Upcroft and Michael Milford
Queensland University of Technology, Australia
Lingqiao Liu, Chunhua Shen and Ian Reid
University of Adelaide, Australia

- Developed a massive place recognition-specific dataset containing 1000s of places under changing conditions;
- Trained two CNN models to learn condition-invariant features for place recognition across extreme appearance conditions;
- By analyzing the network responses, we provide insights into what a network learns when training for place recognition.



Sensor Fusion and Control

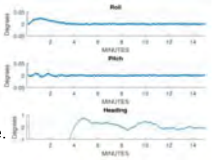
Chair *Markus Miezal, University of Kaiserslautern*
Co-Chair *Fumin Zhang, Georgia Institute of Technology*

11:05–11:10 WeB4.1

A Stable Adaptive Attitude Estimator on SO(3) for True-North Seeking Gyrocompass System

Andrew R. Spielvogel and Louis L. Whitcomb
Department of Mechanical Engineering, Johns Hopkins University, USA

- Theory behind the stable adaptive attitude estimator for true-North gyrocompass system.
- Preliminary simulation of a rotating system employing a KVH 1775 IMU.
- Data suggest the convergence of the adaptive identifier's attitude estimate to the true attitude.
- Future studies will address the general-use-case of simultaneously rotating and translating instrument configuration.



Attitude estimate error.

11:10–11:15 WeB4.2

Ground Substrate Classification for Adaptive Quadruped Locomotion

Xiaoqi Li[1,2], Wei Wang[1,2] and Jianqiang Yi[1,2]
[1]Institute of Automation, Chinese Academy of Sciences, Beijing, China
[2]University of Chinese Academy of Sciences, Beijing, China

- Presenting a COG adjustment method and combining CPGs with a foot path planning method to improve the performance of the quadruped walk gait generated by CPGs.
- Collecting the foot-ground contact force and gyroscope information during locomotion on different ground substrates, and classifying the ground substrates with the feature vector extracted from the collected data using SVM algorithm.

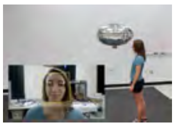

The quadruped robot Biodog locomotes on different ground substrates in walk gait.

11:15–11:20 WeB4.3

Monocular Vision-based Human Following on Miniature Robotic Blimp

Ningshi Yao, Qiuyang Tao, Sungjin Cho and Fumin Zhang
Electrical and Computer Engineering, Georgia Institute of Technology, USA
Emily Anaya
Electrical and Computer Engineering, Wisconsin-Madison, Madison, USA
Hongrui Zheng
College of Computing, Georgia Institute of Technology, USA

- The first human and robotic blimp interaction demonstration on Georgia Tech Miniature Autonomous Blimp (GT-MAB)
- Detecting and following an uninstrumented human using one onboard monocular camera
- Reliable and safe flying robotic platform with long flight time for Human Robot Interaction research

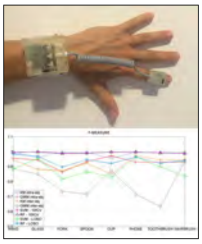

GT-MAB follows the human user

11:20–11:25 WeB4.4

Daily Activity Recognition with Inertial Ring and Bracelet: an Unsupervised Approach

Alessandra Moschetti, Laura Fiorini, Dario Esposito, Paolo Dario and Filippo Cavallo
The BioRobotics Institute, Scuola Superiore Sant'Anna, Pontedera, Italy

- Eight gestures from ADLs recognized through two IMUs on the wrist and index finger;
- Two unsupervised approaches (KM and GMM) with inter-subject and intra-subject analysis to discriminate gestures;
- Comparison with two supervised algorithms (RF and SVM);
- Good value of Accuracy and F-measure for KM inter-subject analysis (0.917 and 0.920 respectively).

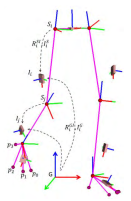


11:25–11:30 WeB4.5

Real-time inertial lower body kinematics and ground contact estimation at anatomical foot points for agile human locomotion

Markus Miezal, Bertram Taetz, Gabriele Bleser
Research group wearHEALTH, University of Kaiserslautern, Germany

- Extension to inertial body tracking approaches for improving segment orientation estimation under locomotion
- Enables global translation estimation (agile motion possible)
- Direct state-less calculation without need for a stationary (stance) phase
- Allow detection of locomotion parameters and patterns



11:30–11:35 WeB4.6

Photometric Patch-based Visual-Inertial Odometry

Xing Zheng*, Zack Moratto†, Mingyang Li† and Anastasios I. Mourikis*
* Dept. of Electrical & Computer Engineering, UC Riverside, USA
† Google Inc., USA

- Visual-inertial odometry algorithm that directly uses intensities of image patches as measurements
- Models the irradiance at each pixel, illumination gains and biases as random variables
- Accounts for the camera response function and lens vignetting
- Testing on 50 datasets: 23% lower estimation errors compared to point-based method

	Typical Error (m)	90-Pctile Error (m)
Original	0.176	0.270
Direct	0.135	0.208

Experimental results: proposed direct method outperforms point-based method in estimation error

Sensor Fusion and Control

Chair *Markus Miezal, University of Kaiserslautern*
Co-Chair *Fumin Zhang, Georgia Institute of Technology*

11:35–11:40 WeB4.7

Robust Sensor Fusion for Finding HRI Partners in a Crowd

Shokoofeh Pourmehr, Jack Thomas, Jake Bruce,
Jens Wawerla and Richard Vaughan
School of Computing Science, Simon Fraser University, Canada

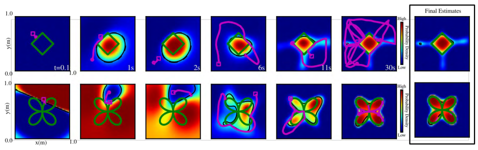
- A method for sensor fusion of human detectors, selecting the most engaging person to approach.
- Demonstrating this method in a robotic attention system for distant human interaction through outdoor experiments.
- Evaluating this interaction system's performance in a user study with non-expert users.
- a ROS-based implementation, freely available online: https://github.com/AutonomyLab/autonomy_hri.git

Husky robot approaching interested human.

11:40–11:45 WeB4.8

Ergodic Exploration Using Binary Sensing for Non-Parametric Shape Estimation

Ian Abraham, Ahalya Prabhakar, Mitra J.Z. Hartmann,
Todd D. Murphey
Mechanical and Biomedical Engineering Department, Northwestern University, United States



Time series shape estimation of diamond and clover shape.

- Ergodic exploration is used to demonstrate active tactile sensing for shape estimation.
- Algorithm shows successful shape estimation that is independent of the number of objects.

Aerial Robot 2

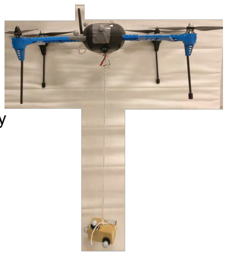
Chair *Antonio Franchi, LAAS-CNRS*
Co-Chair *Davide Scaramuzza, University of Zurich*

11:05–11:10	WeB5.1

Stability of Load Lifting by a Quadrotor under Attitude Control Delay

Pedro Pereira and Dimos Dimarogonas
Automatic Control, KTH Royal Institute of Technology, Sweden

- Simple PID-like control law
- Inclusion of extra term for augmenting stability
- Compensation of battery drainage and model uncertainties by means of integral action
- Lower bound on attitude control gain that guarantees stability of equilibrium



Quadrotor-Slung-Load System

11:10–11:15	WeB5.2

Safe Certificate-Based Maneuvers for Teams of Quadrotors Using Differential Flatness

Li Wang and Magnus Egerstedt
Electrical and Computer Engineering, Georiga Tech, USA
Aaron D. Ames
Mechanical and Civil Engineering, Caltech, USA

- Barrier certificates for safe quadrotor team
- Minimally-invasive trajectory modification to avoid collisions
- Provable safety guarantee
- Algorithm implemented on a team of five palm-sized quadrotors!

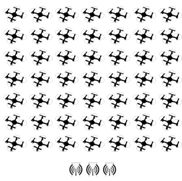
Fig: Safe quadrotor spiral

11:15–11:20	WeB5.3

Crazyswarm: A Large Nano-Quadcopter Swarm

James A. Preiss*, Wolfgang Hönig*,
Gaurav S. Sukhatme, and Nora Ayanian
Department of Computer Science, University of Southern California, USA

- System architecture for 49 Crazyflie quadcopters flying in dense formation indoors
- Off-the-shelf hardware (27 grams, palm-sized)
- Control, state estimation, trajectory planning & evaluation onboard
- Minimal communication requirements: 17 robots per radio
- High-level Python scripting layer
- All software open-source

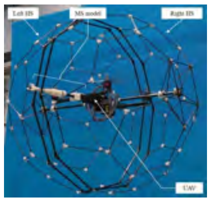


11:20–11:25	WeB5.4

UAV with Two Passive Rotating Hemispherical Shells for Physical Interaction and Power Tethering

C.J. Salaan, K. Tadakuma, Y. Okada, E. Takane,
K. Ohno and S. Tadokoro
Graduate School of Information Sciences, Tohoku University, Japan

- A new mechanism for UAV suitable in a complex environment is proposed.
- The whole spherical shell is cut into two hemispherical shells to provide a gap.
- The gap allows physical interaction and power tethering while the UAV is protected and kept stable.
- The capabilities of the new system are verified using the experimental prototype.



11:25–11:30	WeB5.5

Thrust Mixing, Saturation, and Body-Rate Control for Accurate Aggressive Quadrotor Flight

Matthias Faessler, Davide Falanga, and Davide Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland

Improving trajectory tracking for aggressive quadrotor flight through:

- Iterative thrust mixing
- Prioritizing thrust saturation
- Novel LQR body-rate control with feedback linearization and feed forward

11:30–11:35	WeB5.6

Real-time Motion Planning for Aerial Videography with Dynamic Obstacle Avoidance and Viewpoint Optimization

Tobias Naegeli[1], Javier Alonso-Mora[2,3], Alexander Domahidi[4],
Daniela Rus[3] and Otmar Hilliges[1]
ETH Zurich[1], TU Delft[2], MIT[3], Embotech[4]

- A real-time receding horizon planner that autonomously records scenes with moving targets
- We formulate the minimization problem under constraints as a MPC problem that fulfills aesthetic objectives, adheres to non-linear model and can be solved in real-time (20Hz).

Aerial Robot 2

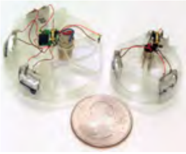
Chair *Antonio Franchi, LAAS-CNRS*
Co-Chair *Davide Scaramuzza, University of Zurich*

11:35–11:40 WeB5.7

Piccolissimo: The Smallest Micro Aerial Vehicle

Matthew Piccoli and Mark Yim
Mechanical Engineering and Applied Mechanics, University of Pennsylvania, USA

- Passively stabilized, single actuator rotorcraft
- 28 mm, 2.5 g, vertical motion version
- 39 mm, 4.5 g, 3 DOF control version
- Mathematical model for passive stability and controllability presented
- Experimental flights demonstrate flight time and steering



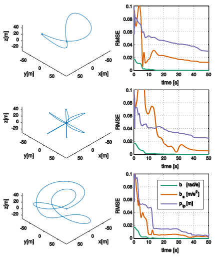
Maneuverable (left) and Mini (right) Piccolissimo compared to a US quarter dollar coin.

11:40–11:45 WeB5.8

Observability-Aware Trajectory Optimization for Self-Calibration with Application to UAVs

Karol Hausman, James Preiss, Gaurav Sukhatme
University of Southern California, CA, USA
Stephan Weiss
Alpen-Adria-Universitat, Austria

- Observability-aware trajectory optimization framework for nonlinear systems
- Prediction of the state estimation quality based on the vehicle's ego-motion
- Novel approximation of the local observability Gramian that captures states not directly visible in the sensor model
- Experiments on simulated and real quadrotors in self-calibration and waypoint-navigation scenarios



Policy Search

Chair *Raja Chatila, ISIR*
Co-Chair *Ruben Martinez-Cantin, Centro Universitario de la Defensa*

11:05–11:10	WeB6.1

PLATO: Policy Learning using Adaptive Trajectory Optimization

Gregory Kahn[1], Tianhao Zhang[1], Sergey Levine[1], Pieter Abbeel[123]
[1]EECS, UC Berkeley, USA
[2]OpenAI, USA
[3]ICSI, USA

- Continuous, reset-free RL algorithm that trains a neural network control policy
- Uses an adaptive model-predictive controller during training
- Avoids dangerous on-policy actions during training
- Prove policy has good long-term performance

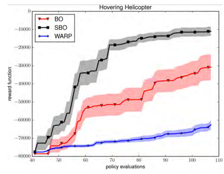
Simulated quadrotor learning to fly in a forest

11:10–11:15	WeB6.2

Bayesian Optimization with Adaptive Kernels for Robot Control

Ruben Martinez-Cantin
Spanish University Center for Defense

- Bayesian optimization (BO) is a sample efficient optimization method ideal for policy search.
- It can be applied efficiently with complex simulations and real setups without prior knowledge.
- We propose a new adaptive kernel (SBO) for Bayesian optimization which outperforms standard kernels.
- The new kernel is specially suitable for reward functions in robot learning.



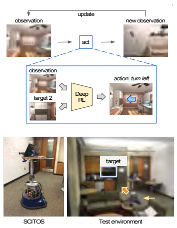
Hovering helicopter problem from RL-challenge

11:15–11:20	WeB6.3

Target-driven Visual Navigation in Indoor Scenes using Deep Reinforcement Learning

Yuke Zhu[1], Roozbeh Mottaghi[2], Eric Kolve[2], Joseph Lim[1], Abhinav Gupta[2,3], Li Fei-Fei[1], Ali Farhadi[2,4]
[1]Stanford University, [2]Allen Institute for Artificial Intelligence, [3]Carnegie Mellon University, [4]University of Washington

- Learning target-driven visual navigation models using end-to-end deep reinforcement learning
- AI2-THOR framework, providing a 3D environment with photo-realistic indoor scenes and a physics engine
- Generalization to new targets, to new scenes, and from simulation to real robots

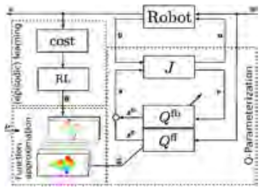


11:20–11:25	WeB6.4

A Robust Stability Approach to Robot Reinforcement Learning Based on a Parameterization of Stabilizing Controllers

Stefan Friedrich and Martin Buss
Chair of Automatic Control Engineering,
Technical University of Munich, Germany

- **Goal:** performance enhancement by safe learning for closed-loop controllers
- **Approach:** construct parameterization of stabilizing controllers based on a PD controller and an idealized model
- **Learning:** RBF approximation of filter coefficients and episodic optimization
- **Experiment:** simulation study and hardware experiment with a rigid-link robot

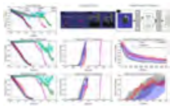


11:25–11:30	WeB6.5

Reset-Free Guided Policy Search: Efficient Deep Reinforcement Learning with Stochastic Initial States

William Montgomery
CSE, University of Washington, USA
Anurag Ajay, Chelsea Finn, Pieter Abbeel, Sergey Levine
EECS, University of California, Berkeley, USA

- Deep reinforcement learning can learn complex policies, but is often sample inefficient
- Guided policy search (GPS) methods are efficient, but require consistent initial states
- We extend GPS to more general case of stochastic initial states
- Learns faster/more stably than standard GPS, and significantly outperforms other deep RL



RFGPS outperforms GPS and standard deep RL

11:30–11:35	WeB6.6

Path Integral Guided Policy Search

Yevgen Chebotar[1], Mrinal Kalakrishnan[2], Ali Yahya[2], Adrian Li[2], Stefan Schaal[1], Sergey Levine[3]
[1]University of Southern California, USA [2]X, USA [3]Google Brain, USA

- **Learn complex neural network policies** that map camera images directly to motor torques with guided policy search.
- **Model-free local trajectory optimization** with PI^2 for tasks with discontinuous dynamics and non-differentiable costs.
- **Sample global neural network policies using raw observations** to train on random task instances and increase generalization.

Door opening and Pick-and-place tasks

Policy Search

Chair *Raja Chatila, ISIR*
Co-Chair *Ruben Martinez-Cantin, Centro Universitario de la Defensa*

11:35–11:40	WeB6.7

Deep Reinforcement Learning for Robotic Manipulation with Async Off-Policy Updates

Shixiang Gu and Ethan Holly
Google Brain, University of Tübingen, University of Cambridge
Timothy Lillicrap and Sergey Levine
Google DeepMind, UC Berkeley

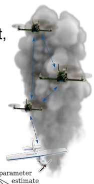
- Learned manipulation policies using Normalized Advantage Function for continuous control Q-learning.
- Demonstrated accelerated learning through parallelized data collection across multiple robotic platforms.
- Learned policies on real-world robots for opening a door in a fixed location.

Door opening with Q learning policy

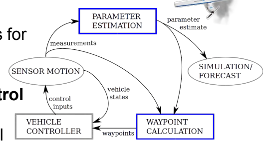
11:40–11:45	WeB6.8

Optimized Vehicle-Specific Trajectories for Cooperative Process Estimation by Sensor-Equipped UAVs

Juliane Euler and Oskar von Stryk
Dept. of Computer Science, Technische Universität Darmstadt, Germany, www.sim.tu-darmstadt.de



- **Sequential optimum design** approach for estimating parameters of an atmospheric dispersion process model
- Provides optimized waypoint sequences for **cooperating sensor-equipped UAVs**
- **Decentralized data-driven online control** scheme coupling parameter estimation, waypoint calculation, and vehicle control
- Effectiveness demonstrated in simulations



Robotic Manipulation

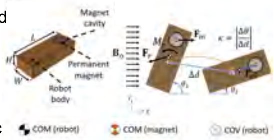
Chair *Rüdiger Dillmann, Karlsruhe Institute of Technology (KIT)*
Co-Chair *Metin Sitti, Max-Planck Institute for Intelligent Systems*

11:05–11:10	WeB7.1

Design and Actuation of a Magnetic Millirobot under a Constant Unidirectional Magnetic Field

Onder Erin[1,2], Joshua Giltinan[1,2], Luke Tsai[2], and Metin Sitti[1,2]
[1]Max Planck Institute for Intelligent Systems, Stuttgart, Germany
[2]Mechanical Engineering Department, Carnegie Mellon University, USA

- MRI-compatible 3-DOF translational and rotational actuation of an untethered magnetic robot on a 2D surface
- Magnet orientation is independent from robot orientation.
- Translation and rotation of the magnetic robot is accomplished by using planar magnetic pulling forces.
- The dependence of the coupling ratio with the magnetic actuation signal and robot dimensions is studied.



Depiction of the magnetic robot

11:10–11:15	WeB7.2

Efficient Kinematic Planning for Mobile Manipulators with Non-holonomic Constraints Using Optimal Control

Markus Giftthaler, Farbod Farshidian, Timothy Sandy, Lukas Stadelmann and Jonas Buchli
Agile & Dexterous Robotics Lab
ETH Zürich, Switzerland

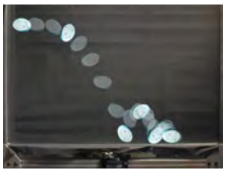
- Constrained Sequential Linear Quadratic Optimal Control for Kinematic Trajectory Planning
- Efficiency through linear time-complexity
- Constraint-consistent kinematic feedback laws
- 100 Hz replanning frequency in a real-world experiment on a tracked mobile manipulator

11:15–11:20	WeB7.3

Empirical Evaluation of Common Contact Models for Planar Impact

Nima Fazeli, Elliott Donlon, and Alberto Rodriguez
Mechanical Engineering Department, MIT, USA
Evan Drumwright
Toyota Research Institute, USA

- Experimental evaluation of contact model prediction for planar impact.
- A post-hoc hybrid model outperforms any single model, indicating consensus models may outperform individual models.
- Perturbation analysis demonstrates the limits of predictions of models and possible bifurcation of predictions.



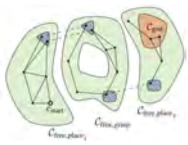
Example of a planar impact

11:20–11:25	WeB7.4

Optimal, Sampling-Based Manipulation Planning

Philipp S. Schmitt, Werner Neubauer, Wendelin Feiten, Kai M. Wurm and Georg v. Wichert
Siemens Corporate Technology, Germany
Wolfram Burgard
Autonomous Intelligent Systems, University of Freiburg, Germany

- Robotic manipulation requires reasoning about a sequence of grasps, placements and robot motions.
- These sequences form paths in the combined configuration space of robot and object.
- We propose a manipulation planner that determines these paths in an asymptotically optimal manner.
- Extensive simulations show significant outperformance of an existing approach.



Roadmap construction for a pick and place task

11:25–11:30	WeB7.5

Design of a Simplified Compliant Anthropomorphic Robot Hand

Tuomas Wiste
ELI Beamlines, CZ
Michael Goldfarb
Center for Intelligent Mechatronics, Vanderbilt University, USA

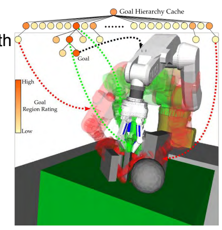
- Self-contained and compliantly actuated
- Low grasp impedance
- 5 motors
- Novel bidirectional underactuated finger design that biases actuator force toward finger flexion
- Additive manufactured
- Low cost and weight
- High durability
- Readily applied to variety of platforms

11:30–11:35	WeB7.6

Integrating Motion and Hierarchical Fingertip Grasp Planning

Joshua A. Haustein, Kaiyu Hang and Danica Kragic
Robotics, Perception, and Learning Lab
KTH Royal Institute of Technology, Sweden

- We integrate hierarchical **fingertip grasp** with **motion planning** for grasping in clutter.
- Our algorithm simultaneously explores a robot's hand-arm configuration space as well as a grasp space.
- The grasp search is guided by proximity to collision-free configurations explored in the motion planning process.



Robotic Manipulation

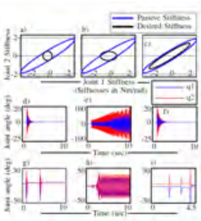
Chair *Rüdiger Dillmann, Karlsruhe Institute of Technology (KIT)*
Co-Chair *Metin Sitti, Max-Planck Institute for Intelligent Systems*

11:35–11:40	WeB7.7

Analyzing Achievable Stiffness Control Bounds of Robotic Hands With Coupled Finger Joints

Prashant Rao, Gray Thomas, Luis Sentis and Ashish D. Deshpande
Mechanical Engineering, The University of Texas at Austin, USA

- Tendon-driven multi-DOF robotic fingers have coupled joint stiffness.
- Proposed passivity analysis of achievable stiffness control bounds for such fingers.
- Results show that maximum controller stiffness is bounded by passive stiffness.
- Such analysis can lead to intelligent mechanical design of robotic fingers with intrinsic stability.



11:40–11:45	WeB7.8

A Two-Fingered Robot Gripper with Large Object Reorientation Range

Walter G. Bircher and Aaron M. Dollar
Department of Mechanical Engineering and Materials Science
Yale University, USA
Nicolas Rojas
Dyson School of Design Engineering, Imperial College, UK

- Kinematic design optimizations result in a gripper able to reorient an object over $\pi/2$ rad
- No contact sensors, active finger surfaces, or complex control systems
- One actuator per finger, each finger has 2DoF
- The GR2 Gripper provides a simple solution for applications demanding a large range of object reorientation without complexity

Humanoid Robots 1

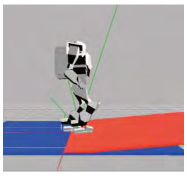
Chair *J.W Grizzle, University of Michigan*
Co-Chair *Ko Yamamoto, University of Tokyo*

11:05–11:10	WeB8.1

Robust Walking by Resolved Viscoelasticity Control Explicitly Considering Structure-Variability of a Humanoid

Ko Yamamoto
Department of Mechanical Engineering, University of Tokyo, Japan

- The author extends the previous work on the resolved viscoelasticity control (RVC) by considering structure-variability.
- The method now considers an open kinematic chain in the single support phase and a closed kinematic chain in the double support phase.
- This extension helps realize stable and robust walking motion on uneven terrains.
- The proposed method is validated using forward dynamics simulations.



Walking on a slope is realized by the RVC method.

11:10–11:15	WeB8.2

Context-Driven Movement Primitive Adaptation

Daniel Wilbers[1] and Rudolf Lioutikov[1] and Jan Peters[1,2]
[1]Intelligent Autonomous Systems, TU Darmstadt, Germany
[2]Max Planck Institute Tuebingen

- We optimize trajectory distributions to environment changes while staying close to human demonstrations
- Simultaneously learning activations for different primitives allows us to adapt to unseen situations
- Our optimization is a new REPS variant, which bounds the KL-Divergence to demonstrations.
- Applied within the ProMP framework

Avoiding an obstacle with a context-adapted primitive.

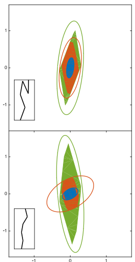
11:15–11:20	WeB8.3

11:20–11:25	WeB8.4

Dynamic Manipulability of the Center of Mass

Morteza Azad[1], Jan Babic[2] and Michael Mistry[3]
[1]University of Birmingham, UK
[2]Jozef Stefan Institute, Slovenia
[3]University of Edinburgh, UK

- Tool to study, analyse and measure physical ability of robots to accelerate the CoM.
- Velocity independent metric which depends only on configuration and inertial parameters.
- Evaluates a robot's physical ability independent of any choice of controller.
- Proper tool to study physical ability of legged robots to balance.



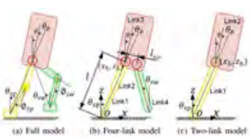
Manipulability with different weighting matrices

11:25–11:30	WeB8.5

A Study of Nonlinear Forward Models for Dynamic Walking

Yangwei You, Chengxu Zhou and Nikos Tsagarakis
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy
Zhibin Li
School of Informatics, University of Edinburgh, United Kingdom

- Constrained COM height is no longer required resulting more natural gaits;
- Leg dynamics is taken into account;
- Leg kinematics is included which eliminates the knee singularity issue;
- The change of mechanical energy due to ground impact is included;
- Actuator dynamics can be incorporated into the forward simulation.



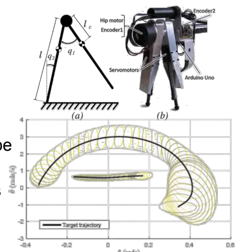
Two nonlinear models derived from a full robot model.

11:30–11:35	WeB8.6

Invariant Funnels for Underactuated Dynamic Walking Robots

Justin Z. Tang, A. Mounir Boudali and Ian R. Manchester
Australian Centre for Field Robotics (ACFR), University of Sydney, Australia

- This paper addresses the problem of finding useful invariant funnels for dynamic walking robots.
- We show that for typical models of walking robots the construction of such funnels can be significantly simplified.
- Hardware verification of the resulting funnels are also presented.



Top: walking robot used
Bottom: verified funnel

Humanoid Robots 1

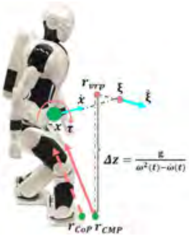
Chair *J.W Grizzle, University of Michigan*
Co-Chair *Ko Yamamoto, University of Tokyo*

11:35–11:40	WeB8.7

Robust Bipedal Locomotion Control Based on Model Predictive Control and Divergent Component of Motion

Milad Shafiee-Ashtiani, Aghil Yousefi-Koma and Masoud Shariat-Panahi
Center of Advanced Systems and Technologies(CAST), University of Tehran, Iran.

- We employ a single MPC which uses a combination of **CoP** and **CMP** modulation and **step adjustment** to design a robust walking controller.
- we exploit the concept of **time-varying DCM** to generalize our walking controller for walking on uneven surfaces.
- Performance verified on **push recovery** simulations for walking on surfaces with a very **limited feasible area for stepping** (such as rock)



11:40–11:45	WeB8.8

The Energetic Benefit of Robotic Gait Selection A Case Study on the Robot RAMone

Nils Smit-Anseeuw, Rodney Gleason, Ram Vasudevan and C. David Remy
Mechanical Engineering, University of Michigan, USA

- Energy optimal gaits found across range of speeds for realistic model of RAM*one*
- Compass gait walking is optimal at low speeds
- Spring mass running with backwards knees is optimal at high speeds
- Both gaits show striking similarity to biological equivalents

Biologically-Inspired Robots 1

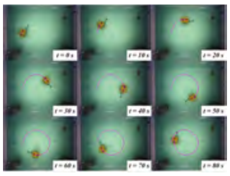
Chair *Inaki Rano, Ulster University*
Co-Chair *Fengzhen Tang, Shenyang Institute of Automation， Chinese Academy of Sciences*

11:05–11:10	WeB9.1

Path Following for a Biomimetic Underwater Vehicle Based on ADRC

Rui Wang, Shuo Wang, Yu Wang, and Chong Tang
State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, China

- Biomimetic underwater vehicles (BUVs), stronger disturbance rejection, more excellent maneuverability, and quieter actuation
- Close-loop control law for a BUV propelled by undulatory fins to ensure path following
- Line-of-sight guidance system decouples the system to steer the surge speed and the course respectively
- Active disturbance rejection control is used in development of surge speed controller and course controller



11:10–11:15	WeB9.2

A Drift Diffusion Model of Biological Source Seeking for Mobile Robots

Inaki Rano and Kongfatt Wong-Lin
Intelligent Systems Research Centre, Ulster University, UK
Mehdi Khamassi
ISIR, University Pierre & Marie Curie, France

- Animals excel at target reaching even under adverse conditions
- We extend a model of biological source seeking to include sensor noise
- The analysis of the corresponding non-linear SDE shows:
  - Differences between the deterministic model and stochastic average
  - Bound in the dispersion (2nd moment)
- Results of interest for: bio-robotics, low-cost robots, micro robots

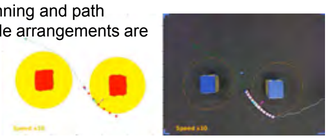
Example of animal target reaching in adverse conditions

11:15–11:20	WeB9.3

Closed-Loop Path Following of Traveling Wave Rectilinear Motion Through Obstacle-Strewn Terrain

Alex H. Chang and Patricio A. Vela
School of ECE, Georgia Institute of Tech., United States

- Derived dynamics of a traveling wave rectilinear gait lead to a mapping from gait parameter space to averaged steady-behavior body velocity
- The system bears resemblance to a fixed forward-velocity unicycle
- Average body curvature serves as the control input driving angular velocity of the system
- Using this approach, motion planning and path following through various obstacle arrangements are successfully completed

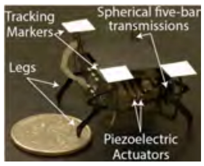


11:20–11:25	WeB9.4

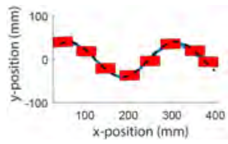
High speed trajectory control using an experimental maneuverability model for an insect-scale legged robot

Benjamin Goldberg, Neel Doshi, and Robert J Wood
Harvard University, Cambridge, MA, USA

- Holonomic trajectory following with a legged microrobot
- Towards a highly maneuverable, autonomous, insect-scale robot



(a)



(b)

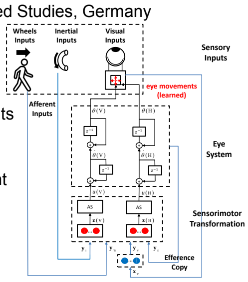
(a) Harvard Ambulatory MicroRobot
(b) Holonomic trajectory following

11:25–11:30	WeB9.5

Learning Multisensory Cue Integration on Mobile Robots

Chong ZHANG and Bertram E. SHI
Department of Electronic and Computer Engineering, Hong Kong University of Science and Technology, Hong Kong
Jochen TRIESCH
Frankfurt Institute for Advanced Studies, Germany

- We have proposed a bio-inspired robotic system to learn multisensory integration and image stabilization.
- Our model learns autonomously and accounts for the development of both multimodal sensory processing and motor action.
- Instead of giving fixed weights to the different sensory cues, our model learns the weights automatically.

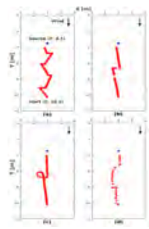


11:30–11:35	WeB9.6

Adaptive Lévy-taxis for Odor Source Localization in Realistic Environmental Conditions

Romain Emery, Faezeh Rahbar, Ali Marjovi, Alcherio Martinoli
Distributed Intelligent Systems and Algorithms Laboratory, EPFL, Switzerland

- Designed a new algorithm called Adaptive Lévy-Taxis (ALT) to address odor plume tracking.
- ALT compared with three well-established algorithms inspired by moth behaviors (casting, surging towards the wind, and spiraling).
- All the methods thoroughly evaluated in a wind tunnel under various environmental conditions (different wind speeds and odor source concentrations).
- ALT shows consistently good performances under all environmental conditions.



Sample trajectories by all 4 algorithms: (a) casting (b) surge-cast, (c) spiral-surge (d) ALT

Biologically-Inspired Robots 1

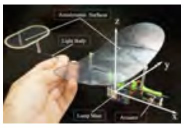
Chair *Inaki Rano, Ulster University*
Co-Chair *Fengzhen Tang, Shenyang Institute of Automation， Chinese Academy of Sciences*

11:35–11:40	WeB9.7

From *Rousettus aegyptiacus* (bat) Landing to Robotic Landing: Regulation of CG-CP Distance Using a Nonlinear Closed-Loop Feedback

Usman A. Syed, Alireza Ramezani and Seth Hutchinson
University of Illinois Urbana-Champaign, USA
Soon Jo Chung
Graduate Aerospace Laboratory, California Institute of Technology, USA

- Bats perform agile maneuvers such as roosting (landing) with great composure.
- Reconstructing bat landing maneuvers with a Micro Aerial Vehicle (MAV) called *Allice.*
- *Allice* is capable of adjusting the position of its CG with respect to its CP using a nonlinear closed-loop feedback.
- The input-output feedback linearization based nonlinear control law, enables attitude regulations through variations in CG-CP distance.



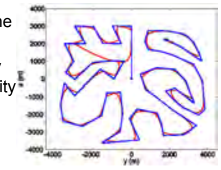
Allice:1-DoF robotic platform used to validate the landing model of a bat

11:40–11:45	WeB9.8

A Prey-Predator Model for Efficient Robot Tracking

Fengzhen Tang and Bailu
State Key Laboratory of Robotics, Shenyang Institute of Automation, Chinese Academy of Science, China
Daxiong Ji
Ocean College, Zhejiang University, China

- Novel robotic tracking strategy inspired by the hunting strategies of predators
- Heading and speed of pursuer automatically adjusted according to the position and velocity of prey
- Three prediction methods for missing observations of prey with various trajectory types
- Tracking simulations under two scenarios demonstrating the efficiency of the proposed tracking scheme



Tracking trajectory

Session WeB10 | Rm. 4911/4912 | Wednesday, May 31, 2017, 11:05–12:20

Medical Robots and Systems 5

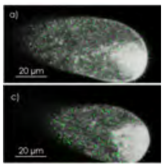
Chair *Max Q.-H. Meng, The Chinese University of Hong Kong*
Co-Chair *Ren Luo, National Taiwan University*

11:05–11:10 WeB10.1

In Vivo Tracking and Measurement of Pollen Tube Vesicle Motion

Chengzhi Hu, Jan T. Burri, Naveen Shamsudhin and Bradley J. Nelson
Institute of Robotics and Intelligent Systems, ETH Zurich, Switzerland
Hannes Vogler and Ueli Grossniklaus
Department of Plant and Microbial Biology University of Zurich, Switzerland

- Optical flow methods with the KLT tracker are studied to solve the difficulties for in vivo vesicle tracking and its motion detection in growing pollen tubes.
- Grid filtering is used to eliminate the effect of bidirectional movement of vesicles, resulting in an improved estimate of vesicle flow speed.
- Both the optical and fluorescent images can be processed.



11:10–11:15 WeB10.2

Development of a Tele-Nursing Mobile Manipulator for Remote Care-Giving in Quarantine Areas

Peter Moran, Qingyuan Dong, Ryan Shaw and Kris Hauser
Electrical and Computer Department, Duke University, USA
Zhi Li
Robotics Engineering, Worcester Polytechnic Institute, USA

- We developed a Tele-Robotic Intelligent Nursing Assistant (**TRINA**) in response to the need of patient-caring for highly infectious diseases (e.g. Ebola).
- **TRINA** is developed to be human-safe, versatile, usable by novices, rapidly assembled, and relatively inexpensive.
- We evaluated **TRINA**'s capability on 26 frequently performed nursing tasks in a simulated patient room at the Nursing School of Duke University.

Tele-Robotic Intelligent Nursing Assistant (TRINA)

11:15–11:20 WeB10.3

Autonomous Scanning for Endomicroscopic Mosaicing and 3D Fusion

Lin Zhang, Menglong Ye, Petros Giataganas, Michael Hughes and Guang-Zhong Yang
The Hamlyn Centre for Robotic Surgery, Imperial College London, UK

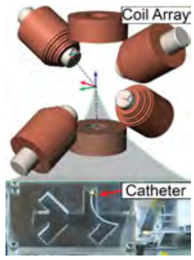
- Automation of surgical robots provides augmented ability, allowing surgeons to perform surgical task more accurately and intuitively.
- An autonomous system for endomicroscopy scanning and mosaicing using the da Vinci surgical robot is proposed.
- Laparoscopic and microscopic images are used to servo the robot.
- 3D fusion of surface reconstruction and cellular-scale endomicroscopy mosaic images.

11:20–11:25 WeB10.4

Introducing BigMag – A Novel System for 3D Magnetic Actuation of Flexible Surgical Manipulators

J. Sikorski[1], I. R. Dawson[1], A. Denasi[1], E.E.G. Hekman[1] and S. Misra[1,2]
[1]University of Twente, The Netherlands [2]University of Groningen and University Medical Center Groningen, The Netherlands

- We present an array of rotating electromagnetic coils for magnetic steering of surgical continuum manipulators.
- We derive, calibrate and validate a mathematical model of the magnetic field within the workspace of the device.
- The field is estimated with an average error of 15.21 % (magnitude) and 9.40° (direction).
- We demonstrate user-controlled steering of continuum manipulators using BigMag.



11:25–11:30 WeB10.5

Experimental Validation of the Pseudo-Rigid-Body Model of the MRI-Actuated Catheter

Tipakorn Greigarn, Russell Jackson, Taoming Liu, M. Cenk Cavusoglu
Department of Electrical Engineering and Computer Science
Case Western Reserve University, USA

- This paper presents experimental validation and parameter optimization of the Pseudo-Rigid-Body (PRB) model of the MRI-Actuated Catheter.
- The parameters of the PRB model is first optimized to improve its accuracy without increasing the degrees of freedom of the model.
- The PRB models with standard and optimal parameters are validated with experimental data.

Experimental setup of the Catheter

11:30–11:35 WeB10.6

Robot Assisted Tapping Control for Therapeutical Percussive Massage Applications

Ren C. Luo, Chin-Po Tsai and Kai-Chun Hsieh
International Center of Excellence on Intelligent Robotics and Automation Research(iCeiRA), Nation Taiwan University, Taiwan

- A well massage tapping could be determined by force, contact time and impulse.
- Cartesian impedance control is utilized to control both the position and force during robotic massage.
- Virtual target points are implemented to adjust the force to ingratiate different desired forces.
- Our work demonstrates that the robotic tapping motion for therapeutical percussive massage is feasible.

Medical Robots and Systems 5

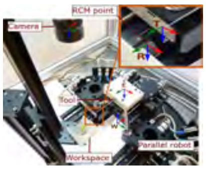
Chair *Max Q.-H. Meng, The Chinese University of Hong Kong*
Co-Chair *Ren Luo, National Taiwan University*

11:35–11:40 WeB10.7

Visual Servoing Controller for Time-Invariant 3D Path Following with Remote Centre of Motion Constraint

Bassem Dahroug and Brahim Tamadazte and Nicolas Andreff
FEMTO-ST Institute, AS2M department, Univ. Bourgogne Franche-Comte/CNRS/ENSMM, Besançon, France

- Formulate a geometric method for describing the Remote Centre of Motion (RCM) in the task-space
- Perform the RCM movement along side the path following controller under the vision guidance
- Show the stability of the path following controller



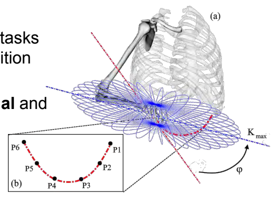
Experimental system configuration with the various reference frames.

11:40–11:45 WeB10.8

Analysis of joint and hand impedance during teleoperation and free-hand task execution

Jacopo Buzzi, Cecilia Gatti, Giancarlo Ferrigno, Elena De Momi
Department of Electronics, Informatics and Bioengineering, Politecnico di Milano, Italy

- **Non disruptive** hand **stiffness matrix estimation** during simulated **suturing** tasks based on users' arm kinematics acquisition
- **Comparison** between **free-hand** and **teleoperated** tasks execution with **serial** and **parallel** link **master** device in terms of:
  - Task **performance**
  - **Maximal** stiffness
  - Stiffness **orientation**



Service Robotics 1

Chair *Shaojie Shen, Hong Kong University of Science and Technology*
Co-Chair *Pablo Valdivia y Alvarado, Singapore University of Technology and Design, MIT*

11:05–11:10 WeB11.1

Deep Fruit Detection in Orchards

Suchet Bargoti and James Underwood
Australian Centre for Field Robotics, The University of Sydney, Australia

- Fruit detection on outdoor orchard images using the Faster R-CNN detection architecture.
- Analysis of data augmentation strategies and transfer learning between orchards.
- Modified framework for detecting over 1000 fruit on high resolution images.
- Published datasets for different fruit and an annotation toolbox[1].


Detecting apples, mangoes and almonds.

[1] http://data.acfr.usyd.edu.au/ag/treecrops/2016-multifruit

11:10–11:15 WeB11.2

The Robotanist: A Ground-Based Agricultural Robot for High-Throughput Crop Phenotyping

Tim Mueller-Sim, Merritt Jenkins, Justin Abel, and George Kantor
The Robotics Institute, Carnegie Mellon University, United States of America

- Design of a novel robotic ground-based sensor platform for crop phenotyping.
- Capable of autonomously navigating below the canopy of row crops such as sorghum or maize.
- Utilizes a custom manipulator to collect contact measurements of the plant.
- Deployed and tested in several *Sorghum bicolor* test plots across South Carolina, USA.

11:15–11:20 WeB11.3

Autonomous Sweet Pepper Harvesting for Protected Cropping Systems

Christopher Lehnert, Andrew English, Christopher McCool, Adam W. Tow and Tristan Perez
School of Electrical Engineering and Computer Science
Queensland University of Technology, Australia

- We present a new robotic harvester (Harvey) that can autonomously harvest sweet pepper in protected cropping environments.
- Scans, detects crop, selects grasp and cutting poses and then attaches and detaches fruit using novel harvesting tool
- Field trials in a real greenhouse environment demonstrate a 58% harvest success rate.

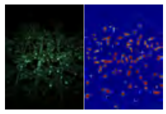

Above is Harvey which can harvest sweet peppers autonomously.

11:20–11:25 WeB11.4

Counting Apples and Oranges with Deep Learning: A Data Driven Approach

Steven W Chen, Shreyas S Shivakumar, Sandeep Dcunha*
Jnaneshwar Das, Edidiong Okon, Chao Qu
Camillo J Taylor, and Vijay Kumar
GRASP Laboratory, University of Pennsylvania, USA
*University of Masschusetts, Amherst, USA

- http://label.ag, a web-based **crowd-sourced labeling** framework to quickly collect ground-truth labels and store in SVG format
- Fully Convolutional Network (FCN) to **segment** fruit clusters from images
- Convolutional Network (CNN) to **count** number of fruit in each cluster


Nighttime Apple: **Left** original image; **Right** segmented fruit clusters

11:25–11:30 WeB11.5

Improving Octree-Based Occupancy Maps using Environment Sparsity with Application to Aerial Robot Navigation

Jing Chen and Shaojie Shen
ECE Department, HKUST, Hong Kong, China

- We equipped the octree-based occupancy map with two operations:
  1. accelerated ray tracing update
  2. efficient volumeric occupacny query
- It significantly outperforms OctoMap, taking advantages of the octree structure
- it is integrated in a complete navigation pipeline for autonomous flight in cluttered environments

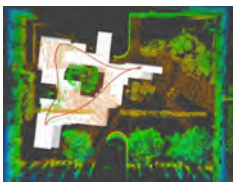


Illustration of the oocupancy map and the generated trajectory for autonomous flight

11:30–11:35 WeB11.6

Feasibility Study of IoRT Platform "Big Sensor Box"

Ryo Kurazume[1], Kazuto Nakashima[1], Akihiro Kawamura[1]
[1] ISEE, Kyushu University, Japan
Yoonseok Pyo[2], Tokuo Tsuji[3]
[2] ROBOTIS Co., Ltd, Korea
[3] Mechanical Engineering, Kanazawa University, Japan

- ROS-based CPS (Cyber Pysical System) software platform named "ROS-TMS ver.4.0" is introduced.
- Hardware platform for an informationally structured environment named "Big Sensor Box" is proposed.
- Robot service experiments using ROS-TMS and Big Sensor Box are successfully conducted.


Big Sensor Box

Service Robotics 1

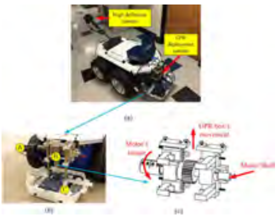
Chair *Shaojie Shen, Hong Kong University of Science and Technology*
Co-Chair *Pablo Valdivia y Alvarado, Singapore University of Technology and Design, MIT*

11:35–11:40	WeB11.7

Autonomous Robotic System using Non-Destructive Evaluation methods for Bridge Deck Inspection

Tuan Le, Spencer Gibb, Nhan Pham, Hung La, Logan Falk, and Tony Berendsen
University of Nevada, Reno, Nevada, USA

- This paper presents an autonomous robotic system integrated with multiple non-destructive evaluation (NDE) sensor for bridge deck inspection.
- Automated rebar detection algorithm based on machine learning for ground penetrating radar (GPR) is developed.
- The robot is able to provide automated bridge deck condition maps during inspection.



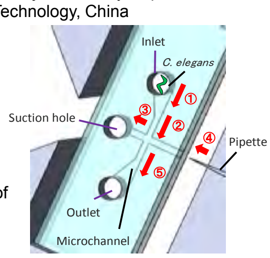
Bridge Deck Inspection Robot

11:40–11:45	WeB11.8

High-Precision Microinjection of Microbeads into *C. elegans* Trapped in a Suction Microchannel

Masahiro Nakajima[1], Yuki Ayamura[1], Masaru Takeuchi[1], Naoki Hisamoto[1], Strahil Pastuhov[1], Yasuhisa Hasegawa[1], Toshio Fukuda[2,3], Qiang Huang[3]
[1]Nagoya University, Japan, [2]Meijo University, Japan, [3]Beijing Institute of Technology, China

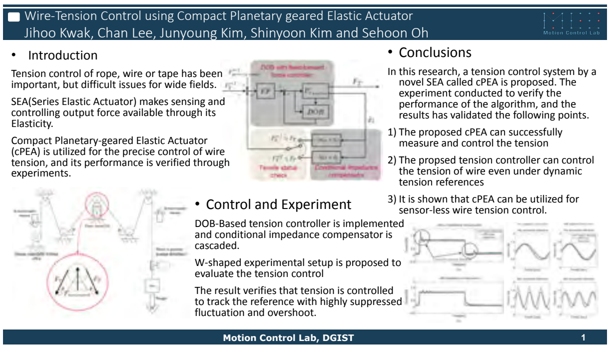
- High-precision microinjection of fluorescent micro-gel beads into *Caenorhabditis elegans (C. elegans)* trapped in a suction microchannel
- The focal plane of the target nerve axon matches that of the fluorescent microbead in the microinjection tool,
- The head-first navigation alignment of *C. elegans* along the microchannel was controlled by electrotaxis.



Tendon/Wire Robotics

Chair *Sunil Agrawal, Columbia University*
Co-Chair *Domenico Campolo, Nanyang Technological University*

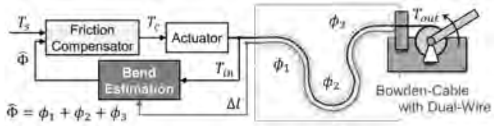
14:30–14:35	WeC1.1



14:35–14:40	WeC1.2

A Feasibility Study on Tension Control of Bowden-Cable Based on a Dual-Wire Scheme

Useok Jeong and Kyu-Jin Cho
School of Mechanical and Aerospace Engineering, Seoul National University, Korea



- **Changing friction** of the **Bowen-cable** depending on the bend angle of the cable restricts the size and simple design of the robot.
- A novel **bend sensing** method is proposed that takes advantage of the position error of the Bowden-cable.
- **Output tension** of the Bowden-cable can be controlled **without the output force sensor** using the friction compensation with the bend estimation.

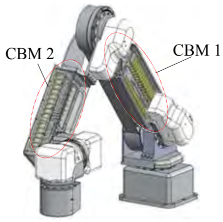
14:40–14:45	WeC1.3

Design of a 6-DOF Collaborative Robot Arm with Counterbalance Mechanisms

Won-Bum Lee, Sang-Duck Lee, and Jae-Bok Song
School of Mechanical Engineering, Korea University, Republic of Korea

- Collaborative robot arm with 6 DOFs.
- Multi-DOF counterbalance mechanism based on double parallelogram linkage is embedded inside the robot links.
- The use of counterbalance mechanisms saves the energy consumption of the robot in various tasks.

CBM: Counterbalance mechanism



14:45–14:50	WeC1.4

Position and Orientation Control of Passive Wire-Driven Motion Support System Using Servo Brakes

Yasuhisa Hirata, Ryo Shirai, and Kazuhiro Kosuge
Department of Robotics, Tohoku University, Japan

- We developed a passive wire-driven motion support system without any motors.
- The system can adjust the wire tension by controlling 7 servo brakes.
- It ensures a safe interaction as the main driving force is applied by the user.
- It can support the user while following a target form by a passive control method considering both position and orientation.

Passive Wire-Driven System for Tennis Beginner

14:50–14:55	WeC1.5

Using Compliant Leg Designs for Impact Attenuation of Airdrop Landings of Quadruped Robots

Yeeho Song and Dirk Luchtenburg
Mechanical Engineering, Cooper Union for the Advancement of Science and Art, USA

- Compliant legs are designed for both walking and airdrop impact attenuation.
- Lumped element models are used for design and analysis.
- Experiments confirm that these models are useful for initial design.
- Experiment show that compliant legs perform better than rigidly actuated legs with active damping.

Picture of the Robot used for the Research

14:55–15:00	WeC1.6

Passive Returning Mechanism for Twisted String Actuators

Muhammad Usman, Bhivraj Suthar, Hyunseok Seong, Igor Gaponov and Jee Hwan Ryu
Mechanical Engineering, KoreaTech, Rep. of Korea
Elliot Hawkes
Mechanical Engineering, University of California, Santa Barbara, CA, USA

- **Two passive buckling** return mechanisms are proposed for bi-directional actuation of **twisted string actuators**
- Utilizing the **beam buckling** concept, a near **constant stiffness** spring is made which assists TSA in untwisting
- Dynamic and kinematic properties of both mechanisms are experimentally evaluated and compared

Passive return mechanism : slit mechanism (right) | Telescopic mechanism (left)

Tendon/Wire Robotics

Chair *Sunil Agrawal, Columbia University*
Co-Chair *Domenico Campolo, Nanyang Technological University*

15:00–15:05	WeC1.7

Designing Anthropomorphic Robot Hand with Active Dual-Mode Twisted String Actuation Mechanism and Tiny Tension Sensors

Seok-Hwan Jeong, Kyung-Soo Kim and Soohyun Kim
Mechanical Engineering, KAIST, Ref. Korea

- Design of Anthropomorphic Robot Hand
- Miniature Power transmission mechanism (wide operating area)
- Twisted String Actuation (TSA) mechanism
- Tiny tension sensor based on Photo-interrupter
- Force feed-back control

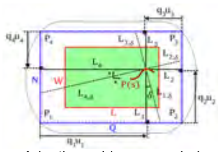
Robot Hand based on TSA mechanism

15:05–15:10	WeC1.8

Performance Evaluation of a New Design of Cable-Suspended Camera System

Saeed Abdolshah, Univ. of Padova, Italy
Damiano Zanotto, Stevens Inst. of Technology, USA
Giulio Rosati, Univ. of Padova, Italy
Sunil Agrawal, Columbia University, USA

- We investigated the application of adaptive cable-driven robots to cable-suspended camera systems
- Results show that the adaptive design outperforms the traditional one in terms of dexterity, elastic stiffness index, and stiffness magnitude.
- A method is presented to derive the smallest adaptive design capable of achieving ideal dexterity and target levels of stiffness within a given workspace.



Adaptive cable-suspended camera system

Motion and Path Planning 1

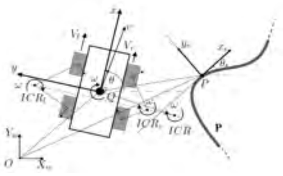
Chair *Daniel D. Lee, University of Pennsylvania*
Co-Chair *Leslie Kaelbling, MIT*

14:30–14:35	WeC2.1

Path Following Control of Skid-Steered Wheeled Mobile Robots at Higher Speeds on Different Terrain Types

Goran Huskić and Sebastian Buck and Andreas Zell
Chair of Cognitive Systems, University of Tübingen, Germany

- A new nonlinear path following control law for skid-steered robots at higher speeds (up to 2.5 m/s) is proposed
- Robotnik Summit XL is used in the experimental evaluation
- Comparison with two state-of-the-art algorithms is made
- Experiments are conducted in three different terrain scenarios (grass, vinyl, and macadam)

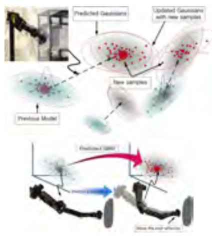


14:35–14:40	WeC2.2

Adaptive Motion Planning with High-Dimensional Mixture Models

Jinwook Huh, Bhoram Lee, and Daniel D. Lee
GRASP, University of Pennsylvania, USA

- Adaptive approach to fast sampling-based motion planning by **learning Gaussian mixture models (GMMs) of collision and collision-free regions** in configuration spaces
- **Rapidly adaptation to environmental changes** by using inverse kinematics to transform the parameters of the GMMs
- The transformed model is **continually updated and refined** as the RRT planning algorithm proceeds in real-time
- **Computationally efficient** compared with traditional approaches on a number of experimental robot arm planning scenarios



The prediction and update

14:40–14:45	WeC2.3

On-line Trajectory Planning with Time-variant Motion Constraints for Industrial Robot Manipulators

Ran Zhao and Svetan Ratchev
Institute for Aerospace Manufacturing
Faculty of Engineering, University of Nottingham, UK

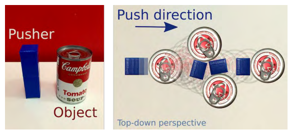
- An algorithm is proposed to generate trajectories with non-constant kinematic constraints.
- Dealing with an arbitrary state of motion whose values exceed the kinematic constraints.
- Simple and computational efficiency.
- An extension of the current cubic-polynomial trajectory planning library.

14:45–14:50	WeC2.4

Focused Model-Learning and Planning for Non-Gaussian Continuous State-Action Systems

Zi Wang Stefanie Jegelka
Leslie Pack Kaelbling Tomás Lozano-Pérez
Computer Science and Artificial Intelligence Laboratory,
Massachusetts Institute of Technology, USA

- A new framework for model learning and planning for continuous state-action and non-Gaussian transitions
- Flexible interface for learning models
- Planner BOIDP uses learned models efficiently via “lazy access” and focused computation on relevant states and actions
- Theoretical and empirical results shows the asymptotic optimality and the effectiveness of our method.



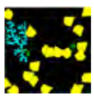
A quasi-static pushing problem: the pusher has a velocity controller with low gain, resulting in non-Gaussian transitions.

14:50–14:55	WeC2.5

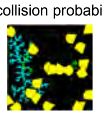
Dynamic Risk Tolerance: Motion Planning by Balancing Short-term and Long-Term Stochastic Dynamic Predictions

Hao-Tien Chiang[1], Baisravan HomChaudhuri[2], Abraham Vinod[2], Meeko Oishi[2] and Lydia Tapia[1]
[1]Computer Science Dept., University of New Mexico, USA
[2]Electrical & Computer Engineering Dept., University of New Mexico, USA

- Dynamic Risk Tolerance (DRT) planning balances avoidance of imminent collision with long-term plans in environments with stochastic dynamic obstacles
- DRT achieves this through a time-varying upper bound on acceptable collision probability of states along a path
- Obstacle prediction done by Forward Stochastic Reachable sets and Monte Carlo simulation
- Empirically evaluated in crowded environments with fast and stochastically moving obstacles



RRT with constant bound of collision probability



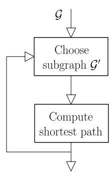
RRT with DRT

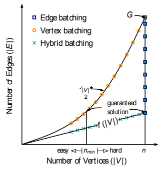
14:55–15:00	WeC2.6

Densification Strategies for Anytime Motion Planning over Large Dense Roadmaps

__Shushman Choudhury__, Oren Salzman, Sanjiban Choudhury and Siddhartha Srinivasa
The Robotics Institute, Carnegie Mellon University, USA

- Search **increasingly dense r-disk subgraphs** of the complete roadmap
- Edge Batching (EB): Use **all vertices** and **add edges** by increasing **r**
- Vertex Batching (VB): **Increase** number of **vertices** and use **all edges** each time
- Hybrid Batching (HB): Add **both vertices and edges** based on dispersion
- We **empirically validate** our analysis on random scenarios in $\mathbb{R}^2$ and $\mathbb{R}^4$ and on **manipulation planning** problems





Theoretical Analysis

EB has **better** effort-quality tradeoff for **low-clearance**, and
VB for **high-clearance** problems.
HB tries to **balance.**

Motion and Path Planning 1

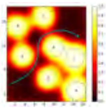
Chair *Daniel D. Lee, University of Pennsylvania*
Co-Chair *Leslie Kaelbling, MIT*

15:00–15:05	WeC2.7

Stochastic Functional Gradient for Motion Planning in Continuous Occupancy Maps

Gilad Francis, Lionel Ott and Fabio Ramos
The School of Information Technologies, University of Sydney, Australia

- Functional gradient path optimisation in continuous occupancy maps – instead of sampling-based methods (RRT, PRM, etc.)
- Utilises stochastic samples as path support to ensure optimisation convergence.
- Expolits continuous map for fast, online gradient computation.

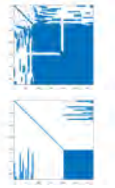


15:05–15:10	WeC2.8

Consistent Sparsification for Efficient Decision Making Under Uncertainty in High Dimensional State Spaces

Khen Elimelech
Robotics and Autonomous Systems Program (TASP), Technion, Israel
Vadim Indelman
Department of Aerospace Engineering, Technion, Israel

- Using a sparse version of the information matrix to examine candidate actions.
- The sparse approximation is action-consistent, i.e. has no influence on the action selection.
- Maintaining the same quality of solution, while reducing the computational complexity.
- A significant improvement in runtime in a SLAM simulation.



Sparsification Example

Visual Servoing

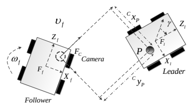
Chair *Peter Corke, QUT*
Co-Chair *Francois Chaumette, Inria Rennes-Bretagne Atlantique*

14:30–14:35	WeC3.1

A Unified Leader-Follower Scheme for Mobile Robots with Uncalibrated On-board Camera

Dejun Guo[1], Hesheng Wang[2], Weidong Chen[2], Ming Liu, Zeyang Xia, and Kam K. Leang[1]
[1]University of Utah Robotics Center, USA
[2] Department of Automation, Shanghai Jiao Tong University, China

- Adaptive image-based leader-follower formation control scheme for mobile robots
- Uncertain camera parameters for either perspective camera or omnidirectional camera
- Lyapunov approach used for stability analysis
- Experimental results show good performance

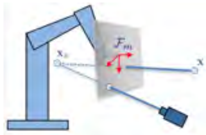


14:35–14:40	WeC3.2

Visual Servoing through mirror reflection

Eric Marchand[1] and François Chaumette[2]
[1]Université de Rennes, IRISA, Rennes France
[2]Inria, IRISA, Rennes, France

- Complete theoretical background of visual servoing through planar mirror reflection
- Able to control a mirror mounted on a robot end-effector
- Proof that, in practice, only 3 mirror d.o.f. are actually controllable
- Experiments using a mirror mounted on the end-effector of a 6 d.o.f robot validates the proposed approaches.

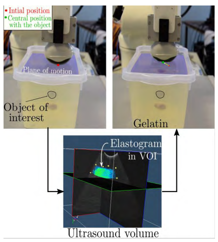


14:40–14:45	WeC3.3

A robotic control framework for 3-D quantitative ultrasound elastography

Pedro A. Patlan-Rosales and Alexandre Krupa
INRIA Rennes-Bretagne Atlantique, France

- Robot control based on **elastic 3-D information** from a volume of interest (VOI) inside a tissue.
- **Teleoperation** of the ultrasound probe orientation using a haptic device to increase the field of view (FOV).
- **Automatic tracking** of stiff tissue in the VOI to keep it in the center of the FOV while teleoperation is performed.



14:45–14:50	WeC3.4

Towards markerless visual servoing of grasping tasks for humanoid robots

Pedro Vicente[1], Lorenzo Jamone[2,1], Alexandre Bernardino[1]
[1]ISR, Técnico-Lisboa, Univ. de Lisboa, Lisbon, Portugal
[2]ARQ, School of Electronic Engineering and Computer Science, Queen Mary University of London, UK

- Eye-to-hand 3D Position-Based Visual Servoing on the iCub humanoid robot:
  - Markerless estimation of the hand pose
  - 3D model-based hand pose estimation with GPU
  - Sequential Monte Carlo parameter estimation
  - Online calibration of the eye-to-hand map
- Open-loop vs Visual Servo Control
  - Grasping task was successful with closed-loop
  - Position error decreased 2X

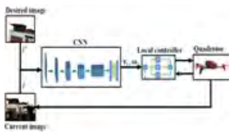
A precise grasping task by the iCub Humanoid Robot

14:50–14:55	WeC3.5

Exploring Convolutional Networks for End-to-End Visual Servoing

Aseem Saxena, Harit Pandya, Gourav Kumar, Ayush Gaud and K. Madhava Krishna
International Institute of Information Technology, Hyderabad, India.

- We aim to learn visual feature representations suitable for servoing tasks in unstructured and unknown environments.
- We present an end-to-end learning based approach for visual servoing in diverse scenes using convolutional neural networks.
- Our approach is able to do visual servoing in the wild where the knowledge of camera parameters and scene geometry is not available apriori.



Given a goal image and current image seen by the robot, our network estimates the velocities required to move the robot towards the goal.

14:55–15:00	WeC3.6

Image-based Visual Servoing with Unknown Point Feature Correspondence

Aaron McFadyen and Peter Corke
Science and Engineering Faculty (SEF), Queensland University of Technology, Australia
Marwen Jabeur
Institute for Flight Mechanics (IFR), University of Stuttgart, Germany

- New image-based visual servoing approach that simultaneously solves the feature correspondence and control problem
- Feature tracking is not required by considering the problem exclusively in the control domain.
- Preliminary experimental results using a small unmanned quadrotor are presented.

Visual control of a quadrotor with non-unique image features (unknown feature correspondence)

Session WeC3 | Rm. 4311/4312 | Wednesday, May 31, 2017, 14:30–15:45

Visual Servoing

Chair *Peter Corke, QUT*
Co-Chair *Francois Chaumette, Inria Rennes-Bretagne Atlantique*

15:00–15:05	WeC3.7

Visual servoing in an optimization framework for the whole-body control of humanoid robots

Don Joven Agravante, Giovanni Claudio, Fabien Spindler, and François Chaumette
Lagadic group, Inria Rennes - Bretagne Atlantique, France

- A visual servoing task is formulated within a QP for whole-body control
- Visual inequality constraints account for occlusion or field-of-view limits
- Tests on HRP4 and Romeo

15:05–15:10	WeC3.8

Determining the Singularities for the Observation of Three Image Lines

Sébastien Briot[1], Philippe Martinet[1,2] and François Chaumette[3]
[1] Lab. des Sciences du Numérique de Nantes (LS2N), CNRS, Nantes, France
[2] Ecole Centrale de Nantes, Nantes, France
[3] INRIA at IRISA, Rennes, France

- For the first time, we provide the singularity cases in the observation of three image lines by using a concept named the “hidden robot”
- We prove that in the most general case, singularities appear when the origin of the observed object frame is either on a quadric or a cubic surface
- In simpler cases where at least two lines belong to the same plane, these two surfaces can degenerate into simpler geometrical loci (e.g. planes, cylinders, lines).

Relative motion of the camera wrt the three observed orthogonal lines and singularity location

SLAM 1

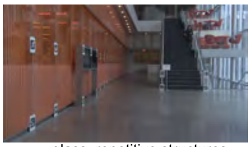
Chair *Sebastian Scherer, Carnegie Mellon University*
Co-Chair *Guillermo Gallego, University of Zurich*

14:30–14:35	WeC4.1

PennCOSYVIO: A Challenging Visual Inertial Odometry Benchmark

Bernd Pfrommer, Nitin Sanket, and Kostas Daniilidis
Dept. of Computer and Information Science, University of Pennsylvania, USA
Jonas Cleveland
Cognitive Operational Systems LLC, USA

- Benchmark/dataset for hand-held VIO algorithms
- VI sensor, Google Tango, GoPro Hero4
- Indoor/outdoor transitions, 150m path length
- Ground truth from fiducial markers

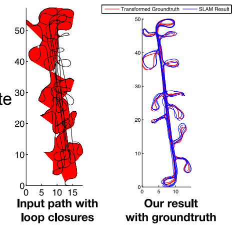

glass, repetitive structures

14:35–14:40	WeC4.2

MSGD: Scalable Back-end for Indoor Magnetic Field-based GraphSLAM

Chao Gao and Robert Harle
Computer Laboratory, University of Cambridge, UK

- A back-end system optimised for very dense sequence-based loop closures
- Extensive real datasets were used to evaluate against state-of-the-art algorithms
- Code and datasets with high-accuracy groundtruths are open sourced



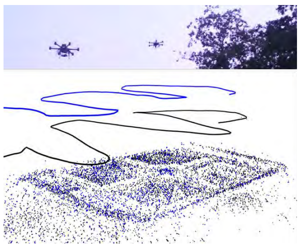
14:40–14:45	WeC4.3

V4RL VISION FOR ROBOTICS LAB   ETH zürich

Multi-UAV Collaborative Monocular SLAM

Patrik Schmuck and Margarita Chli

- Centralized **collaborative monocular SLAM**; the server is a ground station and the agents are aerial vehicles.
- **Two-way communication** between agents & server, handling time delays
- **Real-time** visual odometry runs uninterrupted on each agent, expensive tasks run on server (e.g. place recognition, map optimization)
- Server maintains agents' experiences, ensuring consistent, shared maps

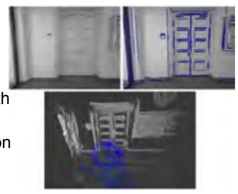

Map constructed by two aerial vehicle agents. Following detection of scene overlap, the server fuses their experiences into a common map, enabling the agents' collaboration.

14:45–14:50	WeC4.4

Direct Monocular Odometry Using Points and Lines

Shichao Yang, Sebastian Scherer
Robotics Institute, Carnegie Mellon University, USA

- A real-time monocular visual odometry incorporating points and edges, especially suitable for texture-less environments.
- Provide an uncertainty analysis and probabilistic fusion of points and lines in both tracking and mapping.
- Develop analytical edge based regularization
- Outperform or comparable to existing VO in many datasets

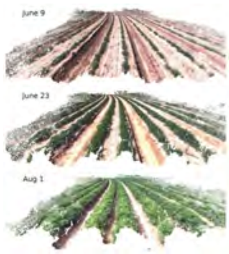


14:50–14:55	WeC4.5

4D Crop Monitoring: Spatio-Temporal Reconstruction for Agriculture

Jing Dong and Byron Boots and Frank Dellaert
College of Computing, Georgia Institute of Technology, USA
John Gary Burnham and Glen Rains
Department of Entomology, University of Georgia, USA

- An approach for 4D reconstruction for fields with continuously changing scenes, targeting crop monitoring applications.
- A robust data association algorithm for images with highly duplicated structures and significant appearance changes.
- A ground vehicle field dataset with ground truth crop statistics for evaluating spatio-temporal reconstruction and crop monitoring algorithms.

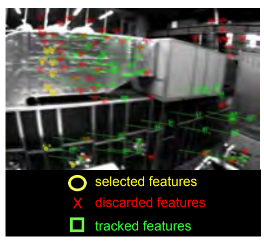


14:55–15:00	WeC4.6

Attention and Anticipation in Fast Visual-Inertial Navigation

Luca Carlone and Sertac Karaman
Laboratory for Information & Decision Systems, MIT, USA

- We propose an attention mechanism for **Visual Inertial Navigation (VIN)**
- Our attention mechanism selects a small subset of relevant visual features to reduce the computation in VIN
- The selection is aware of the motion of the robot, picking features that remain in the field of view during aggressive motion
- The selection can be implemented efficiently and enjoys suboptimality guarantees via submodularity



During a sharp left turn, our feature selector picks features on the left-hand side, which will remain in the field of view during the maneuver

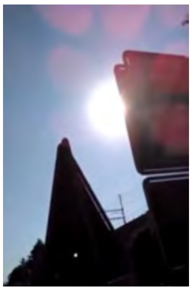
SLAM 1

Chair *Sebastian Scherer, Carnegie Mellon University*
Co-Chair *Guillermo Gallego, University of Zurich*

15:00–15:05	WeC4.7

Active Exposure Control for Robust Visual Odometry in HDR Environments

Zichao Zhang, Christian Forster, Davide Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland



- We propose an active exposure control method to maximize the information for VO
- We propose a robust gradient-based image quality metrics and optimize the metrics based on the response function of the camera
- Evaluation of different exposure compensation methods in VO
- Improved performance in challenging HDR environments is achieved by combining the proposed active exposure control and the exposure compensation in VO

15:05–15:10	WeC4.8

EVO: A Geometric Approach to Event-based 6-DOF Parallel Tracking and Mapping in Real-time

Henri Rebecq*, Timo Horstschaefer*, Guillermo Gallego and Davide Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland

- Event cameras are novel sensors with **low-latency** (1µs), **high-dynamic range** (140 dB), and **no motion blur**
- EVO is a 6-DOF pose tracking and 3D reconstruction algorithm for event cameras, that runs in real-time on a CPU
- Robust to high-speed motions and challenging high-dynamic range lighting conditions

Trajectory and semi-dense 3D map generated by EVO using events only.

* equal contribution

Aerial Robot 3

Chair *Alexis Lussier Desbiens, Université de Sherbrooke*
Co-Chair *Kenjiro Tadakuma, Tohoku University*

14:30–14:35	WeC5.1

Bringing Mobile Robot Olfaction to the Next Dimension – UAV-based Remote Sensing of Gas Clouds and Source Localization

P. P. Neumann[1], H. Kohlhoff[1], D. Hüllmann[1], A. J. Lilienthal[2], and M. Kluge[1]
[1]BAM, Germany. [2]Örebro University, Sweden.

- **Novel robotic platform for aerial remote gas sensing that combines**
  - » open-path gas detector with
  - » 3-axis gimbal for stabilizing and aiming
- **Outdoor evaluation of gas sensing and aiming performance**
- **Aerial platform enables**
  - » tomographic reconstruction of gas plumes and
  - » localization of gas sources

14:35–14:40	WeC5.2

Design and Experiments for a Transformable Solar-UAV

Ruben D'Sa, Travis Henderson, Devon Jenson, Michael Calvert, Thaine Heller, Bobby Schulz, Jack Kilian, and Nikolaos Papanikolopoulos

Department of Computer Science and Engineering, University of Minnesota, USA

- Discussion of the airframe design and performance.
- Evaluation of a variable pitch propulsion system methodology.
- Energetic results from solar flight testing.

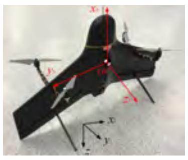
Fixed-wing (top) and quad-rotor states (bottom).

14:40–14:45	WeC5.3

Design and Implementation of a Quadrotor Tail-sitter VTOL UAV

Ximin Lyu, Haowei Gu, Ya Wang, Zexiang Li, Shaojie Shen, and Fu Zhang
ECE, Hong Kong University of Science and Technology, China

- Vehicle design including: addressing wind disturbance, vibration attenuation, and landing gear design.
- Modeling, controller design with aerodynamic feed forward, and simulation result
- Indoor test and outdoor test to show the vehicle performance



The quadrotor tail-sitter prototype

14:45–14:50	WeC5.4

Sampling-based Motion Planning for Active Multirotor System Identification

Rik Bähnemann, Michael Burri, Enric Galceran, Roland Siegwart, and Juan Nieto
Autonomous Systems Lab, ETH Zürich, Switzerland

- We present a real-time capable MAV motion planning framework for parameter identification experiments.
- We use rapidly-exploring random belief trees (RRBT) to find a maximum informative trajectory.
- Our approach is extendable to other platforms and calibration problems.
- Experiments in simulation and on the real platform show the feasibility and repeatability of our approach.

An automatically generated MAV calibration routine

14:50–14:55	WeC5.5

Model-based Transition Optimization for a VTOL Tailsitter

S. Verling, T. Stastny, G. Bätting and R. Siegwart
ASL, ETH Zurich, Switzerland
K. Alexis
University of Nevada, Reno, United States of America

- Closed Loop trajectory optimization
- Transition from cruise to hover
- Minimal altitude deviation
- Verified in simulation and Experiments

14:55–15:00	WeC5.6

Model-Based Wind Estimation for a Hovering VTOL Tailsitter UAV

Youssef Demitri, Sebastian Verling, Thomas Stastny, Amir Melzer, Roland Siegwart
Autonomous Systems Lab, ETH Zurich, Switzerland

- Vertical take-off and landing (VTOL) UAV combines multi-copter and fixed-wing UAV capabilities.
- The vertical wing in hover configuration is highly susceptible to wind disturbances.
- A wind estimator has been developed, based on an aerodynamic model of the aircraft.
- The estimator results have been successfully validated on outdoor flight data.

VTOL Tailsitter UAV

Aerial Robot 3

Chair *Alexis Lussier Desbiens, Université de Sherbrooke*
Co-Chair *Kenjiro Tadakuma, Tohoku University*

15:00–15:05 WeC5.7

Design of a Passive Vertical Takeoff and Landing Aquatic UAV

Richard-Alexandre Peloquin, Dominik Thibault and Alexis Lussier Desbiens
Department of Mechanical Engineering, Université de Sherbrooke, Canada

- Design of a flying wing UAV able to dive land and passively takeoff from lakes
- Development of a dynamic model of the passive takeoff sequence
- Prediction of diving accelerations for various impact speeds
- Prototype capable of repeated cycles of flying, diving, self-righting, and takeoff

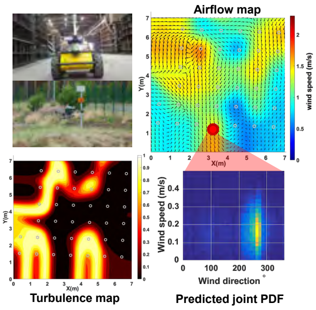
Time lapse of the takeoff sequence

15:05–15:10 WeC5.8

Air Flow Modelling Using Turbulent and Laminar Characteristics for Ground and Aerial Robots

V. Hernandez B.[1], T. P. Kucner[1], E. Schaffernicht[1], P. P. Neumann[2], H. Fan[1] and A. J. Lilienthal[1]
[1]Örebro University, Sweden. [2]BAM, Germany.

- **Air Flow Modeling (AFM) conveys useful information to UAV navigation and surveillance robots**
- **Novel algorithm that models airflow as a linear combination of turbulent and laminar components**
  - Joint representation PDFs (wind speed/direction) and turbulence indicators
  - AFM-specific extrapolation from sparse measurement locations
- **Validation in real world environments**
  - Experiments with UAV and ground robots
  - The proposed algorithm outperforms conventional extrapolation techniques with a high stability to parameter selection



RGB-D Perception

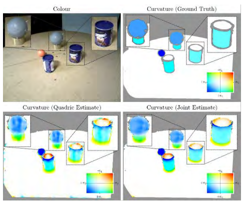
Chair *Kazunori Umeda, Chuo University*
Co-Chair *Tom Drummond, Monash University*

14:30–14:35	WeC6.1

Joint Pose and Principal Curvature Refinement Using Quadrics

Andrew Spek and Tom Drummond
Electrical Engineering, Monash University, Australia

- A method that jointly optimizes for curvature and pose estimates for RGB-D data using locally fit surface quadrics.
- We demonstrate the improvement in performance of solving both tasks, by jointly optimizing, instead of separately
- Can be used in a tracking pipeline to greatly reduce the drift in tracking.

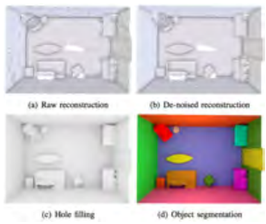


14:35–14:40	WeC6.2

De-noising, Stabilizing and Completing 3D Reconstructions On-the-go using Plane Priors

Maksym Dzitsiuk[1,2], Jürgen Sturm[2]
Robert Maier[1], Lingni Ma[1], Daniel Cremers[1]
[1]Technical University of Munich, Germany
[2]Google

- Real-time 3D reconstruction of indoor environments on mobile devices
- Detect planar surfaces by directly fitting planes to voxel volumes
- Find global planes by merging local planes
- Noise reduction and hole filling in incomplete 3D reconstructions
- Object-level and semantic segmentation (e.g. walls)



14:40–14:45	WeC6.3

Fast Task-Specific Target Detection via Graph Based Constraints Representation and Checking

Wentao Luan, ISR, Univ. of Maryland, USA
Yezhou Yang, CIDSE, Arizona State University, USA
Cornelia Fermüller, CV lab, Univ. of Maryland, USA
John S. Baras, ISR, Univ. of Maryland, USA

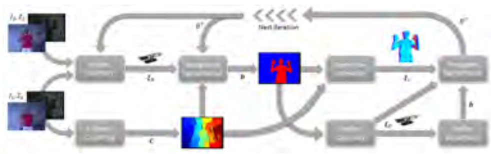
- Introduces target description early into the segmentation and candidate proposal process for object detection
- Proposes a method to optimize the constraints checking order and proves its performance
- Demonstrate framework's performance by one rigid one non-rigid object detection
- Derives a human-robot interaction application from our detection framework.

14:45–14:50	WeC6.4

Fast Odometry and Scene Flow from RGB-D Cameras based on Geometric Clustering

Mariano Jaimez[1,2], Christian Kerl[2],
Javier Gonzalez-Jimenez[1] and Daniel Cremers[2]
[1]Dept. of System Engineering and Automation, University of Malaga, Spain
[2]Dept. of Computer Science, Technical University of Munich, Germany

- Scene segmented into static/moving parts to compute odometry and scene flow, respectively.
- K-Means-based geometric clustering to accelerate scene flow estimation.
- Overall runtime: 80 milliseconds on multi-core CPU (code on Github).



14:50–14:55	WeC6.5

Tracking Objects with Point Clouds from Vision and Touch

Gregory Izatt, Geronimo Mirano,
Edward Adelson, and Russ Tedrake
CSAIL, Massachusetts Institute of Technology, USA

- The GelSight sensor allows **dense, tactile geometric sensing**
- We combine **tactile geometry** with **RGB-D camera data** by treating each as a **point cloud**
- We accurately **track small objects** in **real-time** during **manipulation** and **significant occlusion**

14:55–15:00	WeC6.6

RISAS: A Novel Rotation, Illumination, Scale Invariant Appearance and Shape Feature

Kanzhi Wu, Ravindra Ranasinghe and Gamini Dissanyake
University of Technology Sydney, Australia
Xiaoyang Li and Yong Liu
Zhejiang University, China

- The proposed RGB-D features, RISAS, consists a keypoint detector and a feature descriptor by utilizing geometry and appearance information in both phases;
- This paper highlights the importance of designing hand-crafted detector and descriptor coherently in principle;
- A dataset is built for RGB-D feature evaluation under rotation, illumination and scale variations;

- RISAS shows superior performance compared with existing RGB-D feature under different variations;

RGB-D Perception

Chair *Kazunori Umeda, Chuo University*
Co-Chair *Tom Drummond, Monash University*

15:00–15:05	WeC6.7

An Analytical Lidar Sensor Model Based on Ray Path Information

Alexander Schaefer, Lukas Luft, Wolfram Burgard
Department of Computer Science, University of Freiburg, Germany

- State-of-the-art grid mapping algorithms neglect the distances that a Lidar beam travels within each map cell.
- We present a more general approach that leverages the whole ray path information.
- It models the interaction between laser and environment in a probabilistic way as exponential decay process.
- This is particularly advantageous in cluttered environments.

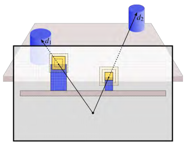

Our off-road robot in the forest.

15:05–15:10	WeC6.8

Learning Depth-aware Deep Representations for Robotic Perception

Lorenzo Porzi[1,2], Samuel Rota Bulò[2], Adrian Penate-Sanchez[3], Elisa Ricci[1,2], Francesc Moreno Noguer[4]
[1]University of Perugia, [2]Fondazione Bruno Kessler, [3]University College, [4]IRI CSIC-UPC

- We introduce DaConv, a general-purpose CNN block which exploits depth to learn scale-aware feature representations.
- **Main idea**: similar objects at different distances should activate the same neurons.
- We achieve this by locally tying the scale of convolutional kernels to the measured depth.
- We demonstrate DaConv on affordance detection, object coordinate regression and contour detection in RGB-D images.



Manipulation Planning 1

Chair *Florent Lamiraux, CNRS*
Co-Chair *Kevin Lynch, Northwestern University*

14:30–14:35	WeC7.1

Manipulation planning: Addressing the crossed foliation issue

Joseph Mirabel and Florent Lamiraux
LAAS-CNRS, Univ. de Toulouse, France

- **Constraint Graph:** the most general formulation of manipulation planning problems.
- **Crossed foliation issue:** although manipulation planning has been extensively studied for the past 20 years, we highlight some unexplored theoretical issues and propose practical solutions.

14:35–14:40	WeC7.2

Noninteracting Constrained Motion Planning and Control for Robot Manipulators

Manuel Bonilla and Antonio Bicchi
Istituto Italiano di Tecnologia
Lucia Pallottino
Università di Pisa

- In constrained compliant robot manipulators there exist a description for the complementary spaces describing rigid body motions and interaction forces
- Geometric control approaches enables the design of a completely decoupled control scheme for the aforementioned spaces
- It in turn allows us to plan motion using state-of-the-art methods using relaxed constraints

Compliant robot manipulators under environment interactions

14:40–14:45	WeC7.3

Multi-Bound Tree Search for Logic-Geometric Programming in Cooperative Manipulation Domains

Marc Toussaint
Machine Learning & Robotics Lab, University of Stuttgart, Germany
Manuel Lopes
Instituto Superior Técnico, Universide de Lisboa, Portugal

- An optimization-based formulation of concurrent, multi-agent cooperative manipulation (task and motion planning)
- Jointly (locally) optimal paths and action parameters for all agents over the full manipulation sequence
- Multiple levels of bounds to better direct tree search over symbolic decisions
- Efficient path optimization across kinematic switches, where configuration space dimensionality varies over time

14:45–14:50	WeC7.4

Open World Grasping with Laser Selection

Abraham Shultz, James Kuczynski, Holly Yanco
Department of Computer Science, UMass Lowell, USA
Marcus Gualtieri, Andreas ten Pas, Robert Platt
College of Computer and Information Science, Northeastern University, USA

- Our system grasps objects that the user indicates with a laser pointer.
- 88% object selection success and 90% grasp success in stationary tests.
- 89% object selection success and 72% grasp success driving the scooter between tests.
- Average time to grasp and return objects of 128s (minimum 44s, max 374s).

14:50–14:55	WeC7.5

C-LEARN: Learning Geometric Constraints from Demonstrations for Multi-Step Manipulation in Shared Autonomy

Claudia Pérez-D'Arpino and Julie A. Shah
Massachusetts Institute of Technology

- C-LEARN: a method of learning from demonstrations that supports the use of hard geometric constraints for planning multi-step functional manipulation tasks with multiple end effectors in quasi-static settings.
- C-LEARN supports multi-step tasks with multiple end effectors;
- reasons about SE(3) volumetric and CAD constraints, and,
- offers a principled way to transfer skills between robots with different kinematics.

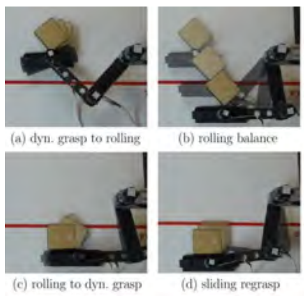
Optimus robot executes tasks with learned geometric constraints

14:55–15:00	WeC7.6

Planning and Control for Dynamic, Nonprehensile, and Hybrid Manipulation Tasks

J. Zachary Woodruff and Kevin M. Lynch
Mechanical Engineering, Northwestern University, USA

- We propose a method for motion planning and feedback control of hybrid manipulation tasks
- We apply the framework to plan a sequence of motions for manipulating a block with a planar 3R manipulator
- We demonstrate experimental results for a block resting on a manipulator moving through different contact modes



Manipulation Planning 1

Chair *Florent Lamiraux, CNRS*
Co-Chair *Kevin Lynch, Northwestern University*

15:00–15:05	WeC7.7

Parts Assembly Planning under Uncertainty with Simulation-Aided Physical Reasoning

Sung-Kyun Kim, Maxim Likhachev
The Robotics Institute, Carnegie Mellon University, USA

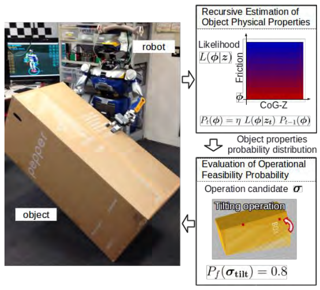
- Search-based motion planning in foliated **belief space** with uncertainty coordinates
- **Physics-based simulator** for more reasonable state transition model
- Informative but inadmissible **heuristics**: **Contact** between objects to *reduce relative pose uncertainty*
- **MHA* (Multi-Heuristic A*)** search that accepts inadmissible heuristics with theoretic guarantee on sub-optimality bound

15:05–15:10	WeC7.8

Feasibility Evaluation of Object Manipulation by a Humanoid Robot Based on Recursive Estimation of the Object's Physical Properties

Masaki Murooka, Shunichi Nozawa, Yohei Kakiuchi, Kei Okada and Masayuki Inaba
(The University of Tokyo, Japan)

- Improve the autonomy of whole-body manipulation by humanoid
- Calculate the likelihood of object's properties from sensor information
- Update physical properties estimation by Bayesian method
- Evaluate feasibility probability of object operation
- Robot selects proper operation depending on object's properties



Humanoid Robots 2

Chair *Katja Mombaur, Heidelberg University*
Co-Chair *Tomomichi Sugihara, Graduate School of Engineering, Osaka University*

14:30–14:35	WeC8.1

Real-Time Pursuit-Evasion with Humanoid Robots

M. Cognetti, D. De Simone, F. Patota, N. Scianca, L. Lanari, G. Oriolo
Sapienza University of Rome, Italy

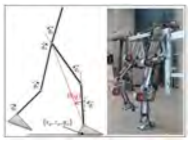
- A pursuer heads for collision with an evader that tries to escape
- Both robots are controlled by a fast replanning scheme based on vision
- Trajectory generation uses a feedback-controlled unicycle as template model
- Simulations and experiments with NAOs reveal a limit cycle behavior

14:35–14:40	WeC8.2

Passivity-based Control of Underactuated Biped Robots within Hybrid Zero Dynamics Approach

Hamid Sadeghian[1], Christian Ott[2], Gianluca Garofalo[2], and Gordon Cheng[3]
[1]Engineering Department, University of Isfahan, Isfahan, Iran
[2]Institute of Robotics and Mechatronics, DLR, Germany
[3]Institute for Cognitive Systems, Faculty of Electrical Engineering and Information Technology, Technical University of Munich, Munich, Germany

- A passivity-based controller for a planar biped with one degree of underactuation is designed within HZD approach.
- It is aimed to preserve the natural dynamics of the system in the transverse dynamics in contrast to input-output linearization method which cancels these dynamics.
- The asymptotic stability of the periodic orbit in lower dimensional state space is extended to the full dimensional space by a Lyapunov stability analysis of the full-order system.



A 7-link planar underactuated system with zero ankle torque in stance foot.

14:40–14:45	WeC8.3

Control of Humanoid Robot Motions with Impacts: Numerical Experiments with Reference Spreading Control

M Rijnen, E de Mooij, N v/d Wouw, A Saccon, H Nijmeijer
Dept. of Mechanical Engineering, TU/e, The Netherlands
S Traversaro and F Nori
iCub facility, IIT Genova, Italy

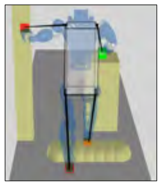
- Reference spreading stabilizes desired robot motions with impacts
- The reference motion is extended about impact times to create multiple segments
- Switching between segments occurs when a contact transition is detected
- Validation: balancing on one foot while impacting a wall with a hand

14:45–14:50	WeC8.4

Dynamic Multi-contact Transitions for Humanoid Robots using Divergent Component of Motion

George Mesesan Johannes Englsberger
Bernd Henze Christian Ott
German Aerospace Center (DLR), Germany

- The motion planner computes feasible step durations and timing of contact transitions
- The Center of Mass trajectory has an analytical form
- A feasible solution is found within seconds by using a simplified robot model
- The controller combines a passivity-based approach with Divergent Component of Motion control.



14:50–14:55	WeC8.5

Smooth-Path-Tracking Control of a Biped Robot at Variable Speed Based on Dynamics Morphing

Hiroshi Atsuta[1], Haruki Nozaki[2] and Tomomichi Sugihara[1]
[1] Grad. School of Enginerring, Osaka University, Japan
[2] Yamazaki Mazak Corporation, Japan

- A biped control to follow an arbitrary smooth curved path is proposed
- The controller is designed with respect to a moving frame fixed to the robot
- Advantageous features include:
  - (i) The referential path can be given as an arbitrary smooth curve
  - (ii) The motion references can be given from the first-person viewpoint of the robot
  - (iii) The states can be observed from the egocentric frame of reference for the robot

14:55–15:00	WeC8.6

Experimental Evaluation of Deadbeat Running on the ATRIAS Biped

William Martin, Albert Wu, and Hartmut Geyer
The Robotics Institute, Carnegie Mellon University, USA

- We investigate how well control strategies developed for the theoretical spring mass model transfer to real-world bipedal robots.
- Our controller regulates running using model-based force control during the stance phase and deadbeat foot placement during flight.
- We find that our controller produces one-step, deadbeat tracking of velocity changes up to ±0.2 m/s at speeds up to 1.0 m/s.
- The control tolerates larger velocity changes, higher speeds, and ground height changes up to ±15 cm, but requires more steps.

ATRIAS, a human-scale bipedal robot with no external sensing

Humanoid Robots 2

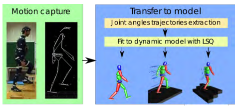
Chair *Katja Mombaur, Heidelberg University*
Co-Chair *Tomomichi Sugihara, Graduate School of Engineering, Osaka University*

15:00–15:05	WeC8.7

Influence of compliance modulation on human locomotion

Yue Hu, Katja Mombaur
Optimization in Robotics and Biomechanics (ORB),
Interdisciplinary Center for Scientific Computing (IWR),
Heidelberg University, Germany

- Motion capture data mapped on a 2D human model with variable stiffness springs in the leg joints.
- Three walking environments: level ground, slope and stairs.
- Punishing stiffness with minimization of stiffness derivatives and stiffness jumps as objective functions.
- Fitting errors computed for different weighting factors on the objective function.



Motion capture data are mapped to the human model considering whole-body dynamics and feasibility constraints

15:05–15:10	WeC8.8

Singularity-tolerant inverse kinematics for bipedal robots

Salman Faraji and Auke Jan Ijspeert
Biorobotics Lab, EPFL, Switzerland

- Extensive analysis of singularity in:
  - A floating-based humanoid
  - For balancing tasks
- Inverse kinematics proposed:
  - **Nonlinear optimization**
  - Joint position/velocity limits
- Approaching singularities
  - **No vibration, instability**
- Escaping from singularities
  - **No delays**

Example: In-place rotation and lateral shift, Asymmetric stretch of the legs

Biologically-Inspired Robots 2

Chair *Joonbum Bae, UNIST*
Co-Chair *jinhua zhang, Xi'an jiaotong university*

14:30–14:35	WeC9.1

CPG-based Control of Smooth Transition for Body Shape and Locomotion Speed of a Snake-like Robot

Zhenshan Bing, Long Cheng, Mingchuan Zhou, and Alois Knoll
Department of Informatics, Technical University of Munich, Germany
Kai Huang
School of Data and Computer Science, Sun Yat-sen University, China

- A light-weight CPG model is designed for locomotion control of snake-like robot. The online execution time and converge speed are compared with other well-known CPG models.
- The body shape and locomotion speed transitions in rolling gait are simulated based on the proposed CPG model.
- Compared with the sinusoid-based method, a smooth transition process can be achieved, without generating undesired movement or abnormal torque.


Snake-like robot is slithering forward

14:35–14:40	WeC9.2

Design and Control of an Inchworm-Inspired Soft Robot with Omega-Arching Locomotion

Huaxia Guo, Jinhua Zhang, Tao Wang, Yuanjie Li, Jun Hong, Yue Li
State Key Laboratory for manufacturing systems Engineering, Xi'an Jiaotong University, China

- An inchworm soft robot with one single silicone square tube being the body.
- Achieving the Omega-Arching locomotion with only one pressure.
- Both the design and control are very simple
- The work illustrate some potential value of using soft materials.

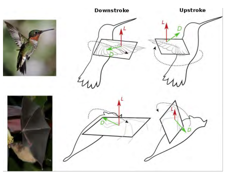
The inchworm soft robot

14:40–14:45	WeC9.3

Guidelines for the Design and Control of Bio-inspired Hovering Robots

Hamid Vejdani and David Boerma and Sharon Swartz and Kenneth Breuer
School of Engineering, Brown University, USA

- Hummingbirds and insects (small dynamical systems) hover with constant wingspan while birds and bats (larger systems) hover with varying wingspan.
- The preferred mode of hovering is studied for systems with different dynamical characteristics.
- The relations between wing kinematics, actuator limitation and energy consumption are presented.



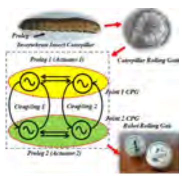
Two hovering mechanisms for different dynamical characteristics

14:45–14:50	WeC9.4

Implementing Caterpillar Inspired Roll Control of a Spherical Robot

Abhra Roy Chowdhury, A. Vibhute, G. S. Soh, S. H. Foong and K. L. Wood
Temasek Laboratories, Engineering Product Development Pillar
Singapore University of Technology and Design Singapore 487372

- Caterpillars (Pleuruptya ruralis) use ballistic rolling gaits to curl rapidly backward into a wheel to escape
- Rolling gait is generated by a CPG (Central Pattern generator). Processed signal output is desired roll angle, directly drives segment joint (dc motors in robot).
- A robust Nonlinear Feedback Controller corrects the produced rolling gait angle in the presence of uncertainties and disturbances (surface friction and actuator noise)

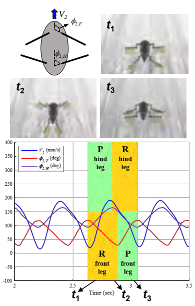

Rolling gait in a caterpillar mimicked by a spherical robot

14:50–14:55	WeC9.5

Design of Hair-like Appendages and their Coordination Inspired by Water Beetles for Steady Swimming on the Water Surface

Bokeon Kwak[1], and Joonbum Bae[1]
[1]Department of Mechanical Engineering, UNIST, Republic of Korea

- Inspired by the locomotion of water beetles, two types of robots (one-pair-leg, two-pair-leg) with novel hair-like appendages were built.
- The hair-like appendages could passively adjust the frontal projected area of the robot to achieve drag-powered swimming.
- The coordination between the two pairs of legs was investigated for steady swimming, and its locomotion was compared with the robot with one pair of legs.
- By properly coordinating the legs, the velocity fluctuation was fairly attenuated, and more energy-efficient swimming was achieved.



14:55–15:00	WeC9.6

Development and Validation of Modeling Framework for Interconnected Tendon Networks

Taylor D. Niehues and Ashish D. Deshpande
Dept. of Mechanical Engineering, The University of Texas at Austin, USA
Raymond J. King and Sean Keller
Oculus & Facebook, USA

- A generalized **model** of tension transmission through a network of branching tendons is developed
- **Simulations** of the human finger extensor mechanism capture realistic dynamic tension variations and passive joint coupling effects
- **Experiments** with a robotic finger illustrate that the model is able to accurately predict force transformation between the muscles and fingertip

Biologically-Inspired Robots 2

Chair *Joonbum Bae, UNIST*
Co-Chair *jinhua zhang, Xi'an jiaotong university*

15:00–15:05	WeC9.7

Mechanical Specialization of Robotic Limbs

Nathan Cahill, Yi Ren, and Thomas Sugar
Mechanical Engineering, Arizona State University, United States of America

- A constrained optimization problem is presented which tunes the kinematics of a multiactuator robotic limb
- Power consumption is minimized locally, and several design families are presented.
- Manipulability is constrained along the task trajectory via the condition number of the Jacobian.
- A gear ratio optimization routine with realistic constraints is also presented.

Kinematically Tuned
Hybrid-Serial Robot Limb

15:05–15:10	WeC9.8

VAM: hypocycloid mechanism for efficient bio-inspired robotic gaits

Espen Knoop[1,2,3], Andrew Conn[2,3], Jonathan Rossiter[2,3]
[1]Disney Research, Zurich, Switzerland
[2]University of Bristol, UK
[3]Bristol Robotics Laboratory, UK

- VAM module produces reciprocating output of continuously-variable amplitude, using a drive input and a control input
- Modular building-block for biomimetic robotic gaits
- Demonstrated with VAMOS: Two-motor hexapod that walks and turns with arbitrary curvature

Surgical Robotics 1

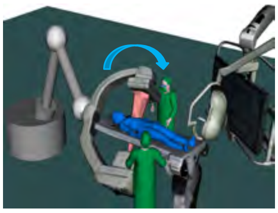
Chair *Jorge Solis, Karlstad University / Waseda University*
Co-Chair *Leonardo Mattos, Istituto Italiano di Tecnologia*

14:30–14:35	WeC10.1

Pose optimization of a C-arm imaging device to reduce intraoperative radiation exposure of staff and patient during interventional procedures

Nicolas Loy Rodas*, Julien Bert**, Dimitris Visvikis**, Michel de Mathelin* and Nicolas Padoy*
*ICube, University of Strasbourg, CNRS, IHU Strasbourg, France
** LaTIM, INSERM, CHRU Brest, France

- X-ray guided interventions expose patient and clinicians to harmful ionizing radiation.
- Method for active radiation exposure reduction by exploiting the robotic capabilities of imaging devices.
- Reduction of patient and staff exposure while maintaining target visibility.
- Optimization in quasi real-time thanks to a novel and fast radiation simulation method.

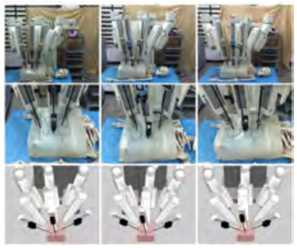


14:35–14:40	WeC10.2

Preoperative Planning for the Multi-arm Surgical Robot using PSO-GP-based Performance Optimization

Fan Zhang[1], Zhiyuan Yan[2] and Zhijiang Du[2]
[1]Imperial College London, United Kingdom
[2]Harbin Institute of Technology, China

- The surgical workspace is divided and the subspaces are assigned with different weights.
- Three metrics are proposed to evaluate the performance of the multi-arm surgical robot.
- A combination of Particle Swarm Optimization (PSO) and Gaussian Process (GP) is proposed to locate the port placement and robot positioning.

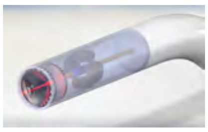


14:40–14:45	WeC10.3

Magnetic Laser Scanner for Endoscopic Microsurgery

Alperen Acemoglu and Leonardo S. Mattos
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Genoa, Italy

- Enables laser scanning in narrow workspaces
- High-speed laser scanning
- Magnetic interaction between coils and the permanent magnet attached to an optical fiber.
- For precise micromanipulation the optical fiber to perform surgical tissue ablations.
- The laser spot can be controlled with 35μm precision.



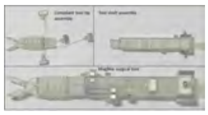
Endoscopic Laser Scanner

14:45–14:50	WeC10.4

MagNex – Expendable robotic surgical tooltip

Karthik Chandrasekaran, Akhil Sathuluri and Asokan Thondiyath
Department of Engineering Design, Indian Institute of Technology Madras, India

- Proposed design has 3 degrees of freedom – pitch, yaw and grasp
- Proposed tooltip design is magnetically coupled to an actuator through a sealed shaft to mitigate biofouling
- Monolithic tooltip has a modified serpentine flexure for increased buckling strength and off axis stiffness
- The single use tool tip is pluggable to tool shaft assembly and provides modularity



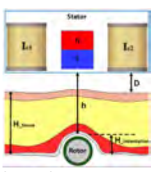
Prototype of the complete tool

14:50–14:55	WeC10.5

Modeling and Analysis of a Laparoscopic Camera's Interaction with Abdomen Tissue

Reza Yazdanpanah A. and Xiaaolong Liu and Jindong Tan
Mechanical Aerospace Biomedical Eng., University of Tennessee, USA

- Mechanical modeling of abdomen bulk tissue (skin, fat, muscle, connective tissues)
- Camera-tissue interaction mathematical model
- Interaction finite element study for various linear and rotational speeds
- Damage prevention, fall prevention and online tissue properties measurement system



Online force estimation and damage prevention system

14:55–15:00	WeC10.6

Implicit Gaze-Assisted Adaptive Motion Scaling for Highly Articulated Instrument Manipulation

Gauthier Gras, Konrad Leibrandt, Piyamate Wisanuvej, Petros Giataganas, Carlo A. Seneci, Menglong Ye, Jianzhong Shang, Guang-Zhong Yang
The Hamlyn Centre for Robotic Surgery, Imperial College London, UK

- By fusing eye tracking data with hand motion and instrument information, user intention to reach distant targets can be recognized.
- Motion scaling is modulated accordingly, without compromising safety or precision.
- Custom-designed instruments mounted on robotic arms are used to test the system.
- The control scheme aims to maximize the dexterity of the system even when the external arms cannot provide sufficient triangulation.

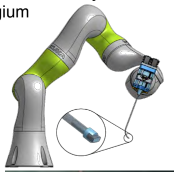
Surgical Robotics 1

Chair *Jorge Solis, Karlstad University / Waseda University*
Co-Chair *Leonardo Mattos, Istituto Italiano di Tecnologia*

15:00–15:05	WeC10.7

A Continuum Robot and Control Interface for Surgical Assist in Fetoscopic Interventions

G Dwyer [1], F Chadebecq [1], M Tella Amo [1], C Bergeles [1], E Maneas [1], V Pawar [1], E Vander Poorten [2], J Deprest [2], S Ourselin [1], P De Coppi [1], T Vercauteren [1] and D Stoyanov [1]
[1] UCL, UK [2] KU Leuven, Belgium



- Fetoscopic interventions are delicate procedures involving the introduction of a small endoscope for visualisation
- Concentric tube manipulator to enhance dexterity at the tip of the endoscope
- 7 DOF robotic arm constrained to remote centre of motion to improve stability
- 3D reconstruction and mosaicing of the placenta is demonstrated

15:05–15:10	WeC10.8

Utilizing Elasticity of Cable Driven Surgical Robot to Estimate Cable Tension and Ext. Force

Mohammad Haghighipanah, Muneaki Miyasaka, and Blake Hannaford
Electrical Engineering, University of Washington, USA

- This paper presents a method to estimate cable pre-tension and external forces acting on the robot
- Cable pre-tension was estimated based on dynamical methods
- Eternal forces acting on the robot in all the four quadrants was estimated based on UKF and cable elasticity

Service Robotics 2

Chair *Peter Luh, University of Connecticut*
Co-Chair *Claudio Melchiorri, University of Bologna*

14:30–14:35	WeC11.1

Improving the Reliability of Service Robots in the Presence of External Faults by Learning Action Execution Models

Alex Mitrevski, Anastassia Kuestenmacher, Santosh Thoduka, and Paul G. Plöger
Department of Computer Science, Hochschule Bonn-Rhein-Sieg, Germany

- We present a **learning-based** method for avoiding the occurrence of **external faults**
- For **generalising** over various environment configurations and objects, the representation of the model includes both **symbolic and geometric components**
- Our **experiments** show that the learned models can represent execution knowledge fairly reliably


From faulty to successful execution

14:35–14:40	WeC11.2

Deploying Social Robots as Teaching Aid in Pre-school K2 Classes: A Proof-of-Concept Study

Albert Causo, Zin Win Phyo, Peng Sheng Guo, I-Ming Chen
School of Mechanical & Aerospace Engineering, Nanyang Technological University, Singapore

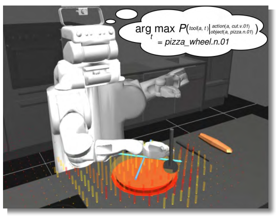
- 16 student each from 2 pre-schools tested Pepper and Nao.
- 6 lessons were developed for each robot and delivered over span of 3 months
- Students and teachers were observed for behaviors like critical thinking, imagination, creativity, and social interaction and creativity, classroom atmosphere, classroom management, and class behavior.
- Study shows the challenges and potential benefits.

14:40–14:45	WeC11.3

Instruction Completion through Instance-based Learning and Semantic Analogical Reasoning

Daniel Nyga, Mareike Picklum, Sebastian Koralewski, Michael Beetz
Institute for Artificial Intelligence, University of Bremen

- Natural-language instructions are vague and lack critical information
- Inference of missing information pieces in natural-language instructions required
- Novel Instance-based learner combining probabilistic with analogical reasoning for deep knowledge transfer

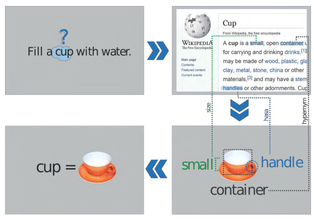


14:45–14:50	WeC11.4

What No Robot Has Seen Before – Probabilistic Interpretation of Natural-language Object Descriptions

Daniel Nyga, Mareike Picklum and Michael Beetz
Institute for Artificial Intelligence, University of Bremen

- recognize objects based on natural-language descriptions
- a novel probabilistic knowledge-driven approach to attribute-based object recognition
  - transform NL description into formal semantic representation wrt. perceptual attributes
  - use semantic representation to find corresponding object in scene

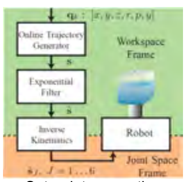


14:50–14:55	WeC11.5

Control of Liquid Handling Robotic Systems: a Feed-Forward Approach to Suppress Sloshing

L. Moriello[*], L. Biagiotti[♦], C. Melchiorri[*], A. Paoli[§]
[*] Department of Electrical, Electronic and Information Engineering, University of Bologna, Italy.
[♦] Department of Engineering, University of Modena and Reggio Emilia, Italy.
[§] School of Engineering, University of Lincoln, UK.

- Sloshing of liquid into a moving container is modelled as a spherical pendulum.
- Liquid handling is approached as a typical vibration suppression problem.
- Mechanical model is used to design an Exponential Filter, which can be implemented in cascade configuration to a generic trajectory generator.
- Experimental tests on an industrial manipulator prove significant sloshing reduction and great robustness to parametrical uncertainties.



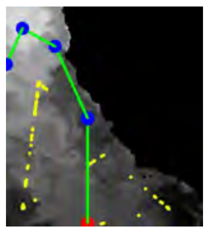
Set-point generation algorithm for the industrial robot.

14:55–15:00	WeC11.6

Informative Planning and Online Learning with Sparse Gaussian Processes

Kai-Chieh Ma, Lantao Liu, Gaurav S. Sukhatme
Department of Computer Science, University of Southern California, USA

- We are motivated by persistent sensing and estimation of an unknown environmental model with spatiotemporal variation.
- We propose a framework that combines an informative planning component and an online learning component.
- The planning component aims at collecting data with maximal information for model prediction.
- The learning component is based on a sparse variant of Gaussian Process; the environment model and hyperparameters are learned online by using only a subset of data.


Informative path with sparse samples

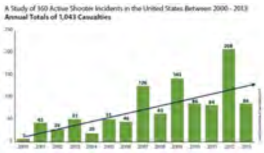
Service Robotics 2

Chair *Peter Luh, University of Connecticut*
Co-Chair *Claudio Melchiorri, University of Bologna*

15:00–15:05	WeC11.7

Sean Gunn, Peter Luh, Xuesong Lu
Electrical & Computer Engineering, University of Connecticut, U.S.A.
Brock Hotaling
Verbi, Inc

- Optimizing Guidance during active shooter events to safely guide evacuees out of the building
- Active shooter events are volatile, each incident average about 6.5 causalities with a fatal shooting every 15 seconds
- Guidance is optimized by utilizing Lagrangian relaxation framework to minimize the risk to evacuees



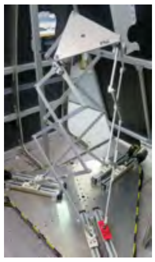
Shooter Events

15:05–15:10	WeC11.8

Design and Analysis of 6-DOF Triple Scissor Extender Robots with Applications in Aircraft Assembly

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

- We derive general case inverse kinematics for different designs of Triple Scissor Extender (TSE) Robots.
- We analyze sensitivity of motion to changing geometric design parameters for the TSE.
- We present a case study where these analyses are utilized for the design of our prototype.



Session WeD1 | Rm. 4011 | Wednesday, May 31, 2017, 16:05–17:20

Soft Robotics 1

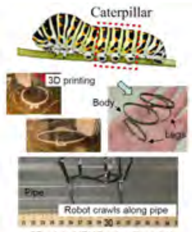
Chair *Shigeki Sugano, Waseda University*
Co-Chair *Barthélemy Cagneau, Université de Versailles Saint-Quentin en Yvelines*

16:05–16:10	WeD1.1

3D-Printed Ionic Polymer-Metal Composite Soft Crawling Robot

*James D. Carrico and Kam K. Leang**
Dept. of Mechanical Engineering, Univ. of Utah Robotics Center, U.S.A.
Kwang J. Kim
Dept. of Mechanical Engineering, Univ. Of Nevada, Las Vegas, U.S.A.

- New 3D printing technique developed to create ionic polymer-metal composite (IPMC) based soft crawling robot
- Crawling robot consists of modular gripper and body units, for caterpillar-like locomotion
- Developed a dynamics model for performance prediction and gait optimization
- Experimental results demonstrate caterpillar-like locomotion



3D-printed IPMC caterpillar robot

16:10–16:15	WeD1.2

A Versatile Conducting Interpenetrating Polymer Network for Sensing and Actuation

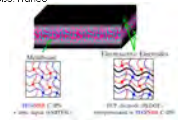
Chia-Ju Peng[1,2] , Tien Anh Nguyen[1], Kätlin Rohtlaid[3] , Cédric Plesse[3],
Shih-Jui Chen[2], Luc Chassagne[1] and Barthélemy Cagneau1
1 Université de Versailles St-Quentin en Yvelines / LISV, France.
2 National central University, Department of Mechanical Engineering, Taoyuan, Taiwan
3 Université de Cergy, LPPI / I-MAT, Cergy-Pontoise, France

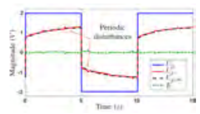
This work deals with conducting interpenetrating polymers (C-IPN).

The main characteristic of C-IPN is that they can be used as sensors and actuators. They require low voltage (under 2.5V) to be actuated.

A model is proposed to actuate the C-IPN in open loop. Moreover, another model is presented for the sensor output.

Future work will include developments at micro- and nanoscale.





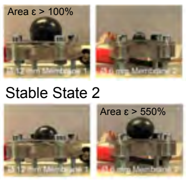
The polymer used in top figure is actuated with a low voltage. While moving, it can detect periodic disturbances shown in bottom figure.

16:15–16:20	WeD1.3

Asymmetric Stable Deformations in Inflated Dielectric Elastomer Actuators

Lindsey Hines[1], Kirsten Petersen[2], and Metin Sitti[1]
1 Max Planck Institute for Intelligent Systems, Germany
2 Cornell University, USA

- We demonstrate fluidically connected dielectric elastomer actuators (DEAs) with stable asymmetric deformations.
- Achieved membrane area strain can be both significant as well as significantly different.
- The inflated system is *sealed*, producing motion without pumps or compressors.
- Use cases may include compliant robotic grippers and joints.



Stable states of fluidically connected DEA membranes, maintained without applied voltage

16:20–16:25	WeD1.4

ICRA2017 NUS National University of Singapore

Networked Soft Actuators with Large Deformations

Feifei Chen, Jiawei Cao, Lei Zhang, Hongying Zhang, Jian Zhu and Y.F. Zhang

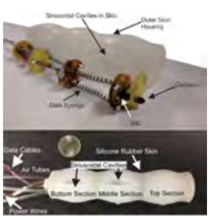
Department of Mechanical Engineering
National University of Singapore
contact: ffchen@u.nus.edu

16:25–16:30	WeD1.5

Design, Modeling and Control of a SMA-Actuated Biomimetic Robot with Functional Skin

Joan Ortega Alcaide, Levi Pearson, Mark E. Rentschler
Department of Mechanical Engineering, University of Colorado, USA

- Novel functional robotic skin optimized to maximize traction while providing sufficient recovery force to the SMA-actuators
- SMA-Actuated peristaltic motion using forced convection to increase robot speed
- Closed-loop non-linear control used to control the three degrees of freedom of each of the three robotic sections

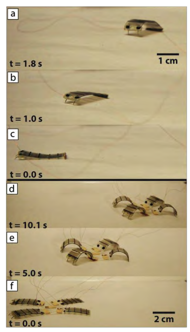


16:30–16:35	WeD1.6

A High Speed Soft Robot Based On Dielectric Elastomer Actuators

Mihai Duduta, David Clarke, and Robert Wood
School of Engineering and Applied Sciences, Harvard University, USA

- A novel manufacturing method has been adapted to create inchworm and multi-legged crawling robots.
- The actuators are multilayered dielectric elastomers unimorphs that allow some robots to crawl at 1 body length / second.
- Future work will be directed at lowering the actuation voltage to make untethered robots for exploration.



Soft Robotics 1

Chair *Shigeki Sugano, Waseda University*
Co-Chair *Barthélemy Cagneau, Université de Versailles Saint-Quentin en Yvelines*

16:35–16:40 WeD1.7

Tunable Friction through Constrained Inflation of an Elastomeric Membrane

Kaitlyn P. Becker, Nicholas W. Bartlett,
Melinda J. D. Malley, Peter M. Kjeer, Robert J. Wood
School of Engineering and Applied Sciences, Harvard University, USA

- A soft robotic device for tunable friction.
- Pressure controls extension of high-friction elastomeric membrane through holes in low-friction restraining layer.
- Achieves an order of magnitude differentiation of friction force between high and low pressure states.
- This mechanism enhanced performance in both a crawling robot and a soft robotic gripper.

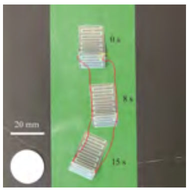
Tunable friction pads attached to the fingertips of a soft robotic gripper.

16:40–16:45 WeD1.8

Printed Paper Robot Driven by Electrostatic Actuator

Hiroki Shigemune, Yoshitaka Iwata, Eiji Iwase
Shuji Hashimoto and Shigeki Sugano
Waseda University, Japan
Shingo Maeda
Shibaura Institute of Technology, Japan
Vito Cacucciolo
Scuola Superiore Sant'Anna, Italy

- We propose a method to fabricate a 3D wiring board with inkjet printing.
- The paper gets electronic function by silver ink and mechanic function with self-folding along the printed ink.
- We developed a printed paper robot driven by electrostatic actuator using the technique.
- The proposed method may also apply for wearable devices or flexible devices.



Driving of the printed paper robot

Motion and Path Planning 2

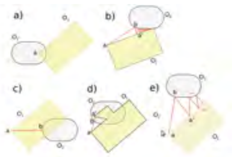
Chair *Nicola Wolpert, HFT Stuttgart*
Co-Chair *Haoyong Yu, National University of Singapore*

16:05–16:10	WeD2.1

Collision Detection for 3D Rigid Body Motion Planning with Narrow Passages

Daniel Schneider, Nicola Wolpert and
University of Applied Science Stuttgart, Germany
Elmar Schömer
Johannes Gutenberg - University Mainz, Germany

- **Contribution**: Acceleration data structure to speed up collision detection.
- **Application**: Random sampling in a motion planner.
- **Idea**: Shooting random rays to find an exact witness for collision at high speed.
- **Result**: Speedup of up to 5.0 compared to well-established collision detection libraries.



16:10–16:15	WeD2.2

Automated Tuning and Configuration of Path Planning Algorithms

Ruben Burger, Mukunda Bharatheesha and Robert Babuska
Faculty of Mechanical Maritime and Materials Engineering,
Delft Univerity of Technology, The Netherlands
Marc van Eert
Applied Scientist, Technolution B. V, The Netherlands

- Software implementations of path planners involve numerical and categorical configuration parameters.
- These parameters influence the performance of the planners.
- Manual tuning is hard: Many parameters interacting in unpredictable ways.
- Automated tuning with Sequential Model-Based Algorithm Configuration (SMAC) significantly improves planner performance.

Planner	Runtime [ms]	Solved [%]	Path length [2-norm]
RRTConnect	165	95	10.9
RRTConnect - SMAC	146	96	10.2
BiTRRT	183	96	10.6
BiTRRT - SMAC	172	96	10.3
BKPIECE	751	45	12.6
BKPIECE - SMAC	450	94	10.6
KPIECE	443	79	11.8
KPIECE - SMAC	337	90	10.6
BIT	286	80	9.7
BIT - SMAC	266	81	9.2

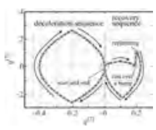
Runtime, Solving Percentage and Path Length comparison of OMPL planners with SMAC tuning.

16:15–16:20	WeD2.3

Perfect Tracking Control Using a Phase Plane for a Wheeled Inverted Pendulum Under Hardware Constraints

Ryosuke Nakamura and Azusa Amino
Center for Technology Innovation, Hitachi, Ltd., Japan

- A motion-planning method for a wheeled inverted pendulum under hardware constraints
- All state values are represented by a linear sum of differential values of one parameter.
- The motion-plan can be designed on phase planes of body angle and angular velocity.



Phase plane of motion simulation

16:20–16:25	WeD2.4

Maximizing Mutual Information for Multipass Target Search in Changing Environments

M. Kuhlman[1], M. Otte[2], D. Sofge[2] and S. Gupta[3]
[1]Dept. of Mech. Eng., Univ. of Maryland, College Park, USA
[2]Naval Research Laboratory, Washington, DC, USA
[3]Aero. and Mech. Eng. Dept, Univ. of Southern California, USA

- Consider target search tasks in changing environments for disaster scenarios
- Algorithms must plan over a long time horizon maximizing mutual information
- Proposed algorithm generates plans that cover the space multiple times as time constraints permit.
- Use of ε-admissible heuristics speed up the search

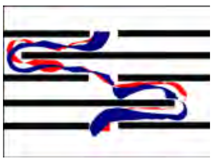
Motion model for graph search for disaster recovery scenario

16:25–16:30	WeD2.5

Efficient Multi-Agent Global Navigation Using Interpolating Bridges

Liang He[1], Jia Pan[2] and Dinesh Manocha[1]
1 The University of North Carolina at Chapel Hill
2 City University of Hong Kong

- A novel approach for collision-free global navigation for continuous time multi-agent systems with general linear dynamics.
- Compute multiple bridges for environments with narrow passages and crowded regions
- Agents leverage bridges for efficient navigation planning



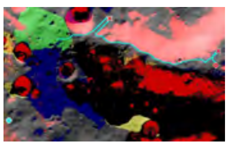
Collision-free results computed using bridges

16:30–16:35	WeD2.6

Accelerating Energy-Aware Spatiotemporal Path Planning for the Lunar Poles

Chris Cunningham, Joseph Amato, Heather L. Jones, William L. Whittaker
The Robotics Institute, Carnegie Mellon University, United States

- Planning missions for rovers on the lunar poles requires consideration of dynamic hazards including lighting and communication shadows.
- This paper accelerates energy-aware planning using a novel set of optimizations and constraints.
- Results show an average 80% runtime reduction over naïve planning with greater improvements in longer, more demanding test cases.



Planned path on lunar terrain showing slope, communication, and lighting hazards as well as the reachable area.

Motion and Path Planning 2

Chair *Nicola Wolpert, HFT Stuttgart*
Co-Chair *Haoyong Yu, National University of Singapore*

16:35–16:40	WeD2.7

Adaptive trajectory control of off-road mobile robots: A multi-model observer approach

Mathieu Deremetz and Roland Lenain
TSCF, IRSTEA, France
Benoit Thuilot
Institut Pascal, Clermont-Ferrand University, France
Vincent Rousseau
TSCF, IRSTEA, France

- An approach gathering extended kinematic and dynamic models into a single framework
- A unique observer regardless of the velocity allowing an accurate and reactive estimation of sliding
- An accurate path tracking, even in harsh conditions and when facing significant dynamic effects
- Full-scale experiments

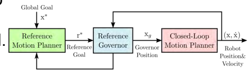
Fig. Picture of the robot during trials

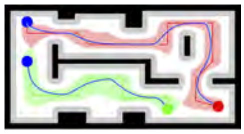
16:40–16:45	WeD2.8

Smooth Extensions of Feedback Motion Planners via Reference Governors

Omur Arslan and Daniel E. Koditschek
Electrical & Systems Engineering, University of Pennsylvania, US

- A novel application of reference governors to motion planning for separating the issues of stability and collision avoidance is presented.
- A provable correct computationally efficient framework for extending low-order motion planners to high-order systems is proposed.
- A new bidirectionally coupled robot-governor system is introduced.
- Smooth extensions of navigation paths to velocity- and force-controlled robot models are presented.





Visual Tracking

Chair *Junaed Sattar, University of Minnesota*
Co-Chair *Homayoun Najjaran, University of British Columbia*

16:05–16:10 WeD3.1

Set space visual servoing of a 6-DOF manipulator

Chicheng Liu[1], Rui Chen[1], Jing Xu[1], Jianguo Zhao[2], Heping Chen[3], Ning Xi[4], Ken Chen[1]
1 Department of Mechanical Engineering, Tsinghua University, China
2 Department of Mechanical Engineering, Colorado State University, USA
3 Ingram School of Engineering, Texas State University, USA
4 Emerging Technologies Institute, The University of Hong Kong, China

- Define image error in set space for control scheme input
- Deduce image interaction matrix to control robot
- Verify the proposed method by 6-DOF manipulation

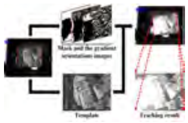
Set space visual servoing for 6-DOF manipulator

16:10–16:15 WeD3.2

Illumination Insensitive Efficient Second-order Minimization for Planar Object Tracking

Lin Chen[1], Fan Zhou[1], Yu Shen[2], Xiang Tian[1], Haibin Ling[2,3], and Yaowu Chen[1]
ADTI, Zhejiang University, China
Meitu HiScene Lab, HiScene IT, China
Computer and Information Sciences Dept, Temple University, USA

- The visual tracking method is robust to severe illumination changes and general challenges.
- The planar object tracking with templates is based on image registration and the ESM method.
- First to introduce the gradient orientations feature into ESM method, instead of the intensity values.
- The Perona-Malik method and mask images are used for handling image noise and low texture.



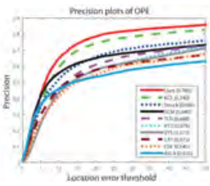
Schematic diagram of the illumination insensitive planar object tracking

16:15–16:20 WeD3.3

Correlation Filter-Based Self-paced Object Tracking

Wenhui Huang[1], Jason Gu[2], Xin Ma[1] and Yibin Li[1]
[1]School of Control Science and Engineering, Shandong University, China
[2]Department of Electrical and Computer Engineering, Dalhousie University, Canada

- Object tracking is an important capability for robots tasked with interacting with humans and the environment.
- A new object tracking method with the learning paradigm of self-paced learning.
- A real-valued error-tolerant self-paced function with a constraint vector to take the characteristics of object tracking into account.
- Under the framework of kernelized correlation filter to accelerate and advance the tracker.



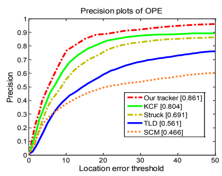
The precision plots for the top 10 trackers on the OTB 2013 data set.

16:20–16:25 WeD3.4

Real-time visual tracking via robust Kernelized Correlation Filter

Xiaoliang Wang, Changle Xiang, Bin Xu
Beijing Institute of Technology, China
Marie O'Brien and Homayoun Najjaran*
The University of British Columbia, Canada

- Increase tracking accuracy for fast moving targets by search window alignment based on motion estimation
- Accelerate tracking speed by reducing the padding value
- Enhance robustness by combined confidence measurement including occlusion information



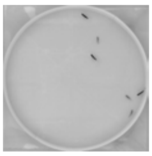
Comparison of the precision of the proposed tracker with the state of the art

16:25–16:30 WeD3.5

Multi-robot control and tracking framework for bio-hybrid systems with closed-loop interaction

Frank Bonnet, Alexey Gribovskiy and Francesco Mondada
Robotic Systems Laboratory, Polytechnic School of Lausanne, Switzerland
Leo Cazenille and José Halloy
Laboratory of Tomorrow's Energies, University Paris Diderot VII, France

- We present a novel framework for experimentation on bio-hybrid systems consisting of fish and robots
- The designed software is highly modular, flexible and efficient to perform closed-loop control of the robots according to the fish behavior
- We could show that a group composed of three robots can behave as the group of three zebrafish in terms of trajectory, speed and inter-individual distances



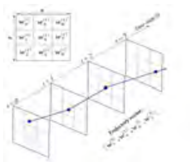
Three robots and three zebrafish moving in the same environment

16:30–16:35 WeD3.6

Mixed-domain Biological Motion Tracking for Underwater Human-Robot Interaction

Md Jahidul Islam and Junaed Sattar
Dept. of Computer Science, University of Minnesota

- Tracking spatial- and frequency-domain features pertaining to human swimming pattern
- Frequency-domain signatures capture periodic flipping along diver's swimming direction
- Hidden Markov Model (HMM)-based search-space pruning using spatial-domain features
- Robust detection of diver swimming in arbitrary motion directions at reasonable computation



Modeling arbitrary motion direction of diver in spatio-temporal volume

Visual Tracking

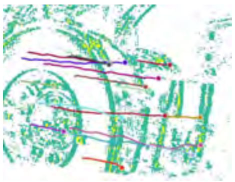
Chair *Junaed Sattar, University of Minnesota*
Co-Chair *Homayoun Najjaran, University of British Columbia*

16:35–16:40	WeD3.7

Event-based Feature Tracking with Probabilistic Data Association

Alex Zihao Zhu[1], Nikolay Atanasov[2] and Kostas Daniilidis[1]
[1]Computer and Information Science, University of Pennsylvania, USA
[2]Mechanical Engineering and Applied Mechanics, University of Pennsylvania, USA

- Events are grouped into features based the length of the optical flow.
- Assignment of events to features is soft and computed as a probability based on flow.
- Flow is computed as a maximization of the expectation over all data associations.
- The feature deformation is modeled as affine and the residual serves as a termination criterion



Semi truck driving 3m in front of the camera at 60 miles/hr

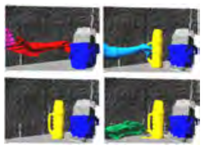
16:40–16:45	WeD3.8

Co-Fusion: Real-time Segmentation, Tracking and Fusion of Multiple Objects

http://visual.cs.ucl.ac.uk/pubs/cofusion/index.html

Martin Rünz and Lourdes Agapito
Department of Computer Science, University College London, United Kingdom

- Co-Fusion is a dense, multi-object SLAM system for RGBD-sequences.
- It tracks camera and objects simultaneously and maintains a surfel-based map per model.
- Co-Fusion segments the scene into different objects in image space, exploiting object motion or semantic cues.
- New synthetic and real evaluation-datasets were created and will be publicly available.



Co-Fusion allows simultaneous segmentation tracking, and fusion of multiple objects in RGB-D sequences

Session WeD4 | Rm. 4411/4412 | Wednesday, May 31, 2017, 16:05–17:20

SLAM 2

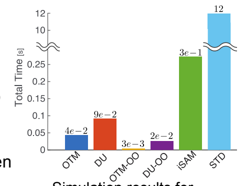
Chair *Vadim Indelman, Technion - Israel Institute of Technology*
Co-Chair *Cyrill Stachniss, University of Bonn*

16:05–16:10 WeD4.1

Towards Efficient Inference Update through Planning via JIP – Joint inference and Belief Space Planning

Elad I. Farhi
Technion Autonomous Systems Program (TASP), Technion, Israel
Vadim Indelman
Department of Aerospace Engineering, Technion, Israel

- Coalesce inference and planning using JIP – Joint Inference and Belief Space Planning paradigm.
- Utilizing Belief Space Planning calculations to efficiently update inference.
- Four inference update methods are offered, assuming consistent Data Association between inference and precursory planning.
- Our methods were compared to iSAM methodology and the standard batch paradigm.



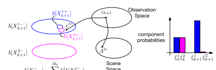
Simulation results for Inference Update running-time comparison.

16:10–16:15 WeD4.2

Nonmyopic Data Association aware Belief Space Planning for Robust Active Perception

Shashank Pathak, Antony Thomas, Vadim Indelman
Department of Aerospace Engineering
Technion – Israel Institute of Technology

- We relax the typical assumption of state-of-the-art Belief Space Planning – that the data association is given and perfect
- We consider uncertain data association within the belief in the context of nonmyopic planning
- Our framework is mathematically sound resulting in beliefs that are GMMs.
- Components of GMM can increase as well as decrease thereby modeling the problem better as shown by experiments on real robot and simulations



GMM beliefs with appropriate weight updates

16:15–16:20 WeD4.3

MonoRGBD-SLAM: Simultaneous Localization and Mapping Using Both Monocular and RGBD Cameras

Khalid Yousif
School of Engineering, RMIT University, Australia
Yuichi Taguchi and Srikumar Ramalingam
Mitsubishi Electric Research Labs (MERL), USA

- We present a SLAM system that uses both an RGBD camera and a wide-angle monocular camera
- Our system enables larger-scale 3D reconstruction with less failure cases than using only an RGBD camera
- We propose to generate multiple virtual images from each monocular image, which improves feature matching and loop closure detection between images captured by the different cameras

3D reconstruction results using the proposed method

16:20–16:25 WeD4.4

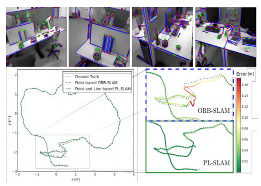
Real-Time Monocular Visual SLAM with Points and Lines

Albert Pumarola[1], Alexander Vakhitov[2], Antonio Agudo[1], Alberto Sanfeliu[1], Francesc Moreno-Noguer[1]
[1]*Institut de Robòtica i Informàtica Industrial, (UPC-CSIC), Spain*
[2]*Mathematics and Mechanics, St. Petersburg University, Russia*

Problem Statement: Given a monocular video, our problem is to simultaneously recover the full camera trajectory and the rigid structure. However, existing approaches are prone to fail when dealing with *poorly textured scenes.*

Our approach: Most real-world scenarios are human-made with low-textured environments. In such settings edges are predominant and one can still reliably estimate line-based geometric primitives.

Results: We obtain *state-of-the-art solutions* while combining *point and line correspondences* even on challenging scenarios.

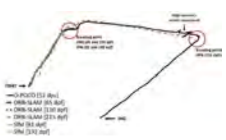


16:25–16:30 WeD4.5

ICRA 2017 Digest Template Paper Title in One or Two Lines

Luis Contreras and Walterio Mayol-Cuevas
Department of Computer Science, University of Bristol, United Kingdom

- We present O-POCO, a visual odometry and SLAM system that makes online decisions regarding what to map and what to ignore.
- We propose and evaluate different information layers such as the descriptor information's relative entropy, map-feature occupancy grid, and the point cloud's geometry error.
- This system outperform several baselines as SfM an ORB SLAM even for conditions using four times less information.

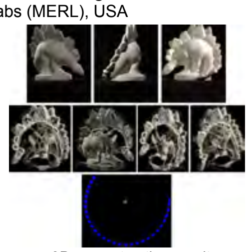


16:30–16:35 WeD4.6

ROS2D: Image Feature Detector Using Rank Order Statistics

Khalid Yousif and Alireza Bab-Hadiashar
School of Engineering, RMIT University, Australia
Yuichi Taguchi and Srikumar Ramalingam
Mitsubishi Electric Research Labs (MERL), USA

- We present a new image feature detection method
- The detector selects features based on segmenting points with high local intensity variations across different scales
- A robust rank order statistics approach is utilized for segmentation
- Our method produces a large number of repeatable features that are invariant to several image transformations



3D reconstruction results using the proposed features

SLAM 2

Chair *Vadim Indelman, Technion - Israel Institute of Technology*
Co-Chair *Cyrill Stachniss, University of Bonn*

16:35–16:40 WeD4.7

Illumination Change Robustness in Direct Visual SLAM

Seonwook Park Thomas Schöps Marc Pollefeys
Department of Computer Science, ETH Zurich, Switzerland

- Standard direct image alignment used in direct SLAM/VO based on Lukas-Kanade assumes brightness constancy.
- We evaluate 10 illumination change robust variants of this alignment for accuracy and robustness.
- Gradient and Census based formulations perform well in our tests.
- We release our test dataset of synthetic and real RGB-D videos with strong illumination changes.

Frames from our synthetic datasets with severe local illumination changes (based on ICL-NUIM)

16:40–16:45 WeD4.8

Cyrillic Manual Alphabet Recognition in (RGB)-D Data for Sign Language Interpreting Robotic System

Nazgul Tazhigaliyeva, Nazerke Kalidolda, Alfarabi Imashev, Shynggys Islam, Kairat Aitpayev, Anara Sandygulova
Nazarbayev University, Astana, Kazakhstan
German I. Parisi
University of Hamburg, Germany

- Aim: to develop an interpreting robotic system for hearing-impaired individuals.
- We collected four fully annotated RGB and RGB-D datasets, two static and two motion datasets, of 33 signs of Cyrillic manual alphabet.
- Applied datasets to standard ML tools and to our neural network-based learning architecture.
- Our motion-based results outperform static results. RGB-D results outperform RGB results.
- Average accuracy for 33 gestures is 93%.

Fingerspelling in process.

Aerial Robot 4

Chair *Kostas Alexis, University of Nevada, Reno*
Co-Chair *Shaojie Shen, Hong Kong University of Science and Technology*

16:05–16:10	WeD5.1

Orientation Filter and Angular Rates Estimation in Monocopter using Accelerometers and Magnetometer with the Extended Kalman Filter

Teguh Santoso Lembono, Jun En Low, Luke Soe Thura Win, Shaohui Foong, *Member, IEEE,* and U-Xuan Tan, *Member, IEEE*
Singapore University of Technology and Design, Singapore

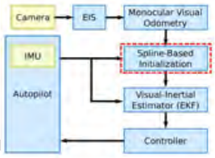
- Two important parameters in monocopter flights: angular rates and orientation (heading direction)
- We propose to use three accelerometers to replace gyroscope for angular rates estimation, especially at high speed
- We propose to use Extended Kalman Filter to estimate the heading direction. The monocopter's angular rates direction is used as the vertical direction reference.

16:10–16:15	WeD5.2

High Altitude Monocular Visual-Inertial State Estimation: Initialization and Sensor Fusion

Tianbo Liu and Shaojie Shen
Dept. of ECE, The Hong Kong University of Science and Technology, Hong Kong S.A.R.

- Monocular visual-inertial systems are difficult to be initialized at high altitude.
- A spline-based high altitude estimator initialization method is proposed in this paper.
- Spline fitting and visual-inertial alignment are optimized to recovery quantities required by initialization.
- A complete closed-loop system is constructed, and experiments are conducted to validate our approach.

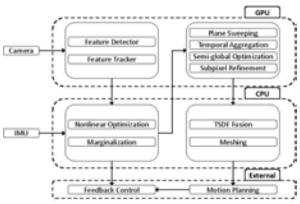


16:15–16:20	WeD5.3

Real-time Monocular Dense Mapping on Aerial Robots Using Visual-Inertial Fusion

Zhenfei Yang, Fei Gao, and Shaojie Shen
Robotics Institute, Hong Kong University of Science and Technology, China

- A dense mapping system that runs real-time on Nvidia Jetson TX1
  - ➢ Visual-inertial localization
  - ➢ Motion stereo
  - ➢ Global map fusion
- Close the perception-action loop: navigate a quadrotor autonomously with collision-free guarantee
- Open Source

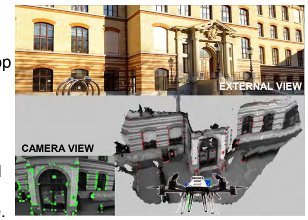


16:20–16:25	WeD5.4

Real-Time Local 3D Reconstruction for Aerial Inspection using Superpixel Expansion

Lucas Teixeira and Margarita Chli
Vision for Robotics Lab, ETH Zurich, Switzerland

- Pipeline for real-time onboard 3D reconstruction from a small aircraft.
- Denser depth estimation builds on top of feature-based monocular-inertial SLAM.
- Strict filtering of depth estimates is applied to remove outliers, after superpixel-based dilation & temporal fusion are used to create a dense, local map of the aircraft's workspace.



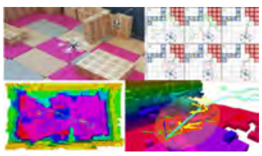
Real-time dense reconstruction of a local scene for aerial inspection

16:25–16:30	WeD5.5

Uncertainty-aware Receding Horizon Exploration and Mapping using Aerial Robots

Christos Papachristos, Shehryar Khattak and Kostas Alexis
Department of Computer Science and Engineering, University of Nenada, Reno, USA

- Two-step Random Sampling-based Probabilistic Exploration and Mapping:
- Exploration based on Volumetric gain and Mapping Probability improvement.
- Localization and Mapping consistency by Propagating Uncertainty of pose and landmarks through simulated inertial measurements for randomly sampled trajectories.
- Open-source code and datasets: https://github.com/unr-arl/rhem_planner



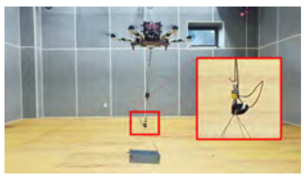
Autonomous Exploration of an unknown environment with Uncertainty-aware Path-planning for Probabilistic Volumetric Mapping

16:30–16:35	WeD5.6

Autonomous Swing-Angle Estimation for Stable Slung-Load Flight of Multi-Rotor UAVs

Seung Jae Lee and H. Jin Kim
Department of Mechanical and Aerospace Engineering, Seoul National University, Republic of Korea

- Presents a disturbance observer (DOB) based autonomous swing angle estimator for multirotor UAV
- Only built-in IMU and single load cell mounted between tether is used for swing-angle estimation
- Autonomous thrust force estimation method without additional sensors is presented



Aerial Robot 4

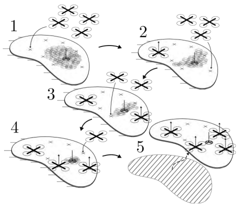
Chair *Kostas Alexis, University of Nevada, Reno*
Co-Chair *Shaojie Shen, Hong Kong University of Science and Technology*

16:35–16:40	WeD5.7

Active Estimation of Mass Properties for Safe Cooperative Lifting

Micah Corah and Nathan Michael
Robotics Institute, Carnegie Mellon University, USA

- Reliable and safe aerial manipulation requires mass parameter estimation and feasible lifting configurations
- Non-parametric Bayesian filtering and minimal interactions provide estimates
- Measurements selected via information-theoretic active sensing
- Simultaneous estimation and formation of lifting configurations via chance-constrained deployment strategy

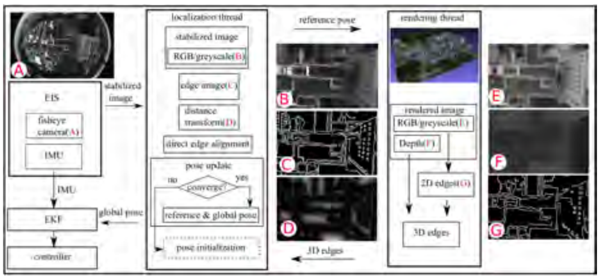


Coordinated aerial manipulation is achieved via: (1) approach, (2-4) deployment and interaction, and (4) object lifting

16:40–16:45	WeD5.8

Model-based Global Localization for Aerial Robots Using Edge Alignment

Kejie Qiu, Tianbo Liu, and Shaojie Shen



Semantic Understanding

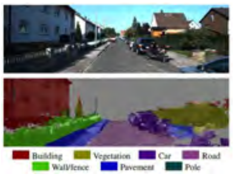
Chair *Fabio Morbidi, Université de Picardie Jules Verne*
Co-Chair *James J. Little, UBC*

16:05–16:10	WeD6.1

MF3D: Model-Free 3D Semantic Scene Parsing

Frederick Tung and James J. Little
Department of Computer Science, University of British Columbia, Canada

- We present a novel model-free method for online 3D semantic scene parsing from video sequences
- Voxel labelling is approached via search-based label transfer instead of discriminative classification
- MF3D is easily extensible to new examples or categories as no model re-training is required



16:10–16:15	WeD6.2

What Can I Do Around Here? Deep Functional Scene Understanding for Cognitive Robots

Chengxi Ye[1], Yezhou Yang[2], Ren Mao[1]
Cornelia Fermüller[1], Yiannis Aloimonos[1]
[1]University of Maryland, USA
[2]CIDSE, Arizona State University, USA

- We address the problem of **localizing** and **recognition** of **functional areas** from an indoor scene.
- We designed a scene functional area ontology for indoor domain.
- Deep network based recognition approach is developed and presented for scene functional understanding.
- The first scene functionality dataset is compiled and made publicly available (with >100,000 annotated training samples).

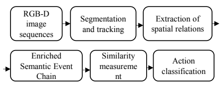
Figure caption is optional, use Arial 18pt

16:15–16:20	WeD6.3

Semantic Analysis of Manipulation Actions using Spatial Relations

Fatemeh Ziaeetabar[1], Eren Erdal Aksoy[2], Florentin Wörgötter[1] and Minija Tamosiunaite[1,3]
[1] Institute for Physics 3- Biophysics, Georg August University, Göttingen, Germany
[2] Institute for Anthropomatics and Robotic, Karlsruher Institute for Technologies (KIT), Karlsruhe, Germany
[3] Faculty of Informatics, Vytautas Magnus University, Kaunas, Lithuania

- A new framework for representation and recognition of manipulation actions.
- Extraction of symbolic relations based on AABB object models and using sequences of spatial relations between manipulated objects for an accurate classification.
- This relational framework is able to differentiate and classify manipulation actions on a big dataset and obtains 97% accuracy.



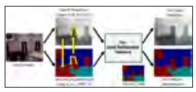
Steps of our spatial reasoning approach

16:20–16:25	WeD6.4

Analyzing Modular CNN Architectures for Joint Depth Prediction and Semantic Segmentation

Omid Hosseini Jafari[1], Oliver Groth[1], Alexander Kirillov[1]
Michael Ying Yang[2] and Carsten Rother[1]
[1]Computer Vision Lab, TU Dresden, Germany
[2]Scene Understanding Group, University of Twente, Netherlands

- Propose Joint refinement network to predict and to refine depth estimation and semantic labeling jointly given a single image
- Propose an experimental set-up to measure cross-modality influence
- Analyzing different network design to show the relationship between cross-modality influence and performance of tasks

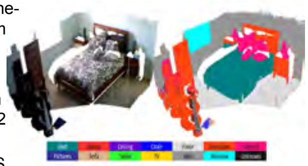


16:25–16:30	WeD6.5

SemanticFusion: Dense 3D Semantic Mapping with Convolutional Neural Networks

John McCormac, Ankur Handa,
Andrew Davison and Stefan Leutenegger
Dyson Robotics Lab, Imperial College London, UK

- Combine CNNs with a state-of-the-art real time dense SLAM system
- Produce globally consistent semantically annotated 3D map
- Fusing multiple 2D predictions in 3D improves accuracy on NYUv2
- The system is fast enough to enables interactive use at 25FPS



16:30–16:35	WeD6.6

Online Learning for Scene Segmentation With Laser-Constrained CRFs

Charika Alvis, Lionel Ott and Fabio Ramos
School of IT, University of Sydney, Australia

- A model to learn CRF parameters which eliminates the need for ground truth labels
- Reference labels obtained by processing multimodal sensor data.
- Stochastic method to update the parameters in online settings
- Adaptive parameter learning for non-stationary data encountered in long-term autonomy settings

Semantic Understanding

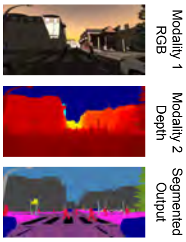
Chair *Fabio Morbidi, Université de Picardie Jules Verne*
Co-Chair *James J. Little, UBC*

16:35–16:40	WeD6.7

AdapNet: Adaptive Semantic Segmentation in Adverse Environmental Conditions

Abhinav Valada, Johan Vertens,
Ankit Dhall, and Wolfram Burgard
University of Freiburg, Germany

- Convolutional neural network based semantic segmentation architecture built upon the residual learning framework
- Scale invariant and fast inference (~59 *ms*)
- Adaptive fusion framework for learning complementary features from multiple modalities
- Robust to lighting changes, seasonal appearance changes, motion-blur and glare
- Demo: http://deepscene.cs.uni-freiburg.de/



16:40–16:45	WeD6.8

Phase Correlation for Dense Visual Compass from Omnidirectional Camera-Robot Images

Fabio Morbidi and Guillaume Caron
MIS laboratory, University of Picardie Jules Verne, Amiens, France

- New dense omnidirectional visual compass based on the *phase correlation method* in the 2-D Fourier domain
- Accurate, robust to image noise, and computationally inexpensive
- Suitable for use with *weakly-calibrated* cameras
- Experimental validation with a hypercatadioptric camera mounted on the end-effector of a Staubli manipulator and on a Pioneer robot
- OVMIS dataset: http://mis.u-picardie.fr/~g-caron/en

Manipulation Planning 2

Chair *Jurgen Leitner, Australian Centre for Robotic Vision / Queensland University of Technology*
Co-Chair *Hai-Jun Su, The Ohio State University*

16:05–16:10	WeD7.1

A Robust Control Scheme for 3D Manipulation of a Microparticle with Electromagnetic Coil System

Weicheng Ma, Junyang Li, Fuzhou Niu, Bo Ouyang and Dong Sun
Department of Mechanical and Biomedical Engineering, City University of Hong Kong, Hong Kong, China
Haibo Ji
Department of Automation, University of Science and Technology of China, China

- A **robust feedback control** approach for precise 3D manipulation of a microparticle actuated by a self-constructed electromagnetic coil system is proposed
- **Model uncertainties**, **environmental disturbances**, as well as **actuator energy loss** problem are all taken into account in the controller design
- The proposed control scheme can enable the entire system to maintain the **input-to-state stability** in presence of various perturbations

An overview of the prototype electromagnetic coil system

16:10–16:15	WeD7.2

Toward Improving Path Following Motion: Hybrid Continuum Robot Design

Ernar Amanov, Josephine Granna and Jessica Burgner-Kahrs
Laboratory for Continuum Robotics,
Leibniz Universität Hannover, Germany

- Hybrid continuum robot design: concentric tube and tendon-driven design combination
- Path following capabilities investigation of tendon-driven continuum robots
- Hybrid design prototype introduction
- Experimental evaluation of path following with the hybrid design prototype

16:15–16:20	WeD7.3

The Manifold Particle Filter for State Estimation on High-dimensional Implicit Manifolds

Michael C. Koval, Matthew Klingensmith,
Siddhartha S. Srinivasa, Nancy S. Pollard, and Michael Kaess
Robotics Institute, Carnegie Mellon University, USA

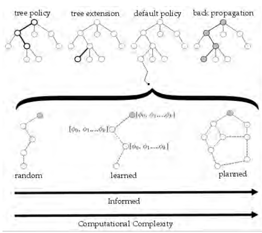
- Use contact sensors to estimate the configuration of a robot with noisy proprioception
- Implicitly represent the *contact* manifold of states consistent with an observation as the iso-contour of the signed distance function
- Use constraint projection to draw samples from the contact manifold to implement the *implicit manifold particle filter*
- Demonstrate the proposed technique on a real robotic arm and under-actuated robotic hand

16:20–16:25	WeD7.4

Unobservable Monte Carlo Planning for Nonprehensile Rearrangement Tasks

Jennifer King, Vinitha Ranganeni, Siddhartha Srinivasa
Robotics Institute, Carnegie Mellon University, USA

- An anytime planner for creating open-loop trajectories that solve rearrangement problems
- Extend Monte Carlo Tree Search to the unobservable domain
- Evaluate three default policies:
  - **Random policy** – generate random action sequences
  - **Learned policy** – use human demonstrations to build a mapping that is queried for action sequences
  - **Planned policy** – heuristically plan in subspace of the full problem



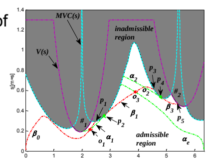
Policies trade-off computational complexity for better informed decision making

16:25–16:30	WeD7.5

Essential Properties of Numerical Integration for Time-optimal Path-constrained Trajectory Planning

Peiyao Shen, Xuebo Zhang and Yongchun Fang
Institute of Robotics and Automatic Information System, Nankai University, China
Tianjin Key Laboratory of Intelligent Robotics, Nankai University, China

- This paper presents several new properties of the Numerical Integration (NI) method.
- Rigorous mathematical proofs of these new properties are presented.
- Some simulation results on a unicycle are provided to verify those presented properties.



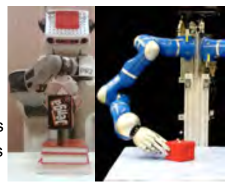
The NI method outputs the time-optimal trajectory.

16:30–16:35	WeD7.6

A Comparison of Autoregressive Hidden Markov Models for Modeling Mass-Dependent Mode Switches in Manipulation Tasks

Oliver Kroemer
RESL, University of Southern California (USC), USA
Jan Peters
IAS, Technische Universitaet Darmstadt, Germany

- Mode switches, such as making or breaking contact, often depend on an object's mass
- We evaluated four types of ARHMMs for modeling mode switches in manipulation tasks
- The robot uses the models to predict the masses and trajectories of manipulated objects
- We successfully evaluated the different models on both pushing and lifting tasks



Manipulation Planning 2

Chair *Jurgen Leitner, Australian Centre for Robotic Vision / Queensland University of Technology*
Co-Chair *Hai-Jun Su, The Ohio State University*

16:35–16:40	WeD7.7

The ACRV Picking Benchmark: A Robotic Shelf Picking Benchmark to Foster Reproducible Research

Jürgen Leitner et al.
Australian Centre for Robotic Vision (ACRV)

The proposed benchmark consists of:
(A)a commonly available shelf
(B)objects

We also presents a baseline system
(C) performing the benchmark tasks
(D) describe its deployment during the Amazon Picking Challenge 2016

http://Juxi.net/dataset/acrv-picking-benchmark/

16:40–16:45	WeD7.8

Feature Selection for Learning Versatile Manipulation Skills based on Observed and Desired Trajectories

Oliver Kroemer and Gaurav S. Sukhatme
RESL, University of Southern California (USC), USA

- Robots need to adapt manipulation skills using a small subset of the objects' features
- Evaluated selecting relevant features based on observed trajectories versus desired trajectories
- Explored including a meta prior to predict the relevance of features based on previous skills
- The methods were successfully evaluated using placing, tilting, and wiping skills

Humanoid Robots 3

Chair *Christian Ott, German Aerospace Center (DLR)*
Co-Chair *Abderrahmane Kheddar, CNRS-AIST JRL (Joint Robotics Laboratory), UMI3218/CRT*

16:05–16:10	WeD8.1

Overlap-based ICP Tuning for Robust Localization of a Humanoid Robot

Simona Nobili, Raluca Scona,
Marco Caravagna and Maurice Fallon
School of Informatics, University of Edinburgh, UK

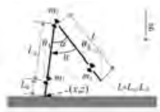
- AICP: a strategy for **non-incremental** 3D scene registration and localization in challenging environments.
- Point clouds registration based on careful pre-filtering and **automatic adjustment to overlap variations**.
- **Motivation:** avoid incremental error and recover from failures.
- **Accurate localization** of the NASA Valkyrie and the Boston Dynamics Atlas humanoid robot during the DARPA Robotics Challenge Finals.

16:10–16:15	WeD8.2

Control Walking Speed by Approximate-kinetic-model-based Self-adaptive Control on Underactuated Compass-like Bipedal Walker

Xuan Xiao and Ou Ma
School of Aerospace Engineering, Tsinghua University, China
Fumihiko Asano
School of Information Science, JAIST, Japan

- The model of underactuated compass-like bipedal walker is built and the gait properties are analyzed based on an open-loop control law.
- The approximate-kinetic model-based self-adaptive (AKS) control system is proposed through updating trajectory and control parameters.
- The capability of disturbance rejection and adjusting walking speed of AKS system are tested through numerical simulations.



A planar underactuated compass-like bipedal walker

16:15–16:20	WeD8.3

Stability Regions for Standing Balance of Biped Humanoid Robots

Jung Hoon Kim, Jongwoo Lee, Yonghwan Oh
Center for Robotics Research, KIST, Republic of Korea

- An analytical method for computing stability regions relevant to standing balance of biped humanoid robots is developed based on their LIPM.
- ZMP should be located in the supporting region for stable standing balance of biped humanoid robots.
- Set 1: The initial values of the CoM position & velocity
- Set 2: Maximum admissible impulse force disturbance.
- Set 3: Maximum admissible external force disturbance of finite energy

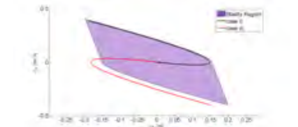
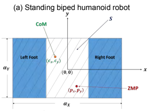


Figure. Stability region. case i) The initial value of the CoM position & velocity inside the stability region. case ii) The initial value of the CoM position & velocity outside the stability region

(a) Standing biped humanoid robot



(b) Supporting region

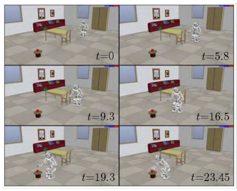
Figure. Standing biped humanoid robot with its supporting region

16:20–16:25	WeD8.4

Humanoid Whole-Body Planning for Loco-Manipulation Tasks

Paolo Ferrari, Marco Cognetti, Giuseppe Oriolo
Sapienza University of Rome, Italy

- Generation of natural whole-body motions for humanoids in loco-manipulation tasks
- Definition of three operational zones: locomotion, loco-manipulation, manipulation
- A synchronization mechanism between the two tasks allows fluid, smooth transitions
- Implemented in V- REP for the NAO and successfully tested in various scenarios

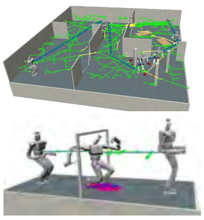


16:25–16:30	WeD8.5

Footstep and Motion Planning in Semi-unstructured Environments Using Randomized Possibility Graphs

Michael X. Grey and C. Karen Liu
School of Interactive Computing, Georgia Tech, USA
Aaron D. Ames
Mech. and Civil Eng. & Control and Dyn. Sys., CalTech, USA

- Quickly evaluate the possibilities of routes though the environment
- Use fast and efficient gait generators to traverse “easy” routes
- Focus low-level whole body motion planners on challenging routes
- Parallelizable to avoid unnecessary bottlenecks

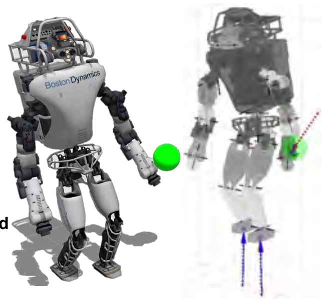


16:30–16:35	WeD8.6

Collision Detection, Isolation and Identification for Humanoids

Jonathan Vorndamme, Moritz Schappler and Sami Haddadin
Insitute of Automatic Control, Leibniz Universität Hannover, Germany

- Unified **collision detection**, **isolation** and **identification** for humanoid robots
- Solution for **single and multi contact without tactile skins**
- Suitable for **any combination** of **joint torque** and **distributed force/torque sensors**
- Acceleration observer based **load compensation** for **distributed force/torque sensors**



Humanoid Robots 3

Chair *Christian Ott, German Aerospace Center (DLR)*
Co-Chair *Abderrahmane Kheddar, CNRS-AIST JRL (Joint Robotics Laboratory), UMI3218/CRT*

16:35–16:40	WeD8.7

QP-based Adaptive-Gains Compliance Control in Humanoid Falls

Vincent Samy and Abderrahmane Kheddar
CNRS - University of Montpellier LIRMM, 34000 Montpellier France
Karim Bouyarmane
University of Lorraine - INRIA - CNRS LORIA, 54600 Villers-lès-Nancy, France

- Handle falls in any direction in a cluttered environment
- Search of impact points and shape the robot to be compliant to the impact.
- Adaptive gains compliance computation to absorb the impact reaction forces.
- A QP is used in both pre-impact and post-impact phases.

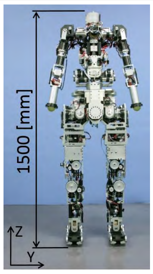

Falling strategy

16:40–16:45	WeD8.8

Angular Momentum Compensation in Yaw Direction using Upper Body based on Human Running

T. Otani[1], K. Hashimoto[1], S. Miyamae[1], H. Ueta[1], M. Sakaguchi[2], Y. Kawakami[1], H. O. Lim[3] and A. Takanishi[1]
[1]Waseda University, Japan [2] University of Calgary, Canada [3]Kanagawa University, Japan

- We developed an angular momentum control method using a humanoid upper body based on human motion. In this method, the angular momentum generated by the movement of the humanoid lower body is calculated, and the torso and arm motions are calculated to compensate for the angular momentum of the lower body.



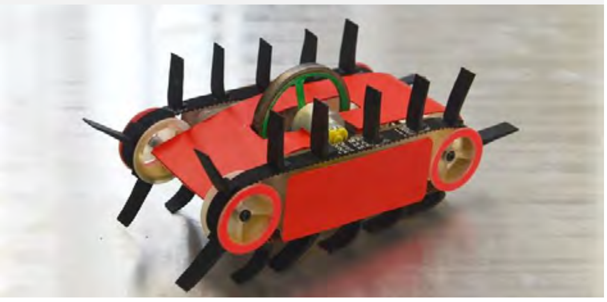
Biologically-Inspired Robots 3

Chair *Stefano Mintchev, École polytechnique fédérale de Lausanne*
Co-Chair *Kamilo Melo, EPFL*

16:05–16:10	WeD9.1

Blade-type Crawler Vehicle with Gyro Wheel for Stably Traversing Uneven Terrain at High Speed

Yasuyuki Yamada[1], Hirotaka Sawada[2],
Takashi Kubota[2] and Taro Nakamura[1]
[1]Chuo University, Japan. [2]Japan Aerospace Exploration Agency (JAXA).

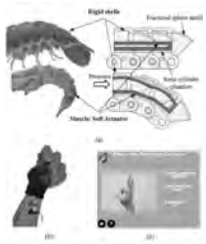


16:10–16:15	WeD9.2

A Lobster-inspired Robotic Glove for Hand Rehabilitation

Yaohui Chen, Sing Le, Qiao Chu Tan, Oscar Lau,
Chaoyang Song*
Faculty of Engineering, Monash University, Australia
Fang Wan
Independent Researcher, China

- A lobster-inspired actuator with both soft and rigid components to address repeatability and vulnerability issues;
- Investigations including design, fabrication and characterization;
- An open-palm glove design integrated with the hybrid actuators to assist hand rehabilitation at home;
- A learning system for hand rehabilitation with EMG control strategy and game interface.



16:15–16:20	WeD9.3

Quadrupedal Locomotion using Trajectory Optimization and Hierarchical Whole Body Control

Christian Gehring, C. Dario Bellicoso, Péter Fankhauser, Marco Hutter
Robotics Systems Lab, ETH Zurich, Switzerland
Stelian Coros
Carnegie Mellon University, USA

- Fast motion planning with trajectory optimization and a simple model of the dynamics
- Robust motion tracking with online plan alignment, corrective stepping and whole body control based on state feedback
- Walking, trotting and transition between the two gaits with the quadruped robot
- Experimental results with the fully torque-controllable 30kg quadruped ANYmal

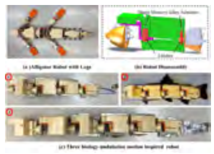
ANYmal

16:20–16:25	WeD9.4

Biological Undulation Inspired Swimming Robot

Xinghua Jia[1], Zongyao Chen[2], JM Petrosino[3], William R Hamel[4], and Mingjun Zhang[5]
The Ohio State University[1,3,5], The University of Tennessee[2,4]

- Three aquatic species including alligator, eel and trout were investigated to uncover the propulsion mechanism and applied for swimming robot design.
- Both simulation and experimental results showed and explained the variation trend as the undulation changed from the anguilliform to the carangiform.



Undulation Inspired Swimming Robot

16:25–16:30	WeD9.5

Introducing Rotary Force to a Template Model can Explain Human Compliant Slope Walking

Xiaochen Wang
AgileBody, Beijing, China
Tao Geng
School of Science and Technology, Middlesex University London, UK

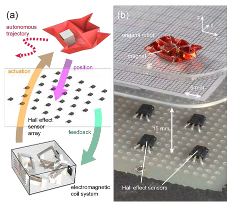
- Humans preserve compliant legged behavior during slope walking
- Introducing rotary force to a template model can explain such human compliant behavior
- Letting rotary force collaborate with radial compliant mechanism can improve energy-efficiency of legged robots

16:30–16:35	WeD9.6

Autonomous Locomotion of a Miniature, Untethered Origami Robot Using Hall Effect Sensor-Based Magnetic Localization

Steven Guitron, Anubhav Guha, Shuguang Li, Daniela Rus
Massachusetts Institute of Technology, USA

- Closed-loop, autonomous position feedback control is enabled utilizing the robot's integrated magnet
- 33 Hall effect sensors arranged in repeated triangles enables position detection (average error of 0.995 ± 0.520 mm).
- The robot's speed response to applied magnetic field was characterized for controller development



Position Feedback System

Biologically-Inspired Robots 3

Chair *Stefano Mintchev, École polytechnique fédérale de Lausanne*
Co-Chair *Kamilo Melo, EPFL*

16:35–16:40	WeD9.7

Insect-inspired Mechanical Resilience for Multicopters

S. Mintchev, S. de Rivaz and D. Floreano
Laboratory of Intelligent Systems, EPFL

- Some insects has dual-stiffness wings that rigidly withstand loads during flight, but soften during collision to avoid damages.
- Based on this findings, the quadcopter has a dual-stiffness frame that reversibly transition between a rigid and a soft state.
- Stiffness under low loads ensures a stable and efficient flight while mechanical compliance under high loads prevents damages during collisions.

16:40–16:45	WeD9.8

Spine Controller for a Sprawling Posture Robot

Tomislav Horvat[1], Kamilo Melo[1] and Auke J. Ijspeert[1]
[1]Biorob, EPFL, Switzerland

- Effective locomotion controller for a robot with the segmented spine
- Importance of spine-limb coordination
- Active usage of the spine for both straight walking and turning
- Robot's maneuverability demonstrated in a simulation and on a real robot

Surgical Robotics 2

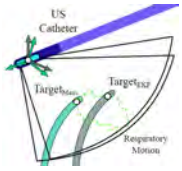
Chair *Sarthak Misra, University of Twente*
Co-Chair *Robert James Webster III, Vanderbilt University*

16:05–16:10	WeD10.1

Predictive Filtering in Motion Compensation with Steerable Cardiac Catheters

Paul M Loschak, Alperen Degirmenci, and Robert D Howe
Paulson School of Engineering and Applied Sciences, Harvard University, USA

- Robotic navigation of cardiac ultrasound (US) imaging catheters provides real time imaging from within the heart
- Accurate navigation is challenging due to physiological disturbances such as respiration
- We use an Extended Kalman Filter (EKF) to predict target motion
- Predictions are used towards automatically steering the US catheter in benchtop experiments



Predictive filtering applied towards ultrasound (US) tracking a target

16:10–16:15	WeD10.2

The Tethered Magnet: Force and 5-DOF Pose Control for Cardiac Ablation

Christophe Chautems and Bradeley J. Nelson
Multi-Scale Robotics Lab , ETH Zurich, Switzerland

- Magnet connected to a tether control with magnetic field and magnetic gradient
- Stable magnet position by means of tether lenght constraint
- Position and orientation control demonstrate inside a magnetic manipulation system
- Catheter tip contact force dependent on magnetic gradient magnitude

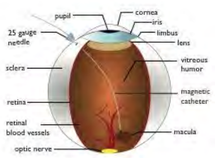
Tethered Magnet floating inside magnetic field

16:15–16:20	WeD10.3

Shared Control of a Magnetic Microcatheter for Vitreoretinal Targeted Drug Delivery

Samuel L. Charreyron, Burak Zeydan and Bradley J. Nelson
Multi Scale Robotics Lab, ETH Zurich, Switzerland

- Age Related Macular Degeneration (AMD) and Diabetic Retinopathy (DR) are retinal pathologies and leading causes of blindness
- A magnetic microcatheter could be used for delivery of therapeutics to precise retinal targets
- We demonstrate a control strategy shared between a human operator and automated magnetic positioning of the microcatheter in a vitreoretinal phantom

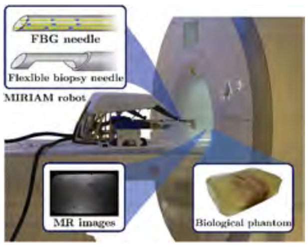


16:20–16:25	WeD10.4

Towards MRI-guided Flexible Needle Steering Using Fiber Bragg Grating-Based Tip Tracking

Pedro Moreira[1], Klaas Jelmer Boskma[2] and Sarthak Misra[1,2]
[1]Department of Biomechanical Engineering, University of Twente, Netherlands
[2]Department of Biomedical Engineering, University Medical Center Groningen and Univerisity of Groningen, Netherlands

- Magnetic Resonance Imaging (MRI)-guided interventions using Fiber Bragg Grating (FBG) sensor to track the needle
- Combining MRI-compatible robot with FBG-based needle tracking
- Closed-loop flexible needle steering
- Average targeting error of 1.74 mm in gelation and biological phantoms

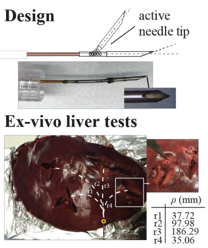


16:25–16:30	WeD10.5

Highly articulated robotic needle achieves distributed ablation of liver tissue

Giada Gerboni[1], Joseph D. Greer[1], Paul F. Laeseke[2], Gloria L. Hwang[3] and Allison M. Okamura[1]
[1] Mechanical Engineering Department, Stanford University, USA
[2] Radiology Department, University of Wisconsin, USA
[3] Radiology Department, Stanford University, USA

- Robotic needle steering enables percutaneous radiofrequency ablation (RFA) of irregular shaped and multifocal liver tumors.
- The active needle tip design increases needle curvature while meeting clinical constraints.
- Needle configuration and curvature in both artificial and *ex-vivo* liver tissue is determined via 3D ultrasound data.
- Distributed RFA of liver tissue under ultrasound imaging was successfully performed in *ex-vivo* porcine model.

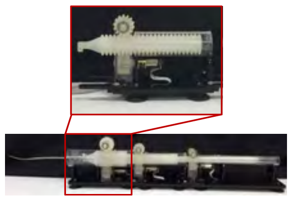


16:30–16:35	WeD10.6

Design of a Compact Actuation and Control System for Flexible Medical Robots

Tania K. Morimoto[1], Elliot W. Hawkes[1,2], and Allison M. Okamura[1]
[1]Mechanical Engineering Department, Stanford University, USA
[2]Department of Mechanical Engineering, University of California, Santa Barbara, USA

- Compact, lightweight, modular actuation system
- Each module drives two degrees of freedom (insertion and rotation)
- Enabled by roller gears with teeth in both axial and radial directions
- Suitable for use in patient- and procedure-specific design process



Modular actuation and control system shown holding three concentric tubes and as a single unit

Surgical Robotics 2

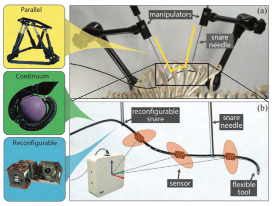
Chair *Sarthak Misra, University of Twente*
Co-Chair *Robert James Webster III, Vanderbilt University*

16:35–16:40	WeD10.7

Continuum Reconfigurable Parallel Robots: Shape Sensing and State Estimation

Patrick Anderson, Art Mahoney, and Robert Webster III
Department of Mechanical Engineering, Vanderbilt University, USA

- Continuum reconfigurable incisionless surgical parallel (CRISP) robots give 6-DOF control to needle instruments
- Sensors such as magnetic trackers are integrated into the needle instruments
- A Kalman filter estimation framework enables shape estimation even under applied forces of unknown magnitude
- Experiments using magnetic trackers confirm better tip pose estimates despite unknown tip loads



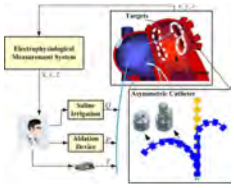
(a) CRISP robots combine the benefits of parallel, continuum, and reconfigurable robots and (b) they can be sensorized for shape estimation despite uncertainty

16:40–16:45	WeD10.8

A Contact-Aided Asymmetric Steerable Catheter for Atrial Fibrillation Ablation

Anzhu Gao, Hao Liu, Yun Zou, Zhidong Wang
State Key Laboratory of Robotics
Shenyang Institute of Automation, Chinese Academy of Sciences, China
Ming Liang, Zulu Wang
General Hospital of Shenyang Command of Chinese PLA, Shenyang, China

- Propose to use the asymmetric catheter to improve the tip orientation capability for the asymmetric lesions at the pulmonary veins;
- Design a 2D steerable catheter with contact aided compliant mechanism to achieve the asymmetric bends;
- Kinematics and lesion exploration algorithm are presented to show its reachability;
- Phantom study shows that the proposed catheter with CCMs can improve the tip orientation and achieve the full exploration.



Cardiac catheter ablation using the asymmetric catheter with CCMs

Marine Robotics

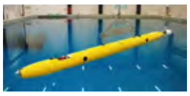
Chair *Gregory Dudek, McGill University*
Co-Chair *Brendan Englot, Stevens Institute of Technology*

16:05–16:10	WeD11.1

Experimental Evaluation of Various Machine Learning Methods for Model Identification of Autonomous Underwater Vehicles

Bilal Wehbe, Marc Hildebrandt, and Frank Kirchner
DFKI – Robotic Innovation Center, Bremen, Germany

- Identification of motion model of an AUV by applying machine learning regression.
- Data is collected from the vehicle's on board sensors.
- Four regression algorithms are used: neural nets, kernel ridge, suppor vector machines, and Gaussian processes.
- Results show that learning methods outperforms classical least squares method for model estimation.



AUV Leng during experimentation

16:10–16:15	WeD11.2

Assisted Painting of 3D Structures Using Shared Control with Under-actuated Robots

Joshua Elsdon and Yiannis Demiris
Electronic and Electrical Engineering, Imperial College London, UK

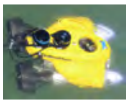
- Development and implementation of a planning algorithm for shared control of a handheld painting robot
- A single autonomously controlled DOF positions the paint spraying head
- Planner is run in a receding-horizon fashion and generates paths in real time
- Planner finds solution that will apply paint to most needed areas efficiently

16:15–16:20	WeD11.3

Underwater Localization and 3D Mapping of Submerged Structures with a Single-Beam Scanning Sonar

Jinkun Wang, Shi Bai and Brendan Englot
Stevens Institute of Technology, USA

- A novel perceptual pipeline is presented that applies SLAM to scanning sonar data, in the absence of inertial/odometry sensing, and accounts for vehicle motion that occurs while scanning
- Clustered sonar range returns are adaptively thresholded, and re-clustered to extract high-quality point features – each corresponds to a distinct pose
- Joint compatibility branch-and-bound is iteratively employed in concert with iSAM2 to achieve accurate data association
- Gaussian process occupancy mapping is applied to the resulting point clouds to produce accurate, descriptive 3D maps of submerged structures



16:20–16:25	WeD11.4

Phytoplankton Hotspot Prediction With an Unsupervised Spatial Community Model

Arnold Kalmbach and Gregory Dudek
School of Computer Science, McGill University, Montreal, Canada
Yogesh Girdhar and Heidi M. Sosik
Woods Hole Oceanographic Institution, Woods Hole, MA, USA

- We model the spatial co-occurrence between sparse, discrete natural phenomena with a Bayesian nonparametric **topic model**.
- Estimating topics from partial observations enables **robust estimation of unobserved target hotspots**.
- We apply this approach to data from a unique marine robotic instrument, learning a **phytoplankton community model and predicting the hotspots of specific missing taxa**.

16:25–16:30	WeD11.5

An Artificial Fish Lateral Line Sensory System Composed of Modular Pressure Sensor Blocks

Kevin Nelson
Electrical & Computer Engineering, University of Florida, USA
Kamran Mohseni
Mechanical & Aerospace Engineering; Electrical & Computer Engineering, University of Florida, USA

- A bioinspired artificial fish lateral line sensory system was developed for use on an underwater vehicle
- The system is composed of modular sensor blocks each containing two differential pressure sensors
- An algorithm is developed and tested to estimate the total hydrodynamic force acting on the cylinder

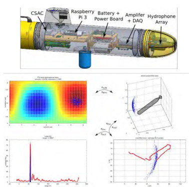
Modular, Artificial Lateral Line Sensory System

16:30–16:35	WeD11.6

One-Way Travel-Time Inverted Ultra-Short Baseline Localization for Low-Cost AUVs

Nicholas R. Rypkema[1], Erin M. Fischell[2] and Henrik Schmidt[2]
[1]Electrical Engineering and Computer Science
[2]Mechanical Engineering
MIT, USA

- Motivation: Accurate localization for low-cost AUVs enables multi-AUV research
- Problem: Size, power and cost constraints prevent the use of high-grade INS, DVL or active acoustics
- Solution: Fixed acoustic beacon periodically transmits wideband up-chirp; AUV CSAC-triggered array passively receives signal
- Array processing and particle filter calculates range, azimuth and inclination to beacon



AUV payload and acoustic processing + filtering

Marine Robotics

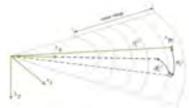
Chair *Gregory Dudek, McGill University*
Co-Chair *Brendan Englot, Stevens Institute of Technology*

16:35–16:40	WeD11.7

Acoustic-Inertial Underwater Navigation

Yulin Yang and Guoquan Huang
Mechanical Engineering, University of Delaware, USA

- Acoustic-inertial odometry with online extrinsic calibration by optimally fusing acoustic and inertial measurements without keeping features in the state.
- Acoustic feature triangulation with bearing and range constraints of sonar measurements.
- Observability analysis to understand the effects of sensor motion on acoustic feature triangulation



Sensor Motion	Conditions for Feature Triangulation
pure x rotation	$\phi_{\mathcal{R}_i}^{(j)} \neq 0$ for at least 3 measurements
pure y rotation	$\phi_{\mathcal{R}_i}^{(j)} \neq 0$ for at least 3 measurements
pure z rotation	Cannot triangulate
pure x translation	Cannot triangulate
pure y translation	Cannot triangulate
pure z translation	$\phi_{\mathcal{R}_i}^{(j)} \neq 0$ for at least 2 measurements

Fig. Effects of sonar motion on feature triangulation

16:40–16:45	WeD11.8

Robots going round the bend—a comparative study of estimators for anticipating river meanders

Kai Qin and Dylan Shell
NXP Semiconductors, U.S.A and Department of Computer Science and Engineering, Texas A&M University, U.S.A

- River meanders are structured.
- Adopted geological model, sine-generated curve, to parameterize state-space to predict unseen portion of the river.
- Collected GPS positions from a boat navigating an extended stretch of river.
- Compared the performance of three Gaussian filters: EKF, UKF and CIUKF.