ICRA2017

May 29 – June 3, 2017 • Singapore

Program Day 3

Thursday, 1 June

May 29-June 3, 2017 • Singapore

IEEE International Conference on Robotics and Automation

IEEE

IEEE Robotics & Automation Society

Soft Robotics 2

Chair *Fumiya Iida, University of Cambridge*
Co-Chair *Kaspar Althoefer, Queen Mary University of London*

09:30–09:35	ThA1.1

Position control of a robot finger with variable stiffness actuated by shape memory alloy

Junfeng Li, Guoliang Zhong, Haibin Yin, Mingchang He, Yuegang Tan and Zhang Li
School of mechanical and electronic engineering, Wuhan University of Technology，China

- The purpose of this research is to present a new method to achieve precise position tracking control for robot finger with variable stiffness mechanism. A control method based on proposed models for the position tracking of robot finger with variable stiffness characteristics is presented. The experimental results show that the proposed method has better performance than traditional PID control when the stiffness changed by heating current, resulting in a reduction of maximum error by 86%.

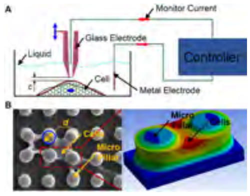

The experiment setup for the position control

09:35–09:40	ThA1.2

Control of Cardiomyocyte Contraction for Actuation of Bio-syncretic Robots

Chuang Zhang[1], Wenxue Wang[1*], Ning Xi[2], Yuechao Wang[1], and Lianqing Liu[1*]
[1] State Key Laboratory of Robotics, Shenyang Institute of Automation, Chinese Academy of Science, China.
[2] Emerging Technologies Institute, Department of Industrial & Manufacturing Systems Engineering, University of Hong Kong, Hong Kong.

- Non-contact measurement of the beating of cardiomyocytes using SICM;
- Cellular contractile force measurement with PDMS micro-pillars chip based on materials mechanics;
- Analysis of the influence on the cellular contractility from the cell concentration, culturing time and relevant drugs.


Measurement of the beating cells.

09:40–09:45	ThA1.3

Real-time simulation of hydraulic components for interactive control of soft robots

Alejandro Rodríguez[1] Eulalie Coevoet[2] Christian Duriez[2]
[1] University of Granada, Spain
[2] INRIA, University of Lille 1, France

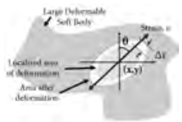
- An online simulation and motion planer for hydraulic actuated soft robots is presented
- The fluid weight distribution is computed in real time with a novel parallel method
- The dynamic behavior of hydraulic actuated cavities is modeled for the inverse kinematics problem
- The solution is integrated within SOFA and tested against a passive fabricated specimen

09:45–09:50	ThA1.4

Localized Differential Sensing of Soft Deformable Surfaces

Josie Hughes and Fumiya Iida
Bio-Inspired Robotics Group, University of Cambridge, United Kingdom

- Differential sensing, a new approach to determining the magnitude, orientation and location of localized deformation in soft robotic systems using pairs of resistive strain sensors is proposed.
- Allows sensors to be incorporated into a large soft body allowing detection of localized strain without limiting the overall compliance.
- Demonstrated using conductive thermoplastic elastomer (CTPE) and applied to the universal gripper


Model of localized soft body deformation on a large soft deformable body.

09:50–09:55	ThA1.5

A Method for Sensorizing Soft Actuators and Its Application to the RBO Hand 2

Vincent Wall, Gabriel Zöller, and Oliver Brock
Robotics and Biology Lab
Technische Universität Berlin, Germany

- The flexibility of soft actuators makes their sensorization challenging but necessary.
- We present a method that, for a given application, finds an appropriate sensor layout.
- We use the method to sensorize the four PneuFlex fingers of the RBO Hand 2.
- Finally, we evaluate the sensorized RBO Hand 2 in two manipulation tasks: compliant grasping and pulling of a door handle.


The sensorized RBO Hand 2 performs a compliant grasp

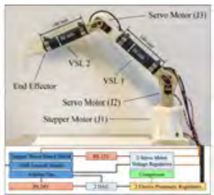
09:55–10:00	ThA1.6

Variable Stiffness Link (VSL): Toward Inherently Safe Robotic Manipulators

Agostino Stilli, Luca Grattarola
Department of Informatics, King's College London,UK
Hauke Feldmann
Faculty of Technology, Hochschule Emden/Leer, Germany
Helge A. Wurdemann
Department of Mechanical Engineering, University College London, UK
Kaspar Althoefer
School of Electronic Engineering & Computer Science, Queen Mary University of London, UK

The presented robot comprises three off-the-self rotary actuators and two VSLs.
The VSLs have been designed to:

- allow continuous stiffness tuning.
- withstand considerable forces without significantly deforming or collapsing.
- act as a distributed sensor and be intrinsically able to detect collisions.
- be scalable according to the size of the manipulator and to the required application's specification


Conceptual architecture of the anthropomorphic manipulator developed to assess the performance of the VSL.

Soft Robotics 2

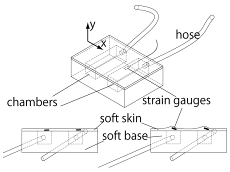
Chair *Fumiya Iida, University of Cambridge*
Co-Chair *Kaspar Althoefer, Queen Mary University of London*

10:00–10:05	ThA1.7

Morphological Computation in Tactile Sensing: The Role of Wrinkle

Van Ho, H. Yamashita, K. Shibuya
Department of Mechanical and Systems Engineering, Ryukoku Univ., Japan
Z.K. Wang and Shinichi Hirai
Department of Robotics, Ritsumeikan Univ., Japan

- This work is inspired by human finger's wrinkles.
- A tactile sensing system is an integration of actuation and sensing elements (strain gauges).
- This device can change its morphology so that the posture of embedded sensing elements can vary, then generate different responses depending on sensing tasks.
- FEA model were constructed for investigation of the strain gauges' responses
- Experimental results show the ability of detection both static indention and dynamic sliding



10:05–10:10	ThA1.8

Design, Modeling, and Control of Pneumatic Artificial Muscles with Integrated Sensing

Jonathan King, Luis E. Valle, Nishant Pol, and Yong-Lae Park
Robotics Institute, Carnegie Mellon University, USA

- Design and fabrication of pneumatic artificial muscles (PAMs) with integrated soft sensors.
- Three-dimensional liquid metal patterns on a thin silicone tube as a soft sensor.
- Contraction sensing is possible through measurement of change in electrical resistance of the liquid metal patterns
- Direct PAM control is possible using integrated soft sensors.

Soft sensor integrated pneumatic artificial muscle with different contractions

Motion and Path Planning 3

Chair *Andreas Kolling, iRobot Corporation*
Co-Chair *Sebastian Scherer, Carnegie Mellon University*

09:30–09:35	ThA2.1

Sampling-based Algorithms for Optimal Motion Planning Using Closed-loop Prediction

Oktay Arslan, Caltech JPL, USA
Karl Berntorp, MERL, USA
Panagiotis Tsiotras, Aerospace Eng.,Georgia Tech, USA

- A novel asymptotically optimal sampling-based motion planner that avoids complex steering procedures is developed.
- Steering procedures for existing kinodynamic motion planners are computationally complex; analytic solutions exist only in restricted cases.
- Proposed CL-RRT# Algorithm instead relies on simulation of closed-loop dynamics.
- Dynamically feasible trajectories by construction
- Connects motion planning with vehicle control


Motion planning for single-track vehicle model

09:35–09:40	ThA2.2

Randomized Algorithm for Informative Path Planning With Budget Constraints

Sankalp Arora and Sebastian Scherer
Robotics Institute, Carnegie Mellon University, USA

- Randomized Anytime Orienteering(RAOr), that can efficiently solve for routes that maximize correlated reward functions subject to constraints on route length.
- The key idea behind RAOr is to restrict the search space to routes that incur minimum distance to visit selected nodes, and rapidly search this space using random sampling.
- Order of magnitude run-time improvement over state of the art.

Grid Size	Budget		eSIP	MIQP	RAOr-G
5X5	30	cost	29.8	29.6	29.4
		utility	24	25	24
		time(s)	6.8	15.3	0.5
7X7	60	cost	56.6	57.3	56.1
		utility	48	49	48
		time(s)	26.7	1358.5	2.4
10X10	100	cost	99.0	99.8	98.9
		utility	87	92	87
		time(s)	143.6	15330	6.9
20X20	100	cost	99.7	-	99.2
		utility	87	-	87
		time(s)	763.7	-	7.2

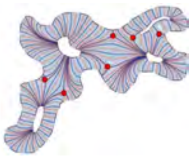
TABLE I: Comparative run time analysis of state of the art v/s RAOr-G. RAOr-G consistently outperforms the state of the art in terms of run times for achieving near-optimal solutions. All the solutions obtained are atleast 95% of the optimal.

09:40–09:45	ThA2.3

Robot Coverage Path Planning for General Surfaces Using Quadratic Differentials

Yu-Yao Lin[1], Chien-Chun Ni[1], Na Lei[2], Xianfeng David Gu[1] and Jie Gao[1]
[1]Department of Computer Science, Stony Brook University, USA
[2]School of Software, Dalian University of Technology, China

- Quadratic differentials provide the surface parameterizations which induce non-intersecting trajectories on a given surface.
- Critical trajectories bring a surface decomposition which is converted to its doubled dual graph.
- Robots can travel on the surface according to the Euler cycle with great coverage.

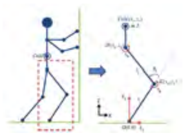

Critical trajectories intersect at the red points and decompose the four-hole non-convex domain.

09:45–09:50	ThA2.4

Torque Efficient Motion through Singularity

Changrak Choi and Emilio Frazzoli
Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, USA

- Constraint on the actuation and power resources is often the critical limiting factor for a robot to perform desired tasks.
- Singularity, which is deemed undesirable due to lose of manipulability, could be utilized to an advantage.
- The analysis shows that a motion at or near singularity not only maximally leverages the torque limits to generate forces in quasi-static motions, but is also optimally energy efficient for dynamical motion when it comes to momentum generation.

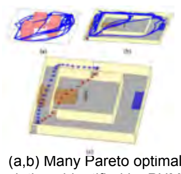


09:50–09:55	ThA2.5

Real-Time Stochastic Kinodynamic Motion Planning via Multiobjective Search on GPUs

Brian Ichter, Edward Schmerling, and Marco Pavone
Aero/Astro and ICME, Stanford University, USA
Ali-akbar Agha-Mohammadi
Jet Propulsion Laboratory, California Institute of Technology, USA

- Approached the stochastic kinodynamic planning problem: seeking a low-cost trajectory under a collision probability (CP)
- Presented the Parallel Uncertainty-aware Multiobjective Planning (PUMP) algorithm
- PUMP exhaustively explores the state space considering the Pareto front of cost and CP
- Real-time performance through an accurate CP approximation strategy and efficient algorithm design for GPUs

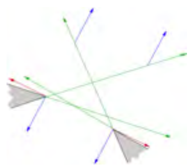

(a,b) Many Pareto optimal solutions identified by PUMP and (c) final certified plans (red 5% CP, blue 2% CP)

09:55–10:00	ThA2.6

Persistent pursuit-evasion: The case of the preoccupied pursuer

Nicholas M. Stiffler[1] Andreas Kolling[2] Jason M. O'Kane[1]
[1]Department of Computer Science and Engineering
University of South Carolina, USA
[2]iRobot Corporation
Pasadena, California, USA

- **Pursuit-evasion** planning algorithm to locate an unpredictably-moving evader with unbounded speed, in spite of short-term false negative **sensor errors**.
- Model errors using **pessimal unoccluded distance.**
- Generate plans by search over a new decomposition of the environment called the **jump decomposition.**



Motion and Path Planning 3

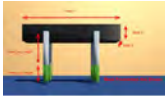
Chair *Andreas Kolling, iRobot Corporation*
Co-Chair *Sebastian Scherer, Carnegie Mellon University*

10:00–10:05	ThA2.7

Functional Co-Optimization Of Articulated Robots

Andrew Spielberg, Brandon Araki, Cynthia Sung, Russ Tedrake, and Daniela Rus
CSAIL, Massachusetts Institute of Technology, USA

- Parametric Trajectory Optimization, method for co-optimizing robots over motions, physical design parameters, and actuation requirements.
- Perform efficient evaluation of costs and constraints and their gradients by representing robot state symbolically.
- Demonstrate resulting motions on virtual robots and a physical prototype created using our approach.



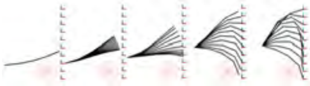
A parameterized quadruped, parameters and motions to be optimized.

10:05–10:10	ThA2.8

Motion Planning For Mobile Robots Using Inverse Kinematics Branching

Daniel Bodily and Marc Killpack
Mechanical Engineering, Brigham Young University, USA
Thomas Allen
Pneubotics, San Francisco, USA

- Base position and joint motions of a robot are simultaneously optimized to follow a smooth desired end-effector trajectory
- Formulated as a quadratic programming problem, allowing high dimensional problems to be solved very quickly
- Secondary objectives (e.g. manipulability, path smoothness, collision avoidance, etc.) and hard constraints (e.g. joint stops) naturally incorporated



Iterations in an optimization to find the best base position and subsequent arm motion for a linear trajectory

Vision and Range Sensing 1

Chair *Christopher M. Clark, Harvey Mudd College*
Co-Chair *Yasushi Nakauchi, University of Tsukuba*

09:30–09:35	ThA3.1

Enabling Aggressive Motion Estimation at Low-drift and Accurate Mapping in Real-time

Ji Zhang and Sanjiv Singh
Kaarta, Inc.

- Odometry and mapping leveraging laser-visual-inertial sensing through multi-layer optimization.
- Modularized data processing pipeline dynamically reconfigures, bypassing degraded modules and combining healthy modules to ensure robustness.
- Can handle aggressive motion (running, jumping) as well as visually degraded (dark, texture-less) or structurally degraded (extruded, flat) environments
- Ego-motion estimation produces 0.2% of drift w.r.t. distance traveled over kilometers of navigation

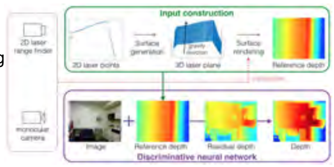

Estimation of aggressive motion and resulting map

09:35–09:40	ThA3.2

Geometry from a Line: Monocular Depth Estimation with Partial Laser Observation

Yiyi Liao[1], Lichao Huang[2], Yue Wang[1], Sarath Kodagoda[3], Yinan Yu[2], Yong Liu[1]
[1]Control Science and Engineering, Zhejinag University, China
[2]Horizon Robotics Inc. Beijing & Shenzhen, China
[3]Centre for Autonomous Systems, The University of Technology, Sydney, Australia

- Resolve scale ambiguity of monocular image with 2D planar depth observation
- Redefine the task as sculpting the depth from reference with a residual of residual network
- Superior results achieved on NYUD2 and KITTI reveal potential usage in obstacle avoidance

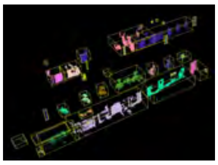


09:40–09:45	ThA3.3

Fast Segmentation of 3D Point Clouds: A Paradigm on LiDAR Data for Autonomous Vehicle Applications

Dimitris Zermas, and Nikolaos Papanikolopoulos
Computer Sceince, University of Minnesota, USA
Izzat Izzat
Advanced Engineering Department, DELPHI Automotive, USA

- A fast and scalable segmentation technique for LiDAR data in an autonomous driving setting
- A ground segmentation step fits several planes to ground points and is adaptable to smooth slope changes
- A non-ground segmentation step takes advantage of the LiDAR data structure and outperforms the running time of generic point cloud clustering algorithms

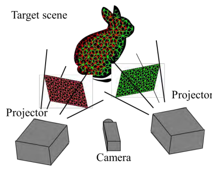

LiDAR segmentation result

09:45–09:50	ThA3.4

Learning-based Feature Extraction for Active 3D Scan with Reducing Color Crosstalk of Multiple Pattern Projections

Ryusuke Sagawa
National Institute of Advanced Industrial Science and Technology, Japan
Ryo Furukawa
Hiroshima City University, Japan
Akiko Matsumoto and Hiroshi Kawasaki
Kagoshima University, Japan

- Structured-light system for with multiple projectors have advantage to enlarge the captured area
- Even if different color channels are used, complete separation of patterns is not possible because of color crosstalk
- Utilize CNN trained to extract low dimensional pattern features for each projector by removing color crosstalk



3D capturing system with two projectors

09:50–09:55	ThA3.5

Real-time 3D Human Tracking for Mobile Robots with Multisensors

Mengmeng Wang and Yong Liu
Control Science and Engineering, Zhejiang University, China
Daobilige Su, Lei Shi, and Jaime Valls Miro
Autonomous Systems Centre, The University of Technology, Sydney, Australia

- We propose an accurate 3-D human tracking system by fusing a vision sensor with an ultrasonic array sensor sequentially
- An improved online visual tracking algorithm is presented to handle the challenging situations like severe occlusion and object missing
- The estimated 3-D information is further exploited to improve the scale accuracy of the target in the image coordinate

09:55–10:00	ThA3.6

Pre-touch Sensing for Sequential Manipulation

Boling Yang
Electrical Engineering, University of Washington, USA
Patrick Lancaster and Joshua R. Smith
Computer Science and Engineering, University of Washington, USA

- A new type of pre-touch sensing based on optical time-of-flight measurements
- The application and evaluation of pre-touch sensing for robot manipulation by solving the Rubik's cube
- The use of ICP algorithm and pre-touch scan to estimate object pose
- Comparison of the performance of optical pre-touch with our prior electric field pre-touch sensor

The robot is able to precisely manipulate the Rubik's cube using the equipped pre-touch sensors.

Vision and Range Sensing 1

Chair *Christopher M. Clark, Harvey Mudd College*
Co-Chair *Yasushi Nakauchi, University of Tsukuba*

10:00–10:05	ThA3.7

AUV Motion-Planning for Photogrammetric Reconstruction of Marine Archaeological Sites

Vaibhav K. Viswanathan[1], Zayra Lobo[1], Jessica Lupanow[1], Sebastian Seibert von Fock[2], Zoe Wood[2], Timmy Gambin[3], and Christopher Clark[1]
[1] Engineering, Harvey Mudd College, USA
[2] Computer Science, California Polytechnic State University, USA
[3] Classics & Archaeology, University of Malta, Malta

- We propose a method for constructing 3D maps of marine archaeological sites using Autonomous Underwater Vehicles (AUVs)
- Our goal is to create trajectories to optimize camera angles of sites
- We implemented modifications to RRT that improved planner performance by up to 152%
- Experiments resulting in 3D reconstructions of two marine archaeological sites validate our algorithm

3D Reconstruction of Bristol Beaufighter wreck using data collected from an AUV mission

10:05–10:10	ThA3.8

A Novel Method for the Extrinsic Calibration of a 2-D Laser-Rangefinder (LRF) & a Camera

Wenbo Dong and Volkan Isler
Computer Science and Engineering, University of Minnesota, Twin Cities, USA

- We present a novel method for extrinsically calibrating a 2-D LRF and a camera. The camera cannot observe the laser
- We show that a single observation of two non-coplanar triangles sharing a common side suffices to unambiguously solve the calibration problem
- This yields a robust method to calibrate from a single observation in the presence of noise
- Optimizing with a few additional observations achieves significantly smaller error than existing methods

The calibration system incorporating a calibration target (formed by two triangular boards with a checkerboard on each one) and a capture rig (consisting of a 2D LRF and stereo cameras)

SLAM 3

Chair *Stefan Leutenegger, Imperial College London*
Co-Chair *Hong Zhang, University of Alberta*

09:30–09:35 ThA4.1

Keyframe-based Dense Planar SLAM (KDP-SLAM)

Ming Hsiao[1], Eric Westman[1],
Guofeng Zhang[2], Michael Kaess[1]
[1]Robotics Institute, Carnegie Mellon University, USA
[2]State Key Lab of CAD&CG, Zhejiang University, China

- Reconstruct dense 3D model of large indoor environments in real-time based on CPU only.
- Reduce drift significantly by modeling plane landmarks in a fully probabilistic global factor graph optimization.
- Track each frame toward the latest keyframe using a fast dense odometry algorithm.
- Extract better planes from locally fused depth maps and associate them using a projective method.

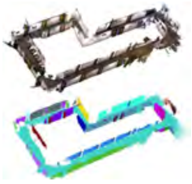


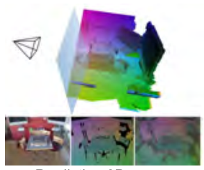
Fig. 1: Dense reconstruction with false-colored planes using our KDP-SLAM

09:35–09:40 ThA4.2

Random Forests versus Neural Networks – What's Best for Camera Localization?

Daniela Massiceti[1], Alexander Krull[2], Eric Brachmann[2], Carsten Rother[2], Philip H.S. Torr[1]
[1]Engineering Science, University of Oxford, United Kingdom
[2]Fakultät Informatik, Technische Universität Dresden, Germany

- **Goal**: Predict the camera pose in a known 3D scene given an input RGB image
- **Approach**: Regress a 3D coordinate for each pixel and sample these to estimate the camera pose via RANSAC
- **Exploration**: Are Random Forests (RFs) or Neural Networks (NNs) better for dense scene coordinate regression?
- **Results**: NNs are superior to fast RFs in coordinate regression but not in final camera pose accuracy



Predicting 3D scene coordinates for each pixel in an input RGB image

09:40–09:45 ThA4.3

Monocular Visual Odometry: Sparse Joint Optimisation or Dense Alternation?

Lukas Platinsky, Andrew J. Davison and Stefan Leutenegger
Department of Computing, Imperial College London, UK

- Both (semi-)dense and sparse methods are used, but rarely compared
- We propose a framework for fair comparisons of the underlying concepts
- An emprical model of computational cost is outlined and used for comparison
- (Semi-)dense methods use simplified optimisation, yet achieve similar results thanks to more data

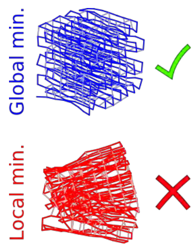
Sparse vs Dense VO

09:45–09:50 ThA4.4

Initialization of 3D Pose Graph Optimization using Lagrangian duality

Jesus Briales[1] and Javier Gonzalez-Jimenez[1],
[1]University of Malaga, Spain

- Pose Graph Optimization (PGO) lies at the core of state-of-the-art SLAM approaches.
- Lagrangian relaxation provides a very good and tractable approximation of PGO.
- Our work recovers the globally optimal solution for PGO if the relaxation is tight.
- Otherwise, we still get a remarkably good guess for initialization that is more effective than state-of-the-art approaches.



09:50–09:55 ThA4.5

Automatic Color Correction for 3D Reconstruction of Underwater Scenes

Katherine A. Skinner
Robotics Program, University of Michigan, USA
Eduardo Iscar and Matthew Johnson-Roberson
Naval Architecture and Marine Engineering, University of Michigan, USA

- Development of end-to-end underwater multi-view stereo reconstruction pipeline.
- Re-formulation of bundle adjustment to integrate the color correction procedure directly into the 3D reconstruction pipeline, solving for a restoration model and depth simultaneously.
- A dataset is provided with an artificial scene surveyed in a pure water test tank with ground truth RGB-D gathered in air for evaluation of underwater 3D reconstruction methods.

09:55–10:00 ThA4.6

RRD-SLAM: Radial-distorted Rolling-shutter Direct SLAM

Jae-Hak Kim, Yasir Latif and Ian Reid
University of Adelaide

- Monocular Semi-dense SLAM system that caters for radial as well as rolling shutter distortion
- Rolling shutter and radial distortions are important real world factors
- Extends notion of generalized epipolar line for the rolling-shutter radial distortion case
- Results shown for synthetic and real data

Output of the proposed RRS-SLAM algorithm

SLAM 3

Chair *Stefan Leutenegger, Imperial College London*
Co-Chair *Hong Zhang, University of Alberta*

10:00–10:05	ThA4.7

VINS on Wheels

Kejian J. Wu, Chao X. Guo, Georgios Georgiou, and Stergios I. Roumeliotis
MARS Lab, University of Minnesota, USA

- **Objective**: Develop a vision-aided inertial navigation system (VINS) for wheeled robots
- **Contributions**:
  - Determined additional *unobservable dof* (roll, pitch, scale) of VINS under certain motions
  - Extended VINS to fuse *odometry data* and thus ensure scale observability
  - Introduced *manifold* VINS to incorporate vehicle motion constraints
  - Demonstrated 3-7x localization accuracy improvement through experiments

Pioneer 3 w/ Tango Tablet

10:05–10:10	ThA4.8

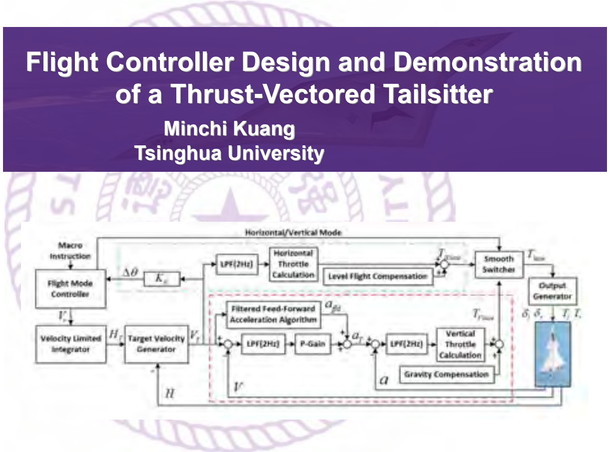
On the Utility of Additional Sensors in Aquatic Simultaneous Localization and Mapping

Authors: Robert Codd-Downey and Michael Jenkin

Aerial Robot 5

Chair *Frank Park, Seoul National University*
Co-Chair *Martin Saska, Czech Technical University in Prague*

09:30–09:35	ThA5.1

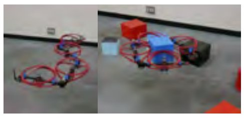


09:35–09:40	ThA5.2

Whole-body Aerial Manipulation by Transformable Multirotor with Two-dimensional Multilinks

Moju Zhao and Koji Kawasaki and Xiangyu Chen
and Shintaro Noda and Kei Okada and Masayuki Inaba
JSK Lab, The University of Tokyo, Japan

- Transformable aerial robot composed by two-dimensional multilinks which can be employed as an entire gripper.
- Original grasping planning and motion control method for the whole-body aerial manipulation based on the kinematics and statics of the multilinks.
- Experiments of grasping and carrying objects which validate the performance of proposed whole-body aerial manipulation.



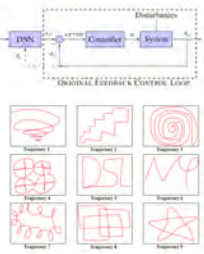
Left: the multirotor with two-dimensional multilinks capable of aerial transformation.
Right: the whole-body aerial manipulation achieved by the transformable aerial robot.

09:40–09:45	ThA5.3

Deep Neural Networks for Improved, Impromptu Trajectory Tracking of Quadrotors

Qiyang Li, Jingxing Qian, Zining Zhu, Xuchan Bao,
Mohamed K. Helwa, and Angela P. Schoellig
University of Toronto, Canada

- Deep Neural Networks (DNNs) designed as an add-on module to improve classical tracking control by adjusting the reference input.
- Extensive experimental testing on quadrotors for an interactive "fly-as-you-draw" application.
- Tracking errors reduced by 40-50% for both training and testing trajectories from users highlighting the DNNs' capability of generalizing knowledge.



09:45–09:50	ThA5.4

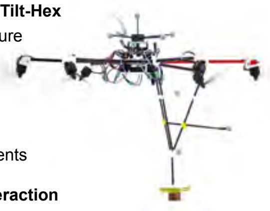
6D Physical Interaction with a Fully Actuated Aerial Robot

Markus Ryll[1], Giuseppe Muscio[2], Francesco Pierri[2], Elisabetta Cataldi[3], Gianluca Antonelli[3], Fabrizio Caccavale[2] and Antonio Franchi[1]

[1] LAAS-CNRS, Université de Toulouse, CNRS, Toulouse, France
[2] University of Basilicata, School of Engineering, Potenza, Italy
[3] University of Cassino and Southern Lazio, Cassino

- Design, control, and experimental validation of a novel **fully–actuated aerial** robot: the **Tilt-Hex**
- **Admittance control paradigm** to ensure safe and stable interaction
- Interaction **wrench estimated** by a momentum based observer

➢ This platform **outperforms** classical underactuated multi-rotors and represents probably the **best choice at date** for tasks requiring **aerial physical interaction**

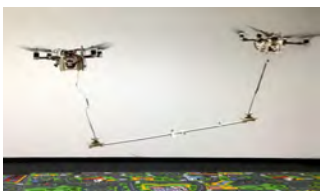


09:50–09:55	ThA5.5

Dynamic Collaboration without Communication: Vision-Based Cable-Suspended Load Transport with Two Quadrotors

Michael Gassner, Titus Cieslewski and Davide Scaramuzza
Robotics and Perception Group, University of Zurich

- New method for transporting a cable-suspended load with two quadrotors
- **No explicit communication** between robots needed
- Fully **on-board** using **only visual and inertial** sensors
- Considers **load dynamics** and copes with accelerations up to 0.5 m/s²

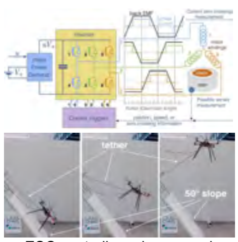


09:55–10:00	ThA5.6

Adaptive Closed-loop Speed Control of BLDC Motors with Applications to Multi-rotor Aerial Vehicles

Antonio Franchi and Anthony Mallet
LAAS-CNRS, Université de Toulouse, CNRS, France

- Adaptive bias and adaptive gain (ABAG) algorithm for **closed-loop electronic speed control** (ESC) of the brushless direct current (BLDC) motors
- **No parameter** knowledge
- **No pre-calibration**
- **No feedforward**/nominal input
- Extremely **low complexity** implementation
- **Open source** software architecture
- Suitable for **aerial physical interaction**



ESC controller scheme and application in tether aerial landing

Aerial Robot 5

Chair *Frank Park, Seoul National University*
Co-Chair *Martin Saska, Czech Technical University in Prague*

10:00–10:05	ThA5.7

Design of the I-BoomCopter UAV for Environmental Interaction

Daniel McArthur, Arindam Chowdhury and David Cappelleri
Mechanical Engineering, Purdue University, USA

- New UAV design for interacting with the environment
- Custom 3D-printed propeller assembly for horizontal thrust generation
- Modular, force-sensing end-effector for aerial manipulation
- Vision guided autonomous control with onboard camera and single board computer


Interacting-BoomCopter UAV

10:05–10:10	ThA5.8

Dubins Orienteering Problem

Robert Penicka, Jan Faigl, Petr Vana and Martin Saska
Czech Technical University in Prague, Czech Republic

- Orienteering Problem (OP) for curvature constrained Dubins vehicle
- For a given set of target locations, each with assigned reward, OP tries to find a tour with maximal collected reward between given starting and ending locations
- The tour length is limited by predefined travel budget constraint
- Proposed solution is based on Variable Neighborhood Search (VNS)


Real experiment with hexarotor UAV of VNS-based method for the Dubins Orienteering Problem

Session ThA6 | Rm. 4611/4612 | Thursday, June 1, 2017, 09:30–10:45

Object Detection and Segmentation

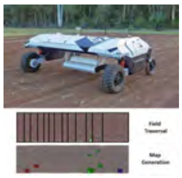
Chair *Feras Dayoub, Queensland University of Technology*
Co-Chair *Torsten Sattler, ETH Zurich*

09:30–09:35	ThA6.1

Towards Unsupervised Weed Scouting for Agricultural Robotics

David Hall, Feras Dayoub, Jason Kulk and Chris McCool
School of Electrical Engineering and Computer Science,
Queensland University of Technology, Australia

- Weed scouting is an important part of integrated weed management.
- Doing this autonomously as been limited by needing knowledge of weed species a priori.
- We work towards an unsupervised approach clustering visually similar plants.
- Contributions include using bottleneck DCNNs as descriptors and a new locking method for hierarchical-based clustering algorithms

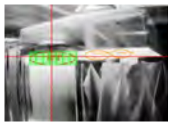


09:35–09:40	ThA6.2

Bayesian Estimation based Real-Time Fire-Heading in Smoke-Filled Indoor Environments Using Thermal Imagery

Jong-Hwan Kim
Mechanical & Systems Engineering, Korea Military Academy, South Korea
Yoonchang Sung and Brian Y. Lattimer
Mechanical Engineering, Virginia Tech, USA

- Bayesian estimation was applied to indicate a horizontal and vertical directions for navigating toward the fire outside the robot FOV
- Five statistical texture features in thermal images were extracted to accurately compute the highest probability for the fire heading
- Large-scale fire tests were conducted to create actual fire environments having various ranges of temperature and smoke conditions



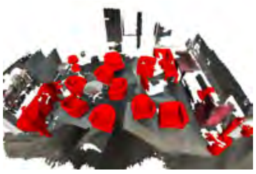
Results with both the fire heading and the classification of smoke and smoke-reflections

09:40–09:45	ThA6.3

TSDF-based Change Detection for Consistent Long-Term Dense Reconstruction and Dynamic Object Discovery

Marius Fehr, Fadri Furrer, Igor Gilitschenski, Roland Siegwart, Cesar Cadena - Autonomous Systems Lab, ETH Zurich
Ivan Dryanovski, Jürgen Sturm - Google Inc.

- A novel TSDF-based algorithm to compute consistent 3D reconstructions of dynamic environments over time by segmenting dynamic objects.
- We exploit the dynamic nature of the environment to discover and extract dynamic object models. These models are used as input to an object database, merged and refined.
- Our datasets are publicly available.

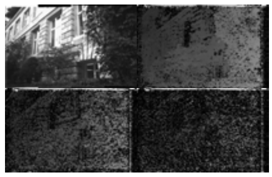


09:45–09:50	ThA6.4

Embedded Real-time Multi-Baseline Stereo

Dominik Honegger, Torsten Sattler and Marc Pollefeys
Computer Science Department, ETH Zürich

- Multi Baseline Stereo Setup with 4 cameras and FPGA
- System calculates dense disparity images with 752*480 resolution at 60fps
- Real-time implementation with 1ms latency.
- 4.25 Watt power consumption, 70 grams total weight



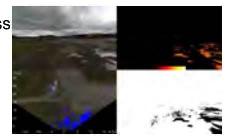
Outdoor scene: Resulting multi-baseline disparity map using four, three or only two cameras.

09:50–09:55	ThA6.5

3D tracking of water hazards with polarized stereo cameras

Chuong Nguyen and Robert Mahony
Research School of Engineering, Australian National University, Australia
Michael Milford
School of Electrical Engineering and Computer Science,
Queensland University of Technology, Australia

- Detection based on saturations and brightness as functions of reflection and azimuth angles.
- Sky polarization is found to affect water color.
- Gaussian Mixture Models learns and detects water up to more than 100m distance.
- On-road and off-road video sequences with ground-truth masks are released to public.



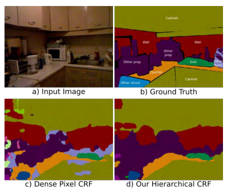
Stereo left image (top left), GMM likelihood ratio (top right), detected water in bird-eye view (bot. left) and mask (bot. right)

09:55–10:00	ThA6.6

Improved Semantic Segmentation for Robotic Applications with Hierarchical Conditional Random Fields

Benjamin J. Meyer and Tom Drummond
Australian Centre for Robotic Vision, Monash University, Australia

- Semantic segmentation for robotics using a region-to-pixel hierarchical conditional random field (CRF).
- Focus on object-level performance, recognising that false object detections are costly in robotic applications.
- Show improved performance over commonly used conventional CRF models at object and pixel-level.



Our approach compared to a conventional pixel CRF.

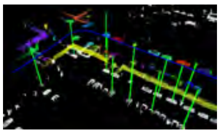
Object Detection and Segmentation

Chair *Feras Dayoub, Queensland University of Technology*
Co-Chair *Torsten Sattler, ETH Zurich*

10:00–10:05 ThA6.7

SegMatch: Segment Based Place Recognition in 3D Point Clouds

Renaud Dubé, Daniel Dugas, Elena Stumm, Juan Nieto, Roland Siegwart and Cesar Cadena
Autonomous Systems Lab. ETH Zurich, Switzerland

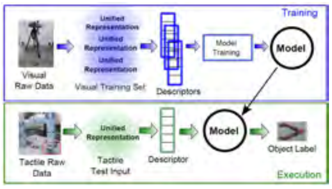


- We present a reliable place recognition algorithm based on the matching of 3D segments.
- The localization and loop-closure detection performances of *SegMatch* are evaluated in real-world application.
- An open-source implementation is available online at https://github.com/ethz-asl/segmatch.

10:05–10:10 ThA6.8

Cross-modal Visuo-Tactile Object Recognition Using Robotic Active Exploration

Pietro Falco, Shuang Lu, Dongheui Lee
Chair of Automatic Control, Technical University of Munich, Germany
Andrea Cirillo, Ciro Natale, Salvatore Pirozzi
Università degli Studi della Campania “Luigi Vanvitelli”, Aversa, Italy



- We propose a framework to handle cross-modal visuo-tactile object recognition
- We build a classifier with visual information
- We recognize objects with tactile perception, using only the prior knowledge acquired by vision

Robot Motion Control

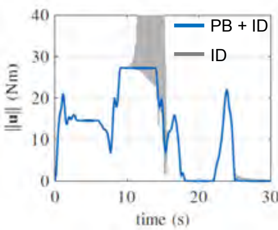
Chair *Andreea Radulescu, Istituto Italiano di Tecnologia*
Co-Chair *Nathan Michael, Carnegie Mellon University*

09:30–09:35	ThA7.1

Combined Inverse-Dynamics/Passivity-Based Control for Robots with Elastic Joints

A. Giusti[1], J. Malzahn[2], N. G. Tsagarakis[2], and M. Althoff[1]
[1]Dept. of Informatics, Technical University of Munich (TUM), Germany
[2]Dept. of Advanced Robotics, Italian Institute of Technology (IIT), Italy

- **Passivity-based** (**PB**) control **merged** with efficient **inverse-dynamics** (ID) control.
- Experiments on a **reconfigurable elastic-joint robot** arm
- **On-the-fly** controller generation

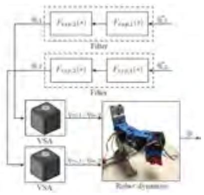


09:35–09:40	ThA7.2

Feedforward Control of Variable Stiffness Joints Robots for Vibrations Suppression

Luigi Biagiotti♦, Lorenzo Moriello*, Claudio Melchiorri*
♦ Department of Engineering, University of Modena and Reggio Emilia, Italy.
* Department of Electrical, Electronic and Information Engineering, University of Bologna, Italy.

- A feedforward control is proposed to suppress oscillations that affect point-to-point motions of variable stiffness joints (VSJ) robots.
- Linearized model of a VSJ robot is used to derive resonant modes of the robot.
- A chain of exponential filters is implemented in cascade configuration on the reference input of the motors.
- Experimental activity on a 2-dofs robotic arm prove that the method is very effective for residual vibration reduction.



Block-scheme representation of the feedforward control.

09:40–09:45	ThA7.3

Model-Based Policy Search for Automatic Tuning of Multivariate PID Controllers

Andreas Doerr, Duy Nguyen-Tuong
Bosch Center for Artificial Intelligence, Germany
Alonso Marco, Stefan Schaal, Sebastian Trimpe
Max Planck Institute for Intelligent Systems, Germany

- Extends PILCO to multivariate and coupled PID control structures.
- Finite horizon optimal control using Gaussian Process dynamics models.
- Policy learning demonstrated on a humanoid upper-body robot for balancing an inverted pendulum.

Multivariate PID control for pole balancing.

09:45–09:50	ThA7.4

Whole-body Trajectory Optimization for Non-periodic Dynamic Motions on Quadrupedal Systems

A. Radulescu[1], I. Havoutis[2,3], D. G. Caldwell[1], C. Semini[1]
[1]Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy
[2]Robot Learning and Interaction, Idiap Research Institute, Switzerland
[3]Oxford Robotics Institute, Department of Engineering Science, University of Oxford, UK

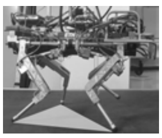
- Whole body optimization methodology for non-periodic dynamic movements
- Trajectory solutions involve multiple contacts, without any predefined feet placement heuristics (e.g., contact points, timing or order of succession)
- Realistic simulation of the hydraulically actuated HyQ2Max quadruped for rearing and posture recovery task

09:50–09:55	ThA7.5

Online Walking Motion and Foothold Optimization for Quadruped Locomotion

Alexander W. Winkler, Farbod Farshidian, Michael Neunert, Diego Pardo and Jonas Buchli
Agile and Dexterous Robotics Lab, ETH Zürich, Switzerland

- We find footholds *and* Center of Mass trajectory simultaneously solving an optimization problem (NLP).
- The frameworks generates the complete motion for quadruped walking (no footstep planner used) in milliseconds.
- We demonstrate this on a real robot.
- We ensure feasibility by keeping the ZMP inside the area of support.



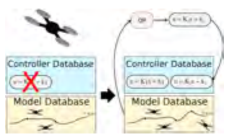
Quadruped "HyQ" walking.

09:55–10:00	ThA7.6

Leveraging Experience for Computationally Efficient Adaptive Nonlinear Model Predictive Control

Vishnu Desaraju and Nathan Michael
Robotics Institute, Carnegie Mellon University, USA

- Safe, accurate control of agile nonlinear systems relies on efficient computation and constraint satisfaction despite uncertain and changing dynamics models
- We construct online a database of adaptive controllers via MPC informed by an online-learned semi-parametric dynamics model
- Switching between parameterized controllers in the database yields constraint satisfaction even as dynamics vary due to external forces
- Simulations show safety, real-time operation, and improved tracking performance as model and controller experience is accumulated



If existing controllers are not optimal for the current state and dynamics model, a new parameterized controller is computed and stored for use in similar situations.

Robot Motion Control

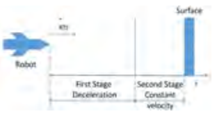
Chair *Andreea Radulescu, Istituto Italiano di Tecnologia*
Co-Chair *Nathan Michael, Carnegie Mellon University*

10:00–10:05	ThA7.7

Extended Tau Theory for Robot Motion Control

Haijie Zhang and Jianguo Zhao
Mechanical Engineering, Colorado State University, USA
Bo Cheng
Mechanical and Nuclear Engineering, Pennsylvania State University, USA

- Tau theory, a biologically concept, can explain how animals/insects land or perch using visual feedback.
- We extend the tau theory to realize nonzero contact velocity by a new two stage strategy
- The strategy can deal with three dimensional case by a new tau coupling method
- A featureless and computationally-efficient method is utilized to estimate time-to-contact from vision feedback.

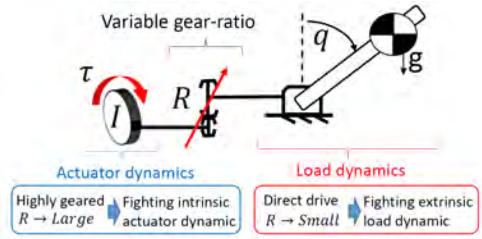


Two stage perching strategy

10:05–10:10	ThA7.8

Leveraging Natural Load Dynamics with Variable Gear-ratio Actuators

Alexandre Girard and Harry Asada
Massachusetts Institute of Technology, USA



- In this paper actuator gear-ratios are dynamically selected online to either exploit or attenuate the natural dynamics of a robotic system.

Telerobotics and Teleoperation

Chair *Akio Namiki, Chiba University*
Co-Chair *Günter Niemeyer, Disney Research*

09:30–09:35	ThA8.1

Haptic Intention Augmentation for Cooperative Teleoperation

Michael Panzirsch, Ribin Balachandran, Jordi Artigas, Cornelia Riecke, Alin Albu-Schaeffer
Institute for Robotics and Mechatronics, DLR Oberpfaffenhofen, Germany
Manuel Ferre
Universidad Politécnica de Madrid, CAR UPM-CSIC, Madrid, Spain

- Cooperative teleoperation with 2-DoF joystick
- Feed forward of Operator A interaction force to Operator B
- Space-link experiments under microgravity conditions on the ISS

09:35–09:40	ThA8.2

Visual-Based Shared Control for Remote Telemanipulation with Integral Haptic Feedback

Nicolò Pedemonte, Firas Abi-Farraj and Paolo Robuffo Giordano
CNRS at Irisa and Inria Rennes, France

- **Shared Control** for **"*steering*"** the future **trajectory** of a serial manipulator in the pre-grasp approaching phase
- **Integral force-feedback** cues informing about the **feasibility** of the whole trajectory against system constraints
- Autonomous **visual-based control** of a second robot following the remote handling task and **providing visual feedback**

09:40–09:45	ThA8.3

Improving Humanoid Posture Teleoperation by Dynamic Synchronization Through Operator Motion Anticipation

Joao Ramos and Sangbae Kim
Mechanical Engineering Department, Massachusetts Institute of Technology, USA

- Human operator and robot slave have independent balance controllers that interact with each other during the experiments.
- By estimating the contact forces that the operator exerts to generate movement, the controller allows the robot to anticipate human motion during posture tracking.
- Results show a considerable reduction of the position tracking overshoot along with substantial reduction of required error-based control forces.

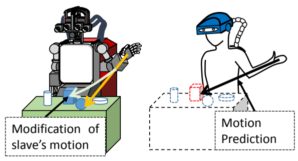
MIT Little HERMES: robot designed for balance experiments during full body teleoperation.

09:45–09:50	ThA8.4

Vision-Based Predictive Assist Control on Master-Slave Systems

Akio NAMIKI[1], Yosuke MATSUMOTO[1], Tomohiro MARUYAMA[1], and Yang LIU[1]
[1]Chiba University, Japan

- Operation assist algorithm based on visual feedback control
- Prediction of the operator's motion by a particle filter
- Estimation of the operator's intention
- Modification of slave's motion in realtime



09:50–09:55	ThA8.5

Flexible Virtual Fixture Interface for Path Specification in Tele-Manipulation

Camilo Perez Quintero, Oscar Ramirez and Martin Jagersand
Computing Science , University of Alberta, Canada
Masood Dehghan and Marcelo H. Ang
Mechanical Engineering, National University of Singapore, Singapore

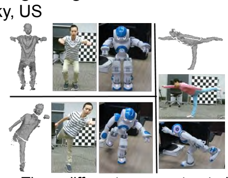
- Novel 2D image interface that simplifies the complex process of specifying a 3D path constraint to a remote manipulator
- Impedance control architecture that constrains the robot manipulator to follow a 3D path, while maintaining the contact with the environment
- Using bilateral and unilateral configurations, we compare our system to direct teleoperation through user studies

09:55–10:00	ThA8.6

A Generative Human-Robot Motion Retargeting Approach using a Single Depth Sensor

Sen Wang Xinxin Zuo Runxiao Wang
Northwestern Polytechnical University, China
Fuhua Cheng Ruigang Yang
University of Kentucky, US

- A generative unified framework to achieve motion retargeting with one single depth sensor
- A novel method that combines motion tracking and retargeting procedure
- Personalized parametric *HUMROB* model
- Energy formulation minimization mainly based on Gaussian Mixture Model and joint/vertex transformation



Three different poses retargted to NAO robot using our proposed approach. The mesh and color image are captured by Kinect V2.

Telerobotics and Teleoperation

Chair *Akio Namiki, Chiba University*
Co-Chair *Günter Niemeyer, Disney Research*

10:00–10:05	ThA8.7

Goal-Predictive Robotic Teleoperation from Noisy Sensors

Christopher Schultz, Sanket Gaurav, Lingfei Zhang, and Brian Ziebart
Department of Computer Science, University of Illinois at Chicago, USA
Mathew Monfort
Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, USA

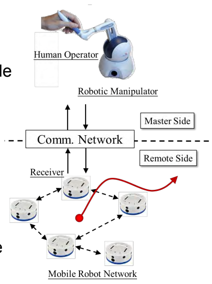
- **Goal directed de-noising** of operator controls
- **Inverse Optimal Control** to predict the intended object of interaction from the current motion trajectory in real time
- **Adaptive autonomy:** Switching between following the operators demonstrations and completing the task autonomously

10:05–10:10	ThA8.8

Decentralized Estimation and Control for Bilateral Teleoperation of Mobile Robot Network with Task Abstraction

Chao-Wei Lin and Yen-Chen Liu
Department of Mechanical Engineering, National Cheng Kung University
Tainan, Taiwan

- A novel decentralized control framework for a human operator to teleoperate a group of mobile robots with task abstraction is presented.
- The human operator is able to remotely manipulate a group of mobile robots by only communicating with one of the robots.
- Decentralized control and task abstraction provide better scalability and flexibility to the size and formation of the mobile robots.
- Experimental results are presented to show the efficacy of system performance.



TRO Session - Multi-Modal Robot Design and Control

Chair *Aude Billard, EPFL*
Co-Chair *Paul Y. Oh, University of Nevada, Las Vegas (UNLV)*

09:30–09:45	ThA9.1

A Multi-Modal Robot for Perching and Climbing on Vertical Outdoor Surfaces

Morgan T. Pope, Christopher W. Kimes, Hao Jiang, Elliot W. Hawkes, Matt A. Estrada, Capella F. Kerst, William R. T. Roderick, Amy K. Han, David L. Christensen, and Mark R. Cutkosky
Mechanical Engineering, Stanford, USA

- Perching extends MAV mission life; climbing allows for easy repositioning on a surface
- The Stanford Climbing & Aerial Maneuvering Platform (SCAMP) operates outdoors using onboard sensing and computation
- The first robot capable of combined flying, perching with passive attachment technology, climbing, and takeoff
- Unique mechanical design and interesting new locomotion strategies emerging from hybrid capabilities

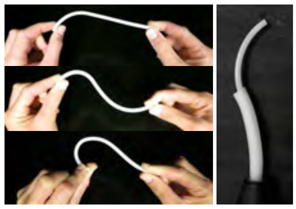
SCAMP in flight (inset) and climbing a tower

09:45–10:00	ThA9.2

Design of 3-D Printed Concentric Tube Robots

Tania K. Morimoto and Allison M. Okamura
Department of Mechanical Engineering, Stanford University, USA

- Goal is to fabricate concentric tube robots on a patient- and procedure-specific basis
- Defined design requirements and fabrication constraints based on patient, procedure, material, and fabrication method
- Experimentally demonstrated capabilities of these 3-D printed robots in target acquisition task



10:00–10:15	ThA9.3

Applying virtual fixtures to the distal end of a Minimally Invasive Surgery (MIS) instrument

Marie-Aude Vitrani, Cécile Poquet and Guillaume Morel
Institute for Intelligent Systems and Robotics (ISIR)
Université P. & M. Curie, Sorbonne Universités, Paris, France

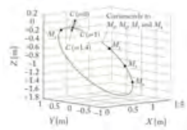
- Virtual fixtures = instrument guidance through force fields exerted by a comanipulator.
- When assisting MIS, the distal tip is to be guided while the force is exerted proximally
- Mathematically, this problem has an infinite number of solutions
- The paper studies two of them, and shows that applying a pure force w/ 3 actuators (+a lever model) performs as well as 6 actuators robot.
- Explanation arises from considerations on the sensorimotor control system of the surgeon.

10:15–10:30	ThA9.4

Revisiting the Determination of the Singularity Cases in the Visual Servoing of Image Points through the Concept of Hidden Robot

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

- The determination of the singularity cases in visual servoing is a tricky problem which is unsolved for most image-based approaches
- We show that a concept named the "hidden robot" can be used for finding the singularities in the visual servoing of image points.
- With this concept, the singularity cylinder when three points are observed is found again
- Moreover, we provide for the first time the singularity conditions when more than three points are observed



Relative motion of the camera wrt four observed points lying on a circle and singularity location at s=0

10:30–10:45	ThA9.5

Dexterous Aerial Robots
Mobile Manipulation using Unmanned Aerial Systems

Matko Orsag, Christopher Korpela, Stjepan Bogdan and Paul Oh

UNIZG UNLV

Benchmark aerial manipulation tasks

Coupling dynamics:
- Pick and place (Momentary coupling)
- Peg-in-hole or insertion tasks (Loose coupling)
- Knob or valve turning (Strong coupling)

Biorobotics

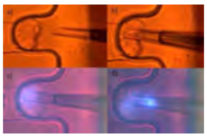
Chair *Dong Sun, City University of Hong Kong*
Co-Chair *Yasuhisa Hasegawa, Nagoya University*

09:30–09:35	ThA10.1

A High-Precision Robot-Aided Single-Cell Biopsy System

Adnan Shakoor[1], Tao Luo[1], Shuxun Chen[1], Mingyang Xie[1], James K. Mills[2], Dong Sun[1]
[1]Department of Mechanical and Biomedical Engineering, City University Hong Kong, Hong Kong
[2]University of Toronto, Canada

- Robot-aided single-cell surgery system to perform single-cell biopsy for cells ≤25 μm in diameter is presented.
- A microfluidic chip is designed to arrange upto 100 individual cells in an array.
- A computer mouse-operated high-precision XY stage is developed to perform single-cell biopsy with a micropipette.
- The fluorescent-labeled nucleus and mitochondria of human foreskin fibroblast cells are biopsied.

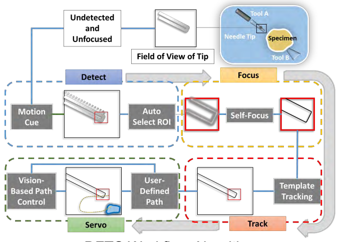

Semi-automated nuclei biopsy from the HFF cell

09:35–09:40	ThA10.2

Detect-Focus-Track-Servo (DFTS): A Vision-Based Workflow Algorithm for Robotic Micromanipulation

Liangjing Yang[1,2], Kamal Youcef-Toumi[2], U-Xuan Tan[1]
[1]Singapore University of Technology and Design, Singapore
[2]Massachusetts Institute of Technology, USA

- auto-Detect, self-Focus, visual Track and Servo of tool tip for image-guided micromanipulation
- flexible solution in robotic vision-based module for cell manipulation
- reduce manual interventions and workflow disruptions



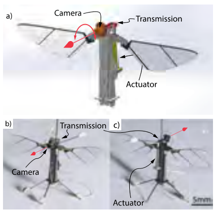
DFTS Workflow Algorithm

09:40–09:45	ThA10.3

An Actuated Gaze Stabilization Platform for a Flapping-Wing Microrobot

Sylvain Mange[1], E. Farrell Helbling[2], Nick Gravish[2,3], Robert J. Wood[2]
[1] School of Engineering, EPFL, Switzerland
[2] SEAS, Harvard University, USA
[3] Mechanical & Aerospace Engineering, UCSD, USA

- Integrated a 3.1mg, 250x250 resolution camera onboard the RoboBee
- Manufactured a 1DOF stabilizer capable of rotating 100 degrees peak to peak
- Demonstrated onboard actuation of the vision sensor during free flight



09:45–09:50	ThA10.4

Geometric Flight Control of A Hovering Robotic Hummingbird

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

- Robotic hummingbird with 12 grams of weight, 34Hz flapping frequency and 20 grams of maximum lift.
- Full nonlinear dynamic model is derived with flapping counter torque and flapping counter force.
- An exponentially stable geometric controller is designed with nonlinear force/torque mapping.
- Liftoff and hover with attitude stabilization were demonstrated.

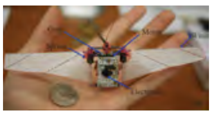

Motor-driven Robotic Hummingbird

09:50–09:55	ThA10.5

Design Optimization and System Integration of Robotic Hummingbird

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

- Systematic approach for design optimization and integration. Formulation covers actuation, dynamics, flight stability and control.
- Optimizations yields 3 prototypes for different design purpose with onboard sensors, electronics, and computation.
- Liftoffs were demonstrated with extra payloads for 30-40Hz flapping frequency, 7.5-12 grams of weight and up to 20 grams of max. lift.

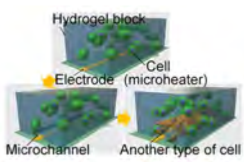

Prototype sample with flexible bi-stable wings and onboard electronics

09:55–10:00	ThA10.6

Multi-layered Channel Patterning by Local Heating of Hydrogels

Masaru Takeuchi[1], Tomoyuki Oya[2], Akihiko Ichikawa[2], Akiyuki Hasegawa[2], Masahiro Nakajima[1], Yasuhisa Hasegawa[1], Toshio Fukuda[2]
[1]Department of Micro-Nano Systems Engineering, Nagoya University, Japan
[2]Department Mechatronics Engineering, Meijo University, Japan

- Fabricate multi-layered channels in cell structures using local heating of hydrogel
- Generate local Joule heat to melt hydrogel using microelectrode on a substrate
- Control channel size by heating duration and cooling condition of the substrate
- Confirm cell viability after channel fabrication using live/dead assay



Biorobotics

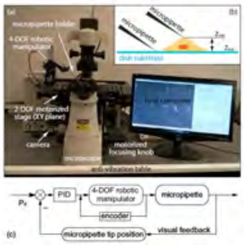
Chair *Dong Sun, City University of Hong Kong*
Co-Chair *Yasuhisa Hasegawa, Nagoya University*

10:00–10:05	ThA10.7

Automated Robotic Measurement of 3D Cell Morphologies

Jun Liu[1*], Zhuoran Zhang[1*], Xian Wang[1], Haijiao Liu[1], Qili Zhao[1], Chao Zhou[2], Min Tan[2], Huayan Pu[3], Shaorong Xie[3] and Yu Sun[1,3]
[1]Dept. of Mechanical & Industrial Engineering, University of Toronto, Canada
[2]Institute of Automation, Chinese Academy of Sciences, China
[3]Department of Mechatronic Engineering, Shanghai University, China

- Automated cell recognition and determination of contact points on a cell
- Contact detection on dish substrate for measuring cell bottom positions
- Contact detection on cell top membrane for measuring cell bottom positions
- Measurement technique has an overall success rate of 95.67%, a measurement speed of 2.63 seconds/contact, and a measurement error of 4.65%



10:05–10:10	ThA10.8

Robotic Pick-and-Place of Multiple Embryos for Vitrification

Zhuoran Zhang[1*], Jun Liu[1*], Xian Wang[1], Qili Zhao[1], Chao Zhou[2], Min Tan[2], Huayan Pu[3], Shaorong Xie[3] and Yu Sun[1]
[1]Dept. of Mechanical & Industrial Engineering, University of Toronto, Canada
[2]Inst. of Automation, Chinese Academy of Sciences, China
[3]Dept. of Mechatronic Engineering, Shanghai University, China

- Automated visual detection of multiple embryos in 3D.
- LQR controller aspirates embryos with a minimum volume of excess medium.
- Thin layer deposition robustly places each embryo on vitrification straw.
- Three times the throughput of manual operation, with a success rate of 95.2%, embryo survival rate of 90.0%, and embryo development rate of 88.8%.

Sequence of multi-embryo vitrification.

Space Robotics

Chair *Myron Diftler, NASA Johnson Space Center*
Co-Chair *Evangelos Papadopoulos, National Technical University of Athens*

09:30–09:35 ThA11.1

Robust Visual Localization in Changing Lighting Conditions

Pyojin Kim and H. Jin Kim
Seoul National University, South Korea
Brian Coltin and Oleg Alexandrov
NASA Ames Research Center, USA
figure_front_page.pdf

- **Goal :** Investigate the effect of lighting variations, and make visual localization robust to changing-light environments.
- **Contribution :** Detailed analysis of the effect of lighting variations, and automatic recognition of current illumination level.
- **Evaluation :** Extensive tests on space robot under various lighting conditions in the granite table simulating the interior of International Space Station (ISS).

09:35–09:40 ThA11.2

On Parameter Estimation of Space Manipulator Systems Using the Angular Momentum Conservation

Olga-Orsalia Christidi-Loumpasefski, Kostas Nanos, and Evangelos Papadopoulos
Department of Mechanical Engineering,
National Technical University of Athens, Greece

- Advanced model-based control strategies require accurate knowledge of Space Manipulator System (SMS) parameters
- SMS dynamic parameters may change on orbit (e.g. fuel consumption, object capture)
- A novel parameter estimation method is proposed, based on free-floating SMS angular momentum conservation
- The method identifies system full dynamics without requiring noisy and hard to obtain acceleration or torque measurements

A space manipulator system on orbit

09:40–09:45 ThA11.3

Pop-up Mars Rover with Textile-Enhanced Rigid-Flex PCB Body

Jaakko T. Karras[1], Christine L. Fuller[1], Kalind C. Carpenter[1], Alessandro Buscicchio[1], Dale McKeeby[2], Christopher J. Norman[3], Carolyn E. Parcheta[1], Ivan Davydychev[4], Ronald S. Fearing[4]
[1] NASA Jet Propulsion Laboratory, USA
[2] Pioneer Circuits Inc., USA
[3] Dept. of Engineering, Curtin University, Australia
[4] Dept. of EECS, Univ. of Calif., Berkeley, USA

- Origami-inspired rover for future low-cost extreme terrain exploration on Mars
- Chassis folds into small volume using rigid-flex PCB construction
- Novel PCB paradigm developed using additional textile layer for mechanical joints
- Prototype can drive overhung rocks and up steep inclines

09:45–09:50 ThA11.4

LEMUR 3: A Limbed Climbing Robot for Extreme Terrain Mobility in Space

Aaron Parness, Neil Abcouwer, Christine Fuller, Nicholas Wiltsie, Jeremy Nash, Brett Kennedy
Robotics, Jet Propulsion Laboratory, USA

- LEMUR 3 has four, 7-DOF limbs
- Swappable end effectors allow climbing of many different surfaces, from rock to glass
- Mechanical, electrical, software, and gripper designs described
- youtube.com/watch?v=8Zdj66ljk0I

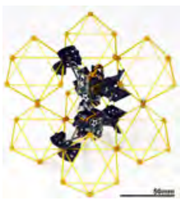
LEMUR 3 climbing a cliff face in a lava tube

09:50–09:55 ThA11.5

A Mobile Robot for Locomotion through a 3D Periodic Lattice Environment

Benjamin Jenett[1] and Daniel Cellucci[2]
[1]Center for Bits and Atoms, MIT, USA
[2]Department of Mechanical and Aerospace Engineering, Cornell, USA

- Climbing robot designed specifically to interface with periodic cellular CubOct lattice.
- Compared to other truss climbing robots, has simpler controls and reduced sensing requirements.
- Robot can climb vertically, horizontally, and rotate to move in X, Y, and Z within lattice environment.
- Further development includes current sensing for structural health monitoring and autonomous exploration.



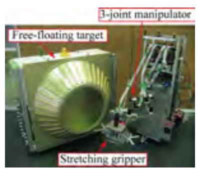
Multi-Objective JOurneying robot (MOJO). Robot is shown in lattice structure.

09:55–10:00 ThA11.6

Caging-Based Grasp with Flexible Manipulation for Robust Capture of a Free-Floating Target

Daichi Hirano, Hiroki Kato, and Nobutaka Tanishima
Japan Aerospace Exploration Agency (JAXA), Japan

- Robust capture of a free-floating target using a robotic arm in space is discussed.
- Caging-based grasp is introduced to capture the target robustly without precise motion tracking.
- Impedance control reduces the force interaction with the target due to position errors.
- The proposed method is verified experimentally using an air-floating system.



Air-floating robot and target for experimental verification

Space Robotics

Chair *Myron Diftler, NASA Johnson Space Center*
Co-Chair *Evangelos Papadopoulos, National Technical University of Athens*

10:00–10:05	ThA11.7

Locally-Adaptive Slip Prediction for Planetary Rovers Using Gaussian Processes

Chris Cunningham, William Whittaker
The Robotics Institute, Carnegie Mellon University, United States
Masahiro Ono, Issa Nesnas, Jeng Yen
The Jet Propulsion Laboratory, California Institute of Technology, United States

- Slip prediction models are learned as a function of slope using monotonically increasing Gaussian Processes.
- Predictions adapt to new terrain using a spatially-varying slip offset.
- Terrain classes are predicted visually and using only proprioceptive slip data.
- The approach is evaluated on data from Curiosity's traverse on Mars.

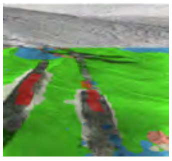


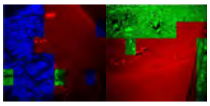
Image of Curosity's traverse through sand on Mars colorized by terrain class. Wheel locations are shown in red.

10:05–10:10	ThA11.8

Simple Texture Descriptors for Classifying Monochrome Planetary Terrains

Dhara Shukla and Krzysztof Skonieczny
Electrical & Computer Engineering
Concordia University, Canada

- Mars Planetary Terrain Classification into 3 classes: **Rock-strewn, Sand & Bedrock** using navigation images from Mars rovers
- Comparison of image descriptors (GIST, HOG, Textons) and Classifiers (NN, KNN, SVM).
- Simplified HOG descriptor demonstrates high performance and low computational complexity making it space mission relevant
- 70% to 93% (81% average) accuracy achieved for the 3-way classification.



Representation of Terrain detection results (Red : Sand, Green : Rock-strewn, Blue : Bedrock)

Soft Robotics 3

Chair *Woojin Chung, Korea University*
Co-Chair *Chen-Hua Yeow, National University of Singapore*

11:05–11:10	ThB1.1

Series Pneumatic Artificial Muscles (sPAMs) and Application to a Soft Continuum Robot

Joseph D. Greer[1], Tania K. Morimoto[1], Allison M. Okamura[1], and Elliot W. Hawkes[1,2]
[1]Department of Mechanical Engineering, Stanford University, United States
[2]Department of Mechanical Engineering, University of California, Santa Barbara, United States

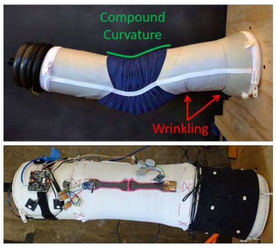
- New series Pneumatic Artificial Muscle (sPAM) enables construction of a soft continuum robot
- Models of the sPAM and soft robot kinematics were developed and experimentally verified
- Control achieved with eye-in-hand visual servo control

11:10–11:15	ThB1.2

Fabric Sensory Sleeves for Soft Robot State Estimation

Michelle C. Yuen[1], Henry Tonoyan[2], Edward L. White[1], Maria Telleria[2], and Rebecca K. Kramer[1]
[1]School of Mechanical Engineering, Purdue University, USA
[2]Otherlab Pneubotics, USA

- Soft robots undergo distributed, continuous deformations, which makes identifying the state of the system challenging
- Fabric sensory sleeves containing embedded strain sensors are able to measure these deformations along the surface of a soft robot
- Here, capacitive strain sensors are used to capture the state of a fabric-based pneumatic arm



11:15–11:20	ThB1.3

Design and Fabrication of a Soft Three-axis Force Sensor Based on Radially Symmetric Pneumatic Chambers

Hyunjin Choi, Pyeong-Gook Jung, and Kyoungchul Kong*
Department of Mechanical Engineering, Sogang University, Korea
Kyungmo Jung
Hyundai Motor Company, Korea

- The force measurement system is made of soft silicone rubber with three air chambers in a radially symmetric pattern.
- Each air chamber embeds a pneumatic sensor, and the directions and magnitudes of the applied force are distinguished by the pressure changes.
- The soft force sensors can be added to the insole of a shoe to measure the ground reaction force.

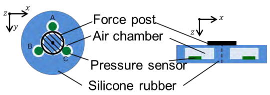


Fig. Schematic diagrams from the top and side view of the system

11:20–11:25	ThB1.4

Functionalized Textiles for Interactive Soft Robotics

Nicholas Farrow, Lauren McIntire and Nikolaus Correll
University of Colorado, Boulder, USA

- Capacitive sensing enables both touch and pretouch sensing in soft robotics
- Novel fabrication method fuses functional fabric and conventional electronics in soft polymer composite
- Pretouch sensor algorithm localizes small conductive objects along the length of an actuator
- Sensorized soft robots may sense objects and people in their environment - improving efficacy and safety

Soft capacitive touch and pretouch sensors

11:25–11:30	ThB1.5

3D Printed Soft Actuators for a Legged Robot Capable of Navigating Unstructured Terrain

Dylan Drotman, Saurabh Jadhav, Mahmood Karimi, Philip deZonia, Michael T. Tolley
Bioinspired Robotics and Design Lab

UC San Diego
Jacobs School of Engineering

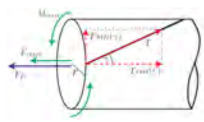
Bioinspired Robotics and Design Lab
http://bioinspired.eng.ucsd.edu

11:30–11:35	ThB1.6

Model Based Control of Fiber Reinforced Elastofluidic Enclosures

Daniel Bruder, Audrey Sedal, Joshua Bishop-Moser, Sridhar Kota, and Ram Vasudevan
Mechanical Engineering, University of Michigan, United States

- Fiber-Reinforced Elastofluidic Enclosures (FREEs), are a subset of pneumatic soft robots able to generate rotation and screw motions.
- We present a model that establishes a relationship between pressure, torque, and rotation to enable a model-driven open-loop control for FREEs.
- We use a FREE to open a combination lock to demonstrate efficacy of this model based control.



Soft Robotics 3

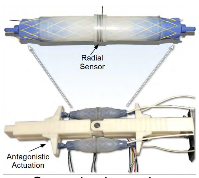
Chair *Woojin Chung, Korea University*
Co-Chair *Chen-Hua Yeow, National University of Singapore*

11:35–11:40 ThB1.7

Sensorized Pneumatic Muscle for Force and Stiffness Control

Lucas Tiziani, Thomas Cahoon, and Frank Hammond III
Woodruff School of Mech. Engineering, Georgia Institute of Technology, USA

- Contractile pneumatic artificial muscle design incorporates axial & radial liquid metal sensors
- Muscle is constrained by discrete fibers to allow deformation of muscle between fibers, decoupling length and diameter displacements
- Use length and diameter measurements to estimate muscle contraction and applied force
- Implemented antagonistic pair of sensorized muscles on 1-DOF linkage to control end-effector force and joint stiffness



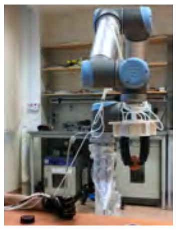
Sensorized muscles connected to 1-DOF linkage

11:40–11:45 ThB1.8

A Hybrid Tele-manipulation System using a Sensorized 3D-printed Soft Robotic Gripper and a Soft Fabric-Based Haptic Glove

J.H. Low, W.W. Lee, P.M. Khin, N.V. Thakor, S.L. Kukreja, H.L. Ren, and C.H. Yeow
Singapore Institute for Neurotechnology, National University of Singapore, Singapore

- The flexible 3D-printed soft robotic gripper are designed for compliant grasping.
- The soft haptic glove is equipped with flex sensors and soft pneumatic haptic actuator, which enables the users to control the grasping, to determine whether the grasp is successful and to identify the grasped objectshape.
- Both the soft finger actuator and haptic actuator involve simple fabrication technique, namely 3D-printed approach and fabric-based approach respectively, which reduce fabrication complexity



Motion and Path Planning 4

Chair *Jean-Paul Laumond, LAAS-CNRS*
Co-Chair *Eiichi Yoshida, National Inst. of AIST*

11:05–11:10	ThB2.1

Autonomous Navigation of Hexapod Robots With Vision-based Controller Adaptation

Marko Bjelonic[1], Timon Homberger[2], Navinda Kottege[3], Paulo Borges[3], Margarita Chli[4] and Philipp Beckerle[5]
[1]Robotic Systems Lab, ETH Zürich
[2]Department of Mechanical and Process Engineering, ETH Zürich
[3]Autonomous Systems Group, CSIRO, Australia
[4]Vision for Robotics Lab, ETH Zürich
[5]Technische Universität Darmstadt, Germany

- Legged robots have the potential to traverse unstructured terrain.
- The proposed hybrid controller implement on the hexapod robot Weaver adapts gait parameters and joint stiffness based on the terrain ahead.
- We also implement autonomous navigation based on visual-inertial for Weaver.
- We demonstrate the energy efficiency for legged locomotion is increased through the proposed controller.

Hexapod robot Weaver

11:10–11:15	ThB2.2

Multi-Objective UAV Path Planning for Search and Rescue

Samira Hayat and Christian Bettstetter
Networked and Embedded Systems, University of Klagenfurt, Austria
Evsen Yanmaz and Christian Bettstetter
Lakeside Labs, Austria
Timothy X Brown
Electrical, Computer, and Energy Engineering, Carnegie Mellon University, USA

- Mission planning algorithm for scenarios with dynamic goals, e.g. Search and Rescue
- Mission time minimization ensures fast coverage and quick communication path setup for target monitoring
- Tunable algorithm to prioritize the coverage or connectivity task, based on mission demands
- Data ferrying, relaying and a hybrid novel strategy evaluated to communicate with the ground personnel

Solid line for data ferrying (immediate target location notification), dashed line for relaying (real-time transfer)

11:15–11:20	ThB2.3

Multi-robot Path Planning for a Swarm of Robots that Can Both Fly and Drive

Brandon Araki, John Strang, Sarah Pohorecky, Celine Qiu, and Daniela Rus
CSAIL, MIT, USA
Tobias Naegeli
Department of Computer Science, ETH Zurich, USA

- We demonstrate a system for multi-robot path planning with multiple locomotion modalities
- Designed a flying-and-driving robot and a system architecture to control a swarm of them
- Developed a suboptimal priority planning algorithm and an optimal ILP to plan paths
- Ran experiments in a miniature town using 8 robots

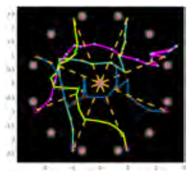
Multi-robot multimodal path planning

11:20–11:25	ThB2.4

MT-LQG: Multi-Agent Planning in Belief Space via Trajectory-Optimized LQG

Mohammadhussein Rafieisakhaei[1], Suman Chakravorty[2] and P. R. Kumar[1]
[1]Electrical and Computer Engineering, [2]Aerospace Engineering
Texas A&M University, USA

- We reduce the dimension of the general multi-agent belief space planning problem from $(mn+(mn)^2)$ to (mn).
- We design (m) LQG policies for (m) agents maximizing the joint performance of the team.
- For a horizon of K, the computational complexity of the planning problem is $O(mKn(n^2+mn))$.
- For Dec-POMDPs the number of joint policies is exponential in (m).



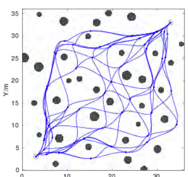
Optimized (solid) vs. initial (dashed) paths

11:25–11:30	ThB2.5

Motion Planning with Graph-Based Trajectories and Gaussian Process Inference

Eric Huang, Mustafa Mukadam, Zhen Liu, and Byron Boots
Institute for Robotics & Intelligent Machines, Georgia Tech, USA

- GPMP-GRAPH – simultaneously optimizes networks of trajectories for motion planning through efficient inference on factor graphs.
- Network structure provides exploration of exponential number of embedded trajectories in a fraction of the time needed to evaluate each of them one at a time.
- Experiments show GPMP-GRAPH gets stuck in fewer local optima and finds more homotopy classes compared to the state-of-the-art.



An optimized network of trajectories.

11:30–11:35	ThB2.6

Numerical Approach to Reachability Guided Sampling-Based Motion Planning Under Differential Constraints

S. D. Pendleton[1], W. Liu[1], H. Andersen[1], Y. H. Eng[2], E. Frazzoli[3], D. Rus[3], M. H. Ang Jr.[1]
[1]National University of Singapore, Singapore
[2]Singapore-MIT Alliance for Research and Technology, Singapore
[3]Massachusetts Institute of Technology, United States

- Planner considers only known reachable states
- Novel method to (i) derive a numerically solved discretized representation of reachable maps offline (Fig. 1), then (ii) apply the reachable map as a prior to guide state sampling and NN searching in online sampling-based motion planning with replanning
- Planning speed improved by a factor of 3 for holonomic model, and factor of 9 for Dubins car model in simulation.
- Enables real-time replanning in space-time

Fig. 1: Reachable space of a Dubin's car robot with max speed constraint. Color spectrum correlated to number of graph states.

Motion and Path Planning 4

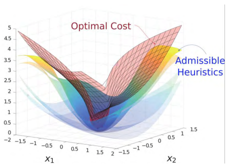
Chair *Jean-Paul Laumond, LAAS-CNRS*
Co-Chair *Eiichi Yoshida, National Inst. of AIST*

11:35–11:40	ThB2.7

Admissible Heuristics for Optimal Kinodynamic Motion Planning

Brian Paden, Valerio Varricchio, and Emilio Frazzoli
Laboratory for Information and Decision Systems,
Massachusetts Institute of Technology, USA

- Discussion of admissible heuristics for optimal kinodynamic motion planning problems
- Admissibility characterized by a partial differential inequality
- Optimization over the set of admissible heuristics is a linear program

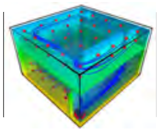


11:40–11:45	ThB2.8

Planning Dynamically Feasible Trajectories for Quadrotors using Safe Flight Corridors in 3-D Complex Environments

S. Liu, M. Watterson, K. Mohta, K. Sun, C.J Taylor, and V. Kumar
GRASP, University of Pennsylvania, USA
Subhrajit Bhattacharya
Mechanical Engineering, Lehigh University, USA

- We solve a trajectory as a QP using the Safe Flight Corridor (SFC)
- An efficient convex decomposition method is used to generate the SFC from a geometric path in a voxel map
- We use this trajectory generation method as a foundation for re-planning such that we are able to navigate the quadrotor in unknown environments



Generated trajectories in a voxel map

Vision and Range Sensing 2

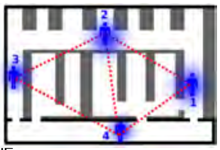
Chair *Nicholas Roy, Massachusetts Institute of Technology*
Co-Chair *Gim Hee Lee, National University of Singapore*

11:05–11:10	ThB3.1

Cooperative Relative Positioning of Mobile Users by Fusing IMU Inertial and UWB Ranging Information

Ran Liu, Chau Yuen, Tri-Nhut Do, and U-Xuan Tan
Singapore University of Technology and Design, Singapore
Dewei Jiao and Xiang Liu
School of Software and Microelectronics, Peking University, China,

- Combine IMU inertial and UWB ranging measurement for relative positioning of mobile users in unknown environment;
- Sensor fusion is done with a particle filter, which allows for cooperatively positioning and recovering from positioning failures.
- Extensive experiments are conducted and the proposed approach can be used for cooperative positioning of personnels in many scenarios, like firefighter operations and searching in disaster areas.

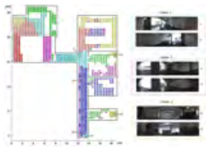


11:10–11:15	ThB3.2

Compression of Topological Models and Localiz. Using Global Appearance of Visual Information

Luis Payá, Sergio Cebollada and Oscar Reinoso
Systems Engineering and Automation, Miguel Hernandez University, Spain
Walterio Mayol
Computer Science, University of Bristol, United Kingdom

- **Spectral clustering** to create **compact** topological models using panoramic images.
- **Global appearance** descriptors invariant to changes of orientation: FS, HOG and *gist*.
- Compactness used to assess the **compression process**. *Gist* is able to create compact clusters despite perceptual aliasing.
- **Re-localization error** to assess the usefulness of the models. HOG presents a good balance between accuracy and time.



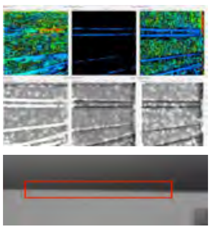
Sample clustering experiment

11:15–11:20	ThB3.3

Real-time Stereo Matching Failure Prediction and Resolution using Orthogonal Stereo Setups

Lorenz Meier, Dominik Honegger, Vilhjalmur Vilhjalmsson and Marc Pollefeys
Computer Science Department, ETH Zurich, Switzerland

- Stereo matching suffers from the well-known limitation of not being able to estimate the depth for 1D features like powerlines in images
- The fundamental limitation leads to missing powerlines in stereo depthmaps
- We resolve this fundamental limitation using matching failure prediction and additional matches from an orthogonal stereo setup

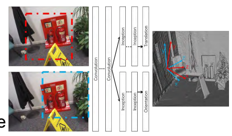


11:20–11:25	ThB3.4

Delving Deeper into Convolutional Neural Networks for Camera Relocalization

Jian Wu and Xiaolin Hu
Department of Computer Science and Technology, Tsinghua University, China
Liwei Ma
Intel Labs China, Intel Corporation, China

- We present three techniques for camera relocalization with CNNs.
- 1. Euler6: a new orientation representation.
- 2. Pose synthesis: a method to augment both data and label.
- 3. BranchNet: a multi-task CNN architecture for camera relocalization.



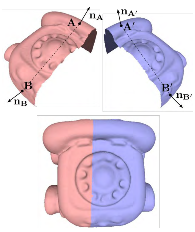
Input, BranchNet and output (from left to right)

11:25–11:30	ThB3.5

Using 2 Point+Normal Sets for Fast Registration of Point Clouds with Small Overlap

Carolina Raposo and João P. Barreto
Institute of Systems and Robotics, University of Coimbra, Portugal

- Global 3D registration has been solved by finding matches for establishing alignment hypotheses
- The SOFTA algorithm finds matches in linear time by making use of sets of 4 coplanar points
- We propose a new approach (2PNS) that advances the SOFTA by using 2 points and their normals
- Experiments show speed-ups of two orders of magnitude in noise-free datasets and up to 5.2x in Kinect scans

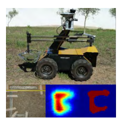


11:30–11:35	ThB3.6

Shape Reconstruction Using a Mobile Robot for Demining and UXO Classification

Sedat Dogru and Lino Marques
Institute of Systems and Robotics,
Department of Electrical and Computer Engineering,
University of Coimbra,
3030-290 Coimbra, Portugal

- New method for shape reconstruction of buried metallic objects using a metal detector.
- Metal detector attached to a 2DoF arm on a mobile robot.
- Arm control done using LRF and its inverse kinematics.



Vision and Range Sensing 2

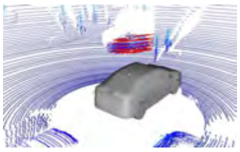
Chair *Nicholas Roy, Massachusetts Institute of Technology*
Co-Chair *Gim Hee Lee, National University of Singapore*

11:35–11:40 ThB3.7

A Learning Approach for Real-Time Temporal Scene Flow Estimation from LIDAR Data

Arash Ushani and Ryan Eustice
University of Michigan, USA
Ryan Wolcott and Jeffrey Walls
Toyota Research Institute, USA

- We propose a system to directly perceive dynamic motion (i.e., scene flow) from LIDAR
- We present a learned framework that allows us to do this in real-time
- We demonstrate results on the KITTI dataset



Sample flow result, depicted in red

11:40–11:45 ThB3.8

Progressive Object Modeling with a Continuum Manipulator in Unknown Environments

Huitan Mao[1], Zhou Teng[1,2] and Jing Xiao[1]
[1]Department of Computer Science, UNC Charlotte, U.S.A.
[2]ABB US Corporate Research Center, U.S.A.

- Enable a continuum manipulator to move an RGB-D sensor around a target object to build a 3D surface model of the target object in a cluttered, unknown environment automatically.
- Interleave perception and manipulation.
- Build the object model progressively through robust RGB-D image registration with global optimization in the presence of pose and motion uncertainty of the robot and camera.

SLAM 4

Chair *Ioannis Rekleitis, University of South Carolina*
Co-Chair *Gamini Dissanayake, University of Technology Sydney*

11:05–11:10	ThB4.1

RGB-T SLAM: A Flexible SLAM Framework By Combining Appearance and Thermal Information

Long Chen, Libo Sun, Teng Yang, Lei Fan, Kai Huang and Zhe Xuanyuan
Sun Yat-sen University

Abstract- Visual SLAM in low illumination scenes remains a considerably challenging task since the available amount of appearance information frequently stays insufficient. To tackle with this problem, we propose a novel SLAM framework by using both appearance information and thermal information, which possesses illumination-free recognizable contents, in a flexible manner. The key idea is to continuously update a RGBT map, which contains both RGB and thermal map points to implement location and mapping. More specifically, in our SLAM system, we detect features in both RGB and thermal images and combine them together to update the RGB-T map and implement simultaneous location and mapping. Both quantitative and qualitative results demonstrate the effectiveness of our framework, especially under low illumination environments.

11:10–11:15	ThB4.2

A Discrete-Time Attitude Observer on SO(3) for Vision and GPS Fusion

Alireza Khosravian, Tat-Jun Chin, Ian Reid
School of Computer Science, University of Adelaide, Australia
Robert Mahony
Research School of Engineering, Australian National University, Australia

- Visual odometry estimates are prone to drift over time and can not be represented with respect to a priory known reference frame.
- Fusing GPS measurements with visual odometry helps mitigating both of the above problems.
- We propose a simple geometric observer for vision-GPS fusion that is formulated directly on the SO(3) manifold.
- We demonstrate excellent performance of the observer in practice.

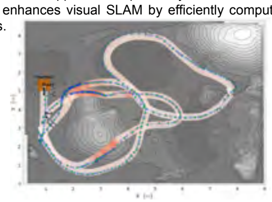
Experimental setup used to verify the performance of the proposed observer

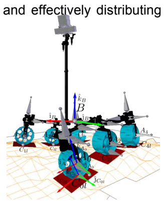
11:15–11:20	ThB4.3

Gaussian Process Estimation of Odometry Errors for Localization and Mapping

J. Hidalgo-Carrió, Daniel Hennes, Jakob Schwendner and F. Kirchner

Since early in robotics the performance of odometry techniques has been of constant research for mobile robots. This is due to its direct influence on localization. The pose error grows unbounded in dead-reckoning systems and its uncertainty has negative impacts in localization and mapping (i.e. SLAM). The dead-reckoning performance in terms of residuals, i.e. the difference between the expected and the real pose state, is related to the statistical error or uncertainty in probabilistic motion models. A novel approach to model odometry errors using Gaussian processes (GPs) is presented. The methodology trains a GP on the residual between the non-linear parametric motion model and the ground truth training data. The result is a GP over odometry residuals which provides an expected value and its uncertainty in order to enhance the belief with respect to the parametric model. The localization and mapping benefits from a comprehensive GP-odometry residuals model. The approach is applied to a planetary rover in an unstructured environment. We show that our approach enhances visual SLAM by efficiently computing image frames and effectively distributing keyframes.



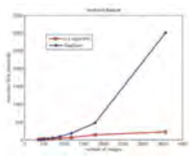


11:20–11:25	ThB4.4

Fast-SeqSLAM: A Fast Appearance Based Place Recognition Algorithm

Sayem Mohammad Siam and Hong Zhang
Department of Computing Science, University of Alberta, Canada

- Fast-SeqSLAM finds a loop closure node in log (n) time complexity.
- We achieve this computational efficiency without loosing performance in accuracy.
- It uses an ANN algorithm for finding image matching scores.
- Search greedily for a sequence of images that best match with the current sequence.
- Robust in severe appearance changed environment.



Execution Time

11:25–11:30	ThB4.5

Underwater Cave Mapping using Stereo Vision

Nick Weidner, Sharmin Rahman, Alberto Quattrini Li, Ioannis Rekleitis
Computer Science and Engineering Department, University of South Carolina, United States of America

- 3-D Reconstruction of underwater cave using GoPro Dual Hero stereo camera and a video-light
- Thresholding based on light intensity to create the edge map boundaries
- Sparse stereo reconstruction using only the matched stereo features on the cave boundaries
- Reconstruction of a ~240 meter underwater cave segment from 8 minutes of footage

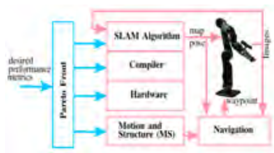
10 second cave segment reconstruction

11:30–11:35	ThB4.6

Application-oriented Design Space Exploration for SLAM Algorithms

S Saeedi*, L. Nardi*, E. Johns*, B. Bodin**, P. H.J. Kelly*, A. J. Davison*
* Robot Vision Group, Imperial College London, UK
** School of Informatics, University of Edinburgh, UK

- We propose to limit the information flow to achieve a robust SLAM
- Information gain is parameterized by relative entropy
- Information gain together with other algorithmic and hardware parameters are used to optimize the SLAM algorithm in different environments



Four design spaces of SLAM (algorithm, compiler, hardware, and motion-and-structure) are optimized to provide robust results.

SLAM 4

Chair *Ioannis Rekleitis, University of South Carolina*
Co-Chair *Gamini Dissanayake, University of Technology Sydney*

11:35–11:40	ThB4.7

Convergence and Consistency Analysis For A 3D Invariant-EKF SLAM

Teng Zhang, Kanzhi Wu, Jingwei Song, Shoudong Huang and Gamini Dissanayake
Center for Autonomous Systems, University of Technology Sydney, Australia

- Sound Theory: the general EKF framework, convergence and consistency analysis, several filters performance comparison
- Extended Concepts: observability, invariance, consistency
- New Concept: stochastic unobservable transformation
- 3D SLAM Algorithm: Right Error Invariant EKF (RI-EKF)

Algorithm 1: The general EKF framework (RI-EKF)
Input: $\hat{X}_n, P_n, u_n, z_{n+1}$;
Output: $\hat{X}_{n+1}, P_{n+1}$;
Propagation:
$\hat{X}_{n+1|n} \leftarrow f(\hat{X}_n, u_n, 0)$; $P_{n+1|n} \leftarrow F_n P_n F_n^T + G_n \Phi_n G_n^T$;
Update:
$S \leftarrow H_{n+1} P_{n+1|n} H_{n+1}^T + \Psi_{n+1}$, $K \leftarrow P_{n+1|n} H_{n+1}^T S^{-1}$;
$y \leftarrow h_{n+1}(\hat{X}_{n+1|n}, 0) - z_{n+1}$;
$\hat{X}_{n+1} \leftarrow \hat{X}_{n+1|n} \oplus Ky$, $P_{n+1} \leftarrow (I - KH_{n+1}) P_{n+1|n}$.

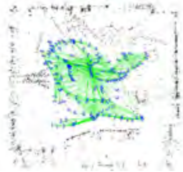
$\sigma_{od} = 1\%$, $\sigma_{ob} = 1\%$	RI-EKF	FEJ-EKF	SO(3)-EKF	Robocentric-EKF	Pseudo-RI-EKF	SE(3)-EKF
RMS of position(m)	**0.25**	0.29	0.32	0.31	0.65	Diverge
RMS of orientation(rad)	**0.0058**	0.0071	0.0065	0.0060	0.0080	Diverge
NEES of orientation	**1.02**	1.12	1.34	1.04	2.91	Diverge
NEES of pose	**1.01**	1.14	1.35	1.15	10	Diverge
$\sigma_{od} = 5\%$, $\sigma_{ob} = 5\%$	RI-EKF	FEJ-EKF	SO(3)-EKF	Robocentric-EKF	Pseudo-RI-EKF	SE(3)-EKF
RMS of position(m)	**1.16**	1.24	2.0	2.4	3.90	Diverge
RMS of orientation(rad)	**0.027**	0.029	0.043	0.041	0.041	Diverge
NEES of orientation	**1.0**	1.05	3.7	3.0	1.77	Diverge
NEES of pose	**1.01**	1.13	3.1	7.5	92	Diverge

11:40–11:45	ThB4.8

Visual-Inertial Monocular SLAM with Map Reuse

Raúl Mur-Artal and Juan D. Tardós
Instituto de Investigación en Ingeniería de Aragón (I3A)
Universidad de Zaragoza, Spain

- Tightly-coupled Visual-Inertial ORB-SLAM with loop closing and map reuse
- Zero-drift localization in mapped areas: more accurate than visual-inertial stereo odometry
- General and complete IMU initialization
- Recovers the true scale within 1% of error



Map of *V1_02_medium*, from the EuRoC dataset

Aerial Robot 6

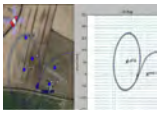
Chair *Koji Kawasaki, The University of Tokyo*
Co-Chair *Paolo Rocco, Politecnico di Milano*

11:05–11:10	ThB5.1

Guidance algorithm for smooth trajectory Tracking of a fixed wing UAV flying in wind flows

Hector Garcia de Marina, Murat Bronz and Gautier Hattenberger
Lab Drones, Ecole Nationale de l'Aviation Civile, France
Yuri A. Kapitanyuk and Ming Cao
ENTEG institute, University of Groningen, the Netherlands

- Digest must be prepared and submitted in **MS PowerPoint** (no other file format accepted)
- Use Arial 28pt font in bold face for the title
- Use Arial 24pt font for the authors and Arial 20pt font their ***brief*** affiliations
- 3 or 4 bullet points (limit each to ***less than 15*** words in Arial 20pt font), ***only*** 1 figure is allowed (replace the figure to the right with your figure)


UAV tracking an elliptical path

11:10–11:15	ThB5.2

Aerial Picking and Delivery of Magnetic Objects with MAVs

Abel Gawel*, Mina Kamel*, Tonci Novkovic*,
Jakob Widauer, Dominik Schindler, Benjamin Pfyffer von Altishofen,
Roland Siegwart and Juan Nieto
*equally contributed.
Autonomous Systems Lab, ETH Zurich

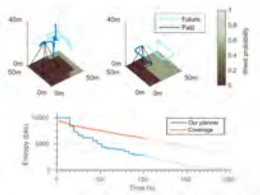
- Aerial delivery is an emerging technology, but autonomous picking and delivery is a hard challenge.
- A low complexity & energy efficient electro-permanent gripper for MAVs for robust gripping with positional offset & different object shapes.
- Development of a real-time visual servoing of the MAV position towards the object.
- Evaluation of the fully integrated system on different types of objects and in different conditions.

11:15–11:20	ThB5.3

Online Informative Path Planning for Active Classification Using UAVs

Marija Popović, Gregory Hitz, Juan Nieto,
Inkyu Sa, Roland Siegwart, and Enric Galceran
Autonomous Systems Lab., ETH Zürich, Switzerland

- Motivation: Efficient weed detection in precision agriculture.
- Approach: Adaptive IPP framework for active classification with probabilistic maps, which combines global viewpoint selection and evolutionary optimization to create dynamically feasible plans.
- Results: Evaluation in simulation against benchmarks and real-time implementation in an artificial farmland set-up.

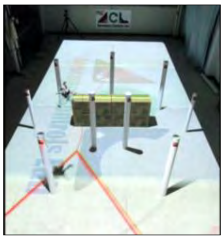

Compared against coverage planning (right), our method (left) produces a map with 45% lower entropy in the same amount of time (100s).

11:20–11:25	ThB5.4

Aggressive 3-D Collision Avoidance for High-Speed Navigation

Brett T. Lopez and Jonathan P. How
Aeronautics and Astronautics, MIT, USA

- Goal: fast collision avoidance algorithm for high-speed navigation
- Triple Integrator Planner (TIP)
- 2-5ms computation time
- Instantaneous sensor data for planning
- Minimum-time, state and control input constrained motion primitives
- Fast collision checking
- Attitude angles >70deg and angular rates >600 deg/s demonstrated in hardware


Quadrotor aggressively navigating through unknown environment

11:25–11:30	ThB5.5

Collaborative Transportation Using MAVs via Passive Force Control

Andrea Tagliabue, Mina Kamel, Sebastian Verling, Roland Siegwart and Juan Nieto
Autonomous Systems Lab., ETH Zürich, Switzerland

- Collaborative aerial transportation strategy based on **master-slave paradigm**.
- Master lifts and pulls the load while slave is compliant with master's actions via an **admittance controller**.
- Agents do **not need to communicate**, nor to know the grasping point or the shape of the payload.
- Slave **external force estimator** is based on the information provided by an **on-board Visual-Inertial navigation system**.

Setup for the **real experiment** of collaborative transportation

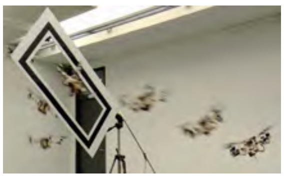
11:30–11:35	ThB5.6

Aggressive Quadrotor Flight through Narrow Gaps with Onboard Sensing and Computing using Active Vision

D. Falanga, E. Mueggler, M. Faessler, D. Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland

Letting quadrotors traverse narrow, inclined, gaps through:

- Onboard, vision-based state estimation and control
- Trajectory planning with perception (active vision) and dynamic constraints
- Automatic recovery and stabilization after traversing the gap



Aerial Robot 6

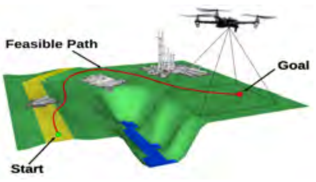
Chair *Koji Kawasaki, The University of Tokyo*
Co-Chair *Paolo Rocco, Politecnico di Milano*

11:35–11:40	ThB5.7

Active Autonomous Aerial Exploration for Ground Robot Path Planning

Jeffrey Delmerico, Elias Mueggler, Julia Nitsch, and Davide Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland

- **Problem:** Plan path for ground robot through unknown environment using terrain map made by a flying robot.
- **Approach:** Explore environment *actively* to optimize the overall response time (aerial mapping + ground traversal).
- **Results:** Significant speedup in response time. Deployed in real-world experiments.



11:40–11:45	ThB5.8

Trajectory Generation for Unmanned Aerial Manipulators through Quadratic Programming

Roberto Rossi[1], Angel Santamaria-Navarro[2], Juan Andrade-Cetto[2], Paolo Rocco[1]
[1]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Italy
[2]Institut de Robòtica i Informàtica Industrial, CSIC-UPC, Spain

- Trajectory generation for an aerial vehicle equipped with a robot arm
- Quadratic programming optimization to accomplish a weighted sum of tasks with defined bounds and constraint inequalities
- Phases of the mission approached with different redundancy resolution strategies, governed by metric functions weights.
- Approach demonstrated through real experiments with all the algorithms running onboard in real time

Failure Detection and Recovery

Chair *Pieter Abbeel, UC Berkeley*
Co-Chair *Oliver Brock, Technische Universität Berlin*

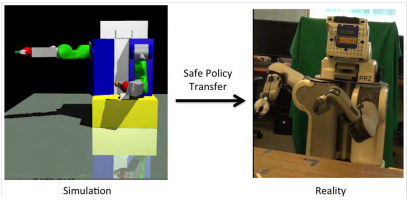
11:05–11:10	ThB6.1

Probabilistically Safe Policy Transfer

David Held, Zoe McCarthy, Michael Zhang, Fred Shentu, Pieter Abbeel
UC Berkeley, Open AI

- Learning-based methods can be dangerous for robots
- Our approach: impose safety-based torque limits during learning

$$\underset{\pi}{\text{maximize}} \quad \mathbb{E}[R(\pi)]$$
$$\text{subject to} \quad p_u(\pi) d_{\max}(\pi) \le D_{\text{safe}}$$



11:10–11:15	ThB6.2

Achieving Robustness by Optimizing Failure Behavior

Manuel Baum and Oliver Brock
Robotics and Biology Laboratory, Technische Universität Berlin, Germany

- Robust systems require failure detection and failure detection requires rich sensor feedback
- Actions can be adapted to generate rich feedback and to reduce failure detection error
- Concurrent action learning and learning of failure detection leads to robust behavior
- Experimental results from real world drawer opening task and Monte Carlo simulation

11:15–11:20	ThB6.3

Generating Semi-Explicit DAEs with Structural Index 1 for Fault Diagnosis Using Structural Analysis

Georgios Zogopoulos-Papaliakos and Kostas J. Kyriakopoulos
Sch. of Mechanical Engineering, National Technical University of Athens, Greece

- Structural Analysis for Fault Diagnosis can parse a detailed, large system model and propose residual generators
- In dynamic systems, Differential Algebraic Equations emerge, which may not be numerically solvable
- We propose 2 conditions which guarantee semi-explicit DAEs with Structural Index 1
- We provide a compliant fixed-wing UAV model and perform residual generation simulation

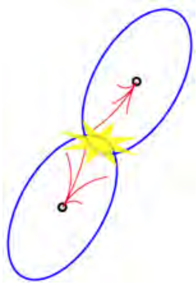
The Simulated Aircraft Environment

11:20–11:25	ThB6.4

Safe Open-Loop Strategies for Handling Intermittent Communications in Multi-Robot Systems

Siddharth Mayya and Magnus Egerstedt
Electrical & Computer Engineering, Georgia Institute of Technology, USA

- **Question:** How can robot teams maximally continue their operations in the presence of intermittent communication failures?
- **Answer:** Move in an open-loop ('blind') manner as long as the motion is provably safe, given the reachable sets of the robots.
- An ellipsoidal approximation of the reachable sets enables fast computations.
- The algorithms are implemented on teams of mobile robots.



11:25–11:30	ThB6.5

Learning Robust Failure Response for Autonomous Vision Based Flight

Dhruv Mauria Saxena and Martial Hebert
The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, USA
Vince Kurtz
Goshen College, Goshen, IN, USA

- Collect training data of failure images, maneuver executed, and result (recovered or not)
- Train two SVMs that predict maneuver maximally likely to lead to recovery, minimally likely to stay in failure
- Combine scores from both SVMs to select best maneuver for execution
- Results: 66% of failures ended in recovery (vs. 43% by random maneuver selection); >1,200m of uninterrupted flight

Algorithm for learning failure responses.

11:30–11:35	ThB6.6

Quadrotor Collision Characterization and Recovery Control

Gareth Dicker, Fiona Chui and Inna Sharf
Mechanical Engineering, McGill University, Canada

- Quadrotors with propeller protection require intelligent control to not crash as a result of collisions with obstacles.
- The collision needs to be detected, characterized, and recovered from.
- We developed a collision recovery strategy incorporating fuzzy logic and aggressive attitude control.
- Experimental results show performance of recovery strategy for a 1.1 kg quadrotor colliding with a vertical wall.

Failure Detection and Recovery

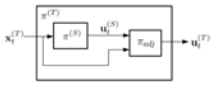
Chair *Pieter Abbeel, UC Berkeley*
Co-Chair *Oliver Brock, Technische Universität Berlin*

11:35–11:40	ThB6.7

Adapting Learned Robotics Behaviours through Policy Adjustment

Juan Camilo Gamboa-Higuera, David Meger and Gregory Dudek
Centre for Intelligent Machines and School of Computer Science, McGill University, Canada

- Method for reusing learned policies/controllers under changes of the robot dynamics.
- Avoids computationally costly search for new policies by *adjusting* the old policies
- Uses a learned inverse dynamics model to find the appropriate adjustments to apply in the target system
- We demonstrate the approach in simulation and on a physical cart-pole balancing task



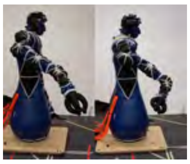
Source controllers are modified via the adjustment model to produce desired behaviours

11:40–11:45	ThB6.8

Variable Stiffness Adaptation to Mitigate System Failure in Inflatable Robots

Joshua Wilson, Charles Best, and Marc Killpack
Mechanical Engineering, Brigham Young University, USA

- Developed a straightforward method that can accurately detect a leak in the structural chamber of an inflatable robot
- Demonstrated the utility of adapting stiffness with variable stiffness joints as a means to slow structural leaks
- Demonstrated that our controller can adapt to slow a leak and achieve greater accuracy than is achieved without adaptation



Robot without and with a structural leak.

Robust and Adaptive Control

Chair *C. C. Cheah, Nanyang Technological University*
Co-Chair *Yasuyoshi Yokokohji, Kobe University*

11:05–11:10	ThB7.1

High-Performing Adaptive Grasp for a Robotic Gripper Using STSMC

Saber Mahboubi Heydarabad, Ferdinando Milella, Steven Davis and Samia Nefti-Meziani
School of Computing, Science and Engineering, University of Salford, UK

- Grasping an unknown object in the presence of unpredictable disturbances represent a significant challenge.
- Two controllers based on FOSMC and STSMC have been tasted in our lab.
- Both controllers use grip force and slip feedback to counteract the slippage.
- Both controllers can robustly overcome external disturbances.

Using our gripper and STSMC design, the robot was able to grasp and lifts objects of different mechanical properties.

11:10–11:15	ThB7.2

Balancing Control of a Robot Bicycle with Uncertain Center of Gravity

Chun-Feng Huang, Yen-Chun Tung, and Ting-Jen Yeh
Department of Power Mechanical Engineering,
National Tsing Hua University, Hsinchu 30013, Taiwan

- A small humanoid robot is designed to pedal, balance and steer a bicycle of comparable size.
- A novel controller is used to estimate the uncertain center of gravity of the robot-bicycle system to enhance control performance.
- Both simulations and experiments verify that the proposed controller can automatically counteract the mass imbalance and allow the robot to perform straight-line steering.

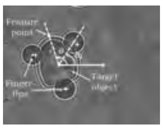
Photo of the robot-bicycle system

11:15–11:20	ThB7.3

Simultaneous Orientation and Positioning Control of a Microscopic Object using Robotic Tweezers

Quang Minh Ta and Chien Chern Cheah
School of Electrical and Electronic Engineering,
Nanyang Technological University, Singapore

- This paper presents a robotic control technique to achieve simultaneous orientation and positioning control of a microscopic object using robotic tweezers.
- Several optically trapped micro-particles are first utilized as the laser-driven fingertips to grasp a target object.
- Simultaneous control of the laser-driven fingertips and the robotic motorized stage is then performed for simultaneous orientation and positioning control of the target micro-object.

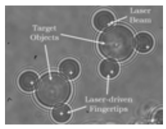


11:20–11:25	ThB7.4

Coordinative Optical Manipulation of Multiple Micro-Objects using Micro-hands with Multiple Fingertips

Quang Minh Ta and Chien Chern Cheah
School of Electrical and Electronic Engineering,
Nanyang Technological University, Singapore

- This paper presents a robotic control technique to achieve coordinative optical manipulation of multiple microscopic objects using micro-hands with multiple fingertips.
- Multiple laser tweezers are first employed to trap identical and trappable micro-particles such as micro-beads.
- By coordinating the trapped micro-particles that serve as the laser-driven fingertips, several micro-hands are thus formed to grasp and coordinatively manipulate the target objects.

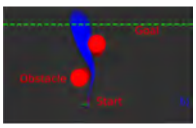


11:25–11:30	ThB7.5

Robust Obstacle Avoidance for Aerial Platforms using Adaptive Model Predictive Control

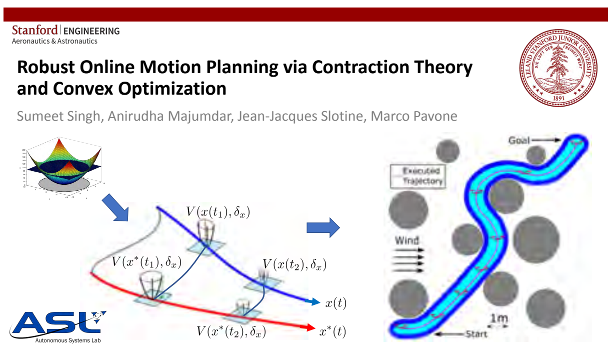
Gowtham Garimella[1], Matthew Sheckells[2] and Marin Kobilarov[1]
Mechanical Engineering, Johns Hopkins University, USA[1]
Computer Science, Johns Hopkins University, USA[2]

- Tackle motion planning of quadrotor among obstacles with external disturbances
- Novel Nonlinear Model Predictive Control (NMPC) technique proposed that incorporates state uncertainty into trajectory planning
- Combining online estimation with NMPC resulted in robust obstacle avoidance behavior
- Experiments showed quadrotor can safely avoid obstacles under external disturbances



Obstacle Avoidance Simulation

11:30–11:35	ThB7.6



Robust and Adaptive Control

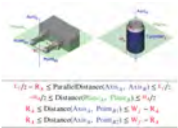
Chair *C. C. Cheah, Nanyang Technological University*
Co-Chair *Yasuyoshi Yokokohji, Kobe University*

11:35–11:40 ThB7.7

An Exact Solver for Geometric Constraints with Inequalities

Nikhil Somani and Alois Knoll
Robotics and Embedded Systems, Technische Universität München, Germany
Markus Rickert
fortiss GmbH, An-InstitutTechnische Universität München, Germany

- Key idea is to use geometric constraints with inequalities to define relative object poses.
- Solver can handle constraints where rotation and translation elements are dependent.
- Exact, repeatable solutions with deterministic runtimes, that are significantly faster than iterative approaches.
- A generic solving approach which is applicable to several domains, e.g. computer vision, motion planning.


A cup grasping task expressed using geometric constraints with inequalities

11:40–11:45 ThB7.8

Reproducing Physical Dynamics with Hardware-in-the-Loop Simulators: A Passive and Explicit Discrete Integrator

Marco De Stefano[1,2], Ribin Balachandran[1], Jordi Artigas[1] and Cristian Secchi[2]
[1] German Aerospace Center (DLR), Germany
[2] University of Modena and Reggio Emilia (UNIMORE), Italy

- Model-based dynamics rendered by a robot
- Standard integration method cause position drifts and energy inconsistency
- A passive and discrete integration method is proposed
- The method restores the energy properties of the simulated dynamics
- The approach has been tested on a robot simulator.


Hardware-in-the-loop Simulator

Human Factors 1

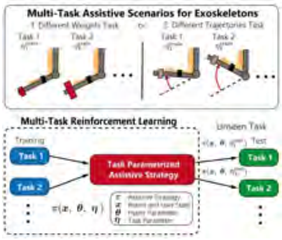
Chair *Harry Asada, MIT*
Co-Chair *Jun Morimoto, ATR Computational Neuroscience Labs*

11:05–11:10 ThB8.1

Learning Task-Parametrized Assistive Strategies for Exoskeleton Robots by Multi-Task Reinforcement Learning

Masashi Hamaya[1,2], Takamitsu Matsubara[1,3], Tomoyuki Noda[1], Tatsuya Teramae[1] and Jun Morimoto[1]
[1]Dept. of Brain Robot Interface, ATR, Kyoto, Japan
[2]Graduate School of Frontier Biosciences, Osaka Univ., Osaka, Japan
[3]Graduate School of Information Science, NAIST, Nara, Japan

- We propose to learn task-parametrized assistive strategies for exoskeleton robots.
- We exploit a data efficient multi-task reinforcement learning framework.
- We applied our proposed method to a powered elbow exoskeleton.
- Our method can learn the strategies generalized for unseen tasks to reduce the user's EMGs.

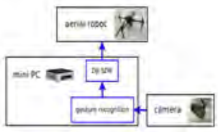


11:10–11:15 ThB8.2

Gesture-based Piloting of an Aerial Robot using Monocular Vision

Ting Sun, Shengyi Nie, and Shaojie Shen
Department of Electronic & Computer Engineering,
Hong Kong University of Science and Technology, Hong Kong
Dit-Yan Yeung
Department of Computer Science,
Hong Kong University of Science and Technology, Hong Kong

- A monocular system is proposed for human-UAV interaction.
- We particularly design our system to pilot an aerial robot using natural gestures.
- Our work focuses on command design and gesture recognition module.
- Various properties of the system are tested.



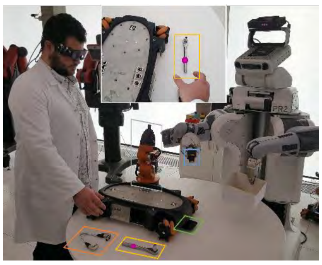
System overview

11:15–11:20 ThB8.3

Physical Symbol Grounding and Instance Learning through Demonstration and Eye Tracking

Svetlin Penkov, Alejandro Bordallo
Subramanian Ramamoorthy
School of Informatics, The University of Edinburgh, United Kingdom

- Inference algorithm exploiting the properties of **fixation programs** enabling **symbol grounding**
- **Localisation** of the **symbol instances**, present in the fixation program, within the environment
- **Learning the appearance** of symbol instances when **no previous knowledge** is present
- Methodology for **recording 3D fixations** within the environment based on visual SLAM


Real world experiments with humans and robots

11:20–11:25 ThB8.4

Control Approach for Arm Exoskeleton Based on Human Muscular Manipulability

Rok Goljat[1], Jan Babič[1], Tadej Petrič[1], Luka Peternel[2], Jun Morimoto[3]
[1]Dept. of Automation, Biocybernetics and Robotics, JSI, Slovenia
[2]HRI Lab, Dept. of Advanced Robotics, IIT, Italy
[3]Dept. of Brain-Robot Interface, ATR, Japan

- A control approach that assists the motion of the human arm
- Based on the muscular manipulability ellipse of the human arm
- Provide assistance in the directions of lower manipulability
- Method reduced muscle activity in low manipulability motions

11:25–11:30 ThB8.5

Local Driving Assistance from Demonstration for Mobility Aids

James Poon[1] and Yunduan Cui[2] and Jaime Valls Miro[1] and Takamitsu Matsubara[2] and Kenji Sugimoto[2]
[1]University of Technology Sydney, Australia
[2]Nara Institute of Science and Technology, Japan

- Short-term intention estimation allows for both safe object approach and obstacle avoidance
- Local scope allows independence from *a-priori* occupancy maps and long-term localization
- Intention inference and path compliance models trained from expert demonstration
- Experimentation with 82-year old volunteer shows promise in assisting mobility aid users

11:30–11:35 ThB8.6

The MantisBot: Design and Impedance Control of Supernumerary Robotic Limbs for Near-Ground Work

Daniel Kurek and H. Harry Asada
Dept. of Mechanical Engineering, Mass. Institute of Technology, United States of America

- Design, prototype, and control of Supernumerary Robotic Limbs (SRLs) that provide support for workers near the ground
- Tuneable impedance controller creates virtual spring-damper system around the wearer's torso
- Wearer's range of motion near the ground is extended and hands remain free to perform useful work

Human Factors 1

Chair *Harry Asada, MIT*
Co-Chair *Jun Morimoto, ATR Computational Neuroscience Labs*

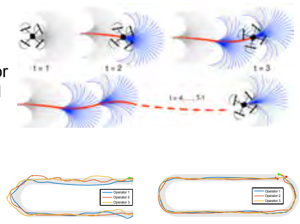
11:35–11:40	ThB8.7

A Framework for Efficient Teleoperation via Online Adaptation

Xuning Yang, Koushil Sreenath, and Nathan Michael
Robotics Institute, Carnegie Mellon University, USA

We present a novel task-independent adaptive teleoperation framework that improves performance and efficiency

- Possible control actions from operator are represented using parameterized **motion primitive libraries**
- The available motion primitive libra is adapted to a **belief distribution** obtained by estimating the user int online
- The framework is validated for sing intent long-duration tasks using steering entropy and smoothness (the resulting trajectories



Bottom: Resulting trajectories with and without adaptation around a racetrack

11:40–11:45	ThB8.8

Independent, Voluntary Control of Extra Robotic Limbs

Federico Parietti and Harry Asada
Mechanical Engineering Department,
Massachusetts Institute of Technology (MIT), USA

- **Supernumerary Robotic Limbs (SRL)**: a wearable robot providing additional robotic limbs.
- In order to control the SRL, we need **voluntary signals** that are **independent** of natural limb motions.
- We tested **three control strategies** based on **torso EMG** signals.
- **Experimental data** show that all the subjects achieved **accurate, independent control** of the extra limbs.

A. Prototype of the additional robotic limbs. **B.** Human subject controlling the robotic limbs with torso EMG signals.

Micro/Nano Robots 1

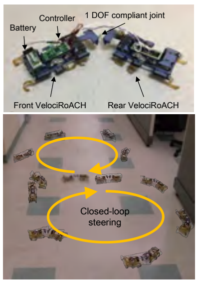
Chair *Toshio Fukuda, Meijo University*
Co-Chair *Islam S.M. Khalil, German University in Cairo*

11:05–11:10	ThB9.1

High-rate controlled turning with a pair of miniature legged robots

TaeWon Seo
Mechanical Engineering, Yeungnam University, Republic of Korea
Carlos S. Casarez, Ronald S. Fearing
Mechanical Engineering, Electrical Engineering and Computer Science, UC Berkeley, USA

- High-rate steering method by connecting two VelociRoACH with a compliant joint.
- Front robot determines the direction of steering and the rear robot generates thrust for high-rate turning.
- Proposed method shows good performances on three different surfaces: carpet, paper, and tile.
- Closed loop steering results is provided to track predefined path.

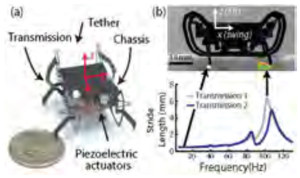


11:10–11:15	ThB9.2

Phase Control for a Legged Microrobot Operating at Resonance

Neel Doshi, Kaushik Jayaram, Benjamin Goldberg, and Robert J Wood
John A Paulson School of Engineering and Applied Sciences, Harvard University, USA

- Empirical characterization of transmission resonance
- Development of high-bandwidth phase estimator and controller
- Control of resonant (100 Hz) leg trajectory in air and with ground contact



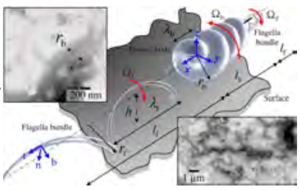
(a) Harvard ambulatory Microrobot and (b) transmission resonance

11:15–11:20	ThB9.3

Near-Surface Effects on the Controlled Motion of Magnetotactic Bacteria

Islam Khalil, Mohamed Mitwally, and Nermeen Serag
The German University in Cairo, Egypt
Ahmet Tabak and Metin Sitti
Max Planck Institute for Intelligent Systems, Germany
Tijmen Hageman, Marc Pichel, and Leon Abelmann
Korean Institute of Science and Technology, Germany

- A hydrodynamic model of bipolarly-flagellated magnetotactic bacteria is developed to investigate the interactions between flagella bundles and the helical body of the cell
- Near-Surface effects on the swimming characteristics of magnetotactic bacteria are studied theoretically and experimentally



Model of a magnetotactic bacterium

11:20–11:25	ThB9.4

Robotics-based Micro-reeling of Magnetic Microfibers to Fabricate Helical Structure for Smooth Muscle Cells Culture

Tao Sun[1], Qing Shi[1], Huaping Wang[1],Xiaoming Liu[1], Chengzhi Hu[3], Masahiro Nakajima[2], Qiang Huang[1],Toshio Fukuda[1]
[1]Beijing Institute of Technology, China [2]Nagoya University, Japan [3]ETH Zürich, Switzerland

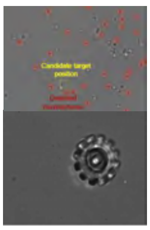
- Robotic system for micromanipulation of reeling microfibers
- Tip control of magnetic tweezers on microfiber
- Force analysis between magnetic tweezers and reeled microfiber

11:25–11:30	ThB9.5

Gaze Contingent Control for Optical Micromanipulation

Maria Grammatikopoulou and Guang-Zhong Yang
The Hamlyn Centre for Robotic Surgery, Imperial College London

- This paper presents a gaze contingent controller for optical micromanipulation of multiple or 3D microstructures
- Haptic constraints are generated from the user's eye gaze to assist positioning of the assembly
- A method for 3D orientation estimation is also presented

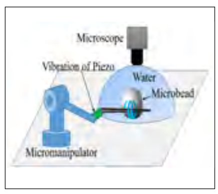


11:30–11:35	ThB9.6

Non-Contact Transportation and Rotation of Micro Objects by Vibrating Glass Needle Circularly Under Water

X. Liu, Q. Shi, H. Wang, T. Sun, Q. Huang, T. Arai and T. Fukuda
School of Mechatronical Engineering, Beijing Institute of Technology, CHINA
M. Kojima, Y. Mae, and T. Arai
Department of Systems Innovation, Osaka University, JAPAN

- Circular vibration induced by piezo actuator
- Local swirl flow generated by vibrating glass needle circularly under water
- Analysis of the swirl flow through CFD simulation
- Non-contact rotation and transportation of micro targets



Micro/Nano Robots 1

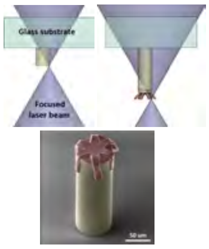
Chair *Toshio Fukuda, Meijo University*
Co-Chair *Islam S.M. Khalil, German University in Cairo*

11:35–11:40	ThB9.7

Towards hybrid microrobots using pH- and photo-responsive hydrogels for cancer targeting and drug delivery

Maura Power, Salzitsa Anastasova, Guang-Zhong Yang
Hamlyn Centre, Imperial College London, UK
Suzanne Shanel
Department of Bioengineering, Imperial College London, UK

- Development of two stimuli-responsive photoresists for two-photon polymerization.
- pH responsive resist demonstrated to navigate towards low pH in fluidic environment.
- Photo-responsive resist demonstrate to shrink under light.
- Microrobot tested in artificial bifurcating channel with low pH target

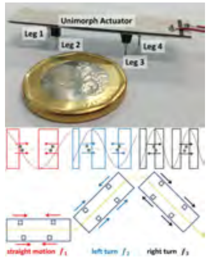


11:40–11:45	ThB9.8

Steerable Miniature Legged Robot Driven by a Single Piezoelectric Bending Unimorph Actuator

Audelia G. Dharmawan, Hassan H. Hariri, Shaohui Foong, Gim Song Soh, and Kristin L. Wood
Engineering Product Development, Singapore University of Technology and Design, Singapore

- Design and development of a novel smallest and lightest maneuverable single-actuator miniature robot
- Underactuated motion is achieved by a combination of piezoelectric bending modes and leg position manipulation
- Robot prototype measures 50x10x9mm, weighs 3g, and has a top speed of 14cm/s
- Future study includes investigation to improve robot's speed, payload capability, and motion precision



Physically Assistive Devices

Chair *Wei Tech Ang, Nanyang Technological University*
Co-Chair *Filippo Arrichiello, Università di Cassino e del Lazio Meridionale*

11:05–11:10	ThB10.1

Semi-Endoskeleton-Type Waist Assist AB-Wear Suit Equipped with Compressive Force Reduction Mechanism

Hiroki Inose, Shun Mohri, Hirokazu Arakawa, Manabu Okui, Yasuyuki Yamada and Taro Nakamura
Department of Precision Mechanics, Chuo University, Japan
Katsuya Koide and Isao Kikutani
Nabtecso corporation, Japan

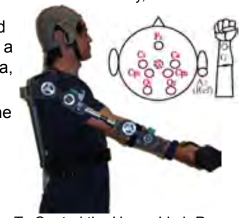
- The device assists the motion of waist joint to reduce low back pain.
- This device has a high output and, flexibility, and light weight (2.9 kg).
- The assist suit is operated based on results of musculoskeletal simulation.

11:10–11:15	ThB10.2

Estimation of EMG Signal for Shoulder Joint Based on EEG Signals for the Control of Upper-Limb Power Assistance Devices

H. Liang, C. Zhu, M. Yoshioka, N. Ueda, Y. Tian, Y. Iwata
Department of Environment and Life Engineering, Maebashi Institute of Technology, Japan
H. Yu, Department of Bioengineering, National University of Singapore, Singapore
F. Duan, Department of Automation, Nankai University, China
Y. Yan, Department of Bioengineering, Santa Clara University, USA

- The distribution of the EEG signals related with movement of shoulder joint exhibited a even distribution not only in the motor area, but also through out the brain cortex.
- We establish a linear model to estimate the shoulder joint EMG from EEG signals to control the power assistance system.
- The proposed approach is confirmed through experiments, and the results demonstrate the feasibility of using the proposed approach.



To Control the Upper-Limb Power Assistance Devices by EEG signals

11:15–11:20	ThB10.3

Comparative Experimental Validation of Human Gait Tracking Algorithms for an Intelligent Robotic Rollator

Georgia Chalvatzaki, Xanthi S. Papageorgiou, Costas S. Tzafestas and Petros Maragos
National Technical University of Athens, Greece

- Accurate and robust **Human Gait Tracking** for an Intelligent Robotic Rollator for the elderly
- Continuous monitoring for **Gait Status Assessment**
- Two Gait Tracking algorithms: a. **Kalman Filter** based, b. two **Particle Filters** with probabilistic data association
- **Real Experiments**, with elders using the robotic platform
- **Validation Study** using data by **laser sensor** mounted on the robotic walker and **ground truth** data from **visual markers**

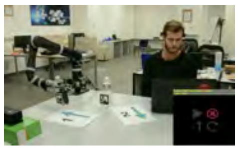
Left: MOBOT robotic platform equipped with a Hokuyo LRF for recording the user's gait data (below knee level).
Right: Snapshot of a subject walking with physical support of MOBOT.

11:20–11:25	ThB10.4

Assistive robot operated via P300-based Brain Computer Interface

Filippo Arrichiello, Paolo Di Lillo, Daniele Di Vito, Gianluca Antonelli, Stefano Chiaverini
Department of Electrical and Information Engineering, University of Cassino and Southern Lazio, Italy

- The lightweight robot manipulator receives high level commands from the user through BCI based on P300 paradigm;
- Robot motion control is based on closed loop inverse kinematic algorithm that manages set-based and equality tasks;
- Software architecture relies on BCI2000 for BCI operation and ROS for robot control;
- Control, perception and communication modules developed for the application at hand.



11:25–11:30	ThB10.5

A Collaborative Control Framework for Driver Assistance System

Duy Tran, Eyosiyas Tadesse, Denis Osipychev, Jianhao Du and Weihua Sheng
School of Electrical and Computer Eng., Oklahoma State University, Stillwater, Oklahoma, USA
Yuge Sun
College of Information Science and Engineering, Northeastern University, Shenyang, China
Heping Chen
Ingram School of Engineering, Texas State University, San Marcos, TX 78666, USA

- Collaborative driving is more practical than fully autonomous driving
- A collaborative driving framework is proposed
- A co-pilot program runs in parallel with the human driver and intervenes only when necessary
- Human drowsiness is taken into consideration in the framework

The Collaborative Control Framework

11:30–11:35	ThB10.6

Haptic Simulation for Robot-Assisted Dressing

Wenhao Yu[1], Ariel Kapusta[2], Jie Tan[1], Charles C. Kemp[2], Greg Turk[1] and C. Karen Liu[1]
[1]School of Interactive Computing [2]Healthcare Robotics Lab
Georgia Institute of Technology, USA

- A PhysX-based cloth simulator to synthesize haptic data during robot-assisted dressing.
- An optimization scheme for tuning cloth simulator with few real-world data.
- An outcome classifiers trained with simulation generated haptic data that can generalize to new person.

Physically Assistive Devices

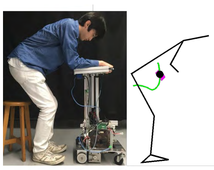
Chair *Wei Tech Ang, Nanyang Technological University*
Co-Chair *Filippo Arrichiello, Università di Cassino e del Lazio Meridionale*

11:35–11:40	ThB10.7

Human CoG Estimation for Assistive Robots Using a Small Number of Sensors

Mizuki Takeda, Yasuhisa Hirata, and Kazuhiro Kosuge
Department of Robotics, Tohoku University, Japan
Takahiro Katayama, Yasuhide Mizuta, and Atsushi Koujina
RT.WORKS co., ltd., Japan

- Propose a method to calculate CoG candidates using a small number of sensors
- We determined the appropriate combination of sensors by comparing the CoG candidates
- It's useful to determine where and which sensors to set when designing assistive robots
- It also can be used for real-time estimation

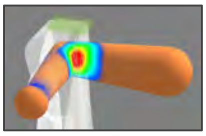


11:40–11:45	ThB10.8

What Does the Person Feel? Learning to Infer Applied Forces During Robot-Assisted Dressing

Zackory Erickson, Alexander Clegg, Wenhao Yu, Greg Turk, C. Karen Liu, and Charles C. Kemp
Georgia Institute of Technology, United States

- Inferring what humans physically feel during robot-assisted dressing using physics-based simulation and deep learning.
- Two tasks: pulling a hospital gown onto an arm and pulling shorts onto a leg.
- LSTM estimates hundreds of forces given a 9 dimensional end effector measurement.
- Estimated force maps were visually similar to ground truth and generalized to limb rotations.



Parallel Robots

Chair *Philipp Tempel, University of Stuttgart*
Co-Chair *François Pierrot, CNRS - LIRMM*

11:05–11:10	ThB11.1

Improving contour accuracy of a 2-DOF planar PKM by smart structure based compensation method

Yao Jiang and Feifanchen
Department of Precision Instrument, Tsinghua University, Beijing, China
Tiemin Li and Liping Wang
Department of Mechanical Engineering, Tsinghua University, Beijing, China

- A novel parallel kinematic machine based on the smart structure chains is developed.
- A smart structure based compensation method is proposed to improve PKM's contour accuracy.
- PKM's Positioning and contour accuracies are tested to validate the effectiveness of the proposed method.

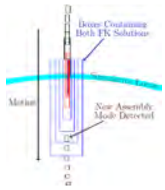
A novel 2-DOF precision PKM based on the smart structure chains

11:10–11:15	ThB11.2

Certified Detection of Parallel Robot Assembly Mode under Type 2 Singularity Crossing Trajectories

Adrien Koessler[1], Alexandre Goldsztejn[2],
Sébastien Briot[2] and Nicolas Bouton[1]
[1]Institut Pascal, Université Clermont Auvergne, France
[2]LS2N, UMR CNRS 6004, Nantes, France

- Crossing Type 2 singularities allows extending reachable workspace of parallel manipulators
- Change in Assembly Mode induced by the crossing should be monitored
- This is achieved using interval-based tracking of end-effector pose and velocity
- Interval Analysis techniques ensure the reliability of the tracking



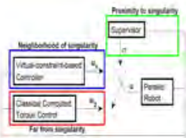
End-effector pose enclosures under singularity crossing

11:15–11:20	ThB11.3

Crossing Type 2 Singularities of Parallel Robots without Pre-planned Trajectory with a Virtual-constraint-based Controller

Rafael Balderas Hill, Damien Six, Abdelhamid Chriette,
Sébastien Briot and Philippe Martinet
Laboratoire des Sciences du Numérique de Nantes,
Ecole Centrale de Nantes, France

- Parallel robots are locally underactuated in a Type 2 Singularity.
- Separation of the controlled and free dynamics is performed, locally, in the singularity locus.
- A control law based on virtual constraints ensures unplanned singularity crossing.
- The multi-controller allows a continuous switching of control laws far from singularity and in the neighborhood of the singularity.

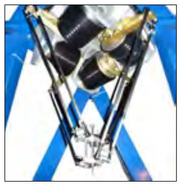


11:20–11:25	ThB11.4

A Novel Adaptive TSM Control for Parallel Manipulators: Design and Real-Time experiments

Moussab Bennehar, Gamal El-Ghazaly, Ahmed Chemori
and François Pierrot
LIRMM Robotics Department, University of Montpellier - CNRS, France.

- A new robust adaptive controller based on terminal sliding mode and adaptive control
- Singularity and chattering issues are solved thanks to continuous terminal sliding mode
- Model-based adaptive feedforward term is appended to improve tracking performance
- Both standard TSM and the proposed controllers are implemented on Veloce robot
- Experimental comparison shows significant improvements of the proposed controller



Veloce: a 4DoF parallel manipulator

11:25–11:30	ThB11.5

Estimating Inertial Parameters of Suspended Cable-Driven Parallel Robots CoGiRo

Philipp Tempel and Andreas Pott
ISW, University of Stuttgart, Germany
Pierre-Elie Herve, Olivier Tempier, and Marc Gouttefarde
LIRMM, Université de Montpellier CNRS, France

- First time application of inertial parameters identification procedures to suspended cable-driven parallel robots
- Cable-driven parallel robots are special class of Gough-Stewart platform with flexible links
- Estimation of parameters more involved with important quantities difficult to measure directly
- Use case on CoGiRo proves applicability of theory to cable robots

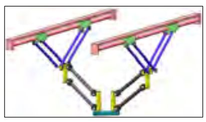
Suspended cable-driven parallel robot CoGiRo

11:30–11:35	ThB11.6

Kinematic Design of a Novel 4-DOF Parallel Manipulator

Cuncun Wu, Guilin Yang, Chin-Yin Chen and Tianjiang Zheng
Zhejiang Key Laboratory of Robotics and Intelligent Equipment Technology,
Ningbo Institute of Materials Technology and Engineering, China
Cuncun Wu and Shulin Liu
School of Mechatronic Engineering and Automation,
Shanghai University, China

- A new Schönflies-motion parallel manipulator with symmetric configuration is proposed;
- It can achieve large workspace and high positioning accuracy;
- Kinematic design issues, such as displacement, workspace, and singularity analyses, have been addressed.



A 4-DOF $4PP_a$-$2P_aR$ parallel manipulator

Parallel Robots

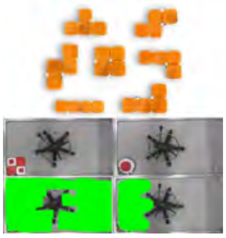
Chair *Philipp Tempel, University of Stuttgart*
Co-Chair *François Pierrot, CNRS - LIRMM*

11:35–11:40	ThB11.7

hTetro: A Tetris Inspired Shape Shifting Floor Cleaning Robot

Veerajagadheswar Prabakaran, Rajesh Elara Mohan, Thejus Pathmakumar, and Shunsuke Nansai
Singapore University of Technology and Design, Singapore

- Recent years have witnessed a steep increase in the number of commercial floor cleaning robots in the marketplace.
- However, the floor coverage performance of those robots are highly limited due to their fixed morphologies.
- To overcome the performance issues, we are developing hTetro, a self reconfigurable floor cleaning robot that transform itself into any of the seven one-sided tetrominoes to maximize floor coverage area.
- In this work, we conducted experiments that demonstrated the superior floor coverage performance of hTetro in comparison to a commercial floor cleaning robot.



Floor coverage performance of hTetro in comparison to a commercial cleaning robot

11:40–11:45	ThB11.8

Kinematic Design of a Dynamic Brace for Measurement of Head/Neck Motion

Haohan Zhang and Sunil K. Agrawal
Department of Mechanical Engineering, Columbia University, USA

- Underlying architecture: 3-RRS parallel mechanism with coupled rotation and translation
- Optimized design using human kinematic data to achieve large range of rotations with minimized translational error
- A lightweight wearable physical brace tested with 10 human subjects with different sizes
- Wearability and accuracy of measurement evaluated by an experiment against a motion capture system

Kinematic Model of a Dynamic Neck Brace

Soft Robotics 4

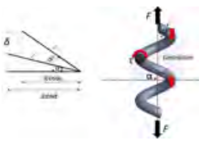
Chair *Stefano Scheggi, University of Twente*
Co-Chair *Ryuma Niiyama, University of Tokyo*

16:10–16:15	ThC1.1

A Physics Based Model for Twisted and Coiled Actuator

Ali Abbas and Jianguo Zhao
Department of Mechanical Engineering, Colorado State University, USA

- We present the static and dynamic model for recently discovered artificial muscle—twisted and coiled actuator (TCA).
- The developed model utilizes parameters related to the working principle and material properties of the actuator.
- The proposed model can predict the static performance and dynamic response for the actuator precisely.



Parameters and geometric relationship for TCA.

16:15–16:20	ThC1.2

A Two-Level Approach for Solving the Inverse Kinematics of an Extensible Soft Arm Considering Viscoelastic Behavior

Hao Jiang, Zhanchi Wang, Xinghua Liu, Xiaotong Chen, Yusong Jin, Xuanke You and Xiaoping Chen
Computer Science, University of Science and Technology of China

- A two-level approach for open-loop control of an extensible HPN arm.
- Pose optimization for the soft arm based on designed cost function.
- Neural-network based control algorithm with consideration of viscoelastic effect.
- A simple strategy turning the open-loop control method into a close-loop.

Fig. 1. Control system overview

16:20–16:25	ThC1.3

Soft Gripper Dynamics Using a Line-Segment Model with Optimization-Based Parameter Identification Method

Zhongkui Wang and Shinichi Hirai
Department of Robotics, Ritsumeikan University, Japan

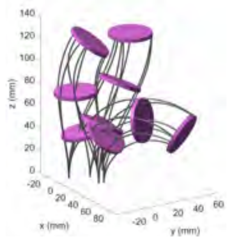
- A 3D printed three-finger soft gripper was introduced;
- A line-segment model was derived to simulate the soft finger dynamics;
- An optimization based method was presented to identify the parameters involved in the dynamic model;
- Experimental tests validated the behavior repeatability in pressurized bending angle;
- The embedded curvature sensor could detect the failed grasping;
- The proposed model can predict grasping force based on the measured curvature.

16:25–16:30	ThC1.4

Modeling Parallel Continuum Robots with General Intermediate Constraints

Andrew L. Orekhov
Department of Mechanical Engineering, Vanderbilt University, USA
Vincent A. Aloi and D. Caleb Rucker
Department of Mechanical, Aerospace, and Biomedical Engineering, University of Tennessee Knoxville, USA

- Parallel continuum robots are compliant and dexterous manipulators suitable for minimally invasive surgery.
- 6-DOF variable-curvature shapes are achievable, but unconstrained leg deflections can limit the workspace.
- We model designs with general intermediate constraints and routing paths which can expand the workspace.

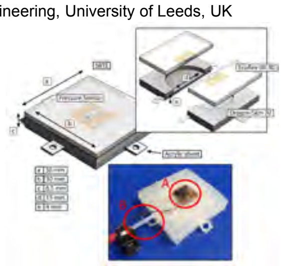


16:30–16:35	ThC1.5

Towards a Soft Robotic Skin for Autonomous Tissue Palpation

Federico Campisano and Nikolaos Gkotsis
Mechanical Engineering, Vanderbilt University, USA
Selim Ozel, Anand Ramakrishnan, Anany Dwivedi and Cagdas Onal
Mechanical Engineering, Worcester Polytechnic Institute, USA
Pietro Valdastri
School of Electronic and Electrical Engineering, University of Leeds, UK

- We have proved the feasibility of tissue palpation using a single soft robotic tactile element (SRTE).
- The SRTE expansion against the tissue is controlled by the variation of volume in the actuation chamber.
- This is the first design of a soft-silicon tool that can be used for intraoperative mapping of tissue cancer.

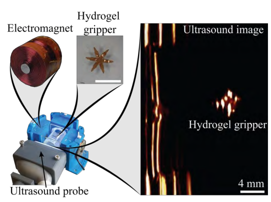


16:35–16:40	ThC1.6

Magnetic Motion Control and Planning of Untethered Soft Grippers using Ultrasound Image Feedback

S. Scheggi[1], K. K. T. Chandrasekar[1], C. Yoon[2], B. Sawaryn[1], G. van de Steeg[1], D. H. Gracias[2] and S. Misra[1,3]
[1]University of Twente, The Netherlands [2]The Johns Hopkins University, USA
[3]University of Groningen and University Medical Center Groningen, The Netherlands

- We demonstrate the wireless magnetic motion control and planning of soft untethered grippers.
- The grippers are visualized using B-mode ultrasound images.
- The grippers are controlled at an average position tracking error of: 0.4 mm without payload; 0.36 mm when the agent performs a transportation task.



Soft Robotics 4

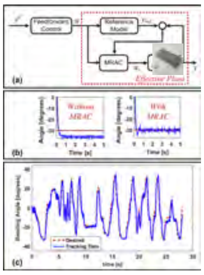
Chair *Stefano Scheggi, University of Twente*
Co-Chair *Ryuma Niiyama, University of Tokyo*

16:40–16:45	ThC1.7

Adapting to Flexibility: Model Reference Adaptive Control of Soft Bending Actuators

Erik H Skorina, Ming Luo, Weijia Tao, Fuchen Chen, Jie Fu, Cagdas D Onal
WPI Soft Robotics Lab, WPI, USA

- We applied MIT Rule Model Reference Adaptive Control (MRAC) to a series of soft bending actuators
- MRAC allowed different actuators to behave similarly to a simple reference model, but could overshoot
- An inverse dynamic controller enabled reliable position tracking by proprioceptive feedback
- We showed the usability of our approach on tracking unstructured reference angles provided by an operator in real time.

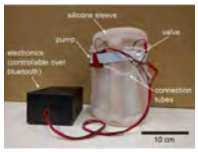


16:45–16:50	ThC1.8

JammJoint: A variable stiffness device based on granular jamming for wearable joint support

Simon Hauser and Auke Ijspeert
Biorobotics Laboratory, EPFL, Switzerland
Matthew Robertson and Jamie Paik
Reconfigurable Robotics Laboratory, EPFL, Switzerland

- Wearable, portable and autonomous, controlled over bluetooth with a smartphone
- Stiffness variation through jamming of compliant granules by creating vacuum pressure with a miniature pump
- Up to fourfold increase in stiffness of the full device, up to sevenfold increase for subelements
- Powerless pressure level holding, multimodal, highly adaptable and safe to use


JammJoint device

Motion and Path Planning 5

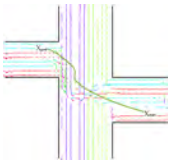
Chair *Nicholas Robert Jonathon Lawrance, Oregon State University*
Co-Chair *Kai Oliver Arras, University of Freiburg*

16:10–16:15	ThC2.1

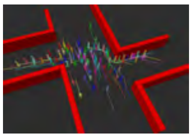
Kinodynamic Motion Planning on Gaussian Mixture Fields

Luigi Palmieri[1,2], Tomasz P. Kucner[3], Martin Magnusson[3], Achim J. Lilienthal[3], Kai O. Arras[1]
Robert Bosch GmbH[1], Albert-Ludwigs-Universität Freiburg[2], Örebro universitet[3]

- We present a mobile robot motion planning approach under kinodynamic constraints that informs and focuses its search by exploiting learned perception priors in the form of Gaussian mixture fields
- We use a circular linear flow field (CLiFF) map based on semi-wrapped Gaussian mixtures to learn the multi-modal motion models of discrete objects or continuous media (e.g. dynamics of air or pedestrian flows)
- The CLiFF map guides sampling and rewiring of an optimal sampling-based motion planner
- The planner is faster and generates smoother and shorter solutions than the baselines, as well as natural yet minimum control effort motions through multi-modal representations of Gaussian mixture fields



Example path computed (see figure above) through a CLiFF map field that represents a pedestrian flow (see figure below)



16:15–16:20	ThC2.2

UB-ANC Planner: Energy Efficient Coverage Path Planning with Multiple Drones

Jalil Modares*, Farshad Ghanei**
Nicholas Mastronarde* and Karthik Dantu**
*Department of Electrical Engineering, University at Buffalo, USA
**Department of Computer Science and Eng., University at Buffalo, USA

- From experimental measurements, we develop a linear model for energy consumption during drone flight.
- Using this model, we formulate the EECPP problem and show that it is NP-hard.
- We decompose the EECPP problem into two sub-problems: a load-balancing problem and a MEPP problem.
- We adapt heuristics proposed for solving the TSP to efficiently solve the MEPP sub-problem.

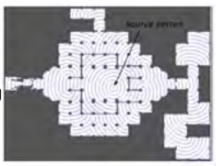
UB North Campus.

16:20–16:25	ThC2.3

CWave: High-Performance Single-Source Any-Angle Path Planning on a Grid

Dmitry A. Sinyukov
Robotics Engineering Program, Worcester Polytechnic Institute, USA
Taşkın Padır
Electrical and Computer Engineering, Northeastern University, USA

- Abandon graph model of the grid, use discrete geometric primitives to represent the wave front
- Efficient Bresenham's algorithms to iterate vertices
- Result: single-source any-angle path planning algorithm that uses only integer addition and bit shifting
- Speed: significantly faster than alternatives
- Accuracy: 0.75 cell width non-accumulative distance error

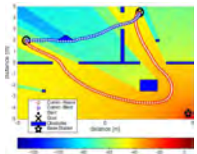


16:25–16:30	ThC2.4

COMMUNICATION-AWARE MOTION and BEAMFORMING in CLUTTERED SPACES

Waqas Afzal and Ahmad Masoud
Electrical Engineering Department, King Fahd Univ. Of Petroleum & Minerals, Saudi Arabia

- This work introduces an optimal communication-aware Navigation control based on Harmonic Potential Fields.
- Avoidance of dead communication zones and physical obstacles is guaranteed.
- Beam-forming is employed at the base-station using future knowledge of the agent's position.
- Technique works for mobile agents with nontrivial dynamics and is extendible to sensor-based navigation where SNR is acquired online.



Comm.-Aware & Comm.-Blind navigation in a cluttered space.

16:30–16:35	ThC2.5

PiPS: Planning in Perception Space

Justin Smith and Patricio Vela
School of Electrical and Computer Engineering, Georgia Tech, USA

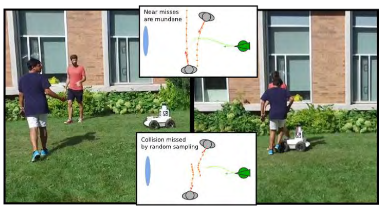
- A perception space approach for reactive obstacle avoidance using depth cameras
- Synthesizes depth images of hallucinated robots following candidate trajectories
- Performs collision checking by comparing actual and synthesized depth images
- Approach validated on obstacle course

Trajectories tested by hallucinated robots

16:35–16:40	ThC2.6

Fast discovery of influential outcomes for risk-aware MPDM

Dhanvin Mehta Gonzalo Ferrer Edwin Olson
CSE Dept., University of Michigan Ann Arbor, USA



MPDM conventionally used random sampling, which may miss high-cost configurations that result in collisions.

In this paper, we bias sampling to discover likely high-cost outcomes.

Motion and Path Planning 5

Chair *Nicholas Robert Jonathon Lawrance, Oregon State University*
Co-Chair *Kai Oliver Arras, University of Freiburg*

16:40–16:45 ThC2.7

Online Inspection Path Planning for Autonomous 3D Modeling using a Micro-Aerial Vehicle

Soohwan Song and Sungho Jo
School of Computing, Korea Advanced Institute of Science and Technology, Republic of Korea

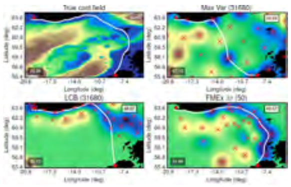
- Novel algorithm for planning exploration paths to generate 3D models of unknown environments by using MAV.
- Propose an online inspection algorithm that consistently provides an optimal coverage path toward a Next-Best-View.
- The online algorithm can improve the exploration performance and modeling quality.

16:45–16:50 ThC2.8

Fast Marching Adaptive Sampling

Nicholas Lawrance, Jen Jen Chung and Geoffrey Hollinger
Mechanical, Industrial and Manufacturing Engineering, Oregon State University, USA

- Goal is to find low-cost routes over a continuous cost field with a limited sampling budget
- Samples are selected by estimating the expected path cost change for proposed sample locations
- Field is modeled using Gaussian process regression
- A novel fast marching update method provides efficient path cost estimates



Adaptive sampling to find the lowest-cost route for a submarine cable

Vision and Range Sensing 3

Chair *Pratap Tokekar, Virginia Tech*
Co-Chair *Lino Marques, University of Coimbra*

16:10–16:15	ThC3.1

Modelling Scene Change for Large-Scale Long Term Laser Localisation

Dan Withers and Paul Newman
Oxford Robotics Institute, University of Oxford, UK

- Our maps are full of junk because the environment is dynamic.
- The artifacts caused by dynamic elements of the scene can cause disastrous localisation failure.
- Can we leverage multiple experiences to model the reliable elements of our map?
- Absolutely!


Urban distractions are common

16:15–16:20	ThC3.2

Robust Localization and Localizability Analysis with a Rotation Laser Scanner

Weikun Zhen,Sam Zeng and Sebastian Scherer
Department Name, University Name, Country

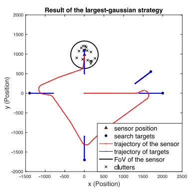
- ESKF localization is able to provide robust real-time state estimation for a 2D rotating laser scanner
- 3D localizability estimation is able to predict robot poses that may result in localization failure

16:20–16:25	ThC3.3

Algorithm for Searching and Tracking an Unknown and Varying Number of Mobile Targets using a Limited FoV Sensor

Yoonchang Sung and Pratap Tokekar
Electrical and Computer Engineering, Virginia Tech, USA

- We address the problem of searching and tracking a collection of moving targets.
- The actual number of targets is unknown and varying with false positive measurements.
- We propose a Gaussian mixture probability hypothesis density filter that allows for simultaneous search and tracking.
- We show how to estimate target trajectories using Gaussian process regression.



Search and rescue simulation

16:25–16:30	ThC3.4

Consistent Map-based 3D Localization on Mobile Devices

Ryan C. DuToit[1], Joel A. Hesch[2], Esha D. Nerurkar[2], and Stergios I. Roumeliotis[1]
[1]MARS Lab., University of Minnesota, [2]Google Inc.

- **Objective:** *Consistently* localize within a prior map, using visual and inertial meas/nts on mobile devices (e.g., cell phones)
- **Approach:** Re-derive the *Schmidt-Kalman filter* to consider the map's *sparse Cholesky* factor instead of its dense covariance
- **Contributions:**
  i) Real-time, high accuracy, consistent VINS localization w/ sub-maps
  ii) Consistent map partitioning and efficient Cholesky factor sparsification

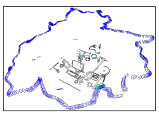

Map-based VINS localization (lower left insert shows current image)

16:30–16:35	ThC3.5

Semi-Dense Visual Odometry for RGB-D Cameras Using Approximate Nearest Neighbour Fields

Yi Zhou, Laurent Kneip and Hongdong Li
Research School of Engineering, Australian National University, Australia

- Introducing the idea of approximate nearest neighbor field, which permits the use of compact Gauss-Newton updates in the registration.
- Exploring the optimal robust weight function for the probabilistically formulated, 2D-3D semi-dense ICP.
- A real-time implementation running at 25 Hz on a laptop using only CPU resources.

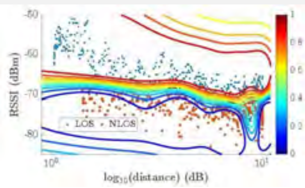

An illustration of the proposed semi-dense visual odometry.

16:35–16:40	ThC3.6

Gaussian Processes Online Observation Classification for RSSI-based Low-cost Indoor Positioning Systems

Maani Ghaffari Jadidi[1], Mitesh Patel[2], and Jaime Valls Miro[1]
[1]University of Technology Sydney, Australia
[2]FX Palo Alto Laboratories Inc., Palo Alto, USA

- We propose a real-time classification scheme to cope with noisy Radio Signal Strength Indicator measurements utilized in indoor positioning systems.
- The proposed method is particularly simpler and more scalable than the popular fingerprinting technique as the training phase is in the sensor space instead of spatial coordinates of an environment.



Vision and Range Sensing 3

Chair *Pratap Tokekar, Virginia Tech*
Co-Chair *Lino Marques, University of Coimbra*

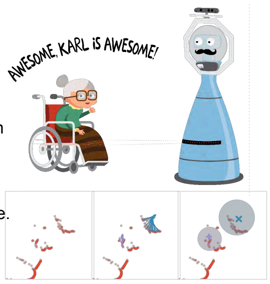
16:40–16:45	ThC3.7

DROW: Real-Time Deep Learning based Wheelchair Detection in 2D Range Data

Lucas Beyer*, Alexander Hermans*, Bastian Leibe
Visual Computing Institute, RWTH Aachen University, Germany

- We show how to do detection in 2D range data with deep learning.
- Naïve application doesn't work, we explain the pitfalls and show how to overcome these.
- Our detector runs at laser frame rate on a mobile robot and obtains state of the art results.
- We release a large annotated dataset, training code, and a detector ROS node.

`github.com/VisualComputingInstitute/DROW`



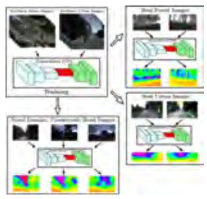
* Equal contribution

16:45–16:50	ThC3.8

Towards Domain Independence for Learning-based Monocular Depth Estimation

Michele Mancini, Gabriele Costante,
Paolo Valigi and Thomas A. Ciarfuglia
Department of Engineering, University of Perugia, Italy
Jeffrey Delmerico and Davide Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland

- We introduce a monocular depth estimation approach that is able to generalize among different scenarios.
- We propose two deep architectures based on Fully Convolutional and Long Short Term Memory paradigms.
- We train our networks with synthetic datasets to avoid expensive data collection processes.
- Domain indipendence is evaluated with respect to three real and etherogeneous environments.



SLAM 5

Chair *Shaohui Foong, Singapore University of Technology and Design*
Co-Chair *Margarita Chli, ETH Zurich*

16:10–16:15	ThC4.1

Find Your Way by Observing the Sun and Other Semantic Cues

Wei-Chiu Ma[1], Shenlong Wang[2], Marcus A. Brubaker[3], Sanja Fidler[2], and Raquel Urtasun[2]
[1]CSAIL, MIT; [2]DCS, U Toronto; [3]EECS, York University

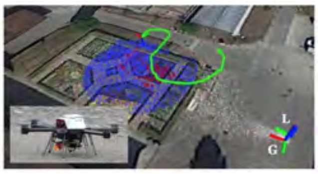
- An automatic pipeline to generate ground truths for various tasks in autonomous driving
- An affordable and robust approach to self-localization using map and semantic cues
- Comparing to prior work, we localize faster, are more robust, and require less computation time

16:15–16:20	ThC4.2

Robust Visual-Inertial Localization with Weak GPS Priors for Repetitive UAV Flights

Julian Surber, Lucas Teixeira, Margarita Chli
Vision for Robotics Lab, ETH Zurich, Switzerland

- Pipeline to build a Reference Map of the aircraft's environment during a reconnaissance flight using monocular & inertial cues.
- In subsequent flights, the UAV's pose in this Map gets estimated via geometric image-based localization & keyframe-based odometry.
- Evaluation on numerous outdoor flights against ground truth, reveals real-time localization eliminating drift and robustness to scene changes.



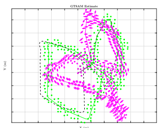
This system allows a UAV to localize accurately within a geo-referenced map that is built during a reconnaissance flight

16:20–16:25	ThC4.3

RFM-SLAM: Exploiting Relative Feature Measurements to Separate Orientation and Position Estimation in SLAM

Saurav Agarwal
Aerospace Engineering, Texas A&M University, USA
Vikram Shree
Aerospace Engineering, IIT Kanpur, India
Suman Chakravorty
Aerospace Engineering, Texas A&M University, USA

- Extends two-step orientation and position estimation to 2D feature-based SLAM
- Enhances robustness to bad initial guess in non-linear optimization
- Reduces computational burden, solves N variables vs. 3N + 2L in standard approach
- Accuracy degrades gracefully as sensor noises increase



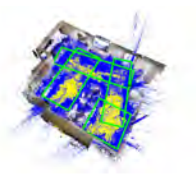
Problem: Existing solvers may suffer from local minima due to bad initial guess

16:25–16:30	ThC4.4

Room Layout Estimation from Rapid Omnidirectional Exploration

Robert Lukierski, Stefan Leutenegger and Andrew J. Davison
Department of Computing, Imperial College London, United Kingdom

- Geometric room understanding from a brief, preferably circular, motion of the robot,
- fitting a box model to the omnidirectional depth map (from dense passive monocular MVS),
- differentiable renderer based, robust,
- Boolean union of boxes estimated during active exploration creates floorplan-like map,
- extensive experimental verification on synthetic, office and residential environment datasets.



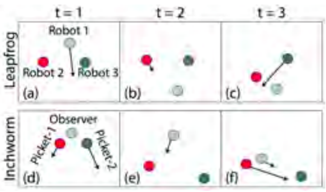
Example of operation: blue – point clouds, green – estimated boxes, yellow – recovered floorplan.

16:30–16:35	ThC4.5

Cooperative Inchworm Localization with a Low Cost Team

Brian Nemsick, Austin Buchan, Anusha Nagabandi, Ronald Fearing, and Avideh Zakhor
Electrical Engineering and Computer Science, UC Berkeley, USA

- 6 DOF localization of a heterogeneous robot team with no landmarks or visual features
- Single observer robot with a monocular webcam and IMU
- Multiple picket robots with RGB LED markers and IMU



Our inchworm approach is shown on the bottom.

16:35–16:40	ThC4.6

SLAMinDB: Centralized graph databases for mobile robotics

D. Fourie, S. Pillai, R. Mata, J. Leonard
MIT and WHOI, Massachusetts, USA
Sam Claassens
General Electric, Chicago, USA

- Random querying across SLAM-aware data;
- Online operation with many agents;
- Access to more powerful computation for robust navigation type inference;
- Towards 'dreaming robots';
- Multi-modal iSAM;
- Allows separation of concerns.

Centralizing robot navigation, data storage & broader inference.

SLAM 5

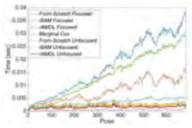
Chair *Shaohui Foong, Singapore University of Technology and Design*
Co-Chair *Margarita Chli, ETH Zurich*

16:40–16:45	ThC4.7

Computationally Efficient Belief Space Planning via Augmented Matrix Determinant Lemma and Re-Use of Calculations

Dmitry Kopitkov and Vadim Indelman
Technion - Israel Institute of Technology, Israel

- An **exact** approach with per-candidate complexity **independent** of state dimensionality:
  - **Augmented Matrix Determinant Lemma** to reduce problem dimensions
  - **Calculation re-use** between impact evaluation of different actions
- **Applicable** to SLAM, autonomous navigation, etc.



16:45–16:50	ThC4.8

Word Ordering and Document Adjacency for Large Loop Closure Detection in 2D Laser Maps

Jérémie Deray
IRI, CSIC-UPC & PAL Robotics, Spain
Joan Solà and Juan Andrade-Cetto
IRI, CSIC-UPC, Spain

- Bag-of-Words based 2D Laser Scan Loop Closure.
- Leveraging the 1D ordering of features in documents comparison.
- Emphasizing feature frequency with document adjacency inferred from the SLAM graph topology.

Aerial Robot 7

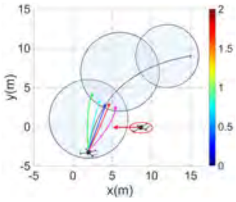
Chair *Vijay Kumar, University of Pennsylvania*
Co-Chair *Shaojie Shen, Hong Kong University of Science and Technology*

16:10–16:15	ThC5.1

Quadrotor Trajectory Generation in Dynamic Environments Using Semi-Definite Relaxation on Nonconvex QCQP

Fei Gao and Shaojie Shen
Dept. of ECE, Hong Kong University of Science and Technology,
Hong Kong S.A.R.

- A generalized nonconvex QCQP formulation for quadrotor trajectory generation in dynamic environments.
- Trajectory bounding in L2 norm flight corridor and collision avoidance with moving objects using motion prediction.
- Detailed solving procedure using semi-definite relaxation (SDR) and randomization techniques.
- Experiment and simulation validation.



Trajectories vs. velocities of the moving obstacle

16:15–16:20	ThC5.2

Aerial Grasping of Cylindrical Object using Visual Servoing based on Stochastic MPC

Hoseong Seo, Suseong Kim, and H. Jin Kim
Mechanical and Aerospace Engineering,
Seoul National University, Korea

- Objective : Grasping a beverage can using an aerial manipulator
- Image-based cylindrical object detection algorithm utilizes geometric characteristic of perspectively projected circles.
- By considering some rotational velocities as random variables, visual servoing problem is formulated as a stochastic MPC.

16:20–16:25	ThC5.3

CNN-based Single Image Obstacle Avoidance on a Quadrotor

Punarjay Chakravarty, Klaas Kelchtermans, Tom Roussel, Stijn Wellens, Tinne Tuytelaars and Luc Van Eycken
ESAT-PSI, KU Leuven, Belgium

- Real-time monocular depth estimation using CNNs
- Behaviour-arbitration based control
- Obstacle avoidance tests in both simulated and real environments


Manoeuvring drone in indoor environment

16:25–16:30	ThC5.4

Dynamic Decentralized Control for Protocentric Aerial Manipulators

Marco Tognon[1], Burak Yüksel[2] ,
Gabriele Buondonno[3] and Antonio Franchi[1]
[1]LAAS-CNRS, Université de Toulouse, CNRS, France
[2]Max Planck Institute for Biological Cybernetics, Tübingen, Germany
[3] Sapienza Universitá di Roma, Roma Italy

- **Controller based on differential flatness:**
  - *Feed forward* term considering the **full-body dynamics** computed by the differential flatness property
  - *Decentralized feedback* on each actuated degrees of freedom
- Precise tracking of **dynamic trajectories**
- Easy to implement on standard hardware

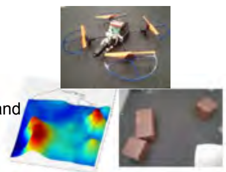
quasi-protocentric lightweight aerial manipulator used in the experiments

16:30–16:35	ThC5.5

Sequential Bayesian Optimisation as a POMDP for Environment Monitoring with UAVs

Philippe Morere, Roman Marchant and Fabio Ramos
School of Information Technologies, University of Sydney, Australia

- Non-myopic planning for informative path planning in monitoring applications
- Information gathered along trajectories improves belief building
- Monitoring behaviour balances exploration and exploitation using Bayesian Optimisation
- POMDP formulation enforces practical constraints and relieves myopia
- Demonstration on cheap UAV

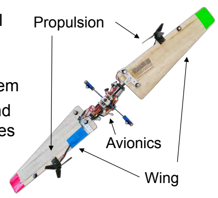

Mapping object height with cheap UAV

16:35–16:40	ThC5.6

Design and Dynamic Analysis of a Transformable HOvering Rotorcraft (THOR)

Jun En Low, Luke Thura Soe Win, Danial Sufiyan Bin Shaiful, Chee How Tan, Gim Song Soh and Shaohui Foong
Engineering Product Development Pillar,
Singapore University of Technology and Design, Singapore

- THOR is a novel hybrid UAV designed for seamless operation between efficient horizontal forward flight and agile hovering modes
- Design approach involves combining a tailless fixed wing with a dual-winged monocopter system
- THOR is structurally efficient with propulsion and aerodynamic surfaces fully utilized in both modes
- Transition between both flight modes achieved through active control of wing servos and can occur mid-flight
- Flight performance of both modes validated experimentally



THOR in hover flight mode
(Wings rotate to switch to forward flight mode)

Aerial Robot 7

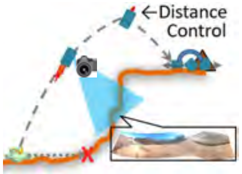
Chair *Vijay Kumar, University of Pennsylvania*
Co-Chair *Shaojie Shen, Hong Kong University of Science and Technology*

16:40–16:45 ThC5.7

Distance Control of Rocket-propelled Miniature Exploration Robot

Hiroki Kato, Nobutaka Tanishima, Keiichi Yanagase, Toshimichi Tsumaki, and Shinji Mitani
Japan Aerospace Exploration Agency (JAXA), Japan

- Rocket-propelled exploration robot for sites rovers cannot reach with efficiency in locomotion distance per mass
- Distance control strategy #1: Flight trajectory forming
- Distance control strategy #2: The flight trajectory prediction including the opposing shot



1. Long traverse by rocket engine
2. Precise distance control by opposing shot
3. Post-landing Inching rotational move by wheel braking force

16:45–16:50 ThC5.8

Estimation, Control and Planning for Aggressive Flight with a Small Quadrotor with a Single Camera and IMU

Giuseppe Loianno[1], Chris Brunner[2], Gary McGrath[2], and Vijay Kumar[1]
[1]University of Pennsylvania, USA
[2]Qualcomm Technologies Inc., USA

- Aggressive flight with a 20 cm diameter, 250 gram quadrotor with a single camera and an Inertial Measurement Unit
- Speeds of 5 m/s and accelerations of over 1.5 g
- Pitch angles of up to 90 degrees, and angular rate of up to 800 deg/s
- No required structure in the environment
- Planning of dynamically feasible 3-D trajectories for slalom paths and flights through narrow windows

The platform traversing a vertical narrow window gap

Probability and Statistical Methods

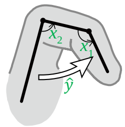
Chair *Juan Andrade-Cetto, CSIC-UPC*
Co-Chair *Takuya Funatomi, Nara Institute of Science and Technology*

16:10–16:15	ThC6.1

Regression of 3D Rigid Transformations on Real-Valued Vectors in Closed Form

Takuya Funatomi[1], Masaaki Iiyama[2], Koh Kakusho[3], and Michihiko Minoh[2]
[1]Nara Institute of Science and Technology, Japan
[2]Kyoto University, Japan [3]Kwansei Gakuin University, Japan

- Regression proposed in this paper maps $x \in \mathbb{R}^P$ to $\hat{y}$ in **3D rigid transformation**.
- We use unit dual quaternion $\hat{\mathbb{H}}$ to represent 3D rigid transformation and BCH approximation for solving in closed form. $\hat{y} = \exp(\tilde{x}^\top \log \hat{b})$
- Advantages: Simple, easy to implement, analytically solvable, and accurate prediction even from a small number of observations.



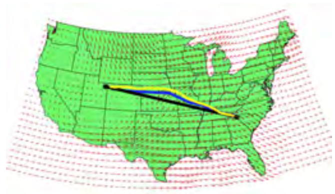
The regressor enables us to estimate 3D position of fingertip from joint angles without its skeleton.

16:15–16:20	ThC6.2

No-Regret Replanning under Uncertainty

Wen Sun[1], Niteesh Sood[2], Debadeepta Dey[2], Gireeja Ranade[2], Siddharth Prakash[2], Ashish Kapoor[2]
[1] Robotics Institute, Carnegie Mellon University, [2] Microsoft Research

1. Problem Definition: Online Receding-horizon Path Planning in Uncertain Environments.
2. Uncertainty is modeled by Gaussian Process (GP).
3. Leverage the state-of-the art in Multi-Armed Bandits literature to achieve *no-regret property* in online path planning.
4. Case study on aircraft navigating under wind uncertainty over the continental United States using real wind data from NOAA.



South Carolina to Utah (Head Wind)

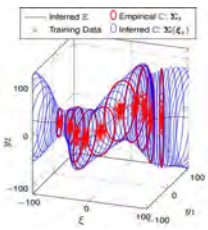
Our Upper Confidence Bound based algorithm (blue) travels much faster than Great Circle Rout (black) and a baseline that simply uses the mean of GPs (Yellow)

16:20–16:25	ThC6.3

Bayesian Uncertainty Modeling for Programming by Demonstration

Jonas Umlauft, Yunis Fanger, Sandra Hirche
Technical University of Munich, Germany

- Modeling of uncertainty and variability of training data important, e.g. for human demonstrations
- Bayesian approach, employs Wishart Processes and Cholesky decomposed covariance matrices
- Outperforms widely used Gaussian Mixture Models
- Successfully application to adaptive stiffness control in Programming by Demonstration

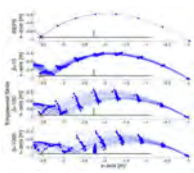


16:25–16:30	ThC6.4

Empowered Skills

Alexander Gabriel, Riad Akrour and Jan Peters
CLAS / IAS, TU Darmstadt, Germany
Gerhard Neumann
L-CAS, University of Lincoln, England
CLAS, TU Darmstadt, Germany

- A new Reinforcement Learning Algorithm that combines intrinisc and extrinsic motivation
- Balances reward and outcome entropy to learn diverse policies
- Introduces Outcomes – Interesting aspects of the sensorimotor space
- Demonstrated on simulated Reaching and Robot Table Tennis Tasks



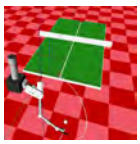
Diverse trajectories learned by our algorithm

16:30–16:35	ThC6.5

Layered Direct Policy Search for Learning Hierarchical Skills

Felix End, Riad Akrour and Jan Peters
CLAS / IAS, TU Darmstadt, Germany
Gerhard Neumann
L-CAS, University of Lincoln, England
CLAS, TU Darmstadt, Germany

- The paper presents a new Hierarchical Reinforcement Learning Approach called Layered Direct Policy Search (LaDiPS)
- LaDiPS not only uses a hierarchical policy but also a hierarchical learning process
- It learns multiple solutions (e.g. forehand and backhand strokes for table tennis)
- Demonstrated on Simulated Table Tennis Task



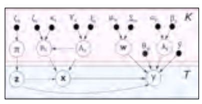
Learned Forehand stroke on Simulated Table Tennis Task

16:35–16:40	ThC6.6

On-line Bayesian Regression Mixture Model for Robot Model Learning

Sooho Park and Junlin Wang
Mechanical Engineering, Carnegie Mellon University, USA
Kenji Shimada
Mechanical Engineering, Carnegie Mellon University, USA

- Gaussian Regression Mixture Model (GRMM)
- Model learning with mixture model of local Gaussian experts
- Efficiency with locality
- On-line local model size management
- Forgetting strategy
- Online outlier non-stationary system handling



Graphical Model of GRMM

Probability and Statistical Methods

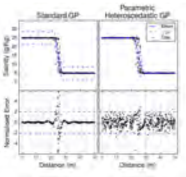
Chair *Juan Andrade-Cetto, CSIC-UPC*
Co-Chair *Takuya Funatomi, Nara Institute of Science and Technology*

16:40–16:45 ThC6.7

Active Sample Selection in Scalar Fields Exhibiting Non-Stationary Noise with Parametric Heteroscedastic Gaussian Process Regression

Troy Wilson and Stefan Williams
Australian Centre for Field Robotics, The University of Sydney, Australia

- Location dependent noise breaks a key assumption of Gaussian Processes (GPs) causing errors in predicted variance
- Heteroscedastic GPs can correct this issue
- Parameterising this noise allows faster computation than variational methods whilst also providing transferable parameters
- Active sample selection is examined with reference to a simulated salinity front
- Mutual Information driven sampling is shown to produce lower errors than other standard information measures.



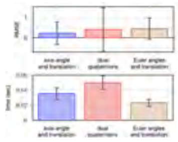
Comparison of predicted standard deviation and normalised errors between standard and parametric heteroscedastic GP

16:45–16:50 ThC6.8

Computationally Efficient Rigid-body Gaussian Process for Motion Dynamics

Muriel Lang and Sandra Hirche
Chair of Information-oriented Control, Department of Electrical and Computer Engineering, Technical University of Munich, Germany

- Learning and predicting motion dynamics in the special Euclidean group *SE(3)*
- 6 DoF pose representation using axis-angle for rotation and Euclidean vector for translation
- Generalization of GP to input domain in non-Euclidean space mathematically rigorous
- Generalized squared exponential kernel proven to be computational efficient and accurate in simulation and on real data


Accuracy and runtime comparison of GP variants

Calibration and Identification

Chair *Alireza Khosravian, University of Adelaide*
Co-Chair *Shabbir Kurbanhusen Mustafa, Singapore Institute of Technology*

16:10–16:15	ThC7.1

Modeling of Rolling Friction by Recurrent Neural Network using LSTM

Noriaki Hirose and Ryosuke Tajima
TOYOTA Central R&D Labs., INC., Japan

- Modeling of Rolling Friction by Recurrent Neural Network(RNN) using LSTM
- Initial Value Design to the internal memory in RNN for mini-batch training
- 6 times more precise model than the conventional model in test data
- This precise model can be used to achieve sensorless force estimation using disturbance observer, precise positioning and so on.

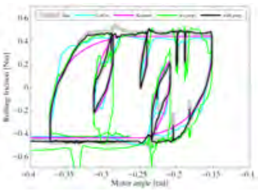


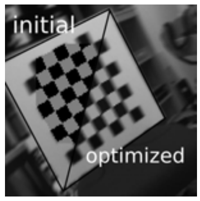
Fig. rolling friction model

16:15–16:20	ThC7.2

A Direct Formulation for Camera Calibration

Joern Rehder, Janosch Nikolic,
Thomas Schneider, and Roland Siegwart
Autonomous System Lab, ETH Zurich, Switzerland

- Our work introduces **geometric camera calibration based on image intensities** instead of keypoint positions
- This approach facilitates a correct treatment of uncertainties and measurement timestamps
- It enables the estimation of **exposure time from motion blur** and **extends intuitively to rolling-shutter cameras**

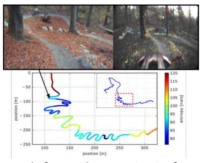


16:20–16:25	ThC7.3

Visual-inertial Self-calibration on Informative Motion Segments

T. Schneider, M. Burri, J. Nieto, R. Siegwart, I. Gilitschenski
Autonosmous Systems Lab, ETH Zurich, Switzerland
Mingyang, Li
Google Inc., USA

- Visual-inertial self-calibration formulation – no target required
- Selection of informative motion segments to sparsify calibration problem
- Insignificant deviation from the full batch solution that uses all data
- Run-time improvements by a factor of 5-10 as compared to full-batch and related work



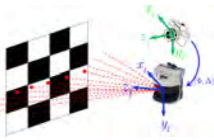
Information content of mountain bike dataset

16:25–16:30	ThC7.4

A Branch-and-Bound Algorithm for Camera-Laser Calibration

Alireza Khosravian, Tat-Jun Chin, Ian Reid
School of Computer Science, University of Adelaide, Australia

- Extrinsic calibration of a camera to a 2D/3D laser range finder using planar checkerboards.
- Checkerboard extraction: detecting the laser points that fall on the checkerboards before proceeding to the camera-laser calibration.
- A Branch-and-Bound technique for robust checkerboard extraction is proposed.
- The proposed technique is applicable robustly in all practical conditions without relying on stationary background or range discontinuities.



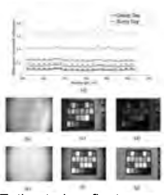
Estimating the constant trasformation between a camera and a laser range finder.

16:30–16:35	ThC7.5

On Field Radiometric Calibration for Multispectral Cameras

Raghav Khanna, Inkyu Sa, Juan Nieto and Roland Siegwart
Autonomous Systems Lab, ETH Zürich, Switzerland

- Three step calibration procedure to obtain reflectance images from grayscale, color and multispectral cameras.
- Does not require homogenous illumination conditions or specialized lab equipment.
- Parameter free representation makes it easy to use for non-experts without prior knowledge of camera and lens properties.
- All calibration data may be acquired on field enabling in situ changes in camera configuration.



Estimated reflectance of standard reflectors with our method under a variety of conditions compare well to known values.

16:35–16:40	ThC7.6

Discrete-time Dynamic Modeling and Calibration of Differential-Drive Mobile Robots with Friction

Jong Jin Park
Amazon Robotics, USA
Seungwon Lee[1] and Benjamin Kuipers[2]
EECS[1] and CSE[2], University of Michigan, USA

- We present a simple, fast (10^5 x real-time), accurate, and easy-to-calibrate dynamic model for a jerk-controlled mobile robot on planar surface.
- Using a discrete-time Coulomb friction model, we can accurately predict deadbands and steady-states, and our velocity predictions do not drift.
- Our model is extremely easy to implement, and calibration only requires time-series of wheel speed measurements.

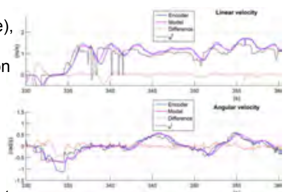


Fig. Example velocity predictions (magenta) after 6 minutes only using measurement (blue) at t=0. There is no asymptotic drift.

Calibration and Identification

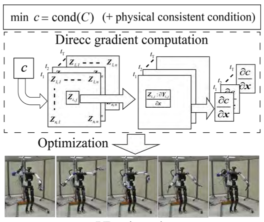
Chair *Alireza Khosravian, University of Adelaide*
Co-Chair *Shabbir Kurbanhusen Mustafa, Singapore Institute of Technology*

16:40–16:45 ThC7.7

Generating persistently exciting trajectory based on condition number optimization

Ko Ayusawa[1], Antoine Rioux[1], Eiichi Yoshida[1], Gentiane Venture[1,2], and Maxime Gautier[3]
[1]CNRS-AIST JRL, Japan, [2] Tokyo University of Agriculture and Technology, Japan, [3]University of Nantes/LS2N, France

- An optimization method for generating persistently exciting trajectories for dynamics identification is presented.
- The gradient of the condition number of the regressor w.r.t. joint trajectories is mathematically formulated.
- The method is especially useful for a large-DOF robot with physical consistent conditions.
- Several PE trajectories of humanoid robot HRP-4 are generated.



PE trajectories

16:45–16:50 ThC7.8

Drift-Correcting Self-Calibration for Visual-Inertial SLAM

Fernando Nobre, Michael Kasper and Christoffer Heckman
Department of Computer Science, University of Colorado at Boulder, USA

- Self-Calibrating visual-inertial SLAM system
- Calibrates camera intrinsics and extrinsics
- Continuous online calibration without use of marginalization
- Detects and corrects drift in calibration parameters over long term operation


Experimental Platform

Human Factors 2

Chair *Joel Burdick, California Institute of Technology*
Co-Chair *Dongheui Lee, Technical University of Munich*

16:10–16:15	ThC8.1

Enabling Independent Navigation for Visually Impaired People through a Wearable Vision-Based Feedback System

Hsueh-Cheng Wang*[,1,2], Robert K. Katzschmann*[,1], Santani Teng[1], Brandon Araki[1], Laura Giarré[3], Daniela Rus[1]
*H. Wang and R. Katzschmann contributed equally to this work.
[1]Computer Science and Artificial Intelligence Laboratory (CSAIL), MIT, USA.
[2]Department of ECE, National Chiao Tung University, Taiwan.
[3]DEIM, Università di Palermo, Italy.

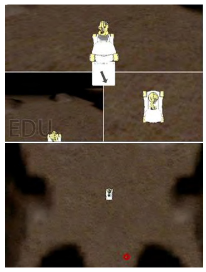
- This work introduces a wearable system to provide situational awareness for blind and visually impaired people.
- The system is designed to (1) identify walkable space; (2) plan step-by-step a safe motion in the space, and (3) recognize and locate certain types of objects, for example the location of an empty chair.
- We present results from user studies with low- and high-level tasks, including walking through a maze without collisions, locating a chair, and walking through a crowded environment while avoiding people.

16:15–16:20	ThC8.2

Using Multisensory Cues for Direction Information in Teleoperation: More Is Not Always Better

Tobias Benz and Verena Nitsch
Human Factors Institute, University of the Bundeswehr Munich, Germany

- Multi-modal feedback (auditory, haptic, visual and their combinations) is used to present direction information
- Localization accuracy is highest for visual feedback and its combinations followed by haptic and auditory feedback
- Auditory-haptic feedback leads to higher accuracy than auditory feedback, but lower accuracy than haptic feedback
- Order of modality attendance may influence sensory perception

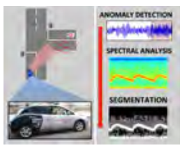


16:20–16:25	ThC8.3

Leveraging the Urban Soundscape: Auditory Perception for Smart Vehicles

Letizia Marchegiani and Ingmar Posner
Oxford Robotics Institute, University of Oxford, United Kingdom

- we propose a framework to detect specific acoustic events (e.g. **sirens**) in driving scenarios
- we use **anomaly detection** techniques to spot the presence of acoustic events
- we perform **spectrogram segmentation** to isolate the acoustic events from the copious background noise
- noise removal yields more accurate acoustic event classification compared to traditional feature representations



16:25–16:30	ThC8.4

ICRA 2017 Digest Template Paper Title in One or Two Lines

FirstName LastName and FirstName LastName
Department Name, University Name, Country
FirstName LastName
Department Name, University Name, Country

- Digest must be prepared and submitted in **MS PowerPoint** (no other file format accepted)
- Use Arial 28pt font in bold face for the title
- Use Arial 24pt font for the authors and Arial 20pt font their ***brief*** affiliations
- 3 or 4 bullet points (limit each to ***less than 15*** words in Arial 20pt font), ***only*** 1 figure is allowed (replace the figure to the right with your figure)

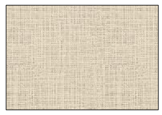


Figure caption is optional, use Arial 18pt

16:30–16:35	ThC8.5

Clinical Patient Tracking in the Presence of Occlusions via Geodesic Feature

Kun Li and Joel W. Burdick
Department of Mechanical and Civil Engineering, California Institute of Technology, USA

- Construct a surface mesh for each human body.
- Describe a mesh node with Geodesic Feature, i.e., the node's geodesic distances to several anchoring nodes.
- The feature is invariant to pose changes and mild surface deformations.
- A multi-hypothesis framework is adopted to handle transient occlusions.

16:35–16:40	ThC8.6

Correcting Robot Mistakes In Real Time Using EEG Signals

Andres F. Salazar-Gomez*, Joseph DelPreto†, Stephanie Gil†, Frank H. Guenther*, and Daniela Rus†
* Guenther Lab, Boston University, United States
† Distributed Robotics Lab, MIT, United States

- Allow detection of robot mistakes in real time using naturally occurring human brain activity
- Detect Error-Related Potentials (ErrPs) in real time and use them in a closed feedback loop
- A robot performing a binary reaching task immediately corrects itself if an ErrP is detected
- Secondary errors occur if the system misclassifies ErrPs, and using these can boost performance accuracy

An object-sorting robot receives feedback via EEG

Human Factors 2

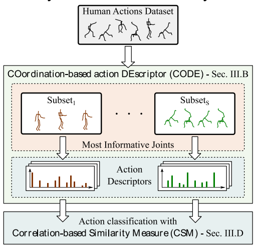
Chair *Joel Burdick, California Institute of Technology*
Co-Chair *Dongheui Lee, Technical University of Munich*

16:40–16:45	ThC8.7

A Human Action Descriptor based on Motion Coordination

Pietro Falco, Matteo Saveriano, Nicholas H. Kirk, Dongheui Lee
Chair of Automatic Control, Technical University of Munich, Germany
Eka Gibran Hasany
Department of Informatics, Technical University of Munich, Germany

- CODE is a COordination-based action DEscriptor to classify human actions
- To discriminate actions, CODE exploits the differences in body coordination, more than in joint angle trajectories
- CODE is tested on two public motion datasets (HDM05 and MHAD)

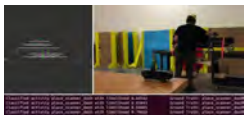


16:45–16:50	ThC8.8

Interpretable Models for Fast Activity Recognition and Anomaly Explanation During Collaborative Robotics Tasks

Bradley Hayes and Julie A. Shah
CSAIL, MIT, United States

- We introduce RAPTOR, an object-oriented, ensemble of Gaussian Mixture Models classifier.
- Achieves state-of-the-art activity recognition using easily computed features
- Highly parallel classifier architecture allows for real-time execution and resilience to temporal variation in demonstrations.
- Provides explanations for (mis)classified activities through outlier identification.



Online activity recognition during an automotive final assembly task

Micro/Nano Robots 2

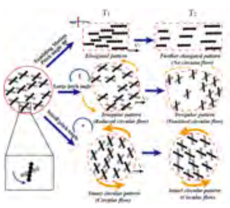
Chair *Metin Sitti, Max-Planck Institute for Intelligent Systems*
Co-Chair *Fumihito Arai, Nagoya University*

16:10–16:15	ThC9.1

Mobile Paramagnetic Nanoparticle-based Vortex for Targeted Cargo Delivery in Fluid

Jiangfan Yu, Dongdong Jin and Li Zhang
Mechanical and Automation Engineering,
The Chinese University of Hong Kong, Hong Kong

- The generation process of the paramagnetic nanoparticle-based vortex is modeled and characterized.
- The mobile vortex has different motion modes with the change of pitch angle, and the particle chains can reach stable synchronized motion with a small pitch angle.
- Batch transportation of non-magnetic cargos into a microchannel is demonstrated.

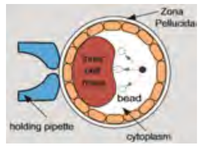


16:15–16:20	ThC9.2

Robotic Control of a 5 μm Magnetic Bead for Intra-Embryonic Navigation and Measurement

Xian Wang, Mengxi Luo, Han Wu, Zhuoran Zhang, Jun Liu, Zhensong Xu, Wesley Johnson, Yu Sun
Dept. of Mechanical & Industrial Engineering, University of Toronto, Canada

- Three-dimensionally positioning of a 5 μm magnetic bead inside a mouse embryo
- Force application up to 120 pN with a resolution of 1.78 pN
- Force calibration through deforming an calibrated AFM cantilever
- Quantified the inhomogeneity of mechanical properties of embryo inner cell mass



16:20–16:25	ThC9.3

Velocity characterization and control strategies for nano-robotic systems based on piezoelectric stick-slip actuators

Shuai Liang[1], Mokrane Boudaoud[1], Barthélemy Cagneau[2] and Stéphane Régnier[1]
1 Sorbonne Universités, UPMC University Paris 06, UMR 7222, ISIR, F-75005 Paris, France.
2 Université de Versailles St-Quentin en Yvelines / LISV, 10-12 Avenue de l'Europe, 78140, France.

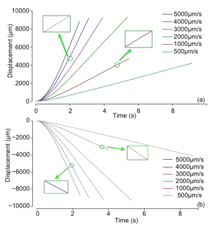
The work deals with velocity characterization and control strategies for nano-robotic systems using PSS actuators.

An analysis and a characterization of the achievable velocities for this class of actuators is performed.

The velocity characteristic curve is used as a basis for the definition of the range of input velocity references that can be used for the control.

Control strategies are studied in terms of stability and tracking capabilities.

Experimental demonstration of velocity control for PSS actuators in medium and high speed configurations.



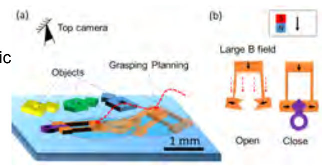
Experimental results of the displacement of the stick-slip actuator with the closed loop instantaneous velocity control. (a) Displacement in forward direction. (b) Displacement in backward direction.

16:25–16:30	ThC9.4

Planning Spin-Walking Locomotion for Automatic Grasping of Microobjects by An Untethered Magnetic Microgripper

Xiaoguang Dong[1,2] and Metin Sitti[1,2]
[1]Max Planck Institute for Intelligent Systems, Stuttgart, 70569, Germany
[2]Department of Mechanical Engineering, Carnegie Mellon University, USA

- We propose a new spin-walking locomotion and an automated 2D grasping motion planner allowing precise and time-efficient automatic grasping of microobjects that has not been achieved yet for untethered microrobots.
- The motion planner could plan different motion primitives for grasping and compensate the uncertainties in the motion by learning the uncertainties and planning accordingly.



Concept of automatic grasping of microobjects by planning the motion of an untethered magnetic microgripper.

16:30–16:35	ThC9.5

Optimization of tail geometry for the propulsion of soft microrobots

Hen-Wei Huang, Qianwen Chao, Mahmut Selman Sakar, and Bradley J. Nelson
Institute of Robotics and Intelligent Systems, ETH Zurich, Switzerland

- Soft microrobots with various body plans are fabricated through self-folding origami.
- Flexibility enhances overall motility of the soft microrobots through a synergistic propulsion by the tubular body and the flagellum.
- A simple model based on resistive force theory explains the direction-dependent changes in swimming motility and the role of tail geometry.

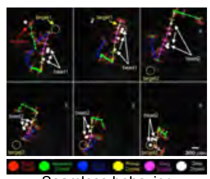
Soft microrobots with various body plans performing different locomotions

16:35–16:40	ThC9.6

Automated Particle Collection for Protein Crystal Harvesting

Burak Zeydan, Andrew J. Petruska, Luca Somm, Roel Pieters, Yang Fang, David F. Sargent, and Bradley J. Nelson
Institute of Robotics and Intelligent Systems, ETH Zurich, Switzerland

- Automated detection of protein crystals is accomplished by a UV imaging system.
- Automated planning and control is achieved through a subsumption-based behavioral planner.
- The resulting system is tested on crystal emulating beads and seen to perform as good as a human expert over a long period of time requiring minimal human assistance.



Seamless behavior transitions for robustness and error recovery.

Micro/Nano Robots 2

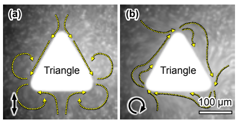
Chair *Metin Sitti, Max-Planck Institute for Intelligent Systems*
Co-Chair *Fumihito Arai, Nagoya University*

16:40–16:45	ThC9.7

On-Chip Micromanipulation Method Based on Mode Switching of Vibration-Induced Asymmetric Flow

Takeshi Hayakawa and Fumihito Arai
Department of Micro-Nano Systems Engineering, Nagoya University, Japan

- Micromanipulation method based on mode switching of vibration-induced flow.
- Local flow pattern can be switched by changing the direction of applied vibration.
- The switching of local flow pattern can be applied to switching of multiple manipulation mode.
- We present two application of proposed method of switching; cell concentration and single particle loading.



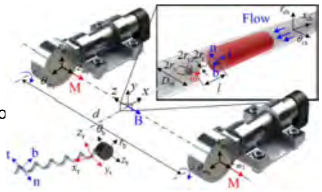
Switching of local flow pattern:
(a) Symmetric flow
with rectilinear vibration,
(b) Asymmetric flow
with circular vibration

16:45–16:50	ThC9.8

Rubbing Against Blood Clots using Helical Robots: Modeling and *In Vitro* Experimental Validation

Islam S. M. Khalil, Khaled Sadek, Dalia Mahdy, and Nabila Hamdi
The German University in Cairo, Egypt
Ahmet Fatih Tabak and Metin Sitti
Max Planck Institute for Intelligent Systems, Germany

- A hydrodynamic model of helical robots based on resistive-force theory is presented to investigate the rubbing behaviour of blood clots using robots driven by two rotating dipole fields
- Comparative study between chemical lysis and mechanical rubbing of blood clot is conducted *in vitro*



A schematic representation of the permanent magnet-based actuation system

Prosthetics and Exoskeletons

Chair *Eugenio Guglielmelli, Universita' Campus Bio-Medico*
Co-Chair *Tommaso Lenzi, University of Utah*

16:10–16:15	ThC10.1

Comparison of different error signals driving the adaptation in assist-as-needed controllers for neurorehabilitation with an upper-limb robotic exoskeleton

T. Proietti, G. Morel, A. Roby-Brami, and N. Jarrassé
Sorbonne Universités - Paris 6
Université Pierre et Marie Curie (UPMC)
Institute for Intelligent Systems and Robotics (ISIR)

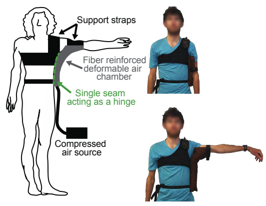
- Is the performance of **assist-as-needed controllers** affected by the choice of the **error signal** which **drives** the **adaptation**?
- What happens if we consider an **end-effector based global solution** rather than a **joint-by-joint local solution**?
- Can we find the **best solution** for pursuing motor **rehabilitation** with **exoskeletons**?

16:15–16:20	ThC10.2

Exomuscle: An inflatable device for shoulder abduction support

Cole S. Simpson[1], Allison M. Okamura[1], and Elliot W. Hawkes[1,2]
[1]Department of Mechanical Engineering, Stanford University, USA
[2]Department of Mechanical Engineering, University of California, Santa Barbara, USA

- Costly and cumbersome grounded devices have been successfully used to rehabilitate and assist hemiparetic individuals by supporting shoulder abduction.
- We developed a lightweight (350 g), inexpensive ($16.34 USD), wearable device to offload shoulder abductor muscles.
- We demonstrate 74% and 72% reductions in muscular effort for isometric and dynamic reaching tasks, respectively, with minimal effect on range of motion (4% decrease).

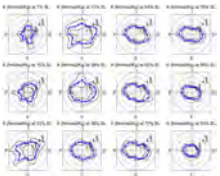


16:20–16:25	ThC10.3

Time-Varying Human Ankle Impedance in the Sagittal and Frontal Planes during Stance Phase of Walking

Evandro Ficanha, Guilherme Ribeiro, Lauren Knop, and Mo Rastgaar
Mechanical Engineering-Engineering Mechanics, MichiganTechnological University, USA

- **This paper describes the estimation of the time-varying impedance of the human ankle.**
- **The estimation was performed in the sagittal and frontal planes during walking.**
- **The ankle impedance was estimated at 16 axes of rotation combining sagittal and frontal rotations.**
- **The ankle impedance showed great variability through the stance length and across axes of rotation.**

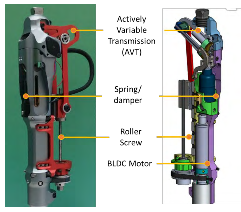

Contour plots of the normalized ankle stiffness at 12 instances of the stance length (SL).

16:25–16:30	ThC10.4

Actively Variable Transmission for Robotic Knee Prostheses

Tommaso Lenzi
Department of Mechanical Engineering, University of Utah, USA
Marco Cempini, Levi J. Hargrove, and Todd A. Kuiken
Center for Bionic Medicine, Rehabilitation Institute of Chicago, USA

- A novel powered knee prosthesis with active variable transmission (AVT) that weighs only 1.7 Kg.
- The AVT works in combination with a spring/damper allowing active and passive operation modes.
- Human experiments shows that the proposed knee prosthesis can support walking in passive mode, and stairs climbing with a reciprocal gait pattern in active mode.



16:30–16:35	ThC10.5

Design of a Quasi-passive Ankle-foot Prosthesis with Biomimetic, Variable Stiffness

Max Shepherd
Biomedical Engineering, Northwestern University, United States
Elliott Rouse
Physical Medicine and Rehabilitation, Northwestern University, United States

- Modern prosthetic ankles can't change their stiffness for different mobility tasks
- Our novel ankle uses a cam transmission and actively modulates a variable-stiffness leaf spring
- The ankle accomplished the desired nonlinear torque-angle curve, and an order of magnitude stiffness variation

16:35–16:40	ThC10.6

Design of an under-actuated wrist based on adaptive synergies

Simona Casini, Vinicio Tincani, Giuseppe Averta, Mattia Poggiani, Cosimo Della Santina, Edoardo Battaglia, Manuel G. Catalano, Matteo Bianchi and Antonio Bicchi
Research Center "E.Piaggio" Faculty of Engineering University of Pisa, Italy
Italian Institute of Technology, Advanced Robotics dept., Genoa, Italy

- Design of an adaptive synergy-based robotic wrist with 2 DoFs
- Tunable wrist which allows to implement different under-actuation patterns
- Preliminary investigation of the main wrist synergy in humans with the PC analysis
- Implementation of the first PC in the proposed robotic wrist

Prosthetics and Exoskeletons

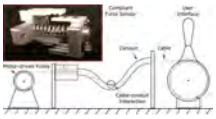
Chair *Eugenio Guglielmelli, Universita' Campus Bio-Medico*
Co-Chair *Tommaso Lenzi, University of Utah*

16:40–16:45	ThC10.7

A Cable-based Series Elastic Actuator with Conduit Sensor for Wearable Exoskeletons

Laura H. Blumenschein
Mechanical Engineering, Stanford University, USA
Craig G. McDonald and Marcia K. O'Malley
Mechanical Engineering, Rice University, USA

- Soft wearable exoskeletons are being developed to provide physical assistance in real world activities
- Actuation methods for soft wearable exoskeletons for the upper limb remain an open question
- The proposed solution: DC motor with flexible cable conduit and custom compliant force sensor



Bowden cable Series Elastic Actuator concept

16:45–16:50	ThC10.8

A Compliant Four-bar Linkage Mechanism that Makes the Fingers of a Prosthetic Hand More Impact Resistant

Kyung Yun Choi[1], Aadeel Akhtar[2], Timothy Bretl[1]
Aerospace Engineering[1], Neuroscience Program and Medical Scholars Program[2], University of Illinois at Urbana-Champaign, USA

- To improve impact resistance in prosthetic hands, we present the design and evaluation of a compliant four-bar linkage mechanism used to make fingers that are mechanically robust.
- The fingers enable a prosthetic hand that is mobile, low-cost ($553), light-weight (312 g), compact (50th percentile female anthropometry), can hold loads of up to 26 kg, and can easily grasp a variety of household objects.


Our four-bar linkage driven-finger is compliant and resistant to impacts from multiple directions.

Flexible Robots

Chair *Chen-Hua Yeow, National University of Singapore*
Co-Chair *Amir Degani, Technion - Israel Institute of Technology*

16:10–16:15 ThC11.1

A Hybrid Plastic-Fabric Soft Bending Actuator with Reconfigurable Bending Profiles

Rainier Natividad and Chen-Hua Yeow
Department of Biomedical Engineering, National University of Singapore
Manuel Del Rosario Jr. and Peter C.Y. Chen
Department of Mechanical Engineering, National University of Singapore

- A pneumatic bending actuator, composed of inflatable, replaceable, fabric modules and a flexible plastic spine is presented.
- The bending profile can be modified by altering the modules' geometries and material characteristics.
- Real-time actuator performance is primarily dictated by the pressure of the supplied pneumatic input.
- Step input response is identical to a first-order system.

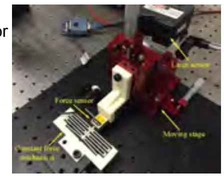
Figure: An inflated actuator featuring a heterogenous bending profile.

16:15–16:20 ThC11.2

Design of a 3D-Printed Polymeric Compliant Constant-Force Buffering Gripping Mechanism

Yilin Liu and Qingsong Xu
Department of Electromechanical Engineering
University of Macau, Macau, China

- A novel polymeric compliant constant-force buffering gripping mechanism is designed for bio-micromanipulation
- It can replace the existing combined force-displacement control strategy to deliver a constant output force
- It can be used to avoid the damage of manipulated fragile object due to excessive displacement output
- A prototype is fabricated by 3D-printed for experimental verification

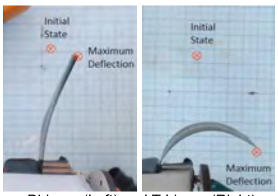


16:20–16:25 ThC11.3

Analytic Modeling and Experiments of Tri-Layer, Electro-thermal Actuators for Thin and Soft Robotics

Gal Tibi
Technion Autonomous Systems Program (TASP), Technion, Israel
Ela Sachyani, Michael Layani, Shlomo Magdassi
Casali Center, The Hebrew University of Jerusalem, Israel
Amir Degani
Civil and Env. Engineering and TASP, Technion, Israel

- ETAs are actuators based on the bi-metal effect that can be used in soft printable robots
- We develop an analytical model for thin bi- and **tri-layer** ETAs
- We show how tri-layer ETAs can have **much better performance**
- This improvement can be understood using our **simplified analytic model**



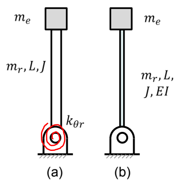
Bi-layer (Left) and Tri-layer (Right) ETA responses to voltage

16:25–16:30 ThC11.4

On the Impact Force of Human-Robot Interaction: Joint Compliance vs. Link Compliance

Yu She[1], Deshan Meng[2], Junxiao Cui[1] and Hai-jun Su[1]
[1]The Ohio State University, USA
[2]Harbin Institute of Technology Shenzhen Graduate School, P.R. China

- This paper studies the effect of mechanical compliance, i.e. joints compliance and link compliance, on the impact force of human-robot interactions.
- The compliant link solution produces a smaller impact force than that of the compliant joint solution, given the same inertial and equivalent later stiffness parameters.
- Simulations and experiments demonstrate that the compliant link could be an alternative solution for addressing safety concerns of human robot interactions.



(a) A rigid link with a compliant joint at the root, (b) a rigid joint with a uniform compliant link.

16:30–16:35 ThC11.5

Intraocular Snake Integrated with the Steady-Hand Eye Robot for Assisted Retinal Microsurgery

Jingzhou Song
Automation School, Beijing University of Posts and Telecommunications, Beijing, China
Berk Gonenc, Jiangzhen Guo, and Iulian Iordachita
Laboratory for Computational Sensing and Robotics, Johns Hopkins University, Baltimore, MD, USA

- Intraocular Snake Robot combined with the cooperatively controlled Steady-Hand Eye Robot for dexterous and tremor free tool manipulation inside the eye during retinal microsurgery.
- Highly miniaturized articulated segment length (3 mm) and very thin tool shaft (Ø 0.9 mm).
- Experiments in an artificial eye model have shown feasibility in reaching targets requiring bends up to 55°

16:35–16:40 ThC11.6

Incorporating Tube-to-Tube Clearances in the Kinematics of Concentric Tube Robots

Junhyoung Ha and Pierre E. Dupont, Fellow, IEEE

- Nonzero tube-to-tube clearances are included in CTR kinematics.
- Tubes are assumed to have different centerlines.
- CTR Kinematics is formulated as an energy minimization with tube contact constraints.
- Dual problem is solved for i) efficiency and ii) contact force computation.

< two tubes with nonzero clearance >

Flexible Robots

Chair *Chen-Hua Yeow, National University of Singapore*
Co-Chair *Amir Degani, Technion - Israel Institute of Technology*

16:40–16:45	ThC11.7

Chromatic surface microstructures on bionic soft robots for non-contact deformation measurement

Yin Zhu, Min Xu, Hu Jin, J Yang and Erbao Dong*
Department of Precision Machinery and Precision Instrumentation, University of Science and Technology of China, China

- This paper presents a bionic soft robot with chromatic surface micro-structure, as a new approach for the measurement of body deformation of the soft robots.
- We implement the method by recording and matching the pattern on the surface of the robot.
- This method may open promising avenues for soft robot's sensing, controlling and deformation measurement.

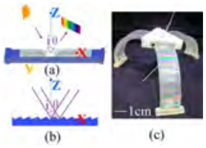


Figure caption is optional, use Arial 18pt

16:45–16:50	ThC11.8

Optimization-based inverse model of Soft Robots with Contact Handling

Eulalie Coevoet[1] Adrien Escande[2] Christian Duriez[1]
[1]INRIA and University of Lille, France
[2]CNRS-AIST Joint Robotic Lab, Japan

- Motion control of soft robots through a simulated inverse model
- Real-time physically-based algorithm that handles cable and pneumatic actuations
- Specific solver to include contacts into the optimization with real-time performance
- Handles interaction with the environment and self-collision regions