ICRA2017

May 29 – June 3, 2017 • Singapore

# PROGRAM Day 1

## Tuesday, 30 May

May 29-June 3, 2017 • Singapore

# IEEE International Conference on Robotics and Automation

IEEE

IEEE Robotics & Automation Society

## Actuators 1

Chair *Kyu-Jin Cho, Seoul National University, Biorobotics Laboratory*
Co-Chair *Hideyuki Tsukagoshi, Tokyo Institute of Technology*

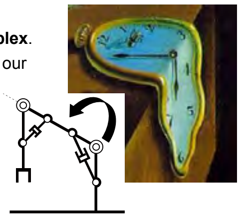
| 09:55–10:00 | TUA1.1 |
|---|---|

### A structure preserving nondimensionalization of hydraulic rotational joints

Satoru Sakai

Department of Mechanical Engineering, Shinshu University, Japan

- The original model of hydraulic joints is **complex**.
- However, the model is **exactly simplified** by our special nondimensionalization.
- In our opinion, the several **advantages**:
  Simulator Applicability,
  Faster Dynamics Computation,
  Efficient Parameter Update, …
  should be highlighted even for 1-DOF case
  **in academic or industrial points of view**.



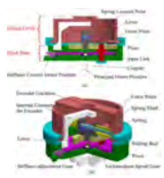
A special set of time, state, and input transformations.

| 10:00–10:05 | TUA1.2 |
|---|---|

### Mechanical Design of a Compact Serial Variable Stiffness Actuator (SVSA) Based on Lever Mechanism

Jiantao. Sun, Yubing. Zhang, Cong. Zhang, Zhao. Guo and Xiaohui. Xiao
School of Power and Mechanical Engineering, Wuhan University, China

- This paper introduce a new kind of Serial Variable Stiffness Actuator (SVSA) is proposed by using an Archimedean Spiral Relocation Mechanism
- The ASRM makes the SVSA design has continuous stiffness adjustment ability and simply mechanical structure.
- The output stiffness of the VSM is changed from 1.72 to 150.56 Nm/rad using a linear spring with stiffness 1882 N/m, working range covered from 0 to 360º.



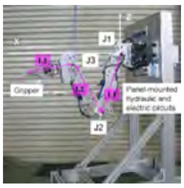
3D model of the Variable Stiffness Mechanism

| 10:05–10:10 | TUA1.3 |
|---|---|

### Toward Compliant, Fast, High-Precision, and Low-Cost Manipulator with Hydraulic Hybrid Servo Booster

Sang-Ho Hyon, Sumihito Tanimoto and Shota Asao
Department of Robotics, Ritsumeikan University, Japan

- Novel hydraulic hybrid servo drive is first applied to a robotic manipulator
- High-speed, large torque, high-precision control are possible at low cost
- Compliant motion is achieved with the intrinsic backdrivability of the small servo-pump
- Experimental results include a simple slider testbed and a planar three-axis manipulator (video attached)



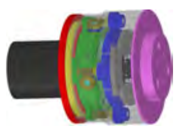
Three-axis H2SB manipulator

| 10:10–10:15 | TUA1.4 |
|---|---|

### Design of a Structure-Controlled Variable Stiffness Actuator Based on Rotary Flexure Hinges

Xiong Li, Wenjie Chen and Wei Lin
Mechatronics Group, Singapore Institute of Manufacturing Technology (SIMTech), A*STAR, Singapore

- The rotational stiffness is theoretically constant for the full range of the applied torque at any particular stiffness setting
- No additional torque is applied for holding a stiffness constant
- Outputs of the actuator for the position and the stiffness are independently controlled
- Low inertia and friction force



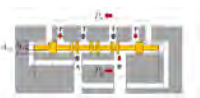
Overview of the VSA

| 10:15–10:20 | TUA1.5 |
|---|---|

### Intrinsically Backdrivable Hydraulic Servovalve for Interactive Robot control

Sunkyum Yoo, Woongyong Lee and Wan Kyun Chung
Mechanical Engineering, POSTECH, Republic of Korea

- Backdrivability brings force transmission, low gear ratio and low output impedance to the mechanical systems
- Conventional servovalve-based Hydraulic actuators lack the capability to interact with the environment due to its non-backdrivable structure.
- Introduction of chamber pressure feedback mechanism on the spool dynamics brings backdrivablity.



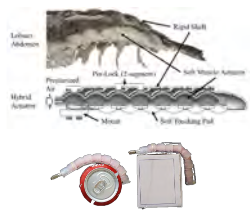
Chamber pressure feedback mechanism of backdrivable servovalve

| 10:20–10:25 | TUA1.6 |
|---|---|

### A Reconfigurable Hybrid Actuator with Rigid and Soft Components

Yaohui Chen, Sing Le, Qiao Chu Tan, Oscar Lau, Chaoyang Song*
Faculty of Engineering, Monash University, Australia
Fang Wan
Independent Researcher, China

- A lobster-inspired actuator with both rigid and soft components addressing repeatability, vulnerability, and programmability issues;
- Investigation including hybrid actuator design, fabrication and characterization;
- Adaptive to object geometry with reconfigurable motion as robotic fingers.



## Actuators 1

Chair *Kyu-Jin Cho, Seoul National University, Biorobotics Laboratory*
Co-Chair *Hideyuki Tsukagoshi, Tokyo Institute of Technology*

| 10:25–10:30 | TUA1.7 |
|---|---|

### Scalable Pneumatic and Tendon Driven Robotic Joint Inspired by Jumping Spiders

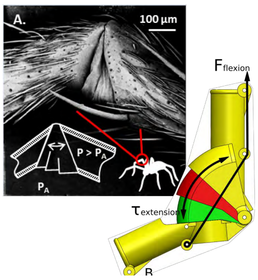
Alexander Spröwitz[1], Chantal Göttler[1], Ayush Sinha[2], Corentin Caer[3], Mehmet Ugur Ötzekin[4], Kirstin Petersen[5], Metin Sitti[1]
[1]MPI IS Germany, Max Planck ETH CLS, [2]IIT Kanpur India, [3]Horace Mann School USA, [4]METU Turkey, [5]Cornell University USA

Novel pneumatically driven torque joint for segmented robotic legs

Mechanism with perp. contact angle between active area and shell elements

Compact, arc-shaped, nested shell structure and pressure bag design

Experimental validation with dynamic vertical jumps up to 11.5cm at 58kPa

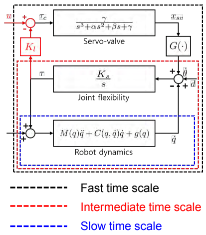



| 10:30–10:35 | TUA1.8 |
|---|---|

### Position-Based PD Control Design for Hydraulic Robots Using Passive Subsystems in Multi-time Scales

Woongyong Lee and Wan Kyun Chung
Mechanical Engineering, POSTECH, Republic of Korea

- Conventional hydraulic robots operate without feedback interconnections because the servovalves used in their actuation systems include non-backdrivable mechanisms.
- Virtual internal leakage injected into the system decomposes the hydraulic robot into passive subsystems.
- Stability-guaranteed Position-Based PD controller with inner-loop torque controller enables to interact passively with unexpected environments



## Optimization and Optimal Control

Chair *Jake Abbott, University of Utah*
Co-Chair *Yasuhisa Hirata, Tohoku University*

09:55–10:00 TUA2.1

### Fast Second-order Cone Programming for Safe Mission Planning

Kai Zhong
Inst. for Comp. Eng. and Sci., University of Texas at Austin, USA
Prateek Jain and Ashish Kapoor
Microsoft Research, India and Microsoft Research, USA

- Safe mission control under uncertain environment requires to solve a series of *SOCP* problems at each time step.
- Traditional interior point methods need to use external libraries.
- Propose a **Wolfe**-based algorithm exploiting geometry of *SOCP* carefully.
- Our algorithm is **fast and memory-efficien**t, enabling energy-efficient real-time onboard planning.

| Precision | WOLFE | PGD | CPM | SDPT3 |
|---|---|---|---|---|
| 1.00E-01 | 0.0006 | 0.0011 | 0.583 | 0.638 |
| 1.00E-02 | 0.0006 | 0.0070 | 3.954 | 0.641 |
| 1.00E-03 | 0.0018 | 0.0543 | 6.518 | 0.644 |
| 1.00E-04 | 0.0068 | 0.9480 | 14.110 | 0.686 |
| 1.00E-05 | 0.0081 | 6.7897 | 25.828 | 0.852 |
| 1.00E-06 | 0.0100 | 12.6294 | 60.233 | 0.647 |

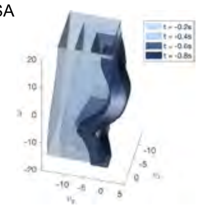
Running time (s) comparison among Wolfe's, projected gradient descent (PGD), cutting plane method (CPM), interior point method (SDPT3)

10:00–10:05 TUA2.2

### Exact and Efficient Hamilton-Jacobi Guaranteed Safety Analysis via System Decomposition

Mo Chen, Sylvia Herbert, and Claire J. Tomlin
EECS, UC Berkeley, USA

- There is an increasing need to verify complex systems such as UAVs and self-driving cars
- Hamilton-Jacobi reachability is a powerful tool for guaranteeing safety, but is computationally intractable for high-dimensional systems
- Our proposed decomposition method addresses the computational challenge without sacrificing exactness and optimality
- Low-dimensional computations are greatly sped up; high-dimensional computations are now tractable for the first time



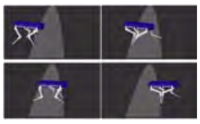
3D slice of a 6D reachable set for a quadrotor; computation is made tractable for the first time.

10:05–10:10 TUA2.3

### An Efficient Optimal Planning and Control Framework For Quadrupedal Locomotion

Farbod Farshidian, Michael Neunert, Alexander Winkler, Gonzalo Rey, Jonas Buchli
Agile & Dexterous Robotics Lab, ETH Zurich, Switzerland

- Proposing an optimal control framework based on switched system modeling for legged robot locomotion
- Introducing a constrained SQL algorithm as an efficient dynamic programming
- Motion planning and control for centroidal dynamics plus full kinematics of HyQ



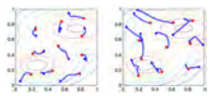
Time series of 1m gap crossing using a walking gait on HyQ

10:10–10:15 TUA2.4

### *Weighted-D²* sampling-based initialization and guaranteed sensor coverage

Ajay Deshpande
IBM T. J. Watson Research Center, USA

- Weighted-D² sampling based procedure is proposed to choose an initial sensor configuration in sensor coverage problem
- Yields **O(*log k*)-competitive** sensor coverage before even applying the Lloyd descent
- Numerical simulations show *initial coverage* is better than uniform random configuration
- Simulations show significant energy savings in terms of the average distance traveled by the sensors to reach the final configuration through the Lloyd descent



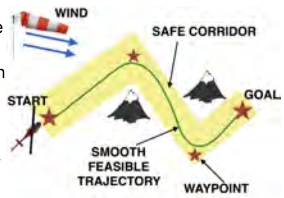
Lloyd descent trajectories: weighted-D² and uniform random initialization

10:15–10:20 TUA2.5

### A κITE in the Wind: Smooth Trajectory Optimization in a Moving Reference Frame

Vishal Dugar, Sanjiban Choudhury and Sebastian Scherer
Robotics Institute, Carnegie Mellon University, USA

- Smooth, time-optimal trajectory optimization for UAVs in the presence of wind.
- Elegantly decouples path optimization from velocity optimization while ensuring dynamic feasibility.
- Validated with experiments on a full-size autonomous helicopter with real-time wind updates.
- Tested with speeds upto 50m/s in winds upto 20m/s.

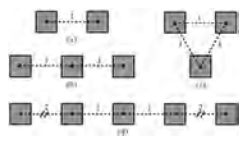



10:20–10:25 TUA2.6

### Computing Minimum-power Dipole Solutions for Interdipole Forces using Nonlinear Constrained Optimization with Application to Electromagnetic Formation Flight

Jake Abbott and Joseph Brink
Department of Mechanical Engineering, University of Utah, USA
Braxton Osting
Department of Mathematics, University of Utah, USA

- In electromagnetic formation flight (EMFF), spacecraft within a cluster are equipped with controllable magnetic dipoles that are used to control their relative positions by generating interdipole forces.
- This paper presents a method for finding a minimum-power solution to achieve a desired set of forces using sequential quadratic programming.



EMFF scenarios considered in numerical validation experiments, with interdipole spacing indicated

**Optimization and Optimal Control**

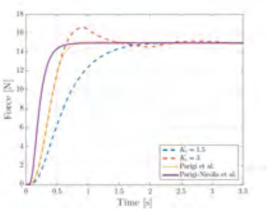
Chair *Jake Abbott, University of Utah*
Co-Chair *Yasuhisa Hirata, Tohoku University*

| 10:25–10:30 | TUA2.7 |
|---|---|

### Implicit Robot Force Control based on Set Invariance

Matteo Parigi Polverini, Davide Nicolis,
Andrea Maria Zanchettin, and Paolo Rocco
DEIB, Politecnico di Milano, Italy

- The proposed controller ensures set invariance and Lyapunov stability
- No additional stabilizing control law required
- High force reference tracking performance compared to state-of-the-art approaches
- No force overshoots for smooth reference tracking

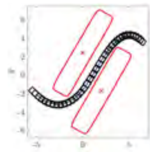



| 10:30–10:35 | TUA2.8 |
|---|---|

### A new framework for optimal path planning of rectangular robots using a weighted $L_p$ norm

Nak-seung Hyun, Patricio Vela and Erik Verriest
Electrical and Computer Engineering, Georgia Institute of Technology, USA

- Obstacle avoidance path planning for rectangular robots and obstacles in $SE(2)$.
- Inspired by a geometry of level sets of weighted $L_p$ norm.
- ***No integer*** variables are required.
- ***Only logical AND*** operations are needed to ***analytically*** characterize safe configuration.



A thin rectangular robot passing two rectangular obstacles.

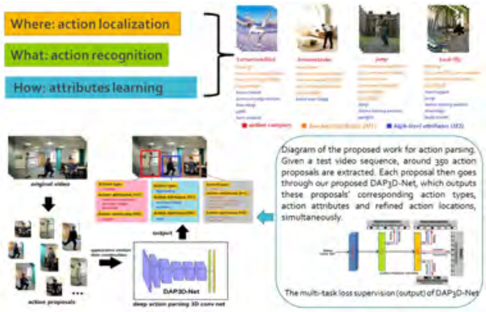
## Computer Vision 1

Chair *Jing Xiao, UNC Charlotte*
Co-Chair *You-Fu Li, City University of Hong Kong*

| 09:55–10:00 | TUA3.1 |
|---|---|

### DAP3D-Net: Where, What and How Actions Occur in Videos?

Li Liu, Yi Zhou, Ling Shao
Department of Computing Science, University of East Anglia, UK

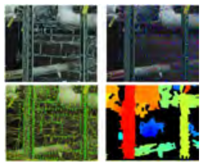



| 10:00–10:05 | TUA3.2 |
|---|---|

### LS-ELAS: Line Segment based Efficient Large Scale Stereo Matching

Radouane Ait-Jellal and Andreas Zell
Cognitive systems, University of Tuebingen, Germany
Manuel Lange, Benjamin Wassermann and Andreas Schilling
Visual computing, University of Tuebingen, Germany

- We propose a Bayesian approach for dense binocular stereo matching.
- Our prior is based on a set of line segments and a set of support points.
- We use the constrained Delaunay triangulation to generate a triangle mesh which preserves possible depth discontinuities.
- We use this triangle mesh to restrict the search domain to a very small interval.


Intermediate steps of our algorithm.

| 10:05–10:10 | TUA3.3 |
|---|---|

### Growth Measurement of Tomato Fruit based on Whole Image Processing

Rui FUKUI, Tsurugi NISHIOKA,
Shinichi WARISAWA*1 and Ichiro YAMADA
Graduate School of Frontier Science, the University of Tokyo
Julien SCHNEIDER
Mechanical Engineering Department, EPFL

- This study tries to estimate the volume of tomato fruits not from fruits individual images but from whole images of tomato plants.
- Our approach is based on features extraction from images using a sub-image clustering technique.
- Images being described as a number of pixel in various labels are used in a regression model to estimate the fruit volume.


Example images acquired by our robot

| 10:10–10:15 | TUA3.4 |
|---|---|

### Development of Precise Mobile Gaze Tracking System based on Online Sparse Gaussian Process Regression and Smooth-Pursuit Identification

Dan Su and Y. F. Li
Dept. of Mech. & Biomed. Eng., City University of Hong Kong, China

- A nature and less-tedious calibration approach is proposed for head-mounted gaze trackers.
- A on-line sparse Gaussian Process method is applied to registering the pupil centers with image gaze point.
- The smooth pursuit identification is designed to identify whether the user is focusing on the calibration point.
- The parallax error is compensated via the virtual affine parallax structure

| 10:15–10:20 | TUA3.5 |
|---|---|

### A Comparative Analysis of Tightly-coupled Monocular, Binocular, and Stereo VINS

Mrinal K. Paul, Kejian Wu, and Stergios I. Roumeliotis
MARS Lab, University of Minnesota, USA
Joel A. Hesch and Esha D. Nerurkar
Project Tango, Google, USA

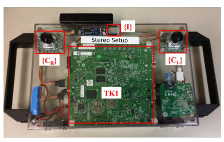
**Objective:** Develop a real-time, two-camera vision-aided inertial navigation system (VINS)

**Contributions:**

•Theoretical explanation of information gain when transitioning from binocular to stereo

•Analyzed impact of

i) Second camera (binocular, stereo)
ii) Image-processing front-ends
iii) Optimization window size
iv) Extrinsics' representation


MARS mobile stereo system

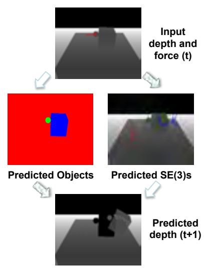
| | MARS | OKVIS | ORB-SLAM2 |
|---|---|---|---|
| Error | 0.12-0.31% | 2-5x | 1-5x (or failure) |
| Time | 100ms | 5-19x | 5-7x |

| 10:20–10:25 | TUA3.6 |
|---|---|

### SE3-Nets: Learning Rigid Body Motion using Deep Neural Networks

Arunkumar Byravan and Dieter Fox
Department of Computer Science & Engineering
University of Washington, USA

- Deep network **learns effect of actions** on objects in an environment, from raw depth data.
- **Segments environment** into objects (without supervision) and **predicts SE(3)** rigid motions for each distinct object.
- Robust to changes in object properties (size, mass, pose, shape, count) and applied forces.
- Tested on **four simulated and one real robot task** (Baxter pushing objects on a table).
- **Significantly outperforms standard deep baseline**.



**SE3-Net**

## Computer Vision 1

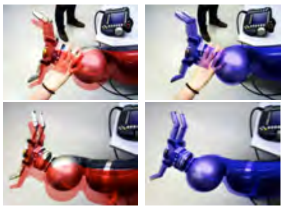
Chair *Jing Xiao, UNC Charlotte*
Co-Chair *You-Fu Li, City University of Hong Kong*

10:25–10:30 TUA3.7

### Probabilistic Articulated Real-Time Tracking for Robot Manipulation

Cristina Garcia Cifuentes, Jan Isaac, Manuel Wüthrich, Stefan Schaal and Jeannette Bohg
Max Planck Institute for Intelligent Systems, Germany

- Precise robot joint state estimation by asynchronous fusion of **depth images** and **angle measurements**.
- Robust to time-varying **angle bias**, **inaccurate kinematics**, and external **occlusions**.
- Extensive **quantitative** evaluation on a challenging **new dataset** from a real robot.
- We release our **code** and dataset.



forward kinematics vs. our method

10:30–10:35 TUA3.8

### Self-Supervised Visual Descriptor Learning for Dense Correspondence

Tanner Schmidt and Dieter Fox
Computer Science & Engineering, University of Washington, USA
Richard Newcombe
Oculus Research, USA

- KinectFusion and DynamicFusion are used to identify corresponding points within RGB-D videos
- A fully-convolutional neural network is trained to output features suitable for identifying within-video correspondences
- Learning to be viewpoint- and lighting-invariant in each video leads to a representation that is consistent across videos
- No human labels required

## ITS perception & planning

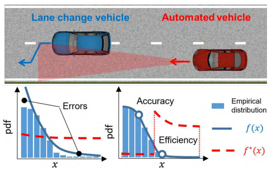
Chair *Alberto F. De Souza, Universidade Federal do Espírito Santo*
Co-Chair *Ingmar Posner, Oxford University*

| 09:55–10:00 | TUA4.1 |
|---|---|

### Evaluation of Automated Vehicles in the Frontal Cut-in Scenario - an Enhanced Approach using Piecewise Mixture Models

Zhiyuan Huang, Ding Zhao, Henry Lam,
David J. LeBlanc, Huei Peng
University of Michigan, USA

- Accelerated Evaluation of Automated Vehicle
- Model the naturalistic driving data using Piecewise Mixture Distribution
- Cross Entropy method with the Piecewise Mixture Model
- Demonstration in the Frontal Cut-in Scenario

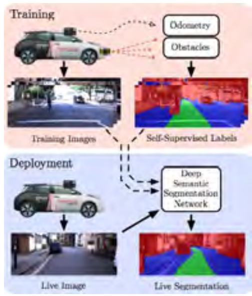



| 10:00–10:05 | TUA4.2 |
|---|---|

### Find Your Own Way: Weakly-Supervised Segmentation of Path Proposals for Urban Autonomy

Dan Barnes, Will Maddern and Ingmar Posner
Oxford Robotics Institute, University of Oxford, UK

- Road scene understanding is critical for autonomous driving, and often relies on clear road markings or expensive manual labelling.
- Using odometry and 3D LIDAR, we generate vast quantities of training data *without manual labelling* covering lighting, weather and traffic conditions.
- We train a semantic segmentation network to predict the pixel-wise class labels, and at run time we segment proposed paths and obstacles with *only a monocular camera*.

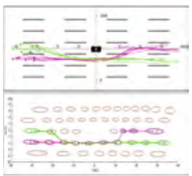



| 10:05–10:10 | TUA4.3 |
|---|---|

### Ego-Centric Traffic Behavior Understanding through Multi-Level Vehicle Trajectory Analysis

Donghao Xu, Xu He, Huijing Zhao, Jinshi Cui, Hongbin Zha
Key Lab of Machine Perception, Peking University, China
Franck Guillemard, Stephane Geronimi, François Aioun
PSA Peugeot Citroen, France

- We propose a multi-level approach to modeling **interactive traffic behaviors** based on surrounding vehicle trajectories collected from the ego-centric perspective.
- The approach consists of 3 steps: **regional modeling**, **path discovery** and **path modeling**.
- Experimental results of each step are shown and applications such as **local and global anomaly detection** and **trajectory prediction** are demonstrated.

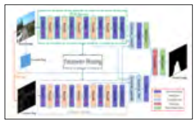


| 10:10–10:15 | TUA4.4 |
|---|---|

### Embedding Structured Contour and Location Prior in Siamesed FCNs for Road Detection

Junyu Gao, Qi Wang* and Yuan Yuan
School of Computer Science and Center for OPTical IMagery Analysis and Learning (OPTIMAL), Northwestern Polytechnical University, P. R. China

- The proposed s-FCN-loc can learn more discriminative features of road boundaries than the original FCN to detect more accurate road regions;
- Location prior is viewed as a type of feature map and directly appended to the final feature map in s-FCN-loc;
- The convergent speed of training s-FCN-loc model is 30% faster than the original FCN during the whole training process.



The architecture of the proposed s-FCN-loc.

| 10:15–10:20 | TUA4.5 |
|---|---|

### A Model-Predictive Motion Planner for the IARA Autonomous Car

Vinicius Cardoso[a], Josias Oliveira[a], Thomas Teixeira[a], Claudine Badue[a], Filipe Mutz[b], Thiago Oliveira-Santos[a], Lucas Veronese[a] and Alberto F. De Souza[a], *Senior Member, IEEE*

[a]*Departmento de Informática, Universidade Federal do Espírito Santo, Brazil*
[b]*Coordenação de Informática, Instituto Federal do Espírito Santo, Brazil*

- We present a model-predictive motion planner (MPMP) for the IARA autonomous car.
- MPMP computes trajectories that precisely follow a path previously produced by a Human driver at a rate of 20 Hz.
- MPMP is able follow the path (distances of 0.15 m in average) while smoothly driving IARA at speeds of up to 32.4 km/h (9 m/s).

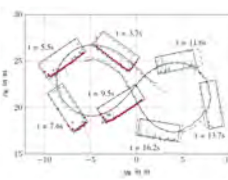
MPMP trajectories (in green/red) avoiding obstacles on the road.

| 10:20–10:25 | TUA4.6 |
|---|---|

### Vehicle Tracking Using Extended Object Methods: An Approach for Fusing Radar and Laser

Alexander Scheel, Stephan Reuter, and Klaus Dietmayer
Institute of Measurement, Control, and Microtechnology,
Ulm University, Germany

- Goal: environment perception for automated vehicles
- Fully probabilistic formulation of the multi-object tracking problem
- Detailed measurement models work with ambiguous sensor data in arbitrary situations
- Filter achieves redundancy and resolves ambiguous situations over time



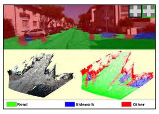
**ITS perception & planning**

Chair *Alberto F. De Souza, Universidade Federal do Espírito Santo*
Co-Chair *Ingmar Posner, Oxford University*

| 10:25–10:30 | TUA4.7 |
|---|---|

## An Online Probabilistic Intersection Detector

Augusto Luis Ballardini and Daniele Cattaneo and Simone Fontana and Domenico G. Sorrenti
Dept Informatica Sistemistica e Comunicazione, Università degli Studi di Milano-Bicocca, Italy



- We propose an online probabilistic approach for detecting and classifying urban road intersections
- We rely on a geometric detection of the road ground plane and on a pixel-level classification
- Temporal coherence between consecutive frames is achieved by means of a probabilistic scheme
- We validate our system on challenging residential sequences from the KITTI dataset

| 10:30–10:35 | TUA4.8 |
|---|---|

## Risk Assessment for Automatic Lane Change Maneuvers on Highways

Samyeul Noh and Kyounghwan An
Intelligent Robotics Research Division, Electronics and Telecommunications Research Institute (ETRI), Republic of Korea

- Capable of reliably assessing a given highway situation in terms of the possibility of collisions
- Capable of robustly giving a recommendation for lane changes
- Evaluated on a closed high-speed test track in simulated traffic through in-vehicle testing
- Evaluated on public highways in real traffic through in-vehicle testing

Experimental results on public highways

## Multi-Robot Systems 1

Chair *Gonzalo Lopez-Nicolas, Universidad de Zaragoza*
Co-Chair *Kostas Kyriakopoulos, National Technical Univ. of Athens*

| 09:55–10:00 | TUA5.1 |
|---|---|

### Detachable Modular Robot capable of Cooperative Climbing and Multi Agent Exploration

Sri Harsha Turlapati, Ankur Srivastava and K. Madhava Krishna
Robotics Research Center, IIIT Hyderabad, India
Suril V. Shah
Dept. Of Mechanical Engineering, IIT Jodhpur, India

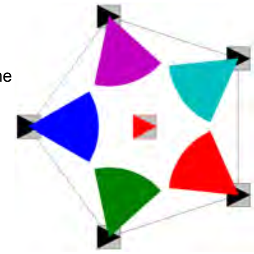
- At the intersection of Multi Agent Systems and Uneven Terrain Navigation
- Capable of collaborative climbing and distributed exploration
- Robot task scheduling inculcating design considerations in MAS optimization
- Manually controlled
- Obstacle/Stair Climbing, Tight space navigation

| 10:00–10:05 | TUA5.2 |
|---|---|

### Formation of differential-drive vehicles with field-of-view constraints for enclosing a moving target

Gonzalo Lopez-Nicolas
Universidad de Zaragoza - I3A, Spain
Miguel Aranda and Youcef Mezouar
Institut Pascal, UCA-SIGMA-CNRS, Clermont-Ferrand, France

- Context: Enclose and track a moving target within a desired formation.
- Goal: Full perception of the target with the vision sensors onboard the robots.
- Problem: Overcome differential-drive motion constraints and cameras with limited field of view.
- Contribution: Formation trajectories to enclose and track the target while respecting the constraints.

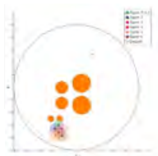


| 10:05–10:10 | TUA5.3 |
|---|---|

### Safe Decentralized and Reconfigurable Multi-Agent Control with Guaranteed Convergence

C. Vrohidis, C. P. Bechlioulis and K. J. Kyriakopoulos
Control Systems Lab,
School of Mechanical Engineering,
National Technical University of Athens, Greece

- Leader – Follower scheme in cluttered environment;
- Formation specifications;
- Discrete connectivity-preserving reconfiguration algorithm;
- Overall control scheme guarantees convergence to the desired configuration.

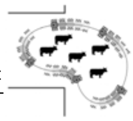


| 10:10–10:15 | TUA5.4 |
|---|---|

### Distributed Multi-Robot Coordination for Dynamic Perimeter Surveillance in Uncertain Environments

Alexander Jahn[1], Reza J. Alitappeh[2], David Saldaña[3],
Luciano C. A. Pimenta[1,4], Andre G. Santos[2], Mario F. M. Campos[3]
[1] PPGEE, UFMG, Brazil
[2] Computer Science, UFV, Brazil
[3] VeRLab, UFMG, Brazil
[4] National Institute of Science and Technology for Cooperative Autonomous Systems Applied to Security and Environment, Brazil

- Multi-agent system creating a virtual fence for escort missions in a partially known environment
- The formation can deform and adapt to the environment
- Decentralized, cooperative path-planning based on RRT
- Decentralized controller that uses only local information



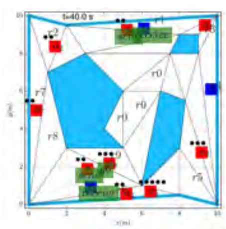
Application as a virtual fence

| 10:15–10:20 | TUA5.5 |
|---|---|

### Distributed Data Gathering with Buffer Constraints and Intermittent Communication

Meng Guo and Michael M. Zavlanos
Department of Mechanical Engineering and Materials Science, Duke University

- •Local data-gathering tasks as LTL formulas.
- •Limited communication radius.
- •Limited buffer to save data.
- •Inter-robot data transfer via intermittent communication.
- •Guaranteed satisfaction of all local tasks.
- •Efficiency over all-time connectivity.



| 10:20–10:25 | TUA5.6 |
|---|---|

### Decentralized Multiagent Collision Avoidance with Deep Reinforcement Learning

Yu Fan Chen, Miao Liu, Michael Everett, and Jonathon P. How
Aero&Astro, Massachusetts Institute of Technology, USA

- Autonomous indoor navigation often requires operating alongside other dynamic agents with unknown intents (goals) and policies
- Used deep reinforcement learning to develop a policy that accounts for uncertainty in other agents' motion
- Achieved 26% improvement in path quality (time to reach goal) compared with ORCA
- Demonstrated efficient, real-time performance on ground robots

Autonomous ground vehicles navigating alongside pedestrians.

## Multi-Robot Systems 1

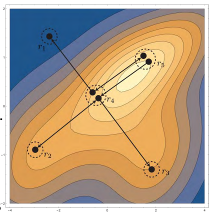
Chair *Gonzalo Lopez-Nicolas, Universidad de Zaragoza*
Co-Chair *Kostas Kyriakopoulos, National Technical Univ. of Athens*

| 10:25–10:30 | TUA5.7 |
|---|---|

### Decentralized Matroid Optimization for Topology Constraints in Multi-Robot Allocation Problems

Ryan Williams
Department of Electrical and Computer Engineering, Virginia Tech, USA
Andrea Gasparri and Giovanni Ulivi
Department of Engineering, Roma Tre University, Italy

- Topological and abstract task constraints in allocation problems by applying the combinatorial theory of matroids.
- Problems modeled as an intersection of matroid constraints, achieving arbitrary combinatorial relationships in allocation space.
- Coupling abstract per-robot constraints with a communication spanning tree constraint; provable suboptimality with greedy algorithm.
- Decentralized algorithm described that applies auction methods to task allocation with matroid intersections.



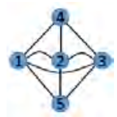
Task allocation with topology constraints

| 10:30–10:35 | TUA5.8 |
|---|---|

### Formations for Resilient Robot Teams

Luis Guerrero-Bonilla, Amanda Prorok and Vijay Kumar
GRASP Laboratory, University of Pennsylvania, United States of America

- Asymptotic consensus in the presence of malicious agents can be achieved by imposing a set of conditions, known as “r-robustness”, on the graph describing the communication among the robots in a team.
- Our work presents algorithms to construct r-robust graphs, given the number of robots and the number of malicious agents among them.
- The constructed graphs can be used to specify resilient formations of robots.




A 3-robust graph with 5 robots

## Learning and Adaptive Systems 1

Chair *Hsiu-Chin Lin, University of Edinburgh*
Co-Chair *Angela P. Schoellig, University of Toronto*

09:55–10:00 TUA6.1

### Learning Task Constraints in Operational Space Formulation

Hsiu-Chin Lin
School of Informatics, University of Edinburgh, United Kingdom
Prabhakar Ray and Matthew Howard
Department of Informatics, Kings College London, United Kingdom

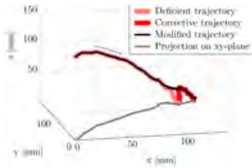
- How should constraints be imposed in order to adapt a control policy to a new constrained movement?
- The problem is formulated into an operational space control framework.
- The proposed method estimates the constraint matrix from observed movement in absence of any prior knowledge.
- The approach has been demonstrated on the AR-10 Robotic Hand performing manual operations.

10:00–10:05 TUA6.2

### Autonomous Interpretation of Demonstrations for Modification of Dynamical Movement Primitives

Martin Karlsson, Anders Robertsson and Rolf Johansson
Dept. Automatic Control, Lund University, Sweden

- Modification of dynamical movement primitives (DMPs) using lead-through programming
- Convex optimization to automatically merge existing DMP with corrective demonstration
- Offers quick modification, without engineering work
- Real-time application was implemented and verified experimentally



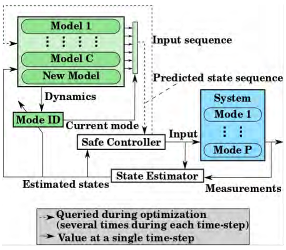

Robot trajectories from one of the experiments.

10:05–10:10 TUA6.3

### Learning Multimodal Models for Robot Dynamics Online with a Mixture of Gaussian Process Experts

Christopher McKinnon and Angela P. Schoellig
Institute for Aerospace Studies, University of Toronto, Canada

- Learning a multimodal system model from data using Gaussian Processes in a Dirichlet Process mixture model.
- Automatically learns a new model when a new and distinct operating condition is encountered.
- Enables a robot to re-use past experiences from an arbitrary number of previously visited operating conditions.
- Demonstrated in experiment on a ground robot.

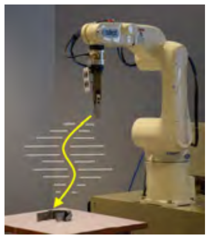



10:10–10:15 TUA6.4

### A Learning-based Shared Control Architecture for Interactive Task Execution

Firas Abi-Farraj[1], Takayuki Osa[2], Nicolò Pedemonte[1], Jan Peters [2,3], Gerhard Neumann [2] and Paolo Robuffo Giordano[1]
[1]CNRS at Irisa and Inria Rennes, France
[2]Institut für Intelligente Autonome Systeme, TU Darmstadt, Germany
[3]Max-Planck-Institut für Intelligente Systeme, Tübingen, Germany

- **Learning from demonstrations** to encode the demonstrated behavior of an expert operator and ***generalize*** it to new situations
- ***Balancing*** controller's **autonomy** and **operator**'s preference during collaborative task executions depending on the ***distribution*** of the demonstrated trajectories
- **Autonomous refinement** of the training **dataset** using an information gain measure

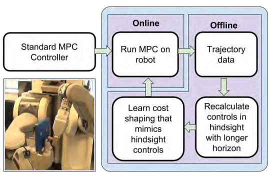


10:15–10:20 TUA6.5

### Learning from the Hindsight Plan -- Episodic MPC Improvement

Aviv Tamar, Garrett Thomas, Tianhao Zhang, Sergey Levine,
EECS Department, UC Berkeley
Pieter Abbeel
UC Berkeley (EECS, ICSI) and OpenAI

- Learn to improve MPC control in iterative (episodic) tasks
- After each episode, re-compute the MPC control **in hindsight**, with a longer planning horizon (offline)
- Learn neural network cost shaping for online MPC that **mimics the hindsight plan**
- Evaluation on robotic manipulation domains

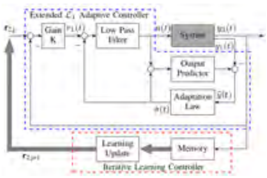



10:20–10:25 TUA6.6

### High-Precision Tracking in Changing Environments Through $\mathcal{L}_1$ Adaptive and Iterative Learning

Karime Pereida, Rikky R. P. R. Duivenvoorden and Angela P. Schoellig
Institute for Aerospace Studies, University of Toronto, Canada

- In unknown and dynamic environments, controllers must cope with disturbances, unmodeled dynamics and parametric uncertainties.
- We propose a framework combining $\mathcal{L}_1$ adaptive control and iterative learning.
- Experimental results show significant improvements in learning convergence and robustness to changing system dynamics.



Proposed $\mathcal{L}_1$ adaptive feedback and iterative learning control framework.

## Learning and Adaptive Systems 1

Chair *Hsiu-Chin Lin, University of Edinburgh*
Co-Chair *Angela P. Schoellig, University of Toronto*

10:25–10:30 TUA6.7

### A Systematic Approach for Minimizing Physical Experiments to Identify Optimal Trajectory Parameters for Robots

Ariyan M. Kabir[1] and Joshua D. Langsfeld[2] and Cunbo Zhuang[2] and Krishnanand N. Kaipa[3] and Satyandra K. Gupta[1]
[1]Center for Advanced Manufacturing, University of Southern California, CA USA,
[2]Maryland Robotics Center, University of Maryland, MD USA
[3]Dept. of Mechanical and Aerospace Engineering, Old Dominion University, VA USA

- Minimize number of experiments to optimize operation parameters
- Enable automation of non-repetitive tasks such as robotic cleaning
- Constrained optimization problem for known objective function with black-box constraints
- Probabilistic decision making based on uncertainty in surrogate models

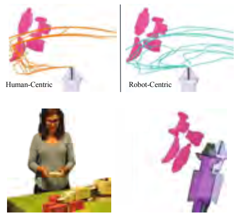
Experimental setup to identify optimal trajectory parameters for robotic cleaning

10:30–10:35 TUA6.8

### Comparing Human-Centric and Robot-Centric Sampling for Robot Deep Learning from Demonstrations

Michael Laskey, Caleb Chuck, Jonathan Lee, Jeffrey Mahler, Sanjay Krishnan, Kevin Jamieson, Anca Dragan and Ken Goldberg
EECS and IEOR, UC-Berkeley, USA

- We compared to different types of LfD algorithms Human-Centric (HC) and Robot-Centric (RC)
- We found that despite the theoretical advantages of RC, HC methods performed better with human supervisors.
- We provide a post analysis that offers new insights into the difference between RC and HC



## Force and Tactile Sensing 1

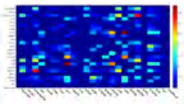
Chair *Gordon Cheng, Technical University Munich*
Co-Chair *Francesco Nori, ISTITUTO ITALIANO DI TECNOLOGIA*

| 09:55–10:00 | TUA7.1 |
|---|---|

### Multi-label Tactile Property Analysis

Huaping Liu, Yupei Wu, Fuchun Sun, Di Guo, Bin Fang
Department of Computer Science and Technology, Tsinghua University
State Key Lab. of Intellient Technology and Systems, Beijing, China

- A novel multi-label dictionary learning framework is established for tactile property recognition.
- A globally convergent iterative algorithm is developed to solve the dictionary learning problem.
- Experimental validations on the public available tactile property dataset are performed to show the advantages of the proposed method.



| 10:00–10:05 | TUA7.2 |
|---|---|

### Reliable object handover through tactile force sensing and effort control in the Shadow Robot hand

Augusto Gómez-Eguíluz and Inaki Rano
and Sonya Coleman and Martin McGinnity
Intelligent Systems Research Centre, Ulster University, UK

- Robot-Human Object Handover system using the Shadow Robot hand.
- Contact force estimation using BioTAC tactile sensor.
- The system guarantees the safety of both the robot and the object during the handover.
- A grasp effort controller provides adaptation against pose object perturbations.
- Releases only when the receiver pulls from the object.

| 10:05–10:10 | TUA7.3 |
|---|---|

### Touch Based Localization For High Precision Manufacturing

Brad Saund, Shiyuan Chen, and Reid Simmons
Robotics Institute, Carnegie Mellon, USA

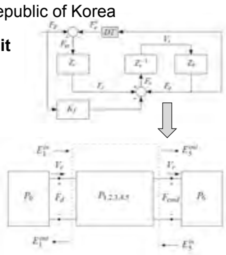
- Autonomous localization of objects from CAD with an emphasis in manufacturing environments
- **Particle filter** using rejection sampling and precomputed distance field
- **Information gain** as a discrete decision process over particles

| 10:10–10:15 | TUA7.4 |
|---|---|

### Passivity-based Stability in Explicit Force Control of Robots

Ribin Balachandran and Jordi Artigas
German Aerospace Center (DLR), Germany
Mikael Jorda and Oussama Khatib
Robotics Lab, Stanford University, USA
Jee-Hwan Ryu
BioRobotics Lab, Koreatech, Republic of Korea

- A step-by-step procedure to stabilise **explicit force control** by deriving:
  - Signal flow diagram
  - Electrical circuit diagram
  - 2-port representation
  - Energy analysis and passivisation using **Time Domain Passivity Control**
- This procedure can be followed in other control methods as well.

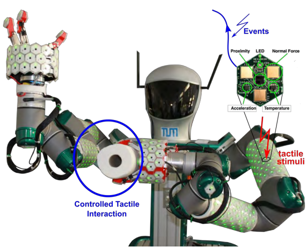


| 10:15–10:20 | TUA7.5 |
|---|---|

### Efficient Event-Driven Reactive Control for Large Scale Robot Skin

Florian Bergner, Emmanuel Dean-Leon and Gordon Cheng
Technical University of Munich, Germany

- New event-driven reactive skin controller reduces CPU usage by 66% in comparison to synchronous reference controller
- comprehensive performance evaluation with our robot TOMM




| 10:20–10:25 | TUA7.6 |
|---|---|

### Skin Normal Force Calibration Using Vacuum Bags

Joan Kangro, Silvio Traversaro, Daniele Pucci, Francesco Nori
Dynamic Interaction Control, Istituto Italiano di Tecnologia, Italy

- Pressure in the bag is lowered => Induces uniform pressure distribution
- Capacitance values for each sensor and pressure value are extracted during calibration
- Each sensor is modelled as:
  $P_i(C_i) = a_i + b_iC_i + c_iC_i^2 + d_iC_i^3 + e_iC_i^4 + f_iC_i^5$
- The calibration takes 1-2 minutes and can be applied to a variety of skin shapes

## Force and Tactile Sensing 1

Chair *Gordon Cheng, Technical University Munich*
Co-Chair *Francesco Nori, ISTITUTO ITALIANO DI TECNOLOGIA*

10:25–10:30 TUA7.7

### A Highly Sensitive Multimodal Capacitive Tactile Sensor

Thuy-Hong-Loan Le, Alexis Maslyczyk, Jean-Philippe Roberge and Vincent Duchaine
Command and Robotics Laboratory (CoRo),
École de Technologie Superieure, Montreal, Canada

- Highly sensitive multimodal capacitive tactile sensor
- Static and dynamic sensing are integrated in the same layer of the capacitive sensor
- Improvements in both mechanical and electrical design, simplifying the manufacture process
- Large range of force sensing and be able to detect contact events

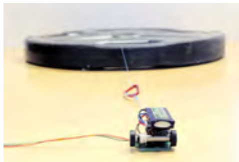

Sensors mounted on Robotiq gripper

10:30–10:35 TUA7.8

### Incipient Slip Detection and Recovery for Controllable Gecko-Inspired Adhesion

X. Alice Wu [1], David L. Christensen [1], **Srinivasan A. Suresh [1]**, Hao Jiang [1], William R. T. Roderick [1], and Mark Cutkosky [1]
[1]Mechanical Engineering, Stanford University, USA

- We present work on incipient slip sensing and recovery for controllable gecko-inspired adhesives.
- Using signals from an on-board tactile sensor, we detect the onset of adhesive failure and execute recovery behavior.
- The system using tactile sensor feedback is able to achieve >92% of the peak adhesion performance.
- Results consistent over a variety of common smooth surfaces, with the system achieving repeatable force loading independent of materials and surface conditions.



*A μTug micro-robot with integrated tactile sensing is able to maximize its pulling capability using force feedback.*

## Haptics and Haptic Interfaces

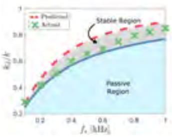
Chair *Allison M. Okamura, Stanford University*
Co-Chair *Masashi Konyo, Tohoku University*

| 09:55–10:00 | TUA8.1 |
|---|---|

### Effects of Discretization on the K-Width of Series Elastic Actuators

Dylan P. Losey and Marcia K. O'Malley
Mechanical Engineering, Rice University, USA

- K-Width refers to the range of virtual stiffnesses that an SEA can safely render
- Discretization introduced by the computer interface influences the K-Width of SEAs
- We derive an equation for the K-Width of SEAs when considering this discretization
- The K-Width can be increased by adding damping or increasing the sampling rate



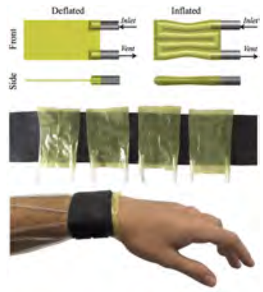
Decreasing the sampling frequency experimentally reduced SEA K-Width

| 10:00–10:05 | TUA8.2 |
|---|---|

### WRAP: Wearable, Restricted-Aperture Pneumatics for Haptic Guidance

Michael Raitor, Julie M. Walker, Allison M. Okamura, and Heather Culbertson
Department of Mechanical Engineering, Stanford University, U.S.A.

- Developed a novel haptic actuator using pressurized air
- Defined actuator design and fabrication constraints
- Demonstrated effectiveness of actuator for identification of direction cues through a user study
- Established versatility of actuator through two additional demonstrations of use cases: ultrasound probe guidance and computer mouse guidance

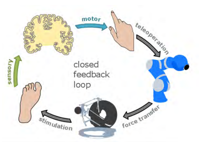



| 10:05–10:10 | TUA8.3 |
|---|---|

### Blindfolded Robotic Teleoperation using Spatial Force Feedback to the Toe

Annette Hagengruber and Hannes Höppner and Jörn Vogel
Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Wessling, Germany

- 12 subjects teleoperated a DLR Light-Weight Robot in a blindfolded task
- A three-dimensional spatial force to the toe was the only available feedback
- The forces reflected the contact forces at the robotic end-effector
- Subjects could successfully finish the task in more than two-thirds of all trials



Schematic illustration of the closed feedback-loop

| 10:10–10:15 | TUA8.4 |
|---|---|

### Proton 2: Increasing the Sensitivity and Portability of a Visuo-haptic Surface Interaction Recorder

Alex Burka, Abhinav Rajvanshi, Sarah Allen, and Katherine J. Kuchenbecker
MEAM, ESE, CIS Departments, GRASP Lab, University of Pennsylvania, USA

- The Proton is a new handheld visuo-haptic sensing system that records surface interactions
- Prior work demonstrated calibration and a proof-of-concept surface classification task
- This work details hardware and software improvements and their validation in a similar classification task
- In one experiment, we examine end-effector size; in another, we compare motion tracking algorithms


CAD model of the Proton 1, shown with the OptoForce end-effector contacting a surface.

| 10:15–10:20 | TUA8.5 |
|---|---|

### On the Passivity of Mechanical Integrators in Haptic Rendering

Myungsin Kim, Juhyeok Kim, Yongjun Lee, and Dongjun Lee
Department of Mechanical & Aerospace Engineering and IAMD, Seoul National University, Republic of Korea

- We propose a novel haptic rendering framework based on ***Passive Midpoint integrator (PMI)***
- Passive rendering of articulated rigid bodies in SE(3) and multipoint contact problem are addressed
- Stable simulation stiff systems and lossless harmonic oscillation with slow update-rate are achieved

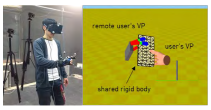


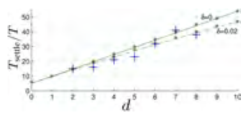
Figure: Multiuser manipulation of shared rigid body over the Internet

| 10:20–10:25 | TUA8.6 |
|---|---|

### A Practically Linear Relation between Time Delay and the Optimal Settling Time of a Haptic Device

Thomas Hulin
German Aerospace Center (DLR), Germany

- The optimal settling time of a haptic device depends practically linearly on time delay
- Hence, a rule of thumb is introduced to predict the optimal performance of a haptic device:
- *Each sampling period of additional time delay causes the optimal settling time to increase by approximately five sampling periods*
- The effect of discrete-time sampling appears to correspond to a delay of one whole sampling period

## Haptics and Haptic Interfaces

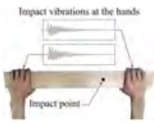
Chair *Allison M. Okamura, Stanford University*
Co-Chair *Masashi Konyo, Tohoku University*

| 10:25–10:30 | TUA8.7 |
|---|---|

### Collision Representation Using Vibrotactile Cues to Bimanual Impact Localization for Mobile Robot Operations

Daniel Gongora[1], Hikaru Nagano[1], Yosuke Suzuki[2], Masashi Konyo[1] and Satoshi Tadokoro[1]
[1]Graduate School of Information Sciences, Tohoku University, Japan
[2]Institute of Science and Engineering, Kanazawa University, Japan

- Impact vibrations of an object held with both hands can be used to estimate the impact point.
- Two vibrotactile cues to bimanual impact localization are differences in amplitude and duration between hands.
- In simple teleoperated tasks, completion time is likely to benefit from vibrotactile collision feedback.



Bimanual Impact Localization

| 10:30–10:35 | TUA8.8 |
|---|---|

### Variable Damping Force Tunnel for Gait Training Using ALEX III

Paul Stegall
Department of Mechanical Engineering, University of Pennsylvania, USA
Damiano Zanotto
Department of Mechanical Engineering, Stevens Institute of Technology, USA
Sunil Agrawal
Department of Mechanical Engineering, Columbia University, USA

- Haptic field where damping coefficient increases with error
- Descriptive feedback
- Higher rates of change in the damping coefficient produced greater adaptation

## TRO Session - Perception and Planning

Chair *Frank Park, Seoul National University*
Co-Chair *Cesar Cadena Lerma, ETH Zurich*

09:55–10:10 TUA9.1

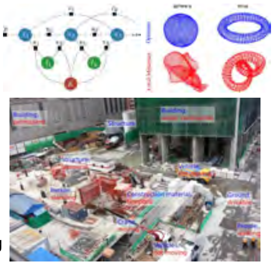
### Past, Present, and Future of Simultaneous Localization And Mapping: Towards the Robust-Perception Age

Cesar Cadena[1], Luca Carlone[2], Henry Carrillo[3], Yasir Latif[4], Davide Scaramuzza[5], José Neira[6], Ian Reid[4], John J. Leonard[7]

[1]Autonomous Systems Lab, ETH Zurich, Switzerland. [2]Laboratory for Information and Decision Systems, MIT, USA. [3]Esc. de Ciencias Exactas e Ing., U. Sergio Arboleda, Colombia. [4]School of Computer Science, University of Adelaide, Australia. [5]Robotics and Perception Group, U. of Zurich, Switzerland. [6]D. de Informática e Ing. de Sistemas, U. de Zaragoza, Spain. [7]Marine Robotics Group, MIT, USA.

Survey and our views for the future of:

- Long-term Autonomy
  - Robustness
  - Scalability
- Representation
  - Metric Map Models
  - Semantic Map Models
- New Theoretical Tools for SLAM
- Active SLAM
- New Frontiers: Sensors and Learning

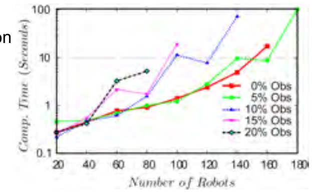


10:10–10:25 TUA9.2

### Optimal Multi-Robot Path Planning on Graphs: Complete Algorithms and Effective Heuristics

Jingjin Yu
Department of Computer Science, Rutgers University, USA
Steven M. LaValle
Department of Computer Science, University of Illinois, USA

- Algorithms for optimal or near-optimal multi-robot path/motion planning on graphs
- Based on network flow and ILP
- Supports common objectives
  - Minimum makespan
  - Minimum total time
  - Minimum maximum distance
  - Minimum total distance
- High performance



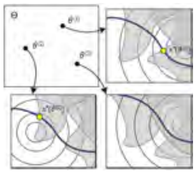

Performance in computing min-makespan solution on a 24x18 grid with obstacles. All solutions are within 1.1-optimal

10:25–10:40 TUA9.3

### Learning the Problem-Optimum Map: Analysis and Application to Global Optimization in Robotics

Kris Hauser
Dept. of Electrical and Computer Engineering, Duke University, USA

- How do optimal solutions to parameterized nonlinear programs vary across parameter space?
- Data-driven approach: seed local optimizations with previous global optima
- Formal “goodness” results and complexity analysis
- Experiments on inverse kinematics problems: high quality solutions with 10-100x speedups



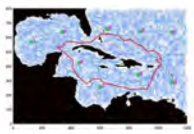
How easy it to learn the map from optimization problems (upper left) to solutions?

10:40–10:55 TUA9.4

### Rapidly-exploring Random Cycles: Persistent Estimation of Spatiotemporal Fields

Xiaodong Lan
Mechanical Engineering, Boston University, USA
Mac Schwager
Aeronautics and Astronautics, Stanford University, USA

- Proposed RRC and RRC* to plan periodic trajectories to estimate spatiotemporal field.
- RRC and RRC* are monotonic.
- RRC and RRC* are efficient in high dimensional configuration space.
- Applied RRC and RRC* to plan periodic trajectories to estimate ocean temperature in Caribbean Sea.



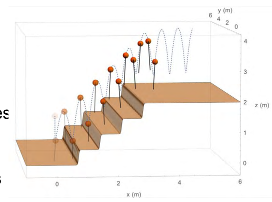
Example RRC trajectory.

10:55–11:10 TUA9.5

### Sequential Action Control: Closed-Form Optimal Control for Nonlinear and Nonsmooth Systems

Alex Ansari and Todd Murphey
Mechanical Engineering, Northwestern University, United States

- Sequential Action Control (SAC) is closed form for general nonlinear and nonsmooth systems
- It is model predictive and often coincides with optimizers obtained using iterative optimization
- SAC obtains results at least as good as best known in literature for numerous benchmarks, and can be easily implemented for a broad range of systems



SAC control of a spring-loaded inverted pendulum on stairs

## Rehabilitation Robotics

Chair *Hyunglae Lee, Arizona State University*
Co-Chair *Jaeheung Park, Seoul National University*

09:55–10:00 TUA10.1

### A Rehabilitation Exercise Robot for Treating Low Back Pain

Wonje Choi, Jongseok Won, Hyunbum Cho and Jaeheung Park
Graduate School of Convergence Science and Technology, Seoul National University, Republic of Korea

- Low back pain is one of the world's most serious health problems.
- The "big 3" exercises proposed by McGill were designed based on scientific evidence.
- SERA is a robot that helps the big 3 exercise for vulnerable patients.
- The SEA of the robot makes it possible to adjust the exercise load by applying anti-gravity force to the necessary part on the body.

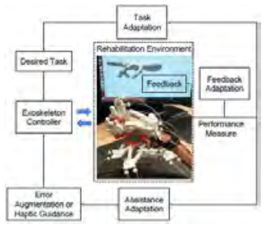
The original exercise of the Big 3 and the exercise on SERA.

10:00–10:05 TUA10.2

### A Novel Framework for Optimizing Motor (Re)-learning with a Robotic Exoskeleton

Priyanshu Agarwal and Ashish D. Deshpande
Mechanical Engineering Department, University of Texas at Austin, USA

- We present a framework for robot-assisted motor (re)-learning for providing subject-specific training.
- Framework allows for simultaneous adaptation of **task**, **assistance** and **feedback** based on the performance of the subject during the task.
- Results from a pilot study suggested that training under **simultaneous adaptation** affects motor learning significantly.

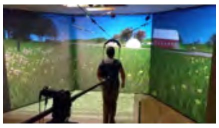



10:05–10:10 TUA10.3

### A 3 Wire Body Weight Support System for a Large Treadmill

Pouya Sabetian
Department of Mechanical Engineering, University of Utah, USA
John M. Hollerbach
The School of Computing, University of Utah, USA

- A 3 Wire Body Weight Support (BWS) System has been developed to span over a large treadmill.
- The BWS system can span the workspace while applying constant unloading force and close to zero forces horizontally on the user.
- Some of BWS applications are locomotion rehabilitation for patients with neurological problems, reduced gravity display, and steep slope display.



10:10–10:15 TUA10.4

### Design and Validation of a Torque Dense, Highly Backdrivable Powered Knee-Ankle Orthosis

H. Zhu[1,2], J. Doan[1,2], C. Stence[1,3], G. Lv[1,2], T. Elery[1,3], R. Gregg[1,3]
[1] Bioengineering, [2] Electrical and Computer Engineering, [3] Mechanical Engineering, The University of Texas at Dallas, USA

- A novel powered knee-ankle orthosis for torque-driven rehabilitation control strategies.
- Precise torque control and backdrivability without series elastic components.
- High output torque without a high-ratio transmission.
- Light weight and compact actuation system.

10:15–10:20 TUA10.5

### Design and Validation of a Multi-Axis Robotic Platform for the Characterization of Ankle Neuromechanics

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

- Presents the design and validation of a robotic platform for the characterization of ankle neuromechanics: mechanical impedance and reflex responses of the ankle.
- Demonstrates the platform's capability of providing highly accurate position perturbations, simulating various mechanical (haptic) environments, and eliciting stretch reflex responses of the ankle muscles.

10:20–10:25 TUA10.6

### A robotic orthosis with a cable-differential mechanism

Jaehwan Park, Seunghan Park, Chan Ho Park, Seungmin Jung, Chankyu Kim, and Junho Choi
Center for Bionics, Korea Institute of Science and Technology, S. Korea
Jong Hyeon Park
Mechanical Engineering, Hanyang University, S. Korea

- A robotic orthosis for stroke patient, which is worn at the affected side of the patient
- Cable-differential mechanism is used for power transmission
- Actuators are located at the base to reduce inertia of the orthosis
- Actuator loads are shared by two actuators using the cable-differential mechanism, which makes smaller actuator to be used

COWALK Mobile 2

## Rehabilitation Robotics

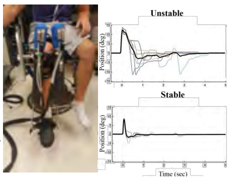
Chair *Hyunglae Lee, Arizona State University*
Co-Chair *Jaeheung Park, Seoul National University*

| 10:25–10:30 | TUA10.7 |
|---|---|

### Stability of the Human Ankle in Relation to Environmental Mechanics

Harrison Hanzlick, Hunter Murphy and Hyunglae Lee
School for Engineering of Matter, Transport, and Energy,
Arizona State University (ASU),USA

- Characterizes lower bound of ankle stability in stiffness-defined haptic environment in two DOF.
- Simple settling time analysis quantifies trends between ankle stability and environmental stiffness.
- Provides essential information for the design of controllers for physically-interactive robots.



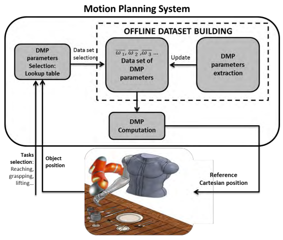

| 10:30–10:35 | TUA10.8 |
|---|---|

### Learning by Demonstration for planning activities of daily living in rehabilitation and assistive robotics

Clemente Lauretti[1], Francesca Cordella [1],
Eugenio Guglielmelli [1] and Loredana Zollo[1]

[1]Laboratory of Biomedical Robotics and Biomicrosystems, Campus Bio-Medico University, Rome, Italy

- A motion planning system for rehabilitation and assistive robotics is proposed.
- It is grounded on a combination of Learning by Demonstration and Dynamic Movement Primitives.
- The theoretical formulation has been described and a comparative analysis with the literature has been performed.
- An experimental validation on eight healthy subjects has been carried out during three activities of daily living with the robot assistance.



## Intelligent and Flexible Automation

Chair *Qinghua Zhu, GuangDong University of Technology*
Co-Chair *Cynthia Sung, University of Pennsylvania*

| 09:55–10:00 | TUA11.1 |
|---|---|

### Static and Dynamic Partitions of Inequalities and Their Application in Supervisor Simplification

Chen Chen and HeSuan Hu
School of EME, Xidian University, China
Yang Liu
School of SCSE, NTU, Singapore

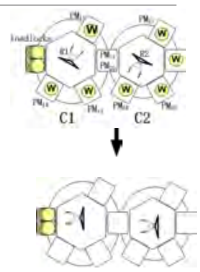
- First, static partition divides linear inequalities into independent and dependent ones based on the analysis of theoretically admissible markings. An dependent inequality is always dependent on the independent ones. This is the meaning of "static".
- Second, dynamic partition separates inequalities into active and inactive ones based on analysis of actually admissible markings. An inequality may be active in a current system but can become an inactive one in the augmented system where some specifications have been enforced. This is the meaning of "dynamic";
- The dynamically active inequality is also a statically independent one, but not vice versa. And the statically dependent inequality is also a dynamically inactive one, but not vice versa.
- Static partition does not require any system information while dynamic one does. They together can complementarily explain many simplification principles.

| 10:00–10:05 | TUA11.2 |
|---|---|

### Close-down Process Scheduling of Wafer Residence Time-Constrained Multi-cluster Tools

Qinghua Zhu
School of Computer Sci. & Tech., Guangdong University of Technology, China
Mengchu Zhou
Dept. of ECE, New Jersey Institute of Technology, USA
Yan Qiao, and Naiqi Wu
Institute of Systems Engineering, Macau University of Science and Technology, Taipa, Macau

- Multi-cluster tools are widely adopted as wafer fabrication equipment.
- It is especially difficult to schedule their frequently occurring close-down processes subject to wafer residency constraints.
- Analyze the synchronization conditions for multiple robots to perform concurrent activities.
- Propose a linear program model to find a feasible and optimal schedule for close-down processes.

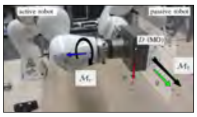


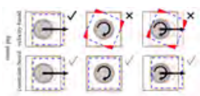

| 10:05–10:10 | TUA11.3 |
|---|---|

### Constraint-based Sample Propagation for Improved State Estimation in Robotic Assembly

Korbinian Nottensteiner, Katharina Hertkorn
Institute of Robotics and Mechatronics (RMC-RM), German Aerospace Center (DLR), Germany

- Observation of robotic assembly tasks with non-fixed parts in the workcell, e.g. sliding motion on table surface.
- Constraint-based sample propagation in state estimation using a sequential Monte Carlo approach.
- Experimental validation in a dual arm robot setup, in which one of the arms is used to simulate the motion of the sliding part in the environment.



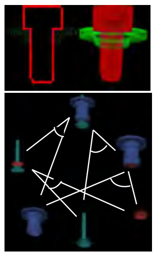


| 10:10–10:15 | TUA11.4 |
|---|---|

### Error Robust and Efficient Assembly Sequence Planning with Haptic Rendering Models

Robert Andre and Ulrike Thomas
Robotics and Human Machine Interaction Lab
Technical University of Chemnitz, Germany

- Anytime optimized assembly sequence planning for rigid and non-rigid assemblies using Haptic Rendering Models (HRMs).
- HRMs obtained from CAD-data, only.
- Automatic model analysis and scaling of HRMs to handle inconsistent meshes and parts of various sizes.
- Applies a strategy for automatic disassembly computation.
- Multi goal optimization on AND/OR graphs for assembly sequence planning.



| 10:15–10:20 | TUA11.5 |
|---|---|

### CoSTAR: Instructing Collaborative Robots with Behavior Trees and Vision

Chris Paxton, Andrew Hundt, Felix Jonathan, and Gregory D. Hager
Department of Computer Science, JHU, USA

- CoSTAR is a modular, cross-platform architecture for authoring robot task plans based on Behavior Trees.
- It allows ordinary end users to quickly author plans with a wide variety of different capabilities.
- It allows us to integrate perception, planning, and simple reasoning into a unified framework.
- CoSTAR won the 2016 KUKA Innovation Award, and source code is available online.

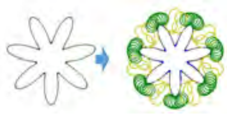
We deployed CoSTAR on two different platforms.

| 10:20–10:25 | TUA11.6 |
|---|---|

### Planning Cuts for Mobile Robots with Bladed Tools

Jeffrey Lipton and Daniela Rus
CSAIL, MIT, USA
Zachary Manchester
SEAS, Harvard University, USA

- Bladed tools in material can be modeled as modified Reeds-Shepp cars
- Unique path following constraints of blades lead to unique solutions.
- By decomposing the path into sections based on closure and curvature, we can find solutions.
- We built a mobile robot with a jigsaw that can cut materials using this algorithm.



Path cuts based on closure and curvature

## Intelligent and Flexible Automation

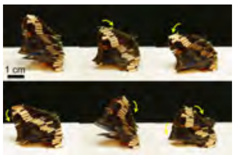
Chair *Qinghua Zhu, GuangDong University of Technology*
Co-Chair *Cynthia Sung, University of Pennsylvania*

| 10:25–10:30 | TUA11.7 |
|---|---|

### Self-folded Soft Robotic Structures with Controllable Joints

Cynthia Sung, Rhea Lin, Sangbae Kim, Daniela Rus
Massachusetts Institute of Technology, USA
Shuhei Miyashita
University of York, UK
Sehyuk Yim
Korea Institute of Science and Technology, Korea

- Rapid fabrication technique creates complex compliant structures that are **self-assembled and actuated in a few hours**
- Algorithms for designing and modeling structures fabricated using this technique
- Experimental verification through three fabricated static structures
- **Two end-to-end examples** demonstrating design, fabrication, and actuation



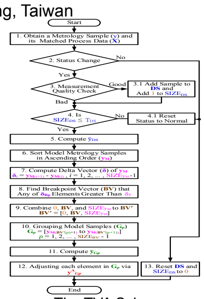
Bending motion of a fabricated model

| 10:30–10:35 | TUA11.8 |
|---|---|

### Automatic Virtual Metrology and Target Value Adjustment for Mass Customization

H. Tieng, C.-F. Chen, F.-T. Cheng
INST OF MEG INF & SYS, NCKU, Tainan, Taiwan
H.-C. Yang
INST. OF EE, NKFUST, Kaohsiung, Taiwan

- Core Values of Industry 4.0: people, products, and system → to advance toward Mass Customization (MC) Level
- Target Value Adjustment (TVA) + Automatic Virtual Metrology (AVM) → to enable AVM to have **Mass Customization** capability
- Illustrative examples of Wheel Machining Automation and Semiconductor Etching Process are adopted for demonstrating the versatility of the AVM-plus-TVA approach



The TVA Scheme

## Actuators 2

Chair *Koichi Suzumori, Tokyo Institute of Technology*
Co-Chair *Gim Song Soh, Singapore University of Technology and Design*

**11:30–11:35 | TUB1.1**

### A New Design Concept of Magnetically Levitated 4 Pole Hybrid Mover Driven by Linear Motor

Mirsad Bucak, Ahmet Fevzi Bozkurt, Kadir Erkan and Hüseyin Üvet
Mechatronic Engineering Department, Yıldız Technical University, TURKEY

- A new concept of magnetically levitated conveyor system
- Zero power control algorithm for efficiency
- Linear motor modelling and controller design
- Simulations and experimental results of proposed design with algorithms.

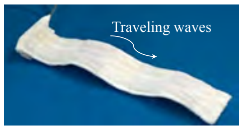
Magnetically levitated proposed conveyor system

**11:35–11:40 | TUB1.2**

### Soft Sheet Actuator Generating Traveling Waves Inspired by Gastropod's Locomotion

Masahiro Watanabe and Hideyuki Tsukagoshi
Department of Mechanical and Control Engineering, Tokyo Institute of Technology, Japan

- Soft sheet actuator capable of generating traveling waves, moving, and carrying is presented.
- Multiple traveling waves can be generated by pneumatics supplied from only three lines.
- It can also pass through even narrow and curved gap, while adapting its own shape to the environment.



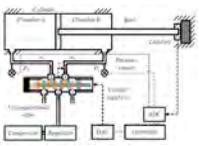

Soft sheet actuator generating traveling waves

**11:40–11:45 | TUB1.3**

### Modified Nonlinear Pressure Estimator of Pneumatic actuator for force controller design

Yun-Pyo Hong, Soohyun Kim and Kyung-Soo Kim
Division of Mechanical Engineering, Korea Advanced Institute of Science and Technology(KAIST), Republic of Korea

- A modified nonlinear pneumatic model for pneumatic force servo systems is proposed.
- By adopting flow coefficient maps, the estimations of pressures are conducted.
- The simulated and experiment data are compared and results show its accuracy compared to a conventional model
- The applicability of the proposed model to model-based controller design is also shown through the experiment of force servo controls

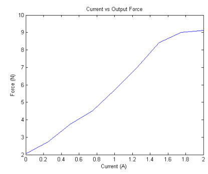


Experiment Setup for Pressure Estimator

**11:45–11:50 | TUB1.4**

### Magneto-Rheological Linear Clutch for Force Controlled Human Safe Applications

Achu Wilson, Sastra Robotics India Pvt Ltd

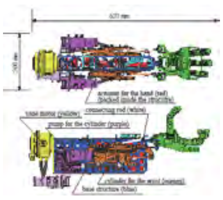


**11:50–11:55 | TUB1.5**

### Underactuated Four-fingered Hand with Five Electro Hydrostatic Actuators in Cluster

Tianyi Ko, Hiroshi Kaminaga and Yoshihiko Nakamura
Graduate School of Information Science and Technology, The University of Tokyo, Japan

- Hand system with high-efficiency electro-hydrostatic actuator(EHA) cluster and low friction tendon guidance.
- Discussion on energy loss in a EHA and design improvement in the hydraulic system.
- Forearm and wrist structure without any sliding contact between tendons and structure.

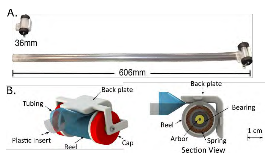


**11:55–12:00 | TUB1.6**

### Pneumatic Reel Actuator: Design, Modeling, and Implementation

Zachary Hammond, Nathan Usevitch, Elliot Hawkes, and Sean Follmer
Mechanical Engineering, Stanford University, USA

- The Pneumatic Reel Actuator (PRA) is highly extensible, lightweight, capable of operating in compression and tension, compliant, and inexpensive
- Extension ratio greater that 16:1
- Force-to-weight ratio of 28.3:1
- Speed of 0.89 meters per second




(A) The PRA in its contracted form and its extended form and (B) the reel mechanism.

**Actuators 2**

Chair *Koichi Suzumori, Tokyo Institute of Technology*
Co-Chair *Gim Song Soh, Singapore University of Technology and Design*

12:00–12:05 TUB1.7

### Deep Reinforcement Learning for Tensegrity Robot Locomotion

Marvin Zhang*, Xinyang Geng*, Jonathan Bruce*,
Ken Caluwaerts, Massimo Vespignani,
Vytas SunSpiral, Pieter Abbeel, Sergey Levine
UC Berkeley, UC Santa Cruz, Autodesk, NASA Ames, OpenAI, ICSI

- Tensegrity robots have a number of appealing properties but are difficult to control
- We automatically learn a locomotion gait for the SUPERball tensegrity robot (right) using mirror descent guided policy search
- Our simulation results show that our learned policies are more efficient than hand-designed open-loop policies and generalize to various environmental and system conditions
- Our real robot results demonstrate the first continuous, reliable locomotion for SUPERball

The SUPERball tensegrity robot. We learn a rolling gait from scratch for this robot with our algorithm.

12:05–12:10 TUB1.8

### Development of Giacometti Arm with Balloon Body

Masashi Takeichi
Department of Mechanical Engineering, Tokyo Institute of Technology, Japan
Koichi Suzumori, Gen Endo, and Hiroyuki Nabae
Graduate major in Mechanical Engineering, Tokyo Institute of Technology, Japan

- A prototype of a 7-m-long cantilever arm is designed, developed, and tested
- It is designed to be essentially safe even if it falls down or hits something
- It is expected to be used for inspection during the early stage of disasters
- It is realized using helium-filled balloon bodies and thin pneumatic muscles


Prototype of 7-link arm
( 7m, 340g, 7DOF )

## Motion Planning and Optimization

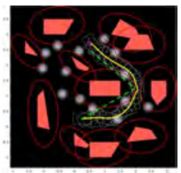
Chair *Kris Hauser, Duke University*
Co-Chair *Quang-Cuong Pham, Nanyang Technological University*

| 11:30–11:35 | TUB2.1 |
|---|---|

### T-LQG: Closed-Loop Belief Space Planning 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 belief space planning problem from ($n+n^2$) to ($n$).
- In contrast to previous methods, we do this in the space of *closed-loop* policies.
- We pose a coupled design of the underlying trajectory of the LQG and the estimator as a nonlinear program.
- We use the separation principle to keep the design of the controller separate from the estimator.



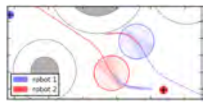
Optimized (solid) vs. initial (dashed) paths

| 11:35–11:40 | TUB2.2 |
|---|---|

### Real-Time Distributed Receding Horizon Motion Planning and Control for Mobile Multi-Robot Dynamic Systems

José M. Mendes Filho[a,b], Eric Lucet[a] and David Filliat[b]
[a] CEA, LIST, Interactive Robotics Laboratory, France
[b] U2IS, Inria FLOWERS team, Université Paris-Saclay, France

- Distributed Receding Horizon Motion Planning (DRHMP) approach is used to perform kinodynamic planning for multi-robot system
- Stabilization of unicycle-like vehicles' state around the planned trajectory is accomplished by a modified nonlinear model predictive control (NCGPC-M)
- Results found in simulation indicate that this approach can be applied to systems subjected to real-time constraints



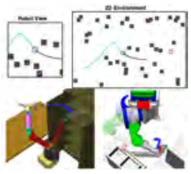

Example of kinodynamic planning of two unicycle-like vehicles

| 11:40–11:45 | TUB2.3 |
|---|---|

### Approximately Optimal Continuous-Time Motion Planning and Control via Probabilistic Inference

Mustafa Mukadam, Ching-An Cheng, Xinyan Yan, and Byron Boots
Institute for Robotics and Intelligent Machines, Georgia Tech, USA

- We provide an efficient algorithm, PIPC, that solves the problem of simultaneous planning and control by providing approximately optimal policies.
- PIPC can consider arbitrary higher-order nonlinear performance indices and scales only linearly in them.
- Efficiency results form a probabilistic interpretation of the problem and Gaussian process representation of trajectories.
- PIPC can handle partially observable linear stochastic systems in dynamic environments.



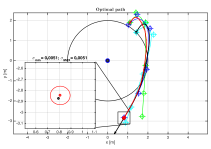
A 2D robot, WAM and PR2 using PIPC

| 11:45–11:50 | TUB2.4 |
|---|---|

### OnLine Optimal Active Sensing Control

Paolo Salaris and Patrick Rives
Inria Sophia-Antipolis Méditerranée
Riccardo Spica, Paolo Robuffo Giordano
CNRS at Irisa and Inria Rennes Bretagne Atlantique

- For a differentially flat system, we improve the estimation accuracy of an observer by determining the inputs of the system that maximize the amount/quality of information gathered by the outputs over a time horizon;
- The smallest eigenvalue $\lambda_{min}$ of the Observability Gramian is used to measure the amount/quality of information;
- The trajectory for the flat outputs of the system are parameterized by using B-Spline curves;
- An online gradient descent strategy is used to move the control points of the B-Spline and hence shaping it in order to actively maximize $\lambda_{min}$



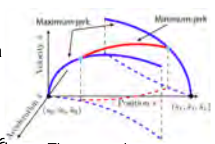
Optimal trajectory for a 2D system with one range output.

| 11:50–11:55 | TUB2.5 |
|---|---|

### The Time-Optimal Path Parameterization Problem with Third-Order Constraints

Hung Pham and Quang-Cuong Pham
School of Mechanical and Aerospace Engineering,
Nanyang Technological University, Singapore

- The Time-Optimal Path Parameterization problem (TOPP) with third-order constraints has as its optimal solutions profiles following a max-min-max structure.
- Frequently, there are third-order singularities which cause algorithm failures.
- This works presents an analysis and propose a treatment for third-order singularities.



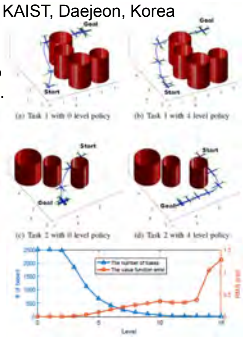

The max-min-max structure of TOPP with third-order constraints.

| 11:55–12:00 | TUB2.6 |
|---|---|

### Multiscale Abstraction, Planning and Control Using Diffusion Wavelets for Stochastic Optimal Control Problems

Jung-Su Ha and Han-Lim Choi
Department of Aerospace Engineering, KAIST, Daejeon, Korea

- This work presents a multiscale framework to solve the stochastic optimal control problems.
- Hierarchical abstraction is obtained from the robot dynamics via diffusion wavelet method.
- Using hierarchy, a global plan with coarse resolution and a detailed local plan for important regions are computed.
- Natural/sophisticated trade-off between the optimality and the computational cost can be exploited.



## Motion Planning and Optimization

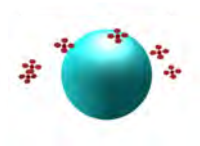
Chair *Kris Hauser, Duke University*
Co-Chair *Quang-Cuong Pham, Nanyang Technological University*

12:00–12:05 TUB2.7

### Differential Dynamic Programming with Nonlinear Constraints

Zhaoming Xie[1] Karen Liu[2] Kris Hauser[3]
1.School of Electrical and Computer Engineering, Georgia Tech, USA
2. School of Interactive Computing, Georgia Tech, USA
3. Department of Electrical and Computer Engineering, Duke University, USA

- New formulation of DDP that accommodates arbitrary nonlinear inequality constraints.
- Derivation of a recursive quadratic approximation formula in the presence of nonlinear constraints.
- Demonstration on several underactuated optimal control problems.



Trajectory of a quadcopter with a sphere obstacles.

12:05–12:10 TUB2.8

### SLIP-model-based Dynamic Gait Generation in a Leg-wheel Transformable Robot with Force Control

Yun-Meng Lin, Hung-Sheng Lin, and Pei-Chun Lin
Department of Mechanical Engineering, National Taiwan University, Taiwan

- Trajectories based on the SLIP model are applied on the robot to initiate trotting and pronking gait behaviors.
- Each leg-wheel of TurboQuad has one rotational DOF and one translational DOF.
- The SLIP-like spring effect of the leg-wheel is achieved using force control with motor current feedback.
- Four different dynamic behaviors with variations in stiffness and gait are tested.

The leg-wheel transformable robot *TurboQuad*.

## Computer Vision 2

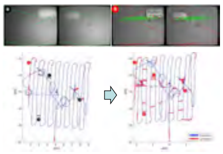
Chair *Andreas Zell, University of Tübingen*
Co-Chair *Rui Fukui, The University of Tokyo*

11:30–11:35 TUB3.1

### Visibility Enhancement for Underwater Visual SLAM based on Underwater Light Scattering Model

Younggun Cho and Ayoung Kim
Civil and Environmental Engineering, KAIST, South Korea

- The underwater images are often critically degraded by poor atmospheric conditions
- Conventional approaches fail on grayscale images and have a long computational time that is impractical
- The proposed algorithm presents the online image enhancement method with complex image model (e.g. light bias, blur, and haze)
- The ultimate objective of the method is to implement it in the visual SLAM pipeline with real-time performance



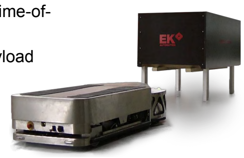
Visibility Enhancement & SLAM Improvement

11:35–11:40 TUB3.2

### Multi-sensor Payload Detection and Acquisition for Truck-Trailer AGVs

Sebastian Buck, Richard Hanten and Andreas Zell
Cognitive Systems, University of Tübingen, Germany
Karsten Bohlmann
EK Automation, Germany

- Real-time detection of payload carts for freely navigating automated guided vehicles.
- Containers are detected with 2D laser scanners.
- The pose is verified and refined using a time-of-flight camera.
- A reactive control law is proposed for payload acquisition.

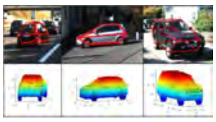


11:40–11:45 TUB3.3

### Reconstructing Vehicles From a Single Image: Shape Priors for Road Scene Understanding

J. Krishna Murthy, G.V. Sai Krishna, Falak Chhaya, and K. Madhava Krishna
Robotics Research Center, KCIS, Hyderabad, India

- Recover the **shape** and **pose** of a vehicle, given a **single** (RGB) image.
- Use object category-specific shape priors to do so
- But, the problem is ill-posed. So, we present a way to decompose the original problem into subproblems which leads to a fast and efficient solution.
- State-of-the-art results on the KITTI object dataset.



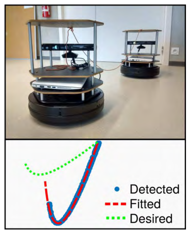
Sample pose and shape estimation output from our system

11:45–11:50 TUB3.4

### Catenary-based Visual Servoing for Tethered Robots

Matheus Laranjeira, Claire Dune and Vincent Hugel
Cosmer Laboratory EA 7398, University of Toulon, France

- Context: two mobile robots linked with a tether
- Objective: control the follower to guaranty that the tether does not hamper the leader motion
- A new visual servoing scheme for deformable-shape objects attached to the robot
- A detection and fitting method for online catenary parameter estimation

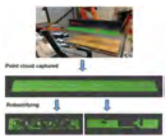



11:50–11:55 TUB3.5

### Robustifying Correspondence Based 6D Object Pose Estimation

Antti Hietanen, J.-K. Kämäräinen
Department of Signal Processing, Tampere University of Technology
Jussi Halme, Jyrki Latokartano
Department of Mechanical engineering and industrial systems, Tampere University of Technology
Anders Glent Buch
Maersk Mc-Kinney Moller Institute, University of Southern Denmark

- Curvature filtering and region pruning methods to improve 3D correspondence based object pose estimation.
- The methods are evaluated using three different state-of-the-art correspondence selection methods.
- Experiments show that the methods consistently robustify the initial versions of the algorithms.



Two filtering methods to improve 6DoF pose estimation

11:55–12:00 TUB3.6

### Driving in the Matrix: Can Virtual Worlds Replace Human-Generated Annotations for Real World Tasks?

Matthew Johnson-Roberson, Charles Barto, Rounak Mehta, Sharath Nittur Sridhar, Karl Rosaen, and Ram Vasudevan
College of Engineering, University of Michigan, USA

- We use purely simulated images to detect cars in real imagery
- We demonstrate the power of training on 200,000 images for improved results over current public data
- We show the challenges of domain adaptation across real data
- We publicly released the code to capture from a modern video game engine and the full dataset containing bounding boxes and pixel annotations

## Computer Vision 2

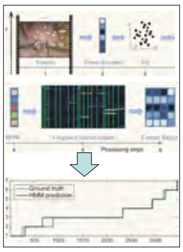
Chair *Andreas Zell, University of Tübingen*
Co-Chair *Rui Fukui, The University of Tokyo*

| 12:00–12:05 | TUB3.7 |
|---|---|

### Machine Learning and Coresets for Automated Real-Time Video Segmentation of Laparoscopic and Robot-Assisted Surgery

Mikhail Volkov[1], Daniel A. Hashimoto[2], Guy Rosman[1], Ozanan R. Meireles[2], Daniela Rus[1]
1) CSAIL, MIT, USA, 2) Department of Surgery, MGH, USA

- K-segment coresets enable real-time analysis of surgical video.
- A spatial BOW model for surgery phase classification w/ small training sets.
- Coresets enable stream segmentation w/ linear segment classifiers.
- Results on laparoscopic surgery videos, w/ 92% accuracy.

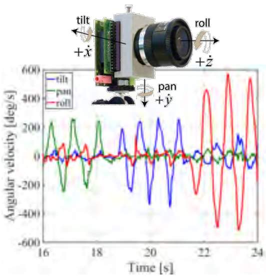


| 12:05–12:10 | TUB3.8 |
|---|---|

### Accurate Angular Velocity Estimation with an Event Camera

Guillermo Gallego and Davide Scaramuzza
Robotics and Perception Group, University of Zurich, Switzerland

- Estimate rotational motion using events.
- No need of optical flow estimation or image intensity reconstruction.
- Idea: Maximize contrast of accumulated event polarities along motion lines.
- Estimate high-speed motions: ~1000 °/s.
- Comparable accuracy to Motion-Capture System or IMU.



## Autonomous Agent

Chair *Christos Verginis, Electrical Engineering, KTH Royal Institute of Technology*
Co-Chair *Yen-Chen Liu, National Cheng Kung University*

| 11:30–11:35 | TUB4.1 |
|---|---|

### Multi-Objective Search for Optimal Multi-Robot Planning with Finite LTL Specifications and Resource Constraints

Philipp Schillinger[1,2] and Mathias Bürger[1]
[1] Bosch Center for Artificial Intelligence, Germany
Dimos V. Dimarogonas[2]
[2] KTH Royal Institute of Technology, Sweden

- Linear Temporal Logic (LTL) allows to formulate complex goals for autonomous systems
- Generating execution strategies for a team requires planning coupled with task allocation
- We model the LTL multi-robot planning problem as a multi-objective search
- Discrete LTL specifications can be combined with continuous resource constraints

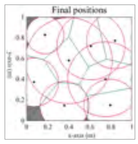
Two of our robots operating in an office environment.

| 11:35–11:40 | TUB4.2 |
|---|---|

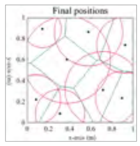
### Dynamic Coverage Control for Mobile Robot Network with Limited and Nonidentical Sensory Ranges

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

- This paper studies the coverage control problem for multiple mobile robot system with limited and dissimilar sensing abilities.
- Distance-dependent performance function is proposed to generate time-varying density function for coverage control.
- Missing areas due to distinct sensing ranges are taken into account to guarantee better coverage performance.
- Simulation and experiments are proposed to validate the system performance.



Traditional method



Proposed method

| 11:40–11:45 | TUB4.3 |
|---|---|

### Decentralized Motion Planning with Collision Avoidance for a Team of UAVs under High Level Goals

Christos K. Verginis, Ziwei Xu and Dimos V. Dimarogonas
School of Electrical Engineering, KTH Royal Institute of Technology, Sweden

- *N* UAVs in spherical workspace with regions of Interest (ROI)
- Local Feedback – limited sensing radius
- LTL formulas over the ROI → Desired path
- Navigation Functions guarantee navigation among the ROI with inter-agent collision avoidance.

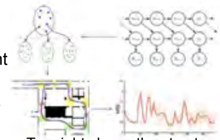
Two agents in a spherical workspace with 4 ROI

| 11:45–11:50 | TUB4.4 |
|---|---|

### A Layered HMM for Predicting Motion of a Leader in Multi-Robot Settings

Sina Solaimanpour and Prashant Doshi
THINC Lab, Department of Computer Science,
University of Georgia, Athens, GA 30602, USA

- Vehicles being e-towed and telepresence robots following others suffer from persistent occlusion while following
- Nested particle filter (NPF) allows both self-localization and tracking of another robot simultaneously using a motion model
- Monte Carlo layered HMM (MCLHMM) is a novel model that allows online prediction of other's motion with good accuracy
- Observations are used for parameter learning



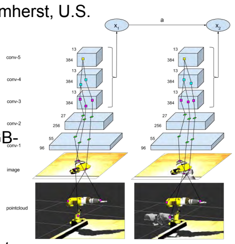
Top-right shows the structure of MCLHMM used in the NPF. Bottom figures depict the path that the robots move in simulation, and accuracy of MCLHMM in tracking the leader robot.

| 11:50–11:55 | TUB4.5 |
|---|---|

### An Aspect Representation for Object Manipulation Based on Convolutional Neural Networks

Li Yang Ku, Erik Learned-Miller, and Roderic Grupen
College of Information and Computer Sciences,
University of Massachusetts Amherst, U.S.

- We propose an *aspect representation* based on hierarchical CNN features that supports manipulation.
- We achieved state of the art results on instance pose estimation on Washington RGB-D Objects Dataset.
- Representation is combined with aspect transition graphs (ATGs) on a drill grasping task on Robonaut-2.
- Given manipulation demonstrations, the robot is capable of planning sequences of actions to compensate for reachability constraints.



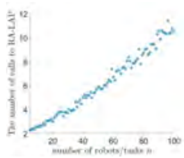
Architecture that incorporates aspect representations with ATGs.

| 11:55–12:00 | TUB4.6 |
|---|---|

### Algorithm for Optimal Chance Constrained Linear Assignment

Fan Yang and Nilanjan Chakraborty
Department of Mechanical Engineering
Stony Brook University, USA

- **Chance Constrained Linear Assignment Problem (CC-LAP)**: Given *n* robots and *n* tasks, with uncertain payoff for robot-task pairs find an assignment with maximum total payoff (say *y*) such that, irrespective of the actual values the random payoffs, the probability of the actual payoff being less than *y* is greater than a pre-specified probability (say 0.99).
- **Solution**: Novel iterative approach that uses the solution of a small number of Risk Averse Linear Assignment Problems (RA-LAP) with *deterministic payoffs* to solve the stochastic CC-LAP.
- RA-LAP is same as classical LAP where the robot-task payoff is a weighted combination of the mean and variance (weight is called risk-aversion index).



The number of calls to RA-LAP as a function of number of robots/tasks

**Autonomous Agent**

Chair *Christos Verginis, Electrical Engineering, KTH Royal Institute of Technology*
Co-Chair *Yen-Chen Liu, National Cheng Kung University*

12:00–12:05 TUB4.7

### An Adaptable, Probabilistic, NBV Algorithm for Reconstruction of Unknown 3D Objects

Jonathan Daudelin and Mark Campbell
Mechanical Engineering, Cornell University, USA

- Next Best View Planner for reconstructing unknown objects
- Probabilistic framework for predicting information gain from candidate viewpoints
- Dynamically adapts to any object size
- Computationally efficient

12:05–12:10 TUB4.8

### A Hybrid Method for Online Trajectory Planning of Mobile Robots in Cluttered Environments

Leobardo Campos-Macías, David Gómez-Gutiérrez, Rodrigo Aldana-López, Rafael de la Guardia and José I. Parra-Vilchis
Multi-Agent Autonomous Systems Lab, Intel Labs

- Our approach is a fusion of sampling-based techniques and model-based optimization via quadratic programming.
- The main contribution of this work is the formulation of a convex optimization problem over the generated obstacle-free path that is guaranteed to be feasible.
- The algorithm was applied to the fluid navigation of a quadcopter in one of the most densely clutter scenario reported to date.

Composite image of a quadcopter in one of the experiments.

## Multi-Robot Systems 2

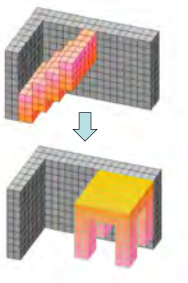
Chair *Mikko Lauri, University of Hamburg*
Co-Chair *Anna Valente, SUPSI-ISTePS*

11:30–11:35 TUB5.1

### Tunneling-based Self-reconfiguration of Heterogeneous Sliding Cube-shaped Modular Robots in Environments with Obstacles

Hiroshi Kawano
NTT Communication Science Laboratories, NTT Corporation, Japan

- The proposed method does not assume convex motion of sliding cubic-module.
- The proposed method combines homogeneous tunneling based transformation and heterogeneous permutation in goal configuration.
- The proposed method can be applied to arbitrary robot structures with 2 x 2 x 2 cubic meta-modules.
- Proof of the quadratic operation time cost of the reconfiguration process is provided.
- Only the space occupied by start and goal configurations is needed in the reconfiguration process; therefore, the method is applicable to the environments with obstacles.



11:35–11:40 TUB5.2

### Distributed Fixed-Time Cooperative Tracking Control for Multi-Robot Systems

Boda Ning, Jiong Jin, Jinchuan Zheng, Qing-Long Han
School of Software and Electrical Engineering, Swinburne University of Technology, Australia
Zongyu Zuo
The Seventh Research Division, Beihang University, China

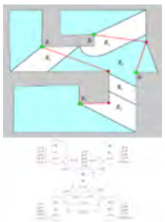
- Achieving the cooperative tracking for multi-robot systems in a fixed time;
- A new class of observers are proposed, under which the leader state is estimated by the followers in a fixed time;
- An observer-based fixed-time controller is proposed such that the estimated leader state is tracked in a fixed time;
- The results are extended to multi-robot systems with non-holonomic dynamics.

11:40–11:45 TUB5.3

### Hybrid System for Target Tracking in Triangulation Graphs

Guillermo Laguna and Sourabh Bhattacharya
Department of Mechanical Engineering, Iowa State University, USA

- A team of mobile guards must track an intruder in a simply-connected environment.
- Each guard moves along a specific diagonal of the triangulation of the environment.
- A hybrid automaton models the problem using event-triggered strategies of the guards.
- Sufficient conditions are presented for n/4 guards for persistent surveillance.



11:45–11:50 TUB5.4

### Smooth joint motion planning for high precision reconfigurable robot manipulators

Stefano Baraldo and Anna Valente
Department of Innovative Technlogies (DTI),
University of Applied Sciences and Arts of Southern Switzerland (SUPSI), Switzerland

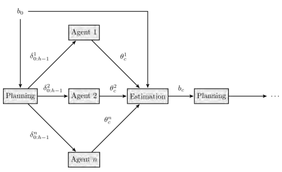
- High-precision manipulation (e.g. optoelectroincs) requires fast but smooth trajectories
- A smooth trajectory model has been reformulated to optimize execution times and limit kinematic quantities
- The proposed method is ideal for modular manipulators, reconfigured and reparametrize basing on on-line self-monitoring
- Experimental results yield smooth trajectories 39% faster than literature benchmark approaches.

11:50–11:55 TUB5.5

### Multi-Robot Active Information Gathering with Periodic Communication

Mikko Lauri and Simone Frintrop
Department of Informatics, University of Hamburg, Germany
Eero Heinänen
Laboratory of Automation and Hydraulics, Tampere University of Tech., Finland

- Team of robots executing information gathering task with periodic communication capability
- Introduce extension of decentralized POMDPs to information gathering rewards
- Feasibility demonstrated in target tracking problem




11:55–12:00 TUB5.6

### Bipartite Graph Matching-based Coordination Mechanism for Multi-robot Path Planning under Communication Constraints

Ayan Dutta and Prithviraj Dasgupta
Department of Computer Science, University of Nebraska at Omaha
Omaha, Nebraska, USA

- We propose a bipartite graph matching-based distributed coordination mechanism for multiple robots to avoid collisions and reach goals by travelling shorter paths.
- Robots have limited communication range and they *only* coordinate with other robots when they are in close proximity.
- Our algorithm is proved to be correct, convergent and helps robots to travel lesser path (up to 4.2 times) than a comparable heuristic.

Illustration: Two robots A and B are in close proximity to coordinate (left); A and B's local copies of bipartite graphs (middle); example of a congested test environment with 8 robots (right).

**Multi-Robot Systems 2**

Chair *Mikko Lauri, University of Hamburg*
Co-Chair *Anna Valente, SUPSI-ISTePS*

| 12:00–12:05 | TUB5.7 |
|---|---|

### Scalable Accelerated Decentralized Multi-Robot Policy Search in Continuous Observation Spaces

Shayegan Omidshafiei[1], Christopher Amato[2], Miao Liu[3]
Michael Everett[1], Jonathan P. How[1], and John Vian[4]
[1]LIDS, MIT, MA [2]CCIS, Northeastern University, MA, USA
[3]IBM, NY, USA [4]Boeing Research & Technology, WA, USA

- We present kernel-based stochastic policy representation for scalable continuous observation space decision-making
- Algorithm outperforms existing discrete search approaches for complex decentralized and partially-observable planning domain

| 12:05–12:10 | TUB5.8 |
|---|---|

### Semantic-level Decentralized Multi-Robot Decision-Making using Probabilistic Macro-Observations

Shayegan Omidshafiei[1], Shih-Yuan Liu[1], Michael Everett[1],
Brett T. Lopez[1], Christopher Amato[2], Miao Liu[3]
Jonathan P. How[1], and John Vian[4]
[1]LIDS, MIT, MA, USA [2]CCIS, Northeastern University, MA, USA
[3]IBM, NY, USA [4]Boeing Research & Technology, WA, USA

- Hierarchical Bayesian approach to model noise statistics of low-level classifier outputs
- Enables multi-agent planners to perform policy search with perception-in-the-loop
- Real-time hardware experiments, observation pipeline fully onboard team of 4 quadrotors


Hardware demo snapshot

## Learning and Adaptive Systems 2

Chair *Lynne Parker, University of Tennessee*
Co-Chair *Matthew Howard, King's College London*

| 11:30–11:35 | TUB6.1 |
|---|---|

### Preference Learning on the Execution of Collaborative Human-Robot Tasks

Thibaut Munzer
Flowers, Inria, France
Marc Toussaint
MLR, USTT, Germany
Manuel Lopes
INESC-ID, IST, Portugal

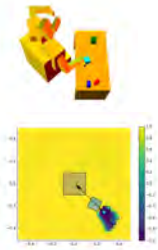
- Preferences Learning in collaborative task
- Built on Relational Activity Process, a model to represent concurrent activities under the semi-MDP framework
- Uses Interactive Learning
- Implementation and evaluation in simulations and on a Baxter robot

| 11:35–11:40 | TUB6.2 |
|---|---|

### Learning composable models of parameterized skills

Leslie Kaelbling and Tomas Lozano-Perez
CSAIL, MIT, USA

- We focus on learning models of the pre-conditions and effects of new parameterized skills.
- We then package these skills as operators that can be combined with other existing abilities by a generative planning and execution system.
- A pilot demonstration illustrates integrating a pushing skill into the existing BHPN pick-and-place planner.



| 11:40–11:45 | TUB6.3 |
|---|---|

### Self-supervised learning of tool affordances from 3D tool representation through parallel SOM mapping

Tanis Mar, Vadim Tikhanoff, Giorgio Metta and Lorenzo Natale
iCub Facility, Italian Institute of Technology, Italy

- Self-supervising tool affordance learning from interaction.
- Gradual representation of tool and affordance spaces by means of dimensionality reduction onto parallel SOMs.
- Application and analysis of robot-centric 3D tool descriptors specifically devised for interaction scenarios.
- High affordance prediction accuracy and task success rate.

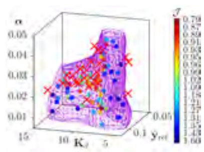
iCub Tool Use Learning Scenario

| 11:45–11:50 | TUB6.4 |
|---|---|

### Constrained Bayesian Optimization of Combined Interaction Force/Task Space Controllers for Manipulations

Danny Drieß, Peter Englert and Marc Toussaint
Machine Learning & Robotics Lab, University of Stuttgart, Germany

- Optimization of controller parameters under a discrete success constraint with constrained Bayesian optimization
- Combined interaction force/task space controller framework
- Evaluation criteria for compliant, force controlled robots
- Experiments with PR2 robot for establishing and maintaining contact while sliding on a surface with desired force reference



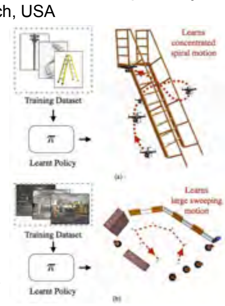
Data points and learned success boundary

| 11:50–11:55 | TUB6.5 |
|---|---|

### Learning to Gather Information via Imitation

Sanjiban Choudhury
Robotics Institute, Carnegie Mellon University, USA
Ashish Kapoor, Gireeja Ranade and Debadeepta Dey
Microsoft Research, USA

- Performance of an information gathering policy is affected by the spatial distribution of objects in an environment (E.g. Inspecting ladders v/s construction sites).
- We present a novel data-driven imitation learning framework to learn customized policies for different environment types.
- Learn effective policies by imitating clairvoyant oracles that have full knowledge about the world at train time.

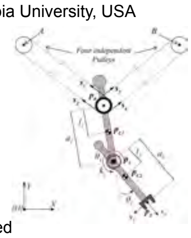



| 11:55–12:00 | TUB6.6 |
|---|---|

### Design and optimal control of an under-actuated cable-driven micro-macro robot

Luca Barbazza and Giulio Rosati
Department of Management and Engineering, University of Padua, Italy
Damiano Zanotto
Department of Mechanical Engineering, Stevens Institute of Technology, USA
Sunil K. Agrawal
Department of Mechanical Engineering, Columbia University, USA

- A planar under-actuated Cable-Driven Micro-Macro Robot (u-CDMMR) is presented.
- The system is a two link passive serial manipulator attached to a Cable-Suspended Parallel Robot.
- The differential flatness framework is applied to make the system controllable for point-to-point movements.
- A novel optimization procedure, based on multi-objective optimization and optimal control, is presented



**Learning and Adaptive Systems 2**

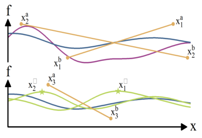
Chair *Lynne Parker, University of Tennessee*
Co-Chair *Matthew Howard, King's College London*

| 12:00–12:05 | TUB6.7 |
|---|---|

### A Sample-Efficient Black-Box Optimizer to Train Policies for Human-in-the-Loop Systems with User Preferences

Nitish Thatte[1], Helei Duan[2], and Hartmut Geyer[1]
[1]Robotics institute, [2]Mechanical Engineering, Carnegie Mellon University, USA

- Optimizing human-in-the-loop systems can be difficult as it can be hard to define the objective
- We may be able to learn from preferences to optimize systems via user feedback
- We present a Bayesian optimization method that uses preferences between pairs of parameters
- The algorithm chooses queries that it expects will decrease uncertainty in the distribution of optima

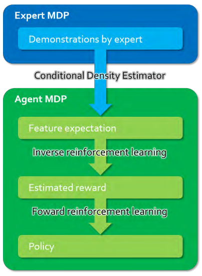


| 12:05–12:10 | TUB6.8 |
|---|---|

### Apprenticeship Learning in an Incompatible Feature Space

Gakuto Masuyama[1] and Kazunori Umeda[1]
[1]Department of Precision Mechanics, Faculty of Science and Engineering, Chuo University, Japan

- Apprenticeship learning in which an expert and agent are assumed to observe different features.
- Feature expectation in the agent feature space is estimated in closed-form by using conditional density estimation technique.
- Simulation results demonstrated the proposed method successfully transferred a reward function among heterogeneous MDP.



## Force and Tactile Sensing 2

Chair *Alexander Schmitz, Waseda University*
Co-Chair *Nathan Lepora, University of Bristol*

| 11:30–11:35 | TUB7.1 |
|---|---|

### Development of an Optical Fiber-based Sensor for Grasping and Axial Force Sensing

Pouya Soltani Zarrin, Abelardo Escoto, Ran Xu, Rajni V. Patel, Michael D. Naish and Ana Luisa Trejos
Canadian Surgical Technologies and Advanced Robotics, Lawson Health Research Institute and Western University, London, Ontario, Canada

- A sterilizable sensorized needle-driver style grasper capable of measuring axial and grasping forces directly at the tip of the instrument has been designed and developed.
- Accuracies of 0.19 N and 0.26 N were achieved for the grasping and axial sensing, respectively.
- Fiber Bragg Grating sensors were chosen due to their sterilizability and high sensitivity.


Optical fiber-based sensor for grasping and axial force sensing in MIS

| 11:35–11:40 | TUB7.2 |
|---|---|

### Sensorless Kinesthetic Teaching of Robotic Manipulators Assisted by Force Control

M. M. G. Ardakani, R. Johansson and A. Robertsson
Automatic Control, LTH, Lund University, Sweden
M. Capurso and P. Rocco
DEIB, Politecnico di Milano, Italy

- Lead-through programming (LTP): the user manually guides the manipulator to teach trajectories.
- This paper presents a sensorless approach to LTP for redundant robots.
- The active implementation (LTP assisted by Force Control) utilizes an admittance control.
- The external forces applied by the user are estimated with a Kalman filter. The static friction is mitigated by a dithering technique.


ABB YuMi was used for experiments

| 11:40–11:45 | TUB7.3 |
|---|---|

### Shape-independent Hardness Estimation Using Deep Learning and a GelSight Tactile Sensor

Wenzhen Yuan[1], Chenzhuo Zhu[2,1], Andrew Owens[1,3], Mandayam Srinivasan[1,4], Edward Adelson[1]
[1]MIT, US [2]Tsinghua University, China [3]UC Berkeley, US [4]UCL, UK

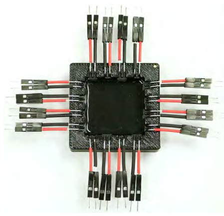
- Proposed a method of measuring hardness with tactile sensor in loosely-controlled contact condition
- Sensor being used: a high-resolution tactile sensor, GelSight, to measure object shape and force
- Applied convolutional neural network (CNN) for data analysis
- Build a dataset of 7,000 contacts on objects with varied shapes and hardness


| 11:45–11:50 | TUB7.4 |
|---|---|

### Accurate contact localization and indentation depth prediction with an optics-based tactile sensor

P. Piacenza[1], W. Dang[2], E. Hannigan[1], J. Espinal[1], I. Hussein[1], I. Kymissis[2] and M. Ciocarlie[1]
Dept. of Mechanical Eng.[1], Electrical Eng.[2], Columbia University, USA

- A tactile sensor based on light transport through an optically clear elastomer.
- We leverage two different modes of light transport to improve our sensor sensitivity to light and hard indentations.
- We use data driven techniques to directly learn the mapping between our signals and the contact location and depth.



| 11:50–11:55 | TUB7.5 |
|---|---|

### Low-cost 3-axis soft tactile sensors for the human-friendly robot Vizzy

T. Paulino[1], P. Ribeiro[1,2], M. Neto[2], S. Cardoso[1,2], A. Schmitz[3], J. Santos-Victor[4], A. Bernardino[4] and L. Jamone[5,4]
[1]D. Physics, IST, Portugal, [2]INESC-MN, Portugal, [3]Waseda University, Japan, [4]ISR, IST, Portugal, [5]ARQ, Queen Mary University of London, UK.

- Low-cost and easy to fabricate 3D soft tactile sensor, based on magnetic technology.
- All components are cheap and easy to retrieve and to assemble.
- High sensitivity, low hysteresis, good repeatability and mechanical robustness.
- Sensors were integrated on a robot hand, and been able to measure normal forces <10 mN and shear forces <20 mN.

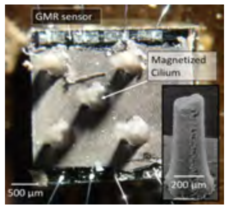

The tactile sensor mounted on the fingers of the Vizzy robot hand.

| 11:55–12:00 | TUB7.6 |
|---|---|

### Bio-inspired ciliary force sensor for robotic platforms

P. Ribeiro[1,2], M. A. Khan[3], A. Alfadhel[3], J. Kosel[3], F. Franco[1,2], S. Cardoso[1,2], A. Bernardino[4], A. Schmitz[5], J. Santos-Victor[4] and L. Jamone[6,4]
[1]INESC-MN, Portugal, [2]D. Physics, IST, Portugal, [3]CEMSE, KAUST, Saudi Arabia, [4]ISR, IST, Portugal, [5]Waseda University, Japan, [6]ARQ, Queen Mary University of London, UK

- We present a miniaturized force sensor inspired by biological cilia, designed to detect very small forces using magnetic technology.
- Experiments show that a minimum force of 333 μN can be detected.
- Accurate simulations were performed to optimize the structure of the fabricated sensor, using a novel simulation model that was successfully validated against the experimental results.



Main figure: the fabricated sensor. Inset: microphotography of a pillar.

## Force and Tactile Sensing 2

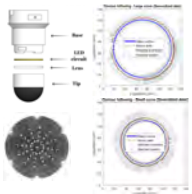
Chair *Alexander Schmitz, Waseda University*
Co-Chair *Nathan Lepora, University of Bristol*

| 12:00–12:05 | TUB7.7 |
|---|---|

### Exploiting sensor symmetry for generalized tactile perception in biomimetic touch

Benjamin Ward-Cherrier, Luke Cramphorn and Nathan Lepora
Bristol Robotics Laboratory and Department of Engineering Mathematics,
University of Bristol, UK

- Standard classification methods in robot touch require extensive training, limiting their practicality.
- We consider angle and position classification with a tactile fingertip (the BRL TacTip)
- Geometric transformations were applied to tactile data based on the TacTip's intrinsic symmetry, reducing training time 12-fold with comparable localization performance.
- Methods were applied to a contour following task, demonstrating greatly reduced training for robust performance.



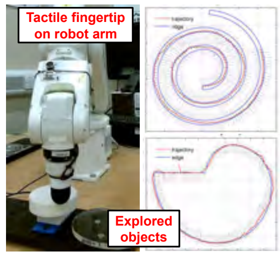
3d-printed TacTip sensor. Symmetric pin layout for generalized perception (left). Contour following (right)

| 12:05–12:10 | TUB7.8 |
|---|---|

### Exploratory tactile servoing with active touch

Nathan F. Lepora, Kirsty Aquilina & Luke Cramphorn
Bristol Robotics Laboratory & Department of Engineering Mathematics,
University of Bristol, U.K.

- Key problem in tactile robotics is to combine **tactile perception & control** for robust and intelligent robot behavior
- Investigated with **contour following** using a **3d-printed tactile fingertip** (the BRL TacTip) on a robot arm
- We use a single control loop for **active perception and tactile exploration**
- Method simplifies with **tactile servoing** to maintain sensor orientation on object
- **Robust & accurate performance** on laminar objects, e.g. disks and spirals



## Human-Robot Interaction 1

Chair *Gordon Cheng, Technical University of Munich*
Co-Chair *Cristian Secchi, Univ. of Modena & Reggio Emilia*

11:30–11:35 TUB8.1

### Safe Navigation and Experimental Evaluation of a Novel Tire Workshop Assistant Robot

Alessio Levratti and Giuseppe Riggio and Cristian Secchi and Cesare Fantuzzi
DISMI - University of Modena and Reggio Emilia, Italy
Antonio De Vuono
CORGHI S.p.a., Correggio (RE), Italy

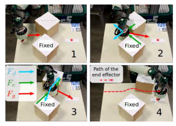
- TIREBOT: TIRE workshop roBOTic assistant
- A novel safe navigation strategy for human/robot cooperation
- Proposed method validated both through simulation and experiments
- Robot's performance evaluated on the field in a real tire workshop.

11:35–11:40 TUB8.2

### Using Intentional Contact to Achieve Tasks in Tight Environments

J. Rogelio Guadarrama-Olvera, Emmanuel Dean-Leon and Gordon Cheng
Institute for Cognitive Systems, Technical University of Munich, Germany
www.ics.ei.tum.de

- Intentional Contact defined to modify the environment to achieve tasks.
- Contact regulated with tactile feedback.
- Collision avoidance with directly measured potential fields.
- Hierarchy rearrangement to escape from classic potential fields local minimum.



Experimental results

11:40–11:45 TUB8.3

### Reducing Errors in Object Fetching Interactions Through Social Feedback

David Whitney[1], Eric Rosen[1], James MacGlashan[2], Lawson L.S. Wong[1], Stefanie Tellex[1]
1. Department of Computer Science, Brown University, USA
2. Cogitai, Inc.

- Question asking in human robot interactions improves accuracy and speed of fetching tasks for robots
- System decides which questions to ask by approximately solving a Partially Observable Markov Decision Process (POMDP)
- Results from user study show our model is 2.17s (25%) faster and 2.1% more accurate than state-of-the-art baseline

Storyboard of system in action

11:45–11:50 TUB8.4

### Transparent Role Assignment and Task Allocation in Human Robot Collaboration

A. Roncone, O. Mangin and B. Scassellati
Yale University, USA

- We implemented a system able to proactively engage in task allocation during collaborative construction tasks
- The system is able to plan under uncertainty about the state of the task and the intentions of the human partner
- It optimizes when to communicate and what to communicate about
- It is transparent by design
- Improved performance in terms of completion time
- General user preference toward the proposed system

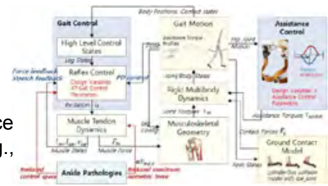
11:50–11:55 TUB8.5

### Simulating Gait Assistance of a Hip Exoskeleton: Case Studies for Ankle Pathologies

Bokman Lim, Seungyong Hyoung, Jusuk Lee, Keehong Seo, Junwon Jang, and Youngbo Shim

Samsung Advanced Institute of Technology, Korea

- This paper presents a simulation framework for gait assistance with a hip exoskeleton.
- We simulate gait assistance with ankle pathologies (e.g., weak dorsiflexion and/or plantarflexion).



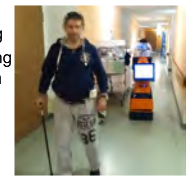
Simulation framework for gait assistance

11:55–12:00 TUB8.6

### Mobile Robot Companion for Walking Training of Stroke Patients in Clinical Post-stroke Rehabilitation

H.-M. Gross*, S. Meyer**, A. Scheidig* et al.
*Ilmenau University of Technology, ** SIBIS Institute for Social Research, Germany

- **Subject**: novel robot-based approach to the stroke rehabilitation scenario, in which a robotic companion accompanies stroke patients during their self-training
- **Our contribution**: approach for systematic evaluating the autonomy & practicability of assistive robots from technical and social sciences point of view
- **Outcome**: results of user trials with N=30 stroke patients performed in a stroke rehabilitation center between 4/2015 and 3/2016
- **Findings**: i) robot-escorted walking training is prefe-able over walking without this service ii) robot motiva-ted patients for independent training, iii) it encouraged them to expand the radius of their training in the clinic



Robot companion following a stroke patient during his walking training

## Human-Robot Interaction 1

Chair *Gordon Cheng, Technical University of Munich*
Co-Chair *Cristian Secchi, Univ. of Modena & Reggio Emilia*

| 12:00–12:05 | TUB8.7 |
|---|---|

### Development of a Block Machine for Volleyball Attack Training

Kosuke Sato[1], Keita Watanabe[2], Shuichi Mizuno[2]
Masayoshi Manabe[2], Hiroaki Yano[1] and Hiroo Iwata[1]
[1]University of Tsukuba, Japan
[2]Japan Volleyball Association, Janan

- A system that consists of three robots to imitate the motion of top volleyball blockers.
- It can be continuously used in an actual practice field to improve attack practice.
- An application with a graphical user interface to enable a coach to manipulate these robots
- It enables the coach to control block motions and change the parameters

| 12:05–12:10 | TUB8.8 |
|---|---|

### ICRA 2017
### Hierarchical Cascade Controller for Assistance Modulation in a Soft Wearable Arm Exoskeleton

Binh Khanh Dinh[1], Michele Xiloyannis[1], Chris Wilson Antuvan[1], Leonardo Cappello[2], and Lorenzo Masia[1]
[1] Mechanical Engineering, Nanyang Technological University, Singapore
[2] School of Engineering and Applied Science, Harvard University, USA

- A novel soft wearable exoskeleton (exosuit) using Bowden-cable transmission for human arm assistance.
- Hierarchical Cascade Controller considering all the aspects ranging from human motion intention detection to adaptive compensation for nonlinear effects (i.e. backlash and friction).
- Assistance modulation by ‘assisted-as-needed’ admittance controller meaning the level of assistance depends on the voluntary motion capacity of the subjects.

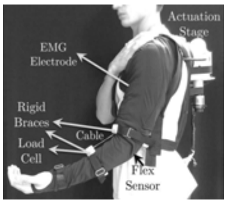



*Figure: The soft arm exosuit with the Bowden-cable transmission worn by the user.*

## Multilegged Robots

Chair *Claudio Semini, Istituto Italiano di Tecnologia*
Co-Chair *Navinda Kottege, CSIRO*

| 11:30–11:35 | TUB9.1 |
|---|---|

### The Multilegged Autonomous eXplorer (MAX)

A. Elfes, R. Steindl, F. Talbot, F. Kendoul, P. Sikka, T. Lowe, N. Kottege, M. Bjelonic, R. Dungavell, T. Bandyopadhyay, M. Hoerger, B. Tam and D. Rytz
CSIRO Robotics and Autonomous Systems Lab

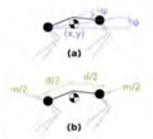
- MAX is an ultralight, six-legged robot with 18 DOFs.
- MAX is 2.25 m tall at full height and weighs 59.8 kg. In a cruise stance the body is 1.5 m above the ground.
- MAX is used for research in modelling, planning, control and autonomous navigation of Ultralight Legged Robots subject to flexing, oscillations and swaying.

| 11:35–11:40 | TUB9.2 |
|---|---|

### Empirical Validation of a Spined Sagittal-Plane Quadrupedal Model

Jeffrey Duperret and Daniel Koditschek
Electrical and Systems Engineering, University of Pennsylvania, U.S.A.

- We present a model for robotic spined sagittal-plane quadrupedal locomotion.
- This model is demonstrated on a power-autonomous bounding spined quadrupedal robot.
- The model is sufficiently accurate as to roughly describe the robot's mass center trajectory.



Reduced order model for a spined sagittal-plane quadrupedal robot.

| 11:40–11:45 | TUB9.3 |
|---|---|

### A Testbed that Evolves Hexapod Controllers in Hardware

Huub Heijnen, David Howard, and Navinda Kottege
Autonomous Systems Lab, CSIRO, Australia

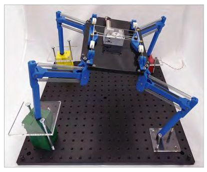
- Testbed allows 24/7 optimisation
- **Stage 1:** Multi-Objective Evolutionary Algorithm bootstraps a population of controllers (PI and foot-tip arcs for 3 leg-pairs) to minimise energy, and maximise stability and smoothness.
- **Stage 2**: Hill-climber specialises a selected controller further based on desired ordering of objectives, per leg.
- Controllers are sensitive to hardware state & mission type.

| 11:45–11:50 | TUB9.4 |
|---|---|

### Between-Leg Coupling Schemes for Passively-Adaptive Non-Redundant Legged Robots

Oren Y. Kanner and Aaron M. Dollar
Dept. of Mechanical Engineering and Materials Science, Yale University, USA
Nicolas Rojas
Dyson School of Design Engineering, Imperial College London, UK

- Legged robots can adapt to terrain with redundant actuation, but this can lead to overconstraint.
- Non-redundant legged robots can achieve full control and adaptability while reducing complexity and cost.
- A strategy for designing between-leg couplings for adaptive swing and robust stance behavior is presented.
- A 4-RR case study is analyzed through stance simulations with experimental validation.

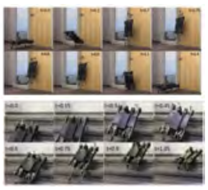


| 11:50–11:55 | TUB9.5 |
|---|---|

### Quasi-Static and Dynamic Mismatch for Door Opening and Stair Climbing With a Legged Robot

T. Turner Topping[1], Gavin Kenneally[2] and Daniel E. Koditschek[1]
[1]ESE, University of Pennsylvania, USA
[2]MEAM, University of Pennsylvania, USA

- We quantify the notion of robotic fitness by developing necessary conditions for quasi-static solutions to human-scale tasks
- We present empirical dynamic workarounds for door opening and stair climbing
- We are able to accomplish human-scale tasks that are otherwise unachievable with a 0.4 meter quadruped using dynamical maneuvers



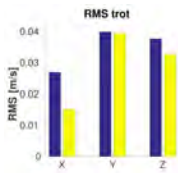
Depictions of dynamic door opening and stair climbing behaviors

| 11:55–12:00 | TUB9.6 |
|---|---|

### Probabilistic Contact Estimation and Impact Detection for State Estimation of Quadruped Robots

Marco Camurri*, Maurice Fallon†, Stéphane Bazeille‡, Andreea Radulescu*, Victor Barasuol*, Darwin G. Caldwell*, and Claudio Semini*
*Advanced Robotics, Istituto Italiano di Tecnologia, Italy
†School of Informatics, University of Edinburgh, UK
‡IRCCyN, Ecole des Mines de Nantes, France

- Leg Odometry without contact sensors, fused with inertial process model in a modular EKF
- Contact classification with logistic regression on GRF computed from joint torques
- Online covariance with impact detection by GRF analysis and inter-leg velocity variance
- Tested on different gaits and more than one hour of experiments with the 85 kg dynamic legged robot HyQ




RMSE on velocity is reduced up to half with the proposed method

## Multilegged Robots

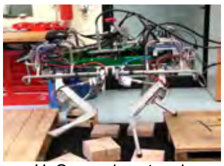
Chair *Claudio Semini, Istituto Italiano di Tecnologia*
Co-Chair *Navinda Kottege, CSIRO*

| 12:00–12:05 | TUB9.7 |
|---|---|

### Trajectory and Foothold Optimization using Low-Dimensional Models for Rough Terrain Locomotion

C. Mastalli[1], M. Focchi[1], I. Havoutis[2,4], A. Radulescu[1], S. Calinon[2], J. Buchli[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]Agile and Dexterous Robotics Lab, ETH Zurich, Zurich, Switzerland
[4]Oxford Robotics Institute, Department of Engineering Science, University of Oxford, UK

- Jointly optimize CoM motions, step durations and foothold locations, while considering terrain topology
- Gait adapts to the terrain by modulating the trunk attitude and ensuring dynamic stability
- Receding horizon planning for synthetizing walking gaits
- Robust and accurate locomotion over challenging terrain

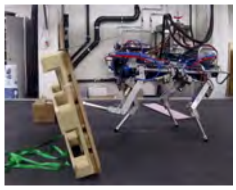

HyQ crossing stepping stones with various heights

| 12:05–12:10 | TUB9.8 |
|---|---|

### Trajectory Optimization Through Contacts and Automatic Gait Discovery for Quadrupeds

Michael Neunert, Farbod Farshidian, Alexander W. Winkler, Jonas Buchli
Agile & Dexterous Robotics Lab, ETH Zurich, Switzerland

- Whole-body Trajectory Optimization through contacts
- Automatic discovery of gaits
- Contact timings are an outcome of the optimization and not pre-specified
- Successful hardware experiments on the quadrupedal robot HyQ



## Medical Robots and Systems 1

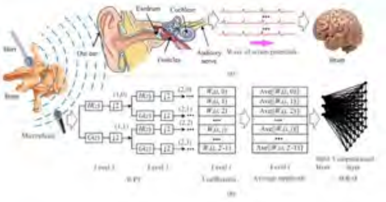
Chair *Paolo Dario, Scuola Superiore Sant'Anna*
Co-Chair *Conor James Walsh, Harvard University*

11:30–11:35 TUB10.1

### Biologically-inspired auditory perception during robotic bone milling

Yu Dai[1], Yuan Xue[2], Jianxun Zhang[1], and Jianmin Li[3]
[1]IRAIS, Nankai University, China
[2]Department of Orthopedic Surgery, Tianjin Medical University, China
[3]Key Lab for Mechanism Theory and Equipment Design, Tianjin University, China

- Microphone is mounted on robot arm and measures sound generated from bone milling.
- Mechanism of human auditory inspires our work, a similar method is proposed to identify the milling states.



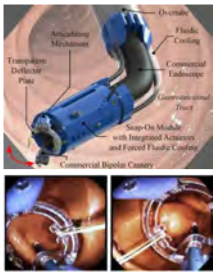
Mechanism of human auditory sense and proposed auditory perception method

11:35–11:40 TUB10.2

### A High-Force, High-Stroke Distal Robotic Add-On for Endoscopy

Joshua Gafford, Robert Wood, Conor Walsh
John A. Paulson School of Engineering and Applied Sciences, Harvard, USA

- Fully-deployable robotic module snaps on to existing endoscopes and provides additional distal dexterity
- System generates maximum 10N lateral force and a stroke of 96 degrees
- Helical SMA antagonists with forced fluidic cooling for improved actuation speed
- Integration with commercial endoscope shows that the system can add active control to otherwise passive flexible tools



*(top)* system render, *(bottom)* view through endoscope camera

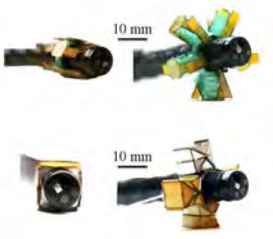
11:40–11:45 TUB10.3

HARVARD School of Engineering and Applied Sciences — HARVARD MICROROBOTICS LABORATORY — Harvard Biodesign Lab — WYSS INSTITUTE

### Deployable stabilization mechanisms for endoscopic procedures

T. Ranzani, S. Russo, F. Schwab, C.J. Walsh, R.J. Wood

- Endoscope's flexibility (necessary for navigating through the GI tract) limits distal manipulation and stability during surgical procedures.
- We propose a deployable endoscopic add-on aimed at locally counteracting forces applied at the tip of an endoscope.
- We focus on the fabrication and experimental characterization of three different structures and present some preliminary designs and integration strategies to mount them on top of current flexible endoscopes.



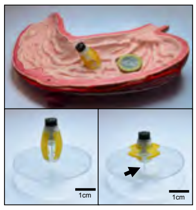


11:45–11:50 TUB10.4

### Magnetically Actuated Soft Capsule Endoscope for Fine-Needle Aspiration Biopsy

Donghoon Son[1,2], Mustafa Doga Dogan[3], and Metin Sitti*[1,2]
[1]Physical Intelligence Department, Max Planck Institute for Intelligent Systems, Germany
[2]Mechanical Engineering Department, Carnegie Mellon University, USA
[3]Electrical and Electronics Engineering Department, Bogazici University, Turkey

- Fine-needle penetrates deeply into tissues to obtain subsurface biopsy sample
- The design utilizes a soft elastomer body as a compliant mechanism and an internal permanent magnet for actuation and tracking
- Roll towards the target and deploy the biopsy needle in a precise location
- Demonstrated rolling locomotion and biopsy of a swine tissue model inside an anatomical human stomach model



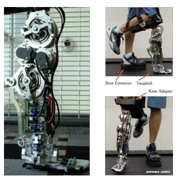
*Prototype and deployment of fine-needle using external magnetic actuation*

11:50–11:55 TUB10.5

### Preliminary Results on Energy Efficient 3D Prosthetic Walking with a Powered Compliant Transfemoral Prosthesis

Huihua Zhao
SRI Robotics, Menlo Park, CA, USA
Eric Ambrose and Aaron Ames
California Institute of Technology, Pasadena, CA, USA.

- A transfemoral prosthetic, AMPRO3, is designed and used to achieve 3D efficient walking
- A Hybrid, 8 Domain, human-and-prosthetic model and optimization generates walking gaits
- Treadmill testing in lab shows the realized multi-contact walking is successful and efficient



11:55–12:00 TUB10.6

### A rolling-diaphragm transmission for remote MR-guided needle insertion

Natalie Burkhard, Samuel Frishman, Alexander Gruebele, Roger E. Goldman, Bruce Daniel, Mark Cutkosky
Mechanical Engineering, Stanford University, United States
John Peter Whitney
Mechanical and Industrial Engineering, Northeastern University, United States

- Passive, force transparent needle manipulator for improved MR-guided interventions
- Position tracking and force transparency characterized and demonstrated to be clinically relevant
- Experiments in phantom tissue indicate a 77% success rate in detecting membrane punctures of ~0.5N

1-DOF needle manipulator

## Medical Robots and Systems 1

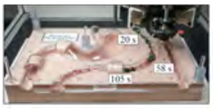
Chair *Paolo Dario, Scuola Superiore Sant'Anna*
Co-Chair *Conor James Walsh, Harvard University*

| 12:00–12:05 | TUB10.7 |
|---|---|

### First Demonstration of Simultaneous Localization and Propulsion of a Magnetic Capsule in a Lumen using a Single Rotating Magnet

Katie Popek and Tucker Hermans
School of Computing, University of Utah, USA
Jake Abbott
Department of Mechanical Engineering, University of Utah, USA

- Prior work in active capsule endoscopy using rotating magnetic fields required decoupled localization and propulsion.
- We experimentally demonstrate simultaneous localization and capsule propulsion through multiple trajectories using a single external rotating magnet.
- This system results in 3x speed up compared to the previous decoupled approach.



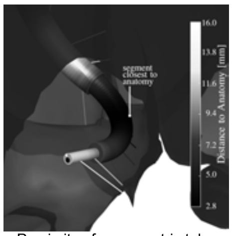
Composite image of closed-loop capsule propulsion in a phantom intestine

| 12:05–12:10 | TUB10.8 |
|---|---|

### Efficient Proximity Queries for Continuum Robots on Parallel Computing Hardware

Konrad Leibrandt and Guang-Zhong Yang
Hamlyn Centre for Robotic Surgery
Imperial College London, United Kingdom

- Proximity calculation for continuum robots using an algebraic approach
- Automatic generation of geometrical primitives based on the robot shape
- Implementation considerations for accelerators such as GPUs
- Benchmark results for GPUs and CPUs:
  - polynomial root-finding
  - proximity calculation



Proximity of a concentric tube robot to brain ventricles

## Design and Manufacturing

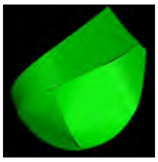
Chair *Hidefumi Wakamatsu, Grad. School of Eng., Osaka Univ.*
Co-Chair *Andrea Censi, MIT*

| 11:30–11:35 | TUB11.1 |
|---|---|

### A Virtual Paper Model of a Three Piece Brassiere Cup to Improve the Efficiency of Cup Design Process

Hidefumi Wakamatsu, Eiji Morinaga, and Eiji Arai
Dept. of Manufacturing Science, Osaka Univ., Japan
Takahiro Kubo
Wacoal Holdings Corp., Japan

- The brassiere cup shape is determined by creating a paper model and refining it.
- Predicting the shape of the paper model with a simulation would improve design efficiency.
- The shape of the paper model is represented as combination of developable surfaces.
- Minimizing the potential energy of surfaces derives a stable shape of the paper model.

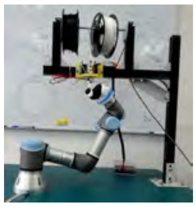


| 11:35–11:40 | TUB11.2 |
|---|---|

### RoboFDM: A Robotic System for Support-Free Fabrication using FDM

Chenming Wu[1], Chengkai Dai[2], Guoxin Fang[2]
Yong-Jin Liu[1] and Charlie C.L. Wang[2]
[1] Department of Computer Science and Technology, Tsinghua University, China
[2] Department of Design Engineering and TU Delft Robotics Institute, Delft University of Technology, Netherlands

- **Target:** print 3D models without support-structures using FDM.
- Use a robotic arm providing 6-DOF motion to the platform of material accumulation.
- A new algorithm is developed to decompose models into support-free parts that can be printed one by one in a collision-free sequence.
- Our results show that the proposed system works well on a variety of 3D models.

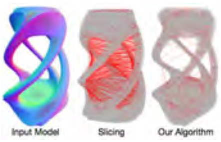


| 11:40–11:45 | TUB11.3 |
|---|---|

### An Improved Tool Path Algorithm for Fused Filament Fabrication

Samuel Lensgraf and Ramgopal Mettu
Department of Computer Science
Tulane University

- We present a local search algorithm for tool path planning that leverages part geometry to minimize the wasted motion during printing.
- On a benchmark of 400+ models we achieve 62% mean reduction in wasted motion over traditional slicing.
- We also give evidence that our local search method is close to optimal in some cases, using calculate an instance specific lower bound for 30 models using a novel Integer Linear Programming formulation.



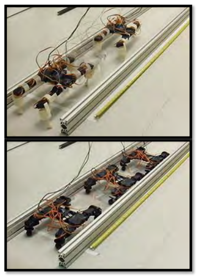

A comparison of toolpaths. Red lines are wasted motion, gray are printed.

| 11:45–11:50 | TUB11.4 |
|---|---|

### Interactive, Iterative Robot Design

Bradley Canaday, Samuel Zapolsky and Evan Drumwright
Computer Science Dept., George Washington University

- Simulation-aided performance analysis of controlled robotic systems
- Iterative morphological update process toward improving robot performance
- Initial, brittle robot design (top) walks and then breaks
- Updated robot design (bottom) demonstrates durable performance and walks twice as fast



| 11:50–11:55 | TUB11.5 |
|---|---|

### Computational Abstractions for Interactive Design of Robotic Devices

Ruta Desai, Ye Yuan and Stelian Coros
Robotics Institute, Carnegie Mellon University, USA

- Our goal is to make robotics more accessible.
- Towards this end, we present a general design abstraction and a visual design system for on-demand generation of customized robots using modular electromechanical components.
- Our system allows users to efficiently create robots through design space exploration and simulation-based feedback.
- In particular, a manual mode that supports forward design, and an auto-completion method are provided for user design.

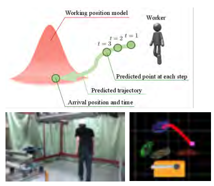

Various robots designed with our system

| 11:55–12:00 | TUB11.6 |
|---|---|

### Adaptive Task Scheduling for an Assembly Task Co-worker Robot Based on Incremental Learning of Human's Motion Patterns

Jun Kinugawa, Akira Kanazawa
Shogo Arai and Kazuhiro Kosuge
Department of Robotics, Tohoku Universiy, Japan

- We propose an adaptive task scheduling system for co-worker robot in an automobile assembly line
- Proposed system learns the working position and worker's motion trajectory using online algorithm
- Using the prediction results, the robot's delivery tasks are determined adaptively
- Experimental results show that the proposed system improves work efficiency by decreasing worker's waiting time



## Design and Manufacturing

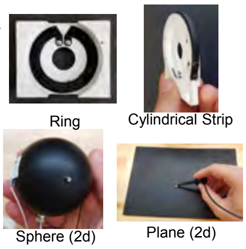
Chair *Hidefumi Wakamatsu, Grad. School of Eng., Osaka Univ.*
Co-Chair *Andrea Censi, MIT*

| 12:00–12:05 | TUB11.7 |
|---|---|

### PaintPots: Low Cost, Accurate, Highly Customizable Potentiometers for Position Sensing

Tarik Tosun, Daniel Edgar, Chao Liu,
Thulani Tsabedze, and Mark Yim
Dept. of Mechanical Engineering and Applied Mechanics,
University of Pennsylvania, USA

- Method to make customizable potentiometers with conductive spray paint
- Many shapes and sizes possible, including curved surfaces
- Easy to make with common tools
- Cost about $1 USD each
- Performance comparable to commercial pots
- Create 2D sensors that capture handwriting (touchpad)




**Custom Sensor Surfaces**

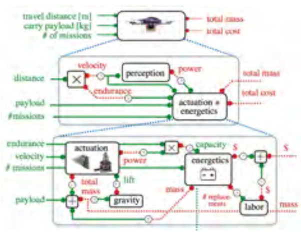
| 12:05–12:10 | TUB11.8 |
|---|---|

### Uncertainty in Monotone Co-Design Problems

Andrea Censi

ETH Zürich

- Context: a compositional theory of co-design, for robotics and beyond.
- This paper deals with the introduction of uncertainty in the co-design framework.
- Software and online demo are available at https://co-design.science



## Actuators 3

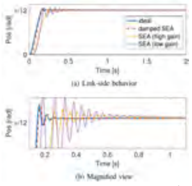
Chair *Nikos Tsagarakis, Istituto Italiano di Tecnologia*
Co-Chair *David Braun, Singapore University of Technology and Design*

| 14:45–14:50 | TUC1.1 |
|---|---|

### Enhancing Joint Torque Control of Series Elastic Actuators with Physical Damping

Min Jun Kim, Alexander Werner, Florian Loeffl, Christian Ott
Robotics and Mechatronics Center, DLR, Germany

- SEA torque control usually requires D-control
  - Desired torque is a function of velocity in most of applications
  - D-control implies acceleration feedback
- Physical damping converts P-control into D-action
  - No acceleration feedback
  - Enhances torque control capability



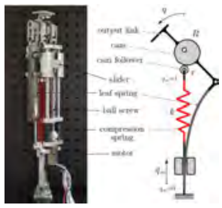
PD control with collision at $q=\pi/12$

| 14:50–14:55 | TUC1.2 |
|---|---|

### Efficiently Tunable Positive-Negative Stiffness Actuator

Abhinav Dahiya and David J. Braun
Dynamics and Control Laboratory
Singapore University of Technology and Design

- Compliant actuation concept allowing control over equilibrium position and joint stiffness using a single motor unit.
- The actuator combines a passive positive feedback mechanism with an efficiently tunable negative feedback mechanism.
- The actuator may enable the design of an efficiently tunable compliant prosthetic leg.

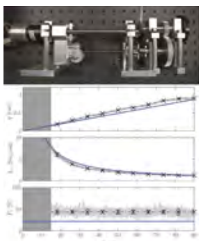


| 14:55–15:00 | TUC1.3 |
|---|---|

### Analytical Conditions for the Design of Variable Stiffness Mechanisms

Tze Hao Chong, Vincent Chalvet and David J. Braun
Dynamics and Control Laboratory
Singapore University of Technology and Design

- Analytical approach to the design of variable stiffness mechanisms.
- Classes of mechanisms were identified using a general potential energy model and user-defined design conditions.
- Identification of mechanisms which enable infinite range stiffness modulation using bounded input motor forces.



| 15:00–15:05 | TUC1.4 |
|---|---|

### A Self-Adaptive Variable Impedance Actuator Based on Intrinsic Non-linear Compliance and Damping Principles

Navvab Kashiri, Darwin G. Caldwell, and Nikos G. Tsagarakis
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

This work proposes a non-linear stiffness compliant module, and introduces a novel non-linear damper which complements the elastic element.

The cam-follower mechanism was employed for rendering the user-defined non-linear behaviour.

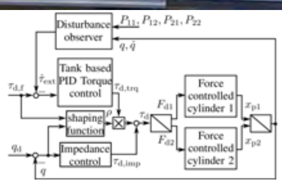
The passive compliance of the module is replicated using a curved leaf spring, and the passive damping is generated by rolling/sliding motion of a rigid cylinder on an elastomer.

| 15:05–15:10 | TUC1.5 |
|---|---|

### Tank Based Unified Torque/Impedance Control for a Pneumatically Actuated Antagonistic Robot Joint

Alexander Toedtheide, Erfan Shahriari and Sami Haddadin
Institute of Automatic Control, Leibniz Universität Hannover, Germany

- Unified torque/impedance control for an antagonistic pneumatic joint
- Simultaneous control of contact torque and impedance with contact loss handling
- Application of a momentum based disturbance observer for contact torque estimation
- Tank based passivity analysis of the robot joint

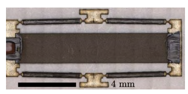




| 15:10–15:15 | TUC1.6 |
|---|---|

### A Geometrically-Amplified In-Plane Piezoelectric Actuator for Mesoscale Robotic Systems

Peter A. York and Robert J. Wood
Harvard University, USA

- Achieves 20x displacement amplification.
- Performance metrics include: blocked force (20 mN), displacement (115 um), bandwidth (3 kHz), and power density (172 W/kg).
- Printed circuit MEMS fabrication process is described in detail.
- Can be used in servo or power delivery applications.




In-plane piezoelectric actuator. Device thickness is 195 um.

## Actuators 3

Chair *Nikos Tsagarakis, Istituto Italiano di Tecnologia*
Co-Chair *David Braun, Singapore University of Technology and Design*

| 15:15–15:20 | TUC1.7 |
|---|---|

### Modeling and Inverse Compensation of Hysteresis in Supercoiled Polymer Artificial Muscles

Jun Zhang, Kaushik Iyer, Anthony Simeonov, and Michael C. Yip

University of California San Diego, La Jolla, CA 92093 USA

- Supercoiled polymer actuators exhibit significant strain and fast speed
- Existing studies unable to model the hysteresis and produce over 15% error
- Proposed models for contraction length – voltage hysteresis under different loads
- Realized open-loop position control through hysteresis inverse compensation

20% tensile actuation and hysteresis in supercoiled polymer actuators.

| 15:20–15:25 | TUC1.8 |
|---|---|

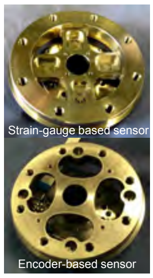
### On the Sensor Design of Torque Controlled Actuators: A Comparison Study of Strain Gauge and Encoder Based Principles

Navvab Kashiri, Jorn Malzahn, and Nikos G. Tsagarakis
Department of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

This work proposes and evaluates two joint torque sensing elements based on strain-gauge and deflection-encoder principles.

The two designs are elaborated and evaluated from different perspectives:

- resolution;
- non-axial moments load crosstalk;
- torque ripple rejection;
- stiffness and bandwidth;
- noise/residual offset level;
- thermal/time dependent signal drift.



## Planning

Chair *Gim Song Soh, Singapore University of Technology and Design*
Co-Chair *Kei Okada, The University of Tokyo*

| 14:45–14:50 | TUC2.1 |
|---|---|

### Planning Method for a Wrapping-with-Fabric task Using Regrasping

Naohiro Hayashi, Takashi Suehiro and Shunsuke Kudoh
The University of Electro-Communications, Japan

- Inter- and intra-hand passing is required for wrapping a long fabric to an object
- The inter- and intra-hand passing is planned from a motion-transition graph of a robot
- The motion-transition graph represents the reliability of wrapping movements

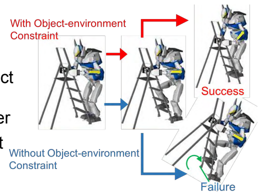
Winding motion using regrasping

| 14:50–14:55 | TUC2.2 |
|---|---|

### Online Estimation of Object–Environment Constraints for Planning of Humanoid Motion on a Movable Object

Shunichi Nozawa and Shintaro Noda and Masaki Murooka and Kei Okada and Masayuki Inaba
Creative Informatics Department, UTokyo, Japan

- Deal with Motion On a Movable Object (MOMO) for a humanoid robot
- Propose representation of robot-and-object balance constraints which can be used in multi-contact motion planner and controller
- Propose estimation of object-environment constraints based on robot's sensor information
- Achieve carrying-and-climbing of a stepladder with unknown mass properties on a real robot




Considering object-environment constraints

| 14:55–15:00 | TUC2.3 |
|---|---|

### A General Formal Framework for Multi-Agent Meeting Problems

Yusuf Izmirlioglu, Bahadir A. Pehlivan, Misra Turp, Esra Erdem
Faculty of Engineering and Natural Sciences, Sabanci University, Turkey

- The multi-agent meeting (MAM) problem asks for a meeting location for multiple heterogeneous agents such that the agents can get together within a given time or budget, possibly using different modes of transportation, subject to some constraints and preferences to visit specific locations on their ways to the meeting location.
- Examples: autonomous driverless cars deciding for a common place so that their passengers can meet; robots at a factory floor deciding for a location to exchange the materials they carry.
- We mathematically model MAM as a graph problem, prove its intractability, and introduce a novel formal method to solve it and its variations using AI methods.

| 15:00–15:05 | TUC2.4 |
|---|---|

### Towards Robotic MAGMaS: Multiple Aerial-Ground Manipulator Systems

[1]Nicolas Staub, [2,3]Mostafa Mohammadi, [1]Davide Bicego, [2,3]Domenico Prattichizzo, and [1]Antonio Franchi
[1]LAAS-CNRS, Université de Toulouse, CNRS, France
[2]Dept.of Information Engineering and Mathematics, University of Siena, Italy
[3]Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Italy

- **Cooperative** manipulation for heterogeneous multi-robot system with **aerial and ground manipulators**
- **Optimization based control** allocation to respect all system constraints and maximize force **manipulability index**
- Disturbance and imperfection **robustness**
- Experiment of cooperative manipulation of **long flexible object**

MAGMaS experiment at LAAS-CNRS

| 15:05–15:10 | TUC2.5 |
|---|---|

### Plan Explicability and Predictability for Robot Task Planning

Yu Zhang, Sarath Sreedharan, Anagha Kulkarni, Tathagata Chakraborti and Subbarao Kambhampati
Computer Science and Engineering, Arizona State University, USA
Hankz Hankui Zhuo
Computer Science, Sun Yat-sen University, China

- Introduce plan explicability and predictability for intelligent robots to synthesize plans that are more comprehensible to humans
- Interpret human understanding of a plan as a labeling process; learn the labeling scheme of humans for agent plans from training examples using conditional random fields
- Use the learned model to label a new plan to compute its explicability and predictability to inform planning
- Provide evaluations on a synthetic domain and with a physical robot

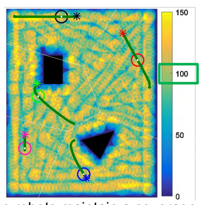

In human-aware planning, a robot maintains a human model ($M_H$), capturing human's intents and etc. In explicable planning, a robot considers the differences between its own model $M_R$ and the same model from the human's perspective (i.e., $M_R$*).

| 15:10–15:15 | TUC2.6 |
|---|---|

### Optimal Path Planning and Coverage Control for Multi-Robot Persistent Coverage in Environments with Obstacles

José M. Palacios-Gasós, Eduardo Montijano and Carlos Sagüés
I3A, University of Zaragoza, Spain
Zeynab Talebpour and Alcherio Martinoli
DISAL, EPFL, Switzerland

- Aim: maintain a desired coverage level (temperature, dust) that deteriorates over time in an environment.
- Each robot locally finds using FMM optimal coverage paths that also avoid obstacles.
- A coverage action controller allows each robot to produce the optimal coverage at each point.
- Simulations and real experiments validate the whole approach.




Five robots maintain a coverage of 100 units in a rectangular environment with two obstacles.

## Planning

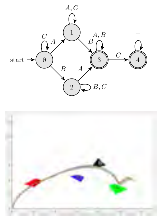
Chair *Gim Song Soh, Singapore University of Technology and Design*
Co-Chair *Kei Okada, The University of Tokyo*

| 15:15–15:20 | TUC2.7 |
|---|---|

### Sampling-based approximate optimal temporal logic planning

Lening Li and Jie Fu
Robotics Engineering, Worcester Polytechnic Institute, USA

- A **sampling-based**, **joint planning** and **control** method under **temporal logic constraints**.
- **Scalable** control design based on the principal of approximate policy iteration in hybrid systems.
- Efficient, **near-anytime** policy search using importance sampling.



Automaton and Trajectory

| 15:20–15:25 | TUC2.8 |
|---|---|

### Toward Robust, Whole-hand Caging Manipulation with Underactuated Hands

Raymond R. Ma, Walter G. Bircher, and Aaron M. Dollar
Department of Mechanical Engineering and Materials Science
Yale University, USA

- Caging manipulation avoids object ejection without detailed knowledge about contact conditions or sensor feedback
- We derived object energy fields that show where objects will move in a caging grasp
- We present experimental object workspaces for a variety of object geometries with an underactuated hand
- Even after regularly breaking finger contact, an object can be repeatedly manipulated without ejection

## Computer Vision 3

Chair *Paolo Russo, Sapienza University of Rome*
Co-Chair *Dieter Fox, University of Washington*

| 14:45–14:50 | TUC3.1 |
|---|---|

### Lidar-histogram for fast road and obstacle detection

Liang Chen, Jian Yang and Hui Kong
School of Computer Science and
Engineering, Nanjing University of Science and Technology, China

- Lidar-histogram integrates the detection of traversable road regions, obstacles into one single framework.
- Lidar-imagery is used to index, describe and store Lidar data.
- The problem of detecting traversable road and obstacles is converted into a simple linear classification task in 2D space.

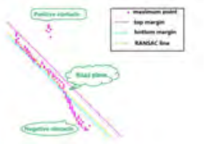


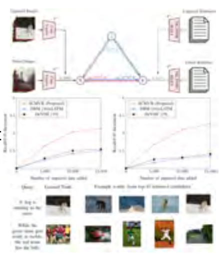
Illustration of the classification rule for road plane, positive and negative obstacles in Lidar-histogram.

| 14:50–14:55 | TUC3.2 |
|---|---|

### Semi-Supervised Vision-Language Mapping via Variational Learning

Yuming Shen and Ling Shao
School of Computing Sciences, University of East Anglia, UK
Li Zhang
Department of Computer Science and Digital Technologies, Northumbria University, UK

- An image-sentence cross-modal retrieval model accepting partially paired training data
- A two-level cross-modal embedding is proposed, extending the Auto-Encoding Variational Bayes algorithm.
- Unpaired images and sentences in training set are involved in the first-level embedding to provide intra-modality statistics.
- The proposed model benefits from deep neural networks, achieving state-of-the-art retrieval performance.

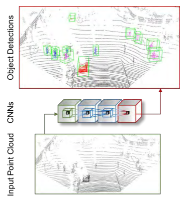


| 14:55–15:00 | TUC3.3 |
|---|---|

### Vote3Deep: Fast Object Detection in 3D Point Clouds Using Efficient Convolutional Neural Networks

Martin Engelcke, Dushyant Rao, Dominic Zeng Wang, Chi Hay Tong, Ingmar Posner
Oxford Robotics Institute, University of Oxford, United Kingdom

- Vote3Deep employs CNNs to perform object detection in point clouds *natively* in 3D
- Convolutions are recast as data-efficient voting operations to exploit the sparsity in the input
- An L1 regulariser further increases the sparsity in intermediate representations and improves detection speed
- Vote3Deep outperforms all previous state-of-the-art methods on the popular KITTI Object Detection benchmark




Native 3D processing of point clouds with CNNs

| 15:00–15:05 | TUC3.4 |
|---|---|

### A deep representation for depth images from synthetic data

Fabio Maria Carlucci and Paolo Russo and Barbara Caputo
DIAG, Sapienza University, Italy
fabiom.carlucci@dis.uniroma1.it
https://sites.google.com/site/vandaldepthnet/

- We hand picked 9.383 CAD models, matching 319 ILSVRC14 classes
- Used them to build a synthetic dataset of over 4 million depth renderings
- We trained the DepthNet on this data and tested it on real datasets
- First off-the-shelf features for object classification in the Depth modality

Sample models from the VANDAL database

| 15:05–15:10 | TUC3.5 |
|---|---|

### A Deep Learning Approach to Traffic Lights: Detection, Tracking, and Classification

Karsten Behrendt, Libor Novak, Rami Botros
Bosch Automated Driving

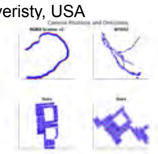
- Bosch Small Traffic Lights Dataset with more than 24000 traffic lights at http://k0b.de/bstld
- Deep learning based detection, tracking, and classification
- Real-time detections of traffic lights down to 3 pixels in width
- Video of the results on the test-set available at http://k0b.de/tld_icra

| 15:10–15:15 | TUC3.6 |
|---|---|

### A Dataset for Developing and Benchmarking Active Vision

Phil Ammirato and Patrick Poirson and Eunbyung Park and Alexander C. Berg
Computer Science, UNC-Chapel Hill, USA
Jana Košecká
Computer Science, George Mason Univeristy, USA

- Enables simulation of robotic motion through environments for object recognition
- 20,000+ RGB-D images, and 50,000+ 2-D bounding boxes of object instances
- Baseline for object instance detection based on state-of-the-art category detector
- Active vision system that demonstrates the utility of our data



Camera locations (red) and viewing directions (blue) from our collections (bottom) and previous datasets (top).

## Computer Vision 3

Chair *Paolo Russo, Sapienza University of Rome*
Co-Chair *Dieter Fox, University of Washington*

| 15:15–15:20 | TUC3.7 |
|---|---|

### Multi-view Self-supervised Deep Learning for 6D Pose Estimation in the Amazon Picking Challenge

Andy Zeng[1], Kuan-Ting Yu[2], Shuran Song[1], Daniel Suo[1]
Ed Walker[3], Alberto Rodriguez[2], Jianxiong Xiao[4]
[1]Princeton University, [2]Massachusetts Institute of Technology
[3]Google, [4]AutoX

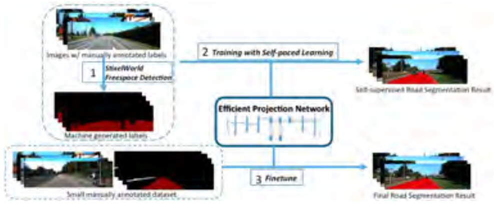
- We present a robust vision approach for 6D object pose estimation from multi-view RGB-D images.
- To enable this approach, we propose a scalable, self-supervised method for automatically collecting large-scale pixel-accurate object segmentation ground truth.
- The approach was part of the MIT-Princeton Team system that took 3rd and 4th place at the Amazon Picking Challenge 2016.

The robot, gripper, and object pose results.

| 15:20–15:25 | TUC3.8 |
|---|---|

### Self-Paced Cross-Modality Transfer Learning for Efficient Road Segmentation

Weiyue Wang[1], Naiyan Wang[2], Xiaomin Wu[3], Suya You[1]
And Ulrich Neumann[1]
[1] USC [2] TuSimple [3] University of Petroleum, China




- We transfer rich scene structure inside stereo images to single RGB image without human labeling.
- Our framework can yield satisfied results with only several hundred of annotated images, and ranks 1st on KITTI road benchmark.

## Autonomous Vehicle

Chair *Seung-Woo Seo, Seoul National University*
Co-Chair *Yonghoon JI, The University of Tokyo*

| 14:45–14:50 | TUC4.1 |
|---|---|

### Predictive Positioning and Quality Of Service Ridesharing for Campus Mobility On Demand Systems

Justin Miller and Jonathan P. How
Aeronautics and Astronautics, MIT, USA

- Goal: Improve customer quality of service (QoS) for campus MOD systems.
- Predictive positioning identifies key fleet positions which minimize expected customer wait time.
- Ridesharing algorithm improves customer service times when arrival rates are high.
- Customer ratings model learns customer preference from 5-star rating feedback.

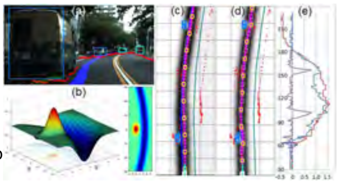
MIT MOD fleet and ride request app. Customers can provide QoS feedback in the form of a 5-star rating.

| 14:50–14:55 | TUC4.2 |
|---|---|

### Toward Human-like Lane Following Behavior in Urban Environment with a Learning-based Behavior-induction Potential Map

Chunzhao Guo, Takashi Owaki, Kiyosumi Kidono, Takashi Machida, Ryuta Terashima and Yoshiko Kojima
Toyota Central R&D Labs., Inc., Japan

- Improved DNN-based algorithm for detecting surrounding cars
- Bayesian network model for classifying cars w.r.t. different states of operation
- Learning-based instance-level behavior-induction potential map for generating human-like local path along a predefined route



(a) Vehicle detection and classification results. (b) Behavior-induction potential map. (c) Local path by proposed approach. (d) Local path by conventional methods. (e) Lateral displacements.

| 14:55–15:00 | TUC4.3 |
|---|---|

### Global Outer-Urban Navigation with OpenStreetMap

Benjamin Suger and Wolfram Burgard
Department of Computer Science, University of Freiburg, Germany

- We present an approach to use OpenStreetMap (OSM) as the global map for outer-urban autonomous navigation
- The approach needs to deal with errors of the map and from the positioning sensors
- We explore semantic terrain information to infer the position of subgoals in the local frame
- Experiments are performed on a real robot that autonomously navigates at previously unseen locations

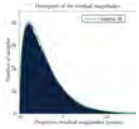
Our approach aligns subgoals from OSM (red) with the street, classified from 3d-lidar data (black).

| 15:00–15:05 | TUC4.4 |
|---|---|

### Accurate Stereo Visual Odometry With Gamma Distributions

Ruben Gomez-Ojeda, Francisco-Angel Moreno, Javier Gonzalez-Jimenez
MAPIR Group, University of Malaga, Spain.

- Typically, visual odometry is solved by minimizing keypoint projection residuals between frames.
- Residuals are usually modeled with Gaussian and t-distributions, but these models are not accurate enough.
- **Proposal**: robust probabilistic model for the *magnitude of the residuals* based on Gamma distributions (better model for the data).
- Experimental validation with synthetic and real data (applied to stereo VO).



| 15:05–15:10 | TUC4.5 |
|---|---|

### Direct Visual-Inertial Navigation with Analytical Preintegration

Kevin Eckenhoff, Patrick Geneva, and Guoquan Huang
University of Delaware

- Visual-inertial navigation: estimate the trajectory of a robot equipped with cameras and IMU
- IMU data processed through closed-form solutions of the "preintegrated" measurement equations
- Camera data processed through direct visual alignment of stereo image pairs
- Measurements fused in a graph-setting for trajectory solution

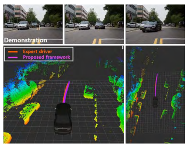
The proposed direct-VINS attains high-precision localization in real-world MAV experiments.

| 15:10–15:15 | TUC4.6 |
|---|---|

### A Learning-Based Framework for Handling Dilemmas in Urban Automated Driving

Sang-Hyun Lee and Seung-Woo Seo
Electrical and Computer Engineering, Seoul National University, Korea

- We introduce a learning-based framework that allows automated vehicles to tackle dilemmas in urban environments
- A driving strategy of expert drivers provides the key insight behind our work
- The proposed framework is based on maximum entropy inverse reinforcement learning and Gaussian process
- We demonstrate that the proposed framework yields trajectories similar to those of expert drivers



Learning the driving strategy of expert drivers

## Autonomous Vehicle

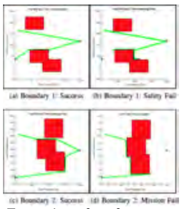
Chair *Seung-Woo Seo, Seoul National University*
Co-Chair *Yonghoon JI, The University of Tokyo*

15:15–15:20 TUC4.7

### Automated Generation of Diverse and Challenging Scenarios for Test and Evaluation of Autonomous Vehicles

Galen Mullins[1], Paul Stankiewicz[2], and Satyandra K. Gupta[3]
[1,2]Johns Hopkins Applied Physics Laboratory, USA
[3]Aerospace and Mechanical Engineering, University of Southern California, USA

- Introduces a test cased generation strategy based upon discovering performance boundaries.
- An adaptive sampling strategy is utilized to minimize the number of simulation runs required to find the performance boundaries.
- Unsupervised density-based clustering algorithms are deployed to generate a test suite composed of boundary cases.



Examples of performance boundaries for a simple navigation scenario.

15:20–15:25 TUC4.8

### Lane-Change Detection Based on Vehicle-Trajectory Prediction

Hanwool Woo, Yonghoon Ji, Hitoshi Kono, Yusuke Tamura, Atsushi Yamashita, and Hajime Asama
Department of Precision Engineering, University of Tokyo, Japan
Yasuhide Kuroda, Takashi Sugano, and Yasunori Yamamoto
Mazda Motor Corporation, Japan

- We improved the detection accuracy by using a vehicle-trajectory prediction
- Our approach considers the possibility of crashes during a lane change
- A trajectory is predicted by using a potential field method
- The trajectory prediction adopts the result of driving-intention estimation and generates potential fields


Result of trajectory prediction

## Distributed Robot Systems 1

Chair *Paolo Robuffo Giordano, Centre National de la Recherche Scientifique (CNRS)*
Co-Chair *Mac Schwager, Stanford University*

| 14:45–14:50 | TUC5.1 |
|---|---|

### Distributed Algo. for Mapping the Graphical Struct. of Complex Envs. w/ a Swarm of Robots

Adam Caccavale
Department of Mechanical Engineering, Stanford University, U.S.A.
Mac Schwager
Department of Aeronautics and Astronautics, Stanford University, U.S.A.

- Swarms of simple robots deployed to discover graphical structure of environment
- Robots have bump sensors, GPS, highly limited memory, and range-limited communication network
- Robots build graph through exploration and communication with neighbors
- Algorithm is distributed, scalable, and all robots achieve the true underlying graph in finite time

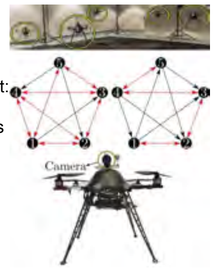
Robots Converging on Graphical Environment Model

| 14:50–14:55 | TUC5.2 |
|---|---|

### Bearing Rigidity Maintenance for Fomations of Quadrotor UAVs

Fabrizio Schiano[1], and Paolo Robuffo Giordano[2]
[1]INRIA Rennes, France, [2]CNRS Rennes, France

- **Control of a formation** of quadrotor UAVs equipped with onboard cameras
- Several **sensing constraints** taken into account: (a) maximum/minimum range of the camera, (b) limited fov of the camera, (c) possible occlusions between the agents
- **Decentralized** gradient-based **controller** for maintaining **bearing rigidity** of the formation
- Real experiments with 5 quadrotor UAVs




| 14:55–15:00 | TUC5.3 |
|---|---|

### A Portable, 3D-Printing Enabled Multi-Vehicle Platform for Robotics Research and Education

Jingjin Yu, Shuai D. Han, Wei N. Tang
Department of Computer Science, Rutgers University, USA
Daniela Rus
Computer Science and Artificial Intelligence Lab, MIT, USA

- An affordable, portable, and open source micro-scale mobile robot platform – microMVP
- 3D-printing enabled design
- Robust performance
- Support centralized or distributed methods
- More information http://arc.cs.rutgers.edu/mvp

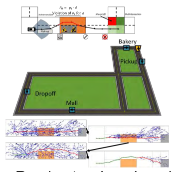
Video

| 15:00–15:05 | TUC5.4 |
|---|---|

### Minimum-violation scLTL motion planning for mobility-on-demand

Cristian-Ioan Vasile[1], Jana Tumova[2], Sertac Karaman[1], Calin Belta[3] and Daniela Rus[1]
[1]Massachusetts Institute of Technology, USA
[2]Department of Robotics, Perception, and Learning, KTH, Sweden
[3]Department of Mechanical Engineering, Boston University, USA

- Road network and autonomous vehicle with limited sensing
- Transportation request (minimize delay) + Rules of the road (minimize violation) + User safety preference (strictly enforced) - scLTL
- **Problem:** Find a control policy that minimizes the total violation penalty
- Solution: combined motion and route planning



Road network and road segment model

| 15:05–15:10 | TUC5.5 |
|---|---|

### Distributed Aggregation for Modular Robots in the Pivoting Cube Model

Sebastian Claici, John Romanishin, Jeffrey Lipton, Stephane Bonardi, Kyle Gilpin, and Daniela Rus
CSAIL, MIT, USA

- We present a distributed control strategy for the aggregation of multiple modular robots.
- Our algorithm has provable convergence guarantees.
- We demonstrate our approach in simulation and on the 3D M-Blocks hardware.

| 15:10–15:15 | TUC5.6 |
|---|---|

### Duckietown: an Open, Inexpensive and Flexible Platform for Autonomy Education and Research

Liam Paull, Jacopo Tani, Heejin Ahn, Javier Alonso-Mora, Luca Carlone, Michal Cap, Yu Fan Chen, Changhyun Choi, Jeff Dusek, Yajun Fang, Daniel Hoehener, Shih-Yuan Liu, Michael Novitzky, Igor Franzoni Okuyama, Jason Pazis, Guy Rosman, Valerio Varricchio, Hsueh-Cheng Wang, Dmitry Yershov, Hang Zhao, Michael Benjamin, Christopher Carr, Maria Zuber, Sertac Karaman, Emilio Frazzoli, Domitilla Del Vecchio, Daniela Rus, Jonathan How, John Leonard, Andrea Censi
Massachusetts Institute of Technology

- An educational, research, and outreach effort
- Duckiebots are inexpensive yet capable and realistic (follow lanes, avoid objects, navigate, coordinate)
- All of the materials have been released open source, see duckietown.mit.edu for details

Duckietown is an autonomous mobility on demand service for duckies

**Distributed Robot Systems 1**

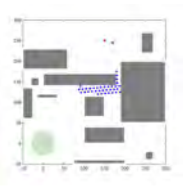
Chair *Paolo Robuffo Giordano, Centre National de la Recherche Scientifique (CNRS)*
Co-Chair *Mac Schwager, Stanford University*

| 15:15–15:20 | TUC5.7 |
|---|---|

### Decentralized Coordinated Motion for a Large Team of Robots Preserving Connectivity and Avoiding Collisions

Anqi Li, Wenhao Luo, Sasanka Nagavalli and Katia Sycara
Robotics Institute, Carnegie Mellon University, USA

- **Goal:** Coordination of a group of robots towards a goal region while avoiding collisions and ensuring connectivity
- Capable of avoiding deadlock in cluttered environment
- Scalable as the number of robots grows
- Robust to insertion and deletion of individual robot

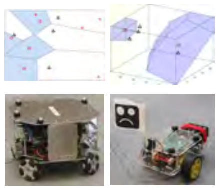


| 15:20–15:25 | TUC5.8 |
|---|---|

### Intercepting Rogue Robots: An Algorithm for Capturing Multiple Evaders with Multiple Pursuers

Alyssa Pierson[1], Zijian Wang[2], and Mac Schwager[2]
[1]Dept. of Mechanical Engineering, Boston University, USA
[2]Dept. of Aero/Astro, Stanford University, USA

- Guaranteed capture of multiple evaders in finite time by one or more pursuer in $\mathbb{R}^N$
- Pursuers use “Area-minimization” strategy, utilize properties of Voronoi tessellation
- Agnostic to evader control policy
- Experiments with Ouijabots and GoPiGo robots running controllers on-board



## Learning and Adaptive Systems 3

Chair *Gakuto Masuyama, Chuo University*
Co-Chair *Ioannis Havoutis, Idiap Research Institute*

| 14:45–14:50 | TUC6.1 |
|---|---|

### Efficient Learning of Constraints and Generic Null Space Policies

Leopoldo Armesto
Universitat Politecnica de Valencia, Spain
Jorren Bosga and Vladimir Ivan and Sethu Vijayakumar
University of Edinburgh, United Kingdom

- We proposed a method to learned constrained tasks and policies from demonstrations
- We decompose observations into task/null-space components.
- Our method outperforms the state of art in both accuracy and computation speed.
- The learnt policy generalizes across different constraints.
- Experimental setup: we train a model on motion data demonstrated by a human.

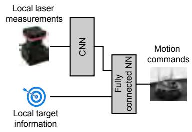
See our video for the complete experiment setup

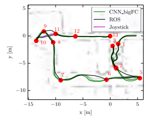
| 14:50–14:55 | TUC6.2 |
|---|---|

### From Perception to Decision: A Data-driven Approach to End-to-end Motion Planning for Autonomous Ground Robots

Mark Pfeiffer, Michael Schaeuble, Juan Nieto, Roland Siegwart and Cesar Cadena
Autonomous Systems Lab, ETH Zurich, Switzerland

- Learning navigation policy from expert demonstrations
- End-to-end neural network model
- Local measurements → motion commands
- Train in simulation, deploy successfully on real robot
- Cross-validation on different maps to show the generalizability of the approach



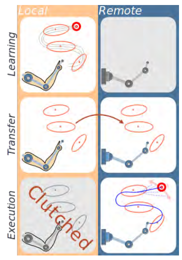



| 14:55–15:00 | TUC6.3 |
|---|---|

### Supervisory teleoperation with online learning and optimal control

Ioannis Havoutis[1,2] and Sylvain Calinon[1]
[1] Idiap Research Institute, Martigny, Switzerland
[2] Oxford Robotics Institute, University of Oxford, United Kingdom

- Learning from demonstration (LfD) applied to supervisory teleoperation, in the context of manipulation with underwater ROVs.
- Online Bayesian nonparametric learning of task-parametrized models, that capture the characteristics of demonstrated motions.
- On the operator's side, the model is build based on a set of demonstrations. On the robot side, the model is used to autonomously complete the task using model predictive control (MPC) and locally adapting to the dynamically changing environment.

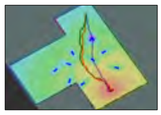



| 15:00–15:05 | TUC6.4 |
|---|---|

### Rapidly Exploring Learning Trees

Kyriacos Shiarlis Joao Messias
Institute of Informatics, Amsterdam, The Netherlands
Shimon Whiteson
Department of Computer Science, University of Oxford, UK

- Rapidly Exploring Learning Trees (RLT*) learns RRT* cost functions from demonstrations.
- A caching scheme makes learning faster and more effective.
- We apply RLT* to social navigation tasks for real and simulated mobile robots.
- Results suggest that RLT* performs and scales better than the baseline method, Maximum Margin Planning.



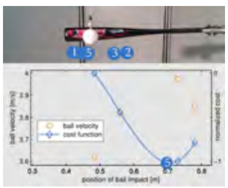
RLT* (red) learns to replicate the expert path (black) in a social navigation scenario.

| 15:05–15:10 | TUC6.5 |
|---|---|

### Hitting the sweet spot: automatic optimization of energy transfer during tool-held hits

Jörn Vogel, Naohiro Takemura, Hannes Höppner, Patrick van der Smagt, and Gowrishankar Ganesh

- robot hitter optimizes swing trajectory to hit at the sweet spot of a bat
- torque ratio and angular jerk are robust indicators of the sweet spot
- maximization of energy transfer is achieved without observation of the manipulated environment
- torque ratio and angular jerk can be used to isolate the sweet spot also bats of non-uniform cross-section



convergence towards the sweet spot, when using a baseball bat

| 15:10–15:15 | TUC6.6 |
|---|---|

### Virtual vs. Real: Trading Off Simulations and Physical Experiments in Reinforcement Learning with Bayesian Optimization

Alonso Marco[1], Felix Berkenkamp[2], Philipp Hennig[1], Angela P. Schoellig[3], Andreas Krause[2], Stefan Schaal[1], and Sebastian Trimpe[1]
[1] Autonomous Motion Department, MPI for Intelligent Systems, Germany
[2] Learning & Adaptive Systems Group, ETH Zürich, Switzerland
[3] Dynamic Systems Lab, University of Toronto, Canada

- Tuning controller gains is frustrating and time-consuming
- Simulations: cheap, inaccurate,
- Physical experiments: expensive, accurate
- Entropy-based Bayesian Optimizer alternatively selects the most informative source per unit of cost, saving unnecessary physical experiments


Multi-fidelity Bayesian Optimization with two information sources

## Learning and Adaptive Systems 3

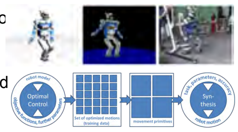
Chair *Gakuto Masuyama, Chuo University*
Co-Chair *Ioannis Havoutis, Idiap Research Institute*

| 15:15–15:20 | TUC6.7 |
|---|---|

### COCoMoPL: A Novel Approach for Humanoid Walking Generation Combining Optimal Control, Movement Primitives and Learning and its Transfer to the Real Robot HRP-2

Debora Clever, Monika Harant, Katja Mombaur
Interdisciplinary Center for Scientific Computing, University of Heidelberg, Germany
Maximilien Naveau, Olivier Stasse
CNRS - LAAS, Toulouse, France
Dominik Endres
Theoretical Neuroscience Group, Dept. Psychology, Philipps-University Marburg, Germany

- Use optimal control and detailed HRP-2-robo model to compute optimal and dynamically feasible walking motions
- Learn morphable movement primitives based on Gaussian processes and principal component analysis
- COCoMoPL leads to nearly optimal movements, which can be feasible on a real robot, here HRP-2.



Gait generation using movement primitives learned from optimal control based motions

| 15:20–15:25 | TUC6.8 |
|---|---|

### Repeatable Folding Task by Humanoid Robot Worker using Deep Learning

Pin-Chu Yang[1] and Shigeki Sugano[5]
Department of Modern Mechanical Engineering, Waseda University, Japan
Kazuma Sasaki[2], Kanata Suzuki[3], Kei Kase[4] and Tetsuya Ogata[6]
Department of Intermedia Art and Science, Waseda University, Japan

- Humanoid Robot + Deep Learning :
  = Ideal F.A. Solution for Complex Task
- Reiterating Soft Object Folding Motion:
  = Long & Repeatable Task Performable
- End-to-End Training with Teleoperation:
  = Easy to Train and Apply

Robot performing folding task through Deep Learning

## Grasping 1

Chair *Amir Shapiro, Ben Gurion University of the Negev*
Co-Chair *Lorenzo Natale, Istituto Italiano di Tecnologia*

| 14:45–14:50 | TUC7.1 |
|---|---|

### A Grasping Approach Based on Superquadric Models

Giulia Vezzani, Ugo Pattacini and Lorenzo Natale
iCub Facility, Istituto Italiano di Tecnologia, Italy
University of Genova, Italy

- Grasping of unknown objects
- The object and the volume graspable by the hand are modeled with superquadric functions
- Pose computation is formulated as a nonlinear constrained optimization problem
- The method computes poses suitable also for grasping small objects, while avoiding hitting the table with fingers and taking into account also object portions occluded by vision

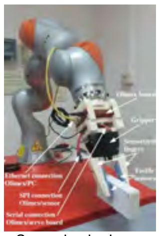
The iCub humanoid robot used for testing the proposed grasping approach

| 14:50–14:55 | TUC7.2 |
|---|---|

### Control of Linear and Rotational Slippage Based on Six-axis Force/Tactile Sensor

Andrea Cirillo, Pasquale Cirillo, Giuseppe De Maria
Ciro Natale, Salvatore Pirozzi,
DIII, Università degli Studi della Campania «L. Vanvitelli», Italy

- Sensorized gripper with a six-axis force/tactile sensor
- Measurement of both object orientation and six components of the applied wrench
- Control strategy for avoiding both linear and rotational slipping in dynamic conditions
- Experimental results of dynamic slipping avoidance in presence of uncertainties



Sensorized gripper mounted to a robot arm

| 14:55–15:00 | TUC7.3 |
|---|---|

### Grasp Qualification Done Right

Robert Krug
AASS Research Center, Örebro University, Sweden
Yasemin Bekiroglu
Corporate Research, ABB AB, Sweden
Maximo A. Roa
Institute of Robotics and Mechatronics, DLR, Germany

- We study the influence of sum-magnitude and independent grasp contact force bounds.
- We empirically show that grasp quality metrics are often severely underestimated.
- The work highlights the importance of task-based quality assessment.
- Our findings are based on a large set of real-world grasps.

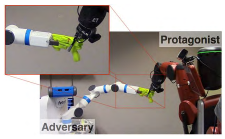
Tactile feedback is exploited for contact modeling.

| 15:00–15:05 | TUC7.4 |
|---|---|

### Supervision via Competition: Robot Adversaries for Learning Tasks

Lerrel Pinto, James Davidson and Abhinav Gupta
Carnegie Mellon University, Google

- We propose an adversarial framework for effective self-supervised learning and demonstrate for **grasping** objects.
- We show improvement from 68% without adversaries to **82%** grasping accuracy with adversaries like **shaking** and **snatching**.
- We also demonstrate that robots in adversarial setting might be better than collaborative robots.

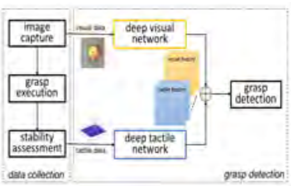



| 15:05–15:10 | TUC7.5 |
|---|---|

### A Hybrid Deep Architecture For Robotic Grasp Detection

Di Guo, Fuchun Sun, Huaping Liu, Tao Kong, Bin Fang
Tsinghua University, Beijing, China
Ning Xi
University of Hong Kong, Hong Kong, China

- A novel hybrid deep architecture is proposed for real world robotic grasp detection.
- A THU grasp dataset is collected on a real robotic platform.
- The dataset contains the visual information, tactile information and grasp configurations.



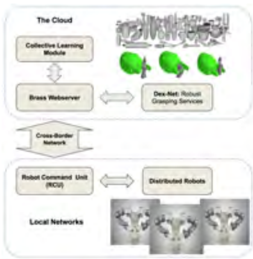

A hybrid architecture for robotic grasp detection

| 15:10–15:15 | TUC7.6 |
|---|---|

### A Cloud Robot System Using Dex-Net and Berkeley Robotics and Automation as a Service (Brass)

Nan Tian*, Matthew Matl*, Jeffrey Mahler, Yu Xiang Zhou, Samantha Staszak, Christopher Correa, Steven Zheng, Qiang Li, Robert Zhang, Ken Goldberg
UC Berkeley AUTOLAB Berkeley CA, USA

- Increases grasp reliability over locally-computed grasping strategies
- network latencies of 30 and 200 msec for servers 500 and 6000 miles away, respectively.
- Execution reports from robots in the field update grasp recommendations over time.



## Grasping 1

Chair *Amir Shapiro, Ben Gurion University of the Negev*
Co-Chair *Lorenzo Natale, Istituto Italiano di Tecnologia*

| 15:15–15:20 | TUC7.7 |
|---|---|

### Modeling Grasp Motor Imagery though Deep Conditional Generative Models

Matthew Veres, Medhat Moussa and Graham W. Taylor
School of Engineering, University of Guelph, Canada

- Grasping is dependent on extrinsic and intrinsic object properties (e.g. geometry, surface friction)
- Grasping follows a many-to-many mapping between objects and actions
- Hypothesis: possible to learn integrated object-action representations for grasping
- Deep conditional generative models can learn to generate grasps following multi-modal distributions

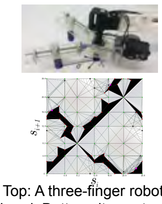
Grasping objects using multiple grasping modes

| 15:20–15:25 | TUC7.8 |
|---|---|

### Caging Polygonal Objects Using Equilateral Three-Finger Hands

H. A. Bunis and E. D. Rimon
Dpt. of Mechanical Engineering, Technion, Israel
Y. Golan and A. Shapiro
Dpt. of Mechanical Engineering, Ben-Gurion University, Israel

- **Three-finger robot hands** in equilateral triangle finger formations are used to cage polygonal objects.
- While the configuration space of such hands is four dimensional, their **contact space** is only two-dimensional.
- The paper describes a **caging graph** that is constructed in the hand's contact space.
- The caging graph can be searched for three-finger **caging regions** surrounding the object.



Top: A three-finger robot hand. Bottom: its contact space and caging graph

## Human-Robot Interaction 2

Chair *Ko Ayusawa, AIST*
Co-Chair *Jaime Valls Miro, University of Technology Sydney*

| 14:45–14:50 | TUC8.1 |
|---|---|

### Show, Attend and Interact: Perceivable Human-Robot Social Interaction through Neural Attention Q-Network

A. H. Qureshi, Y. Nakamura, Y. Yoshikawa & H. Ishiguro
Department of System Innovation, Osaka University, Japan

- This paper introduces the Neural Attention Q-Network using which the robot learned human-like social interaction skills through interaction with people in uncontrolled real environments.
- The results indicate that the robot has learned to respond to complex human behaviors in a perceivable and socially acceptable manner.

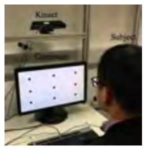
Robot learning social interaction skills from people.

| 14:50–14:55 | TUC8.2 |
|---|---|

### Two-Eye Model-Based Gaze Estimation from A Kinect Sensor

Xiaolong Zhou
College of Computer Science and Technology, Zhejiang University of Technology, China
Haibin Cai and Honghai Liu
School of Computing, University of Portsmouth, UK
Youfu Li
Dept. of Mechanical and Biomedical Engineering, City University of Hong Kong, China

- An effective gaze estimation method based on two-eye model with accuracy is about 1.99°
- An improved convolution-based means of gradients iris center localization method
- A new personal calibration method based on a simplified eye model
- The proposed gaze estimation method outperforms many leading methods in the state-of-the-art



System setup

| 14:55–15:00 | TUC8.3 |
|---|---|

### ModLight: Designing a Modular Light Signaling Tool for Human-Robot Interaction

Elizabeth Cha, Tushar Trehon, Lancelot Watthieu, Christian Wagner, Anurag Shukla and Maja Mataric
Computer Science, University of Southern California, USA

- Recent work has shown the promise for light-based communication for robots.
- The large design space of light communication as well as the large range of robots and applications presents unique challenges for researchers.
- In this work, we present the design of ModLight, a modular research tool consisting of a set of low cost light blocks, that can be easily reconfigured to fit various platforms, and a software library.

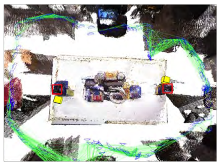
A prototype of ModLight

| 15:00–15:05 | TUC8.4 |
|---|---|

### Towards Real-Time 3D Sound Sources Mapping with Linear Microphone Arrays

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

- Multi hypotheses tracking is combined with a new sound source parametrisation to provide with a good initial guess for an online optimisation strategy.
- A dedicated sensor model is proposed to accurately model the noise of the DOA observation when using a linear microphone array.
- A joint optimisation is carried out to estimate 6 DOF sensor poses and 3 DOF landmarks together with sound sources locations.



Mapping of 2 sound sources using a 3D camera with a linear microphone array

| 15:05–15:10 | TUC8.5 |
|---|---|

### Learning Social Affordance Grammar from Videos: Transferring Human Interactions to Human-Robot Interactions

Tianmin Shu[1], Xiaofeng Gao[2], Michael S. Ryoo[3] and Song-Chun Zhu[1]
[1]University of California, Los Angeles, USA [2]Fudan University, China
[3]Indiana University, Bloomington, USA

- A general framework for learning social affordance grammar as a spatiotemporal AND-OR graph (ST-AOG)
- Weakly supervised learning from RGB-D Videos
- Real-time motion inference and motion transfer from human interactions to human-robot interactions
- Simulations and real Baxter tests were performed to evaluate our system

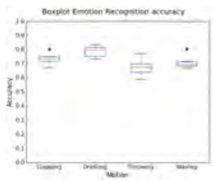
The framework of our approach

| 15:10–15:15 | TUC8.6 |
|---|---|

### Emotional Intelligence in Robots: Recognizing Human Emotions from Daily-Life Gestures

Mohammad Reza Loghmani
ACIN, Vienna Univ. Of Tech., Austria
Stefano Rovetta
DIBRIS, University of Genoa, Italy
Gentiane Venture
Tokyo Univ. of Agric. And Tech., Japan

- Recognize emotions from non-stylized body gestures
- Multi-sensor system based on commercial sensors: Microsoft Kinect, Wii Balance Board, IMU Shimmer
- Two-stage algorithm based on Recurrent Neural Networks



Box-plot of algorithm's accuracy for Emotion Recognition

**Human-Robot Interaction 2**

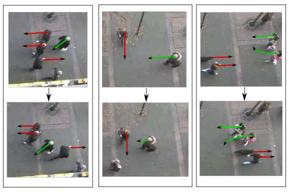
Chair *Ko Ayusawa, AIST*
Co-Chair *Jaime Valls Miro, University of Technology Sydney*

| 15:15–15:20 | TUC8.7 |
|---|---|

### Modeling Cooperative Navigation in Dense Human Crowds

Anirudh Vemula, Katharina Muelling and Jean Oh
Robotics Institute, Carnegie Mellon University, USA

- Model velocity conditioned on goal and occupancy grid, using gaussian processes to fit observed data
- Infer goal from set of known goals using learned model and observed part of trajectory
- Predict future trajectories by sampling velocities from model using multi-step Monte Carlo
- Learned model captures behavior such as cooperative navigation and collision avoidance



Different kind of pedestrian interactions in crowds

| 15:20–15:25 | TUC8.8 |
|---|---|

### Coordination Dynamics in Multi-human Multi-robot Teams

Tariq Iqbal and Laurel D. Riek
Department of Computer Science and Engineering,
University of California San Diego, USA

- We investigate how the presence of robots affects group coordination when both the anticipation algorithms they employ and their number vary.
- Results suggest that group coordination is significantly affected when a robot joins a human-only group.
- It is further affected when a second robot joins the group and employs a different anticipation algorithm from the other robot.

Three participants danced together with two robots

## Best Conference Paper Award

Chair *John Hollerbach, University of Utah*
Co-Chair *Oussama Khatib, Stanford University*

| 14:45–14:50 | TUC9.1 |
|---|---|

### The Robotarium: A remotely accessible swarm robotics research testbed

Daniel Pickem, Paul Glotfelter, Li Wang, Mark Mote, Aaron Ames, Eric Feron, Magnus Egerstedt
Georgia Institute of Technology

**Goal:** Enable safe remote access to large numbers of robots!

- Provides remote access to state-of-the-art multi-robot facility
- Automates experiment execution and maintenance of robots
- Provides built-in minimally invasive safety mechanisms
- Is accessible through web interface

Georgia Robotics and InTelligent Systems Laboratory

| 14:50–14:55 | TUC9.2 |
|---|---|

### Design, Development and Experimental Assessment of a Robotic End-effector for Non-standard Concrete Applications

N. Kumar, J. Buchli: ADRL, ETH Zurich, Switzerland
N. Hack, K. Doerfler, A. Walzer, F. Gramazio, M. Kohler: ITA, ETH Zurich
G. Rey: MOOG Inc., USA

- A novel robotic construction technique called Mesh Mould Metal has been prototyped
- Saves Material, allows greater geometric freedom, fabricates metal meshes to act as reinforcement and formwork
- A robotic end-effector has been custom designed to execute the fabrication process
- Preliminary experiments leading to fabrication of single curved and double curved metal meshes

Mesh Mould Metal End-effector and fabricated mesh

| 14:55–15:00 | TUC9.3 |
|---|---|

### Information Theoretic MPC for Model-Based Reinforcement Learning

Grady Williams, Nolan Wagener, Brian Goldfain, Paul Drews, James M. Rehg, Byron Boots, and Evangelos A. Theodorou
Institute for Robotics and Intelligent Machines
Georgia Institute of Technology, USA

- We introduce an information theoretic model predictive control (MPC) algorithm.
- The algorithm is capable of handling non-linear dynamics and complex cost criteria.
- We apply the algorithm to reinforcement learning tasks by learning models with deep neural networks.
- We demonstrate the capability of the method in simulation and in a real-world aggressive driving task.

Aggressive Driving on the AutoRally platform

| 15:00–15:05 | TUC9.4 |
|---|---|

### Probabilistic Data Association for Semantic SLAM

Sean Bowman, Nikolay Atanasov, Kostas Daniilidis, and George Pappas
GRASP Laboratory,
University of Pennsylvania, USA

- SLAM system that directly integrates semantic, geometric, and inertial information
- Semantic objects facilitate viewpoint-independent loop closure but can be ambiguous
- Incorporate semantic measurements probabilistically without computing explicit data association
- Experiments on several indoor and outdoor datasets

| 15:05–15:10 | TUC9.5 |
|---|---|

### Estimating unknown object dynamics in human-robot manipulation tasks

D. Cehajic, P. Budde gen. Dohmann and S. Hirche
Technical University of Munich, Germany

- Estimation strategy for identifying unknown object dynamics avoiding undesired human interaction wrenches
- Identification-relevant motions derived such to excite the estimator
- Identification motions projected in the null space of the partial grasp matrix relating the human and robot
- Experimental validation in a human-robot cooperative object manipulation setting

## Medical Robots and Systems 2

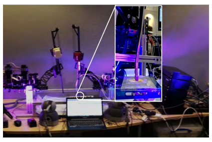
Chair *Yunhui Liu, Chinese University of Hong Kong*
Co-Chair *Kazuo Kiguchi, Kyushu University*

14:45–14:50 TUC10.1

### A Framework for Sensorless and Autonomous Probe-Tissue Contact Management in Robotic Endomicroscopic Scanning

Rejin John Varghese, Pierre Berthet-Rayne, Petros Giataganas
Valentina Vitiello, Guang-Zhong Yang
The Hamlyn Centre for Robotic Surgery, Imperial College London, UK

- Robotic endomicroscopy framework for real-time *in-vivo* tissue characterization
- Sensorless probe-tissue contact management based on real-time image analysis
- Optimal contact maintained using model-free controller based on reinforcement learning
- Experimental results demonstrate near real-time ability to resolve both loss-of-contact and excess-deformation scenarios

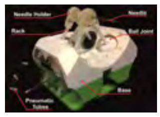

Raven II Surgical Robot with Endomicroscopy Probe

14:50–14:55 TUC10.2

### Controlling the Stormram 2: An MRI-compatible Robotic System for Breast Biopsy

Mohamed E. M. K. Abdelaziz, Vincent Groenhuis,
Françoise Siepel, Stefano Stramigioli
Robotics and Mechatronics, University of Twente, The Netherlands
Jeroen Veltman
Ziekenhuisgroep Twente, The Netherlands

- Compact pneumatically-actuated 5 DOF MRI-compatible breast biopsy robot was developed and controlled by a computerized valve manifold.
- Accuracy/efficiency measurements are performed using 2 different breast phantoms inside 0.25T MRI scanner.
- Developed robotic system has potential to perform MRI-guided breast biopsies accurately and improve clinical workflow.

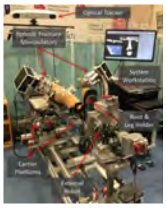

The Stormram 2 robot

14:55–15:00 TUC10.3

### RAFS: a computer-assisted robotic system for minimally invasive joint fracture surgery, based on pre- and intra-operative imaging

Giulio Dagnino, Ioannis Georgilas, Samir Morad, Peter Gibbons,
Payam Tarassoli, Roger Atkins, and Sanja Dogramadzi
Bristol Robotics Laboratory, Bristol, UK

- Simultaneous manipulation of two fragments;
- Lower limb traction capability;
- Full pre-operative surgical planning (virtual reduction);
- Intra-operative real-time 3D image guidance;
- Enhanced clinical workflow;
- Preliminary cadaveric trials provided positive outcome pointing to the RAFS system usability in the operating theatre.

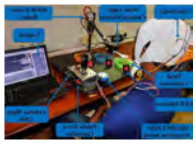

RAFS system

15:00–15:05 TUC10.4

### EEG-Controlled Meal Assistance Robot with Camera-Based Automatic Mouth Position Tracking and Mouth Open Detection

Chamika Janith Perera and Thilina Dulantha Lalitharatne
Department of Mechanical Engineering, University of Moratuwa, Sri Lanka
Kazuo Kiguchi
Department of Mechanical Engineering, Kyushu University, Japan

- This paper proposes an EEG-SSVEP-based controlled Meal Assistance Robot with camera-based automatic mouth position tracking and automatic mouth open/closed detection system.
- User selects the desired food item by looking at the corresponding flickering LED panel and the user intention is recognized using EEG-SSVEP signals.
- Automatic mouth position tracking method is used to align the spoon along with the mouth and mouth open/closed identification is used to feed the food when user is ready to consume.

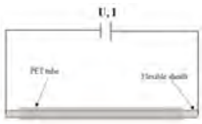


15:05–15:10 TUC10.5

### Towards Active Variable Stiffness Manipulators for Surgical Robots

Huu Minh Le, Cao Lin, and Soo Jay Phee
Robotics Research Centre, School of MAE, NTU, Singapore.
Thanh Nho Do
California NanoSystems Institute, University of California, Santa Barbara,
Elings Hall, Mesa Road, Goleta, USA

- Simple variable stiffness design using PET tube and stainless steel flexible sheath.
- Experiments show the promising results: this VST can be more flexible or stiffer than a typical endoscope.
- Modelling, control, and application design problems will be address in the future works.


Structure and working principle of the variable stiffness tube

15:10–15:15 TUC10.6

### Effects of Exoskeleton Weight and Inertia on Human Walking

Xin Jin, Yusheng Cai, Antonio Prado and Sunil K. Agrawal
Dept of Mechanical Engineering, Columbia University, USA

- An improved design of Cable-driven Active Leg Exoskeleton (C-ALEX, right figure) was made
- Besides being light-weight and joint-free, the new C-ALEX also has large joint RoM and no restriction to the pelvic motion
- An experiment using C-ALEX was performed to investigate the effect of exoskeleton weight and inertia on natural gait
- The result showed weight and inertia each has their unique effect, suggesting a light-weight design can better preserve the natural gait

**Medical Robots and Systems 2**

Chair *Yunhui Liu, Chinese University of Hong Kong*
Co-Chair *Kazuo Kiguchi, Kyushu University*

| 15:15–15:20 | TUC10.7 |
|---|---|

### Enhancing Seated Stability Using Trunk Support Trainer (TruST)

Moiz Khan, Jiyeon Kang, Brian Bradley, and Sunil Agrawal
Mechanical Engineering, Columbia University, USA
Victor Santamaria and Andrew Gordon
Teachers College, Columbia University, USA
Joseph Dutkowsky
Orthopedic Surgery, Columbia University Medical Center, USA

- Our group has developed the first active posture training robot (TruST).
- It can apply assistive or resistive forces/moments, provide multi-directional perturbations, and provide a force-tunnel.
- We use an assist-as-needed force strategy to train posture at the boundary of stability.
- A single session training with TruST significantly increases lower trunk and pelvis translations and rotations.

TruST Schematic

| 15:20–15:25 | TUC10.8 |
|---|---|

### Developing a Compact Robotic Needle Driver for MRI-Guided Breast Biopsy in Tight Environments

[1]D Navarro-Alarcon, [1]S Singh, [1]T Zhang, [2]HL Chung
[1]KW Ng, [1]MK Chow, [1]YH Liu
[1]Dept. of Mechanical and Automation Engineering, CUHK, Hong Kong SAR
[2]Time Medical Limited, Hong Kong SAR

- We developed a new 3-DOF robot for MRI-guided breast biopsy
- The robot's structure, sensors, and actuators are MRI-compatible
- Two piezo-electric motors align the needle's axis with the lesion
- A pneumatic cylinder drives the needle into the breast tissues

The robotic prototype

## Industrial Robots

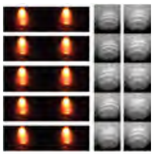
Chair *William R. Hamel, University of Tennessee*
Co-Chair *Liao Wu, Queensland University of Technology*

| 14:45–14:50 | TUC11.1 |
|---|---|

### Real Time Welding Parameter Prediction for Desired Character Performance

Hang Dong and Ming Cong
Dalian University of Technology, China
Yukang Liu and Yuming Zhang
University of Kentucky, USA
Heping Chen
Texas State University, USA

- Use Gaussian Process Regression to model the Dynamic weld poor Character Performance.
- Use Bayesian Optimization to predict robust welding parameters.
- Use performance measurement system to obtain experiment data.
- The prediction results are detailed.



| 14:50–14:55 | TUC11.2 |
|---|---|

### An Ultra-Compact Infinitely Variable Transmission for Robotics

Alexander S. Kernbaum, Murphy Kitchell and Max Crittenden
SRI Robotics, SRI International, USA

- Small enough it can be used in many robotic applications where previously not possible
- Output direction can invert while maintaining constant input direction
- Can be used for significant energy savings by aligning the motor speed with its peak efficiency or by recovering kinetic energy from robot motions
- Potential applications in haptics and human-safe robotics

Working prototype

| 14:55–15:00 | TUC11.3 |
|---|---|

### Toward controlling a KUKA LBR IIWA for interactive tracking

Vinay Chawda and Günter Niemeyer
Disney Research Los Angeles, USA

- KUKA's Fast Robot Interface (FRI) is used to design and implement a tracking controller on the Lightweight Robot (LBR) IIWA.
- Internal torque control structure and its characteristics are identified to design controllers of varying complexity
- Using full state feedback, we achieve smooth and good tracking of the unsensed link positions.

KUKA LBR IIWA

| 15:00–15:05 | TUC11.4 |
|---|---|

### ICRA 2017 Digest
### Quick Positional Health Assessment for Industrial Robot Prognostics and Health Management (PHM)

Guixiu Qiao, Craig Schlenoff, and Brian A. Weiss
National Institute of Standards and Technology (NIST), USA

- A subset of PHM research involves developing a quick health assessment methodology emphasizing the identification of the positional health (position and orientation accuracy) changes.
- NIST's effort to develop the measurement science to support this development, including the modeling and algorithm development for the test method, the advanced sensor development to measure 7-D information (time, X, Y, Z, roll, pitch, and yaw), algorithms to analyze the data, and a use case to present the results.

Key building blocks of the PHMC for Robotics structure

| 15:05–15:10 | TUC11.5 |
|---|---|

### Automatic Robot Taping with Force Feedback

Qilong Yuan
School of Electro-Mechanical Engineering, Foshan Univ., China
Teguh Santoso Lembono
Engineering Product Development, SUTD, Sinapore
I-Ming Chen
School of Mechanical and Aerospace Engineering, NTU, Singapore.
Simon Nelson Landén, Victor Malmgren
School of Industrial Engineering and Management, KTH, Sweden.

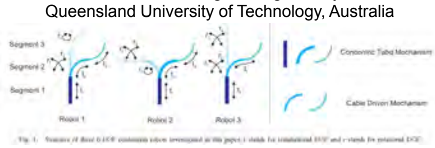
- An automatic robotic taping system for surface protection through attaching masking tapes
- The taping path planning method apply 3D scanning model to generate the surface covering trajectory.
- Specific taping end-effectors are designed to enable tape attachment, force control and cutting.
- A very useful taping package for surface protection before painting, plasma spraying etc..


Automatic taping system

| 15:10–15:15 | TUC11.6 |
|---|---|

### Dexterity Analysis of Three 6-DOF Continuum Robots Combining Concentric Tube Mechanisms and Cable Driven Mechanisms

Liao Wu, Ross Crawford, and Jonathan Roberts
Australian Centre for Robotic Vision
Science and Engineering Faculty,
Queensland University of Technology, Australia




- We investigated the dexterity of three continuum robots by introducing indices based on the concept of orientability.
- Results imply that evenly allocating degrees of freedom (DOFs) among the segments achieves the best workspace and dexterity.
- Otherwise, assigning more DOFs to the proximal segment tends to enlarge the workspace and adding more DOFs to the distal segment tends to improve the dexterity.

## Industrial Robots

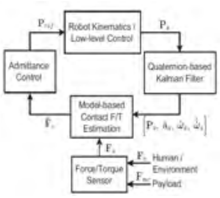
Chair *William R. Hamel, University of Tennessee*
Co-Chair *Liao Wu, Queensland University of Technology*

| 15:15–15:20 | TUC11.7 |
|---|---|

### Compensation of Load Dynamics for Admittance Controlled Interactive Industrial Robots using a Quaternion-based Kalman Filter

Saverio Farsoni, Marcello Bonfè
Engineering Department, University of Ferrara, Italy
Chiara Talignani Landi, Federica Ferraguti, Cristian Secchi
DISMI, University of Modena and Reggio Emilia, Italy

- Human inputs, applied to F/T sensors on interactive robots, can be distinguished from load dynamic effects only with an accurate estimation of load accelerations/velocities
- We propose a novel estimation approach using a Quaternion-based Kalman filter and only pose measurements (available from any industrial robot controller)
- Experiments demonstrate the superiority of our approach w.r.t. to numerical differentiation and inertial measurements

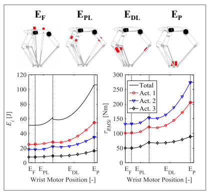



| 15:20–15:25 | TUC11.8 |
|---|---|

### Comparative Study of Serial-Parallel Delta Robots with Full Orientation Capabilities

J. Brinker[1], N. Funk[1], P. Ingenlath[1], Y. Takeda[2], and B. Corves[1]
[1] Dept. of Mechanism Theory and Dyn. of Machines, RWTH Aachen, DE
[2] Dept. of Mechanical Engineering, Tokyo Institute of Technology, JP

- By functionally extending the Delta robot, commercial concepts obtain up to three additional rotational dof
- Even though the complexity is higher, energy-based dynamic models can be solved in reasonable times
- Energy efficiency of $E_F$ is superior, whereas $E_{DL}$ does not incorporate telescopic members
- $E_{DL}$ equally obtains reasonable results in respect of energy consumption and torques




Energy consumption and RMS torque

## Actuators 4

Chair *Kyoungchul Kong, Sogang University*
Co-Chair *Sami Haddadin, Leibniz University Hanover*

| 16:25–16:30 | TUD1.1 |
|---|---|

### Biomimetic robotic joint mechanism driven by soft linear actuators

Kyeong Ho Cho, Min Geun Song, Hosang Jung, Sang Yul Yang, Hugo Rodrigue, Hyungpil Moon, Ja Choon Koo, and Hyouk Ryeol Choi
Mechanical Engineering, Sungkyunkwan University, Korea

- Limitations of soft linear actuators
- Mimicking the working principle of skeletal muscle (sliding filament mechanism)
- Development of two types of Sliding Filament Joint Mechanisms (SFJMs)
- Verification of the feasibilities of SFJMs with shape memory alloy wires

| 16:30–16:35 | TUD1.2 |
|---|---|

### Electric Phase-change Actuator with Inkjet Printed Circuit For Printable and Integrated Robot Prototyping

Kenichi Nakahara, Koya Narumi, Ryuma Niiyama and Yoshihiro Kawahara
Graduate School of Information Science and Technology, The University of Tokyo, Japan

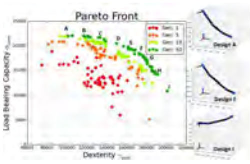
- Proposes an electrically driven printable actuator
- It consists of inkjet-printed electric heater and heat-bonded nylon pouch with liquid inside
- It can be easily integrated into origami robots
- Theoretical model, fabrication process, real examples are shown in the paper

| 16:35–16:40 | TUD1.3 |
|---|---|

### Multi-Objective Design Optimization Of a Soft, Pneumatic Robot

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

- Genetic Algorithm used to optimize the kinematic structure of a soft, inflatable robot
- Multi-objective, maximin fitness function used to efficiently identify the Pareto front
- Designs are evaluated at many randomly generated configurations on multiple, user-defined metrics
- Link lengths and base mount of an inflatable manipulator optimized for dexterity and load lifting capacity



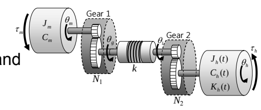

A Pareto front is identified using a multi-objective fitness function

| 16:40–16:45 | TUD1.4 |
|---|---|

### Design of a Compact Rotary Series Elastic Actuator for Improved Actuation Transparency and Mechanical Safety

Hanseung Woo, Byeonghun Na and Kyoungchul Kong
Department of Mechanical Engineering, Sogang University, Korea

- For human-interactive robot systems, actuation transparency and mechanical safety are the most important requirements
- In this paper, a compact rotary series elastic actuator (cRSEA) is designed considering the actuation transparency and the mechanical safety
- The mechanical parameters of a cRSEA are selected considering the controllability, the input and output torque transmissibility, and the mechanical impedance
- Also mechanical clutch to automatically disengage the transmission is introduced.




| 16:45–16:50 | TUD1.5 |
|---|---|

### A Robotic Manipulator Design with Novel Soft Actuators

Xiaojiao Chen[1], Jing Peng[1], Jianshu Zhou[1], Yonghua Chen[1], Michael Yu Wang[2], and Zheng Wang[1,3]*
[1] Department of Mechanical Engineering, the University of Hong Kong, Hong Kong
[2]Department of Mechanical and Aerospace Engineering, the Hong Kong University of Science and Technology, Hong Kong
[3]The University of Hong Kong Shenzhen Institute of Research and Innovation (HKU-SIRI), Shenzhen, China

- Novel soft linear actuator "SHENLINDER" with maximum 300% elongation and linear force output.
- A novel 6-DOF manipulator with biomimetic kinematic structure driven by 12 SHELINDERs
- A tri-fingered soft robotic hand with continuous rotation on each finger

The proposed soft manipulator design

| 16:50–16:55 | TUD1.6 |
|---|---|

### Serially Actuated Locomotion for Soft Robots in Tube-like Environments

Mark D Gilbertson, Gillian McDonald, Gabriel Korinek, James D Van de Ven, PhD and Timothy M Kowalewski, PhD
Mechanical Engineering, University of Minnesota, USA


Soft robot locomotion through a tube.

- Serial Actuation
- Fiber reinforced actuators
- Optimized design for tube locomotion

**Actuators 4**

Chair *Kyoungchul Kong, Sogang University*
Co-Chair *Sami Haddadin, Leibniz University Hanover*

| 16:55–17:00 | TUD1.7 |
|---|---|

### Force Measurement towards the Instability Theory of Soft Pneumatic Actuators

Yi Sun, Xinquan Liang, Jiawei Cao, Marcelo H. Ang. Jr.
Dept. Mechanical Engineering, National University of Singapore, Singapore
Hong Kai Yap, Raye Chen Hua Yeow
Dept. Biomedical Engineering, National University of Singapore, Singapore

- This paper brings up the instability issue of the SPA force application with detailed description.
- A new perspective is provided to view the bending SPAs as curved beams to understand the force failing problems as instability.
- Newly-designed bending SPAs were fabricated, and measured using a less confined measuring condition.
- Material, length, pressure and measuring angle are investigated to study their effects on the buckling occurrences

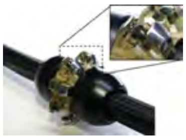
SPA yielding and buckling issues.

| 17:00–17:05 | TUD1.8 |
|---|---|

### A Self-locking-type Expansion Mechanism to Achieve High Holding Force and Pipe-passing Capability for a Pneumatic In-pipe Robot

Tomonari Yamamoto, Masashi Konyo
Kenjiro Tadakuma, and Satoshi Tadokoro
Graduate School of Information Sciences, Tohoku University, Japan

- Novel concept and design to generate high holding force for in-pipe robot is proposed.
- Retractable pin mechanism to invoke self-locking phenomenon realizes high holding force and smooth pipe-passing.
- Maximum holding force, 69.7 N, was 5.2 times higher than our previous mechanism.
- Robot equipped with the proposed mechanism successfully moves through horizontal, vertical, and bent pipes.



Self-locking-type expansion mechanism to generate high holding force with pins.

## Collision Avoidance

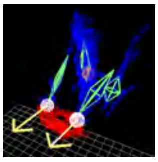
Chair *Dinesh Manocha, University of North Carolina at Chapel Hill*
Co-Chair *Giuseppe Oriolo, Sapienza University of Rome*

| 16:25–16:30 | TUD2.1 |
|---|---|

### Human Body Part Multicontact Recognition and Detection Methodology

Kwan Suk Kim and Luis Sentis
Mechanical Engineering, The University of Texas at Austin, USA

- Estimate contact force, contact location, and human body part
- Multiple contacts can be detected
- Sensor fusion from 3D LIDAR and torque sensors in drivetrain
- Conceptual application example on omnidirectional mobile platform

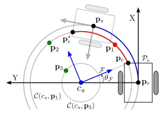

Multiple contacts are detected

| 16:30–16:35 | TUD2.2 |
|---|---|

### The Admissible Gap (AG) Method for Reactive Collision Avoidance

Muhannad Mujahed and Bärbel Mertsching
GET Lab, University of Paderborn, Germany

- New concept, the Admissible Gap, developed
- Robot moves through AG gap by executing a single motion command
- Navigation in unknown cluttered environments successfully achieved, where the exact shape and kinematics are respected
- State-of-the-art techniques outperformed in terms of efficiency, safety, and smoothness


Collision check along the path towards $p_s$ given 3 obstacle points $p_1$ - $p_3$

| 16:35–16:40 | TUD2.3 |
|---|---|

### Collision Avoidance with Limited Field of View Sensing: A Velocity Obstacle Approach

Steven Roelofsen, Alcherio Martinoli
Distributed Intelligent Systems and Algorithms Laboratory, EPFL, Switzerland
Denis Gillet
Coordination and Interaction System Group, EPFL, Switzerland

- Studies collision avoidance with sensors that have a limited field of view
- Shows that the velocity has to be constrained to a specific set because of limited field of view.
- Presents a velocity obstacle collision avoidance that satisfies the constrained sensory set.
- Validates the new collision avoidance algorithm respecting the constrained sensory set in simulation and real-world experiments.

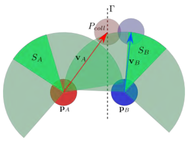


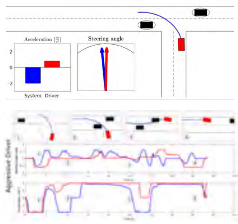
Illustration why the motion needs to be constrained to be in the constrained sensory set (dark green)

| 16:40–16:45 | TUD2.4 |
|---|---|

### Parallel Autonomy in Automated Vehicles: Safe Motion Generation with Minimal Intervention

Wilko Schwarting, Javier Alonso-Mora, Liam Paull, Sertac Karaman and Daniela Rus
CSAIL, Massachusetts Institute of Technology, USA

- Safe Guardian Angel: Minimizing intervention subject to a set of safety constraints
- Analytic description of road boundaries and of traffic participants subject to time-varying uncertainty
- Real-time NMPC over long time-horizons (9s) of both acceleration and steering
- Fast computation time: >100Hz in static and >10Hz in dynamic environments



| 16:45–16:50 | TUD2.5 |
|---|---|

### Parallel Collision Check for Sensor Based Real-Time Motion Planning

Massimo Cefalo, Emanuele Magrini, Giuseppe Oriolo
DIAG, Sapienza University of Rome, Italy

- A real-time collision check approach built for GPU parallel computations
- Based on the visual feedback of a 2.5D image sensor
- Applied to real-time Task-Constrained Motion Planning problems
- Simulations and experiments on a real robot show the effectiveness of the method

| 16:50–16:55 | TUD2.6 |
|---|---|

### Efficient Probabilistic Collision Detection for Non-Convex Shapes

Jae Sung Park and Chonhyon Park and Dinesh Manocha
University of North Carolina at Chapel Hill, USA
http://gamma.cs.unc.edu/PCOLLISION

- Compute the probability of collisions between two shapes, given positional error distribution
- Linearize 3D Gaussian probability distribution to compute the upper bound of collision probability
- Combine bounding volume hierarchies with collision probability bounds
- Used for real-time trajectory planning of high DOF manipulators with geometric uncertainty


Human obstacle with positional error (red)

**Collision Avoidance**

Chair *Dinesh Manocha, University of North Carolina at Chapel Hill*
Co-Chair *Giuseppe Oriolo, Sapienza University of Rome*

| 16:55–17:00 | TUD2.7 |
|---|---|

### Fast, On-line Collision Avoidance for Dynamic Vehicles using Buffered Voronoi Cells

Dingjiang Zhou[1], Zijian Wang[2]
Saptarshi Bandyopadhyay[3] and Mac Schwager[2]
[1] Mechanincal Engineering Department, Boston University, USA
[2] Aeronautics & Astronautics Department, Stanford University, USA
[3]Jet Propulsion Laboratory, Caltech, USA

- Distributed collision avoidance algorithm for multiple dynamic vehicle, each robot plans a path within the BVC in a receding horizon fashion
- Algorithm has a computational complexity of O(k), comparable to ORCA, better than MPC and MPC-SCP
- Benchmark simulation compared to ORCA
- Experiments with five micro aerial vehicles over more than 70 trials

| 17:00–17:05 | TUD2.8 |
|---|---|

### Dynamical System based Robotic Motion Generation with Obstacle Avoidance

Sotiris Stavridis[1], Dimitrios Papageorgiou[1,2] and Zoe Doulgeri[1,2]
[1]Department of Electrical and Computer Engineering,
Aristotle University of Thessaloniki, Greece
[2]Center for Research and Technology Hellas (CERTH), Greece

- Additive control input to a dynamical system for obstacle avoidance.
- Obstacle Avoidance control synthesis based on Prescribed Performance Control.
- Guarantee of stability and obstacle avoidance.
- Comparison with modulated dynamical systems and task priority framework solutions.

Experiment with KUKA LWR4+

## Computer Vision 4

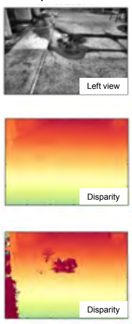
Chair *Hongliang Ren, Faculty of Engineering, National University of Singapore*
Co-Chair *Kai Berger, JPL*

| 16:25–16:30 | TUD3.1 |
|---|---|

### Depth from Stereo Polarization in Specular Scenes for Urban Robotics

Kai Berger and Larry Matthies
Jet Propulsion Laboratory, USA
Randolph Voorhies
inVia Robotics, USA

Water puddle scene



Ours

SGBM

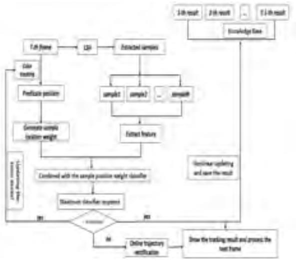
- Graph-Cut approach to stereo vision with 2nd order surface normal prior
- Surface normal prior from polarization information (AOP)
- Use Micropolarizer camera to get 4 polarized images per frame, compute AOP and DOLP
- Overcomes challenging scenes with specular surfaces (PVC floors, water puddles, metals)

| 16:30–16:35 | TUD3.2 |
|---|---|

### Compressive Tracking with Locality Sensitive Histograms Features

Sixian Chan, Xiaolong Zhou, Zhuo Zhang and Shengyong Chen
College of Computer Science and Technology, Zhejiang University of Technology, Hangzhou, China

- The Haar-like features generated from LSH are used to represent the target appearance model.
- A color attributes tracker is employed to predict the target position and to re-build the new discriminant function.
- A novel model updating mechanism is proposed to maintain the stability of features while avoiding noisy.
- A trajectory rectification method is adopted to make the finally estimated location more accurate.



The framework of the ALSHCT algorithm

| 16:35–16:40 | TUD3.3 |
|---|---|

### ng Trees with a Monocular MAV: Towards Preventing Deforestation

, Rishabh Khawad, and K Madhava Krishna
RRC, IIIT Hyderabad, India

- Deep learning for tree detection and translation maneuver to obtain dense disparity map.

| 16:40–16:45 | TUD3.4 |
|---|---|

### Combined Image- and World-Space Tracking in Traffic Scenes

Aljoša Ošep and Wolfgang Mehner and Markus Mathias and Bastian Leibe
Visual Computing Institute, RWTH Aachen University, Germany

- Vision-based multi-object tracking framework, suitable for robotics applications.
- We use category-agnostic 3D object proposals for precise localization of detections in 3D space.
- Joint image-space and 3D-space tracking formulation.
- We obtain state-of-the-art results on vision benchmarks, while demonstrating significant improvements in 3D localization.

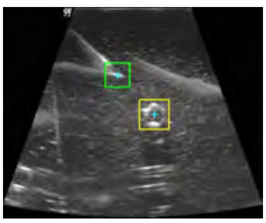
Example output of our method.

| 16:45–16:50 | TUD3.5 |
|---|---|

### Visual Tracking of Multiple Moving Targets in 2D Ultrasound Guided Robotic Percutaneous Interventions

Mert Kaya, Enes Senel, Awais Ahmad, Ozkan Bebek
Ozyegin University, Istanbul, Turkey

- Visual tracking of multiple moving points, such as biopsy needles and targets, in 2D US images
- Affine motion model is used for small and moving target tracking
- Thin plate spline motion model is used for deformable target tracking
- Needle and target template images are updated with a template update strategy



Simultaneous needle tip and moving target tracking in 2D US images

| 16:50–16:55 | TUD3.6 |
|---|---|

### Deep Representation of Industrial Components using Simulated Images

Seong-heum Kim, Gyeongmin Choe, Byungtae Ahn, and In So Kweon
School of Electrical Engineering, KAIST, Republic of Korea

(a) Automatic Assembly (b) 3D model retrieval (c) Pose estimation

- Visual learning framework to retrieve a 3D model and estimate its pose.
- Simulation space in NIR and quasi-Monte Carlo (MC) method for scalable photo-realistic rendering, and two types of CNNs trained with mixed data.
- Validation of our method with 88 models, including one practical product.

## Computer Vision 4

Chair *Hongliang Ren, Faculty of Engineering, National University of Singapore*
Co-Chair *Kai Berger, JPL*

| 16:55–17:00 | TUD3.7 |
|---|---|

### 6-DoF Object Pose from Semantic Keypoints

Georgios Pavlakos[1], Xiaowei Zhou[1], Aaron Chan[1],
Konstantinos G. Derpanis[2], Kostas Daniilidis[1]
[1]Computer and Information Science, University of Pennsylvania, USA
[2]Computer Science, Ryerson University, Canada

- We estimate the 6-DoF pose of an object from a single RGB image.
- A Convolutional Network is used to localize 2D semantic keypoints on the image.
- A pose optimization step enforces global consistency of the detected keypoints.
- Our method deals both with instance-based as well as class-based scenarios.

Steps of our approach

| 17:00–17:05 | TUD3.8 |
|---|---|

### Mixtures of Lightweight Deep Convolutional Neural Networks: applied to agricultural robotics

Chris McCool, Tristan Perez and Ben Upcroft
School of Electrical Engineering and Computer Science
Queensland University of Technology, Australia

- Applying deep learning for real-time pixel-level weed classification
- Tradeoff complexity (processing speed) vs accuracy
- Combining multiple compressed models using a mixture of deep convolutional neural networks
- Achieves accuracy > 90% while improving speed by up to an order of magnitude with up to an order of magnitude fewer parameters

Above is AgBot II which can detect and classify weeds in real-time using this approach.

## Visual-Based Navigation

Chair *Henrik Iskov Christensen, UC San Diego*
Co-Chair *Timothy Barfoot, University of Toronto*

| 16:25–16:30 | TUD4.1 |
|---|---|

### Falling in Line: Visual Route Following on Extreme Terrain for a Tethered Mobile Robot

Patrick McGarey, Max Polzin, Timothy D. Barfoot
University of Toronto Institute for Aerospace Studies, Canada

- When a tethered robot navigates steep, cluttered environments, its supportive tether can become 'anchored' on obstacles.
- To avoid entanglement, the robot must retrace its outgoing path to sequentially detach the tether from obstacles (anchors).
- We use the Visual Teach & Repeat (VT&R) algorithm to autonomously retrace a manually taught path on extreme terrain.
- For VT&R to work for tethered robots, we have developed a taut tether controller that (i) allows the robot to drive freely regardless of slope, and (ii) provides motion assistance when wheel traction is reduced.

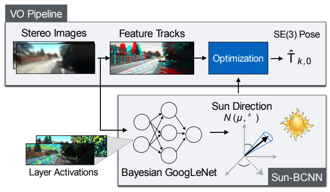
Our TReX robot autonomously repeats a path on steep, cluttered terrain to avoid entanglement.

| 16:30–16:35 | TUD4.2 |
|---|---|

### Reducing Drift in Visual Odometry by Inferring Sun Direction Using a Bayesian CNN

Valentin Peretroukh
Institute for Aerospac

- We train a Bayesian CNN t infer the 3D direction of the sun from a single RGB image (where the sun is nc visible).
- The Bayesian CNN outputs a mean and a principled covariance, with median te errors of ~12 degrees.
- We use the predictions to improve sliding window stereo VO on the KITTI dataset by up to 42%.

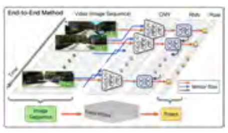



| 16:35–16:40 | TUD4.3 |
|---|---|

### DeepVO: Towards End-to-End Visual Odometry with Recurrent Convolutional Neural Networks

Sen Wang, Ronald Clark, Hongkai Wen and Niki Trigoni
Department of Computer Science, University of Oxford, United Kindom

- End-to-end monocular Visual Odometry framework is developed to infer poses directly from a sequence of raw RGB images (video).
- It can learn effective feature representation for the Visual Odometry problem through Convolutional Neural Networks.
- Sequential dynamics and relations are modelled implicitly by using Recurrent Neural Networks.
- Experiments based on KITTI dataset verify its good generalization ability in totally new, untrained environments.



| 16:40–16:45 | TUD4.4 |
|---|---|

### Point and line feature-based observer design on SL(3) for Homography estimation and its application to image stabilization

Minh-Duc Hua*, Jochen Trumpf**, Tarek Hamel*, Robert Mahony**, Pascal Morin***
*I3S UNS-CNRS (France), **ANU (Australia), *** ISIR UPMC (France)

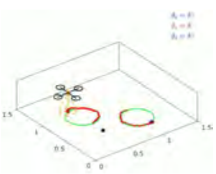
A nonlinear observer for online estimation of a sequence of homographies applicable to image sequences obtained from robotic vehicles equipped with a monocular camera is proposed. The approach taken exploits the underlying Special Linear group SL(3) structure of the set of homographies along with gyrometer measurements and direct point- and line-feature correspondences between images to develop temporal filter for the homography estimate. Theoretical analysis and experimental results are provided to demonstrate the robustness of the proposed algorithm. The experimental results show excellent performance even in the case of very fast camera motion (relative to frame rate), and in presence of severe occlusion, specular reflection, image blur, and light saturation.

| 16:45–16:50 | TUD4.5 |
|---|---|

### Visual Servoing Using Model Predictive Control to Assist Multiple Trajectory Tracking

Nicolas Cazy[1], Pierre-Brice Wieber[1],
Paolo Robuffo Giordano[2] and François Chaumette[1]
[1]INRIA, France, [2]CNRS, France

- Multi-Robot **Active Perception** scheme based on Model Predictive Control
- **Two ground robots** needing localization services for following desired trajectories
- **One Quadrotor UAV** periodically visiting the ground robots and a fixed landmark for keeping the **localization covariance** as low as possible
- **Automatic sequencing** of the visiting task by taking into account field of view and actuation constraints
- Simulation results confirm effectiveness of the idea



| 16:50–16:55 | TUD4.6 |
|---|---|

### Visual Triage: A Bag-of-Words Experience Selector for Long-Term Visual Route Following

Kirk MacTavish, Michael Paton, and Timothy D. Barfoot
Institute for Aerospace Studies, University of Toronto, Canada

- Builds on Visual Teach & Repeat 2: a vision-in-the-loop autonomous navigation system with multi-experience localization.
- Selects visually relevant experiences from a large driving history based on what the vehicle is observing *right now*.
- Enables long-term autonomy by focusing the multi-experience localization on a small but relevant temporal-subset of the map.

## Visual-Based Navigation

Chair *Henrik Iskov Christensen, UC San Diego*
Co-Chair *Timothy Barfoot, University of Toronto*

| 16:55–17:00 | TUD4.7 |
|---|---|

### Satellite Image-based Localization via Learned Embeddings

Dong-Ki Kim
The Robotics Institute, Carnegie Mellon University, United States
Matthew Walter
Toyota Technological Institute at Chicago, United States

- **Goal:** Estimate a vehicle's pose by registering ground-level images against a georeferenced satellite view of the environment
- Multi-view neural network learns location-discriminative embeddings matching ground-level images to their corresponding satellite view
- Particle filter maintains pose distribution using the learned embedding as observation model
- **Result:** Localization in environments novel relative to training, despite challenge of significant viewpoint and appearance variation

| 17:00–17:05 | TUD4.8 |
|---|---|

### Direct Visual Odometry in Low Light Using Binary Descriptors

Hatem Alismail, Michael Kaess, Brett Browning, Simon Lucey
The Robotics Institute, Carnegie Mellon University

- Robust visual odometry in poor imaging conditions
- Direct VO with **binary** descriptors (no keypoints)
- Real-time performance
- Demonstrated in low light underground mines
- Code: https://github.com/halismai/bpvo

## Distributed Robot Systems 2

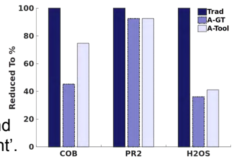
Chair *George J. Pappas, University of Pennsylvania*
Co-Chair *Jakub Lengiewicz, Institute of Fundamental Technological Research, Polish Academy of Sciences*

| 16:25–16:30 | TUD5.1 |
|---|---|

### Rate Impact Analysis in Robotic Systems

Nishant Sharma, Sebastian Elbaum, and Carrick Detweiler
Department of Computer Science and Engineering
University of Nebraska-Lincoln, USA

- Changing the publish rate of a message can impact large portions of robot systems.
- The proposed approach helps developers understand the impact of a data rate change.
- It works by analyzing the code of every component, building a dependency graph, and marking edges as 'dependent' or 'independent'.
- It reduces the impact set identified by comparable approaches by only exploring 'dependent' edges for any given rate change.
- A study on three real ROS systems shows that the approach implementation reduced the impact set by up to 41%.




Impact set reduction ratio of proposed technique ground truth (A-GT) and proposed techniques as implemented in our Tool (A-Tool) over traditional (Trad) impact analysis techniques.

| 16:30–16:35 | TUD5.2 |
|---|---|

### Achieving the Desired Dynamic Behavior in Multi-Robot Systems Interacting with the Environment

Lorenzo Sabattini, Cristian Secchi and Cesare Fantuzzi
Dept. of Sciences and Methods for Engineering
University of Modena and Reggio Emilia, Italy

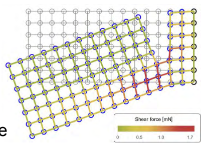
- Multi-robot system interacting with the environment
- Locally scaling the interaction, we achieve the desired viscoelastic dynamic behavior
- Passivity is guaranteed to be preserved

| 16:35–16:40 | TUD5.3 |
|---|---|

### Distributed comput. of forces in modular-robotic ensembles as part of reconfiguration planning

Pawel Holobut and Jakub Lengiewicz
Institute of Fundamental Technological Research, PAS, Poland

- Distributed algorithm to predict deformation and intermodular forces resulting from a planned reconfiguration step
- Algorithm can be run by a modular robot itself
- Elastic frame model of robot was assumed, and Weighted-Jacobi iterative solution scheme was adapted
- Efficiency of the algorithm was checked for robots with different numbers of modules



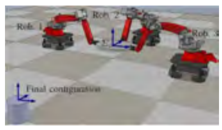
Predicted shear forces for a configuration with four connections removed

| 16:40–16:45 | TUD5.4 |
|---|---|

### Distributed cooperative object parameter estimation and manipulation without explicit communication

Alessandro Marino
University of Salerno, Italy
Giuseppe Muscio and Francesco Pierri
University of Basilicata, Italy

- A two-stage distributed algorithm for cooperative manipulating an unknown object rigidly grasped by mobile manipulators
- Absence of any explicit information exchange among robots
- In the first stage robots cooperatively estimate the main object kinematic and dynamic parameters
- The estimated parameters are adopted in the control stage to ensure the motion of the object while limiting the squeezing and external wrenches exerted respectively by the manipulators and the environment on the object.



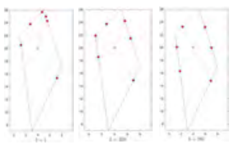
Work-cell with three mobile manipulators grasping an object

| 16:45–16:50 | TUD5.5 |
|---|---|

### Active Target Tracking with Self-Triggered Communications

Lifeng Zhou and Pratap Tokekar
Electrical and Computer Engineering, Virginia Tech, USA

- We study the problem of reducing communications for multi-robot target tracking.
- The robots need to exchange information to coordinate their actions.
- We propose a self-triggered communication strategy that decides when robots should seek up-to-date information from their neighbors.
- We prove that the self-triggered strategy converges to the optimal configuration.



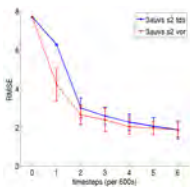
Self-triggered tracking with six robots moving on the boundary of a convex polygon with a known, stationary target.

| 16:50–16:55 | TUD5.6 |
|---|---|

### Multi-Robot Coordination through Dynamic Voronoi Partitioning for Informative Adaptive Sampling in Communication-Constrained Environments

Stephanie Kemna and Gaurav Sukhatme
Computer Science, University of Southern California, USA
John G. Rogers III and Carlos Nieto-Granda* and Stuart Young
US Army Research Laboratory and *IRIM, Georgia Institute of Technology, USA

- A multi-robot coordination approach for adaptive sampling in spatial modeling.
- Our robots repeatedly calculate (decentralized) weighted Voronoi partitions, and runs adaptive sampling within.
- Underwater communication constraints are handled via request-based surfacing events.
- Simulation results show that the addition of the coordination approach results in obtaining higher quality models faster.



**Distributed Robot Systems 2**

Chair *George J. Pappas, University of Pennsylvania*
Co-Chair *Jakub Lengiewicz, Institute of Fundamental Technological Research, Polish Academy of Sciences*

16:55–17:00 TUD5.7

## Modular Robot using Helical Magnet for Bonding and Transformation

Yosuke Suzuki,
Kanazawa Univ., Japan
Yuhei Tsutsui,
UEC, Japan
Masato Yaegashi,
UEC, Japan
Satoshi Kobayashi
Univ. of Tsukuba, Japan

- A new design of a modular robot using **helically magnetized axes** is proposed.
- The axes are arranged at **all of the edges** of the cubic-shaped module.
- The axes contribute to **both connection and transformation** among the modules.
- Motion experiments are carried out to evaluate the performance.

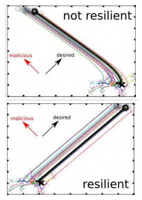
Overview of modular robots using helically magnetized axes

17:00–17:05 TUD5.8

## Resilient Flocking for Mobile Robot Teams

Kelsey Saulnier, David Saldaña,
Amanda Prorok, George Pappas, and Vijay Kumar
GRASP Lab, Univeristy of Pennsylvania, USA

- Goal: Robots should perform resilient consensus on direction of motion.
- Method: Network resilience is maintained by a hybrid controller which utilizes a lower bound measure and dynamic connectivity management.
- Result: Consensus is guaranteed to converge to a safe heading, even in the presence of non-cooperative communication from team members.




Without resilient flocking a non-cooperative robot controls the team

**Learning and Adaptive Systems 4**

Chair *Tetsuya Ogata, Waseda University*
Co-Chair *Sergey Levine, UC Berkeley*

| 16:25–16:30 | TUD6.1 |
|---|---|

## Combining Self-Supervised Learning and Imitation for Vision-Based Rope Manipulation

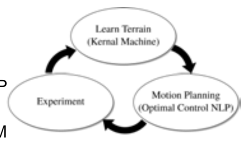
Ashvin Nair, Pulkit Agrawal, Dian Chen, Phillip Isola, Pieter Abbeel, Jitendra Malik, Sergey Levine

| 16:30–16:35 | TUD6.2 |
|---|---|

## Learning to Jump in Granular Media: Unifying Optimal Control Synthesis with Gaussian Process-Based Regression

Alex H. Chang and Patricio A. Vela
School of ECE, Georgia Institute of Tech., United States
Christian M. Hubicki and Aaron D. Ames
School of ME, Georgia Institute of Tech., United States
Jeff J. Aguilar and Daniel I. Goldman
School of Physics, Georgia Institute of Tech., United States

- Granular media (GM) imposes complex, nonlinear forcing profiles on intruders
- A Gaussian Process (GP) is applied to learn GM forcing acting on a 1-D hopper
- An iterative strategy repeatedly generates an optimal control, applies it and then trains a GP
- After a handful of iterations, the GP-based model of the ground converges to the true GM model

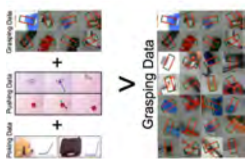



| 16:35–16:40 | TUD6.3 |
|---|---|

## Learning to Push by Grasping: Using multiple tasks for effective learning

Lerrel Pinto and Abhinav Gupta
Carnegie Mellon University

- By using a multi task learning framework, we learn shared representations that help individual tasks as well.
- We show that models with multi-task learning perform better than task-specific tasks (on **grasping** and **pushing** objects).
- The paper opens up a new subfield of multi-task learning in robotics; specifically focussing on sharing across tasks.

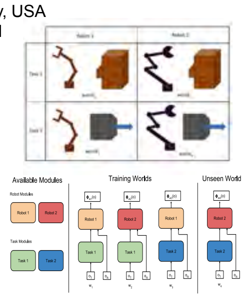



| 16:40–16:45 | TUD6.4 |
|---|---|

## Learning Modular Neural Network Policies for Multi-Task and Multi-Robot Transfer

Coline Devin[1], Abhishek Gupta[1], Trevor Darrell[1], Pieter Abbeel[123], Sergey Levine[1]
[1]EECS, UC Berkeley, USA
[2]OpenAI [3]ICSI

- **Transfer skills** across multiple tasks and multiple robots with different morphologies
- Learn **modular and composable policies** end-to-end using reinforcement learning.
- Obtain **zero-shot performance** on unseen robot-task combinations enabling effective transfer of skills.

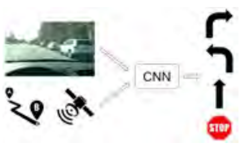



| 16:45–16:50 | TUD6.5 |
|---|---|

## Incorporating Side-Channel Information into Convolutional Neural Networks for Robotic Tasks

Yilun Zhou and Kris Hauser
Department of Electrical & Computer Engineering, Duke University, USA

- It is unclear how to best use CNN in robotics tasks
- Main-channel sensor input + side-channel task-specific parameters
- Four candidate CNN architectures for fusing the two modalities
- Benchmark on toy planning and control problems



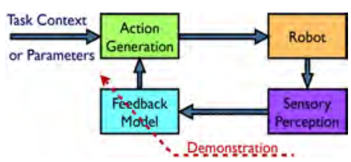

Both main-channel image-like information (e.g. camera image) and side-channel information (e.g. GPS location and route) are needed to predict maneuver

| 16:50–16:55 | TUD6.6 |
|---|---|

## Learning Feedback Terms for Reactive Planning and Control

Akshara Rai[2,3,*], Giovanni Sutanto[1,2,*], Stefan Schaal[1,2] and Franziska Meier[1,2]
[1]USC, USA, [2]AMD, MPI-IS, Germany, [3]RI, CMU, USA
[*]contributed equally

- A general framework for learning feedback terms from demonstrations.
- Modify ongoing movement plan using feedback represented as a neural network
- Spatial and temporal generalization
- Evaluated in simulation and on a 7-DoF Barrett WAM arm




Proposed framework for learning feedback terms

**Learning and Adaptive Systems 4**

Chair *Tetsuya Ogata, Waseda University*
Co-Chair *Sergey Levine, UC Berkeley*

| 16:55–17:00 | TUD6.7 |
|---|---|

## An Approach for Imitation Learning on Riemannian Manifolds

Martijn J.A. Zeestraten[1], Ioannis Havoutis[2,3], João Silvério[1], Sylvain Calinon[2,1], Darwin G. Caldwell[1]
[1]Advanced Robotics Department, Istituto Italiano di Tecnologia, Italy
[2]Idiap Research Institute, Switzerland
[3]Oxford Robotics Institute, University of Oxford, United Kingdom

- **Generalization** of common tools for **Imitation Learning** to **Riemannian Manifolds** (Gaussian Conditioning and Product, GMR and TP-GMM).
- **Probabilistic regression** of robot pose by exploiting variation and coordination.
- Experiment: **bi-manual task** encoded with a **single Riemannian Gaussian**.
- The framework is **extensible** to other types of **Riemannian Manifolds**.

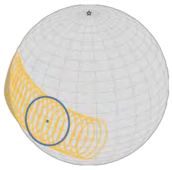


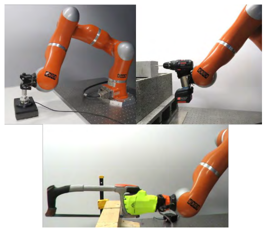
*Figure*: Gaussian conditioning on the 2-sphere.

| 17:00–17:05 | TUD6.8 |
|---|---|

## A Method for Derivation of Robot Task-Frame Control Authority from Repeated Sensory Observations

Luka Peternel, Leonel Rozo, Darwin Caldwell and Arash Ajoudani
HRI[2] Lab and Learning and Interaction Lab
Dept. of Advanced Robotics, Istituto Italiano di Tecnologia, Genoa, Italy

- We propose a method that enables the robot to autonomously devise an appropriate control strategy from human demonstrations without prior knowledge of the demonstrated task.
- The method is primarily based on analysing patterns and consistency in the observed dataset.
- The dataset is obtained through a demonstration setup that uses motion capture system, force sensor and muscle activity measurement.



Experiments with different tasks: wiping, drilling and sawing

## Grasping 2

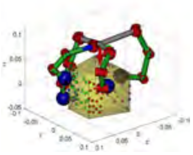
Chair *Yu Zheng, University of Michigan-Dearborn*
Co-Chair *Zhaopeng Chen, Institute of Robotics and Mechatronics, GermanAerospaceCenter, DLR*

16:25–16:30 TUD7.1

### Computing the Best Grasp in a Discrete Point Set

Yu Zheng
Department of Electrical and Computer Engineering,
University of Michigan-Dearborn, USA

- An efficient algorithm for the best grasp among discrete points
- Can be applied with a group of wrench-based grasp quality measures
- Can be applied to any number and type of contacts
- Can be applied on real robot hands



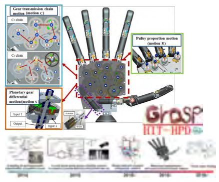
The best grasp of a robot hand at a given pose

16:30–16:35 TUD7.2

### A novel actuation configuration of robotic hand and the mechanical implementation via postural synergies

Yuan Liu, Li Jiang, Shaowei Fan*, Dapeng Yang, Jingdong Zhao and Hong Liu
State Key Laboratory of Robotics and System, Harbin Institute of Technology, China

- A human grasp posture collection protocol is proposed to collect the human grasp postures
- A novel module-division actuation configuration of robotic hand based on the built actuation configuration strategies
- Motion of human four finger joints is decomposed to proportion motion, differential motion and chain proportion motion
- Mechanically implemented by pulley, planetary gear differential module and gear transmission chain



Analysis of human hand move characteristic and mechanical implementation

16:35–16:40 TUD7.3

### Grasp Quality Evaluation and Planning for Objects with Negative Curvature

Shuo Liu and Stefano Carpin
EECS, University of California Merced, USA
Zhe Hu, Hao Zhang,Mingu Kwon, Zhikang Wang, Yi Xu
Dorabot Inc, Shenzhen, China

- Integrate local geometry around each contact with **grasp quality evaluation**.
- Use **adapted friction cone** to link negative curvature and grasp quality metrics for force closure grasps
- Generated databases for multiple objects which has negative curvature and tested on real robot (UR5+Dora-Hand)
- Outperformed random grasp quality-wise and on real robot performance

16:40–16:45 TUD7.4

### Hierarchical Salient Object Detection for Assisted Grasping

Dominik A. Klein, Boris Illing, Bastian Gaspers, and Dirk Schulz
Cognitive Mobile Systems, Fraunhofer FKIE, Germany
Armin B. Cremers
Bonn-Aachen Int. Center for Information Technology (B-IT), Germany

- Grouping and saliency as same fundamental process, just from two opposing viewpoints
- Saliency calculation adds negligible runtime after hierarchical grouping
- Saliency tree used for object detection defines most salient region and scale for each pixel
- Easy-to-use manipulation system showcases the advantage of a deeply geared segmentation and saliency estimation

Figure caption is optional, use Arial 18pt

16:45–16:50 TUD7.5

### Grasp Stability Assessment Through Unsupervised Feature Learning of Tactile Images

Deen Cockburn, Jean-Philippe Roberge, Thuy-Hong-Loan Le, Alexis Maslyczyk, and Vincent Duchaine
Command and Robotics Laboratory (CoRo),
École de Technologie Superieure, Montreal, Canada

- Improving robotic grasping by enabling a robot to distinguish between stable and unstable grasps for a variety of objects.
- Unsupervised feature-learning using pressure images captured by a tactile sensor.
- Learning was made using a database of 540 picks made on 54 everyday objects.
- The sparse coding algorithm in conjunction with an SVM has allow to predict accurately ~79% of the grasp outcome

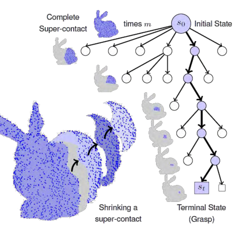
Tactile sensor used in this work

16:50–16:55 TUD7.6

### A Framework for Optimal Grasp Contact Planning

K. Hang[1], J. A. Stork[1], N. S. Pollard[2] and D. Kragic[1]
[1]RPL/CAS, KTH Royal Institute of Technology, Sweden
[2]Robotics Institute, Carnegie Mellon University, USA

- Formulates **optimal fingertip grasping** as a **path finding** problem
- Introduces **super-contact grasps** and **domain specific successor** and **heuristics** functions
- Allows grasp computation by **efficient and complete heuristic search** algorithms on **arbitrary shapes**
- Provides **sub-optimality bounds** for grasp quality



## Grasping 2

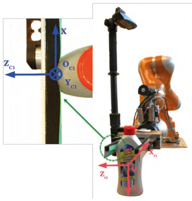
Chair *Yu Zheng, University of Michigan-Dearborn*
Co-Chair *Zhaopeng Chen, Institute of Robotics and Mechatronics, GermanAerospaceCenter, DLR*

| 16:55–17:00 | TUD7.7 |
|---|---|

### Grasping Posture Estimation for a Two-Finger Parallel Gripper with Soft Material Jaws using a Curved Contact Area Friction Model

Jingyi Xu, Nicolas Alt, Zhongyao Zhang, Eckehard Steinbach
Chair of Media Technology, Technical University of Munich, Germany

- We present a friction model for the curved contact area between a deformable object and soft parallel gripper jaws
- We show that the classical planar contact model leads to an overestimation of the friction
- We apply the presented model for grasping posture estimation by simulating the contact for all grasp candidates



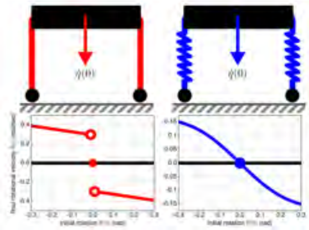
Curved contact area of the gripper equipped with soft material jaws

| 17:00–17:05 | TUD7.8 |
|---|---|

### Decoupled limbs yield differentiable trajectory outcomes in locomotion and manipulation

Andrew M. Pace and Samuel A. Burden
Electrical Engineering, University of Washington, USA

- Differentiability with respect to initial conditions and away from contacts
- Decoupled limbs assumes inertial decoupling and force decoupling of limbs
- Important consequences for optimization and learning



Trajectory outcomes for rigid (left) and decoupled limbs (right) robots

## Human-Robot Interaction 3

Chair *Qiang Huang, Beijing Institute of Technology*
Co-Chair *Ryo Kurazume, Kyushu University*

**16:25–16:30 TUD8.1**

### Design of an SSVEP-based BCI System with Visual Servo Module for a Service Robot to Execute Multiple Tasks

Shili Sheng, Peipei Song, Lingyue Xie,
Zhendong Luo, Wennan Chang, Shurui Jiang and Feng Duan*
Nankai University, China
Haoyong Yu
National University of Singapore, Singapore
Chi Zhu
Maebashi Institute of Technology, Japan.
Jeffrey Too Chuan Tan
The University of Tokyo, Japan

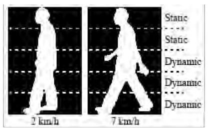
- Single-channel SSVEP
- Visual servo module
- Service robot
- Multiple tasks


**16:30–16:35 TUD8.2**

### Making Gait Recognition Robust to Speed Changes using Mutual Subspace Method

Yumi Iwashita[1], Mafune Kakeshita[2],
Hitoshi Sakano[3], and Ryo Kurazume[2]
[1]Jet Propulsion Laboratory, California Institute of Technology, USA
[2]Kyushu University, Japan
[3]NTT Data Corporation, Japan

- Propose the extension of the Mutual Subspace Method (MSM)-based method
- Evaluate a covariance matrix of MSM with high accuracy by reducing dimension of the matrix
- **The best performance ever in cross-speed gait recognition** with two challenging gait databases




Cross-speed walking gait recognition

**16:35–16:40 TUD8.3**

### End-Effector Airbags to Accelerate Human-Robot Collaboration

Roman Weitschat, Jörn Vogel, Sophie Lantermann,
and Hannes Höppner
German Aerospace Center (DLR)
Institute of Robotics and Mechatronics

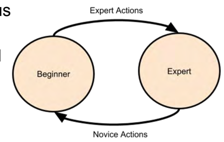
- New hardware approach for physical human-robot collaboration in industrial scenarios
- An analysis of peak force and pressure measurements in experiments with a crash-test dummy
- Higher efficiency in industrial tasks while satisfying the requirements of the ISO/TS 15066

**16:40–16:45 TUD8.4**

### Modeling User Expertise for Choosing Levels of Shared Autonomy

Lauren Milliken and Geoffrey A. Hollinger
School of Mechanical, Industrial and Manufacturing Engineering
Oregon State University, United States

- User expertise is modeled as a POMDP from observations made during shared autonomous teleoperation
- Macro-action controllers vary levels of control shared between the human and the robot autonomy
- User study shows model identifies users of different skill level
- Low expertise users had greater improvement from increased robot autonomy than users of higher expertise




**16:45–16:50 TUD8.5**

### Port-Hamiltonian based control for human-robot team interaction

Martin Angerer, Selma Musić, Sandra Hirche

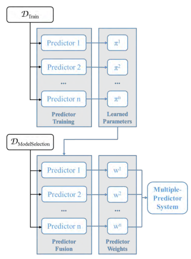
- Port-Hamiltonian based modeling of a constrained cooperative manipulator system
- Passivity-based control approach in the port-Hamiltonian framework
- Energy tank introduced to guarantee passivity of the human-robot team interaction system and safe interaction with humans

**16:50–16:55 TUD8.6**

### A Multiple-Predictor Approach to Human Motion Prediction

Przemyslaw A. Lasota and Julie A. Shah
Department of Aeronautics and Astronautics
MIT, United States

- We introduce the Multiple Predictor System (MPS), a method for integrating complementary motion prediction approaches
- MPS trains on available task data and learns to exploit the predictors' relative strengths
- Implementation combines velocity-based position projection, time series classification, and sequence prediction methods
- Evaluation shows MPS outperforms the individual predictors by 18.5 - 37.3%



**Human-Robot Interaction 3**

Chair *Qiang Huang, Beijing Institute of Technology*
Co-Chair *Ryo Kurazume, Kyushu University*

| 16:55–17:00 | TUD8.7 |
|---|---|

### Backchannel Opportunity Prediction for Social Robot Listeners

Hae Won Park, Mirko Gelsomini,
Jin Joo Lee, Tonghui Zhu, and Cynthia Breazeal
Personal Robots Group, MIT Media Lab, USA

- A social robot listener has been developed that produces listener backchannel feedback while listening to children's storytelling.
- Backchannel opportunity prediction (BOP) model detects speaker-cue events based on prosodic features in a speech.
- Within- and between-subjects studies revealed that children gaze and speak more to a contingent backchanneling robot. Children perceive the contingent robot as more attentive and more interested in their stories.

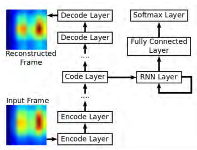
Figure: An attentive robot listener deeply engages children in storytelling.

| 17:00–17:05 | TUD8.8 |
|---|---|

### Recognizing Social Touch Gestures using Recurrent and Convolutional Neural Networks

Dana Hughes and Nikolaus Correll
Department of Computer Science, University of Colorado Boulder, USA
Alon Krauthammer
The Aerospace Corporation, USA

- Affective touch recognition using pressure-sensitive arrays may be addressed as a robotic material.
- Deep learning models (CNN, CNN-RNN and Autoencoder-RNN) are explored.
- Continuous, real-time classification.
- Memory and computing requirements allow for in-material implementation using small microcontrollers




Autoencoder-RNN model

## Best Student Paper Award

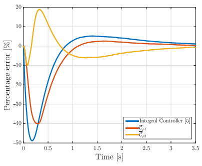
Chair *Oussama Khatib, Stanford University*
Co-Chair *John Hollerbach, University of Utah*

| 16:25–16:30 | TUD9.1 |
|---|---|

### Data-Driven Design of Implicit Force Control for Industrial Robots

Matteo Parigi Polverini, Simone Formentin,
Le Anh Dao and Paolo Rocco
D.E.I.B., Politecnico di MIlano, Milan (Italy)

- A data-driven control approach, based on VRFT algorithm, is applied to the implicit robot force control problem.
- A suitable feedback loop is introduced to make the system entirely depending on the unknown environment transfer function.
- Increased force tracking performance w.r.t. state-of-the-art model-based integral controller, avoiding the risk of instability due to a rough knowledge of the environment model



Closed-loop experiments force tracking error comparison

| 16:30–16:35 | TUD9.2 |
|---|---|

### Motion Planning with Movement Primitives in Obstacle Environment

Hyoin Kim, Hyeonbeom Lee, Seungwon Choi, Yung-kyun Noh and H. Jin Kim
Aerospace Engineering, Seoul National Univ, South Korea

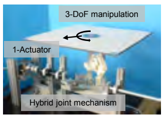
- On-line motion planning framework
- Combination parametric dynamic movement primitives (PDMPs) and rapidly randomized exploring random trees star (RRT*)
- Extraction of parameter function utilizing Gaussian Process Regression (GPR)

| 16:35–16:40 | TUD9.3 |
|---|---|

### 1-Actuator 3-DoF Parts Feeding Using Hybrid Joint Mechanism with Twisted Axis Layout

Ryohei Sakashita and Mitsuru Higashimori
Department of Mechanical Engineering
Osaka University, Japan

- A nonprehensile manipulation scheme that controls a 3-DoF motion of a part is proposed.
- The manipulator employs only one actuator and hybrid joint mechanism with twisted axis layout.
- Whirlpool-like trajectories of point masses on the plate are controlled by the sinusoidal input.
- The 3-DoF parts feeding task based on five primitives is demonstrated.



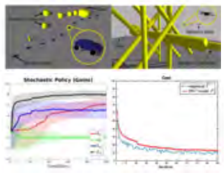
Prototype robot

| 16:40–16:45 | TUD9.4 |
|---|---|

### Robust Policy Search with Applications to Safe Vehicle Navigation

Matthew Sheckells, Gowtham Garimella, and Marin Kobilarov
Department of Computer Science, Johns Hopkins University, USA

- Policy search technique based on minimizing probably approximately correct (PAC) bounds on the expected performance of control policies.
- Applied to simulated navigation of a car with side-slip and a quadrotor in obstacle-ridden environments.
- Algorithm evaluated against existing techniques, like RWR, REPS, PGPE, LSFD.

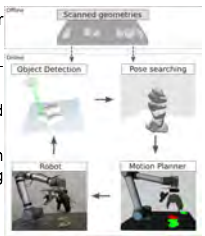


| 16:45–16:50 | TUD9.5 |
|---|---|

### Autonomous Robotic Stone Stacking with Online next Best Object Target Pose Planning

F. Furrer*,1, M. Wermelinger *,2, H. Yoshida*,
F. Gramazio[3], M. Kohler[3], R. Siegwart[1], M. Hutter[2]
[1]Autonomous Systems Lab (ASL), ETH Zurich, Switzerland
[2]Robotic Systems Lab (RSL), ETH Zurich, Switzerland
[3]Gramazio Kohler Research (GKR), ETH Zurich, Switzerland
*The three first authors contributed equally to this work.

- Autonomous discrete assembly work-flow for found material without additional adhesives.
- Object detection of randomly placed irregular-ly shaped objects with a depth camera.
- Online target pose searching algorithm to find stable placing poses, using a physics engine.
- Validation by eleven consecutive trials with robotic manipulator building vertical balancing stacks with unprocessed lime stones.



## Medical Robots and Systems 3

Chair *Ken Goldberg, UC Berkeley*
Co-Chair *Jacob Rosen, University of California at Santa Cruz*

| 16:25–16:30 | TUD10.1 |
|---|---|

### A Learning Based Training and Skill Assessment Platform with Haptic Guidance for Endovascular Catheterization

Wenqiang Chi, Hedyeh Rafii-Tari, Christopher J. Payne, Jindong Liu and Guang-Zhong Yang
Hamlyn Centre, Imperial College London, United Kingdom
Celia Riga and Colin Bicknell
Department of Surgery & Cancer, Imperial College London, United Kingdom

- Train inexperienced operators through informing the correct catheterization maneuvers via tactile feedback
- A haptic interface that can be affixed to existing catheters
- Continuous HMMs for capturing the essential motion patterns from expert demonstrations
- User studies showed significant improvements in the performance of catheterization tasks

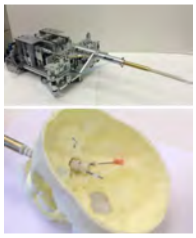
Fig. The Proposed Training Platform

| 16:30–16:35 | TUD10.2 |
|---|---|

### Roboscope: A Flexible and Bendable Surgical Robot for Single Portal Minimally Invasive Surgery

Jacob Rosen
Deptartment of Mechanical and Aerospace Engineering, University of California, Los Angels, USA
Laligam N. Sekar
Department of Neurological Surgery, University of Washington, USA
Daniel Glozman
Magenta Medical Ltd., Israel
Muneaki Miyasaka, Yangming Li, and Blake Hannaford
Department of Electrical Engineering, University of Washington, USA

- Roboscope is a surgical robot for minimally invasive surgery designed for skullbase surgery and neurosurgery.
- The system achieved 12 mechanical DOFs.
- The flexible manipulator has two arms which allow surgeons perform complex surgical tasks (The instruments in the picture have 2 mm diameter).
- 3D endoscopic vision is provided by 1.2 mm Scanning Fiber Endoscope.



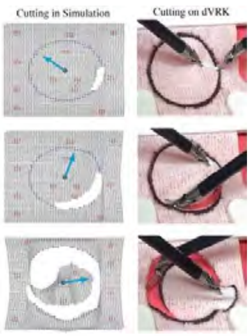
| 16:35–16:40 | TUD10.3 |
|---|---|

### Multilateral Surgical Pattern Cutting in 2D Orthotropic Gauze with Deep Reinforcement Learning Policies for Tensioning

Deep Reinforcement Learning for Tensioning Policies in Pattern Cutting in deformable 2D material with Da Vinci Resaerch Kit. Evaluation of Robustness to changes in physical parameters and execution on a physical system

Brijen Thananjeyan, Animesh Garg, Sanjay Krishnan, Carolyn Chen, Lauren Miller, Ken Goldberg

UC Berkeley

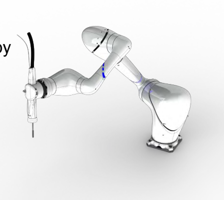



| 16:40–16:45 | TUD10.4 |
|---|---|

### Three-dimensional Robotic-assisted Endomicroscopy with a Force Adaptive Robotic Arm

Piyamate Wisanuvej, Petros Giataganas, Konrad Leibrandt, Jindong Liu, Michael Hughes, and Guang-Zhong Yang
Hamlyn Centre for Robotic Surgery, Imperial College London, UK

- The work presents the Hamlyn Arm, 6-DoF manipulator equipped with an endomicroscopy tool for real-time “optical biopsy” application.
- Automated force and perpendicular contact control provides optimum image quality on arbitrary 3D tissue surfaces.
- Responsive feedback controllers make the system capable of scanning tissue under motion during *in vivo* examinations.

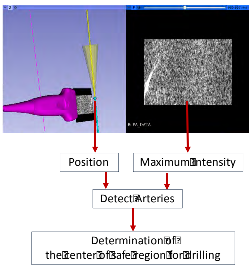


| 16:45–16:50 | TUD10.5 |
|---|---|

### Improving the Safety of Telerobotic Drilling of the Skull Base via Photoacoustic Sensing of the Carotid Arteries

Sungmin Kim, N. Gandhi, M.A. Lediju Bell and P. Kazanzides
Johns Hopkins University, USA

- Telerobotic system based on research da Vinci System and 3D Slicer for visualization
- Pulsed laser attached to robot instrument (e.g., drill)
- Robot-mounted ultrasound probe receives real-time photoacoustic measurement using the highest intensity of image data to detect carotid arteries
- Define safe region for drilling based on photoacoustic measurement, with ~1 mm accuracy in phantom experiments

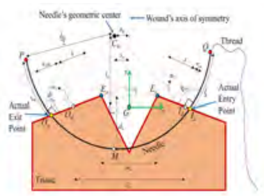



| 16:50–16:55 | TUD10.6 |
|---|---|

### Autonomous Suturing Via Surgical Robot: An Algorithm for Optimal Selection of Needle Diameter, Shape, and Path

Sahba Aghajani Pedram, Peter Ferguson, Ji Ma, and Jacob Rosen
Mechanical and Aerospace Engineering Department, UCLA, USA
Erik Dutson
Department of Surgery, UCLA, USA

- Needle shape, diameter, and path directly affect suture depth and tissue trauma in automated suturing.
- Kinematic model of needle-tissue interaction used to formulate needle path planning as nonlinear optimization.
- Off-line simulations were used to evaluate the accuracy and performance of the proposed algorithm.
- The optimization results were confirmed experimentally with the Raven II system.



**Medical Robots and Systems 3**

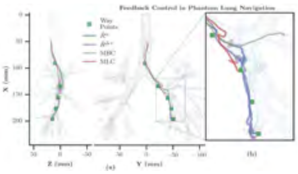
Chair *Ken Goldberg, UC Berkeley*
Co-Chair *Jacob Rosen, University of California at Santa Cruz*

| 16:55–17:00 | TUD10.7 |
|---|---|

## Orientation Estimation of a Continuum Manipulator in a Phantom Lung

Jake Sganga and David Camarillo
Department of Bioengineering, Stanford University, USA

- Task space control of a continuum manipulator in a phantom lung is presented
- 2 estimation methods are developed to learn the orientation of the manipulator
- The methods are tested on a clinically viable system



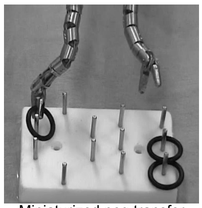
The position traces of the distal tip of the robot is shown for each of the control methods

| 17:00–17:05 | TUD10.8 |
|---|---|

## Effective Manipulation in Confined Spaces of Highly Articulated Robotic Instruments for Single Access Surgery

Konrad Leibrandt, Piyamate Wisanuvej, Gauthier Gras, Jianzhong Shang, Carlo A. Seneci, Petros Giataganas, Valentina Vitiello, Ara Darzi, Guang-Zhong Yang
Hamlyn Centre for Robotic Surgery, Imperial College London, United Kingdom

- Kinematic description of a 9 joint / 7 DoF robot for single access surgery
- Intuitive manipulation close to joint limits allowing dexterous manipulation in confined spaces
- Calibration for backlash compensation to enable precise manipulation
- Experimental evaluation through bench test (peg-transfer, suturing), and *ex-vivo* test (tumor resection and closure)



Miniaturized peg transfer experiment

## Wheeled Robots

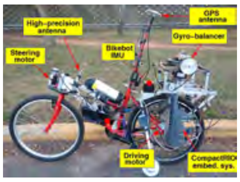
Chair *Carl Glen Henshaw, US Naval Research Laboratory*
Co-Chair *Mark Yim, University of Pennsylvania*

| 16:25–16:30 | TUD11.1 |
|---|---|

### Trajectory Tracking and Balance Control of an Autonomous Bikebot

**Pengcheng Wang and Jingang Yi**
Department of Mechanical & Aerospace Engineering, Rutgers University, USA
**Tao Liu**
School of Mechanical Engineering, Zhejiang University, China
**Yizhai Zhang**
School of Astronautics, Northwestern Polytechnical University, China

- Bikebot was developed as a platform for study physical human-robot interactions
- The dynamic model of the bikebot satisfies the external/internal convertible (EIC) properties
- We designed and implemented an EIC-based trajectory tracking and balance control
- Extensive experiments and comparison with human riding experiments



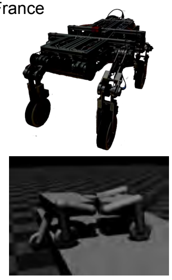
The autonomous bikebot developed at Rutgers University

| 16:30–16:35 | TUD11.2 |
|---|---|

### Obstacle Negotiation Learning for a Compliant Wheel-on-Leg Robot

Arthur Bouton and Faïz Ben Amar
ISIR, UPMC Université Paris 6, France
Christophe Grand
ONERA, France

- •Use of a compliant design that can measure the external forces applied on legs
- •Robot advances without any prior knowledge on the ground geometry or obstacle shapes
- •A Q-learning algorithm maps a discrete set of actions to the continuous state space of the robot
- •Simulation results prove that the obtained policy allows the robot to successfully cross complex and unknown obstacles


The Complios robot and its simulation model

| 16:35–16:40 | TUD11.3 |
|---|---|

### Harnessing Steering Singularities In Passive Path Following For Robotic Walkers

Marco Andreetto, Stefano Divan, Daniele Fontanelli, Luigi Palopoli
University of Trento, Italy

- Assistive robotic walker equipped with front steering wheels;
- Path following controller completely insensitive to the singularity of zero velocity;
- Comprehensive experimental tests.

| 16:40–16:45 | TUD11.4 |
|---|---|

### Path Following Controller for Planar Robots with Articulated, Actuated and Independently …

Ville Pitkänen, Antti Tikanmäki, Anssi Kemppainen and Juha Röning
Department of Computer Science and Engineering, University Of Oulu, Finland

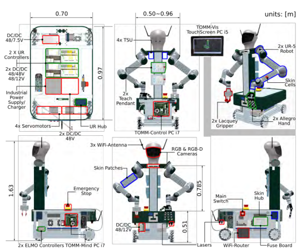
- Multi-purpose path following controller for planar robots with multiple velocity limited steerable wheels.
- Smooth path convergence using critically damped virtual springs.
- Allows relative motion between robot and wheels, yet mathematically simple.
- Computational cost increases only linearly with number of wheels.

| 16:45–16:50 | TUD11.5 |
|---|---|

### TOMM: Tactile Omnidirectional Mobile Manipulator

Emmanuel Dean, Brennand Pierce, Florian Bergner, Philipp Mittendorfer, Karinne Ramirez-Amaro, Wolfgang Burger and Gordon Cheng
**Institute for Cognitive Systems, Technical University of Munich, Germany**

- Multi-modal robot skin
- Self-configuring, self-calibrating
- Event-driven-system
- Multi-modal control framework
- Semantic reasoning system
- Compliance in non-compliant robots

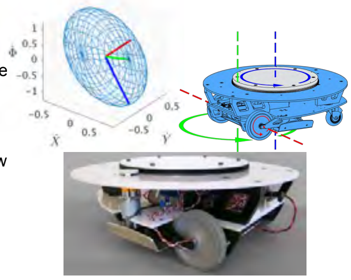


| 16:50–16:55 | TUD11.6 |
|---|---|

### Designing for Uniform Mobility Using Holonomicity

John Tighe Costa and Mark Yim
Mechanical Engineering and Applied Mechanics, University of Pennsylvania USA

- *Holonomicity H:* the extent to which a vehicle can move equally in all global DOF.
- Mobility Ellipses can be used to optimize mobility
- Holonomic vehicles with low cost offset differential drive and turret have skewed mobility ellipses



**Wheeled Robots**

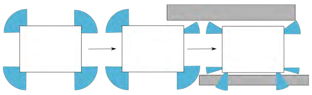
Chair *Carl Glen Henshaw, US Naval Research Laboratory*
Co-Chair *Mark Yim, University of Pennsylvania*

| 16:55–17:00 | TUD11.7 |
|---|---|

**Efficient Path Planning for Mobile Robots with Adjustable Wheel Positions**

Freya Fleckenstein, Christian Dornhege and Wolfram Burgard
Department of Computer Science, University of Freiburg, Germany

- Path planning for robots with additional degrees of freedom (adjustable lever arms)
- Planning for full x,y,theta motions and all arm angles (7 DoF)
- Efficient interval-based state space representation



| 17:00–17:05 | TUD11.8 |
|---|---|

**Motion Discontinuity-Robust Controller for Steerable Mobile Robots**

By: Mohamed SOROUR
Andrea CHERUBINI
Philippe FRAISSE
Robin PASSAMA