Proceedings of the 20th IEEE-RAS International Conference on Humanoid Robots (HUMANOIDS 2020)

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1. Welcome Message

Dear Attendees!

Welcome to Humanoids 2020, the 20th IEEE-RAS International Conference on Humanoid Robots! Originally, we planned to welcome you all in December 2020 in Munich to celebrate with you the 20th anniversary of the Humanoids conference. We had hoped to host all of you in our beautiful city and show you around in our labs and experience our research first hand. The rise of the Corona pandemic required a change of plan.

When the Corona pandemic spread across the globe in early 2020, it also had significant effects on the Humanoid robotics research community. Around the time of the original paper deadlines, many humanoids' researchers worldwide had no or only severely restricted access to their labs. After intensive consultations between the Organizing Committee and the Steering Committee of the IEEE Conference on Humanoid Robots, it was finally decided to postpone the Humanoids 2020 conference for half a year until July 2021. Our main priority in this decision was the safety of our community. By postponing the conference, we were also hoping to be able to conduct Humanoids 2020 as an in-person event. By April 2021, it became clear that the vaccination plans in many countries would only be partially implemented by the start of the conference and the existing travel restrictions in Germany made it difficult to realize the conference in Munich. The decision to finally change the conference format into a fully virtual one was not an easy one.

Even under such a difficult time, humanoid robotics research must continue, this can be seen by the great supports of the community. We received a total of 126 paper submissions, 87 for the Humanoids conference and 39 for IEEE Robotics and Automation Letters (RA-L). 71 were accepted for presentation at the conference, which represents an acceptance rate of 56%. The smaller number of submissions compared to previous years can be partly related to the unusual submission deadlines in December/January resulting from the postponement of the conference. Nevertheless, looking at the selection of oral talks and interactive presentations, we are very happy to present a strong technical program to you. We have two great plenary speakers on human sensory-motor control and humanoid robotics. In addition, six workshops were accepted, which will be conducted at the beginning of the technical program on July 19, 2021.

The virtual conference is organized by a combination of multiple tools aiming at giving you an interactive conference experience as much as possible. We use Whova as a main event platform combined with iPosters for interactive presentations. Social networking is possible either directly in Whova as well as by an additional virtual networking space implemented in Wonder.

The organization of this conference required the collective efforts of many people. First of all, we would like to thank all the members of the Organizing Committee for all their continuing support and the pleasant collaboration over the last two years. The conversion of the conference into a virtual format put extra effort on our financial chair Roland Unterhinninghofen as well as on our Local Arrangement chair Dongheui Lee. We would also like to thank the Editorial boards of the conference and RA-L led by Editors-In-Chief Tamim Asfour and Allison Okamura for the efficient review process keeping the high standards of this conference.

Finally, we would also like to thank our Sponsors, volunteers, and the Advisory board members for their support. Last but not least, we would like to thank all the authors and registrants for contributing to this conference and hope you will enjoy the program of this first fully virtual Humanoids conference!

Christian Ott
German Aerospace Center (DLR)
General Chair

Gordon Cheng
Technische Universität München (TUM)
General Chair

2. Committees

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- Allison Okamura, Stanford University, USA

RA-Letters Editorial Board: https://www.ieee-ras.org/publications/ra-l/ra-letters-editorial-board

3. Conference Information

3.1 Plenary lectures

Plenary Talk 1,

Monday 19.07.2021, 16:15-17:00

Prof. Daniel Wolpert

Bio: Daniel Wolpert read medicine at Cambridge before completing an Oxford Physiology DPhil and a postdoctoral fellowship at MIT. He joined the faculty at the Institute of Neurology, UCL in 1995 and moved to Cambridge University in 2005 where he was Professor of Engineering and a Royal Society Research Professor. In 2018 he joined the Zuckerman Mind Brain Behavior Institute at Columbia University as Professor of Neuroscience. He was elected a Fellow of the Royal Society (2012) and has been awarded the Royal Society Francis Crick Prize Lecture (2005), the Minerva Foundation Golden Brain Award (2010) and the Royal Society Ferrier medal (2020). His research interests are computational and experimental approaches to human movement (www.wolpertlab.com).

Title: Computational principles underlying the learning of sensorimotor repertoires

Abstract: Humans spend a lifetime learning, storing and refining a repertoire of motor memories appropriate for the multitude of tasks we perform. However, it is unknown what principle underlies the way our continuous stream of sensorimotor experience is segmented into separate memories and how we adapt and use this growing repertoire. I will review our work on how humans learn to make skilled movements focussing on the role of context in activating motor memories and how statistical learning can lead to multimodal object representations. I will then present a principled theory of motor learning based on the key insight that memory creation, updating, and expression are all controlled by a single computation – contextual inference. Unlike dominant theories of single-context learning, our repertoire-learning model accounts for key features of motor learning that had no unified explanation and predicts novel phenomena, which we confirm experimentally. These results suggest that contextual inference is the key principle underlying how a diverse set of experiences is reflected in motor behavior.

Plenary Talk 2,

Tuesday 20.07.2021, 13:30-14:15

Prof. Antonio Bicchi

Bio: Antonio Bicchi is a scientist interested in robotics and intelligent machines. After graduating in Pisa and receiving a Ph.D. from the University of Bologna, he spent a few years at the MIT AI Lab of Cambridge before becoming Professor in Robotics at the University of Pisa. In 2009 he founded the Soft Robotics Laboratory at the Italian Institute of Technology in Genoa. Since 2013 he is Adjunct Professor at Arizona State University, Tempe, AZ. He has coordinated many international projects, including four grants from the European Research Council (ERC).
He served the research community in several ways, including by launching the WorldHaptics conference and the IEEE Robotics and Automation Letters. He is currently the President of the Italian Institute of Robotics and Intelligent Machines.
He has authored over 500 scientific papers cited more than 25,000 times. He supervised over 60 doctoral students and more than 20 postdocs, most of whom are now professors in universities and international research centers, or have launched their own spin-off companies. His students have received prestigious awards, including three first prizes and two nominations for the best theses in Europe on robotics and haptics. He is a Fellow of IEEE since 2005. In 2018 he received the prestigious IEEE Saridis Leadership Award.

Title: How to design and control naturally moving machines, and why.

Abstract: How can we make a robot move ``naturally''? What makes a natural motion, and how can we reproduce it in an artificial body? To what extent is physical compliance, and its variability, contributing to reduce the gap between the performance and efficiency of present-day robotics and natural motion? In this talk, I will review some of the background, motivations and state of the art in the understanding, design and control of ``naturally moving'' machines. New interfaces between such machines and humans, to favor safe and effective physical interaction, will be introduced. The point will be made that naturally moving machines are more easily integrated in human motor control schemes, and may thus provide better solutions in applications ranging from prosthetics to rehabilitation, and from teleoperation to learning from demonstration.

3.2 Workshops

Humanoids 2020 has six accepted workshops, which will be held on Monday, July 19, before the first technical sessions.

WS1: Adapting service robots to the future industry and not vice versa
Organizers: Luca Marchionni (Pal Robotics)

Abstract: It is proven that robotics has an enormous potential to transform our daily lives and help overcome important challenges that our society is facing. The world of humanoid service robots is increasing in importance as robots continuously improve their capabilities to be able to support humans with routine tasks in a variety of environments. Human-Robot Interaction (HRI) in day to day life is becoming a closer reality, beyond the more traditional areas of robot application including industrial robots. Carrying out inspectional tasks in industrial environments can provide more information for improved applications.
It is clearer every day that robotics applications can benefit all sectors, from Healthcare to Industry 4.0, public services, or customer care. All these scenarios have in common that they require a direct interaction between robots and people.
For example, a technology able to generate more complex movements in robots with arms and legs operating in a dynamic environment would open up a range of possibilities in both industry and service robotics. More advanced technology would allow robots to react in real-time to changes in their environment and even changes during tasks. The EU project Memmo approaches trying to solve this problem by relying on massive off-line caching of pre-computed optimal motions that are recovered and adapted online to new situations with real-time tractable model predictive control and where all available sensor modalities are exploited for feedback control going beyond the mere state of the robot for more robust behaviors.
EU Project Memmo (which stands for memory of motion) is a research project which aims to develop memory of motion – a unified approach to motion generation for complex robots with arms and legs. The project works towards the development of three industrial demonstrators in the future of aircraft manufacturing, rehabilitation of paraplegic patients, and inspection of large engineering structures.

WS2: Machine Learning and Optimization for Humanoids Loco-Manipulation
Organizers: Tamim Asfour (Karlsruhe Institute of Technology), Noémie Jaquier (Karlsruhe Institute of Technology), You Zhou (Karlsruhe Institute of Technology), Aude Billard (Ecole Polytechnique Fédérale de Lausanne)

Abstract: This workshop is aimed as a discussion on the interplay of machine learning and optimization methods in the current and future developments of efficient and dexterous loco-manipulation skills for humanoid robots. We aim at bringing together researchers from various robotics fields to explore and tackle the upcoming challenges involving humanoids loco-manipulation skills. Finally, we expect this workshop to complement the awareness of the humanoids community not only on the utility of data-driven approaches, but on the importance of a conscious design of these approaches for providing humanoids with close-to-human-level learning and adaptation capabilities.

WS3: Workshop on Floating-base Robots in Manufacturing and Logistics Operations: Opportunities and Challenges
Organizers: Arash Ajoudani (Istituto Italiano di Tecnologia), Juan M. Gandarias (Istituto Italiano di Tecnologia), Jesus Manuel Gomez de Gabriel (University of Málaga), Jaeheung Park (Seoul National University)

Abstract: Floating-base manipulators represent the short-term future core technology in factories and are aimed to achieve sophisticated, high-performance industrial processes allowing flexibility and reliability. These robots offer substantial benefits for many industrial applications due to enhanced dynamic and interaction skills. They are less specialized systems than fixed-based robots, providing several opportunities in terms of versatility and adaptability. However, this also implies that new issues not presented in traditional industrial robotics have to be faced. Some of the most relevant ones include a high level of complexity due to kinematic redundancy, working in unstructured environments, coexistence/cooperation with human workers, and lack of systematic industrial design of human-robot interaction interfaces. Overall, numerous challenges regarding such wide-opened topics as whole-body control, underactuated systems, motion planning, physical robot interaction, or human-robot collaboration, among others, have to be determined.

In this respect, the correct definition of the opportunities involved in implementing these platforms is key to attracting the industrial sector's interest. Likewise, it is imperative to determine the challenges that must be faced in order to make the use of floating base robots in real industrial applications a reality. This workshop will address the application of floating-base robots in manufacturing and logistics environments. In particular, the workshop will focus on setting up the challenges and opportunities on this topic according to the following questions:

1. What are the main issues and challenges regarding the application of floating-base robots to manufacturing and logistics operations?
2. How should these challenges be tackled?
3. What benefits would the solution to these challenges bring to society and the manufacturing and logistics processes?

Consequently, this workshop aims to provide a platform for top researchers from the robotics and industrial communities to share their work and inspire cross-discipline collaboration, motivating the application of more integrated research approaches to apply floating-base robots in manufacturing and logistics.

WS4: Superhuman Abilities in Current Humanoids
Organizers: Joohyung Kim (University of Illinois Urbana-Champaign), Jinoh Lee (German Aerospace Center), Alex Alspach (Toyota Research Institute), Katsu Yamane (Honda Research Institute), Christopher Atkeson (Carnegie Mellon University)

Abstract: This will be the 6th workshop, titled “Can we build Baymax? Part VI. Superhuman Abilities in Current Humanoids”. Since the first workshop was organized in 2015, our workshop series has taken place at the IEEE-RAS International Conference on Humanoid Robots every year. Baymax is a humanoid character in the Disney feature animation “Big Hero 6.” It is a healthcare robot with an inflatable body, capable of walking, bumping into surrounding objects, learning motions and physically interacting with people. However, in the real world, it is not easy to build such a robot. In the previous workshops, we have discussed topics on soft robot mechanisms, sensors, control, fail-safety, learning and social interaction of humanoid robots. As a continuation of the discussion, this workshop will bring together researchers looking for superhuman abilities in current humanoid robot technology. In particular, we will tackle challenges in superhuman sensors, actuators and processors, dynamic robots such as robot athletes/gymnasts/entertainers, size-scaled humanoid robots, powerful exoskeleton/prosthesis, and superhuman perception/intelligence.

WS5: Towards physical-social human-robot interaction
Organizers: Marie Charbonneau (University of Waterloo), Francisco Javier Andrade Chavez (University of Waterloo), Katja Mombaur (University of Waterloo)

Abstract: Robots will continue to permeate our daily lives in the coming future, making human-robot interaction (HRI) a crucial research topic. Robots will find themselves interacting with humans in a variety of situations, such as manufacturing, disaster recovery, household and health care settings. Many of these situations will require the robot to enter in direct contact with humans, resulting in very close physical HRI (pHRI) scenarios. To make humans feel comfortable with the interaction, robots need to act not only in a reliable and safe way, but also in a socially and psychologically acceptable one. Current pHRI research largely focuses on interacting with the human through an object or passively waiting for the human to start the interaction. On the other side, social HRI (sHRI) is so far mainly concerned with distanced HRI through speech and gestures. The objectives of this workshop are to (i) bring together the pHRI and sHRI research communities, and (ii) generate discussions consolidating these two fields, for instance on the social and ethical implications of physical contact in HRI, as well as the use of non-verbal communication through gestures, robot design, appearance or control.

WS6: Talos: Status & Progress
Organizers: Alexander Werner (University of Waterloo), Olivier Stasse (LAAS-CNRS)
Abstract: The goal of this workshop is to exchange information about control approaches for humanoid robots, with the torque controlled robots such as the Talos platform in mind. Starting from a report on the experimentally discovered abilities of the hardware, further needed improvements will be discussed. To put this in context, speakers who work on other humanoid platforms have been invited. The objective here is to describe and compare viable ways to improve dynamic capabilities of this robot. Building on this discourse about structure and actuators, talks about whole body control control solutions are presented. Again, an open discussion in this workshop about particular topic will help the community to compare approaches and their properties. To complete the picture of progress on the Talos platform, talks about integrated contact planning and teleoperation are on the agenda. There are now 6 Talos robots in the world (PAL, LAAS, IJS, Waterloo, INRIA, Edinburgh) and this workshop will initiate further collaboration.

3.3 Virtual Labtour

On Wednesday July 21, Humanoids 2020 features a virtual lab tour after the last technical session and the Awards Ceremony. The labtour includes both demos and Q&A with contributions from at least the following labs:

- PAL Robotics
- TUM Institute for Cognitive Systems (TUM-ICS)
- Karlsruhe Institute of Technology (KIT)
- Italian Institute of Technology (IIT)
- TUM Institute of Applied Mechanics (TUM-AM)
- German Aerospace Center (DLR)

3.4 Awards

The Humanoids 2020 Awards Ceremony will be held on Wednesday July 21, 18:00-18:15, as the final part of the technical program. The following awards will be given:

- **Humanoids 2020 Best Oral Paper Award:** This award recognizes the most outstanding paper presented by an oral talk.
- **Humanoids 2020 Best Interactive Paper Award:** This award recognizes the most outstanding paper presented by an interactive presentation.
- **Mike Stilman Paper Award:** In memoriam of our colleague Mike Stilman this award recognizes the most unconventional/pioneering design or solution presented by one of the awards finalists.
- **Humanoids Most Influential Paper Award:** As a tribute to the anniversary of the conference (20th Humanoids conference scheduled for the year 2020) this award recognizes the most influential paper published in the Proceedings of the HUMANOIDS conferences up to the year 2020.

The best paper awards of Humanoids 2020 are financially supported by Intouch-Robotics.

3.5 Sponsors

Gold Sponsor: PAL Robotics, https://pal-robotics.com/

Bronze: Sponsor: Agile Robots, https://www.agile-robots.com/

Society Sponsor: IEEE Robotics and Automation Society (RAS), https://www.ieee-ras.org/

4. Technical Program

4.1 Program at a Glance

<table>
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(Seoul,Tokyo)</th><th>19.07.</th><th>20.07.</th><th>21.07.</th></tr>
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<tr><td>12:00 - 12:15</td><td>18:00 - 18:15</td><td>01:00 - 01:15</td><td>Awards Ceremony</td></tr>
<tr><td>12:15 - 12:45</td><td>18:15 - 18:45</td><td>01:15 - 01:45</td><td>Welcome Reception</td><td>Social Time</td><td>Closing
Farewell Party</td></tr>
</table>

4.1 Detailed Program

Mechatronic Design

Chair *Nikos Tsagarakis, Istituto Italiano di Tecnologia*
Co-Chair *Baek-Kyu Cho, Kookmin University*

17:00–17:15	MoOral1_1.1

MIT Humanoid Robot: Design, Motion Planning, and Control For Acrobatic Behaviors

Matthew Chignoli[1], Donghyun Kim[2],
Elijah Stanger-Jones[3], and Sangbae Kim[1]
[1]Department of Mechanical Eng., Mass. Institute of Technology (MIT)
[2]College of Information and Computer Sciences, Univ. of Mass. Amherst
[3]Department of Electrical Eng. & Computer Science, MIT

- Design of a new humanoid robot with custom proprioceptive actuators
- Kino-dynamic motion planning that explicitly accounts for actuation capabilities of the robot
- MPC-based landing controller
- Simulation experiments using realistic dynamic simulator

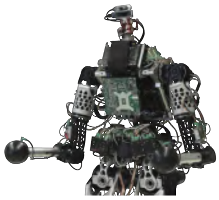
MIT Humanoid Robot performing a backflip off a 40cm platform.

17:15–17:30	MoOral1_1.2

LOLA v1.1 – An Upgrade in Hard- and Software Design for Dynamic Multi-Contact Locomotion

Philipp Seiwald, Felix Sygulla, Tobias Berninger, Nora-Sophie Staufenberg, Moritz Sattler, Nicolas Neuburger and Daniel Rixen
Department of Mechanical Engineering, TUM, Germany
Shun-Cheng Wu and Federico Tombari
Department of Informatics, TUM, Germany

- **Upgrade** of humanoid robot LOLA for additional hand-environment support during autonomous walking
- **Hardware:** complete redesign of upper body with kinematic optimization and lightweight structures
- **Software:** major redesign of computer vision, motion planning and stabilization framework (work in progress)
- **Validation:** experimental modal analysis, multi-contact experiments



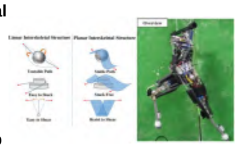
The new upper body of the humanoid robot LOLA.

17:30–17:45	MoOral1_1.3

Development of Musculoskeletal Legs with Planar Interskeletal Structures to Realize Human Comparable Moving Function

Moritaka Onitsuka, Manabu Nishiura, Kento Kawaharazuka, Kei Tsuzuki, Yasunori Toshimitsu, Yusuke Omura, Yuki Asano, Kei Okada and Masayuki Inaba
Department of Mechano-Informatics, University of Tokyo, Japan
Koji Kawasaki
Toyota Motor Corporation, Japan

- We discussed the role of **planar interskeletal structures** that cover joints and span between different skeletal structures.
- The planar interskeletal structures are classified into two types; the passive planar interskeletal structures and the active ones.
- We attached planar interskeletal structures to musculoskeletal humanoids and verified it enables the robot to realize human comparable motion; **deep squat, screw home movement and pedal switching**.



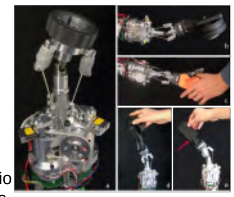
Schematic diagram of intertskeletal structures and the musculoskeletal legs MusashiOLegs.

17:45–18:00	MoOral1_1.4

An Integrated, Tendon-Driven, Humanoid Wrist: Design, Modeling, and Control

Alexander Toedtheide, Johannes Kühn, Edmundo Pozo Fortunic, Sami Haddadin
Munich School of Robotics and Machine Intelligence, Technical University of Munich, Germany

- A compliantly controlled 3SPS-1U parallel wrist is shown, which is actuated by three force controlled tendons.
- A model-based calculation of joint torques enables joint-level impedance control, virtual walls and momentum observation.
- A design of an integrated tendon-based and force sensitive drive train is realized.
- Maximum torque of 6.1 Nm/9.3 Nm (gear ratio depending), and a speed of up to 400 deg/s is achieved.



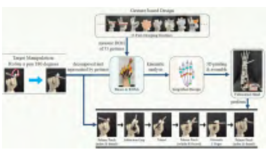
Humanoid 3SPS-1U wrist

18:00–18:15	MoOral1_1.5

Towards Complex and Continuous Manipulation: A Gesture Based Anthropomorphic Robotic Hand Design

Li Tian, Hanhui Li, Qifa Wang, Xuezeng Du, Jialin Tao, Jordan Sia Chong, Nadia Magnenat Thalmann, and Jianmin Zheng
Institute for Media Innovation, Nanyang Technological University, Singapore

- 3D printable anthropomorphic design robotic hand with rigid bones and deformable tissue
- 13 degrees of actuation, driven by Bowden cable
- 62 test gestures and CCM (complex and continuous manipulation)



Demonstration of the proposed gesture based framework

Locomotion

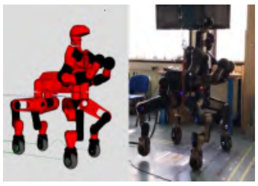
Chair *Shuuji Kajita, National Inst. of AIST*
Co-Chair *Johannes Englsberger, DLR (German Aerospace Center)*

14:15–14:30	TuOral2_2.1

Optimization-Based Quadrupedal Hybrid Wheeled-Legged Locomotion

I. Belli[1], M. Parigi Polverini[2], A. Laurenzi[2], E. Mingo Hoffman[2], P. Rocco[1] and N. Tsagarakis[2]
[1] DEIB, Politecnico di Milano, Italy [2] HHCM Research Line, IIT, Italy

- Trajectory Optimization approach to generate hybrid locomotion motion strategies for a humanoid quadrupedal robot with steerable wheels.
- Single Rigid Body Dynamics modelling of the robot CENTAURO, combined with a unicycle model for each foot.
- Extensive experimental validation, generating offline also wheeled and quadrupedal locomotion.



14:30–14:45	TuOral2_2.2

Whole-body walking pattern using pelvis-rotation for long stride and arm swing for yaw angular momentum compensation

Beomyeong Park, Myeong-Ju Kim, Eunho Sung, Junhyung Kim and Jaeheung Park
Seoul National University, South Korea

- The whole-body walking pattern using pelvis-rotation and arm swing for long stride walking was proposed.
- To generate pelvis rotation walking pattern, the lower body consists of redundant system including waist yaw joint.
- Quadratic programming is used to generate whole-body walking pattern for pelvis rotation and arm swing.
- The whole-body walking pattern was verified in simulation and experiment.

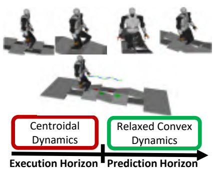
Fig.1 Whole-body walking with pelvis rotation and arm swing

14:45–15:00	TuOral2_2.3

Multi-Fidelity Receding Horizon Planning for Multi-Contact Locomotion

Jiayi Wang[1] Sanghyun Kim[2] Sethu Vijayakumar[1,3] Steve Tonneau[1]
[1] IPAB, The University of Edinburgh, UK [2] Korea Institute of Machinery & Materials, South Korea [3] The Alan Turing Institute, UK

- Planning uneven terrain locomotion requires multiple steps lookahead. But do we need accurate modeling for the entire horizon (computationally expensive)?
- We find the first step (to be executed) requires accurate modeling, while the rest can use **convex approximations**.
- However, **angular dynamics** should be incorporated.
- Result: **Multi-fidelity** Receding Horizon Planning, avg. 2.4x faster than the single-fidelity counterparts for planning centroidal trajectories.

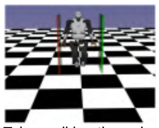


15:00–15:15	TuOral2_2.4

Stochastic and Robust MPC for Bipedal Locomotion: A Comparative Study on Robustness and Performance

Ahmad Gazar*,Majid Khadiv*,Andrea Del Prete† and Ludovic Righetti*‡
Movement Generation and Control, MPI-IS, Germany*
Industrial Engineering Department, University of Trento, Italy†
Tandon School of Engineering, New York University, New York, USA*‡

- we introduce SMPC to generate stable walking motions subject to chance constraints
- we analyze the robustness of SMPC to worst-case disturbances in comparison with RMPC
- we compare SMPC against RMPC and nominal MPC highlighting the trade-off in robustness and performance



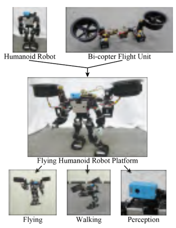
Talos walking through a narrow hall way s.t. disturbances on lateral CoM

15:15–15:30	TuOral2_2.5

Design and Development of a Flying Humanoid Robot Platform with Bi-copter Flight Unit

Tomoki Anzai, Yuta Kojio,Tasuku Makabe, Kei Okada and Masayuki Inaba
Department of Mechano-Informatics, The University of Tokyo, Japan

- We propose a flying humanoid robot platform with bi-copter flight unit to enhance mobility.
- We describe the modeling and flight control of the flying humanoid robot.
- We show the hardware implementation of the bi-copter flight unit and the humanoid robot.
- We perform experiments to verify the effectiveness of the flight control and the proposed robot system.



The proposed flying humanoid robot platform.

Interactive Session 1

15:45–17:00 TuInteractive1_2.1

Pick-and-place in dynamic environments with a mobile dual-arm robot equipped with distributed distance sensors

Sotiris Stavridis and Zoe Doulgeri
Electrical & Computer Engineering, Aristotle University of Thessaloniki, Greece
Pietro Falco
ABB Corporate Research, Automations Solutions, Vasteras, Sweden

- An integrated framework for mobile bimanual tasks under prioritized constraints
- Robot-centered reactive collision avoidance approach with distributed distance sensors and lidar sensors
- A set of fundamental motion tasks are formulated that can be used to synthesize more complex ones
- Experimental demonstration on a complete pick-and-place scenario

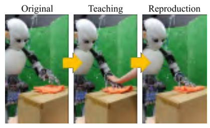

Sensor-based reactive collision avoidance in the null space of the task

15:45–17:00 TuInteractive1_2.2

Motion Modification Method of Musculoskeletal Humanoids by Human Teaching Using Muscle-Based Compensation Control

Kento Kawaharazuka, Yuya Koga, Manabu Nishiura,
Yusuke Omura, Yuki Asano, Kei Okada, Masayuki Inaba
Department of Mechano-Informatics, The University of Tokyo, Japan
Koji Kawasaki
TOYOTA MOTOR CORPORATION, Japan

- We describe a method to modify the movement of the musculoskeletal humanoid by applying external force during the movement, taking advantage of its flexible body.
- Considering the fact that **the joint angles cannot be measured, and that the external force greatly affects the nonlinear elastic element and not the actuator**, the modified motion is reproduced by the proposed **muscle-based compensation control**.



Teaching by humans during the original movement and its reproduction

15:45–17:00 TuInteractive1_2.3

Wolfgang-OP: A Robust Humanoid Robot Platform for Research and Competitions

Marc Bestmann, Jasper Güldenstein,
Florian Vahl und Jianwei Zhang
Department of Informatics, University of Hamburg, Germany

- Open source software and hardware with custom electronics
- Robustness against falls with 3D printed elastic elements and falling detection
- Torque reduction in the knee by using a torsion spring
- Increased computational power by combining CPU and TPU


Photo of the robot

15:45–17:00 TuInteractive1_2.4

Calibration of an Elastic Humanoid Upper Body and Efficient Compensation for Motion Planning

Johannes Tenhumberg, German Aerospace Center
Berthold Bäuml, German Aerospace Center (DLR)

15:45–17:00 TuInteractive1_2.5

Development of Amphibious Humanoid for Behavior Acquisition on Land and Underwater

Tasuku Makabe, Tomiki Anzai, Yohei Kakiuchi,
Kei Okada and Masayuki Inaba
Mechano-Informatics, Universityof Tokyo, Japan

- **Developped Amphibious Humanoid platform which can achieve whole-body motion and change reaction force from world**
- Development of **Amphibious Humanoid**
  - Low-cost Waterproofed Servomotors
  - 3D-printed Free Shape Buoyant Material
- Experiments in **Multi Environments**
  - Walking Motion on Land and Water
  - Swimming Motion with Floating Link

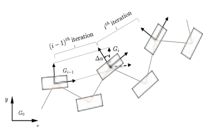

Swimming Motion of Amphibious Humanoid

15:45–17:00 TuInteractive1_2.6

Online Virtual Repellent Point Adaptation for Biped Walking using Iterative Learning Control

Shengzhi Wang and Dongheui Lee
Electrical and Computer Engineering, Technical University of Munich, Germany
George Mesesan, Johannes Englsberger, Dongheui Lee, and Christian Ott
Institute of Robotics and Mechatronics, German Aerospace Center, Germany

- An online learning framework based on Iterative Learning Control is developed.
- The framework learns an adjusted VRP reference trajectory to reduce the VRP tracking error.
- The framework reduces the effect of model inaccuracies and improves the robustness of DCM-based walking.
- The stability of the framework is proved.

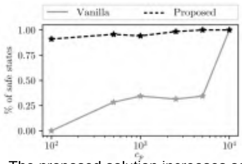

Definition of “iteration” for Iterative Learning Control.

15:45–17:00 TuInteractive1_2.7

Safe Data-Driven Contact-Rich Manipulation

Ioanna Mitsioni*, Pouria Tajvar*, Danica Kragic,
Jana Tumova, Christian Pek
Division of Robotics, Perception and Learning, KTH, Sweden
* Authors contributed equally

- Data-driven controllers (DDC) are not inherently safe.
- We propose to approximate the set of safe states and construct feedback motion primitives to keep the system in the safe sets.
- We improve the safety of DDC frameworks without impeding their performance.



The proposed solution increases safety over all controller parameters

15:45–17:00 TuInteractive1_2.8

Feature-based Deep Learning of Proprioceptive Models for Robotic Force Estimation

Erik Berger
Siemens AG, Germany
Alexander Uhlig
The SQLNet Company GmbH, Germany

- Generate features from the robot's common internal sensor readings acquired during regular and perturbed behavior executions
- **Behavior-specific proprioception models (BSPMs)** predict intrinsic and total forces through the use of deep learning
- Perceiving extrinsic forces (total – intrinsic) allows to implement interaction capabilities without the need of special purpose sensors
- The accuracy of force estimates on the TCP of an UR5 robotic arm achieved 2.78N MAE

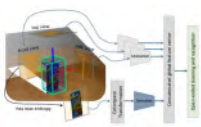

The robot reliably detects external forces resulting from physical interactions

15:45–17:00 TuInteractive1_2.9

Open-Ended Fine-Grained 3D Object Categorization by Combining Shape & Texture Features in Multiple Colorspaces

Nils Keunecke and S. Hamidreza Kasaei
Department of Artificial Intelligence, University of Gronigen, Netherlands

- Proposition of a scale and pose invariant object representation considering shape and texture information
- Our instance-based open-ended learning approach shows state-of-the-art accuracy and scalability
- Demonstrated real-time performance in a robot experiment in the context of a "serve-a-beer" scenario

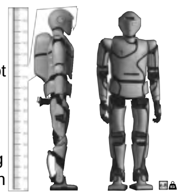

Proposed Architecture for Fine-Grained 3D Object Categorization

15:45–17:00 TuInteractive1_2.10

SURENA IV: Towards A Cost-effective Full-size Humanoid Robot for Real-world Scenarios

Aghil Yousefi-Koma, Behnam Maleki, Hessam Maleki, Amin Amani, Mohammad Ali Bazrafshani,Hossein Keshavarz, Ala Iranmanesh, Alireza Yazdanpanah, Hamidreza Alai, Sahel Salehi, Mahyar Ashkvari , Milad Mousavi, Milad Shafiee
*All authors contributed equally
Center of Advanced Systems and Technologies (CAST), University of Tehran

- SURENA IV has 43 DoFs with a height of 170 cm and mass of 68 kg
- SURENA IV consists a novel and cheap predictive foot sensor
- The predictive foot sensor enables the robot to walk on unknown obstacles without any force sensor.
- Drilling, visual servoing of a moving object, and writing on the white-board are some other tasks that has been demonstrated by the robot


SURENA IV

15:45–17:00 TuInteractive1_2.11

Combining Task and Motion Planning using Policy Improvement with Path Integrals

Dominik Urbaniak[1], Alejandro Agostini[1,2], and Dongheui Lee[1,3]
[1]Dep. of Electrical and Comp. Eng., Technical University of Munich, Germany
[2]Dep. of Computer Science, University of Innsbruck, Austria
[3]Institute of Robotics and Mechatronics, German Aerospace Center, Germany

- The proposed TAMP framework performs complex tasks comprising long action sequences with obstacle avoidance.
- Symbolic actions are grounded using DMP parameters for variable object configurations.
- PI^2 efficiently generates divers sets of optimal collision-free trajectories for policy learning.
- The action policy is encoded in a neural network.

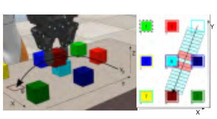


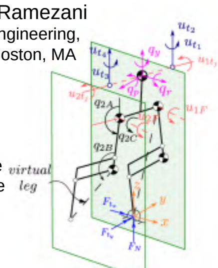
Illustration of a collision-free pick-and-place action within a sequential task

15:45–17:00 TuInteractive1_2.12

A HZD-based Framework for the Real-time, Optimization-free Enforcement of Gait Feasibility Constraints

Pravin Dangol, Andrew Lessieur,
Eric Sihite and Alireza Ramezani
Electrical and Computer Engineering,
Northeastern University, Boston, MA

- We assume pre-stabilized joint models in a thruster-assisted bipedal robot model
- We re-shape the zero-dynamics manifold throughout the entire gaitcycle to ensure the solutions remain in the constraint-admissible space
- The internal dynamics adjustments are achieved following rules of reference governors from control system theory



Illustrates our thruster-assisted legged model

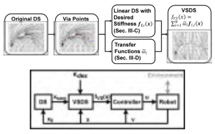
Interactive Session 1

15:45–17:00	TuInteractive1_2.13

Closed-Loop Variable Stiffness Control of Dynamical Systems

Xiao Chen(1), Youssef Michel(1) and Dongheui Lee(1,2)
[1]Department of Electrical and Computer Engineering, Technical University of Munich, Germany
[2]Institute of Robotics and Mechatronics, German Aerospace Center, Germany

- An approach to encode a desired stiffness profile into first order Dynamical systems (DS) is proposed.
- The DS is controlled in closed-loop, providing safety and robustness to perturbations
- The modified DS is built as weighted sum of springs around via-points from an original DS.
- Robot experiments validate the safety and performance during contact tasks like charger insertion.



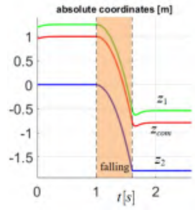
Overview of our Variable Stiffness Dynamical Systems (VSDS) concept

15:45–17:00	TuInteractive1_2.14

From Space to Earth – Relative-CoM-to-Foot (RCF) control yields high contact robustness

Johannes Englsberger, Alessandro M. Giordano, Achraf Hiddane, Robert Schuller, Florian Loeffl, George Mesesan, Christian Ott
German Aerospace Center (DLR), Germany

- Simplest Articulated Free-Floating (SAFF) model is introduced (free-floating, two masses, 1 actuated DOF, subject to gravity).
- Two state-of-the-art controllers are shown to be exponentially stable in the nominal case, while becoming unstable if the contact is lost.
- In contrast, newly proposed Relative CoM-to-Foot (RCF) controller is nominally exponentially stable, while remaining BIBO stable in case of a contact loss.
- Analysis is based on theoretical derivations and various simulations.



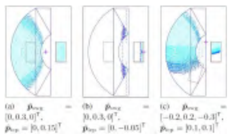
RCF is robust w.r.t. contact loss ("falling"), while achieving perfect tracking in nominal case

15:45–17:00	TuInteractive1_2.15

Footstep and Timing Adaptation for Humanoid Robots Utilizing Pre-computation of Capture Regions

Yuichi Tazaki
Department on Mechanical Engineering, Kobe University, Japan

- Development of a novel capturability-based step adaptation method based on multi-step prediction of low-dimensional dynamics.
- N-step viable capture basins are precomputed and stored in a database to be utilized for real-time adaptation of foot placement and step duration.
- Performance of the proposed controller is tested in dynamical simulations using the full DoF model of a humanoid robot.

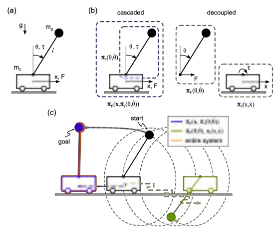

Visualization of capture regions computed using the proposed method

15:45–17:00	TuInteractive1_2.16

Policy Decomposition: Approximate Optimal Control with Suboptimality Estimates

Ashwin Khadke and Hartmut Geyer
The Robotics Institute, Carnegie Mellon University, USA

- Computing global policies to optimal control problems for complex systems becomes almost intractable
- We reduce the search for the optimal control policy to a search for a collection of sub-policies that are faster to compute
- We introduce a suboptimality measure to identify reduction strategies that sacrifice minimally in closed-loop performance



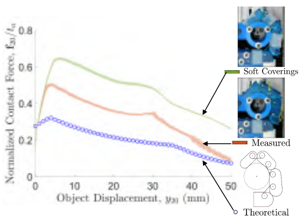
Cascaded and Decoupled strategies to decompose the synthesis of control policies for the cart-pole system

15:45–17:00	TuInteractive1_2.17

On the Optimal Design of Underactuated Fingers Using Rolling Contact Joints

Jean-Michel Boisclair, Thierry Laliberté and Clément Gosselin
Department of Mechanical Engineering, Université Laval, Canada

- The goal is to provide an optimization framework for underactuated fingers using rolling contact joints.
- Force-directed performance metrics are used to find an optimized and a comparative solution.
- Designs are experimentally tested to compare model predictions and to determine the maximum performance achievable.
- Results show that the model is conservative and allows choice among designs.



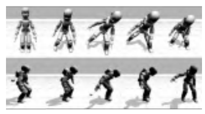
Theoretical and measured performance metric (with and without soft coverings). Legend shows the configuration leading to the maximum force applied on the object.

15:45–17:00	TuInteractive1_2.18

On the Emergence of Whole-body Strategies from Humanoid Push-recovery Learning

Diego Ferigo, Raffaello Camoriano, Paolo Maria Viceconte, Daniele Calandriello, Silvio Traversaro, Lorenzo Rosasco, Daniele Pucci
Istituto Italiano di Tecnologia, Genoa, Italy

- Model-free Deep Reinforcement Learning for whole-body humanoid balancing and push recovery
- Multiple strategies with a single policy
- State space inspired by floating-base dynamics
- Reward designed from first principles in robot control
- Evaluation of robustness and generalization in simulation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Interactive Session 1

15:45–17:00	TuInteractive1_2.19

HubRobo: A Lightweight Multi-Limbed Climbing Robot for Exploration in Challenging Terrain

Kentaro Uno, Naomasa Takada, Taku Okawara, Keigo Haji, Arthur Candalot, Warley F. R. Ribeiro, and Kazuya Yoshida
Departmentment of Aerospace Engineering, Tohoku University, Japan
Kenji Nagaoka
Department of Mechanical and Control Engineering, Kyushu Institute of Technology, Japan

- HubRobo is a 3 kg quadrupedal climbing robot testbed for challenging terrain exploration.
- HubRobo is equipped with passive spine grippers so that the robot grasp rocky terrain.
- Sequential execution of the climbing motion enabled the robot to climb 45º inclined terrain.
- Gripper sensorization and graspability evaluation in the terrain map is ongoing.

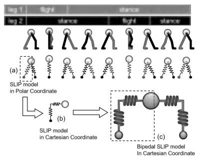
Developed four-limbed climbing robot: HubRobo

15:45–17:00	TuInteractive1_2.20

Minimum Energy-cost Walking Exploiting Natural Dynamics of Multiple Spring-Mass Model

Sangjin Bae, Chan Lee and Sehoon Oh
Department of Robotics Engineering, DGIST, Republic of Korea

- The motion of a simplified spring-mass model is analyzed for minimum energy-cost walking.
- The walking motion is obtained by calculating the equations of motion along each phases analytically.
- The proposed method generates a naturally periodic walking motion of the model.



Walking motion of the Spring-Mass model

15:45–17:00	TuInteractive1_2.21

Exploiting In-Hand Knowledge in Hybrid Joint-Cartesian Mapping for Anthropomorphic Robotic Hands

Roberto Meattini, Davide Chiaravalli, Gianluca Palli and Claudio Melchiorri
Dept. of Electrical, Electronic and Information Engineering (DEI), University of Bologna, Bologna, Italy.

- We propose a **hybrid joint-Cartesian mapping** exploiting an aspect poorly explored in previous works: the **in-hand information** available a priori
- Specifically, we consider the **areas of the hand workspaces in which the contact between thumb and finger fingertips is possible**
- We exploit this knowledge to realize a **smooth transition between joint and Cartesian mappings**
- This is guided by the rationale of **preserving, within a single strategy, the master finger shapes** during gesture and volar grasp executions, **and correctness of the fingertip positioning** during precision grasp/posture executions

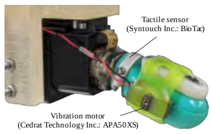
Gestures and grasps mapped on the UB-Hand

15:45–17:00	TuInteractive1_2.22

Tactile Perception based on Injected Vibration in Soft Sensor

Naoto Komeno and Takamitsu Matsubara
Nara Institute of Science and Technology (NAIST), Japan

- This paper explores a novel approach to achieve vibration-based tactile perception without a sliding motion.
- Our system obtains the texture information of touched objects by injecting mechanical vibration into a soft tactile sensor.
- Our system accomplished classification tasks with comparable or better accuracy than sliding motion.



Prototype system of injected vibration-based tactile perception.

15:45–17:00	TuInteractive1_2.23

The Elliott and Connolly Benchmark: A Test for Evaluating the In-Hand Dexterity of Robot Hands

Ryan Coulson, Nancy Pollard, and Carmel Majidi
Robotics Institute, Carnegie Mellon University, United States
Chao Li
Department of Electrical and Computer Engineering, Carnegie Mellon University, United States

- A new benchmark is developed for assessing the in-hand dexterity of humanoid type robot hands
- Benchmark consists of 13 in-hand manipulation patterns, based on a classification from Elliott and Connolly
- A dexterous robot hand – the CMU Foam Hand III – is evaluated using the benchmark
- The CMU Foam Hand III successfully completes 10 of 13 manipulations

CMU Foam Hand III performing an in-hand manipulation.

15:45–17:00	TuInteractive1_2.24

Introducing GARMI - a Service Robotics Platform to Support the Elderly at Home: Design Philosophy, System Overview and First Results

Mario Tröbinger[1], Christoph Jähne[2], Zheng Qu[2], Jean Elsner[1], Anton Reindl[1], Sebastian Getz[2], Thore Goll[2], Benjamin Loinger[2], Tamara Loibl[2], Christoph Kugler[2], Carles Calafell[2], Mohamadreza Sabaghian[2], Tobias Ende[2], Daniel Wahrmann[2], Sven Parusel[2], Simon Haddadin[2] and Sami Haddadin[1]
[1]Munich School of Robotics and Machine Intelligence, TUM, Germany; [2]Franka Emika GmbH, Germany

- A unique whole-body control with multimodal dynamic integration between head, arms and base;
- Different modes of interaction based on activation sub-components to become haptic teaching devices;
- Specialized use-driven avatar stations designed for technical operators and medical experts;

The use-driven service robotics platform GARMI.

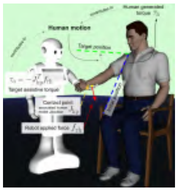
Interactive Session 1

15:45–17:00	TuInteractive1_2.25

Adaptive Task-Space Force Control for Humanoid-to-Human Assistance

Anastasia Bolotnikova
École Polytechnique Fédérale de Lausanne, Switzerland
Sébastien Courtois
SoftBank Robotics Europe, Paris, France
Abderrahmane Kheddar
CNRS-AIST JRL, Japan and CNRS-University of Montpellier, France

- We envision a humanoid robot to provide **motion-support forces** for frail human assistance
- We present a control strategy for a humanoid to **adaptively regulate its assistive force** contribution
- We emulate human frailty and apply our adaptive force control strategy to demonstrate the results of a **humanoid successfully assisting the simulated human** model to restore the optimal motion task performance



Humanoid-to-human physical assistance

Optimization and Optimal Control

Chair *Zhangguo YU, Beijing Institute of Technology*
Co-Chair *Ludovic Righetti, New York University*

17:00–17:15	TuOral3_2.1

A vertical jump optimization strategy for one-legged robot with variable reduction ratio joint

Haoxiang Qi, Xuechao Chen, Zhangguo Yu, Gao Huang, Libo Meng, Wenxi Liao, Qiang Huang
School of Mechanical Engineering, Beijing Insititute of Technology, China
Kenji Hashimoto
Humanoid Robotics Institute (HRI), Waseda University, Japan

- Analysis about variable reduction ratio joint of a one-legged robot
- Optimization of jump strategy with respect to variable reduction ratio joint
- Experiment and simulation of vertical jump


The one-legged robot platform

17:15–17:30	TuOral3_2.2

Online Centroidal Angular Momentum Reference Generation for Humanoid Push Recovery

Robert Schuller, George Mesesan,
Johannes Englsberger, Jinoh Lee, and Christian Ott
Institute of Robotics and Mechatronics,
German Aerospace Center (DLR), Germany

- Push recovery algorithm for balancing scenarios by exploiting the centroidal angular momentum (CAM).
- CAM is generated to prevent the center of pressure from reaching the support area's border.
- The CAM reference is generated online in three phases.
- Based on the CAM reference, a motion optimizer generates whole-body trajectories.

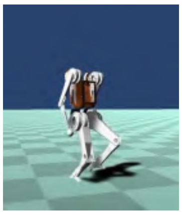

TORO generating centroidal angular momentum after being pushed.

17:30–17:45	TuOral3_2.3

MPC-based Locomotion Control of Bipedal Robots with Line-Feet Contact using Centroidal Dynamics

Gabriel Garcia, Robert Griffin, Jerry Pratt
The IHMC, FL, US

- Simulated Contact Wrench Cone in the MIT Physical Simulator.
- Used a Variational Approach applied to the Centroidal Dynamics
- New Dynamics considers the effects of the limbs taking angular momentum and the time-varying Composite-Inertia

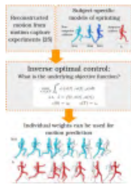


17:45–18:00	TuOral3_2.4

Using Subject-Specific Models to find Differences in Underlying Optimization Criteria of Sprinting with and without Prostheses

Anna Lena Emonds
Institute of Computer Engineering (ZITI), University of Heidelberg, Germany
Katja Mombaur
Canada Excellence Research Chair in Human-Centred Robotics and Machine Intelligence, Systems Design Engineering & Mechanical and Mechatronics Engineering, University of Waterloo, Canada

- Amputee motions to understand how humans interact with technical aids
- Methods: Rigid multi-body system modeling and optimal control problems, especially inverse optimal control for weight identification
- Realistic human-like sprinting motions
- Larger asymmetries in weight factors of amputee athlete; angular momentum control plays decisive role in amputee sprinting.


Workflow of the inverse optimal control problem

18:00–18:15	TuOral3_2.5

GVLAB Tokyo University of Agriculture and Technology 東京農工大学 TAT National Institute of Advanced Industrial Science and Technology AIST

Pseudo Direct and Inverse Optimal Control based on Motion Synthesis using FPCA

Soya Shimizu[1], Ko Ayusawa[2,3], and Gentiane Venture[1,2,3]
[1]Tokyo University of Agriculture and Technology, Japan
[2]CNRS-AIST JRL (Joint Robotics Laboratory), IRL, Japan
[3]National Institute of Advanced Industrial Science and Technology, Japan

- Proposed new method using FPCA instead of Direct and Inverse Optimal Control.
- Calculate approximation ratio using the distance between subject and neighboring data.
- New method is about 200 times faster than the conventional method, without losing accuracy.


Close view of overlayed figures of synthesized motions

Interaction & Perception

Chair *Kei Okada, The University of Tokyo*
Co-Chair *Serena Ivaldi, INRIA*

13:30–13:45	WeOral4_3.1

Human to Robot Whole-Body Motion Transfer

Miguel Arduengo[1], Ana Arduengo[1], Adrià Colomé[1], Joan Lobo-Prat[1] and Carme Torras[1]
[1]Institut de Robòtica i Informàtica Industrial (IRI), CSIC-UPC, Spain

- Transferring human motion to robots is crucial for automating complex manipulation tasks.
- General solution to the correspondence problem.
- Hierarchical Whole-Body controller.
- A variable admittance controller is proposed for ensuring safe physical human-robot interaction.

13:45–14:00	WeOral4_3.2

Semantic Scene Manipulation Based on 3D Spatial Relations and Language Commands

Rainer Kartmann*, Danqing Liu and Tamim Asfour
Institute of Anthropomatics and Robotics,
Karlsruhe Institute of Technology, Germany

- Scene manipulation according to spatial relations specified by language commands
- Generative model of 3D spatial relations between multiple reference objects based on cylindrical probability distribution
- Estimate models for static and dynamic 3D spatial relations (e.g., *on top*, *between*, *other side*) from demonstrations provided by human
- Sample, filter and select target positions to adapt via-point movement primitive to generate robot motion

ARMAR-6 moves an object according to the specified 3D spatial relation.

14:00–14:15	WeOral4_3.3

Android Printing: Towards On-Demand Android Development Employing Multi-Material 3-D Printer

Satoshi Yagi and Hiroshi Ishiguro
Graduate School of Engineering Science, Osaka University, Japan
Yoshihiro Nakata
Graduate School of Informatics and Engineering,
The University of Electro-Communications, Japan

- Android Printing, printing an android all at once using a multi-material 3-D printer, is proposed.
- Tested the skin deformation could be adjusted by implementing different ridge structures behind it.
- Designed and fabricated a 3-D printed android head with 31 degrees of freedom.
- The printed android head generated some facial movements based on measured human data.

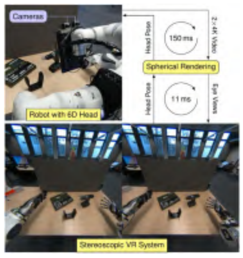

3-D printed android head

14:15–14:30	WeOral4_3.4

Low-Latency Immersive 6D Televisualization with Spherical Rendering

Max Schwarz and Sven Behnke
Autonomous Intelligent Systems (AIS), University of Bonn, Germany

- Method for real-time stereo scene capture and remote VR visualization
- Allows latency-free 6D head movement
- Existing methods have either high movement latency or cannot handle dynamic scenes
- Spherical rendering is used for reprojection on short timescales to compensate for movement latencies
- Lab experiments and a user study confirm our method outperforms two baseline methods



Overview of our method

14:30–14:45	WeOral4_3.5

Vision for Prosthesis Control Using Unsupervised Labeling of Training Data

Vijeth Rai, David Boe, and Dr Eric Rombokas
Department of Electrical and Computer Engineering,
University of Washington, USA

- Terrain transitions in prostheses is hard.
- **Vision sensors can look ahead** and anticipate desired control transitions.
- Acquiring labelled training data is resource intensive and prone to bias.
- **Kinematics can be applied to automatically acquire labels**.
- CNN classifier trained on automatically labelled data detected transitions almost **+2.2 secs in advance**.


Vision can help anticipate terrain transitions for better prosthesis control.

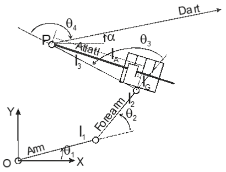
Interactive Session 2

14:45–15:45	WeInteractive2_3.1

The Atltal as a Cyborg Kinematic Device

Bertrand Tondu
Université Fédérale de Toulouse, France and LAAS/CNRS, Toulouse, France

- The atlat is a primitive weapon generally understood as a simple wrist lever
- A simple kinematic analysis is proposed for highlighting the ability of the atlatl to derive benefit from the elbow singularity
- The atlatl would then be a clever cyborg device understood as a substitute of the hand making possible to combine the large movements in shoulder and elbow extension with the limited wrist movements for getting high release speed and accurate final dart orientation



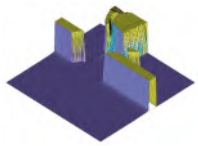
Simple planar robotic model of the human arm throwing a dart with an atlatl

14:45–15:45	WeInteractive2_3.2

Fitness Shaping on SLIP Locomotion Optimization

Claudio S. Ravasio[1,2], Fumiya Iida[1] and Andre Rosendo[3]
[1] University of Cambridge, UK
[2] UCL & KCL, UK
[3] ShanghaiTech University, China

- Exploring the ground truth fitness landscape and corresponding gait patterns
- Fitness shaping to aid optimization by utilizing additional categorical simulation output
- Investigating the use of simple neural networks for locomotion optimization
- Benchmarking of four optimization methods on different initial conditions

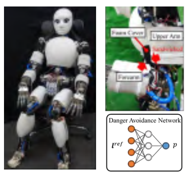

Ground truth of the fitness landscape for SLIP model bipedal locomotion

14:45–15:45	WeInteractive2_3.3

Online Learning of Danger Avoidance for Complex Structures of Musculoskeletal Humanoids and Its Applications

Kento Kawaharazuka, Naoki Hiraoka, Yuya Koga, Manabu Nishiura, Yusuke Omura, Yuki Asano, Kei Okada, and Masayuki Inaba
The University of Tokyo, Japan
Koji Kawasaki
TOYOTA MOTOR CORPORATION, Japan

- The complex structure of musculoskeletal humanoids is difficult to modelize.
- The inter-body interference and high internal muscle force are unavoidable.
- It is important **not only to deal with the danger when they occur but also to prevent them from happening**.
- We propose **a method to learn a network outputting danger probability corresponding to the muscle length online** so that the robot can gradually prevent dangers from occurring.



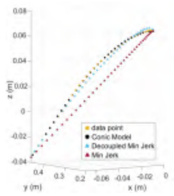
The Musculoskeletal Humanoid Musashi and Danger Avoidance Network

14:45–15:45	WeInteractive2_3.4

Experimental Validation and Comparison of Reaching Motion Models for Handovers

Wesley Chan, Tin Tran, Sara Sheikholeslami, and Elizabeth Croft
Department of Electrical and Computer Systems Engineering, Monash University, Australia

- Use of Minimum Jerk Trajectory model for human-robot handovers has largely assumed the model fitted human handover motions.
- We provide the first experimental validation and comparison of 3 motion models using a motion capture dataset of 1200 handovers.
- The Conic motion model was found to be the best fit model, reducing fitting errors up to 84%.
- Unlike human solo reaching motions, which were found to be mostly elliptical, handover reaching motions are split between hyperbolic (59%) and elliptical (34.1%) types.



Handover motion capture trajectory and fitted modles

14:45–15:45	WeInteractive2_3.5

Motion Generation and Control of Acrobatic Motion Synergies Emerging From the MEP[#]

Ryo Iizuka[1], Dragomir N. Nenchev[2] and Daisuke Sato[1]
[1]Graduate School of Engineering, Tokyo City University, Japan
[2]Department of Information, Kaishi Professional University, Japan

- The distribution of the angular momentum among the body segments is discussed.
- Weights proportional to the moments of inertia of the body segments are used.
- Emergent movements are generated in the pelvis, torso and arms.
- The skillful performance of highly dynamic motion tasks (flips, long jump, jump with twist) is achieved in a simulated environment.
- The robustness of the control approach w.r.t. parameter variations is confirmed.

[#]Momentum Equilibrium Principle

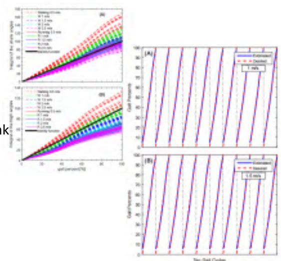

Example of a generated standing forward flip performance

14:45–15:45	WeInteractive2_3.6

Gait Percent Estimation during Walking and Running using Sagittal Shank or Thigh Angles

Mahdy Eslamy, Arndt Schilling
Applied Rehabilitation Technology ART Lab, Department for Trauma Surgery, Orthopaedics and Plastic Surgery, Universitaetsmedizin Gottingen (UMG), 37075, Gottingen, Germany

- In this work we analyzed the relationship between the shank and thigh angles (separately) and the gait percent estimation.
- To do so, those angles were integrated.
- Our findings show that the integral of shank and thigh angle has a monotonic behavior
- Average R^2 values close to one and average RMS errors less than 2.2 were achieved.



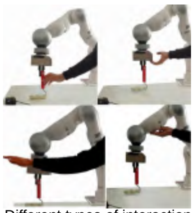
Interactive Session 2

14:45–15:45 WeInteractive2_3.7

Detection of Collaboration and Collision Events during Contact Task Execution

Felix Franzel[2], Thomas Eiband[1,2] and Dongheui Lee[1,2]
[1] German Aerospace Center (DLR), Germany
[2] Technical University of Munich (TUM), Germany

- Increases safety in close proximity physical human-robot collaboration based on only proprioceptive and external ft-sensor data
- Robust detection of human interaction with on only one recording of the task as reference sample
- Fast contact classification based on newly designed physical features that outperforms the state of the art (reaction time < 0.2 s)
- Evaluation with offline classification and experiment with user study (5 subjects)

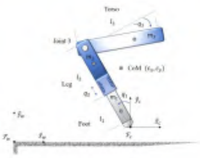

Different types of interaction during experiment

14:45–15:45 WeInteractive2_3.8

Robust Balancing Control of a Spring-legged Robot based on a HOSM Observer

Juan D. Gamba and Roy Featherstone
Dept. Advanced Robotics, Istituto Italiano di Tecnologia, Italy
Antonio C. Leite
Faculty of Science and Technology, Norwegian University of Life Science.

- High performance balance and absolute motion control.
- HOSM observer applied to spring estimation during landing and tracking.
- Part of a series on the design of a high-performance monopedal robot, called Skippy.

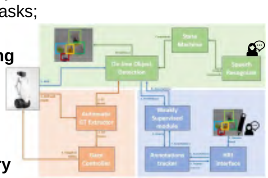

Spring-Loaded Monoped

14:45–15:45 WeInteractive2_3.9

Weakly-Supervised Object Detection Learning through Human-Robot Interaction

Elisa Maiettini[1] and Vadim Tikhanoff[2] and Lorenzo Natale[1]
[1]Humanoid Sensing and Perception, Istituto Italiano di Tecnologia, Genoa, Italy
[2]iCub Tech, Istituto Italiano di Tecnologia, Genoa, Italy

- We propose a robotic **object detection** system that can be **naturally adapted** to novel tasks;
- We integrated a **weakly-supervised learning** with **HRI** and an **on-line training** protocol;
- We **benchmarked** the system with experiments on a robotic dataset;
- We **deployed** the application on the **R1 humanoid robot**, integrating **exploratory** behaviors.

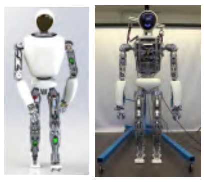

Overview of the proposed object detection application

14:45–15:45 WeInteractive2_3.10

Design, analysis and control of the series-parallel hybrid RH5 humanoid robot

Julian Esser, Shivesh Kumar, Heiner Peters, Vinzenz Bargsten, Jose de Gea Fernandez, Frank Kirchner
DFKI Robotics Innovation Center, Bremen, Germany
Carlos Mastalli
Alan Turing Institute, University of Edinburgh, Edinburgh, United Kingdom
Olivier Stasse
LAAS-CNRS, Toulouse, France

- Novel series-parallel hybrid RH5 humanoid with light-weight design (weighs only 62.5 Kg) and good dynamic characteristics (dynamic tasks with 5 Kg in each hand)
- Analysis of the robot design using DDP based whole body trajectory optimization method
- Improved contact stability soft constrained DDP which generates physically consistent walking trajectories that can be stabilized by simple PD position control in simulators.

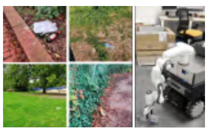

RH5 Humanoid

14:45–15:45 WeInteractive2_3.11

Garbage Collection and Sorting with a Mobile Manipulator using Deep Learning and Whole-Body Control

J. Liu, K. Ellis, D. Hadjivelichkov, D. Stoyanov, and D. Kanoulas
Dept. Computer Science, UCL, UK
P. Balatti and A. Ajoudani
HRI[2] laboratory, IIT, Italy

- Introduction of a garbage **classification** and **localization** system for grasping and sorting in the correct recycling bin.
- Use of a deep neural network (**GarbageNet**) trained to detect different recyclable types of garbage.
- Development of **grasp localization** and **whole-body control**, to pick and sort garbage from the ground.
- Experimental validation of the system on a **real mobile robot**, using visual data.

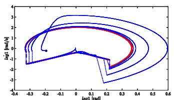

Garbage items on the ground and the IIT-MOCA/UCL-MPPL robot, collecting/sorting garbage.

14:45–15:45 WeInteractive2_3.12

Energy pumping-and-damping for gait robustification of underactuated planar biped robots within the hybrid zero dynamics framework

Pierluigi Arpenti, Fabio Ruggiero, and Vincenzo Lippiello
DIETI, University of Naples Federico II, Italy
Alejandro Donaire
School of Engineering, University of Newcastle , Australia

- Compass-like biped robot (CBR) is the simplest planar biped robot exhibiting human gait
- Passive dynamic walking is the stable gait performed by CBR under the effect of gravity only
- EPD-PBC to enlarge the basin of attraction of passive or generated limit cycles
- Passivity, invariant set theory, and hybrid zero dynamics to study the stability of the controlled system

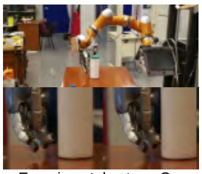

Limit cycles comparison for the first leg. Red arcs represent the passive limit cycle while blue arcs represent the limit cycle during a test carried out starting by perturbed initial conditions

14:45–15:45	WeInteractive2_3.13

Pushing Cylinders: Expanding on Object Based Manipulation

Daniel García-Vaglio, Javier Peralta-Sáenz and Fedrico Ruiz-Ugalde
Electrical Engineering, University of Costa Rica, Costa Rica

- Model for pushing cylinders over a planar surface to a goal in a single shot.
- Part of a system for connecting high level instructions with robotic movement.
- Object parameters are estimated using the robot's sensing capabilities.
- The method was tested with a real robot. All tasks were successful.


Experimental set up. Our robot pushing a cylinder.

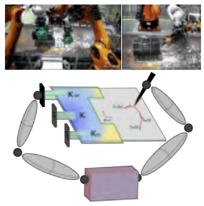
ARCOS-LAB UCR

14:45–15:45	WeInteractive2_3.14

Optimal grasp selection, and control for stabilising a grasped object, with respect to slippage and external forces

Tommaso Pardi*, Amir Ghalamzan E.**, Valerio Ortenzi***, Rustam Stolkin*
*University of Birmingham, UK
**University of Lincoln, UK
***Max Planck Institute for Intelligent Systems, Germany

- We explore the problem of how to grasp an object and then control a robot arm to stabilise the object under external forces.
- Force-full dual arm tasks on a single object are common tasks in industrial scenarios, and they are challenging to tackle.
- We propose a method to account for slippage between gripper and object before grasping.
- We propose a robust controller to minimise the robot effort while stabilising the object.


Left arm must balance the plate, while the right arm is applying a force profile

14:45–15:45	WeInteractive2_3.15

Human Posture Prediction during Physical Human-Robot Interaction

Lorenzo Vianello, Jean-Baptiste Mouret, Eloise Dalin, Alexis Aubry, Serena Ivaldi
Inria, LORIA, University of Lorraine, France
CRAN, University of Lorraine, France

- Collaborative robots in industry can be used to assist human co-workers
- During interaction is necessary to optimize human's ergonomics
- The human is not controllable: the robot can only optimize its end-effector trajectory
- Reasoning in terms of ergonomics requires the estimation of the human's most probable posture
- Can we predict the human posture, given the robot end-effector position?

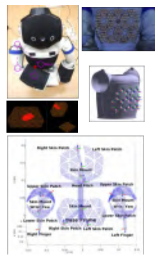
The human posture is influenced by the robot's trajectory during physical interaction, but the human may adopt different postures during each task execution.

14:45–15:45	WeInteractive2_3.16

Spatial calibration of whole-body artificial skin on a humanoid robot: comparing self-contact, 3D reconstruction, and CAD-based calibration

Lukas Rustler[1], Bohumila Potocna[1], Michal Polic[1,2], Karla Stepanova[1,2], and Matej Hoffmann[1]
[1]Department of Cybernetics, Faculty of Electrical Engineering
[2]Czech Institute of Informatics, Robotics, and Cybernetics
Czech Technical University in Prague, Czech Republic

- Nao humanoid robot retrofitted with pressure-sensitive skin on the head, torso, and arms
- Comparison of the accuracy and effort for the following skin spatial calibration approaches:
  - combining CAD models and 2D skin layout
  - 3D reconstruction from images
  - using robot kinematics to calibrate skin by self-contact
  - Combination of these
- Mean calibration errors below taxel radius (2 mm) (self-contact + 3D reconstruction)



14:45–15:45	WeInteractive2_3.17

Walking-in-Place Foot Interface for Locomotion Control and Telepresence of Humanoid Robots

Ata Otaran and Ildar Farkhatdinov
Queen Mary University of London, UK

- A seated walking-in-place interface for teleoperation of a humanoid robot
- 1-DoF ankle platform is used
- Human-operator uses foot tapping to control walking of a robot
- Seated and hands-free teleoperation
- Easy to use to control speed of walking
- Experimental study with virtual humanoid robot

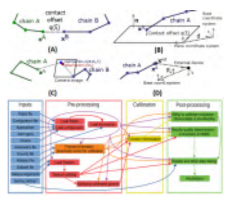
Queen Mary University of London

14:45–15:45	WeInteractive2_3.18

Multisensorial robot calibration framework and toolbox

Jakub Rozlivek[1,*], Lukas Rustler[1,*], Karla Stepanova[1,2], and Matej Hoffmann[1]
[1]Dep. of Cybernetics, Faculty of Electrical Engineering, CTU in Prague, Czech Republic
[2]Czech Inst. of Informatics, Robotics, and Cybernetics, CTU in Prague, Czech Republic
*Both authors contributed equally

- Extending the kinematic calibration theory by incorporating new sensory modalities, calibration types, and their combinations.
  - External device (D), contact with a plane (B)
  - Self-calibration available to humanoids - self-contact (A), self-observation (C)
- Unified formulation combining calibration approaches in a single cost function.
- Tested through calibration of
  - humanoid robots (iCub, Nao)
  - industrial manipulator (dual-arm setup)
- Open-source Matlab toolbox available at https://github.com/ctu-vras/multirobot-calibration


Schematics of calibration approaches (top), Matlab Toolbox pipeline (bottom)

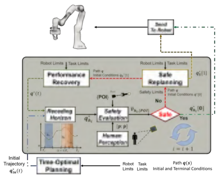
Interactive Session 2

14:45–15:45	WeInteractive2_3.19

Fast and Safe Trajectory Planning: Solving the Cobot Safety/Performance Tradeoff in Human-Robot Shared Environment

A. Palleschi and M. Garabini and L. Pallottino
DII, Research Center “E. Piaggio”, University of Pisa, Italy
M. Hamad and S. Abdolshah and S. Haddadin
MSRM, Technical University of Munich, Germany

- Collaborative robotics allows robots and humans to work side-by-side.
- The challenge is integrating human safety without compromising performance.
- This paper proposes a reactive trajectory planning algorithm for safe and high-performance robot motions.
- A Safety Module evaluates the safety of the time-optimal trajectory and optimally adapts it to guarantee human safety online.



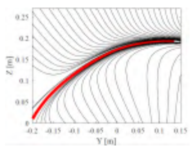
Block diagram of the proposed fast and safe trajectory planning algorithm.

14:45–15:45	WeInteractive2_3.20

Predictive Exoskeleton Control Based on ProMPs Combined With a Flow Controller

Marko Jamšek, Tjaša Kunavar, Urban Bobek, and Jan Babič
Department for Automation, Biocybernetics, and Robotics, Jožef Stefan Institute, Slovenia
Elmar Rueckert
Institute for Robotics and Cognitive Systems,University of Luebeck, Germany

- Human movement intention prediction using probabilistic movement primitives (ProMPs)
- The predicted user trajectory is used to generate an assistive flow field
- The control scheme is evaluated with human subjects in a reaching task
- Combining movement prediction with a flow controller resulted in an intuitive and safe assistance for the task



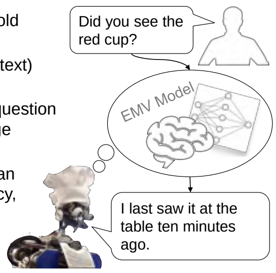
Assistive flow field over the predicted trajectory

14:45–15:45	WeInteractive2_3.21

Deep Episodic Memory for Verbalization of Robot Experience

Leonard Bärmann, Fabian Peller-Konrad, Stefan Constantin, Tamim Asfour, Alex Waibel
IAR, Karlsruhe Institute of Technology, Germany

- Humanoid robot collects daily household experiences in episodic memory (EM)
- User asks question (natural language text) about the robot's past
- Deep verbalization model processes question w.r.t. latent EM to give natural language answer appropriately
- Externalization of EM to improve human robot interaction: usability, transparency, trust, failure communication



Learning & AI

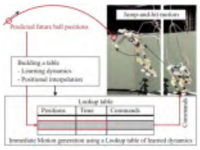
Chair *Dongheui Lee, Technical University of Munich*
Co-Chair *Arash Ajoudani, Istituto Italiano di Tecnologia*

16:00–16:15 WeOral5_3.1

Immediate generation of jump-and-hit motions by a pneumatic humanoid robot using a lookup table of learned dynamics

Kazutoshi Tanaka, Satoshi Nishikawa, Ryuma Niiyama, and Yasuo Kuniyoshi
The Graduate School of Information Science and Technology, Mechano-informatics, The University of Tokyo, Japan

- Our proposed method immediately generates the jump-and-hit motion of a pneumatic humanoid robot.
- The method uses a lookup table of learned dynamics.
- To test this method, we developed a humanoid robot called “Liberobot”.
- The robot jumped and hit the flying ball in the experiment.



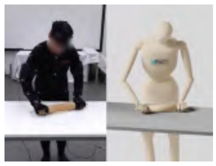
A pneumatic humanoid robot immediately generates and executes the jump-and-hit motion.

16:15–16:30 WeOral5_3.2

The KIT Bimanual Manipulation Dataset

Franziska Krebs*, André Meixner*, Isabel Patzer & Tamim Asfour
Institute for Anthropomatics and Robotics
Karlsruhe Institute of Technology, Germany

- Multi-modal dataset of bimanual manipulation (marker-based motion capture, data gloves, IMUs, egocentric RGB and RGB-D)
- 12 bimanual daily household actions with a large number of intra-action variations recorded for 2 subjects
- Individual segmentation and action annotation for each hand
- Unified representation in the format of the Master Motor Map (MMM)



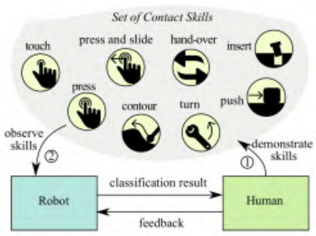
Motion capture recording mapped to MMM reference model

16:30–16:45 WeOral5_3.3

Identification of Common Force-based Robot Skills from the Human and Robot Perspective

Thomas Eiband[1] and Dongheui Lee[2]
German Aerospace Center (DLR), Institute of Robotics and Mechatronics, Germany
Technical University of Munich, Chair of Human-centered Assistive Robotics, Germany

- Human perspective: studies prove that skill set is interpretable
- Robot perspective: use motion and force data from human demonstration to recognize contact skills
- Comparison of human and robot classification results

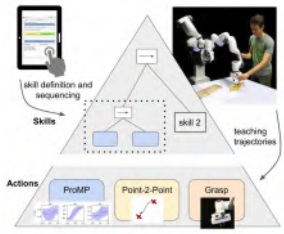


16:45–17:00 WeOral5_3.4

Guided Robot Skill Learning: A User-Study on Learning Probabilistic Movement Primitives with Non-Experts

Moritz Knaust [1,2] and Dorothea Koert [2,3]
[1] Control Methods and Robotics, TU Darmstadt, Germany
[2] Intelligent Autonomous Systems, TU Darmstadt, Germany
[3] Center for Cognitive Science, TU Darmstadt, Germany

- We present a framework for Guided Robot Skill Learning of ProMP based tasks
- We combine ProMPs and basic motions in a hierarchical skill structure
- Learned skills are represented as sequential Behavior Trees
- Pilot Study for two robotic tasks on a bimanual humanoid robot with 10 inexperienced users



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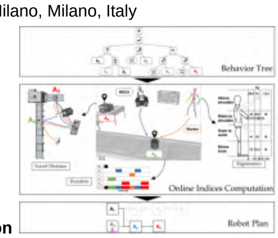
A Human-Aware Method to Plan Complex Cooperative and Autonomous Tasks using Behavior Trees

Fabio Fusaro[1,2], Edoardo Lamon[1], and Arash Ajoudani[1]
[1]Istituto Italiano di Tecnologia, Genova, Italy
Elena De Momi[2]
[2]DEIB, Politecnico di Milano, Milano, Italy

- Robot **online reactive planner** with optimal decision-making.
- Single **dynamical cost** associated to each action.
- Actions are executed in an order dependent to the cost.
- **Human decisions/intentions** are prioritized.
- Handles **H-R coexistence/cooperation** and **autonomous** task execution.



The reactive task planner selects online the new robot task according to the minimization of a cost.