RAAD 2025

BOOK OF ABSTRACTS

34th International Conference on Robotics in Alpe-Adria-Danube Region

18 - 20 June, 2025
Belgrade, Serbia

Organized by:
School of Electrical Engineering, University of Belgrade
Faculty of Technical Sciences, University of Novi Sad
Mihajlo Pupin Institute, Belgrade

UNIVERSITY OF BELGRADE
SCHOOL OF ELECTRICAL ENGINEERING

ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА НОВИ САД

institut MIHAJLO PUPIN

Preface

This book represents a collection of 78 papers selected from the 34th International Conference on Robotics in Alpe-Adria-Danube Region (RAAD 2025) held at the Palace of Science, Miodrag Kostić Endowment in Belgrade, Serbia. This volume encapsulates the cutting-edge research and innovative developments presented at RAAD 2025, continuing a proud tradition of fostering scientific exchange and collaboration in the field of robotics in the Alpe-Adria-Danube region, the rest of Europe and the world. The book is organized into several tracks, each represented as a chapter of the proceedings:

- Cognitive Intelligence in Industrial Robots and Manufacturing,
- Grasping and Manipulation,
- Compliant robot design,
- Medical and Assistive Robots,
- Design, Kinematics and Dynamics,
- Interoperable AI-Based Robotics for the Factory of the Future,
- Collaborative Robotics,
- Robot Sensing,
- Robots and Arts and
- Autonomous Robots.

For over three decades, the RAAD conference has served as a premier forum for researchers, academics, and industry professionals to share their latest findings, discuss emerging trends, and forge new partnerships. Our unique geographical focus on the Alpe-Adria-Danube region has consistently brought together diverse perspectives and expertise, contributing to a meeting for ideas exchange that pushes the boundaries of robotic science and application. We are particularly honored to have the following plenary speakers:

- Alin Albu Schäffer, Head of the Institute of Robotics and Mechatronics at the German Aerospace Center (DLR) and a professor at the Technical University of Munich.
- Arash Ajoudani, Italian Institute of Technology, Genoa, Italy
- Katja Mombaur, Karlsruhe Institute of Technology, Germany, and University of Waterloo, Canada

This year's conference was honored to feature keynote addresses by distinguished researchers of Serbian origin: Prof. Zoran Obradović from Temple University, USA, and Prof. Strahinja Došen from Aalborg University, Denmark. In addition, the conference hosts a special honorary session titled *"Robotics in the 'Fertile Crescent' of RAAD – Past and Future"*, celebrating influential contributors from the RAAD region. Esteemed speakers include Prof. Branislav Borovac (University of Novi Sad, Serbia), Prof. Giuseppe Carbone (University of Calabria, Italy), Prof. Jadran Lenarčič (Jožef Stefan Institute, Slovenia), and Prof. Imre Rudas and Prof. Péter

Galambos (Óbuda University, Hungary). Dr. Uwe Haass, a long-standing friend of the RAAD community, moderated the Honorary session.

This year's conference, RAAD 2025, has once again showcased the remarkable progress being made across many aspects of robotics. The papers contained within these proceedings cover a wide spectrum of topics, including but not limited to: human-robot interaction, mobile robotics, robot control, grasping and manipulation, perception and sensori-motor systems, industrial robotics, and AI in robotics. The quality and breadth of the submissions underscore the dynamic nature of our field and the dedication of the global robotics community.

This conference was proudly supported by scientific sponsors IFToMM and IEEE Computational Intelligence Society, along with generous contributions from our industry partners: Renex, ABB, Fanuc, KUKA, Festo, Robert Bosch, Yandex, Synapticon, and mBrainTrain.

We extend our sincere gratitude to all the authors for their invaluable contributions, the program committee members for their diligent reviews, and the organizing committee for their efforts in making RAAD 2025 a resounding success. We are particularly thankful to all the reviewers for ensuring the quality of work presented at RAAD 2025, and Springer for their continued partnership and commitment to disseminating high-quality scientific literature.

It is our hope that this volume will serve as a valuable resource for researchers and practitioners, inspiring new ideas, stimulating further research, and strengthening the collaborative spirit that defines the RAAD community. We invite you to look at the papers in the book and explore the exciting advancements that will affect and shape the future of robotics.

June 2025

Kosta Jovanović
Aleksandar Rodić
Mirko Raković

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	Wednesday, 18th June, 2025	Thursday, 19th June, 2025	Friday, 20th June, 2025
8:00	**Registration:** Central Hall (08:00-08:45)		
	Opening: Central Hall (08:45-09:00)	**Registration:** Central Hall (08:45-09:00)	**Registration:** Central Hall (08:45-09:00)
9:00	**Plenary session I: Arash Ajoudani** The AI continuum: From Human Monitoring to Autonomous Robots in Contact-Rich Applications Central Hall (09:00-10:00)	**Plenary session II: Alin Albu-Schäffer** Humanoid Robotics: A Hype or the Next Big Thing in AI? Central Hall (09:00-10:00)	**Plenary session III: Katja Mombaur** From Biology to Embodied AI: Shaping Humanoid Motion Through Optimization and Learning Central Hall (09:00-10:00)
10:00	**Coffee break** Ground floor exhibition area (10:00-10:30)	**Coffee break** Ground floor exhibition area (10:00-10:30)	**Coffee break and Palace of Science tour** (10:00-10:45)
	WS1.1: **Cognitive Intelligence in Industrial Robots and Manufacturing I** Room REČ, 4th floor (10:30-12:00) WS1.2: **Grasping and Manipulation** Room HORIZONT, 4th floor (10:30-12:00)	TS1.1 **Interoperable AI-Based Robotics for the Factory of the Future I** Room REČ, 4th floor (10:30-12:00) TS1.2 **Collaborative Robotics** Room HORIZONT, 4th floor (10:30-12:00)	
			FS1.1 **Robots and Arts** Room REČ, 4th floor (10:45-12:30) FS1.2 **Autonomous Robots** Room HORIZONT, 4th floor (10:45-12:30)
12:00	**Keynote session I: Zoran Obradović** Autonomous navigation for swarms of unmanned aerial vehicles in severe environments Room HORIZONT, 4th floor (12:00-12:30)	**Keynote session II: Strahinja Došen** New trends in the control of bionic limbs Room HORIZONT, 4th floor (12:00-12:30)	
	Meeting of RAAD ISC Ceremonial Hal, 1st floor (12:30-14:00) **Lunch break** Restoraunt, 5th floor (12:30-14:00)	**Lunch break** Restoraunt, 5th floor (12:30-13:30)	**Closing ceremony and lunch** Restoraunt, 5th floor (12:30-14:00)
		TS2.1 **Interoperable AI-Based Robotics for the Factory of the Future II** Room REČ, 4th floor (13:30-15:00) TS2.2 **Robot Sensing** Room HORIZONT, 4th floor (13:30-15:00)	
14:00	WS2.1 **Cognitive Intelligence in Industrial Robots and Manufacturing II** Room REČ, 4th floor (14:00-15:45) WS2.2 **Compliant robot design** Room HORIZONT, 4th floor (14:00-15:45)		
15:00		**Honorable speakers, Session:** **“Robotics in the “Fertile Crescent” of RAAD – Past and Future”** Moderator: **Uwe Haass** Room HORIZONT, 4th floor (15:00-16:30)	
	Coffee break Ground floor exhibition area (15:45-16:30)		
	Sponsor keynote session: **Renex** Cobots in Action: Vision to See. AI to Judge. Techman and Renex to Deliver. Room HORIZONT, 4th floor (16:30-17:00)	**Coffee break** Ground floor exhibition area (16:30-17:30)	
17:00	WS3.1 **Medical and Assistive Robots** Room REČ, 4th floor (17:00-18:45) WS3.2 **Design, Kinematics and Dynamics** Room HORIZONT, 4th floor (17:00-18:45)		
		City tour and visit to Museum of Science and Technology (17:30-20:15)	
	Break (18:45-19:30)		
	Welcome reception: **Beli dvor (White Palace)** (19:30-22:00)		
		Gala dinner: Restaurant Ambar (20:15-23:00)	
22:00			

BOOK OF ABSTRACTS

Plenary session I

Wednesday, 18th of June 2025 Central Hall 09:00-10:00

Chair: **Mirko Raković**

The AI continuum: From Human Monitoring to Autonomous Robots in Contact-Rich Applications

Arash Ajoudani

This talk explores the evolving landscape of applied machine learning across the continuum of human-robot interaction, with a focus on contact-rich environments. Starting from human monitoring for cognitive and physical states, the presentation will highlight how adaptive AI systems can personalize robot behavior to individual needs, enhance safety, and improve collaboration. It will then transition to fully autonomous robotic systems capable of handling complex manipulation tasks in unstructured settings. Through insights from recent research in human-in-the-loop learning, adaptive control, and foundational models, the talk will outline the path toward resilient, intelligent, and context-aware robots that can seamlessly integrate into both industrial and assistive scenarios.

Cognitive Intelligence in Industrial Robots and Manufacturing I

Wednesday, 18th of June 2025 Room REČ 10:30-12:00

Chair: **Zoran Miljković**; Co-chair: **Bojan Nemec**

Towards Using Natural Language to Perform Robotic Tasks

Bojan Nemec, Mihael Simonič, Boris Kuster, Leon Žlajpah, and Aleš Ude

This study explores automating robot programming using human-readable instructions, integrating textual and visual inputs. We present a framework combining a Visual Language Model (VLM), a vision processing model, and an adaptive skill library based on compliant control. The VLM converts textual instructions into executable commands linked to the skill library, while the vision model identifies and localizes referenced objects. This approach removes the need for additional training, enabling robots to execute tasks directly from natural language directives. Our method was evaluated using an internet-connected benchmarking device. It aims to streamline robot programming and enhance natural language communication in industrial and everyday settings.

Implementing IoT Technology on Mobile Platform: Edge-Cloud Integration and Data Handling

Jakub Krejčí, Marek Babiuch, Rostislav Wierbica, and Vaclav Krys

This paper examines the integration of IoT technology on mobile platforms, emphasizing edge-cloud collaboration and data management. Modern robots rely on advanced sensors and cameras to generate critical data for operation in dynamic environments. Efficient data collection, processing, and transmission to cloud platforms are key to optimizing performance. The paper highlights systems using depth cameras and wireless protocols like MQTT for reliable, low-latency communication with minimal data loss. Edge devices handle preprocessing, such as noise filtering and compression, to improve transmission. In the cloud, automated workflows store, analyze, and provide real-time insights, enhancing performance and enabling deployment in industrial and service applications.

Vision-based Robot System for Object Manipulation

Bogdan Momčilović, Nikola Slavković, Milica Petrović, and Zoran Miljković

The paper presents a robotic system for object manipulation based on information obtained from a camera. The developed system enables the differentiation of four classes of objects with regular geometric shapes. To achieve that, a semantic segmentation model was trained using a set of images of objects in different positions. An algorithm for objects' position and orientation determination was developed so objects can be placed in arbitrary positions and orientations within the camera's field of view. The developed algorithms ensure the necessary information for automatic robot programming for moving the objects to desired poses. To prove the proposed concept on the 4-axis SCARA robot equipped with a vacuum gripper for object grasping, a camera calibration procedure was performed and necessary coordinate transformations were obtained. The verification of the developed system was conducted through several experiments. The experiments showed good reliability of the trained model for objects' classification and accurate positioning of the robot end-effector above the objects.

A General Peg-in-Hole Assembly Policy Based on Domain Randomized Reinforcement Learning

Xinyu Liu, Aljaz Kramberger, and Leon Bodenhagen

Generalization is important for peg-in-hole assembly, a fundamental industrial operation, to adapt to dynamic industrial scenarios and enhance manufacturing efficiency. While prior work has enhanced generalization ability for pose variations, spatial generalization to six degrees of freedom (6-DOF) is less researched, limiting application in real-world scenarios. This paper addresses this limitation by developing a general policy GenPiH using Proximal Policy Optimization(PPO) and dynamic simulation with domain randomization. The policy learning experiment demonstrates the policy's generalization ability with nearly 100% success insertion across over eight thousand unique hole poses in parallel environments, and sim-to-real validation on a UR10e robot confirms the policy's performance through direct trajectory execution without task-specific tuning.

Concept of a reconfigurable CNC machine with distributed control

Dusan Nedeljkovic, Zivana Jakovljevic, Lazar Matijasevic, and Miroslav Pajic

The emergence of Industry 4.0 has changed manufacturing by integrating advanced digital technologies, enabling extensive real-time interconnection between information technologies and operational technologies within Industrial Control Systems. This ubiquitous information exchange enables manufacturing systems to operate flexibly and respond quickly to changing market demands and a growing diversity of products. The reconfiguration of manufacturing systems, both physical and functional, is driven by the Industrial Internet of Things, which employ Cyber-Physical Systems as its core enabling technology. This transition initiates a shift from centralized control systems, where a single central unit manages all control tasks, to a distributed control system architecture. Within a distributed control system, the main control task is achieved through the intensive cooperation of smart devices, such as sensors and actuators, equipped with computation and communication modules. In this work, we present a concept of a Computerized Numerical Control (CNC) system with distributed control, based on the cooperation of Low-Level Controllers, which execute local tasks while receiving primary control commands from a High-Level Controller. The proposed approach considers both functional and physical properties to ensure system reconfigurability and scalability.

A Cognitive Robotics Approach for Manipulation of Freeform Objects Using CNN-based Perception and Soft Gripping

Nikola Ivačko, Ivan Ćirić, Dušan Stojiljković, Žarko Ćojbašić, and Dušan Jevtić

This paper presents a cognitive robotic system for detecting, classifying, and grasping elongated and deformable objects, such as bananas, carrots, and other produce, which requires precise gripper alignment and orientation. The system integrates deep learning-based object detection using CNNs for real-world positioning and pose estimation to enable adaptive grasping. A 5-DOF robotic arm equipped with a soft-gripping end effector is employed to execute grasping tasks, ensuring gentle handling while minimizing damage. The vision system detects objects, determines their spatial coordinates, and computes an optimal grasping pose based on object shape and orientation. The proposed method leverages real-time image segmentation and contour analysis to assess the gripping width, while an orientation-aware approach enhances grasp stability. The results demonstrate the effectiveness of combining cognitive perception and soft robotics for handling delicate and non-rigid objects in real-world agricultural and industrial applications, improving efficiency and reducing manual intervention.

Grasping and Manipulation

Wednesday, 18th of June 2025 Room HORIZONT 10:30-12:00

Chair: **Giuseppe Quaglia;** Co-chair: **Leon Žlajpah**

RobotBlockSet (RBS) - Path and Trajectory Generation

Leon Žlajpah and Tadej Petrič

This paper presents path and trajectory generation tools within the RobotBlockSet (RBS) framework, emphasizing efficient robotic motion planning and execution. The methods enable the generation of smooth paths in joint and Cartesian spaces, considering motion constraints like velocity and acceleration limits. The framework also supports advanced trajectory parameterization techniques, including interpolation, time-optimal parameterization, and obstacle avoidance. A case study on a redundant manipulator highlights the practical application of these tools, demonstrating their ability to generate safe and optimal motion paths in complex environments.

Robot Path and Trajectory Planning Considering a Spatially Fixed TCP

Bernhard Rameder, Hubert Gattringer, Andreas Mülller, and Ronald Naderer

This paper presents a method for planning a trajectory in workspace coordinates using a spatially fixed tool center point (TCP), while taking into account the processing path on a part. This approach is beneficial if it is easier to move the part rather than moving the tool. Whether a mathematical description that defines the shape to be processed or single points from a design program are used, the robot path is finally represented using B-splines. The use of splines enables the path to be continuous with a desired degree, which finally leads to a smooth robot trajectory. While calculating the robot trajectory through prescribed orientation, additionally a given velocity at the TCP has to be considered. The procedure was validated on a real system using an industrial robot moving an arbitrary defined part.

Robot Learning to Catch Objects in Flight using an LSTM Deep Neural Network

Lazar Milić, Jefimija Borojević, Tanja Berisavljević, Srđan Savić, and Mirko Raković

The paper outlines the integration of a motion-tracking system and robotic arm to intercept and catch an object thrown by a human. The objective is to achieve a precise position for the robot before the ball enters it's workspace. Predicting the trajectory of the thrown object is an essential task. Information on the object's motion during the early stage of flight is obtained from the motion-tracking system. Trajectory estimation uses two methods: an analytical equation for an oblique projectile and a trained deep neural network for time-series data prediction. The software implementation of this solution has been tested in real-world conditions, and results show that the proposed pipeline is able to catch the ball in flight.

Sensor-Based Contact Point Estimation for Extended Robotic Structures

Jan Šifrer and Tadej Petrič

This paper presents a method for estimating contact points on an extended robotic structure using only the built-in sensors of the Franka Emika Panda robot. The proposed approach combines a Kalman filter to mitigate sensor noise and a two-step optimization strategy, using global and local methods, to accurately determine contact positions. Experimental validation in both static and dynamic scenarios confirms the method's accuracy, even in noisy conditions. By eliminating the need for additional external sensors, this method provides a cost-effective solution for collaborative robotics.

LSTM-based hand motion recognition for myoelectric control of a compliant robot gripper

Gorana Milovanović, Goran Kvaščev, and Kosta Jovanović

The stiffness of a hand joint is correlated to the co-contraction of the agonist and antagonist muscles surrounding the joint. First step towards using co-contraction and other hand motions for a control command of a robot or prosthesis is to reliably recognize and distinguish them. In this paper we implement, train and validate five Recurrent Neural Network (RNN) models using Long-Short Term Memory (LSTM) layers to develop a high-quality classifier of three hand gestures: flexion, extension and co-contraction intended to command closing, opening and stiffness modulation of the robot, respectively. 16-channel surface electromyography (sEMG) signals were recorded using a MaxSens system to form three datasets, two of which contain the downsampled data of the third, original dataset. The performance of the models was similar and sufficiently high while using all three datasets: F1-score values were over 98 %. However, the model containing three LSTM and three fully connected layers stood out from the others for its inference time and training stability. The best-performing candidate was further tested with a reduced number of EMG channels and reached F1-score equal to 94.31 % for the original dataset, 89.71 % and 93.68 % for two downsampled datasets when 2 EMG channels were used.

Soft Pneumatic Sensing Chambers for Robotic Grasping

Simone Duretto, Giovanni Colucci, Andrea Botta, Luigi Tagliavini, Mohammad Jabari, Lorenzo Baglieri, Lorenzo Toccaceli, Francesco Amodio, and Giuseppe Quaglia

This work presents the concept and prototyping of a tactile sensing system to enhance robots' exteroception. The proposed solution comprises soft tactile sensing elements, which are 3D-printed as monolithic structures. With a geometry inspired by human fingertips, these elements can sense contact both on the fingertip pulp and on the distal free edge, and Force Sensitive Resistors are integrated under their surface. Thus, this system mimics the human sense of touch, providing localized and global information on contact, and it can adjust its stiffness to grasp objects of different nature. Finally, preliminary results showing the system capabilities are presented.

Keynote session I

Wednesday, 18th of June 2025 Room HORIZONT 12:00-12:30

Chair: **Maja Trumić**

Autonomous navigation for swarms of unmanned aerial vehicles in severe environments

Zoran Obradović

This presentation will discuss our constrained machine learning based approach for swarm of unmanned aerial vehicles (UAVs) path planning and obstacle avoidance. Using 3D LiDAR and intra swarm communication, this model allows zero-shot learning which optimizes swarm of UAVs flying time without extensive training. A comparative analysis highlights the model's advantages for path optimization, collision avoidance, and time efficiency in severe environments. In addition, to facilitate navigation where GPS signal is disrupted, our reliable and cost-effective method will be described to infer the positions of drones based on information extracted from aerial images taken during flight using the drones' onboard cameras.

Cognitive Intelligence in Industrial Robots and Manufacturing II

Wednesday, 18th of June 2025 Room REČ 14:00-15:45

Chair: **Milica Petrović;** Co-chair: **Žarko Ćojbašić**

Neural Network-based Visual Servoing of Wheeled Mobile Robot with Fish- eye Camera

Aleksandar Jokić, Milica Petrović and Zoran Miljković

In the era of rapid technological invitation, artificial intelligence techniques have become a driving force in the evolution of various fields, and the robotics domain is no exception. One of the areas where AI has proven to be especially influential is in robotics vision, where machine learning algorithms, particularly artificial neural networks, are revolutionizing how robots perceive and interact with their environment. Therefore, in this paper, we examine the use of artificial neural networks in the context of mobile robot visual servoing. Differential drive mobile robot RAICO equipped with a fish-eye lens camera is utilized. The fish-eye lenses have a significant advantage regarding their wide-angle field of view; however, they also introduce significant optical distortions that can affect the accuracy of the robot's perception and, therefore, 3D pose estimation, which is paramount for visual servoing. Position-based visual servoing based on the ArUco marker is employed within the 3-step switching mobile robot controller. Given the pose estimation errors inherited by distortions in the fish-eye lens, the accuracy of pose estimation is enhanced by utilizing neural networks. The experimental results show a high level of final pose accuracy achieved by RAICO with the proposed control algorithm.

Deep Learning for Visual Inspection of Ball Bearings

Tea Tepavčević, Saša Lazović, and Vladimir M. Petrović

Extensive research in the field of artificial intelligence (AI) over the years has enabled advancements in versatile industry applications, including automated visual inspection, which represents an essential aspect of modern automation and manufacturing processes. This study demonstrates the use of deep learning for visual inspection and damage detection of ball bearings. We applied two deep learning techniques for detecting defects in bearings: classification based on Convolutional Neural Networks (CNN) and defect localization based on the You Only Look Once (YOLO) algorithm. We used the bearing dataset for defect localization obtained from Roboflow to train and evaluate three CNN models, including ResNet50, for classification. While these models achieved high accuracy, with ResNet50 reaching 99%, they lacked the ability to localize defects. In contrast, we trained YOLOv5 and YOLOv8 models for real-time defect detection and localization, with YOLOv5s providing the best test mAP@0.5 score of 86.1%, with efficient computation. Our study demonstrated that while CNN models had performed excellently in classification tasks, YOLO models provided the best balance between accurate detection and real-time localization, making them suitable for automated visual inspection in modern computer-integrated manufacturing (CIM) systems.

Assessing the Feasibility of Deep Lagrangian Networks for Industrial-Level Control of a Parallel Kinematic Manipulator

Marcel Lahoud, Daniel Gnad, Gabriele Marchello, Ferdinando Cannella, and Andreas Müller

Model-based control is crucial for efficient robotic operations, yet accurately identifying robot dynamics remains challenging, particularly for parallel kinematic manipulators (PKMs). This work leverages physics-informed neural networks (PINNs), specifically the Deep Lagrangian Network in combination with non-symmetric Coulomb friction, to achieve physically consistent dynamics models by incorporating principles such as energy conservation and friction modeling. Validated on the ABB IRB 360-6/1600 Delta robot, the approach demonstrates high fidelity in torque prediction and effective real-time control implementation on industrial hardware under stringent computational constraints. Experimental results highlight improved torque prediction accuracy, reduced trajectory tracking lag, and robust handling of complex dynamic interactions, paving the way for adaptive and efficient industrial automation.

Danger of AI in Robotics: A Systematic Analysis of Ethical, Regulatory, and Economic Challenges

Jacob Otasowie, Alexander Blum, Mohamed El Sayed Ahmed, and Mathias Brandstötter

As AI-driven robotics increasingly integrate into the physical world, they bring both transformative opportunities and significant risks. The greater the level of autonomous intervention, the more complex safety concerns, regulatory challenges, and ethical dilemmas become. As a result. regulations are becoming more stringent, such as the AI Act, especially in high-risk domains like healthcare, autonomous robotics, and industrial automation. However, the intensity of the regulatory process will also depend on broader ethical and societal impacts, not just physical interaction. This paper provides a critical integrative review of ethical, security, and societal implications of AI in robotics and assesses how emerging regulations attempt to address these concerns. It illustrates how the development, deployment, and governance of AI-supported robotic systems are being shaped by evolving regulations and societal expectations.

Evolutionary Approach to Time-Limited Profit-based Traveling Salesman Problem in Mobile Robotics

Jelena Ćurčić, Željko Kanović, Milutin Nikolić, and Srđan Savić

The paper presents evolutionary approach, based on genetic algorithm, to solving a variation of the traveling salesman problem in mobile robotics. It is a modified version of time-constrained profit-based traveling salesman problem with additional constraint on the volume capacity of the traveling agent. The research was motivated by the problem of optimal strategy synthesis for autonomous mobile robot for competition in mobile robotics Eurobot 2024. However, the addressed problem is general enough to cover the wide spectrum of applications in different domains, including package collecting/delivery or field sample collecting for laboratory analysis. The addressed problem is global combinatorial optimization problem and due to its NP-hard complexity and multiple imposed constraints, we have solved it using genetic algorithm. We have particularly investigated the process of initial population engineering, i.e. the influence of the amount of hand-coded domain-related knowledge to the convergence of the algorithm.

Intelligent Sensor Integration in Robotic Systems for High-Precision Automation in the Automotive Industry

Pavle Stepanić, Predrag Nikolić, Nedeljko Dučić, Nebojša Mitrović, and Žarko Ćojbašić

The networking of production systems and the communication between production processes, machines, and personnel across various industries is being elevated to a significantly higher level. This advancement leads to the optimization of production processes and raises the overall industry standard. As data exchange and analysis play a pivotal role in optimizing and enhancing system productivity, the reliability and accuracy of the collected information are equally important. This paper presents an example of the successful integration of intelligent sensor systems with robotic solutions for the assembly of specific components in the automotive industry. By using smart sensors and actuators and their networking, parts are assembled more precisely and the possibility of errors is reduced to a minimum.

Enhancing Safe Navigation in Industrial Environments via Vision-Language Human-Robot Interaction

Sepideh Valiollahi, Chen Li, Emil Frydenholm, Jonas Thorhauge-Hansen, San Sami Hanona, Yacine Abdelsadok, Shahab Heshmati-Alamdari, Stefan Nordborg Eriksen, and Preben E. Mogensen

Safe and efficient mobile robot navigation remains a critical challenge in industrial environments, particularly in the presence of humans, whose movements are inherently unpredictable. To address this, we propose an AI-driven human-robot interaction (HRI) framework that integrates vision-language models (VLMs) and large language models (LLMs) to enhance navigation safety. Implemented in NVIDIA Isaac Sim, our system detects humans, enforces a minimum safe distance of 1 m, signals for attention, and awaits instructions before proceeding. If instructed to continue, the robot resumes movement at a reduced speed of 0.6 m/s. Experimental results demonstrate 85.7% human detection accuracy, 93% gesture recognition accuracy, and a recorded minimum distance of 0.93 m from humans. By enabling natural communication through vision and language, the system enhances robot adaptability and accessibility, facilitating seamless human interaction without requiring technical expertise. These findings underscore the potential of AI-driven navigation for safer and more collaborative industrial environments. The code used in this study is available open-source at GitHub Repository.

Compliant robot design:

Wednesday, 18th of June 2025 Room HORIZONT 14:00-15:45

Chair: **Tadej Petrič;** Co-chair: **Maja Trumić**

Velocity-Level Kinematics of a Continuously Variable Transmission System for pHRI

Emir Mobedi, and Mehmet İsmet Can Dede

New generation robots pave the way for physical human-robot interaction (pHRI) through improvements in control and design techniques. While the former is achieved with the help of a number of sensory information, variable stiffness actuators (VSA) are exploited for the design of these robots to achieve inherent compliance. Recently, continuously variable transmission-based VSA has been developed to be used for pHRI, specifically for haptics. The fundamental characteristic of this new CVT mechanism is that it regulates output position and torque independently via the sphere transmission element. In this study, velocity-level kinematics of this new CVT system is carried out to demonstrate its step-less speed variation feature. Moreover, simulations are conducted in ADAMS and Solidworks software packages at 8 transmission points selected unequally. Results show that the average value of overall ADAMS and Solidworks errors computed with respect to the computed velocity are reported as 1.09 %, and 0.53 %, respectively.

Design and Kinematics of Cable-driven Underactuated Manipulators with Variable Stiffness Devices

Qizhi Meng, Ruijie Tang, Xin-Jun Liu, and Andres Kecskemethy

Cable-driven underactuated manipulators (CDUMs) have garnered increasing attention due to their characteristics of slender structures, high flexibility, and potential for miniaturization as well as modularity. To further improve the efficiency and reliability of CDUMs, additional efforts are needed to enhance the speed and amplitude of their stiffness variation. This paper presents two CDUMs, which are characterized by variable stiffness devices that utilize the principle of force amplification near the dead point position of the crank slider mechanism, along with a double-direction threading strategy. These CDUMs are expected to exhibit rapid and dramatic stiffness variation, as well as efficient and reliable actuation when working in conjunction with the proposed driving strategies. Kinematic analysis is conducted to further understand the mapping relationship between the cable lengths and the configurations of the proposed CDUMs.

Open-source Design of Hardware and Software for a Modular Testbed for Highly-elastic Tendon-driven Soft Robots

Miloš Rašić, Cosimo Della Santina, Kosta Jovanović, and Maja Trumić

Soft robotics integrates engineering, materials science, and biology to tackle challenges that conventional robotics cannot solve. Alongside the advancements in soft robot technology, there is also a need for a standardized hardware platform that can enable benchmarking of various control methods developed for soft-bodied robots. This paper contributes to the state-of-the-art by designing a modular testbed that features a tendon-driven soft-bodied robot with integrated closed-loop force control.

Requirements and design problems for a new LARMbot humanoid from testing a prototype

Chloé Gabarren, Marco Ceccarelli, and Matteo Russo

The LARMbot is a low-cost user-oriented humanoid robot developed by the LARM2 laboratory in University of Rome Tor Vergata. This paper aims to propose a new conceptual design for the assembly of the LARMbot v3 after considering lab experiences with its components. Laboratory experiments of two subsystems of the LARMbot v2 are reported, namely arms for manipulation and torso for payload. New requirements and design problems are then identified and discussed to propose a new conceptual design for the LARMbot v3 with improved features, adopting a parallel architecture for the arm to replace the original serial mechanisms and to improve the payload and precision of the humanoid.

A Review of Some Mechanical Metamaterials for Building Robotic Devices and Sensors

Jaroslav Hricko and Stefan Havlik

Advanced technologies allow the creation of new artificial construction materials with very specific properties, according to given functional requirements. The paper briefly reviews the development of such mechanical metamaterials and shows some principal configurations of internal mechanical structures. Considering these materials presents a fundamentally new approach to the design of various robotic devices with new functionalities/properties. Applying this new technology provides the possibility to achieve compliant mechanisms/mechanical parts with specific flexural characteristics, or sensors with sensory elements directly integrated into the material structure. The examples of using these metamaterials in the construction of some robotic devices are briefly discussed.

robotblockset_python: Python version of the RobotBlockSet *

Mihael Simonič, Boris Kuster, Matija Mavsar, Peter Nimac, and Leon Žlajpah

This paper presents a Python-based reimplementation of the RobotBlockSet, originally developed as a MATLAB toolbox. The library provides a unified solution for rapid prototyping of complex robotic applications. It adopts a modular approach to enable extensibility, offering interfaces for various robot manipulators, control strategies, sensors, and peripheral devices. The main advantage of the toolbox are consistent high-level commands, ensuring smooth transitions between different robotic platforms, both in simulation and real-world.

Optimal Control for Human Vertical Jump Motion

David Mesaroš, Maxime Sabbah, Vincent Bonnet, and Filip Bečanović

This paper explores an optimal control framework for simulating casual human vertical jumps, emphasizing relaxed, low-effort motion. We propose a whole-body motion planning model with realistic contact constraints and a compound objective function that balances achieving sufficient vertical center-of-mass velocity at take-off with minimizing energy expenditure. The framework integrates inverse dynamics and trajectory optimization under physiological constraints. Preliminary comparisons with experimental data show qualitative agreement (CC $\approx$ 0.88 for joint trajectories) in the counter-movement phase and joint kinematics, though quantitative mismatches persist (RMSE $\approx 20^\circ$ for joint trajectories). Future work will refine objective function weights using inverse optimal control to better align simulations with human data.

Medical and Assistive Robots:

Wednesday, 18th of June 2025 Room REČ 17:00-18:45

Chair: **Doina Pisla**; Co-chair: **Daniela Tarnita**

Virtual modeling, static and dynamic analyses of an orthotic device used for human elbow rehabilitation

Cristian E. Chihaia, Daniela Tarnita, Ionut Geonea, and Danut N. Tarnita

This study depicts the use of a three-dimensional virtual modeling approach to create a representation of a physical orthosis commonly utilized in the clinical rehabilitation of the elbow joint. A finite element analysis (FEA) was conducted, involving static and dynamic analysis. A comprehensive understanding of orthosis stiffness, coupled with the ability to regulate it both statically and dynamically, holds considerable promise in the treatment of elbow diseases. A data acquisition system (Biometrics Ltd.) was employed to record elbow flexion-extension and rotation angles before and after a rehabilitation program for a patient suffering from arthritis disease. The findings from this research show that an elbow orthotic device designed for stability has a considerable impact.

Kinematic modelling and design of a parallel robot for wrist rehabilitation

Paul Tucan, Alin Horsia, Calin Vaida, Iosif Birlescu, Pisla Adrian, Jose Machado, and Doina Pisla

The paper presents the kinematic modelling of a 2 Degrees of Freedom (DOF) parallel robot for wrist rehabilitation. The parallel robot is capable of performing flexion-extension and radial-ulnar deviation of the wrist. The device can be used both for left and right wrist rehabilitation without requiring prolonged setup times. The current paper describes the kinematic modelling of the robot, workspaces and singularities followed by model validation using numerical and graphical simulation, providing a comprehensive overview of its capabilities and effectiveness in facilitating wrist rehabilitation.

Descriptive Ontology for Home-Based Smart Rehabilitation Environments for Motor and Cognitive Therapy in Patients with Neurological Disorders

Fabio Zanoletti and Alberto Borboni

Home-based rehabilitation provides accessible motor and cognitive therapy for individuals with neurological conditions outside clinical settings. Although traditional rehabilitation environments, such as hospitals and clinical centers, follow established design standards, the transition of rehabilitation to home settings needs to be analyzed. Currently, home environments for rehabilitation lack structured guidelines for integrating rehabilitation and assistive technologies. This study addresses this gap by analyzing existing literature to define the key elements of home rehabilitation environments. By proposing an ontological framework, validated through brainstorming sessions with medical experts, the study categorizes agents, norms, and material conditions that are involved in home-based rehabilitation. This ontology, alongside the involvement of stakeholders – such as clinicians, engineers and designers – could serve as a foundation for standardizing home rehabilitation environment design and the integrating new technologies into home settings.

Functional Design and Kinematic Analysis of a Novel 3RS End-Effector Robot for Wrist Rehabilitation and Assistance

Andrea Botta, Luigi Tagliavini, Giovanni Colucci, Lorenzo Baglieri, Simone Duretto, Lorenzo Toccaceli, Francesco Amodio, and Giuseppe Quaglia

Robot-aided rehabilitation is increasingly important to meet the challenges posed by an ageing population and a global shortage of healthcare workers. This paper presents a 3RS (3 Revolute Joints – 1 Spherical Joint) end-effector robot for wrist joint rehabilitation and daily activity assistance. It assists flexion/extension and radial/ulnar deviation avoiding the problem of joint misalignment typical of exoskeletons and covering the workspace of the hand. The design parameters are tuned to ensure high dexterity and safe user interaction, laying a solid foundation for the development of a functional prototype.

Evaluation of facial landmark localization performance in a surgical setting

Ines Frajtag, Marko Švaco, and Filip Šuligoj

The use of robotics, computer vision, and their applications is becoming increasingly widespread in various fields, including medicine. Many face detection algorithms have found applications in neurosurgery, ophthalmology, and plastic surgery. A common challenge in using these algorithms is variable lighting conditions and the flexibility of detection positions to identify and precisely localize patients. The proposed experiment tests the MediaPipe algorithm for detecting facial landmarks in a controlled setting, using a robotic arm that automatically adjusts positions while the surgical light and the phantom remain in a fixed position. The results of this study demonstrate that the improved accuracy of facial landmark detection under surgical lighting significantly enhances the detection performance at larger yaw and pitch angles. The increase in standard deviation/dispersion occurs due to imprecise detection of selected facial landmarks. This analysis allows for a discussion on the potential integration of the MediaPipe algorithm into medical procedures.

Development of an Optimal Prototype of an Exoskeleton Robotic System for Locomotor Rehabilitation

Ionut Geonea, Nicolae Dumitru, and Daniela Tarnita

This paper presents research on the development of a robotic exoskeleton system for human lower limb rehabilitation. In the first stage, an innovative structural solution for the exoskeleton leg is developed, based on a pantographic kinematic chain. A virtual prototype of the exoskeleton robotic system intended for rehabilitation is designed for use by a human subject with a height of 1.70 m. Based on the virtual model, a kinematic simulation is initially performed, followed by a dynamic simulation, in which the exoskeleton performs stepping movements on the ground using ADAMS software for multibody system analysis. Since the physical prototype is produced using rapid prototyping, a structural optimization of all kinematic elements in the robot’s structure has been carried out. For this purpose, finite element method (FEM)-based structural optimization was applied to achieve an optimal design, ensuring minimum mass and adequate stiffness of the kinematic elements. In future studies, the developed prototype will undergo experimental testing.

An Intelligent Optimized Reduced Model of the Musculoskeletal System for the Head-Neck Joints

Ismail Raslan, Mohammad A. Jaradat, and Lotfi Romdhane

A novel approach utilizing Genetic Algorithms (GAs) is introduced for the reduction of musculoskeletal (MSK) model complexity. Through this optimization technique, the effectiveness of GAs in streamlining model representations while preserving essential dynamics, is demonstrated. Using this technique, a reduced model using 15 pairs of muscles was shown to yield similar results to those obtained using the full model of 36 muscle-pairs (or 72 muscles) in the HYOID model.

Design, Kinematics and Dynamics:

Wednesday, 18th of June 2025 Room HORIZONT 17:00-18:45

Chair: **Andreas Müller;** Co-chair: **Giuseppe Carbone**

Design Exploration of Planar Continuum Parallel Robots with Constrained Platform Orientation

Congjian Gao, Quentin Peyron, and Sébastien Briot

Continuum parallel robots are a new class of parallel robots in which the end-effector is moved by controlling the deformations of their flexible legs. In general, all degrees of freedom of the robot platform are coupled, leading to the necessity to have the same number of motors as the number of degrees of freedom offered by the space of displacements. Recent works showed that it is possible to design continuum parallel robots such that the orientation of their platform is constrained to be constant. Planar designs able to obtain this interesting performance are made with the use of flexible parallelograms. However, a single design has been studied which presents legs' overlap. There is a lack of a deeper study of the other possible designs able to obtain the same types of mobilities while being more practical to build. In the present paper, we thus explore how different platform shapes influence the angular deviations of the platform as well as the robot's workspace.

Dynamic Analysis of a 5-DOF Parallel-Serial Manipulator Using Kane's Method

Anton Antonov

The article analyzes the dynamics of a five-degree-of-freedom (5-DOF) parallel-serial manipulator with three translational and two rotational DOFs. The manipulator includes a 3-DOF 1-PU/2-PSS parallel and a 2-DOF PP serial mechanism (P, U, and S indicate prismatic, universal, and spherical joints), where all prismatic joints are actuated. Following Kane's method, we derive the manipulator dynamic model, considering the dynamics of both serial and parallel mechanisms. The set of generalized speeds includes three speeds in active and two speeds in passive joints. To illustrate the developed techniques, we solve the inverse dynamic problem for a spiral-like end-effector trajectory.

Kinematic structure optimization of a modular planar 3DOF robotic manipulator for a given task

Rostislav Wierbica, Tomáš Kot, Jakub Krejčí, and Václav Krys

This paper focuses on optimizing the kinematic structure of a robotic manipulator for a given task. It is a planar manipulator with three degrees of freedom. The problem of designing the kinematic structure of the robotic manipulator, which is assumed to have a modular structure, is addressed. The aim is to find the optimal combination of the lengths of the individual segments that will allow the execution of the specified task. A Genetic Algorithm is used to find the optimal combination of lengths. Planning for collision-free paths is also part of the solution. The path must ensure that the manipulator completes the required task without collisions. The Rapidly exploring Random Tree (RRT) algorithm is used for path planning. Based on this path, the motion trajectory of each link of the manipulator is then designed and optimized. A hybrid optimization approach is used for trajectory planning, considering both time and jerk. The overall approach is directly linked to the concept of modular robots, where flexibility in the composition and adaptation of the kinematic structure play a crucial role in solving diverse tasks in robotics. This work presents a methodology for addressing these challenges through a systematic optimization approach.

Extended URDF: Accounting for parallel mechanism in robot description

Virgile Batto, Ludovic DeMatteïs, and Nicolas Mansard

Robotic designs played an important role in recent advances by providing powerful robots with complex mechanics. Many recent systems rely on parallel actuation to provide lighter limbs and allow more complex motion. However, these emerging architectures fall outside the scope of most used description formats, leading to difficulties when designing, storing, and sharing the models of these systems. This paper introduces an extension to the widely used Unified Robot Description Format (URDF) to support closed-loop kinematic structures. Our approach relies on augmenting URDF with minimal additional information to allow more efficient modeling of complex robotic systems while maintaining compatibility with existing design and simulation frameworks. This method sets the basic requirement for a description format to handle parallel mechanisms efficiently. We demonstrate the applicability of our approach by providing an open-source collection of parallel robots, along with tools for generating and parsing this extended description format. The proposed extension simplifies robot modeling, reduces redundancy, and improves usability for advanced robotic applications.

Kinematic Modeling of the End-Effector of a Plum-Picking Robot using the Rodrigues' Rotation Formula

Uroš Ilić, Mihailo Lazarević, Ilija Stevanović, and Aleksandar Rodić

This paper presents the kinematic analysis of a designed end-effector for a plum-picking robot. The study includes solving both the direct and inverse kinematics problems to determine the position and orientation of the gripper relative to the end-effector’s base. The kinematic analysis is performed using Rodrigues’ transformation formula, ensuring an accurate representation of rotational motion. All robot parameters are derived from the designed model in SolidWorks, providing a realistic basis for the mathematical model. In addition, a workspace analysis is performed to evaluate the reachability and

efficiency of the robotic system in the fruit picking process. The results obtained offer insight into the capabilities of the system and contribute to the optimization of robotic harvesting by ensuring precise motion control.

Robotic Gripper Mechanism for Plum Harvesting: Mechanical Design and Actuation

Ilija Stevanovic, Uroš Ilić, Aleksandar Milenkovic, and Aleksandar Rodić

This paper presents a customized mechanical design and kinematic analysis of the robotic gripper intended for automated plum harvesting. This paper presents a robotic solution that integrates a gimbal joint mechanism of a long-range telescopic robot arm with a cutting gripper mechanism to achieve this goal. The design avoids traditional scissor-like mechanisms and instead utilizes a parallel cutting system for enhanced precision and dual function in single operation, cutting and griping. The research focuses on kinematic analysis and design of the electromechanical fruit-picking system and transformation of rotational motion into two opposite linear motions required for efficient cutting and gripping. Additionally, the study includes complementary kinematic and dynamic analyses, as well as potential improvements for future novel applications.

The influence of wrist design on the inverse kinematics of a 6-axis robot

Boštjan Baras and Marko Munih

This paper investigates the influence of wrist design on the inverse kinematics of robots with 6 degrees of freedom (DOF), comparing roll-bend-twist (RBT) and bend-roll-twist (BRT). The analytical inverse kinematics were derived for both designs, focusing on the robot's working envelope and the avoidance of irregularities. Autodesk Inventor and Python were used to visualize and evaluate performance metrics, including workspace coverage and workspace flexibility. The manipulability parameters highlight the strengths of both wrists and show that neither wrist consistently outperforms the other.

Plenary session II

Thursday, 19th of June 2025 — Central Hall — 09:00-10:00

Chair: **Kosta Jovanović**

Humanoid Robotics: A Hype or the Next Big Thing in AI?

Alin Albu Schäffer

Robots are not only machines which are supposed to relieve humans from dangerous or routine work – they are also a scientific endeavour attempting to better understand human and animal motion and intelligence in a synthetizing way, by using the system analytic tools of engineering and computer science. As such, humanoid robots, be it on legs or on a wheeled mobile base, attracted a lot of attention and research effort in recent years. From mechatronics and control standpoint, humanoids became a quite mature technology during the last years, and still, the development in this field continues at a high pace of innovation. The convergence of these developments with rapidly evolving artificial intelligence techniques has created the foundation for a new generation of cognitive, adaptive, multi-purpose machines - commonly referred to as Physical AI or Embodied Intelligence, or AI-Powered Robotics. The exploding commercial interest in humanoids in the last two years underlines the huge potential of this technology.

Interoperable AI-Based Robotics for the Factory of the Future I

Thursday, 19th of June 2025 Room REČ 10:30-12:00

Chair: **Achim Wagner;** Co-chair: **Sotiris Makris**

A digital twin procedure for the design, simulation, and optimization of machine tending layout

Francesco Aggogeri and Nicola Pellegrini

This paper presents a structured design framework that aims to enhance the functionalities of robotized work cells in machine tending applications. The framework, developed through digital twin simulations in an educational context, addresses the increasing demand for off-line programming, reconfigurable workstations, and reduced installation time. The primary goal of this contribution is to disseminate the specific competencies in engineering students and technicians. The iterative methodology described in this approach enables the design of new systems or the adjustment of existing layouts to meet industrial demands and mitigate current constraints in a virtual environment.

Simulation-Based Evaluation of Adaptive Safety Zones for Human-Robot Interaction Driven by Deep Reinforcement Learning and LSTM

Mohammad-Ehsan Matour and Alexander Winkler

Ensuring safety in shared human-robot workspaces requires dynamic solutions to address unpredictable human behavior. Traditional fixed safety zones or reactive methods often fail to adapt in real time, leading to inefficiencies and risks. This paper proposes a framework that integrates deep reinforcement learning and long short-term memory-based trajectory prediction to dynamically manage safety zones. The system uses a laser scanner for intruder detection, deep reinforcement learning agents for adaptive zone management, and a long short-term memory network for motion prediction. By proactively adjusting safety margins and auxiliary points, the framework optimizes coverage while minimizing workspace restrictions. Simulations with a robotic arm and laser scanner validate the approach, showing improved safety, adaptability, and operational efficiency over conventional methods.

Sustainable Transfer Learning for Adaptive Robot Skills

Khalil Abuibaid, Vinit Hegiste, Nigora Gafur, Achim Wagner, and Martin Ruskwoski

Learning robot skills from scratch is often time-consuming, while reusing data promotes sustainability, and improves time efficiency. This study investigates policy transfer across different robotic platforms, focusing on peg-in-hole task using reinforcement learning (RL). Policy training is carried out on two different robots. Their policies are training from scratch, transferred and evaluated for zero-shot and fine-tuning. Results indicate that zero-shot transfer leads to lower success rates and relatively longer task execution times while fine-tuning significantly improves performance with fewer training time-steps.

These findings highlight that policy transfer with adaptation techniques improves training efficiency and generalization, reducing the need for extensive retraining and supporting sustainable robotic learning.

Digital Twin-Enabled Robotic Automation of Electrolyzer Assemblies for Power-to-X Solutions

Erik D. Lindby, Henrik G. Petersen and Aljaz Kramberger

This work presents a robotic assembly system designed to automate the manufacturing process of electrolyzers, particularly the stacking of internal components divided into a set of 207 identical repeated cycles. The system integrates a digital twin in NVIDIA Isaac Sim for motion validation and task execution, and a UR10e robot arm with a tool-exchange system to handle rigid and deformable components with specifically designed pneumatic suction- and magnet-based grippers. A cycle of the repeated assembly order was evaluated, demonstrating significantly reduced cycle times compared to manual assembly. However, tool-exchange delays highlighted limitations in real-word execution. Future work will focus on scaling the system for industrial deployment.

Optimizing Camera Placement in Agile Robotic Cells for Visual Inspection

Miha Deniša, Timotej Gašpar, Leon Žlajpah, and Aleš Ude

In modern manufacturing, agility and adaptability are crucial for meeting diverse production demands in high-mix, low-volume settings while ensuring quality. Visual inspection plays a vital role, with robotic inspection cells providing a scalable, automated solution. However, optimizing these systems remains challenging, particularly in minimizing inspection time while accommodating various workpiece geometries.

This research presents an agile robotic cell for visual inspection, where the input is a 3D model of the workpiece with predefined inspection poses. The system optimizes the placement of two cameras to minimize total inspection duration, defined as the time required for the robot to present all inspection points to at least one camera.

The inspection process is formulated as a state-space optimization problem, where each state represents a combination of an inspection point and a camera. For each state, we compute the required workpiece pose and derive the corresponding robot joint configuration. A fully connected, undirected, weighted graph is constructed, with nodes representing states and edges corresponding to transition times between robot joint configurations. A shortest path algorithm determines the optimal sequence of transitions, ensuring each inspection point is visited exactly once while minimizing movement time.

To optimize camera placement, an iterative algorithm adjusts camera locations to minimize inspection duration. The system's agility enables automatic reconfiguration for different workpieces and inspection needs, making it adaptable to various manufacturing scenarios. Experimental validation demonstrates that the proposed optimization approach reduces inspection cycle time while ensuring full coverage.

Isaac Sim Integrated Digital Twin for Feasibility Checks in Skill-Based Engineering

Hossam Khalil, Aleksandr Sidorenko, Maciej Kolek, Martin Ruskowski, and Achim Wagner

Skill-based engineering is an approach that encapsulates the complexity of control software into reusable and parameterizable components, making it easier to develop low-level functions and combine them effectively according to the specific needs of a process, thus enabling scalable and modular solutions in diverse applications. Digital Twins (DTs) are technologies that use virtual representations of physical assets in various ways, spanning the design of a system and the adaptive control of an asset during operation and maintenance. By incorporating both approaches, feasibility checks can be performed to predict the future behavior of the skills required for a specific action. In this work, we introduce a methodology for combining NVIDIA's Isaac Sim framework for high-quality, physics-capable DT-based simulations with an integrated interoperable control component based on ROS and OPC UA standards. We also demonstrate skill-based robot feasibility checks using physical control (Hardware-in-the-Loop), virtual control (Software-in-the-Loop), and a combination of both techniques.

Collaborative Robotics

Thursday, 19th of June 2025 Room HORIZONT 10:30-12:00

Chair: **Luka Peternel;** Co-chair: **Aljaž Kramberger**

Human-Human Teleoperated Interaction for Sit-to-Stand Assistance with Humanoid Robots

Tilen Brecelj, Ana Gabriela Kostanjevec, and Tadej Petrič

In this study, we investigate physical collaboration between two individuals during sit-to-stand assistance, facilitated by two coupled robots, the anthropomorphic KUKA LWR robot and the humanoid robot Talos. First, a haptic controller based on the forces applied to both robots to establish the connection between the two individuals is described. Subsequently, physical human-human collaboration during a sit-to-stand task is presented and analysed. Lastly, a generalisation of the sit-to-stand assisted movement task obtained through teleoperation is provided for potential enhancements of the sit-to-stand assistance task.

Integrated Control Strategy for Nonholonomic Mobile Robots with Anthropomorphic Manipulators

Tadej Petrič, Tilen Brecelj, and Leon Žlajpah

Mobile manipulators, integrating nonholonomic bases with robotic arms, play a crucial role in dynamic and unstructured environments. However, conventional trajectory tracking methods, often based on predefined planning, struggle to adapt to real-time changes such as moving obstacles or evolving task requirements. This paper presents a novel joint control framework that incorporates real-time feedback, enabling continuous adjustments to both the mobile base and manipulator for smooth and coordinated motion. By treating them as a unified system rather than separate entities, the approach enhances end-effector precision, adaptability, and operational efficiency. Extensive simulations demonstrate its superiority over traditional methods, particularly in environments requiring high responsiveness and accuracy. These findings highlight the framework's potential for industrial robotics, service automation, and other demanding applications.

Embodiment of AI-Driven Collaborative Awareness with Industrial Service Robots

Aleksandar Rodić

The integration of AI-driven collaborative robots (cobots) into industrial environments has led to significant advancements in adaptive automation, particularly in custom-oriented manufacturing processes where human-robot interaction is critical. This paper presents a novel approach to embedding artificial intelligence within the control architecture of a collaborative robot, enabling real-time assessment of a human worker's psychophysical state and adaptive support mechanisms. The system leverages a multi-modal perception interface consisting of depth cameras, motion sensors, and physiological indicators to continuously monitor worker fatigue, loss of concentration, stress due to lack of training, or potential health impairments. A fuzzy inference system (FIS) is employed to process these heterogeneous inputs, providing dynamic estimations of worker states on a scale from 0 (non-existent) to 1 (critical), facilitating an intelligent decision-making framework for robotic assistance. Based on the estimated worker condition, the cobot autonomously generates appropriate responses—ranging from verbal or gestural alerts to direct physical assistance, such as adjusting task execution speed, tool handling, or temporary workload redistribution. The collaborative robot is fully networked within an information-driven workspace, ensuring seamless access to production schedules, technical documentation, and real-time operational data. This AI-enhanced embodiment of collaborative awareness ensures a safer, more efficient human-robot partnership, reducing occupational risks while improving productivity in flexible, low-volume manufacturing environments. The paper details the system architecture, AI-driven perception and inference mechanisms, and practical implementation in a structured industrial setting.

Vision Transformer-based Multimodal Fusion of Gesture and Object Classification in Human-Robot Collaboration

Selma Subašić, Lejla Banjanović-Mehmedović, Haris Subašić, Isak Karabegović, and Ermin Husak

Aligned with the principles of Industry 5.0, Human-Centric Smart Manufacturing (HSM) emphasizes human well-being by integrating AI-driven solutions to enhance human-robot collaboration (HRC). In recent years, Convolutional Neural Networks (CNNs) have played a key role in advancing machine learning, computer vision, and robotics. Vision Transformers (ViTs) have emerged as powerful models for various vision tasks, sparking interest in their broader applications. However, their adoption in robotics remains relatively unexplored. This study explores the application of Vision Transformers for classifying human gestures and objects, enhancing human-robot collaboration (HRC) through advanced image recognition techniques. By employing a multimodal late fusion approach, visual data from multiple streams are integrated, leveraging complementary information to improve decision-making accuracy. Experimental results show that the accuracy of ViT-based unimodal classification models and the performance of robot task execution using a fusion model highlight the significance of multimodal fusion models in human-robot collaboration. Furthermore, this research is important for the realization of multimodal-based robotic learning, planning, and decision-making, contributing to advancements in Human-Centric Smart Manufacturing.

Human-Robot Assembly of 3D-printed Building Components Combining Motion Planning and Dynamic Movement Primitives

Arwin Hidding, Tom Lim, Henriette Bier, and Luka Peternel

Constructing a Martian habitat presents significant challenges due to extreme temperature variations and a low-density and - pressure atmosphere. To address these challenges a habitat constructed from prefabricated, interlocking Voronoi-based components that are assembled by human-robot collaboration has been explored in the Rhizome projects at TU Delft. In this paper, we propose a combined robot motion planning and learning method that can optimize human involvement in assembly tasks in on-site construction. The proposed hybrid approach exploits motion planning to create motion trajectories for aspects of the task where robot autonomy is capable of solving the problem on its own using sensors and intelligence. When the task becomes too difficult for existing planning capabilities, the human can step in and teach motion trajectories via kinaesthetic demonstration using Dynamic Movement Primitives (DMPs). The trajectories are then executed on the low level by an impedance controller to handle the physical interaction with the environment during the assembly. The decision-making process is managed by a behavior tree.

Comparative Analysis of Loss Functions for LSTM-Based Motion Prediction

Matija Mavsar, Andraž Čepič, and Aleš Ude

Accurate motion prediction is crucial for human-robot collaboration (HRC), enhancing responsiveness and safety in tasks like object handover. Long Short-Term Memory (LSTM) networks effectively model temporal dependencies in motion data, but their performance is highly dependent on the choice of loss function. This paper compares loss functions based on trajectory and Dynamic Movement Primitive (DMP) errors, utilizing both Mean Squared Error (MSE) and Huber loss. Additionally, we assess VGG-11 and AlexNet as feature extractors to optimize prediction accuracy. Our findings provide insights into improving loss selection and network architectures for real-time collaborative robotics.

Keynote session II

Thursday, 19th of June 2025 — Room HORIZONT — 12:00-12:30

Chair: **Filip Bečanović**

Autonomous navigation for swarms of unmanned aerial vehicles in severe environments

Strahinja Došen

The lecture will start by introducing the conventional state-of-the-art methods for the control of robotic prostheses based on the processing of myoelectric signals, including the use of machine learning (pattern recognition and regression). We will then address the drawbacks of these methods and related challenges for clinical translation and wider use. An alternative approach to controlling bionic limbs will be presented, where the main idea is to enhance these systems with additional sensors and cognitive-like processing so that they can perform some functions autonomously (semi-automatic control). Semi-autonomous prosthesis prototypes will be described, and it will be shown how they can improve prosthesis performance while decreasing the cognitive and physical effort of control. Finally, we will introduce the new generation of bionic limbs that are enhanced with connectivity, allowing them to access the virtually unlimited computational resources of the Cloud and Edge. The radically new functions enabled by the Cloud/Edge computing will be discussed, including computational offloading, continuous data logging, adaptation, and learning, as well as remote intervention. The lecture will end by summarizing the pros and cons of the three approaches to prosthesis control (namely, conventional, semi-autonomous, and connected bionics) and discussing the perspectives for the future of bionic limbs.

Interoperable AI-Based Robotics for the Factory of the Future II

Thursday, 19th of June 2025 Room REČ 13:30-15:00

Chair: **Sotiris Makris;** Co-chair: **Achim Wagner**

Enabling Generic Robot Skill Implementation Using Object Oriented Programming

Abdullah Farrukh, Achim Wagner, and Martin Ruskowski

In a highly competitive economy, efficiency is the key to staying competitive. In manufacturing, efficiency is achieved through intelligent, robust and automated processes and production systems. One way to achieve greater efficiency in production is through the use of robotic systems, particularly six-degree industrial robots. A challenge in integrating such a system is the variability of interfaces for different robot manufacturers and types. In this work, we propose an object-oriented modular open-source software architecture to address the high variability of interfaces, called GRIP (Generic Robot Interface & Platform). The aim is to use existing available hardware- and interfaces abstractions, create vendor-specific software modules and have a common method to describe the properties of a robot. This work lays the foundation for a vendor independent implementation of robot skills.

On a versatile production station using cognitive mechatronic devices coordinated by a multi-layer control framework

Panagiotis Karagiannis, Dionisios Andronas, Christos Giannoulis, George Michalos, and Sotiris Makris

This paper introduces a versatile production station that integrates cognitive mechatronic devices and synchronization systems to perform handling operation on products with complex geometries. The hardware of the station is composed of industrial robots, 6-DoF gripper and a flexible assembly mechanism, all equipped with cognition-based control. This enables them to handle different product geometries when performing grasping and manipulation operations, based on sensor input received by an external camera. On the software side, a multi-layer control system monitors and orchestrates all the operations of each subsystem to complete the assembly task. A case study stemming from the consumer goods industry demonstrated the flexibility, dexterity, and adaptability of the proposed solution.

Advancements and Challenges in Emotion Extraction from Speech: A PRISMA-Guided Systematic Review of Machine and Deep Learning Techniques

Suryakant Tyagi and Sándor Szénási

This PRISMA-compliant systematic review synthesizes 127 studies (2018–2023) on emotion extraction from speech, focusing on machine learning (ML) and deep learning (DL) advancements. We analyze traditional methods (SVMs, HMMs), DL architectures (CNNs, transformers), and emerging trends (self-supervised learning, multimodal fusion). Our methodology includes rigorous quality assessment, meta-analysis, and bias evaluation. Results reveal DL models achieve 85% accuracy on IEMOCAP, surpassing ML's plateau at 68%, but critical gaps persist in cultural bias, reproducibility, and ethics. We propose standardized benchmarks and ethical frameworks for future research. This review serves as a comprehensive guide for researchers and practitioners in affective computing.

A Modular Software Framework for Cost Effective Deployment of Robots in Manufacturing SMEs

Zaviša Gordić, Francisco Melendez-Fernandez, and Ali Muhammad

Reconfiguration and programming of robots requires skilled resources and hence, it is only cost effective when a programmed robotic solution can be used for mass production. This has been a significant bottleneck for the Small and Medium Enterprises (SMEs) to deploy robots in their small batch production. This paper presents a modular software framework where components can be reconfigured to quickly recreate a new solution. The approach was developed and tested in 26 different experiments across a multitude of manufacturing SMEs distributed across Europe. The results show that such a modular framework can pave the way for increasing the deployment of robots in manufacturing SMEs. The developed framework is based on open-source platform FIWARE, which allows the quick deployment of digital solutions in industry.

Improving Unfolding Success Rate through Cloth Pose Correction

Jan Jerićević, Peter Nimac, Domen Tabernik, and Andrej Gams

Cloth unfolding is a prerequisite action for most cloth manipulation tasks. Its importance has led to the development of a benchmark and a competition of cloth unfolding through re-grasping in the air, which took place at the 2024 IEEE International Conference on Robotics and Automation (ICRA). While the competition took place on a common dual-arm robot configuration, recreating it with different robot arms to develop and test algorithms has led to hardware-specific issues and solutions. In this paper, we present our implementation of the dual-arm configuration based on the one used in the competition. We also demonstrate how even a relatively rudimentary exploitation of the robot's capability to move has led to a substantial increase in the number of possible grasps.

A Modular Approach to Motor Control: The CANopenDrivers Library

Natalija Topalovic, Jorge Playan Garai, Giancarlo D'Ago, and Eloise Matheson

Robotic systems at CERN are regularly used for inspection, maintenance and repair tasks. They can be used for many different applications in different configurations, that may require quick system changes and setup. The operation of these robotic systems relies on precise low-level control and real-time communication, using protocols like CANopen and EtherCAT. The previously used CANopenDevices library at CERN was limited in its modularity, error handling and overall documentation. This paper introduces the CANopenDrivers library, a comprehensive and adaptable framework for motor control for robotic systems. Incorporating features from Lely CANopen and SOEM libraries, the CANopen-Drivers library supports CANopen over CAN (CoC) and EtherCAT (CoE) protocols while following the CiA 402 standard. Testing on diverse robotic platforms demonstrated its robust functionality, versatile operating modes, and compatibility with different driver configurations. This development further enables high-performance robotic systems for maintenance and operation in CERN's accelerator facilities.

Robot Sensing

Thursday, 19th of June 2025 Room HORIZONT 13:30-15:00

Chair: **Marko Munih;** Co-chair: **Panagiotis Koustoumpardis**

Improving position estimation of 3D gridboard with ArUco markers in robotic multi-camera systems

Jan Maslowski, Jakub Chlebek, and Zdenko Bobovsky

Calibration of the external parameters of multiple cameras is an essential step to accurately determine the relative position and orientation of cameras in multi-camera systems, especially in applications such as robot workspace tracking for safety, trajectory planning, or process control. Traditional methods using ArUco markers exhibit instability in position estimation, especially in situations where the axis of the markers intersects the camera axis. This inaccuracy can be partially eliminated by using a 3D calibration object (gridboard), with multiple visual markers. Our study focuses on the effect of different gridboard tilt settings on its detection accuracy. This paper presents the experimental measurement design, a new gridboard design, and a detailed evaluation of the measurement of the effect of different gridboard tilt settings on detection accuracy. Our findings provide an improvement in gridboard detection accuracy, leading to more accurate estimation of the relative position and orientation of multiple cameras at the sites.

Generative Grasp Detection and Estimation with Concept Learning-based Safety Criteria

Al-Harith Farhad, Khalil Abuibaid, Christiane Plociennik, Achim Wagner, and Martin Ruskowski

Neural networks are often regarded as universal equations that can estimate any function. This flexibility, however, comes with the drawback of high complexity, rendering these networks into black box models, which is especially relevant in safety-centric applications. To that end, we propose a pipeline for a collaborative robot (Cobot) grasping algorithm that detects relevant tools and generates the optimal grasp. To increase the transparency and reliability of this approach, we integrate an explainable AI method that provides an explanation for the underlying prediction of a model by extracting the learned features and correlating them to corresponding classes from the input. These concepts are then used as additional criteria to ensure the safe handling of work tools.

Sensor placement determination of wearable device for a weight manipulation task

Djordje Urukalo, Jelena Ilić, Marija Radmilović, Franco Munoz Nates, and Pierre Blazevic

This paper introduces a method for optimizing wearable sensor placement in warehouse weight-lifting tasks to enable accurate classification of lifted weights while minimizing hardware requirements. The approach employs a virtual human mesh model to identify the most informative sensor location by analyzing the maximum standard deviations of orientation readings. A Long Short-Term Memory (LSTM) neural network processes data from the optimally positioned sensor to classify loads into six weight categories. Key contributions include: first, reducing the number of sensors required by determining the most informative anatomical position and, and second, enabling accurate weight estimation without relying on muscle activity measurements. Experimental evaluation demonstrates a 95% probability of correctly classifying the lifted load. The proposed method allows for precise load weight estimation without requiring physiological data.

Initial-pose self-calibration for deployable overconstrained Cable-Driven Parallel Robots

Filippo Zoffoli, Edoardo Idà, and Marco Carricato

Deployable Cable-Driven Parallel Robots (CDPRs) are often designed to be lightweight so that they can be easily transported and mounted in the field. They often rely on simplified cable transmission systems with non-constant and uncertain transmission ratios. These uncertainties complicate the kinematic model, making pose estimation and calibration challenging, as motor angles are not easily linked to cable lengths. This paper presents a comparative study of three self-calibration algorithms for deployable CDPRs, analyzing the impact of different sensor configurations on initial-pose estimation accuracy. Simulations evaluate each sensor set using position and orientation errors as metrics. Recommendations are proposed on optimal sensor configurations for deployable CDPRs, accounting for measurement and modeling errors and the practical limitations of simplified transmission systems.

Estimating 2D position from magnetic sensor readings using artificial neural network

Vladimir Sibinović, Mirko Raković, Milutin Nikolic, and Vladimir Mitić

This paper presents a systematic approach to data acquisition and analysis for estimating the 2D position of a permanent magnet using neural networks. In a step-by-step manner, the data were collected using a functional prototype, and the training was analyzed. Multiple neural network architectures were evaluated, and the best possible results were selected. This most effective network was exported as API and subjected to further real-world tests, and the results are presented. This research was conducted in an effort to create a sensor that can measure contact forces for robotic hands and grippers by measuring the change of the magnetic field of magnets suspended in a flexible substrate. The idea is that the methodology developed for determining the position of the magnet can be used to find the correlation between the contact forces and magnet displacement.

Evaluation of the K4PCS global registration algorithm

Roč Stilinović, Bojan Šekoranja, and Filip Šuligoj

This paper presents a statistical analysis of the Keypoint-based 4-point Congruent System (K4PCS) algorithm's performance in global image registration. The evaluation is conducted on three test sets: Armadillo, Bunny, and Cat. We evaluate the precision of transformation matrices using root mean square error and the Frobenius norm, as well as real-time performance. Each registration is performed over 30 iterations to assume a normal distribution of results. Our results indicate that K4PCS consistently achieves satisfactory registration accuracy when aligning identical point clouds, regardless of their initial positions, and that the registration times, especially with downsampling, suggest the potential for real time performance. However, performance decreases when we introduce perturbations by adding Gaussian noise or by removing data points from the datasets. In the presence of added Gaussian noise, registration results maintain normality assumption up to 15% added noise. Computation times remain stable and close to real-time performance for each noise level. For partial-to-whole registration, error rate stays on the same level as for whole-to-whole registration. On the other hand, registration times vary depending on the number of removed points.

Honorable speakers, Session: Robotics in the “Fertile Crescent” of RAAD – Past and Future

Thursday, 19th of June 2025 Room HORIZONT 15:00-16:30

Moderator: **Uwe Haass**

Professor Vukobratović - personality and work that inspire

Branislav Borovac

Prof. Vukobratović initiated research not only in this region, but it is safe to say all over the world. We will also mention his work that preceded robotics, but in the presentation we will try to shed light on his character and work as a pioneer of robotics who left his mark in many areas of robotics, such as: ZMP concept and semi-inverse method, active rehabilitation exoskeletons, recursive formulation of robot dynamics, robot dynamic control, centralized and decentralized control, force feedback in dynamic control of robots, robot interacting with dynamic environment, control of multi-arm cooperating robots, application of connectionist algorithms for advanced learning control of robot interacting with dynamic environment, fuzzy logic robot control with model-based dynamic compensation, integrated dynamic control of robotized road vehicles.

In this presentation, I will try to show that the appearance of the first fundamental results of the Belgrade School of Robotics has, to a great extent, coincided with the foundation of robotics as a scientific discipline in the field of technical sciences.

Before reviewing our most important contributions in the domain of robotics I would like to emphasize that this presentation is an homage to professor Vukobratović work, within which I have acted in the course of thirty five years, practically the whole my working life. It appeared that the milestones in this development represent at the same time the fundamental results of robotics in general.

We will also refer to his relationship with his collaborators, which is an example of extraordinary cooperation.

Italian Distinguished IFToMMist Figures in Mechanism and Machine Science and Their Links with RAAD

Giuseppe Carbone

This presentation examines the contributions of Italian pioneers in the field of Mechanism and Machine Science within the framework of IFToMM (International Federation for the Promotion of Mechanism and Machine Science).

Special emphasis is placed on their connections with the RAAD (International Conference on Robotics in Alpe Adria-Danube Region), highlighting the pivotal role these individuals have played in shaping the RAAD scientific community, fostering its collaborative spirit, and building its enduring legacy over the years.

Institute Jožef Stefan – Between Research, Development and use of Robots
Jadran Lenarčič

Slovenia is one of the countries with the highest density of robots per employee globally. This is certainly the result of the fairly early start of robotics development in Slovenia, which dates back to the late 1970s and especially to the early 1980s. The main industrial carriers were initially successful export companies such as Gorenje and Iskra, and a little later also Riko. All three also intended to become manufacturers of robotic technology. Specialized robot integrators also appeared. Scientific research in Slovenia was also well coordinated between the University of Ljubljana, the University of Maribor and the Institute Jožef Stefan. The majority of research at the IJS was focused on robot kinematics and dynamics, dynamic control, modern programming languages and computer vision, and research of human motion with an emphasis on the shoulder. The ARK conference, which IJS has led from 1988 to the present, is also recognized worldwide.

A Brief History of Robotics Development Efforts in Hungary
Imre Rudas and Péter Galambos

In Hungary the first efforts in robotics development started in the early 70s. The presentation starts with the brief summary of the institutions, companies those were involved in robotics in the early stages and their achievements.
The more organized robotic community was born in the mid-80s with establishment of Hungarian Robotics Association. The Association started to launch international relations; with International Federation of Robotics and especially with the surrounding countries.
Hungarian researchers (partly with government support) started to attend regional Robotics Workshops and Conferences, for example JUROB, RAAD, and other robotics events organized by the Technical University of Vienna and Mihajlo Pupin Institute. Hungarian representatives joined to the RAAD community in the mid-90s and organized RAAD 1996, 2002, 2006, 2010 in Hungary. The presentation will contain the personal involvement of the author in these events and his memories about the distinguished pioneers of robotics in our region and RAAD founders.

Plenary session III

Friday, 20th of June 2025 — Central Hall — 09:00-10:00

Chair: **Aleksandar Rodić**

From Biology to Embodied AI: Shaping Humanoid Motion Through Optimization and Learning
Katja Mombaur

Humanoid robotics has advanced rapidly, with new prototypes emerging from both industry and academia. These robots are increasingly capable and bring us closer to the vision of machines assisting humans in dirty, dull, or dangerous tasks—and even serving as companions or caregivers. However, achieving human-level motor skills in humanoids remains challenging due to their complex dynamics, high degrees of freedom, underactuation, and instability.

In this talk, I will present our research on endowing humanoid robots with *embodied artificial intelligence*—the ability to understand and adapt their motion in dynamic environments with physical and social interactions. Our goal is to uncover fundamental principles of human movement, such as stability, efficiency, and behavioral optimality, and translate these into computational models. These models not only provide bioinspiration for robot motion but also help infer human intent during interaction. We combine model-based methods, like optimization and learning in simulation with model-free approaches to develop motion strategies that are both efficient and adaptable. I will showcase a range of results, including locomotion over uneven terrain, dynamic balancing, bimanual manipulation, and close human-robot interaction in contexts such as dancing or medical assistance. These examples illustrate how integrating principles from biology and computation leads to more intelligent, responsive humanoid behavior.

Robots and Arts

Friday, 20th of June 2025 | Room REČ | 10:45-12:30

Chair: **Maria Rita Canina**; Co-chair: **Ali Muhammad**

Deployment of Robots for the Automation in the Composites Industry

Simon Chris Vinkel, Ali Muhammad

Advancements in perception technologies and computational science are enabling robots to handle increasingly unstructured and dynamic tasks, expanding their applications across various industries. This paper presents an automation solution for the composites sector, where manufacturing remains heavily reliant on manual labor. The proposed system is tested in the production of composite components for wind turbine blades and luxury boats—industries facing growing demand and a shortage of skilled workers, particularly in the renewable energy sector. The automation framework employs a dynamic path-planning methodology that recalculates robot trajectories for each production cycle to accommodate varying part geometries. To achieve real-time, collision-free motion, the solution integrates Linear Interpolation (LIP) and Spherical Linear Interpolation (SLIP) with a precisely calibrated digital twin. This approach ensures adaptive and efficient robotic operation, paving the way for increased automation in composite manufacturing.

Robotic Arm: Extension of Artistic Actions

Miljan Stevanovic, Jelena Pejić, and Petar Pejić

This paper, Robotic Arm: Extension of Artistic Actions, addresses the transformative role that advanced technologies play in the realm of artistic creation, exploring their implications for the expressiveness of works of art in the making. With robotic systems used in artistic expression, key concerns arise regarding the authenticity of the artworks produced in this way and the validity of the use of such technologies in artistic endeavors. Key questions are raised: do these robotic entities function merely as sophisticated tools within the framework of creative expression, or do they establish a new form of artistic authorship independent of human influence? This research stimulates a debate about whether robot-assisted artworks can be considered creations of machines themselves, or whether the essence of human activity continues to underpin artistic expression. Through the examination of contemporary artistic practices and technological innovations, this paper seeks to illuminate the dynamic relationship between human creativity and the use of robots in art. It critically examines the role of robotics as a facilitator or co-creator in artistic production, exploring whether such technologies are fundamentally transformative tools or simply augment traditional methodologies of artistic expression. In doing so, this study aims to contribute to the broader discourse surrounding the impact of technology on art, clarifying the emerging relationships in contemporary artistic practices: new technology - art - artist.

Robotic Fabrication of Spherical Joints for Freeform Structures

Tamara Miljković, Igor Babić, Marko Jovanović, and Mirko Raković

In contemporary architecture, freeform designs have become increasingly important due to their complex geometries and the need for innovative approaches to structural assembly. These forms often require specific panelization or tessellation techniques to ensure their stability, relying on underlying substructures to connect and support the elements. The fabrication of joints for such freeform structures poses significant challenges, particularly when components intersect at irregular angles. Existing solutions, such as cubical connectors, face limitations in terms of precision and aesthetics, highlighting the need for new approaches to improve both the functional and aesthetic aspects of freeform architectural designs. This paper explores the use of spherical connectors for freeform wooden substructures, focusing on the fabrication of these connectors using robotic systems. The spherical geometry simplifies the fabrication process by ensuring that holes for the connectors are always drilled perpendicular to the surface, eliminating the potential for drilling misalignment and additional angular calculations. This research aims to provide a novel solution for the fabrication of joints in freeform structures, improving both the efficiency and aesthetic integration of the joints within the overall design.

Agricultural Robotics for Carbon Emission Reduction: A Synergistic Perspective on Technology, Sustainability, and Art

Giancarlo Furcieri, Giuseppe Culotta, Davide Gerbino, Antonio Franceschielli, and Adriano Fagiolini

This paper examines the role of agricultural robotics in reducing carbon emissions, emphasizing technological advancements, sustainable practices, and their interaction with artistic approaches. Precision agriculture, autonomous systems, and soil carbon sequestration are analyzed for their effectiveness in mitigating greenhouse gases. Further-more, the study explores how art can contribute to enhancing public engagement and promoting ecological awareness. The integration of these fields underscores the potential of robotics and art in advancing agricultural sustainability and fostering a global consciousness of climate challenges.

Comparative Analysis of Timber Joint Fabrication: Precision and Efficiency in Robotic and Augmented Reality-Assisted Methods

Nikoletta Vitti, Evangelia Ioannou, Styliani Ioakeim, Anastasia Spyrou, and Odysseas Kontovourkis

Emerging technologies have brought about radical changes in the construction sector, paving the way for the effective implementation of innovative and non-standard architectural projects. One sector that particularly benefits is the construction of non-conventional timber structural systems. The development of techniques for complex joint fabrication remains a central challenge, with robotic and Augmented Reality (AR) technologies playing a crucial role in creating accurate, efficient, and flexible geometries. This study presents a comparative analysis of the precision achieved in timber joint fabrication using robotic automation and AR-assisted methods. By assessing accuracy through 3D scanning, error elimination, and fabrication efficiency, the research highlights the advantages and limitations of each approach. Experimental findings show that robotic fabrication ensures high precision in joint cutting, while AR-based cutting and assembly guidance improves adaptability, workflow optimization, and real-time flexibility. The findings contribute to a deeper understanding of how emerging technologies and human intervention can enhance the precision, efficiency, and feasibility of complex timber structure fabrication.

Streamlining Drywall Assembly: CAD-Driven Robotic Assembly

Jovan Bajić, Milica Damnjanović, Nikola Knežević, Saša Jokić, and Kosta Jovanović

The construction industry is undergoing a transformative shift with the integration of robotics and automation, particularly in repetitive and labor-intensive tasks such as drywall assembly. This paper presents a comprehensive framework for streamlining drywall construction through CAD-driven robotic assembly. By leveraging advanced CAD tools (Autodesk Fusion 360), this paper presents a seamless workflow that translates digital designs into precise robotic execution. The proposed system integrates computer vision, path planning, and robotic control algorithms to automate drywall assembly with high accuracy and efficiency. In addition, one of the key innovations of this approach is the incorporation of real-time quality assurance, where depth cameras and computer vision systems continuously monitor the installation process, ensuring precise alignment and proper fastening. We demonstrate the feasibility of this approach through a couple of different drywalls. Furthermore, the system’s adaptability to varying architectural designs highlights its potential for widespread adoption in the construction industry.

Growing Futures: Mycelium - Robots - Human Ecosystem

Daniela Amandolese, Zana Bosnic, Eduardo Loreto, and Francisco Kuhar

The depletion of natural resources and the urgency for sustainable alternatives have driven the exploration of biofabrication and nature-based solutions. In this context, mycelium-based materials have emerged as a promising avenue due to their regenerative potential and adaptability. Recent advancements in robotics and material science further enhance their applicability, opening possibilities for bio-integrated systems.

This paper presents the Growing Futures Process, a mycelium-robot-human ecosystem that envisions biodegradable, adaptable habitats created through the collaboration of living organisms and autonomous systems. The project aims to create biodegradable, adaptable habitats built within an ecosystem where mycelium, robots and humans, collaborate to transform local food waste into biodegradable, adaptable structures through a new design and production process. It outlines the key research, experimentation, and prototyping phases that led to the concept’s development.

Building upon a speculative future scenario developed within the MUSAE project, the concept evolved through four key phases: challenge exploration, inspirational research, idea generation, and concept development.

The prototype-building phase was structured into twelve iterative steps, testing mycelium growth, sensor integration, and robotic interaction to optimize biofabrication in the ecosystem. Four experimental settings were explored: unconstrained growth, controlled casting, robots as nutrient dispensers, and ecosystem integration.
By integrating biological intelligence, robotics, and material science, Growing Futures proposes a novel approach to construction, product design, and environmental restoration through co-creation with nature.

Autonomous Robots

Friday, 20th of June 2025 Room HORIZONT 10:45-12:30

Chair: **Karsten Berns**; Co-chair: **Marko Švaco**

Individual Psychological Characteristics of Operators When Controlling a Quadrocopter-Type UAV with a Myographic Interface

Ya. A. Turovsky, R. A. Tokarev, D. S. Ognev, V. A. Tishchenko, L. A. Rybak, and D. I. Malyshev

The paper studies individual psychological characteristics of operators controlling a UAV via a video communication channel. The quadcopter-type UAV was controlled using both a traditional keyboard interface and a myographic interface that generates discrete commands depending on the level of electrical activity of the muscles located on the user's two hands. The experiment required selecting and flying through three rows of gates, each of which contained gates of three different sizes. The operator's psychological profile was determined using the Eysenck, Spielberg, Corsi tests, the tapping test, and the leading perceptual modality test. It was determined that the subjects used a number of keyboard control commands significantly more actively, while making a greater absolute number of errors. However, when considering the relative strength of errors, the number of errors was statistically significantly greater for the myographic interface. A relationship was established between the severity of the visual channel of perception and the number of errors, regardless of the type of interface used. In this case, pronounced extroversion led to a greater number of errors when using the myographic interface, without affecting the work with the keyboard. It was revealed that the most significant predictors for the myographic interface are the indicators of working memory and extroversion. However, it was not possible to establish the dominance of predictors when controlling the UAV from the device keyboard.

Autonomous UAV Navigation for Search and Rescue Missions Using Computer Vision and Convolutional Neural Networks

Luka Šiktar, Branimir Ćaran, Bojan Šekoranja, and Marko Švaco

In this paper, we present a subsystem, using Unmanned Aerial Vehicles (UAV), for search and rescue missions, focusing on people detection, face recognition and tracking of identified individuals. The proposed solution integrates a UAV with ROS2 framework, that utilizes multiple convolutional neural networks (CNN) for search missions. System identification and PD controller deployment are performed for autonomous UAV navigation. The ROS2 environment utilizes the YOLOv11 and YOLOv11-pose CNNs for tracking purposes, and the dlib library's CNN for face recognition. The system detects a specific individual, performs face recognition and starts tracking. If the individual is not yet known, the UAV operator can manually locate the person, save their facial image and immediately initiate the tracking process. The tracking process relies on specific keypoints identified on the human body using the YOLOv11-pose CNN model. These keypoints are used to track a specific individual and maintain a safe distance. To enhance accurate tracking, system identification is performed, based on measurement data from the UAV's IMU. The identified system parameters are used to design PD controllers that utilize YOLOv11-pose to estimate the distance between the UAV's camera and the identified individual. The initial experiments, conducted on 14 known individuals, demonstrated that the proposed subsystem can be successfully used in real time. The next step involves implementing the system on a large experimental UAV for field use and integrating autonomous navigation with GPS-guided control for rescue operations planning.

Telescopic Landing System for Drones: A Solution for Uneven Terrain Operations

Giovanni Di Leo, Benedetto Perrone, Antonio Mancuso, Antonio Agrelli, Lorenzo Montuori, Stefano Branca, Simone Leone, and Giuseppe Carbone

This paper introduces an innovative landing system for drones, designed to operate effectively in complex and uneven terrain. The system employs telescopic legs powered by linear actuators, enabling dynamic adaptation to terrain irregularities for enhanced stability and safety. Constructed with lightweight yet durable PLA materials, it incorporates contact switches at the feet for real-time terrain detection, ensuring precise stabilization during landings. A proportional-integral-derivative (PID) control strategy is employed to optimize actuator movements, delivering improved reliability and performance. Experimental tests demonstrate the system's capability to achieve stable landings on challenging surfaces, minimizing collision risks, and enhancing efficiency. By addressing limitations of current technologies, this robust and adaptable solution supports diverse applications, such as search-and-rescue missions and urban operations, where reliability and adaptability are critical.

Cooperative Control of Rope-Tethered Quadcopters for Grasping and Transporting Objects

Aris Morsink Paloumpas, and Panagiotis Koustoumpardis

Aerial robots like quadcopters, and their ability to move freely indoors and in confined spaces, gives them an advantage over other ground robots. Collaborating quadcopters form an aerial swarm, enabling various real-world industrial applications. One such application is the transport of payloads using a rope hanging from the quadcopters in the swarm. The current literature is mostly focused on the manipulation of flexible objects and the transport of a payload by two or more quadcopters, while the autonomous grasp of the payload is not fully addressed. Therefore, a path planning algorithm is introduced that is responsible to carry out the whole process of approaching, grasping, lifting and transporting the load by a swarm of two quadcopters. Its inputs are the initial positions of the quadcopters and the load, while utilizing the results from the rope modelling. This outputs the flight sequence for the swarm from takeoff to landing. The experiments are carried out by two rope-tethered Crazyflie 2.1 nano quadcopters and their control by a cascaded PID controller structure. The experimental results prove the system's viability and set the foundations for further use in industrial and other applications with larger swarms.

Towards Real-World Deployment of Reinforcement Learning for Autonomous Bus Navigation in Pedestrian Zones

Abdalla Ahmed Roshdi Mohamed and Karsten Berns

Autonomous buses navigating pedestrian zones face challenges due to unpredictable pedestrian behavior and dynamic obstacles. While previous research on autonomous bus navigation has demonstrated success in controlled environments, existing control and planning approaches often struggle to adapt to the complex, unpredictable nature of pedestrian zones. This paper presents a reinforcement learning (RL) based end-to-end navigation approach designed for autonomous buses in pedestrian-rich zones. The RL model was developed and tested in a high-fidelity simulation of the RPTU campus, created with Unreal Engine. Utilizing minimal sensor data (GPS and IMU), the agent achieved goal-directed navigation within a static environment at a capped speed of 6 km/h, converging in approximately 20 minutes of training.

Optimizing Multi-Robot Autonomous Crop Collection

Sumbal Malik, Nikola Ruzic, Majid Khonji, Kosta Jovanovic, Jorge Dias, Nikola Knezevic, and Lakmal Seneviratne

The integration of autonomous robots in agriculture presents significant potential for optimizing post-harvest crop collection, addressing challenges such as labor shortages, operational inefficiencies, and scalability in large-scale farming. This paper introduces a novel optimization model for the Crop Collection Problem, formulated as a Flexible Multi-Depot Capacitated Vehicle Routing Pickup Problem (FMDCVRP-P). The proposed model coordinates a fleet of autonomous robots to collect harvested crops from multiple field locations and deliver them to various depots. By allowing flexible depot assignments, the model minimizes unnecessary travel, enhancing operational efficiency compared to traditional fixed-depot approaches. The FMDCVRP-P is formulated as a mixed-integer linear programming (MILP) problem, aiming to minimize the total makespan. Numerical experiments demonstrate that flexible depot assignments significantly improve crop collection efficiency. Additionally, a real-world robotic demonstration validates the model, showcasing its feasibility and effectiveness in practical scenarios.

CODEL: Collaborative Multi-Robot Parcel Delivery for Last-Mile Logistics

Sumbal Malik, Majid Khonji, Khaled Elbassioni, and Jorge Dias

This research presents a novel optimization framework for collaborative last-mile delivery, integrating trucks, drones, and quadruped robots, to address the complexities of urban logistics. The problem is formulated as a Vehicle Routing Problem with Drones and Robots (VRP-DR), incorporating real-world constraints such as payload capacities, energy consumption, and accessibility limitations. Within this framework, trucks serve as mobile platforms, facilitating the launch and recovery of drones and robots to enhance operational flexibility. A mixed-integer linear programming model is developed to minimize total cost and delivery time, while ensuring seamless fleet synchronization. The proposed model supports multi-visit sorties, enabling drones and robots to serve multiple customers within a single trip. Computational results demonstrate the model’s efficacy in generating optimal solutions for small to medium-scale instances, contributing to the advancement of scalable, multimodal approaches for efficient last-mile delivery.


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