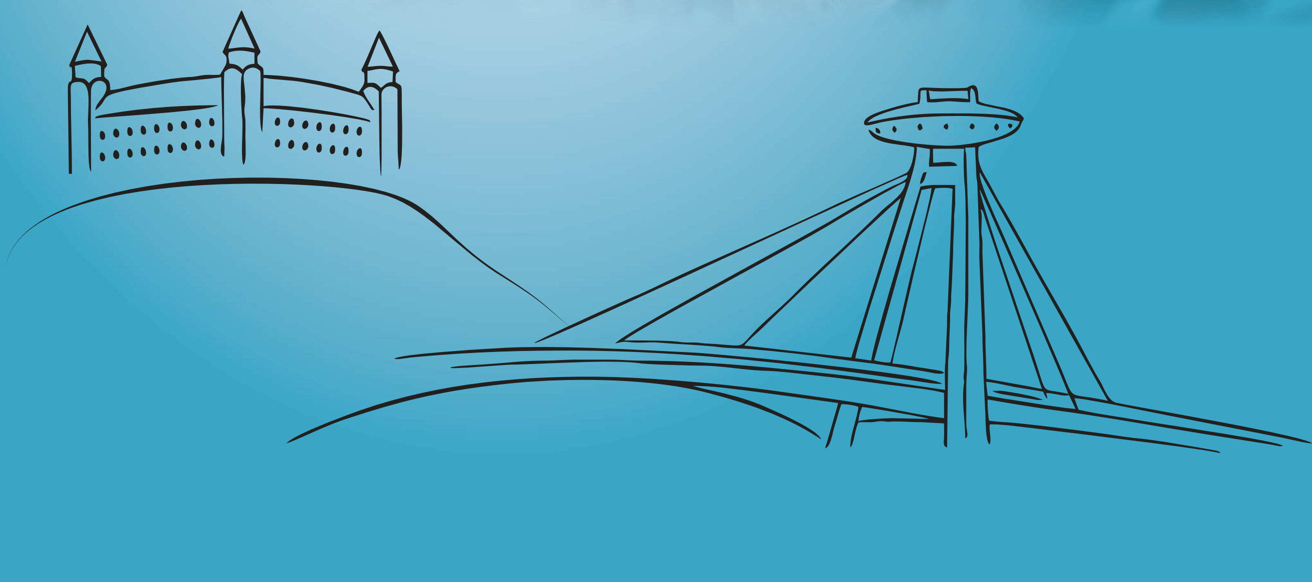
35th International Conference
on Robotics
in Alpe-Adria-Danube Region

Bratislava, Slovakia
June 17 – 19, 2026

RAAD 2026
Book *of* Abstracts



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Jana Bečková
Jaroslav Hricko
(Eds.)

35th International Conference on Robotics in Alpe-Adria-Danube Region RAAD 2026 Book of Abstracts

The proceedings of RAAD 2026 is published in an ISI and Scopus indexed book in the Springer series Mechanisms and Machine Science, it is provided to all registrants in the PDF format.

Mechanisms and Machine Science: Advances in Service and Industrial Robotics, RAAD 2026
Štefan Havlík, Andreas Müller, František Duchoň, Štefan Kozák, Jan Vachálek
Editors
https://link.springer.com/book/9783032291264

ISBN 978-80-974468-3-3

Printed by TLAČIAREŇ DÓŠA, s. r. o., Bratislava, Slovakia

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Table of Contents

Preface

The 35th International Conference on Robotics in Alpe-Adria-Danube Region (RAAD 2026) took place within June 17 – 19, 2026 in Bratislava, Slovakia. This long-standing annual event brings together multiple generations of researchers in robotic technology from countries of the Alpe-Adria-Danube region and other partners from over the world. It provides an excellent opportunity for presenting their recent research achievements, shearing experiences and open-inspiring insights into the future robotics, especially for young scientists.

This book volume in form of 35th RAAD 2026 Conference proceedings contains 59 contributed papers selected for oral presentation. Authors of presented papers come from 19 countries. The scope and quality of all papers submitted to the conference show remarkable progress and dynamic nature of research across a wide spectrum of topics in robotic disciplines to sophisticated applications.

The research subjects discussed in contributed papers cover relevant topics and ongoing research trends in manufacturing and developments in robotic technology. The papers in book are organized in parts / chapters that roughly correspond to technical sessions in the conference program.

There are:

- Future manufacturing and robotic technologies powered by AI
- Robot kinematics and motion control
- Novel design of robotic mechanisms and tools for intelligent manipulation
- Sensing and information- control systems
- Medical, rehabilitation and surgery assisting robots
- Mobile, aerial (UAV) and swarm robotics
- Innovative solutions of robotic applications

The conference program included three plenary lectures oriented to research and applications of advanced robotics. We are particularly thankful to plenary speakers for sharing their ideas on current and future research topics in lectures:

Development and Applications of Robotics in Taiwan, presented by Dr. Hung-Yin Tsai from National Institutes of Applied Research, Taiwan

Geometric Algebra and Quantum Computing for Robot Modelling and Control, presented by Prof. Dr. MSc. Eng. Eduardo Bayro-Corrochano from Poznan University of Technology Poznan, Poland

Robotic surgery; experiences and ideas for research, presented by MUDr. Vladimír Baláž, PhD., from Robotic Surgery Center, F.D. Roosevelt University Hospital, Slovakia.

We express our thanks to all authors and speakers for their valuable contributions. Our gratitude goes to all reviewers for ensuring the quality of presented papers, the program committee members for their diligent reviews, and the organizing committee for their efforts in making success of this conference.

It is our hope that this volume will serve as a valuable resource of knowledge for researchers and practitioners; it will inspire new ideas for stimulating further research and strengthening the collaborative spirit that defines the RAAD community.

Four institutions participated in the organization of the conference, for which we would like to express our gratitude: Institute of Informatics of the Slovak Academy of Sciences, Faculty of Mechanical engineering of the Slovak University of Technology, Slovak Society for Cybernetics and Informatics and National Centre for Robotics. Our special thank is devoted to the Slovak University of Technology in Bratislava for its availability to host the RAAD 2026 event.

We acknowledge the support of the International Federation for the Promotion of Mechanism and Machine Science (IFToMM, https://iftomm-world.org/) and Springer for their continued partnership and commitment to disseminating high-quality scientific literature.

Our specific thanks is devoted to the Ministry of Education, Research, Development and Youth of the Slovak Republic for the patronage and financial support through the government program: "Coordination of Cross-sectional Activities of State Science and Technology Policy".

June 2026

Štefan Havlík
Andreas Müller
The conference chairs

Conference Program

June 16, 2026

19.00 – 21.00	Informal welcome for conference participants. STU University Centre – Science Café

June 17, 2026

8.00 – 9.00	Registration
9.00 – 9.20	Opening ceremony
9.20 – 10.20	**Keynote lecture I** **Prof. Dr. MSc. Eng. Eduardo Bayro-Corrochano** *Geometric Algebra and Quantum Computing for Robot Modelling and Control*
10.20 – 10.40	Coffee break
10.40 – 12.45	**Technical sessions** - Robot kinematics and motion control I - Future manufacturing and robotic technologies powered by AI I
12.45 – 14.00	Lunch
14.00 – 16.00	**Technical sessions** - Robot kinematics and motion control II - Future manufacturing and robotic technologies powered by AI II
16.00 – 16.30	Coffee break
16.30 – 18.30	**Technical sessions** - Mobile, aerial (UAV) and swarm robotics - Sensing and information – control systems
19.30	Welcome reception Pálffy Palace at Zámocká Street 47

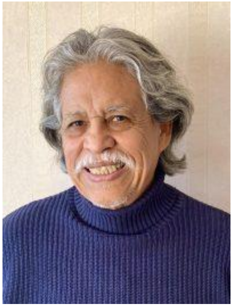
June 18, 2026

8.30 – 9.00	Registration
9.00 – 10.00	**Keynote lecture II** **MUDr. Vladimír Baláž, PhD.** *Robotic surgery; experiences and ideas for research*
10.00 – 10.30	Coffee break
10.30 – 12.30	**Technical sessions** - Medical, rehabilitation and surgery assisting robots - Innovative solutions of robotic applications I
12.45 – 14.00	Lunch/RAAD ISC meeting
14.00 – 15.00	**Plenary session** - From the Mining Machines to Robotics: History of Development in the Slovak Territory
16.00 – 18.30	Excursion
18.30	Gala dinner Restaurant Dunajský pivovar

June 19, 2026

9.00 – 10.00	**Keynote lecture III** **Dr. Hung-Yin Tsai** *Development and Applications of Robotics in Taiwan*
10.00 – 10.30	Coffee break
10.30 – 12.30	**Technical sessions** - Innovative solutions of robotic applications II - Novel design of robotic mechanisms and tools for intelligent manipulation
12.30	Closing ceremony and lunch

Plenary Speakers



Prof. Dr. MSc. Eng. Eduardo Bayro-Corrochano
Poznan University of Technology Poznan, Poland

Geometric Algebra and Quantum Computing for Robot Modelling and Control

Classical methodologies in mathematical physics and robotics suffer from several fundamental limitations. First, accessibility is restricted because ideas, concepts, methods, and results are fragmented across multiple mathematical formalisms. Mastery of only a subset of these systems prevents effective access to knowledge expressed in others. Second, redundancy arises from the repeated representation of the same information in different mathematical languages, leading to reduced efficiency. Third, there is insufficient integration and articulation among these formalisms, resulting in inconsistencies, lack of unification, limited generalization, and weak interoperability. Geometric Algebra was developed in response to these challenges, and, in light of advances in modern scientific theory, it provides a powerful and compact framework for unifying and optimizing the expression of fundamental concepts and their consequences.

This keynote lecture will center on three complementary geometric frameworks: signed distance fields, geometric algebra, and Riemannian geometry, which together offer expressive and computationally efficient representations for learning, planning, control, and optimization in robotics. Signed distance fields enable implicit shape representation through distance functions, which can be encoded and learned using various modeling and data-driven approaches. Geometric algebra provides a unified treatment of geometric primitives and transformations, including 6D poses, planes, lines, circles, and spheres, allowing constraints and interactions in robotic systems to be expressed in a compact and consistent manner. Riemannian geometry extends models and algorithms originally formulated in Euclidean spaces to curved manifolds, enabling principled handling of structured objects such as spheres, matrices, and subspaces, as well as more general smooth manifolds equipped with a Riemannian metric for distance measurement.

The lecture will clarify the distinctions, complementarities, and interconnections among these three geometric paradigms and demonstrate how they jointly contribute to key robotic applications, with particular emphasis on navigation, path planning, and manipulation. From a dynamics and control perspective, both Euler–Lagrange formulations and Hamiltonian mechanics on phase space will be expressed within the geometric algebra framework. The control architecture is centered on a quadratic programming formulation that integrates motion objectives expressed as geometric constraints on joint accelerations with physical limitations arising from unilateral contacts and force-constrained grasping.

Furthermore, modern learning techniques, including neural networks, convolutional neural networks, and physics-informed neural networks, will be incorporated into the control loop using geometric algebra as a unifying representational backbone. The lecture will also present the application of Quantum Fuzzy Control strategies to robotic manipulators. Practical demonstrations will include modeling and control of robotic arms for grasping and manipulation tasks, as well as applications to quadrotors and humanoid robots.

MUDr. Vladimír Baláž, PhD.
Robotic Surgery Center, F.D. Roosevelt University Hospital, Slovakia

Robotic surgery; experiences and ideas for research

An overview of current practices in robotic surgery, highlighting practical experiences from clinical use and the evolving role of robotic systems in modern operating rooms, will be discussed. It outlines key benefits and limitations observed in real-world settings, discusses emerging technological trends, and proposes promising directions for future research. The goal is to inspire deeper exploration of how robotics can enhance surgical precision, safety, and training while identifying gaps that merit scientific investigation.

Dr. Hung-Yin Tsai
National Institutes of Applied Research, Taiwan

Development and Applications of Robotics in Taiwan

National Institutes of Applied Research (NIAR) is the largest non-profit incorporated organization supervised by the National Science and Technology Council. There are eight research institutes or centers under NIAR. One of them is established in Q2 in 2026 and called the National Center for AI Robotics. The global trends of robotics and the robotics industries in Taiwan will be introduced. Furthermore, the development program of intelligent robotics industries in Taiwan will be shared, and the expected benefits will be disclosed.

Abstracts

Technical session 1

Robot kinematics and motion control

Postural Optimization of Mobile Manipulators under End-Effector Constraints through Local Redundancy Exploitation*

Tadej Petrič and Leon Žlajpah

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Abstract. Mobile manipulators possess inherent kinematic redundancy that can be exploited beyond workspace extension to improve posture, manipulability, and joint utilization during task execution. This paper addresses postural optimization of mobile manipulators under explicit end-effector constraints, where the pose of the end-effector is preserved while the mobile base is repositioned to improve the internal kinematic configuration of the system. The proposed approach determines an optimal base configuration solely from the relative position of the end-effector, without relying on global localization, environment maps, or continuous base tracking. By decoupling task execution from postural optimization, the method allows the end-effector to remain stationary or to follow an externally commanded trajectory, while the mobile base is autonomously relocated to configurations that enhance manipulability and promote joint range centering. The framework exploits system redundancy at the kinematic level and can be applied intermittently or on demand, rather than as a continuous control policy. Experimental results on a real nonholonomic mobile manipulator demonstrate that the proposed strategy effectively improves kinematic conditioning and joint utilization while maintaining stable end-effector behavior, highlighting its suitability for redundancy-aware whole-body optimization in dynamic and unstructured environments.

Keywords: mobile manipulators, postural optimization, end-effector constraints, kinematic redundancy, manipulability optimization, joint range centering.

* This work was supported by DIGITOP, GA no. TN-06-0106, funded by Ministry of Higher Education, Science and Innovation of Slovenia, Slovenian Research and Innovation Agency, and European Union – NextGenerationEU, and by Slovenian Research Agency grant P2-0076

A Low-Cost Inertial Framework for Dynamic Posturography: From Preliminary Validation to Kinematic Integration

Emiliano Bottoni[1], Lorenzo Galletta[1], Carlo De Benedictis[1*], Maria Paterna[1], Daniel Pacheco Quiñones[1], Daniela Maffiodo[1], Silvestro Roatta[2], and Carlo Ferraresi[1]

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Abstract. This work presents the development and experimental validation of a low-cost inertial acquisition framework for postural stability analysis. The system consists of three custom inertial measurement units (IMU), positioned on pelvis, right thigh and right shank, and a dedicated processing pipeline that includes sensor fusion, sensor-to-segment calibration, and joint angle computation. The system was validated against stereophotogrammetry and a commercial IMU reference, achieving high accuracy in hip and knee flexion-extension ($RMSE_{\%} < 4.8$, $r > 0.98$). Integrated into a robotic dynamic posturography platform, the proposed framework demonstrated that IMU-derived parameters complement force-platform data, enhancing the interpretation of postural responses and enabling discrimination of perturbation intensity, application point, and patient visual condition.

Keywords: inertial measurement units, balance assessment, postural control, wearable sensors, biomechanical modeling

Fault Detection in Collaborative Robots using Semi-supervised Techniques

Francesco Aggogeri and Nicola Pellegrini*

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Abstract. Collaborative robots are increasingly adopted in modern manufacturing due to their ability to safely coexist with human operators in shared work-spaces. However, close human–robot interaction introduces new challenges in safety, reliability, and operational continuity, making effective anomaly detection needed. This paper investigates supervised and unsupervised anomaly detection approaches for collaborative robot monitoring using multivariate signals acquired from an experimental setup. Random forest and Principal Component Analysis (PCA) are employed to identify normal behavior, incipient failures, and anomalous conditions. Quantitative performance evaluation demonstrates that supervised methods achieve very high accuracy when labeled data are available, while unsupervised clustering-based techniques provide competitive results without requiring fault labeling. The results highlight the trade-off between detection accuracy and data availability, confirming the suitability of unsupervised approaches for dynamic industrial environments. The proposed analysis supports the development of robust, scalable anomaly detection frameworks for collaborative robotic applications.

Keywords: cobots, anomaly, random forest, principal component analysis

Abstracts of RAAD 2026
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Stewart-Platform Six-DoF Haptic Joystick with Force-Feedback via Cartesian Wrench Compensation

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Abstract. This paper presents the development of a novel six-degree-of-freedom (DoF) force-feedback (FF) joystick, which is designed for controlling large mobile manipulators. We first present the joystick design based on a compact Stewart-platform mechanism to generate motion in all transnational and rotational DoF. A computationally efficient closed-form inverse-kinematics formulation is derived, and the necessary forward-kinematics solution is presented. The forward-kinematics solver is implemented on an Arduino-class microcontroller, demonstrating that the approach is suitable for embedded real-time operation. In addition, FF is provided in each DoF to support operator during manipulation. With our novel compensation scheme, the nonlinearities of the parallel mechanism are addressed to achieve a linear force-displacement characteristic, improving operator comfort. Finally, the proposed joystick is integrated into a human-in-the-loop simulator, and a control mapping is implemented exemplarily. Initial tests demonstrate the approach is feasible and suggest broad utility for future applications.

Keywords: six DOF joystick, force feedback, haptics, Stewart platform, parallel robot kinematics

Kinematic Design Optimization of RCM-Constrained Surgical Robots Based on Minimum Singular Value

Adam Wolniakowski[1], Vassilis Moulianitis[2], Roman Trochimczuk[1], Zhuoqi Cheng[3], Michał Kuciej[4], Kanstantsin Miatluk[4], and Nikos Aspragathos[5]

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Abstract. Robotic systems for minimally invasive surgery must satisfy the Remote Center of Motion (RCM) position constraints while maintaining adequate kinematic performance throughout the surgical workspace. This paper presents a design-oriented optimization procedure in which both the manipulator link lengths and the RCM point location are treated as decision variables. Kinematic performance is evaluated using the minimum singular value of the RCM-constrained Jacobian, providing a conservative and physically interpretable measure of distance to singularities. A direct search of the design space is employed to assess candidate designs over a discretized workspace, enabling a transparent and globally informative analysis of the effects of manipulator geometry and RCM placement. Simulation results for a four-degree-of-freedom serial manipulator demonstrate that combined optimization of link lengths and RCM location leads to significant improvements in constrained kinematic conditioning compared to designs with fixed link lengths and predefined RCM points. The proposed approach provides valuable insights into the structure of the feasible design space and establishes a reference for optimization and surgical robot design methodologies.

Keywords: remote center of motion, minimum singular value, minimally invasive surgery, kinematic singularities

Practicalities of Symmetric vs.One-Side-Dominant Absolute Task Control in Bimanual Robots*

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Abstract. Control of bimanual robot tasks can be implemented in different manners. When considering such tasks, it is not uncommon to exploit their combined kinematic structure and separate the control in absolute and relative motion. The reference point for the absolute motion can be set at a desired point, however, despite similarities in the derivation of the kinematic control and the behavior itself, the selection of the absolute pose reference point can result in different behavior and different interface for bimanual collaborative tasks. In this paper we explore practical differences when applying bimanual symmetric and one-side-dominant control and the effects it has on the interface with a person operating such setups.

Keywords: bimanual robot, dual-arm robot, symmetric control, absolute and relative task

* The work was funded by the Slovenian Research and Innovation Agency (ARIS) grant nr. N2-0384 HORACE (https://horace-robotics.github.io/).

Robust Fixed-Point Transformation-Based Adaptive Control with Prescribed Transient Behavior

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Abstract. In this paper a robust control idea is outlined based on Prescribed Performance Function (PPF) with an iterative deformation, that is applicable for controlling second order systems such as robots or other electro-mechanical devices. The presented approach is a modification of Computed Torque Control (CTC) which can ensure that the trajectory tracking error evolves in a bounded region, resulting in a defined transient behavior. The robust iterative deformation function employed in the control design, can guarantee the implementation of the kinematic prescription given by the PPF-CTC controller. It was shown on simulation basis that the control design works well even in presence of modeling imprecision.

Keywords: adaptive control, robust fixed-point transformation, prescribed performance control, computed torque control

Technical session 2

Future manufacturing and robotic technologies powered by AI I

A Robot Skill-Based Framework for Complex Assembly Processes in Agile Manufacturing

Polykarpos Zarmakoupis, Loukas Prezas, Zoi Arkouli, Nikos Dimitropoulos, and Sotiris Makris*

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Abstract. Modern manufacturing companies face increasingly dynamic production demands, leading to shorter product and process lifecycles. Planning, commissioning and execution of manufacturing processes are increasingly complex especially when systems integrate heterogeneous resources and are deployed on dynamic shopfloors. This paper introduces a skill-based robot task execution framework that supports modularity, interpretability, and scalability in robot programming and process control for multi-step assembly workflows. The backbone of this approach is the use of Behavior Trees (BTs), which structure tasks around reusable and parameterized robot skills, ensuring a modular architecture that supports product variant and operational scalability. Adaptation to dynamic shopfloor conditions, including error recovery, is achieved through the integration of perception systems and cognitive mechatronic modules within the unified BT-based architecture. The validation of the approach in an automotive battery pack assembly case study confirmed high modularity, interoperability, and adaptability across different conditions, leading to reduced programming effort, faster reconfiguration, and an improved operator experience.

Keywords: robot skills, behavior trees for robotics, skill-based task execution

Learning-based Strategy for Composite Robot Assembly Skill Adaptation

Khalil Abuibaid[1], Aleksandr Sidorenko[2], Achim Wagner[2], and Martin Ruskowski[1,2]

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Abstract. Contact-rich robotic skills remain challenging for industrial robots due to tight geometric tolerances, frictional variability, and uncertain contact dynamics. Although compliant controllers exist, their effectiveness depends on manually tuned parameters and fixed execution logic, limiting adaptability under varying contact conditions. Reinforcement Learning (RL) offers a promising direction for adaptive behavior but remains difficult to apply safely in contact-rich assembly tasks. This work proposes a reusable and encapsulated skill-based strategy for peg-in-hole assembly in which adaptation is achieved through Residual Reinforcement Learning (RRL). The assembly process is represented as a composition of two interaction skills, namely alignment and insertion, each defined through explicit pre-conditions, invariant conditions, and post-conditions. This formulation preserves modularity and well-defined execution semantics while enabling flexible reuse of assembly skills across different task configurations.

Instead of replacing the nominal controller, reinforcement learning is restricted to residual refinements of the baseline controller, namely the hybrid force–motion controller. The baseline controller provides stable interaction behavior during contact-rich manipulation, while the residual policy learns corrective actions that compensate for pose misalignment, friction variability, and contact uncertainty during execution. In this way, learning remains confined within the execution boundaries of predefined skills, promoting safety and sample efficiency while maintaining the overall orchestration of the assembly process.

The proposed approach is evaluated in simulation using a UR5e manipulator equipped with a Robotiq gripper in the MuJoCo physics environment. Training is performed using Soft Actor–Critic with JAX, while domain randomization is introduced through perturbations in joint states, force measurements, and goal configurations. Experimental results show that the proposed approach achieves a 96% success rate, compared to 38% for a nominal hybrid force–motion controller under the same conditions. These results indicate that combining skill-based engineering with residual reinforcement learning enables robust adaptation in contact-rich robotic assembly while preserving the modular design principles of industrial robot programming.

Keywords: skill-based engineering, reusable robot skills, residual reinforcement learning, contact-rich assembly

Factors Influencing Immersion in Desktop-Based Human–Robot Collaboration Simulations*

Jonathan Hümmer, Tino Perz, and Dominik Henrich

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Abstract. Human-Robot Collaboration (HRC) systems are commonly evaluated in laboratory studies, which are resource-intensive and often involve a limited number of participants. Online crowdsourcing offers a scalable alternative but requires sufficiently immersive simulations to ensure valid results. This work investigates how control schemes and visualization styles affect immersion in a simulation-based HRC study. We evaluated agency, ownership, usability, and workload in a study (N = 24) comparing a *Raycast* control scheme, which projects the mouse position into the 3D scene, and a *3D-Control* scheme, which maps mouse input to a direct spatial movement of the model, across three visualization styles: a standard 2D mouse *Cursor*, a realistic virtual *Hand*, and an extended *Arm* model including hand, forearm, and upper arm.
The results show that ownership is primarily driven by the control scheme, rather than by the visualization style. The *Raycast* control scheme consistently achieved higher agency and ownership with a lower workload than *3D-Control*. In particular, the same *Hand* visualization received different ownership ratings under *Raycast* versus *3D-Control*. Contrary to previous results in VR studies, we found that increased visual fidelity does not improve immersion in our desktop-based HRC simulation.
All in all, the results indicate that an intuitive control scheme is a critical factor for user experience and immersion in such environments. In future work, we will conduct a larger crowdsourcing study with power analysis to investigate the role of visual fidelity in isolation. Furthermore, we will explore customizable avatars, auditory feedback, and touch-based control schemes.

Keywords: virtual commissioning, human-robot collaboration, crowdsourcing, immersion, human factors

* This work was partly funded by the German Research Foundation (DFG) under grant agreement HE2696/29 CroViCo.

A Modular Behavior Tree Engine for Smart Manufacturing: An AAS-Driven Framework for Autonomous Skill Execution

Mahdi Rezapour[1], Abdallah Darwish[2], Achim Wagner[1], Daniel Görges[2], and Martin Ruskowski[1,2]

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Abstract. The shift toward adaptive production ecosystems has increased the demand for automation frameworks capable of coordinating complex skills across heterogeneous manufacturing assets. Behavior Trees (BTs) offer strong potential for orchestrating robotic and cyber-physical systems. A unified notion of behavior would further enhance their industrial applicability. In parallel, the Asset Administration Shell (AAS) is emerging as the core digital-twin representation of Industry 4.0, providing structured and interoperable asset descriptions. Yet executable logic is seldom integrated into AAS structures, creating a gap between semantic descriptions and operational skill execution. This work investigates how behaviors can be represented through BTs and deployed via the AAS to enable decentralized and autonomous skill execution. To address this, we introduce a Modular BT Engine that retrieves BT models stored in AAS submodels and autonomously executes skills through an Information Technology/ Operational Technology (IT/OT) interface. The framework is implemented and quantitatively evaluated on the SmartFactory Kaiserslautern (SFKL) testbed, where BT loading time measurements from the AAS and robustness tests under induced skill failures confirm reliable runtime deployment across IT/OT layers.

Keywords: behavior trees, smart manufacturing, cyber-physical systems, asset administration shell, distributed and modular control

Middleware-Driven Vision Offloading for Mixed Reality Assisted Robotics

Csaba Hajdu[1], Zoltán Szilágyi[2], Péter Galambos[3], and Károly Széll[2]

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Abstract. Extended reality (XR) is increasingly used in industrial robotics for spatial visualization and interaction. However, performing fiducial marker–based vision processing directly on XR devices often leads to increased latency, unstable performance, and inefficient resource utilization.
This paper presents a middleware-driven vision offloading architecture for XR-assisted industrial robotics. Raw camera data are streamed from the XR device to an external middleware unit, where marker detection and spatial registration are performed, while the XR device remains a lightweight sensing and visualization endpoint.
The proposed system integrates XR devices and industrial robots through a hybrid ZeroMQ, MQTT, and ROS 2 communication framework. Experimental validation evaluates processing latency, end-to-end delay, and temporal stability during continuous operation. Results show that middleware-based vision offloading improves performance predictability and resource management, supporting more scalable XR-assisted robotic systems.

Keywords: mixed reality (XR), industrial robotics, middleware-based vision offloading, marker-based spatial registration

Mixed Reality–Based Spatial Task Definition and Reward Shaping for Deep Reinforcement Learning in Robotics

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Abstract. Configuring robot learning tasks and shaping motion behavior typically require expert knowledge and manual adjustment of environment parameters and reward functions. These configurations are often tightly coupled to specific task layouts and safety constraints, limiting reuse and transfer. Mixed Reality (MR) offers an intuitive way to specify spatial information directly in the robot workspace, yet its integration into Deep Reinforcement Learning (DRL) remains limited. This paper presents a system-level approach that integrates MR into DRL as a spatial interface for task specification and semantic guidance, while leaving the learning algorithm unchanged. Using a HoloLens-based inter-face, targets, obstacles, and semantic regions are defined at real scale in the physical workspace and transferred to the learning environment as static parameters, ensuring spatial consistency between simulation and real execution.
Three use cases demonstrate pipeline correctness, generalization across multiple task layouts, and semantic reward shaping. Simulation and real robot experiments confirm practical applicability and show that MR-based spatial alignment reduces simulation-to-real transfer effort.

Keywords: deep reinforcement learning, mixed reality, robot task specification, semantic reward shaping

AI-Driven Cloud–Edge Data Pipelines for Proactive Maintenance and Operation in Automated Manufacturing

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Abstract. This paper presents a cloud–edge platform designed to simplify the analysis of data and logs generated within organizational and operational environments. The platform addresses scenarios in which large volumes of heterogeneous data remain underutilized due to the complexity or absence of suitable analysis tools. By distributing data acquisition and preprocessing at the edge while leveraging cloud-based storage and analytics, the proposed architecture enables scalable, efficient, and privacy-aware data handling across the computing continuum.

The platform is designed to empower domain experts without programming expertise to create and deploy custom workflows for tasks such as monitoring, preventive maintenance, and fault detection. This is achieved through a graphical workflow builder based on Domino, integrated with Apache Airflow as a robust execution backend, together with an automated, LLM-based component capable of translating free-text user descriptions into executable workflows. The AI-driven composer operates iteratively, incorporating user feedback to refine generated pipelines until they meet operator expectations, thereby combining automation with human oversight.

The approach lowers the barrier to advanced data-driven practices, improves system reliability, and reduces operational downtime. Industrial laser cutting systems serve as the representative application domain, where the platform supports continuous, unattended operation by automating condition monitoring tasks such as nozzle damage detection from image data. The work aims to deliver secure, trustworthy, and explainable data pipelines across heterogeneous computing environments.

Keywords: AI, LLM, manufacturing, laser cutting, cloud–edge computing, workflow automation

Technical session 3

Robot kinematics and motion control II

Design of a Bipedal Locomotion Mechanism for Obstacle Avoidance

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Abstract. This research presents the conceptual design of a novel leg mechanism intended for a bipedal robotic locomotion system capable of crossing over obstacles. Multiple mechanism configurations are systematically evaluated from both structural and functional perspectives to identify an efficient and practical solution. Based on this comparative analysis, a leg mechanism is proposed that emphasizes mechanical simplicity, cost-effectiveness, and ease of operation. The proposed design is assessed through kinematic modeling and virtual simulations to verify its motion capabilities and obstacle-crossing performance. Simulation results demonstrate the feasibility of the mechanism for integration into a bipedal robotic platform designed for stable and efficient locomotion in environments with obstacles. The study contributes a viable low-complexity alternative for bi-pedal mobility systems intended for practical engineering applications.

Keywords: human locomotion, biped mechanisms, obstacle avoidance, biped mechanism

Abstracts of RAAD 2026
35th International Conference on Robotics in Alpe-Adria-Danube Region
June 17 – 19, 2026, Bratislava, Slovakia

Physics-Based Collision-Free Motion Planning in RobotBlockSet Using OMPL and MuJoCo*

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Abstract. This paper introduces a new extension to the RobotBlockSet (RBS) framework that integrates physics-based collision detection from the MuJoCo engine with the Open Motion Planning Library (OMPL) to enable advanced collision-free motion planning for robotic manipulators. Building on previous RBS capabilities – smooth path generation, spline- and RBF-based interpolation, and time-optimal trajectory parameterization – we augment the framework with a unified planning module that supports OMPL's sampling-based and optimal planners. The module provides efficient state-space construction, bi-directional conversions between OMPL states and RBS joint vectors, and MuJoCopowered state validity checking using contact information. Additionally, it supports clearance inflation and multi-robot scenes, producing both raw planner paths and smooth interpolated motion profiles. A case study on a robotic manipulator demonstrates that the integrated system can compute collision-free paths in cluttered environments and transform them into time-optimal trajectories using existing RBS methods. The results confirm that physics-based collision checking significantly improves safety, robustness, and planning reliability, positioning RBS as a comprehensive framework for modern robotic motion planning.

Keywords: robotic motion planning, physics-based collision checking, OMPL, MuJoCo, trajectory generation

* This work was supported by DIGITOP, GA no. TN-06-0106, funded by Ministry of Higher Education, Science and Innovation of Slovenia, Slovenian Research and Innovation Agency, and European Union - NextGenerationEU, and by Slovenian Research Agency grant P2-0076.

Residual Physics-Informed Neural Networks for Joint Parameter Identification in Belt-Driven Robotic Systems

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Abstract. Accurate identification of dynamic parameters in robotic joints is essential for model-based control. Traditional methods struggle with belt-driven transmission systems where friction and compliance effects dominate dynamics and violate standard modeling assumptions. This paper presents a residual Physics-Informed Neural Network (PINN) architecture that addresses a critical limitation of standard PINNs: the tendency to memorize input–output mappings rather than learning physically meaningful parameters. Our architecture explicitly decomposes measured torque into a physics-based component (with learnable inertia and damping parameters) and a neural network residual capturing unmodeled dynamics. After validating the method on a simulated PMSM motor system we validate the approach on the Solo-12 quadruped robot's hip flexion/extension joints using multiple datasets with varying sampling rates. The method provides interpretable parameter estimates directly applicable to model-based control while offering insights into the dominant dynamics of belt-driven transmissions.

Keywords: physics-informed neural networks, parameter identification, robot dynamics, belt-driven transmission, solo robot

Autonomous Overtaking Trajectory Optimization using Reinforcement Learning and Opponent Pose Estimation

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Abstract. Autonomous overtaking represents one of the most challenging maneuvers in self-driving and autonomous racing systems due to its inherently dynamic, adversarial, and safety-critical nature. This paper presents an integrated framework for autonomous overtaking trajectory optimization that combines reinforcement learning (RL) with real-time opponent pose estimation via sensor fusion, and validates the approach in both simulation and real-world experiments on an F1TENTH racing platform.

The proposed system consists of two tightly coupled components: opponent pose estimation using multi-sensor fusion and a multi-agent reinforcement learning (MARL) controller for overtaking. Opponent pose estimation is performed by fusing measurements from a Hokuyo 2D LiDAR and an Intel RealSense depth camera using an Unscented Kalman Filter (UKF). The LiDAR employs a clustering and rectangle-fitting algorithm to estimate the opponent's 2D position, while the depth camera uses a YOLO-based object detection to identify the opponent vehicle and estimate its distance based on bounding-box geometry and depth data. The UKF fuses asynchronous measurements into a continuous state estimate, enabling robust opponent tracking at a control-relevant frequency while addressing LiDAR's cluster ambiguity and camera's field of view limitations.

For decision making and control, a reinforcement learning algorithm is employed in a multi-agent racing environment using Proximal Policy Optimization (PPO). The RL policy outputs continuous steering angle and velocity commands and is trained using observations that include reduced LiDAR scans, agent and opponent odometry, and future waypoints derived from a precomputed optimal racing line. The reward function is specifically designed to encourage efficient and safe overtaking behavior. The system is trained in simulation using the F1TENTH gym environment and subsequently deployed on a real-world F1TENTH vehicle. Experimental validation using a motion-capture ground truth system demonstrates that the fused UKF pose estimate achieves root mean square errors of 0.0816 m and 0.0531 m in the longitudinal and lateral directions, respectively. Real-world experiments confirm that the trained RL agent can successfully execute overtaking maneuvers without collisions under conditions similar to those seen during training.

Keywords: reinforcement learning, autonomous racing, sensor fusion, LiDAR, depth camera, YOLO

Technical session 4

Future manufacturing and robotic technologies powered by AI II

Design and Validation of AMR-based Tool Distribution in Aerospace Manufacturing: A Case Study

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Abstract. This paper presents a methodical approach to the optimization and subsequent automation of tool set distribution in a high-precision aerospace manufacturing environment. The study focuses on the transition from manual, decentralized tool preparation to an automated system employing Autonomous Mobile Robots (AMRs). The methodology includes detailed process analysis, the design of a centralized "Tool-room," and the verification of robotic suitability through discrete event simulation and complex AMR simulation. Results indicate that the proposed robotic integration increases CNC machine utilization by 14.8% and eliminates 180 minutes of non-value-added operator tasks per shift. The findings provide a robust framework for implementing autonomous logistics in brown-field production facilities.

Keywords: autonomous mobile robots, process optimization, manufacturing automation, discrete event simulation, tool management, aerospace industry

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35th International Conference on Robotics in Alpe-Adria-Danube Region
June 17 – 19, 2026, Bratislava, Slovakia

LLM-based Integration of Contextual Knowledge in Natural Language Commands for Enhanced Robot Programming

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Abstract. Natural language is an intuitive interface for non-expert robot programming, but remains unreliable due to speech recognition errors and linguistic ambiguities. As users issue commands based on their expectations of the robot and its environment, the commands may conflict with the programming system's constraints. Rather than generating robot programs directly, we solve these conflicts by enriching the commands with context about the natural language programming system. We introduce context-based command refinement: first, a speech recognition module transcribes the spoken command, and a large language model (LLM) refines it using the context of a given programming system. The refined command remains natural while being optimized to meet the programming system's expectations, enhancing the quality of program synthesis. Thereby, the programming system preserves predictability and formal correctness while the LLM expands the range of admissible inputs. We distinguish between static and dynamic context. Static context is fixed for a given programming system, such as robot operation or linguistic knowledge. In contrast, dynamic context (e.g., the workplace or the robot's state) changes during execution.
We evaluate the impact of contextual refinement on programming correctness using spoken commands collected in a user study (N = 22). Participants issued 176 spoken commands across eight tasks with varying programming complexity. We analyze whether the knowledge-based system synthesizes a correct program from each command, comparing raw transcriptions with static and dynamic context enrichment. Only 8.5% of the raw transcriptions lead to correct robot programs. Incorporating static context reduces abstraction and syntax errors during program generation, increasing correctness to 22.7%. Further incorporating dynamic context improves correctness to 49.5% by resolving ambiguous object references and grounding commands in the environment. Increasing contextual information reduces linguistic richness, but allows for more reliable program synthesis. Our results indicate that contextual command refinement effectively improves the performance of existing programming systems. Additionally, the amount and specificity of context are relevant

Keywords: natural language robot programming, context, semantic enhancement, instruction refinement, human-centered robotics

Determination of Stable Conditions for Robotic Milling to Reduce Vibrations

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Abstract. Manufacturing tasks and production requirements are increasingly emerging, where it is advantageous to use the kinematic structure of an industrial robot. The presented paper is devoted to the results of our own research and map the application possibilities of multi-axis robotic milling in industrial practice. This paper focuses on robotic milling and the effect of technological parameters on the final operation conditions of robotic arm, aiming to determine stable conditions and setting for robotic milling from vibrations point of view. The presented results of research activities focused on robotic milling of a selected raw material (plastic Corian and aluminum alloy EN AW-6060 T6) were achieved in the experimental milling process under different technological conditions using a robotic arm. In our experiment, we used an ABB IRB 1100 robotic arm with a payload of 4 kg and a maximum reach of 0.58 m. During the robotic milling experiment, parameters were recorded, through which it was possible to evaluate the operating states of the robotic arm during milling. The manufactured surfaces were subjected to surface roughness determination. From the measured surface roughness data and the recorded vibration values of the robotic arm, it was possible to define direct functional dependencies of surface roughness and vibration frequency on changes in the technological parameters of the robotic milling process (spindle speed, feed per tooth, and depth of cut). These dependencies were the basis for defining application frameworks and intervals for robotic milling, and will allow for the management and control of the robotic milling process.

Keywords: industrial robot, milling, vibrations, surface roughness, technological parameters, spindle speed, feed per tooth, depth of cut.

A Survey on Soft PLC Integration within Modern Robotic and Industrial Control Architectures

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Abstract. The technological basis of industrial automation and robotic control systems has been traditional programmable logic controllers (PLCs) for a long time, especially where deterministic timing is necessary and high reliability of operational performance is required. However, modern industrial and robotic systems tend to be more defined by their closer association with information technologies, increased computational load, better diagnostics, and distributed structures. This has led to renewed interest in software-based programmable logic controllers (Soft PLCs), which use control logic as software to be executed on general-purpose computing platforms. Soft PLC architectures have better flexibility, modularity and integration features when compared to those of hardware-constrained PLC solutions. Meanwhile, their appropriateness to industrial and robotic settings is still the topic of debate particularly in terms of deterministic behavior, real-time performance, fault tolerance, certification issues, and long-term system stability. The paper is a thematic review of Soft PLC technologies in the perspective of industrial and robotic control architectures. The paper explores the principles of architecture, model of execution and real-time strategies and compares the application of Soft PLC with conventional PLC systems in terms of timing determinism, reliability, integration features, and deployment limitations. The paper aims to provide a systematic framework of assessing the realistic potential of Soft PLCs in modern robotic and industrial automation systems and to establish the existing gaps that require future research by synthesizing the existing literature and industrial practice.

Keywords: soft PLC, industrial automation, robotic system integration, timing determinism, Industry 4.0, fault tolerance, control system reliability

Educational Use of Industrial Simulation Tools in Digital Factory and Robotics-Oriented Study Programs

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Abstract. Industrial simulation tools are essential in modern engineering education, specifically within industrial engineering, robotics, and cybernetics. This paper analyzes student learning outcomes from structured assignments in Tecnomatix Process Simulate and Plant Simulation at the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava.
We detail pedagogical objectives, typical assignments, and the technical competencies developed during the semester. Using student work examples and multi-semester performance data, we evaluate the educational impact. The results demonstrate that combining continuous and discrete event simulation significantly enhances industrially relevant analytical, programming, and system-integration skills.

Keywords: industrial simulation, digital factory, engineering education, process simulate, plant simulation

Technical session 5

Mobile, aerial (UAV) and swarm robotics

Framework for Coordination of Heterogeneous UAV's

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Abstract. A natural development in the field of drone-based environmental monitoring is to enhance the method's effectiveness through parallelization. Swarm robotic drones are increasingly a focus of research in this area. Several works address this issue[4]. But these are homogeneous closed systems. This work aims to integrate multiple devices into a single functional solution. It was created as a result of the international Silvanus H2020 project. This work presents a comprehensive and tested framework for coordinating drones, with support for loading *.klm files. It also introduces the integration of no-fly zones to protect selected environments during an intervention. All of this has been tested in several real-world environments across different countries.

Keywords: multitrajectory, swarm robotic, drone

Controlling the Distribution of UAVs using Artificial Pheromone Tags: Parameter Tuning

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Abstract. As a result of global warming and changing climate conditions, we are facing increasingly severe weather fluctuations. In addition to other disasters, large-scale fires are occurring more frequently. One of the important means of fighting fires is their monitoring. This work offers a framework focused on long-term, scalable automated monitoring of areas of interest. The basic idea is to use swarms of autonomous drones that behave like reactive agents. They are coordinated only using pheromone marks and, in this way, ensure optimal long-term spatial distribution. The article describes the swarm setup and the evaluated experiments.

Keywords: monitoring, swarm coordination

Setpoint Control for Wheeled Mobile Robots Using Geometry-Conforming Model Predictive Controllers*

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Abstract. Although wheeled mobile robots are a mass-produced commodity nowadays, precisely driving them to desired setpoints remains a challenging control task. The nonholonomic constraints inherent to such systems reduce the number of instantaneously feasible motion directions, which significantly complicates controller design. By employing concepts from sub-Riemannian geometry, however, the geometric structure of nonholonomic systems can be systematically incorporated into optimization-based control schemes. This paper combines sub-Riemannian geometry and model predictive control, resulting in geometry-conforming control schemes capable of governing very generic configurations of wheeled mobile robots, thereby extending our previous work. The functionality of the proposed control scheme is demonstrated by parking a car-like robot to a sophisticated configuration in simulation and a real-world experiment.

Keywords: wheeled mobile robots, nonholonomic systems, MPC

* This work is supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Grants 433183605 and 545246093.

Risk-minimizing Planning in Partially Controlled Multi-Agent Systems

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Abstract. During task execution in multi-agent systems (MAS), cascading effects can propagate faults across task operations. Specifically, a fault during the execution of one operation may invalidate previously completed operations, thereby increasing its total impact. These cascading faults compromise safety and efficiency, necessitating strategies for mitigation. In partially controlled MAS, such as human-robot collaboration (HRC), only some agents can be actively controlled. Uncontrolled agents may act according to different, possibly non-deterministic strategies. Therefore, planning in these MAS is only feasible for the controlled agents. In this paper, we present a graph-based approach to model fault cascades by introducing cause-effect graphs (CEGs). These graphs explicitly capture direct fault dependencies between operations and allow the estimation of first-order cascading fault risk, measured by the expected number of operations invalidated per fault. Based on the CEG and the underlying task model (represented as a precedence graph), we formulate a planning problem that aims to minimize this risk, taking the current task state and cascading effects into account. To solve this problem, we introduce a dynamic Monte Carlo Tree Search (MCTS) planner that models the task execution as a sequential decision process represented as a search tree. The planner takes relative differences in execution speed between agents into consideration, by integrating probabilistic turn assignment based on that disparity. This allows the planner to approximate asynchronous execution between agents without explicitly modeling execution times or temporal constraints. In addition, a strategy-aware selection is used during the tree search, modeling behavior of uncontrolled agents, such as random, cooperative or antagonistic strategies. Experimental evaluation on randomly generated synthetic task scenarios demonstrates that the proposed approach consistently reduces cascading fault risk compared to random and greedy baselines while remaining robust across varying task sizes, agent speeds, and uncontrolled agent strategies.

Keywords: scheduling, risk minimization, fault prevention, human-robot collaboration, planning under uncertainty

Decision support system for selecting the optimal structure and parameters of a group of mobile robots*

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Abstract. A decision support system has been developed to select the optimal structure and parameters of a group of mobile robots, the configuration of which is determined by the mobile platform and auxiliary components. Within the framework of the decision support system, a method of multicriteria optimization of the group composition and agent parameters has been developed. Two concepts for the selection of importance coefficients in the course of multi-criteria optimization are proposed. The first concept evaluates regions of a parametric space by "intensity" (how many configurations have been tested) and "quality" (how dominant the configurations are). Areas with a high total score are considered the most promising to search for. The second concept evaluates the voids between non-dominant configurations in the criteria space, where a greater distance between them makes the area more promising. A methodology has been developed for analyzing the preference of options obtained as a result of multi-criteria optimization using sensitivity assessment of non-dominant options. Various ways of normalizing the values of criteria in sensitivity analysis, as well as various sensitivity metrics, have been investigated. The influence of parameter uncertainty on the choice of the best solution when using various sensitivity metrics is investigated. The adaptive strategy for selecting importance coefficients significantly reduces the number of required optimization iterations compared to uniform weighting. Sensitivity-based ranking improves robustness of the final selection under uncertain preference information. The geometric mean and rank–sum metrics provide balanced and robust decision.

Keywords: mobile robot group composition, multi-criteria optimization, decision support system, genetic algorithm

* The investigation funded by grant of the Russian Science Foundation № 24-49-02073, https://rscf.ru/project/24-49-02073/ using equipment of High Technology Center at BSTU named after V.G. Shukhov.

Deep Learning-based Algorithm for Detection of Cyber-attacks on Mobile Robot with Visual Servoing Controller

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Abstract. The unpredictable global situation is prompting manufacturing systems to transition to Industry 4.0 to meet increasingly customized demand. Industry 4.0 reinforces the idea of interconnected Cyber-Physical Systems (CPS) that use their communication abilities to perform manufacturing tasks collectively. However, these new communication capabilities introduce new possible threats in the form of cyber-attacks on machine tools, mobile robots, and other manufacturing equipment. Therefore, in this paper, we develop a deep learning-based model for detecting cyber-attacks on a mobile robotic visual controller. The deep learning model consists of a feature extraction encoder based on the ResNet model. The output of the feature extraction network is used for binary classification to determine whether images streamed to the mobile robot are tampered with (cyber-attacked). The final class of the input is determined by analyzing the Mahalanobis distance of a new datapoint and determining whether it is out of distribution relative to the training data. The network is trained on our custom dataset generated within a laboratory environment. The experimental evaluation is performed on the PAL TIAGo mobile robot with a position-based visual servoing controller.

Keywords: convolutional neural networks, mobile robot, cyber-attack detection, cyber security, Industry 4.0, Visual Servoing

Technical session 6

Sensing and information – control systems

Object Distance Estimation from Electromagnetic Interactions in Robotics

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Abstract. Estimating an object's distance from electromagnetic wave interactions is critical for robotic perception – especially in scenarios with occlusion or degraded visibility. Traditional radar systems rely on handcrafted signal processing pipelines which limit adaptability to novel sensor configurations. In this work, we present a hybrid approach that combines lightweight signal processing with a data-driven inverse mapping from transmit–receive wave measurements to object distance. We first transform raw signals, FMCW radar intermediate-frequency signals and S-parameters, into the frequency and time domain, respectively, applying peak detection and Hamming windowing to extract propagation path features. These features are then used to train Gaussian Process Regression models that predict object coordinates with uncertainty estimates. We evaluate the method on both simulated S-parameters and measured radar data designed to emulate future flexible electromagnetic skins. The results demonstrate enhanced sensing modalities and inherently learned geometry of the sensor, highlighting the potential of combining minimal signal preprocessing with probabilistic learning for general-purpose robotic electromagnetic perception.

Keywords: Gaussian processes, radar, S-parameters, distance estimation

Abstracts of RAAD 2026
35th International Conference on Robotics in Alpe-Adria-Danube Region
June 17 – 19, 2026, Bratislava, Slovakia

Robot Assisted Freehand Ultrasound Scanning for 3D Blood Vessel Model Reconstruction

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Abstract. This paper presents a system for three-dimensional (3D) visualization of blood vessel models based on robotically guided freehand ultrasound scanning. Using the Franka Emika Panda collaborative robotic arm, the Mindray Consona N6 Pro ultrasound system, and a medical phantom, *3D freehand* ultrasound imaging was performed. A software processing pipeline was implemented that includes segmentation and visualization of blood vessels. The evaluation was conducted by comparing the obtained results with an adopted ground-truth blood vessel model, using the Dice coefficient as quantitative metrics. This work demonstrates the concept of integrating a collaborative robot with freehand ultrasound and freehand ultrasound diagnostics to ensure smooth ultrasound imaging with a constant speed of the probe and maintaining constant contact with the tissue during the process. The paper presents an initial step towards standardizing the freehand ultrasound imaging process and improving the quality visualization of the vascular structure.

Keywords: ultrasound, collaborative robot, contact tasks, 3D visualization, robotic scanning

A Survey on Neuromorphic Vision Systems in the Perception of Industrial Robotics

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Abstract. Industrial robotics within industry 4.0 operate under strict constraints of latency, robustness and energy requirements, especially in high-speed and dynamically illuminated environments. Conventional frame-based vision systems have been unable to achieve these requirements because of motion blur, fixed exposure times and redundant data acquisition. Event-based cameras are also known as neuromorphic vision systems which provide an alternative sensing paradigm with an asynchronous reporting of a per-pixel brightness change at a microsecond temporal resolution with a high dynamic range. These features grant event-based vision a prospective technology for industrial robotic perception. This article presents a review of thematic narrative survey of neuromorphic vision systems in the domain of industrial robotics. The study discusses basic sensing concepts, event representations, processing models and learning methods, and discusses how they have been applied to major robotic tasks such as localization and mapping, high-speed manipulation, navigation, safety and new industrial inspection problems. In addition, widely used evaluation metrics and reporting practices are evaluated, and significant barriers to industrial adoption, including the unavailability of standardized benchmarks, hardware limitations and deployment factors, are addressed. This survey is expected to serve as a systematic guide for researchers and practitioners by summarizing previous studies, uncovering gaps in the literature, and assisting to establish future experimental benchmarking and industrial applications for event-based vision systems.

Keywords: event-based cameras, neuromorphic vision systems, industrial robotics, Industry 4.0, high-speed perception, dynamic illuminance

A Biologically Inspired Vision–Language Pipeline for Explainable Scene Reconstruction from RGB Data

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Abstract. This paper presents a biologically inspired vision–language pipeline for explainable scene reconstruction from RGB data, motivated by fundamental principles of human visual perception and cognition. Conventional machine vision systems, predominantly based on deep convolutional neural networks, achieve high performance in recognition and reconstruction tasks but often suffer from limited interpretability, high data dependency, and weak generalization outside trained domains. In contrast, the proposed approach draws inspiration from natural vision, where perception emerges from the integration of low-level sensory cues, spatial reasoning, memory, and linguistic abstraction. The core idea is to couple RGB-D perception with a vision–language model that transforms visual observations into structured linguistic attributes describing objects, spatial relations, geometry, and context. These attributes act as an intermediate, human-interpretable representation that enables explainable scene understanding and supports higher-level reasoning and decision-making in robotic systems. The pipeline integrates biologically motivated stages, including feature grouping, depth-based spatial organization, object-centric representation, and semantic grounding through language. To validate the concept, the paper outlines an experimental framework comparing classical image reconstruction techniques implemented in MATLAB with vision–language-based reconstruction and interpretation. Evaluation focuses on reconstruction fidelity, robustness, computational efficiency, and explainability. The results demonstrate that linguistic scene representations can effectively complement geometric reconstruction, providing transparency and semantic richness that are difficult to achieve with purely numeric models. The proposed vision–language pipeline contributes a novel, cognitively inspired direction for artificial and robotic vision, bridging perception and language to achieve interpretable, flexible, and human-aligned scene understanding from RGB-D sensory data.

Keywords: vision–language models, explainable robotic vision, biologically inspired perception

Classification of Contact Type Based on the Magnetic Field Data for Tactile Sensor

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Abstract. This paper presents a machine learning approach for real time contact geometry classification for an magnetic tactile sensor array used in a robotic hand. Tactile sensing capabilities are essential for dexterous manipulation tasks that humanoid robots need for entering the workforce. For testing the developed sensor a reproducible methodology was developed for classifying point, line and surface contacts. An array of 16 3D Hall-effect sensor is used to detect the change in the magnetic field as the magnets that are suspended in silicon are displaced due to contact on the sensor surface. To collect data the framework employs a CNC milling machine that is used to systematically press custom designed contact profiles against the sensor array. Multiple classifiers architectures are evaluated offline to demonstrate the adaptive nature of the proposed methodology. Results demonstrate that narrow neural network classifier with a single hidden layer od 10 neurons can achieve optimal performance, reaching 99.5% validation accuracy for three-class classification (point, line, surface) and 99.1% for four-class classification (including no contact), with a compact model size of 15 kB suitable for microcontroller deployment.

Keywords: tactile sensing, magnetic sensors, contact classification, machine learning

Development of the Test Facility for Wireless Pressure Sensors

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Abstract. This paper presents the design and evaluation of a specialised test platform for verifying a novel wireless force and pressure sensor – the main contribution of this research. Because the sensor operates on electromagnetic field changes within an integrated LC circuit, all mechanical components within 50 cm must be made from low-permittivity dielectric materials. This excludes conventional metal-based test rigs.

Three loading approaches were examined: hydrostatic loading, gravity-based systems, and a compliant mechanism tool. Hydrostatic loading provides repeatability and symmetric pressure but requires impermeable prototypes, which are unsuitable in early development. FEM simulations of a gravity-based system revealed insufficient load symmetry and divergent plate displacements, leading to brittle failure of the sensor's glass plates.

The study, therefore, proposes a planar compliant mechanism with multi-lever kinematics as a superior HIL testing method. It converts *10–25 mm* input strokes into precise approx. *250 µm* displacements matching the sensor's glass plate deflection. The mechanism ensures symmetric amplification and parallel motion, preventing damage and effectively replacing uniform pressure loads. A stiffness model based on the compliant matrix method was developed to relate load and displacement.

Integrating this tool into the Model-Based Design workflow enables robust verification of the sensor's mathematical models. Future work will optimise the multi-lever kinematics and experimentally characterise the prototype. The research establishes a necessary framework for testing next-generation wireless sensors under strict electromagnetic constraints.

Keywords: compliant mechanism, wireless force/pressure sensor, test bed, mathematical modelling

Technical session 7

Medical, rehabilitation and surgery assisting robots

Abstracts of RAAD 2026
35th International Conference on Robotics in Alpe-Adria-Danube Region
June 17 – 19, 2026, Bratislava, Slovakia

Visual Servoing Based Patient Movement Compensation for Prostate Biopsy Procedure

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Abstract. Prostate cancer remains a major global health concern, and accurate transrectal ultrasound (TRUS)–guided biopsy requires substantial clinical expertise. During the procedure, unintended patient motion can cause prostate displacement, forcing clinicians to continuously readjust the ultrasound probe and increasing cognitive workload. To address this challenge, we propose a robotic system for prostate biopsy that compensates for patient movement using a visual servoing strategy inspired by clinical practice.

The experimental setup consists of two robotic manipulators, an ultrasound system, and a prostate phantom. One robot holds a TRUS probe and performs automated prostate sweeps, while the second robot manipulates the phantom to simulate patient motion. Prostate segmentation is performed in real time using a modified MicroSegNet model to extract gland contours, while urethra segmentation is obtained using YOLOv8 to provide a stable anatomical landmark for registration and tracking. Each acquired ultrasound frame is stored together with probe pose information, enabling 3D reconstruction of the prostate as a point cloud.

To compensate for motion perpendicular to the probe, a force controller maintains constant probe–tissue interaction. For motion along the probe axis, we introduce a clinically inspired recovery strategy: once displacement is detected, the robot re-identifies the urethra, performs a short urethra-focused sweep, and registers this data to the previously reconstructed prostate model. This registration allows the system to reposition the probe and resume scanning while maintaining consistent spatial alignment.

We evaluated the approach using simulated phantom displacements of 5, 10, and 20 mm, with 30 trials per case. Movement compensation accuracy was assessed by registering prostate point clouds reconstructed before and after displacement using the Iterative Closest Point algorithm. Results showed consistently high registration fitness values above 0.99, low inlier RMSE (0.13–0.19 mm) and minimal rotational deviation. Translational errors remained below *1 mm* on average, indicating that the proposed system can reliably restore the original probe–prostate alignment after motion.

Keywords: robotics; motion compensation; visual servoing; machine learning

Structural Optimization and Prototype Development of a Lower-Limb Exoskeleton for Human Gait Rehabilitation

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Abstract. This extended abstract presents an integrated workflow for developing a manufacturable lower-limb exoskeleton for gait rehabilitation, linking kinematic synthesis to prototype-ready CAD, multibody dynamics (MBD) evaluation, and finite element (FE) structural optimization. Practical devices still face barriers related to safe human–robot interaction, joint alignment and comfort, personalization, and objective performance assessment; therefore, design pipe-lines should connect biomechanically compatible mechanisms with simulation-driven load prediction and structurally efficient parts. The proposed device is based on a planar linkage with nine rigid links and fourteen revolute joints, leading to a single-input actuation layout. Two identical leg mechanisms are mounted on a common frame; step alternation is obtained by assembling the left and right driving links with a 180° phase shift. The architecture is first defined as a planar kinematic scheme and then transformed into a 3D stick-model and a manufacturable CAD assembly prepared for rapid prototyping (3D printing and assembly constraints). Dynamic assessment is performed in MSC.ADAMS using a coupled exoskeleton–human mannequin model. The hip, knee, and ankle joints are aligned with the corresponding exoskeleton revolute pairs to ensure kinematic compatibility and avoid artificial constraint forces. Foot–ground interaction is represented by an impact-based contact model with compliant normal forces and dissipation; the foot is approximated by a heel sphere (heel strike) and a forefoot cylindrical element (rolling/push-off). The simulations provide joint-angle histories and joint reaction forces that are subsequently used as structural load cases. The simulated kinematics exhibit gait-like periodic patterns comparable to healthy reference trends: hip motion ranges approximately between +15° flexion and −25° extension, while the knee reaches about 60–65° peak flexion and returns near full extension (~0°) during stance. ADAMS-predicted joint reaction forces show repeatable peaks associated with gait phases, enabling consistent loading extraction. Following MBD, a key clevis-type connecting link is optimized in ANSYS Workbench. A parametric CAD model is controlled through geometric design variables (main lengths, thickness-related dimensions, local radii), while structural responses include maximum deformation, maximum von Mises stress, and mass. Response surfaces from a design-of-experiments study are combined with a Multi-Objective Genetic Algorithm (MOGA) to identify a minimum-mass manufacturable solution that satisfies stress (and, when required, deformation) constraints under gait-related loads. Overall, the work advances from a linkage-based concept to a prototype-ready, 3D-printable exoskeleton leg solution supported by a consistent CAD–MBD–FE workflow. Future work will focus on experimental validation, optimization of additional load-bearing components, and

enhanced safety features (e.g., actuator overload protection and an emergency stop).

Keywords: lower-limb exoskeleton, gait rehabilitation, multibody simulation, structural optimization, rapid prototyping

Biomechanical Simulation of Neck Muscle Activations for Cervical Dystonia Assessment*

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Abstract. Cervical dystonia is a neurological movement disorder characterised by involuntary and sustained contractions of neck muscles, resulting in abnormal head–neck postures, tremor, and significant functional impairment. Due to the anatomical complexity and high redundancy of the cervical musculoskeletal system, identifying the specific muscles responsible for pathological postures remains a considerable clinical challenge. Current assessment methods rely largely on visual inspection and clinical experience, which may lead to variability in treatment planning, particularly due to imprecise identification of target muscles. In this work, we present a biomechanical simulation framework designed to systematically investigate the relationship between individual neck muscle activations and resulting head–neck postures. The approach is based on an anatomically detailed head–neck musculoskeletal model implemented in the OpenSim simulation environment. First, a physiologically consistent baseline neuromuscular control strategy was computed using inverse kinematics and computed muscle control to maintain an upright head posture under gravitational loading. This baseline state ensured dynamic consistency and realistic muscle activation patterns. Subsequently, forward dynamics simulations were performed in which individual muscles were selectively activated while maintaining baseline activations in the remaining muscles. This procedure enabled controlled analysis of the postural signatures associated with isolated muscle activations.
The resulting simulations yielded a structured dataset mapping specific muscle activations to the corresponding cervical joint kinematic patterns and global head orientations. This dataset provides the foundation for the development of learning-based classification methods aimed at autonomously identifying muscles contributing to dystonic head–neck configurations. The proposed framework represents a step toward objective, model-based muscle identification and establishes the basis for future extensions involving multi-muscle activations, patient-specific modelling, and data-driven clinical decision support.

Keywords: dynamical biomechanical head-neck model, musculoskeletal cervical model, muscular motor control, muscle activity identification, motion simulation

* Supported by the Slovenian Research Agency grant J2-60036.

Optimization of Robot Base Placement for Prostate Biopsy Planning

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Abstract. Precise positioning of robots is essential for ensuring safety and efficacy in robot-assisted medical procedures. In the context of prostate biopsy planning, incorrect positioning of the robotic base can hinder reachability, diminish dexterity, bring the system closer to joint limits, and heighten the likelihood of encountering kinematic singularities. Such constraints can adversely impact targeting accuracy and the overall reliability of the procedure. This research introduces a comprehensive framework aimed at optimizing the base placement of a KUKA LBR iiwa manipulator within a system designed for robot-assisted prostate scanning and biopsy planning.

Three complementary methodologies are explored and assessed comparatively. First, a reachability and manipulability evaluation based on capability maps is conducted to examine workspace coverage across various base configurations and tool orientations. This evaluation offers a comprehensive understanding of the robot's kinematic performance within the clinically relevant task space. Second, an automated optimization approach utilizing a genetic algorithm is employed to identify the optimal base position. This optimization incorporates tailored kinematic performance metrics specifically designed for prostate biopsy needs, which include dexterity, distance from singularities, and avoidance of joint limits.

Third, the robustness of the chosen configuration is analyzed by assessing kinematic feasibility within a defined spatial volume that simulates potential patient movement during the intervention.

The suggested framework facilitates a quantitative assessment of different robot placements and diminishes dependence on empirical, trial-and-error setup methods typically employed in clinical settings. By integrating performance optimization with robustness analysis, this methodology improves the reliability and safety of robot-assisted procedures. Experimental findings indicate a 72% enhancement in reachable target configurations when compared to non-optimized placement strategies. These results underscore the significance of systematic optimization of base placement in enhancing task feasibility and ensuring the reliable deployment of robotic systems in precision-guided prostate interventions.

Keywords: robot-assisted medical systems, robot base optimization, reachability analysis, genetic algorithm

Development of a Robotic System with Force Control for Dynamic Hip Screw (DHS) Insertion Procedure Towards Autonomous Orthopedic Trauma Surgery

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Abstract. Dynamic Hip Screw (DHS) fixation is a widely adopted surgical technique for treating intertrochanteric femoral fractures; however, the procedure remains highly dependent on surgeon skill and tactile perception, particularly during lag-screw insertion. Inadequate force regulation and trajectory deviations may lead to mechanical failure, cortical breach, or suboptimal fracture fixation. This work presents the design, simulation, and preliminary experimental validation of a robotic system with force-feedback control aimed at improving accuracy and safety during DHS insertion orthopedic trauma surgery. A six-degree-of-freedom collaborative robotic arm (MyCobot 320-M5) was integrated with a six-axis ATI Nano25 force/torque sensor and controlled through a ROS 2-based architecture. A hybrid position–force (admittance-based) controller was implemented to regulate insertion forces along the screw axis while maintaining precise trajectory tracking. The system was first validated in a Gazebo simulation environment, where force regulation and positional stability were assessed. Subsequently, experimental tests were conducted on synthetic femur bone models using a clinically relevant intramedullary lag-screw system. Simulation results demonstrated stable force convergence to predefined setpoints and accurate end-effector motion along the insertion axis. Experimental validation confirmed reliable force sensing and trajectory execution. The proposed system demonstrates the feasibility of integrating force-aware control into orthopedic robotic procedures, offering a low-cost and open-source platform for future research in robotic trauma surgery.

Keywords: force-feedback control, dynamic hip screw, surgical robotics, hybrid position-force control, ROS 2, Gazebo simulation, orthopedic trauma surgery, experimental validation

Implementation of Digital Twins in Unity with React Native and MQTT Communication for Rehabilitation Robotics

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Abstract. This paper presents a unified cross-platform digital twin system that integrates Unity 3D visualization, React Native mobile interface, and MQTT (Message Queuing Telemetry Transport) communication protocol for real-time control of a rehabilitation robotic device. The system addresses key challenges in cross-platform integration by providing seamless communication between the mobile application and the 3D digital twin while maintaining synchronization with physical rehabilitation equipment. By utilizing a state reconciliation protocol to resolve initialization disparities, our implementation demonstrates effective real-time bidirectional communication across heterogeneous platforms, enabling remote monitoring and control of an Artromot rehabilitation device through a unified digital twin architecture. The system ensures broad compatibility across a wide range of Android device generations and hardware architectures, providing intuitive touch-based controls with real-time visual feedback. Internal evaluations indicate high system responsiveness and baseline interface usability. The architecture demonstrated reliable operation in testing, effectively maintaining connection stability and state consistency across different devices.

Keywords: digital twin, mobile application, MQTT protocol, react native, rehabilitation robotics, unity 3D

Technical session 8

Innovative solutions of robotic applications I

Impact of Snow Cover on Mobile Robots Traversability in Urban Areas*

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Abstract. Recent developments in mobile robots have broaden their application to a wide range of domains, including operation in challenging outdoor environments. Nevertheless, the mobility of such platforms remains strongly dependent on terrain characteristics. In urban areas, uneven pavements, curbs, ramps, and stairs may significantly influence the ability of a robot to move safely and efficiently. The problem becomes particularly pronounced during winter, when snowfall alters the terrain structure and may reduce accessibility. Even if an area remains accessible to pedestrians, snow accumulation can degrade mobile robot traversability depending on the locomotion mechanism.

In this paper, traversability study is performed for two wheeled platforms Husarion ROSbot and Husarion Panther and one quadruped robot Spot. Traversability is estimated from 3D point clouds using local terrain slope and surface roughness derived via Principal Component Analysis. These components are normalized according to each robot's mechanical limits and combined into a unified traversability score. Preliminary laboratory experiments with obstacles of varying height validate the adopted method. The main analysis is performed on urban point clouds collected in snow-free and snow-covered conditions. In the results, a comparison of traversability between snow-free and snow-covered environments is presented. Comparative results show that snow affects the evaluated robots differently. The smaller wheeled robot exhibits a noticeable decrease in traversability, the larger wheeled platform shows only a slight reduction, and the quadruped robot remains largely unaffected.

The results confirm that locomotion mechanism plays a crucial role in winter operation and demonstrate that legged platforms provide greater robustness in snow-covered urban environments.

Keywords: mobile robots, quadruped robot, traversability, point cloud, snow-covered environments

* The research was funded by the Dean's Grant of the Faculty of Mechanical Engineering and Robotics at AGH University of Krakow, No. 16.16.130.942 (Grant 35), within the 2025 grant program.

Onboarding Developers into Robotics Ecosystems: A Modeling-Driven Approach with LLM Assistance

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Abstract. Onboarding developers into major software and hardware ecosystems remains a challenge. This is especially true for robotics, as robots are inherently complex and require expertise across many domains. Modern robot frameworks partition software components into reusable and dedicated sub-systems with well-defined interfaces and variation points. This reduces the complexity of individual building blocks and facilitates reuse, automation, and system modeling. This work proposes a modeling tool that enables the design and combination of reusable building blocks. We leverage its knowledge by combining it with a language model to build an LLM Agent. The agent uses the modeling tool to inspect, manipulate, and explain the building blocks. Component retrieval, documentation assistance, and answering questions reduce the entry barrier, improve efficiency, minimize errors, and enhance modeling. The agent is evaluated through developer onboarding scenarios in which new building blocks are created and existing ones of an autonomous tractor are inspected.

Keywords: developer onboarding, modeling, LLM agent, robot control software

Automation in Metamaterial Design Applied by Large Language Models - Case study

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Abstract. This paper presents research on the development of a sensory system suitable for robotic applications in specialized environments where wired connections between the sensor and the evaluation unit are not feasible. Sensors play a key role in Industry 4.0 and robotic systems, providing essential information about the operating environment. Some applications require miniaturized wireless sensors that eliminate wired connections between the sensing unit and the evaluation electronics. Our recent work focuses on sensing mechanical parameters using a wireless sensor system (Slovak utility model SK9895Y1, application number PUV 172-2022). The proposed approach is inspired by research on reconfigurable elastic metamaterials, which consist of unit cells arranged into complex structural architectures. Designing such structures usually requires extensive simulations to verify their mechanical behaviour. To accelerate this process, we propose a workflow that uses artificial intelligence methods to generate and optimize metamaterial structures.

In this work, Graph Neural Networks (GNNs) are employed because they naturally represent relationships between structural elements as nodes and edges in a graph. Through message passing between neighbouring nodes, the network learns representations that capture both local geometry and global structural context. This enables the generation of structural topologies that meet specific mechanical constraints. The generated structures are exported as STL models suitable for additive manufacturing. However, STL geometry is represented as triangulated surfaces, which complicates mesh generation for finite element method (FEM) analysis. Consequently, further methodological improvements are required to enable efficient mechanical simulations of the generated structures.

The main contribution of this study is an analysis of AI-assisted procedures for generating metamaterial structures using Python-based algorithms. The proposed GNN architecture generates frame-like structures whose behaviour is evaluated using a custom loss function that considers structural response under defined boundary conditions. The produced metamaterial bodies can be manufactured using additive technologies. Experimental validation was performed using ABS material available in our laboratory. The results demonstrate a proof of concept for AI-assisted design of metamaterial structures for sensing applications.

Keywords: metamaterial, sensor, wireless, solid body, large language models

An Integrated Robotics Framework for Inspection, Monitoring, and Cleaning of Photovoltaic Installations

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Abstract. Soiling, surface deposits, and localized faults can significantly reduce the energy yield of photovoltaic systems, while manual inspection and fixed cleaning practices are costly and inefficient for large-scale installations. This paper presents progress towards an integrated framework for condition-based maintenance that links monitoring and inspection with automated robotic cleaning. The proposed system employs UAV-based sensing and vision analytics to detect and localize soiling and defects, providing input to a decision layer that translates inspection results into prioritized cleaning tasks. Two prototype PV cleaning robots equipped with brush mechanisms are presented. Initial testing and evaluation provide insights into system performance and demonstrate the potential impact of these technologies on efficient maintenance of PV plants.

Keywords: robotic photovoltaics cleaning, photovoltaics maintenance, photovoltaics monitoring, UAV inspection

Abstracts of RAAD 2026
35th International Conference on Robotics in Alpe-Adria-Danube Region
June 17 – 19, 2026, Bratislava, Slovakia

Industrial Cleaning Robots in Dynamic AMR-populated Environments: A Case Study

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Abstract. Industrial automation has traditionally focused on improving the efficiency of direct production processes. Manufacturing companies have primarily aimed to increase productivity, reduce operational costs, and ensure stable product quality. In recent years, however, automation has increasingly expanded toward supporting processes that, although not directly value-creating, still have a strong influence on operational safety and system stability. Industrial cleaning represents one such activity, particularly in environments where multiple autonomous mobile robots (AMRs) operate simultaneously.

In AMR-based intralogistics systems, the condition of the floor surface directly influences navigation reliability, sensing performance, and the mechanical wear of robotic platforms. Dust and fine debris may accumulate in sensors and moving components, potentially affecting long-term operational stability. Despite these effects, industrial cleaning has traditionally remained a manual process with limited automation.

This paper presents a case study on the deployment of an industrial cleaning robot in a highly automated warehouse and production environment operating with autonomous mobile robots. The investigated facility operates a tote-to-person automated warehouse where multiple AMRs perform material handling tasks along dynamically changing routes. In this environment, manual cleaning between storage racks and in robot traffic zones represents a potential occupational safety risk due to continuous robot movement and limited visibility.

The study examines technological, safety-related, and operational aspects of integrating an industrial cleaning robot into this dynamic industrial environment. Particular attention was given to navigation reliability in narrow aisles, dynamic obstacle avoidance in shared workspaces, and predictable robot behavior in interaction with humans and other autonomous systems. The selected platform uses LiDAR-based mapping, camera-assisted localization, and multi-sensor obstacle detection to ensure stable operation in a changing industrial environment.

A structured pilot test was conducted under real industrial conditions to evaluate system behavior and operational reliability. During a representative cleaning cycle lasting 1 hour and 53 minutes, the robot covered an effective cleaning area of approximately 2528 m^2, corresponding to an effective coverage rate of about 1343 m^2/h. The results confirm that the system can operate reliably in narrow aisles and shared industrial spaces while adapting its motion to dynamic obstacles.

Beyond technological validation, the study also discusses the return on investment of industrial cleaning automation using a multidimensional perspective. In addition to direct economic effects, the analysis considers indirect technical impacts such as improved operational stability of AMR systems and occupational safety improvements through the elimination of manual cleaning in high-risk zones. The findings suggest that automated industrial cleaning can be effectively integrated into AMR-based environments and may contribute to improved work-place safety and long-term operational stability.

Keywords: service robotics in manufacturing, industrial cleaning robots, autonomous mobile robots (AMR), human–robot collaboration, return on investment

Care Lift Enabling "Two-Hand Support" Motion to Provide Reassurance to Care Recipients

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Abstract. This study presents the development of a care lift capable of performing a "two-hand support" motion, aimed at providing reassurance to care recipients and reducing physical burden on caregivers during transfer assistance in care facilities. Conventional lifts require simultaneous control box operation and wheelchair stabilization, leading to usability and safety concerns. We developed a new lift that enables intuitive, safe operation and arm movement synchronized with caregiver input, while also incorporating load measurement functionality. The effectiveness of the system was evaluated through demonstrations with therapists.

Keywords: care lift, wheel chair, biomechanics

Technical session 9

Innovative solutions of robotic applications II

Vision-Based Reconstruction of Silicon Ingots for Surface Resistivity Measurements

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Abstract. Vision-based diameter estimation systems are widely used during Czochralski growth of monocrystalline silicon, primarily for real-time process control. Although these systems also provide data for downstream activities, such as supporting resistivity measurements, their geometric accuracy has not been rigorously validated. This study investigates the reliability of diameter estimation by experimentally comparing theoretical three-dimensional reconstructions – obtained by revolving diameter profiles around the pull axis – with high-resolution 3D scans of real silicon ingot segments. Five ingots, differing in nominal diameter and length and originating from different crystals, were analysed under industrial conditions. Real geometries were acquired using structured-light 3D scanning and aligned with the corresponding theoretical models to enable point-wise deviation analysis. This approach allows a quantitative assessment of diameter estimation accuracy. In addition, the results show that such reconstructions can be effectively used to calibrate dimensional control actions and to support preliminary evaluations of surface roughness.

Keywords: vision-based inspection, silicon crystal, diameter estimation, 3D reconstruction, quality assessment

Robotized Assembly of Metal Panels using Compliant Vacuum-based End-effector

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Abstract. This paper presents a compliant robotized assembly solution for thin metal sheet lateral panels in household appliance manufacturing. The problem of repetitive precision insertion operations of deformable components and geometric tolerances is solved through mechanical compliance integrated into a vacuum-based end-effector design and guided motion strategy. A dual-point vacuum gripper with spacing depending on the assembled sheet size provides balanced gripping force of the robot while allowing controlled flexibility. Simulation analysis in ABB RobotStudio with 120 scenarios demonstrates stable operation for initial deviations up to 3 mm, achieving more than 90% success rate with insertion times under 3 seconds. Finite Element Method (FEM) analysis confirms overall elastic behaviour with von Mises stresses below 15 MPa. The results prove that effective compliant assembly can be achieved through simplified mechanical design and optimized kinematic parameters without the need for active robot force control.

Keywords: robotic assembly, passive compliance, vacuum gripper, elastic deformation, robot control strategy

Robotic Removal of Sand Residuals from Castings Using Reinforcement Learning

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Abstract. Removing sand residues from internal cavities of cast components poses significant challenges in manufacturing, particularly when access is limited to small openings. This paper presents a reinforcement learning-based approach for robot trajectory optimization to efficiently empty sand from enclosed casting geometries. We employ Proximal Policy Optimization in a simulation environment including sand particles to learn a joint-level control policy for a UR10 manipulator. The learned policy achieves excellent performance in terms of sand removal while respecting joint limits and avoiding self-collisions. Resulting position trajectories demonstrate that the policy discovers effective shaking motions with periodic patterns optimized for the specific casting geometry.

Keywords: reinforcement learning, robot manipulation, trajectory optimization, particle simulation

Real-Time Apple Detection and Tracking in Orchard Environments Using Deep Learning and Computer Vision

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Abstract. Accurate yield estimation in orchards requires reliable apple counting under challenging field conditions. While modern detectors such as YOLOv8 can localize apples efficiently, per-frame detection alone leads to double counting because fruits reappear across frames as the camera moves. We propose a real-time tracking-by-detection pipeline that combines fast deep-learning detection with robust multi-object tracking and lightweight appearance verification.
The system integrates a YOLOv8 detector with the ByteTrack tracker, which maintains track continuity by associating both high- and low-confidence detections, improving robustness under partial occlusions caused by foliage. To reduce identity fragmentation during abrupt camera motion, we extend ByteTrack with an ORB-based visual re-identification module: ORB descriptors are extracted from each detected bounding box and aggregated into a compact appearance representation. Association uses a hybrid cost that combines geometric overlap (IoU) with cosine similarity between appearance vectors. In addition, global camera motion compensation is applied by estimating an inter-frame homography from ORB feature matches using RANSAC, enabling correction of predicted track positions under UAV vibrations and viewpoint shifts.
We evaluated the approach on UAV orchard footage captured with a DJI Mavic 3 Multispectral platform (1920 × 1080, 30 fps, 450 frames). Due to the lack of frame-level ground truth annotations, a manual reference count of approximately 100 apples was used. The system produced 114 unique tracked IDs, corresponding to a net deviation of 14% relative to the manual count. Log-based inspection indicates the deviation is mainly driven by missed detections under extreme illumination and heavy occlusions rather than duplicate counting. An ablation study showed that global motion compensation is critical: disabling it increased the total count to 123 unique IDs, consistent with increased identity fragmentation under camera motion.
Overall, the proposed pipeline demonstrates practical real-time performance and robustness for apple tracking and counting in realistic orchard conditions.

Keywords: apple detection, object tracking, YOLOv8, ByteTrack, deep learning, computer vision, precision agriculture, real-time monitoring

Model-based Path Planning for Robotic Wire and Arc Additive Manufacturing of hybrid porous components

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Abstract. Wire and Arc Additive Manufacturing (WAAM) of hybrid porous (HyPo-) components requires path plans that simultaneously achieve near-net-shape geometry and prescribed porosity distributions – a capability largely absent from existing WAAM planning methods. This paper introduces a model-based path planning framework that treats porosity as an explicit design target alongside weld track geometry. The framework provides a pipeline from CAD design to executable robot trajectories for WAAM of HyPo-components. A planner proposes a near-net first-layer toolpath with bead, porosity, and thermal objectives. An iterative loop couples forward and inverted process models with a transient thermal simulation to synthesize parameters (energy, wire feed, speed), predict process outcomes, and adapt path parameters until the desired process results are met. During planning of consecutive layers, geometry and thermal state of previous layers is considered. Novelty lies in porosity as a design variable, tight thermal coupling, and layer-aware modeling, enabling accurate small-batch near-net fabrication. The distinctive contribution is a path planning method that embeds porosity-aware process models and thermal predictions into trajectory generation for WAAM of HyPo-components. While developed for WAAM, the methodology is designed for transfer to laser-directed energy deposition, supporting broader model-based planning and control of porous additive manufacturing (AM).

Keywords: WAAM, additive manufacturing, model-based path planning. HyPo-components

Design of a Constant-Force Mechanism for Stack Pressure Control in Solid-State Battery Modules

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Abstract. Stack pressure plays a critical role in maintaining mechanical contact and electrochemical performance in all-solid-state battery stacks. However, solid-state batteries inevitably undergo thickness variation during charge–discharge cycling, introducing displacement input to the pressurization system. From a mechanical perspective, a key challenge is to accommodate this displacement without inducing undesirable fluctuations in the applied compressive force. This paper presents a constant-force stack pressure module based on a double-slider constant-force mechanism as a passive solution to this problem. The proposed mechanism is designed to deliver an approximately invariant compressive force over a prescribed displacement range, thereby decoupling force transmission from battery expansion. A compact prototype module is fabricated and experimentally evaluated under solid-state battery cycling conditions. Battery expansion-induced displacement and the corresponding stack pressure response are measured to assess mechanical performance. Experimental results demonstrate that, despite measurable displacement during cycling, the applied stack pressure remains nearly constant. These findings confirm the feasibility of constant-force mechanisms for stable and reliable stack pressure regulation in solid-state battery modules.

Keywords: constant-force mechanism, solid-state battery, stack pressure control, battery module, mechanism design

Technical session 10

Novel design of robotic mechanisms and tools for intelligent manipulation

Kinematic Analysis of an Aircraft Wing Trailing Edge Based on Flexible Morphing Mechanisms

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Abstract. Flexible trailing edges (FTE) represent one of morphing wing technologies to replace traditional mechanical flaps by flexible control surfaces as an integral part of the wing. Our FTE design combines a planar continuum parallel mechanism mimicking the FTE skins with a grid of six-bar planar parallel mechanisms mimicking the morphing ribs. This paper presents a new analytical approach using a Quasi-Rigid Inverse Kinematic (Q-RIK) framework to model the motion behaviour of morphing ribs. The Q-RIK method eliminates the need for computationally demanding finite element analysis (FEA) to predict the motion of morphing ribs through simplified quasi-rigid body kinematics. The simulation results demonstrate that the Q-RIK framework predicts deflection profiles within 10 % error of FEA results while reducing computational overhead by a significant order of magnitude. The approach provides an effective tool for morphing wing applications and lays the groundwork for real-time morphing structure control.

Keywords: morphing wings, flexible trailing edge, auxetic structures, quasi-rigid inverse kinematics (Q-RIK), planar parallel continuum mechanisms; compliant mechanisms, finite element analysis (FEA)

MARINERO: Robot Digital Twin for Simulation of Autonomous Navigation in Nautical Marinas

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Abstract. Implementation of autonomous robotic systems in challenging areas, such as marinas, characterized by varying terrain, tight spaces, obstacles, specialized equipment, and human activity, poses a significant integration challenge. The robotic system deployment in dynamic and unpredictable conditions requires a feasibility study, with environment digital twin as vital segment.
This paper presents MARINERO digital twin that integrates a 4WIS4WID mobile robot, a high-fidelity 3D marina model, realistic sensor simulation, and enables ROS 2-based autonomous navigation and vessel inspection. The MARINERO automates marina's daily tasks execution, such as vessel checks on marinas' docks. The proposed system enables navigation strategies development, safe testing, and performance evaluation before real-world deployment. Additionally, the platform demonstrates deep learning-based visual vessel monitoring from the dock, integrated with automatic report generation, aimed for marina's general traffic report and owner-specific vessel inspections. The evaluation of the created digital twin demonstrated the robot reaches the targeted position with a geolocation error of 0.25 m and the targeted orientation with an error of 0.15 rad.

Keywords: digital twin, autonomous navigation, marine robotics, deep learning, object detection, vessel inspection

Kinematic Null-Space Torque Minimization for Extended-Tool Manipulation*

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Abstract. This paper presents a kinematic null-space control framework for extended-tool manipulation using redundant robotic manipulators. The primary task is defined at the tool endpoint, while kinematic redundancy is exploited to minimize externally induced joint torques caused by tool weight. The approach operates purely at the kinematic level and directly utilizes measured external joint torques, without requiring explicit models of the environment, contact geometry, or robot dynamics. Experimental validation on an FR3 robot equipped with a long rigid tool includes static positioning, trajectory tracking, and wall contact tasks. The results demonstrate smooth posture adaptation while preserving task-space execution under varying motion and contact conditions.

Keywords: redundant manipulators, null-space control, torque minimization, extended-tool manipulation, contact-rich manipulation

* This work was supported by Slovenian Research Agency grant N2-0269.

Abstracts of RAAD 2026
35th International Conference on Robotics in Alpe-Adria-Danube Region
June 17 – 19, 2026, Bratislava, Slovakia

Workspace Analysis of an Industrial Robot for Precision Machining Applications

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Abstract. Collaborative robots are increasingly adopted in modern manufacturing due to their ability to safely coexist with human operators in shared work-spaces. However, close human–robot interaction introduces new challenges in safety, reliability, and operational continuity, making effective anomaly detection needed. This paper investigates supervised and unsupervised anomaly detection approaches for collaborative robot monitoring using multivariate signals acquired from an experimental setup. Random forest and Principal Component Analysis (PCA) are employed to identify normal behavior, incipient failures, and anomalous conditions. Quantitative performance evaluation demonstrates that supervised methods achieve very high accuracy when labeled data are available, while unsupervised clustering-based techniques provide competitive results without requiring fault labeling. The results highlight the trade-off between detection accuracy and data availability, confirming the suitability of unsupervised approaches for dynamic industrial environments. The proposed analysis supports the development of robust, scalable anomaly detection frameworks for collaborative robotic applications.

Keywords: cobots, anomaly, random forest, principal component analysis

Probabilistic Grasping with Soft Multi-Fingered Grippers: Experimental Success-Rate Matrices

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Abstract. Robust grasping of fresh produce remains difficult for agricultural robots because crops vary widely in shape and are easily damaged, while perception and control errors introduce significant uncertainty. Soft robotic grippers are a promising solution due to their compliant contact and gentle handling, but their reliability strongly depends on both object geometry and gripper morphology. In this work, we present an empirical probabilistic evaluation of a reconfigurable soft gripper across multiple finger configurations and two produce categories, round and elongated. We conduct 960 grasp trials under controlled variations in pose, including positional offsets and orientation changes, and model grasp outcomes as success probabilities rather than binary rates. The results show a clear geometry dependent trade-off: the 6-finger configuration is most robust for round items, maintaining high success even under several centimeters of offset, while the 4-finger configuration performs best for elongated objects by forming stable opposing contacts along the long axis. Across all trials, the soft gripper achieved damage-free handling with no bruising observed. These probability maps provide actionable guidance for selecting gripper designs and planning grasps based on expected reliability under real-world uncertainty, supporting more robust autonomous harvesting.

Keywords: reconfigurable gripper, soft robotic gripper, grasp success probability, agricultural robotics

Mechanical Architectures and Locomotion Concepts in In-Pipe Robotics: A Brief Review

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Abstract. Pipeline networks constitute an important component of industrial infrastructure and, as a result, need to be inspected periodically for safety and reliability. In situations where accessibility is limited and geometric complexity is pronounced, robots designed for internal operation inside pipelines have been found to be viable alternatives for inspection. This paper provides a brief overview of the main mechanical configurations and locomotion concepts used in in-pipe robotic systems. The review includes the most common design approaches, such as wheeled, tracked, walking, screw-driven, PIG-type, and snake-like robots. Particular attention is given to their functional characteristics, including the ability to adapt to bends and changes in pipe diameter, continuity of motion, stability of contact with the pipe wall, control complexity, and energy efficiency.

To assess the applicability of different locomotion principles, a structured comparison framework is proposed. The framework considers robot performance in pipelines containing curved sections, vertical segments, and various internal obstacles. Because the robots described in the literature differ significantly in size, payload capacity, and operating conditions, the comparison is primarily qualitative in order to maintain consistency between the evaluated systems.

The analysis indicates that none of the locomotion concepts can be regarded as universally optimal. Wheeled and tracked robots are found to perform efficiently in regular sections of the pipelines, screw-driven robots ensure good traction in vertical orientations, and snake-like structures have been found to possess high adaptability in geometrically complex pipelines.

The results emphasize the necessity of using appropriate mechanical design in conjunction with scalable control. The proposed review can help to better understand existing design solutions and can point to promising directions in the development of modular and adaptable robotic platforms, which can be used in industrial pipeline inspection.

Keywords: mini robots, mobile robots, constrained workspace, in-pipe, inspection

Authors' Index

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ISBN 978-80-974468-3-3