CLAWAR

04 SEPT — 06 SEPT 2024 KAISERSLAUTERN, GERMANY

BOOK OF ABSTRACT CLAWAR 2024

WALKING ROBOTS INTO REAL WORLD

Foreword

We would like to welcome you to the 27th International Conference on Climbing and Walking Robots – CLAWAR 2024! Founded in 1997, the CLAWAR conference has become a well-established annual event in the international robotics community.

This year, CLAWAR 2024 is organized by the Robotics Research Lab of the department of computer science, RPTU Kaiserslautern-Landau and the FZI, Research Center for Information Technology. We are proud to welcome you to this year's conference in the city of Kaiserslautern.
Kaiserslautern is an industrial and university city in the state of Rhineland-Palatinate in the southwest of Germany. Our city is directly attached to the northwest edge of the Palatinate Forest, the biggest continuous forest of Germany. Hence, Kaiserslautern is beautifully framed in the south and east by wooded heights like the Humberg or the Kahlenberg.

CLAWAR 2024 is located within the internationally well-known research institute Fraunhofer Zentrum Kaiserslautern. CLAWAR 2024 covers all major areas of walking and climbing robotic research, development and innovation. Among others, new applications and current trends, AI-based solutions for perception and control, innovative design concepts, rehabilitation and prosthetics systems, as well as, bipedal and quadruped walking machines are presented. We are very proud that three renowned plenary speakers present the state, as well as, future innovations in their main research areas. These are Marco Hutter (27 Years of Climbing and Walking Robots – Are we There?), Alin Albu-Schäffer (Torque Controlled or Intrinsically Compliant? DLR's perspective on robust and efficient biped and quadruped locomotion) and Navinda Kottege (Two, Four, or Six? Legged Robots for Exploration and Inspection in the Real World).

It is a great honor for us to have two more keynote speakers - Benjamin Mottis (Creating a Workforce of Autonomous Robots) and Katja Mombaur (Bipedal Locomotion in Humanoid Robots and Exoskeletons - from Benchmarking Frameworks to Efficient Controllers)
The high quality of the conference demanded a rigorous review process be held for paper acceptance. The review process resulted in the acceptance of 49 regular papers and 14 posters contributions out of 75 original submissions. All accepted contributions are presented throughout the conference, organized in 14 technical sessions, bringing together leading robotic researchers from 15 countries. A special acknowledgement goes to all authors for their excellent work and to all reviewers for their professional and detailed feedback to the authors.
Beside the academic talks, several technical and social events are organized to support a friendly, cooperative and innovative spirit throughout the conference. Among others, these include technical exhibitions, excursions and guided tours.

In particular, we would like to thank the exhibitors MAB Robotics, MYBOT Shop, DFKI Robotics Innovation Center Bremen, DLR Institute of Robotics and Mechatronics, Robotic Systems Lab at ETH, Service Robotics Lab at FZI, Machine Intelligence and Robotics Lab at KIT and the Robotics Research Lab at RPTU Kaiserslautern-Landau for the demonstration of their cutting edge walking machines.

A lot of work is required for organizing this conference, we would like to thank all involved personnel for their time and effort. A heartfelt thank you goes out to our main sponsor, the Deutsche Forschungsgemeinschaft (DFG) and the Hübner Foundation. Furthermore, we would like to thank the Fraunhofer Center Kaiserslautern for providing the conference locations. Our sincere gratitude also goes to the CLAWAR association, the international scientific committee, the conference's advisory board and the national and local organizing committees for their valuable support.

Equally, many thanks to the team members of the local organizers Service Robotics Lab at FZI, Machine Intelligence and Robotics Lab at KIT and the Robotics Research Lab at RPTU Kaiserslautern-Landau for all of their hard work before and during the conference. Finally, we would like to thank all of you for participation at CLAWAR 2024.

We wish you a pleasant stay here in Kaiserslautern and a fruitful conference attendance.

Karsten Berns, Arne Rönnau, Osman Tokhi
General Chair of Clawar 2024

Wednesday, 4th September

Room LAURON	Technical Session 1 Planning and Control	Wednesday, 4th Sept. 9:30 - 10:50
Chair: Osman Tokhi		

Intelligent PID Controller for Vibration Suppression of Horizontal Flexible Plate Based on Social Spider Optimization

9:30 - 9:50

Muhamad Sukri Hadi (Universiti Teknologi MARA, Malaysia)
Latifah Kamilah Jamal Abdul Hekim (Universiti Teknologi MARA, Malaysia)
Annisa Jamali (Universiti Malaysia Sarawak, Malaysia)
Intan Zaurah Mat Darus (Universiti Teknologi Malaysia, Malaysia)
Mohammad Osman Tokhi (London South Bank University, England)

Abstract. Low energy consumption, light weight and quick system reaction are advantages of a flexible plate. Flexible plates, however are vulnerable to high vibration, which causes system failure. Vibrations can affect the stability and effectiveness of flexible plate structures as the vibrations generated in the system causes fatigue, noise, wear, human pain which all indirectly leading to the failure of such flexible plate structures. This research aims to reduce undesired vibrations which impair flexible plates' performance to maintain system efficiency and longevity by implementing social spider optimization (SSO) as means to optimize the parametric values of a proportional-integral-derivative (PID) controller. Initially, the input-output vibration data was acquired experimentally. Then, the proposed controller was developed using swarm intelligence algorithm via a SSO algorithm in a MATLAB/Simulink environment. The performance of the designed controller was compared to conventional approaches for vibration suppression, also known as PID controller tuned by Ziegler-Nichols (PID-ZN) in terms of its lowest mean squared error (MSE) and high attenuation at the first mode of vibration. The robustness of the proposed controller is also assessed by introducing different types of disturbances to the controller. It was noticed that the PID controller tuned by SSO algorithm (PID-SSO) exhibited a superior performance by achieving higher attenuation level at the first mode of vibration which was the dominant mode of the system. PID-SSO controller successfully achieved an 26.93 dB attenuation level, equivalent to 26.02 % of reduction percentage as compared to PID-ZN controller which exhibited a 12.80 dB attenuation level, equivalent to 12.38 % of reduction percentage.

LAURON VP, a Six-Legged Walking Robot, with a new ROS 2-based Behavior Control

9:50 – 10:10

Carsten Plasberg (FZI Forschungszentrum Informatik, Germany)
Hendrik Nessau (FZI Forschungszentrum Informatik, Germany)
Kantesh Sinha (FZI Forschungszentrum Informatik, Germany)
Imama Hafeez (FZI Forschungszentrum Informatik, Germany)
David Kubeneck (FZI Forschungszentrum Informatik, Germany)
Georg Heppner (FZI Forschungszentrum Informatik, Germany)
Rüdiger Dillmann (FZI Forschungszentrum Informatik, Germany)

Abstract. Hexapods have the ability to exert a strange fascination on humans. Once working with such a system, they develop a personality, and engineers create a special bond with the robot. Emerging from such a bond, LAURON V requires some upgrades to remain a future-proof system and to further prove its unused potential. Those changes contain new motor controllers but, more importantly, a reimplementation of the behavior network in an up-to-date framework. Therefore, an approach is developed on how to model behavior networks using ROS 2. This approach is then tested on the updated robot LAURON VP. With the ability to use the same software stack with only a different option during startup to run either on the robot or in simulation, testing new features becomes effortless.

Development of Gait Rehabilitation Robot to Promote Voluntary Movements for Normal Walking

10:10 – 10:30

Daisuke Chugo (Kwansei Gakuin University, Japan)
Yuya Miyazaki (Kwansei Gakuin University, Japan)
Honoka Kubo (Kwansei Gakuin University, Japan)
Satoshi Muramatsu (Tokai University, Japan)
Sho Yokota (Tokyo University, Japan)
Jin-Hua She (Tokyo University of Technology, Japan)
Keio Ishiguro (Tokyo University of Technology, Japan)
Hiroshi Hashimoto (Advanced Institute of Industrial Technology, Japan)

Abstract. This paper proposes a lower limb rehabilitation robot for normal walking in post-stroke hemiplegic patients. Ergometers are generally used for lower limb rehabilitation, but their use has depended on the experience of physio-therapists. Therefore, this paper proposes a new rehabilitation robot based on an ergometer that guides the patient's voluntary muscle activity and helps the patient learn how to use the muscles required for normal gait. The key ideas of this paper are twofold. The first is to design an appropriate external force (assist force/load) to be applied to the pedals during the pedaling motion, so that the patient can effectively train the muscles commonly used during normal walking. The external force design considers the human characteristic of multiple muscles working in coordination and uses muscle synergy, which indicates the degree of coordination, as the evaluation axis. Second, in order to effectively train the paralyzed limb, the pedals of the ergometer have independent left and right mechanisms. The left and right pedals are synchronized by master-slave control, with the paralyzed limb side acting as master. This en-courages the patient to move the paralyzed limb spontaneously. The proposed method de- scribed above has been implemented in our prototype robot and its effectiveness confirmed in experiments with post-stroke hemiplegic pa-tients as subjects.

Humanoids Operating Mobility Devices Designed for Humans: Experiments on a Segway

10:30 – 10:50

Vidyasagar Rajendran (University of Waterloo, Canada)
Katja Mombaur (University of Waterloo, Canada)

Abstract. Humanoid locomotion is versatile, but typically reserved to reach targets in the close vicinity. The option to employ a personal trans- porter (PT) made for humans, such as a Segway, presents an intriguing alternative for humanoids navigating the real world and allows them to switch from walking to wheeled locomotion for covering larger distances. In this work, we devise control strategies to allow humanoids to operate PTs while maintaining balance. This control task is different from walk- ing control, but equally challenging, and requires fast reactions. The con-troller is based on a stack of tasks quadratic program (QP) formulation which takes into account, contacts, stability and bimanual manipulation constraints. We show experimental results of a REEM-C humanoid operating a Segway x2 SE.

Room BISAM	Technical Session 2 AI-based Systems and Solutions	Wednesday, 4th Sept. 9:30 - 10:50
Chair: Lennart Puck		

Efficient Stream-Based Active Learning Initialization for Legged Robots based on a PCA/K-Means Image Selection Approach

9:30 - 9:50

Niklas Spielbauer (FZI Research Center for Information Technology, Germany)
Andrey Tkachenko (FZI Research Center for Information Technology, Germany)
David Oberacker (FZI Research Center for Information Technology, Germany)
Arne Roennau (FZI Research Center for Information Technology, Germany)
Ruediger Dillmann (FZI Research Center for Information Technology, Germany)

Abstract. In recent years walking robots have become a promising tool in exploration and search and rescue missions in partially unknown and changing environments. When utilizing machine learning models for segmentation and classification unknown environments can decrease the performance of the deployed models, as they might encounter objects for which they don't have sufficient training data. Active Learning can be used to select new data to be annotated during the mission and provide the model with the required knowledge as long as data that is useful to the model can be identified. Shortly after the start of the robot mission, this might not be the case and data might be selected randomly, leading to worse performance of the model or outright failure of the training process. In this work, we both discuss the initialization problem and propose an approach to use image set analysis algorithms on the unlabeled set of data the robot would have access to to find key images that can be utilized to successfully start a Stream-Based Active Learning process. We evaluate our approach on a small set of images as well as multiple data streams to show the validity of the approach itself as well as important metrics in identifying the right time to transition from the initialization to the main learning process.

Precision Vehicle Pose Estimation with Uncertainty-aware Neural Network

9:50 – 10:10

Tomasz Nowak (Poznań University of Technology, Poland)
Piotr Skrzypczynski (Poznań University of Technology, Poland)

Abstract. This study presents a neural network designed for precise vehicle pose estimation from single images in complex settings. Utilising neural network backbones known for accurate human pose keypoint detection, our architecture effectively localises vehicle characteristic points. Task-specific modules estimate point coordinates and quality for pose computation. Training on ApolloCar3D with auto-generated 3D labels, our approach achieves the high pose estimation accuracy. We highlight the crucial role of accurate keypoint detection in addressing single-view geometry ambiguities, enhancing pose estimation precision.

HAPmamba: Linear-Time Sequence Modeling for Terrain Classification by Legged Robots

10:10 - 10:30

Wilinski Michal (Poznan University of Technology, Poland)
Mikolaj Lysakowski (Poznan University of Technology, Poland)
Krzysztof Walas (Poznan University of Technology, Poland)

Abstract. This paper proposes a neural network model for terrain classification using force/torque signals registered with sensors mounted on robot feet. The proposed model is based on the latest architecture for Linear-Time Sequence Modeling using Selective State Spaces, called Mamba. We obtained lightweight models with very low inference times, which are two times faster than comparable transformer-based solutions. We evaluated HAPmamba alongside other state-of-the-art approaches, and while the classification measures are comparable, HAPmamba is the fastest among all evaluated models.

Neural-based Self-collision Checking for a Quadruped Robot	10:30 - 10:50

Bartłomiej Kulecki (Poznan University of Technology, Poland)
Dominik Belter (Poznan University of Technology, Poland)

Abstract. Motion planning of legged robots requires constraints check- ing. The primary constraint is related to the robot's kinematic model and self-collision checking. Checking this constraint allows the full utilization of the robot workspace during motion planning. The most popular self- collision checking methods utilize a 3D mesh model of the robot and iterative methods to find colliding parts of the robot. This approach is accurate but slow, so in this paper, we study the application of Multi- layer Perceptron to build a 3D self-collision model of the legged robot. We employ the neural network to classify the state of the robot into two collision and collision-free binary values. A similar ap- proach has already been applied for manipulating robots, but legged systems are defined in higher-dimensional space, so the problem is significantly more challenging. In this paper, we study the influence of input to the model on the neural network performance. Then, we show that the application of Fourier features enhances the input vector and improves the classification results. We demonstrate the results on the model of the quadruped walking robot ANYmal C.

Room LAURON	**Technical Session 3 Innovative Robot Design I**	**Wednesday, 4th Sept. 11:50 - 12:50**
Chair: Krzysztof Mianowski		

Magnecko: Design and Control of a Quadrupedal Magnetic Climbing Robot	11:50 – 12:10

Stefan Leuthard (Robotic Systems Lab, ETH Zürich, Switzerland)
Timo Eugster (Robotic Systems Lab, ETH Zürich, Switzerland)
Nicolas Faesch (Robotic Systems Lab, ETH Zürich, Switzerland)
Riccardo Feingold (Robotic Systems Lab, ETH Zürich, Switzerland)
Connor Flynn (Robotic Systems Lab, ETH Zürich, Switzerland)
Michael Fritsche (Robotic Systems Lab, ETH Zürich, Switzerland)
Nicolas Hürlimann (Robotic Systems Lab, ETH Zürich, Switzerland)
Elena Morbach (Robotic Systems Lab, ETH Zürich, Switzerland)
Fabian Tischhauser (Robotic Systems Lab, ETH Zürich, Switzerland)
Matthias Müller (Robotic Systems Lab, ETH Zürich, Switzerland)
Markus Montenegro (Robotic Systems Lab, ETH Zürich, Switzerland)
Valerio Schelbert (Robotic Systems Lab, ETH Zürich, Switzerland)
Jia-Ruei Chiu (Robotic Systems Lab, ETH Zürich, Switzerland)
Philip Arm (Robotic Systems Lab, ETH Zürich, Switzerland)
Marco Hutter (Robotic Systems Lab, ETH Zürich, Switzerland)

Abstract. Climbing robots hold significant promise for applications such as industrial inspection and maintenance, particularly in hazardous or hard-to-reach environments. This paper describes the quadrupedal climbing robot Mag-necko, developed with the major goal of providing a research platform for legged climbing locomotion. With its 12 actu- ated degrees of freedom arranged in an insect-style joint configuration, Magnecko's high manipulability and high range of motion allow it to handle challenging environments like overcoming concave 90 ° corners. A model predictive controller enables Magnecko to crawl on the ground, on horizontal overhangs, and on vertical walls. Thanks to the custom actuators and the electro-permanent magnets that are used for adhesion on ferrous surfaces, the system is powerful enough to carry additional payloads of at least 65 % of its own weight in all orientations. The Mag- necko platform serves as a foundation for climbing locomotion in complex three-dimensional environments.

Development of a Flapping Micro Flying Robot Using Micro Ultrasonic Motors

12:10 – 12:30

Ryo Watanabe (Okayama University, Japan)
Naoki Yoshiwaki (Okayama University, Japan)
Tomoaki Mashimo (Okayama University, Japan)

Abstract. In recent years, demand for insect-scale MAVs (Micro Aerial Vehicles) that can fly in confined spaces has been increasing at disaster sites and agricultural sites, and research on MAVs has been active. In this study, we develop an insect-scale flapping winged flying robot using a micro ultrasonic motor with high torque density and simple structure. The prototype motor employs the vibration mode of bending as its principle, and uses a stator with piezoe-lectric elements attached to a metal rectangle of size 1 mm × 1 mm × 3 mm. Experimental results showed that this motor could achieve a rotational speed of 25,000 rpm with a voltage of 80 V_{p-p} applied. Then, a flapping mechanism with elastic links was designed. The total weight of this flapping mechanism is less than 100 mg. Frictional torque was measured, with a maximum of 38 μNm.

An Approach to Soft Jumping Robots	12:30 – 12:50

Eduardo Navas (Centre for Automation and Robotics (CAR) CSIC-UPM, Spain)
Kai Blanco (Centre for Automation and Robotics (CAR) CSIC-UPM, Spain)
Daniel Rodríguez-Nieto (Centre for Automation and Robotics (CAR) CSIC-UPM, Spain)
Roemi Fernández (Centre for Automation and Robotics (CAR) CSIC-UPM, Spain)

Abstract. The development of legged robots capable of operating in unstructured environments continues to present a significant challenge to this day. The jumping ability commonly found in terrestrial-legged animals could offer a potential solution for solving this problem to some extent. Over the years, numerous designs based on rigid robotics, bio- inspired or not, have sought to emulate this capability. However, it is clear that there is a need for innovative actuators that facilitate more natural and adaptable movements that allow legged robots to traverse uneven terrain more effectively. Soft robotics could offer several advantages for improving the jumping capabilities of robots due to the ability to deform and reshape their limbs. In this regard, this paper proposes an approach that uses additive manufacturing of thermoplastic elastomers (TPE) for a soft jumping quadruped robot based on bicameral pneumatic actuators with the ability to move rapidly and continuously jumping at a maximum speed of 116.7 mm/s, as well as with the ability to rotate and adapt to unstructured environments.

Room BISAM	**Technical Session 4 Biologically-inspired Systems and Solutions I**	**Wednesday, 4th Sept. 11:50 - 12:50**
Chair: Tristan Schnell		

POMA: Propagation-based Obstacle Negotiation Control for Multi-Segmented Robot Adaptation	11:50 – 12:10

Woramethi Nantareekum (Vidyasirimedhi Institute of Science and Technology, Thailand)
Binggwong Leung (Vidyasirimedhi Institute of Science and Technology, Thailand)
Arthicha Srisuchinnawong (Vidyasirimedhi Institute of Science and Technology, Thailand)
Jettanan Homchanthanakul (Vidyasirimedhi Institute of Science and Technology, Thailand)
Suppachai Pewkliang (PTT Exploration and Production Public Company Limited, Thailand)
Poramate Manoonpong (Vidyasirimedhi Institute of Science and Technology, Thailand)

Abstract. This paper presents Propagation-based Obstacle negotiation control for Multi-segmented robot Adaptation (POMA) in complex environments. POMA integrates three neural control mechanisms: central pattern generator (CPG)-based leg control for generating gaits, horizontal body control for avoiding high obstacles, and vertical body control for climbing ramps and small obstacles. We validated the performance of POMA in a physical simulation. Our experimental results show that POMA enables a bio-inspired multi-segmented, legged robot to adaptively and successfully navigate through a maze with up and down ramps without a map of the environment. This demonstrates the effectiveness of integrating different neural control mechanisms for multi-segmented robots to deal with complex environments.

Self-organized Locomotion with Multiple Stepping Frequencies in an Insect-like Robot under Decentralized Adaptive Neural Control	12:10 – 12:30

Thirawat Chuthong (Vidyasirimedhi Institute of Science and Technology, Thailand)
Poramate Manoonpong (Vidyasirimedhi Institute of Science and Technology, Thailand)

Abstract. While walking robots typically employ a homogeneous stepping frequency across all legs to establish interlimb coordination, certain insects, such as locusts, interestingly exhibit adaptive interlimb coordination by employing heterogeneous stepping frequencies for different leg pairs. This adaptation arises from the distinct structures and lengths of their front, middle, and hind legs. Inspired by this biological phenomenon, this paper proposes decentralized adaptive neural control with multiple central pattern generators capable of realizing the adaptive interlimb coordination observed in insect walking. This neural control system can automatically generate gaits from heterogeneous stepping frequencies without the need for predefined interlimb coordination. Our preliminary results demonstrate that this neural control approach enables an insect-like robot, equipped with distinctly heterogeneous leg lengths, to achieve stable gaits autonomously and rapidly under various combinations of leg-stepping frequencies.

Using a Bio-inspired Solution for Double Support Force Distribution in Humanoid Robot Locomotion	12:30 – 12:50

Francisco Javier Andrade Chavez (University of Waterloo, Canada)
Vidayasagar Rajendran (University of Waterloo, Canada)
Katja Mombaur (Karlsruhe Institute of Technology, Germany)

Abstract. In locomotion, the likelihood of slipping or maintaining contact is determined by the forces applied on the environment. Therefore, it is crucial to find methods for maintaining forces within friction constraints. In single support, the relationship between center of mass acceleration and forces is unique. However, in double support, it becomes a non-deterministic problem. It is often assumed that forces are distributed to minimize a certain effort criterion. An interesting alternative is to distribute the forces in a manner similar to how a human would, which could result in a more human-like gait for humanoid robots. The modified Twin Polynomial Method (mTPM) as a technique to accurately distribute double support forces in a human-like way. It has proven better than other state of the art algorithms. In this paper, we show how human data differs from a 'typical' robot walk and propose a way to use mTPM to generate a more human-like distribution for robots.

Room LAURON	**Plenary Talk**	**Wednesday, 4th Sept. 13:50 - 14:50**
Chair: Arne Roennau		

27 Years of Climbing and Walking Robots – Are we There?

Marco Hutter (ETH Zurich, Switzerland)

Abstract. In recent years, we have seen tremendous progress in the field of legged robotics and the application of quadrupedal systems in real-world scenarios. Besides the massive improvement of the hardware systems to rugged and certified products by a number of companies, recent developments in perception, navigation planning, and reinforcement learning for locomotion control have unleashed a new level of robot mobility and autonomy to operate in challenging terrain. In this presentation, I will talk about our work on control and autonomy for legged robots and other mobile machines. I will give insights into the underlying methodologies, present some of the most interesting findings, and talk about real-world deployments in the wild. With thousands of (commercial) legged robots in the field and tremendous progress in the technology of the last decade, what are the remaining research questions for our community?

Biography. Marco is a professor for robotic systems and director of the center for robotics at ETH Zurich. His research interests are in the development of novel machines and machines and their intelligence to operate in rough and challenging environments. Together with his team, he realized a number of legged robots, mobile manipulators, and autonomous excavators that find applications including industrial inspection, construction and forest operations, household assistance, and extraterrestrial exploration. Marco is part of the National Centers of Competence in Research (NCCR) Robotics, Digital Fabrication, and Automation, PI in various international projects (e.g. EU NI, DigiForest), and winner of international challenges such as the DARPA SubT competition. Moreover, Marco is a co-founder of several ETH Startups, such as ANYbotics AG or Gravis Robotics AG, which commercialize legged robots and autonomous construction equipment.

Room LAURON	Technical Session 5 Application I	Wednesday, 4th Sept. 14:50 - 15:50

Chair: Giovanni Muscato

Omnidirectional climbing robot for maintenance services on hard to reach places of ship hulls — 14:50 – 15:10

Felipe Faria (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Marco Machado (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Cesar Meira (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Valéria Luz (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Verônica Pazda (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Doglas Negri (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Diego Souza (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Ismael Secco (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Luís Gonzaga Trabasso (SENAI Innovation Institute for Manufacturing Systems, Brazil)

Abstract. This study explores the development of a climbing robot for offshore applications with a focus on mitigating human risk exposure (HRE) and Environmental, Social, and Governance (ESG) metrics. Heavy tools are required during maintenance work, thus technical challenges related to surface adaptation, adhesion, locomotion, powertrain and control systems are accomplished. The proposed climbing robot is subjected to a field test and its overall performance proves the potential to improve safety, efficiency and environmental sustainability.

Demonstration of a Micro Wall-Climbing Robot Moving on Metal Surfaces — 15:10 – 15:30

Takuro Akadochi (Okayama University, Japan)
Mohamed M Khalil (Arab Academy for Science, Egypt)
Tomoaki Mashimo (Okayama University, Japan)

Abstract. In recent years, many of the piping systems used in Japan are more than 50 years old, and the risk of rupture due to aging is increasing. Therefore, many researches related to inspection robots that can navigate inside pipes are presented. However, general mobile robots can only be used in large-diameter pipes. In this study, a micro-robot that can be used for small-diameter in-pipe inspection tasks is introduced. The robot is fitted with magnetic wheels that permit locomotion on metal surfaces even in the vertical direction. In addition, a micro ultrasonic motor that can generate high torque is developed for the actuation mechanism. The micromotor generates a torque of about 30 μNm at 40 V_{p-p}. To achieve higher mobility, the micro ultrasonic motor is integrated with the smallest planetary gear system ever built. In the demonstration, the mobility performance of the robot is evaluated through a series of experiments.

Linkage Length Optimization of a Climbing Inspection Robot Using an Area Overlap Method

15:30 – 15:50

Shijia Wu (University of Leeds, England)
Linyan Han (University of Leeds, England)
George Jackson-Mills (University of Leeds, England)
Andrew Barber (University of Leeds, England)
Robert Richardson (University of Leeds, England)

Abstract. This paper develops a new area overlap method (AOM) to optimize the linkage length of a ladder-climbing robot. Unlike the traditional path generation methods that use precise synthesis points, AOM evaluates the optimisation result by the area overlap ratio of two enclosed trajectories. The proposed method is suitable for the case that trajectory planning of a mechanism moves over obstacles, where the generated desired trajectory must completely contain the target area. Since the linkage trajectory optimized by AOM will not intersect with the target area, the AOM's result will help prevent the robot from being inter- fered with by obstacles during climbing. Based on the AOM, this paper optimizes the standard Hoeken linkage structure. The simulation results show that the AOM performs better than the traditional path generation method in this case. To further verify the effectiveness of the proposed method, a ladder-climbing robot driven by one motor was designed. The experimental evaluations show that the robot can successfully climb a ladder.

Room BISAM	Technical Session 6 Quadruped Robots	Wednesday, 4th Sept. 14:50 - 16:10

Chair: Manuel Silva

High-Speed Quadruped Walking in Constant-Posture/Velocity by Counterweight Legs

14:50 – 15:10

Yuta Miura (Tokyo University of Agriculture and Technology, Japan)
Ikuo Mizuuchi (Tokyo University of Agriculture and Technology, Japan)

Abstract. Gait styles of quadruped robots can be classified into two main types: static walking and dynamic walking. In both styles, achieving constant-posture/velocity and high speed walking is impossible with- out additional actuators or joints on the torso side. This is due to the large inertial forces generated by the robot's legs moving at high speed. We propose a method to cancel the inertial translational forces generated by leg motion by attaching counterweights to the upper sides of the legs, and a gait setting method that allows the trunk to maintain con- stant posture and velocity during high-speed walking. Furthermore, as a result of kinetic analysis and actual machine experiments with the Counterweight Legs quadruped robot, we demonstrated that it is possible to suppress the influence of inertial translational forces.

SLOT: A Soft-Legged Omnidirectional Tetrapod

15:10 – 15:30

Saumya Karan (Indian Institute of Technology, India)
Harikrishnan R (Indian Institute of Technology, India)
Yukta Dodia (Indian Institute of Technology, India)
Tanish Phopalkar (Indian Institute of Technology, India)
Suraj Borate (Indian Institute of Technology, India)
Madhu Vadali (Indian Institute of Technology, India)

Abstract. Soft-legged robots are inherently more compliant to the operating environment. Rigid-legged robots require several degrees of freedom to achieve motion in all directions. This paper introduces a novel, low-cost and simple design of a soft-legged quadruped called SLOT (soft- legged omnidirectional tetrapod), which is capable of motion in all six degrees of freedom. Crawling, walking, sitting, standing, moving in longitudinal and lateral directions, turning left and right, and pitch and roll motion are achieved by only using four motors. SLOT can be operated wirelessly using Bluetooth or autonomously. Pitch, roll and height control is achieved by controlling the contraction of the legs using PID control. Handcrafted gaits are developed for crawl, turn, longitudinal, lateral and omnidirectional walk. A PID-based autonomous longitudinal control based on an ultrasonic sensor has also been demonstrated. Videos are available at https://github.com/Saumya-Karan/SLOT

Comparative Analyses of ROS Local Planners for Quadrupedal Locomotion: A Study in Real and Simulated Environments

15:30 – 15:50

Gabriel Bermudez (University of São Paulo, Brazil)
Gabriel Duarte Gonçalves Pedro (University of São Paulo, Brazil)
Vivian Suzano Medeiros and Thiago Boaventura (University of São Paulo, Brazil)

Abstract. Advancements in hardware, computation, and algorithms are driving a revolution in the field of mobile robots. This study compares the ROS-based local planner navigation algorithms Dynamic Window Approach (DWA), Timed Elastic Band (TEB), and Trajectory Rollout for application in legged locomotion. The tests were performed in simulation and on a real quadruped robot using a small maze-type environment. The experiments measured the total time and distance achieved for each local planner. The results reveal a comparable performance among navigation algorithms in real and simulated environments. Specifically, the Timed Elastic Band (TEB) algorithm demonstrates superior performance, exhibiting an average traversal duration of 31.3 s in simulated environments and 30.8 s in real-world conditions, coupled with an aver- age traversal distance of 14.5 m (simulated) and 13.7 m (real-world).

A Hybrid Force/Impedance Motion Controller for Robust Quadruped Locomotion on Sandy, Slippery, and Collapsing Terrains	15:50 – 16:10

Alex Tanapon Leonardi (University of Genova, Italy)
Vivian Suzano Medeiros (São Paulo University, Brazil)
Claudio Semini (Istituto Italiano di Tecnologia, Italy)
Victor Barasuol (Istituto Italiano di Tecnologia, Italy)

Abstract. Slippery, sandy, or collapsing terrains still represent a challenging scenario for quadruped locomotion. Mainly in situations where not a single robot failure is admissible. In this paper, we propose a new control structure that combines well-known optimization-based strategies applied to legged motion control, i.e. whole-body controllers (WBC), with indirect force control strategies, i.e. impedance control, to increase quadruped locomotion robustness when navigating on such terrains. The proposed strategy is mainly designed for gaits that allow for statically stable locomotion and its core aspect lies in the maintenance of the locomotion support polygon. We introduce a new assessment metric and extensively evaluate the controller performance through simulation and experimental trials using a Unitree's Aliengo quadruped robot.

Poster Session	**Room LAURON**	**Wednesday, 4th Sept. 14:50 – 15:20**
Chair: Patrick Vonwirth		

14:50 – 15:20	***2 min Introduction for each Poster***

Thursday, 5th September

Room LAURON	Keynote	Thursday, 5th Sept. 9:00 – 9:30
Chair: Arne Roennau		
Creating a Workforce of Autonomous Robots		
Benjamin Mottis		

Room LAURON	Technical Session 7 Human-like Robots	Thursday, 5th Sept. 9:00 – 9:30
Chair: Carsten Plasberg		

Intuitive Motion: Acceleration-based Inverse Kinematics on Arbitrary Coordinates

9:30 – 9:50

Patrick Vonwirth (RPTU Kaiserslautern-Landau, Germany)
Axel Vierling (RPTU Kaiserslautern-Landau, Germany)
Oleksandr Sivak (RPTU Kaiserslautern-Landau, Germany)
Karsten Berns (RPTU Kaiserslautern-Landau, Germany)

Abstract. Inverse kinematics is a well-known but mathematically hard problem in robotics. Existing algorithms especially fail at singularities. Unfortunately, being in a singular knee joint position is the usual case for humans. Herein, an acceleration-based approach is proposed, capable of handling arbitrary coordinate transformations, including singular ones. The algorithm is analyzed and evaluated at the hand of a robotic leg.

Lightweight Bi-articular Human-Like Robotic Leg with Four-Bar Joints

9:50 – 10:10

Oleksandr Sivak (RPTU Kaiserslautern-Landau, Germany)
Krzysztof Mianowski (RPTU Kaiserslautern-Landau, Germany)
Patrick Vonwirth (RPTU Kaiserslautern-Landau, Germany)
Karsten Berns (RPTU Kaiserslautern-Landau, Germany)

Abstract. This paper presents the design and kinematic modeling of a lightweight 2-D robot leg prototype equipped with four-bar mechanism joints. Leveraging principles from human biomechanics and robotic engineering, the leg design aims to mimic natural human movement pat- terns while maintaining structural integrity and efficiency. Through a comprehensive kinematic model, we analyze joint angles, velocities, and torques to ensure the leg capability to execute walking and squatting movements. The model parameters are adjusted based on biomechanical considerations and human locomotion data.

Proposal for a Series-driven Catapult Using Soft Actuators to Increase the Jumping Height of Hyper Jumping Humanoid Robot	10:10 – 10:30

Takeshi Itsuno (Chuo University, Japan)
Yusuke Ishii (Chuo University, Japan)
Masahiro Doi (Chuo University, Japan)
Hiroyuki Kondo (Chuo University, Japan)
Fumio Ito (Chuo University, Japan)
Taro Nakamura (Chuo University, Japan)

Abstract. This paper proposes a series-driven catapult to increase the jumping height of humanoid robots to improve the mobility on an uneven ground at disaster sites or in the industrial industry. This research aims to increase the single vertical jumping height of humanoid robots by using the developed series-driven catapult. The humanoid robot in the existing study with McKibben-type artificial muscles in parallel to the body have disadvantages: the muscles act on the joints in an assistive manner and the jumping height improve only a few tens of millimetres. In this paper, a series-driven catapult connected in series to a human robot is developed. Its effect on jumping height was verified experimentally. As a result, a maximum jumping height of 0.35 m was recorded. The use of a series-driven catapult increased the jumping height by up to 0.15 m, which is 1.78 times higher than the jumping height without a series-driven catapult. These results show that the use of a series-driven catapult increase the jumping height of humanoid robots and is expected to extend their dynamic behaviors.

Learning Velocity-based Humanoid Locomotion: Massively Parallel Learning with Brax and MJX	10:30 – 10:50

William Thibault (University of Waterloo, Canada)
William Melek (University of Waterloo, Canada)
Katja Mombaur (Karlsruhe Institute of Technology, Germany)

Abstract. Humanoid locomotion is a key skill to bring humanoids out of the lab and into the real-world. Many motion generation methods for locomotion have been proposed including reinforcement learning (RL). RL locomotion policies offer great versatility and generalizability along with the ability to experience new knowledge to improve over time. This work presents a velocity-based RL locomotion policy for the REEM- C robot. The policy uses a periodic reward formulation and is implemented in Brax/MJX for fast training. Simulation results for the policy are demonstrated with future experimental results in progress.

Room BISAM	**Technical Session 8 Planetary Exploration**	**Thursday, 5th Sept. 9:30 - 10:50**
Chair: Marvin Grosse Besselmann		

Verification of decreasing bearing capacity while imparting vibration to ground in discrete element method simulation	9:30 – 9:50

Watanabe Tomohiro (Niigata University, Japan)
Kojiro Iizuka (Shibaura Institute of Technology, Japan)
Dai Watanabe (Shibaura Institute of Technology, Japan)

Abstract. Numerous missions have been launched to explore various planets. Enhancing these rovers' mobility is imperative to broaden the exploration scope. Our study group has been investigating a vibration-based movement method for planetary exploration rovers. After imparting vibration, the ground compacts and becomes hard. On the other hand, the ground becomes soft, and the ground particles behave like flu- ids while vibrating. In these proposed movement mechanisms, the condition of the ground, altered by vibration, is crucial. In this study, we used the discrete element method (DEM) to simulate the bearing capacity of the ground when vibrations are applied for optimizing the design of the vibration-based movement mechanisms. This study simulated an experiment in which a rod was dragged on the ground while vibrating from the rod to the ground. The bearing capacity was measured when the rod was dragged on the ground. The simulated results were compared with the experimental results.

Soft Gripping System for Space Exploration Legged Robots

9:50 – 10:10

Arthur Candalot (Tohoku University, Japan)
Malik-Manel Hashim (Tohoku University, Japan)
Brigid Hickey (Tohoku University, Japan)
Mickael Laine (Tohoku University, Japan)
Mitch Hunter-Scullion (Tohoku University, Japan)
Kazuya Yoshida (Tohoku University, Japan)

Abstract. Although wheeled robots have been predominant for planetary exploration, their geometry limits their ca- pabilities when traveling over steep slopes, through rocky terrains, and in microgravity. Legged robots equipped with grippers are a viable alternative to overcome these obstacles. This paper proposes a gripping system that can provide legged space-explorer robots a reliable anchor on uneven rocky terrain. This gripper provides the benefits of soft gripping technology by using segmented tendon-driven fingers to adapt to the target shape, and creates a strong adhesion to rocky surfaces with the help of microspines. The gripping performances are showcased, and multiple experiments demonstrate the impact of the pulling angle, target shape, spine configuration, and actuation power on the performances. The results show that the pro- posed gripper can be a suitable solution for advanced space explo- ration, including climbing, lunar caves, or exploration of the surface of asteroids.

Admittance Control-based Floating Base Reaction Mitigation for Limbed Climbing Robots

10:10 – 10:30

Masazumi Imai (Tohoku University, Japan)
Kentaro Uno (Tohoku University, Japan)
Kazuya Yoshida (Tohoku University, Japan)

Abstract. Reaction force-aware control is essential for legged climbing robots to ensure a safer and more stable operation. This becomes particularly crucial when navigating steep terrain or operating in microgravity environments, where excessive reaction forces may result in the loss of foot contact with the ground, leading to potential falls or floating over in microgravity. Furthermore, such robots are often tasked with manipulation activities, exposing them to external forces in addition to those generated during locomotion. To effectively handle such disturbances while maintaining precise motion trajectory tracking, we propose a novel control scheme based on position-based impedance control, also known as admittance control. We validated this control method through simulation- based case studies by intentionally introducing continuous and impact interference forces to simulate scenarios such as object manipulation or obstacle collisions. The results demonstrated a significant reduction in both the reaction force and joint torque when employing the proposed method.

Advantages of Active and Passive Suspension Systems in Obstacle Negotiation for Planetary Rovers	10:30 – 10:50

Malte Wirkus (Deutsches Forschungszentrum für Künstliche Intelligenz, Germany)
Jonathan Babel (Deutsches Forschungszentrum für Künstliche Intelligenz, Germany)
Christian Backe (Deutsches Forschungszentrum für Künstliche Intelligenz, Germany)

Abstract. Hybrid locomotion systems with actively controlled wheeled- legged suspension offer high off-road mobility, feature ground adaptation and are capable of overcoming large obstacles. Rovers with passive suspension also have remarkable climbing abilities and are much easier to control. In this paper, experiments on overcoming obstacles with two robots with different suspension systems, one with an active wheeled- legged suspension and one with a passive triple-bogie suspension, are analysed and the advantages and disadvantages for different applications are shown. The control effort of the active suspension significantly slows down the rover in situations that can also be handled with a passive suspension. However, the unique ability of the active suspension to overcome obstacles without contact is a promising feature that requires further research and development to realise its full technological potential for autonomous operation.

Poster Session	**Room AirBug**	**Thursday, 5th Sept. 10:50 - 11:50**
Chair: Karsten Berns		

	Sparsity in Social Robotics Experiments João Sequeira
	Intelligent Rising Sprawl Tuned Autonomous Robot Tomer Siboni

	Amphibious Wave Robot for Monitoring Fish Farming Nisim Kachlon and David Zarrouk
	Autonomous landing pad with a closed cover for a medium-sized drone to support typical research and reconnaissance tasks in the local environment Krzysztof Mianowski, Robert Głębocki, Antoni Kopyt, Tomasz Barczak, Mateusz Strachowski, Dawid Florczak and Tomasz Krakowiak
	Towards 3D Path Planning for Free Climbing Robots Friedrich Graaf, Tristan Schnell, Georg Heppner and Ruediger Dillmann
	Foundations of Probabilistic Behavior Networks - Structured, Distributed Control of Complex Systems like Legged Robots Patrick Vonwirth
	The GreenAuto mobile robots fleet management and scheduling system Manuel F. Silva
	High-level teleoperation system for autonomous forklifts using VR over the 5G public network Manuel F. Silva
	LAURON VI: A Six-Legged Walking Robot for Dynamic Walking Christian Eichmann, Georg Heppner, Arne Roennau, Ruediger Dillmann
	A Benchmarking and Test Lab for Legged Robots Sabine Bellmann, Martina Overbeck, Tristan Schnell, Arne Roennau

	Quantum Algorithms for Trajectory Optimization Problems, a Roboticist Guideline Feline Pirchmoser, Genessis Perez Rivera, Ruediger Dillmann
	Legged Probing of the Immediate Environment Lennart Puck, David Schwarze, Tristan Schnell, Georg Heppner, Ruediger Dillmann
	Morphological Environment Analysis of High-Resolution Volumetric Maps Marvin Große Besselmann, Lennart Puck, Ruediger Dillmann
	Evaluation of the Unitree Go2 as an Education and Development Platform Roberto Corlito, Amer Sawan, Arne Roennau

Room LAURON	**Technical Session 9 Application II**	**Thursday, 5th Sept. 11:50 - 12:50**
Chair: Genessis Perez Rivera		
Rotary Push-in Mechanism for Variable Outer Diameter PIGs with Multiple-Connected Using Pneumatic Artificial Muscles.		11:50 – 12:10
Kana Hiromoto (Chuo University, Japan) Yuta Naruse (Chuo University, Japan) Fumio Ito (Chuo University, Japan) Jun'Ichi Watanabe (Pigeon Home Products Corporation, Japan) Taro Nakamura (Chuo University)		

Abstract. This paper describes the effect of the presence or absence of a rotary push-in mechanism on the movement speed of a variable outside diameter pipe inspection gauge (VOD-PIG). In existing studies, inspection robots that tow endoscopes and other wiring into the pipe can inspect the inside of the pipe in real time even in environments where radio reception is difficult, such as in metal pipes. However, the maximum inspection distance is limited by the increase in friction acting on the wiring during long-distance inspection. In the previous study, we developed VOD-PIGs to seal the piping and move through the pipe by converting the air pressure applied to the piping into a propulsive force. Despite its simple structure, the VOD-PIG can be sealed and opened arbitrarily at the VOD-PIG installation points in the piping. Air pressure can be applied to each VOD-PIG independently to obtain distributed propulsive force on entire wiring to reduce the tension. In previous studies, we manually pushed in the wiring in to the pipes, which made it difficult to push in the wiring into the pipes in accordance with the VOD-PIG operation. In this study, we developed a mechanism that can push in the wiring in accordance with the movement pattern of the VOD-PIG. We describe an experiment to compare the inspection speeds with and without the developed mechanism. As a result, the inspection speed was 9.7 times faster, which is expected to improve the inspection speed of VOD-PIG.

Proposal of a In-pipe Inspection Robot Using a Hyper-extension Unit - Basic Study on Application of Hyper-extension Unit to Improve Inspection Speed -

12:10 – 12:30

Ryusei Okuma (Chuo University, Japan)
Sogo Matsuo (Chuo University, Japan)
Fumio Ito (Chuo University, Japan)
Taro Nakamura (Chuo University, Japan)

Abstract. This paper proposes a peristaltic motion-type in-pipe inspection robot with a hyper-extension unit in the front part, to inspect small-diameter and long-distance pipes. This study aims to inspect long, narrow, and complex pipes. In conventional in-pipe inspection robots with a simple structure, it has been difficult to increase both the pull-in force of the traction wiring and the push-in force of the robot's head when passing through the bending pipe. Therefore, this paper proposed a peristaltic motion-type in-pipe inspection robot with a hyper-extension unit in the front of the robot, which can extend 294 % even at low expansion rates. This robot operates in two distinct patterns: an inchworm-earthworm pattern that can exert large traction and an inchworm pattern that can operate at highspeed under low loads. To verify the effect of changing the above two patterns on the inspection speed, horizontal straight pipe movement experiments were conducted by varying the applied traction. The speed of the inchworm pattern is 12.01 mm/s, and that of the inchworm-earthworm pattern is 3.43 mm/s without load. By contrast, the speed of the inchworm pattern is 1.28 mm/s, and that of the inchworm-earthworm pattern is 1.94 mm/s with the load. These results show that the proposed robot can effectively inspect pipes with various movement patterns, adapting to the traction exerted on the wiring.

Proposal of Operation Methods of the Square-Duct Cleaning Machine with Multistage Planetary Gear Mechanism

12:30 – 12:50

Yosuke Momma (Chuo University, Japan)
Fumio Ito (Chuo University, Japan)
Taro Nakamura (Chuo University, Japan)

Abstract. This paper describes operation methods of a cleaning machine using a multistage planetary gear mechanism to select a propulsion speed of the machine based on the cleaning rate required by the user when the machine is used in a real environment, to develop a design theory for a cleaning machine that cleans duct walls while running in ducts. In a previous study, a cleaning machine capable of scrubbing the entire inner wall of a square duct was developed. However, the propulsion speed at which the machine runs in ducts to clean duct walls while propelling on its own was not clarified. This paper describes a grease cleaning experiment to verify the propulsion speed. In addition, we propose the operating methods of the machine according as the required cleaning rate. The user of the machine can select the propulsion speed based on the required cleaning rate.

Room BISAM	Technical Session 10 Biologically-inspired Systems and Solutions	Thursday, 5th Sept. 11:50 - 12:50

Chair: Patrick Vonwirth

Concept of Pneumatic Soft Robot: Suction-Driven Locomotion

11:50 – 12:10

Soham Parlikar (Warsaw University of Technology, Poland)
Teresa Zielińska (Warsaw University of Technology, Poland)
Konrad Gumowski (Warsaw University of Technology, Poland)

Abstract. This paper presents the concept of a soft-body robot. The robot applies a pneumatic drive system. Suction cups enable attachment to the ground and adaptive movement in various environments. The design concept of a robot is presented, emphasizing its universality. The design, production and mobility testing phases are summarised. Design variants are discussed. The experimental results illustrating the robot's movement capabilities are briefly described. The work contributes to soft robotics, which uses the advantages of pneumatic drives.

Climbing Robot Inspired by Inchworms: Adaptable for Tubular and Flat Surfaces with Multi-Plane Work Capability

12:10 – 12:30

Saulo Melotti (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Brenno Domingues (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Eduardo Kamitani (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Verônica Pazda (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Thamiris Costa (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Amanda Fusinato (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Doglas Negri (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Diego Souza (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Ismael Secco (SENAI Innovation Institute for Manufacturing Systems, Brazil)
Luís Gonzaga Trabasso (SENAI Innovation Institute for Manufacturing Systems, Brazil)

Abstract. In numerous industries, the execution of high-rise tasks necessitates robots equipped with climbing capabilities to reduce human risk exposure (HRE) and meet Environmental, Social, and Governance (ESG) metrics. In response to these demands and drawing inspiration from the climbing behavior observed in animals like inchworms, we have designed an innovative inchworm-like robot. Featuring a 6-degree-of-freedom (DOF) configuration and permanent magnetic adhesion feet, the robot's adhesion is enhanced by the ability to toggle the mag- nets on and off through magnetic pack rotation. This versatile design enables the robot not only to ascend various surfaces but also to dynamically adjust its working plane—a crucial advantage for navigating tubular environments and scaling truss structures.

High Propulsive Trunk Flexion-extension Mechanism using Cheetah-inspired S-shaped spine	12:30 – 12:50

Shoei Hattori (Tohoku University, Japan)
Akira Fukuhara (Tohoku University, Japan)
Takeshi Kano (Future University Hakodate, Japan)
Akio Ishiguro (Tohoku University, Japan)

Abstract. In this paper, to improve the agility of quadruped robots, we propose a high-propulsive flexion–extension mechanism using an S- shaped flexible spine inspired by the curved shape of the back of a cheetah. To confirm the effectiveness of the proposed mechanism, we built a trunk-driven running robot and compared its performance with that of a conventional flexion–extension mechanism. The experimental results showed that the running speed of the robot with the proposed flexion– extension mechanism was approximately 1.5 times higher than that of the conventional model.

Room LAURON	**Plenary Talk**	**Thursday, 5th Sept. 13:30 - 14:30**
Chair: Rüdiger Dillmann		

Torque Controlled or Intrinsically Compliant? DLR's perspective on robust and efficient biped and quadruped locomotion

Alin Albu-Schäffer (Technical University of Munich, Germany)

Abstract. Robots are not only machines which are supposed to relieve humans from dangerous or routine work – they are also a scientific endeavour attempting to better understand human and animal motion and intelligence in a synthetizing way, by using the system analytic tools of engineering and computer science. As such, legged robots, in particular humanoids and quadrupeds, attracted a lot of attention and research effort in recent years. The exploding commercial interest in humanoids in the last two years underlines the huge potential of this technology.

Walking robots are supposed to closely interact with their human users or to operate in remote, unknown environments – in both cases, robustness is a central issue, as precise mathematical models for the interaction cannot be expected.

I will present in this talk two approaches to legged locomotion, which we followed during the last decade at DLR in order to achieve performance and robustness. The first approach, used for the development of the humanoid TORO, leverages the torque-controlled technology initiated at DLR for robot manipulators, which was subsequently commercialized by KUKA, Franka.Emika, Agile Robots and Medtronic. Precise joint torque interfaces allow performant whole-body control and motion planning for bipedal locomotion, also on uneven ground, as well as safe interaction with

humans. Controlling motion at low energetic cost, both from mechanical and computational point of view, certainly constitutes one of the major locomotion challenges in biology and robotics.

With the design of our experimental elastic quadruped robot Bert we attempt to demonstrate that robots can be designed and controlled to walk highly efficient by exploiting resonance body effects. To do so, however, legged robots need to achieve limit cycle motions of the highly coupled, non-linear body dynamics. This led us to fundamental research on the theory of intrinsic modal oscillations of nonlinear systems as well as on their stabilisation and control. I will present recent results in this direction from my ERC Advanced Grant project M-Runners. Finally, putting the human in the centre of robot development also means going beyond the pure field of engineering and interacting with bio-sciences. I will particularly highlight in this respect the interplay of biomechanics and neuro-control with advanced robotics design and control. Humans can also directly benefit from this research through the development of better human-machine interfaces, robotized medical procedures, and prosthetic and rehabilitation devices which will even more reduce the barrier between humans and robots in the future.

Biography. Alin Albu-Schäffer received his M.S. in electrical engineering from the Technical University of Timisoara, Romania in 1993 and his Ph.D. in automatic control from the Technical University of Munich in 2002. Since 2012 he is the head of the Institute of Robotics and Mechatronics at the German Aerospace Center (DLR). Moreover, he is a professor at the Technical University of Munich, holding the Chair for "Sensor Based Robotic Systems and Intelligent Assistance Systems" at the Computer Science Department.
His research interests include robot design, modeling and control, nonlinear control, flexible joints and variable compliance robots, impedance and force control, physical human-robot interaction, bio-inspired robot design and control. He received several awards, including the IEEE King-Sun Fu Best Paper Award of the Transactions on Robotics in 2012 and 2014; several ICRA and IROS Best Paper Awards as well as the DLR Science Award. He was strongly involved in the development of the DLR light-weight robot and its commercialization through technology transfer to KUKA. He is the coordinator of euROBIN, the European network of excellence on intelligent robotics.

Friday, 6th September

Room LAURON	Keynote	Friday, 6th Sept. 9:00 – 9:30
Chair: Karsten Berns		
Bipedal Locomotion in Humanoid Robots and Exoskeletons - from Benchmarking Frameworks to Efficient Controllers		
Katja Mombaur		

Room LAURON	Technical Session 11 Innovative Grippers	Friday, 6th Sept. 9:30 - 10:50
Chair: Arne Roennau		
Universal Wearable Haptic Glove for Force Measurement During Object Manipulation		9:30 – 9:50

Ksawery Giera (Poznan University of Technology, Poland)
Mikolaj Nowacki (Poznan University of Technology, Poland)
Dominik Belter (Poznan University of Technology, Poland)

Abstract. Most robotic hands are equipped with relatively simple force sensors to detect contact with manipulated objects. Very often, they are only attached to the finger's tips and are not sufficient to measure the interaction forces for all shapes of objects and grasp types. The goal of this research is to develop a sensory glove named PUT-Tactile-Glove that can be used on the existing robot's hands to enhance the sensing capabilities of the robot. The proposed sensory glove can measure forces acting on an object held in the hand. The robotic glove can also be used on the human hand to collect reference data for training robots to interact with the objects. The paper presents the mechanical design of the glove, the results of the sensor's calibration, the software system for ROS2, and the results of the experiments performed with the glove while grasping various objects.

A Soft Robotic Gripper for Pancake Handling: Design, Modeling, and Experimental Assessment

9:50 – 10:10

Ser Vin Chan
Behnaz Sohani
Khaled Goher

Optimization of an Underactuated Two Finger Robotic Hand Using Genetic Algorithms

10:10 – 10:30

Dylan Denizon (University of Coimbra, Portugal)
Sedat Dogru (University of Coimbra, Portugal)
Lino Marques (University of Coimbra, Portugal)

Abstract. In this work we focus on the design of an underactuated anthropomorphic tendon driven robotic gripper with two fingers. The gripper is required to be able to perform strong stable flat pinching and enveloping grasps for a fixed actuation force by maximizing the total contact force with the object. In order to design this gripper, we use a Genetic Algorithm (GA) based optimization approach, where geometrical parameters, such as position, stiffness and size of the joints, the length of each link and the palm, the distance from the tendons to the joint centers as well as the starting angle of the fingers are used. The approach runs the whole grasping process for each individual of the GA in simulation, detecting first constraint violations, and then measuring the contact forces. The optimization procedure was experimentally validated by 3D printing a prototype of the optimal design and showing its grasping capability.

Development of a Flexible Propulsion Mechanism Using a Braided Structure of Metal Plate for a Lunar Exploration Drilling Robot

10:30 – 10:50

Ryunosuke Sawahashi (Chuo University, Japan)
Hiroto Nagashima (Chuo University, Japan)
Chikage Fujikawa (Chuo University, Japan)
Takashi Kubota (Chuo University, Japan)
Taro Nakamura (Japan Aerospace Exploration Agency, Japan)

Abstract. In previous studies on drilling robots for lunar exploration, it has been challenging for robots to create adequately sized boreholes and achieve significant depth during drilling. In this study, we are endeavoring to develop a lunar drilling robot named "LEAVO," designed in a worm-like configuration, with the purpose of drilling holes to accommodate environmental sensors and to collect samples from targeted layers. LEAVO has successfully excavated vertically to a depth exceeding 938 mm, thereby validating its efficacy for the initial mission objective. Nevertheless, the current propulsion unit of LEAVO lacks the capability to adequately maneuver around or grip onto curved or uneven surfaces. Therefore, this paper proposes a new propulsion mechanism using Braid structure of metal plate to realize curved surface excavation for the second target mission. In order to verify whether this unit can move while gripping, moving tests were conducted on horizontal, vertical, and tapered pipes. From the experimental results, it is clear that this propulsion mechanism and current-controlled peristaltic motion are useful for various types of pipes.

Room BISAM	Technical Session 12 Prosthetics and Rehabilitation	Friday, 6th Sept. 9:30 - 10:50

Chair: Rüdiger Dillmann

Omni-Directional Mobile Wheelchair Capable of Ascending Stairs Using Only Wheels

9:30 – 9:50

Yuki Ueno (Tokyo University of Technology, Japan)
Haruto Homma (Tokyo University of Technology, Japan)

Abstract. We have developed an omni-directional mobile wheelchair that can ascend stairs using only wheels even if the stairs have different dimensions. Omni-directional movement reduces the burden of moving in tight spaces and enables intuitive operation. However, stair climbing is still an issue for powered wheelchairs in general. In this research, we focus on a dual-wheel active-caster mechanism that has a simple structure and can move in all directions using normal tires, and examine stair ascending. We investigate the conditions required for ascending stairs and show that it is possible to ascend stairs by making the wheelbase variable and installing a center of gravity movement mechanism. We verify the effectiveness of the proposed mechanism through experiments using a 1/2 scale experimental machine and simulations using MATLAB/Simulink and Simscape. The results showed that ascending stairs can be achieved by changing the wheelbase to match the stair dimensions and equalizing wheel loads during ascending stairs.

Enhancing Knee Arthroplasty Precision: Design and Evaluation of a Parallel Kinematic Robotic Assistance System

9:50 – 10:10

Amir Rahmani
Sylvester Ndidiamaka Nnadi
Kieran Mercer
Owen Nelson-Smith
Charlotte Butcher
Scott Hazell
Aliyu Aliyu
Behnaz Sohani
Khaled Goher

Study of Electric Wheelchair Enabling Ascend and Descend a Spiral Stair Using Crawlers and Wheels

10:10 – 10:30

Keiji Akasaki (Tokyo University of Technology, Japan)
Yuki Ueno (Tokyo University of Technology, Japan)

Abstract. We have developed a simple mechanism that can ascend spiral stairs using two steering wheels, one prismatic joint on the rear wheel, and rotating arms with crawler and wheel that keeps a wheelchair body horizontal. In this study, first, we defined four problems when ascending the spiral stairs. Second, we proposed a mechanism to solve four problems which combines above mentioned components, and designed a one third scale experimental machine. Finally, the experiment using one third scale spiral stairs are conducted, and results showed that proposed mechanism can ascend to the second step of stairs keeping its posture horizontally. Furthermore, it turned out that it is unable to climb from the third step onwards because the rear wheel is floating. By applying pushing force to the front wheel appropriately, it is known that the experimental machine can ascend stairs.

Adaptable Segmented Straps with Anti-slip Pads for Modular Assistive Knee Exoskeleton Enhancement

10:30 – 10:50

Kanut Tarapongnivat (Vidyasirimedhi Institute of Science and Technology, Thailand)
Sanpoom Punapanont (Vidyasirimedhi Institute of Science and Technology, Thailand)
Run Janna (Vidyasirimedhi Institute of Science and Technology, Thailand)
Matas Manawakul (Vidyasirimedhi Institute of Science and Technology, Thailand)
Chaicharn Akkawutvanich (Vidyasirimedhi Institute of Science and Technology, Thailand)
Poramate Manoonpong (Vidyasirimedhi Institute of Science and Technology, Thailand)

Abstract. This paper introduces a modular assistive knee exoskeleton designed to enhance physical gait assistance. The exoskeleton is engineered to support flexion/extension motions of the knee joint to mitigate slippage across various activities (walking, sit-stand, and walking up-down stairs) and accommodate personalized adjustments. A specific design approach involving a flexible strap with an anti-slip pad feature is proposed to address these require- ments. The results indicate that our de- sign is more effective in maintaining its position than the traditional one in all testing activities and can reduce a peak torque at the extreme slip- ping position during walking by 47% compared to the traditional design. This research contributes to the advancement of assistive technologies for mobility support and offers insights into the practical implementation of modular exoskeleton systems.

Room LAURON	Plenary Talk	Friday, 6th Sept. 11:50 - 12:50
Chair: Karsten Berns		

Two, Four, or Six? Legged Robots for Exploration and Inspection in the Real World

Navinda Kottege (Queensland University of Technology and University of Queensland, Australia)

Abstract. The past decade has seen a massive increase in interest in legged robots. This was mainly driven by the commercial availability of affordable quadruped platforms as well as the advancements made in legged robot locomotion research. The combination of AI/ML based control, robust perception systems and the availability of lower cost computing hardware has brought these machines out of research labs, into the consumer domain. This talk will cover the many examples of legged robots; two legged, four legged as well as six legged, along with insights into how they are being used to perform tasks in the real world.

Biography. Dr Navinda Kottege is the Research Director of the Cyber-Physical Systems Research Program (Robotics, Computer Vision and Distributed Sensing Systems) at Commonwealth Scientific and Industrial Research Organization (CSIRO), partner within the Queensland Center for Advanced Technologies (QCAT).
Navinda joined the CSIRO as a Postdoctoral Fellow soon after receiving his PhD in Engineering from The Australian National University in 2009. In 2011, Navinda initiated and then led the legged robot research within CSIRO, an activity grown into a world-class R&D capability. Before becoming the Research Director, he led the Robotics and Autonomous Systems group and conducted research in multi-legged robot navigation, perception, and control. The main focus of his activities he laid on legged navigation in complex, unstructured environments. From 2020 to 2021 he was the Chair of the IEEE Queensland joint chapter for Control Systems/Robotics and Automation Societies. Today, he is a senior member of the IEEE, a member of the ACM, and an Adjunct Associate Professor at both Queensland University of Technology and University of Queensland.

Room LAURON	Technical Session 13 Application III	Friday, 6th Sept. 13:30 - 14:30
Chair: Lino Marques		

Earth-shaping with Heterogeneous Robotic Teams: from Sim to Real 13:30 – 13:50

Federico Oliva (Israel Institute of Technology, Israel)
Tom Shaked (Israel Institute of Technology, Israel)
Karen-Lee Bar-Sinai (Israel Institute of Technology, Israel)
Omer Shalev (Israel Institute of Technology, Israel)
Oren Elmakis (Israel Institute of Technology, Israel)
Ari Meles-Braverman (Israel Institute of Technology, Israel)
Amir Degani (Israel Institute of Technology, Israel)

Abstract. This work presents an overview of autonomous earth-shaping and aggregate-forming tasks, which we address with a heterogeneous team of Unmanned Ground Vehicles equipped with shovels. Firstly, we introduce Sheperd, a Hardware In the Loop development tool integrated with ROS and physical engines like Gazebo and FlexHopper. We further address the problem of computational cost in these kinds of simulators, providing preliminary results to replace them with a probabilistic model for aggregate motion. We proceed by addressing the following major challenges: localizing the team of robots and mapping the aggregates, as well as efficient motion planning strategies. We address UGV localization and material mapping, utilizing vision-based UAV-UGV collaboration and optimization techniques for robustness. Then, we discuss motion planning, providing solutions to shape on-site material exclusively using pushing actions rather than more standard pick-and-place solutions.

Mobile Victim Signs Monitoring through Non-invasive Robotic System

13:50 – 14:10

David Rolando Orbea Jerez(Universidad Politécnica de Madrid, Spain)
Christyan Cruz (Universidad Politécnica de Madrid, Spain)
Jaime Del Cerro (Universidad Politécnica de Madrid, Spain)
Antonio Barrientos (Universidad Politécnica de Madrid, Spain)

Abstract. Robotic assistance for search and rescue (SAR) tasks in post- disaster environments focuses on offering faster response times for detecting potential victims and acquiring relevant information for prompt medical evaluation. An important potential feature of these robotic systems is the ability to rapidly and efficiently access victims' vital signs, such as heart rate, respiratory rate, or body temperature. Current methods are still based on manual inhalation – exhalation counts in a minute to obtain the breathing rate. From the approach of mobile robotics, this work proposes a robotic system for analyzing the respiratory rate condition of victims in SAR missions. The system is composed of a legged-manipulator robot equipped with a RGB sensor at the end effector, which, through convolutional neural networks (CNN), identifies a victim and defines a close relative position, then deploys the manipulator to a pose near the victim's thoracic region, performs motion data acquisition through optical flow technique, and process the data to estimate respiratory rate. The system has been tested in indoor and outdoor environments. System evidences robustness on difficult lighting conditions and different patterns on victims' clothes.

Multi-UAV Coverage Path Planning for agricultural applications

14:10 – 14:30

Marco Frau (University of Catania, Italy)
Dario Calogero Guastella (University of Catania, Italy)
Giovanni Muscato (University of Catania, Italy)
Giuseppe Sutera (University of Catania, Italy)

Abstract. In this work a new algorithm to optimize coverage path planning for a flock of UAVs is described. The method is the evolution of previously implemented works by the authors and aims to improve the power consumption by clustering adjacent coverage cells to be surveyed into macro-cells. The generation of trajectories is performed with a GIS-like tool developed in MATLAB. Several simulations are reported to show the validity of the proposed approach.

Room BISAM	Technical Session 14 Innovative Robot Design II	Friday, 6th Sept. 13:30 - 14:30
Chair: Tristan Schnell		

Addressing Foot Geometry Trade-offs to Achieve Amphibious Surf Zone Transitions with a Crab Robot	13:30 – 13:50

Nicole Graf (Case Western Reserve University, USA)
John Grezmak (Case Western Reserve University, USA)
Nathan Carmichael (Case Western Reserve University, USA)
Yifeng Gong (Case Western Reserve University, USA)
Kathryn Daltorio (Case Western Reserve University, USA)

Abstract. Crabs have specialized curved dactyls that can be used during locomotion to anchor and control penetration in dry and wet substrates. To investigate the effect of crab leg's geometry, we added rings similar to ski pole baskets around the dactyl to show that distributing ground reaction forces over a larger surface area would permit our crab-like hexapod Sebastian to carry heavier loads and reduce cost of transport by controlling dactyl penetration depth. The rings help pre- vent slip, enabling the robot to walk farther and more efficiently in dry sand with payload. The results show a trade-off between locomotion efficiency with payload and anchoring force. We then developed a new dactyl which enabled Sebastian to successfully walk from being fully submerged through the transition zone on to dry land. This research aims to help other researchers to develop inexpensive robots for efficient shallow water locomotion in the future.

Modern methods of designing and producing elements for walking robots working in highly dynamic conditions	13:50 – 14:10

Krzysztof Mianowski (Warsaw University of Technology, Poland)
Karsten Berns (RPTU Kaiserslautern-Landau, Germany)
Patrick Vonwirth (RPTU Kaiserslautern-Landau, Germany)
Oleksandr Sivak (RPTU Kaiserslautern-Landau, Germany)

Abstract. The article discusses the issues of using modern methods of designing and manufacturing elements of walking robots operating in conditions of high dynamics. The work concerns the practical application of elastic compliance using composite springs with carbon fiber plates as springs in a robot leg driven by electric actuators with ball screw gears, used as redundant double-joint drives in biped robot systems. The construction of the robot's skeleton also uses an additive model manufacturing technique called 3D printing. It is a highly specialized technique for producing geometric models, often with complex shapes. This publication considers the possibility of using this technique to produce prototypes of structural parts that can be directly used in the construction of a bipedal robot with flexible drives.

3D-printed Robust Ground Contact Sensors for Haptic Feedback using Functional Materials	14:10 – 14:30

Matthias Hering (University of Münster, Germany)
Simon Höving (University of Münster, Germany)
Malte Schilling (University of Münster, Germany)

Abstract. When navigating challenging, uneven terrain, walking robots must rely on reliable sensory feedback. Detection of ground contact has proven sufficient for controlling and coordinating movements. In this paper, we present a novel, cost-effective 3D-printed foot contact sensor designed to enhance proprioceptive capabilities in small legged robots. We introduce a fully 3D-printed design that incorporates the switching mechanism itself, utilizing multiple materials including conductive ones. This approach facilitates easy assembly and produces robust signals without the need for additional processing requirements. We compare various sensor designs to a baseline, highlighting improvements in responsiveness, ease of integration, and cost-effectiveness.