EuroEAP 2025

13th international conference on Soft Transducers and Electromechanically Active Polymers

Linz, Austria
10-12 June 2025

Technical programme

Book of abstracts

List of participants

EuroEAP 2025 supported by

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Contents

Conference venue

Johannes Kepler University Linz,
Altenbergerstrasse 69,
4040 Linz,
Austria

Conference Chairperson

Assoc. Prof. Ingrid Graz
School of Education
Institute for Biophysics
Johannes Kepler University Linz,
Altenbergerstrasse 69,
4040 Linz,
Austria

e-mail: ingrid.graz@jku.at
ph: +43(0)732-2468/7955

Local organization

Johannes Kepler University Linz,
Altenbergerstrasse 69,
4040 Linz, Austria

Presentation of the EuroEAP conference series

The 21st century is experiencing a paradigm change from the age of passive synthetic materials to the age of stimuli-responsive and multi-functional materials. Among them, Soft Transducers and Electromechanically Active Materials represent a fast-growing scientific field of research and development. They consist of soft polymeric materials, devices or systems that can convert, react or adapt to an external stimulus (such as electrical, magnetic,electromagnetic, mechanical, pneumatic, thermal or chemical) and transduce it into a different form of energy, exhibiting changes (e.g. in terms of shape, size, force, stiffness, surface texture, polarization, colour, etc.), which can be used for diverse needs, including actuation, sensing and energy harvesting. Their numerous and different working principles, as well as their use in practical applications, make this research field inherently and highly interdisciplinary,bridging the gap between chemistry and physics of materials, modelling, electrical and mechanical engineering, manufacturing and user interface science.

These materials and technologies will play an increasingly important role in the future, thanks to their unique combination of stimuli-responsiveness and soft structure. They are already opening numerous possibilities of application in various fields, such as soft robotics, energy harvesting, biomedical devices, human-machine interaction, wearables and smart textiles (to name a few), which so far have been unachievable with conventional and stiff transduction technologies.

The EuroEAP international conference, organized by the EuroEAP Society with a not-for-profit distinctive character and always held in Europe, in charming and easy-to-reach locations, is primarily aimed at sharing and disseminating the latest advances and findings in this emerging field. It gathers experts from all over the world in a highly multidisciplinary event, driven by scientific quality and industrial impact, with an organisation and daily schedule that enable significant opportunities for one-to-one discussions, in a friendly atmosphere.

Since 2011, the conference has been focused on Electromechanically Active Polymers. Today, the event expands its scope to the larger international and diverse research community of soft smart materials and soft transducers.

Philipp Rothemund
EuroEAP Conference Committee

Conference committees

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The EuroEAP conference is steered by the conference committee of the EuroEAP Society:

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Stefan Seelecke, Saarland University (Germany)
Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
Anne Skov, Technical University of Denmark

Programme Overview

Monday, 9 June 2025

Arrival	16:00-18:00	**Registration**

Tuesday, 10 June 2025

Opening	8:45-9:00	Welcome & introductory remarks **Ingrid Graz** JKU Linz, Austria
Keynote Lecture	Session 1.1 part I *Chair: Ingrid Graz, JKU Linz, Austria*	
	9:00-9:30	**Iain Anderson** Auckland University, New Zealand
Invited Lectures	Session 1.1 part II *Chair: Iain Anderson, Auckland University*	
	9:30-9:50	**Fabien Sorin** EPFL Lausanne, Switzerland
	9:50-10:10	**Giacomo Moretti** University Of Trento, Italy
	10.10-10.30	**Jürgen Maas** Technical University Berlin, Germany
Break	10:30-10:50	Coffee break
Interactive Talks	Session 1.2 part I *Chair: Jürgen Maas, Technical University Berlin, Germany*	
	10:50-11:50	**Oral presentations** 18 presentations of research activities (3 minutes each)
Interactive Poster Presentations	Session 1.2 part II	
	11:50-12:50	**Posters & exhibitions** 18 posters
Lunch	12:50-13:50	Lunch

Interactive Talks	Session 1.3 part I *Chair: Fabien Sorin, EPFL, Lausanne, Switzerland*	
	13:50- 15:00	**Oral presentations** 18 presentations of research activities (3 minutes each)
Interactive Poster Presentations	15:00- 16:00	**Posters & exhibitions** 18 posters Coffee served during the session
EuroEAP Society meeting	16:00- 17:00	**Annual meeting of the EuroEAP Society**
Social Event	17:00- 21:00	**Exhibition "Where soft actuators meets textiles"** at the University of Arts, Linz
Social Dinner	19:00- 21:00	Reception at Exhibition

Wednesday, 11 June 2025

Keynote Lecture	Session 2.1 part I *Chair: Philipp Rothemund, Stuttgart University, Germany*	
	9:00- 9:30	**Ivan Minev** Leibniz Institute Dresden, Germany
Invited Lectures	Session 2.1 part II *Chair: Ivan Minev, Leibniz Institute Dresden, Germany*	
	9:30- 9:50	**Christine Selhuber-Unkel** Heidelberg University, Germany
	9:50- 10:10	**Frederic Vidal** CY Cergy Paris Université, France
	10.10- 10:30	**Hidori Okuzaki** University Of Yamanashi, Japan
Break	10:30- 10:50	Coffee break
Invited Talks	Session 2.1 part III *Chair: Frederic Vidal. CY Cergy Paris Université, France*	
	10:50- 11:10	**Ellen Rumley** MPI Stuttgart, Germany

	11:10-11:30	**Tobias Willian** ZeMA, Saarbruecken, Germany
Interactive Talks	Session 2.2 part I *Chair: Jose G. Martinez, Linköping University, Sweden*	
	11:30-12:40	**Oral presentations** 18 presentations of research activities (3 minutes each)
Lunch	12:40-13:40	Lunch
Interactive Poster Presentations	Session 2.2 part II	
	13:40-14:40	**Posters & exhibitions** 18 posters
Break	14:40-14:55	Coffee break
Industry Talk	Session 2.3 *Chair: Florian Hartmann, MPI Stuttgart, Germany*	
	14:55-15:10	**Johannes Neuwirth** Wacker Chemie AG
	15:10-15:25	**Ieuan Collins** Wave Energy Scotland, Inverness, UK
EuroEAP Society Challenge	15:25-15:45	**Video projection** 6 Challenge videos (3 minutes each)
Social Event	16.00-19:00	Tour through VOEST Steel Plant
Social Dinner	19:00-22:00	Gala dinner at Stahlwelt @ VOEST Steel Plant

Thursday, 12 June 2025

Keynote Lecture	Session 3.1 part I *Chair: Anne Ladegard Skov, DTU, Denmark*	
	9:00-9:30	**Jonathan Rossiter** University of Bristol, UK
Invited Lectures	Session 3.1 part II *Chair: Cedric Plesse, CY Cergy Paris Université, France*	
	9:30-9:50	**Florian Hartmann** Max-Planck-Institute Stuttgart, Germany
	9:50-10:10	**Tobias Kraus** INM - Leibniz-Institute, Saarbruecken, Germany
Break	10:10-10:30	Coffee break
Interactive Talks	Session 3.2 part I *Chair: Jonathan Rossiter, University of Bristol, UK*	
	10:30-11:15	**Oral presentations** 15 presentations of research activities (3 minutes each)
Interactive Poster Presentations	11:15-12:15	**Posters & exhibitions** 15 posters
		Final collection and counting of the votes
Lunch	12:15-13:15	Lunch
Best Poster & Society Challenge Awards	Session 1.2 part II	
	13:15-13:30	**Announcement of the first three classified teams of the EuroEAP Society Challenge Award**
		Announcement of the winner of the best poster award
Closing Ceremony	13:30-13:40	Conference closure, handover to the next year`s chairperson and presentations of the next year`s conference venue

Tuesday, 10 June 2025

Session 1.1
(abstracts are listed in the order of presentation)

1.1.1 Do van der Waals forces play a role in the anomalous piezoresistive behaviour of conducting elastomer composites?

Logan Ritchie (1), Elke Pahl (2), Iain A. Anderson (1)

(1) Biomimetics Lab, Auckland Bioengineering Institute
(2) Dept. Of Physics, University Of Auckland

Presentation given by Prof. Iain A. Anderson

Mixing carbon aggregates into a curing silicone can produce a stretchable conducting composite through the formation of a continuously connected network of filler particles. Its piezoresisitivity promises easy-to-produce stretch sensors. But such composites exhibit highly non-linear and strain-rate dependent changes to electrical resistance. We hypothesize that weak intermolecular attractive Van der Waals interactions play a role in this. To test this hypothesis we have constructed a mesh-free 2D modelling approach where carbon is represented as rigid aggregates of circular particles. Energy minimization was performed using a potential energy function that defined inter-particle behavior based on attractive van der Waals interaction between separated particles with rigid repulsion when particles come close to overlapping. The polymer was also modelled as linear viscoelastic element connecting particles. Our models produce the typical piezoresistive response seen experimentally. We conclude that the cured carbon-filled composite elastomer behaves as a van der Waals mediated minimum energy structure that will experience an increase in electrical resistance whether stretched or compressed. This provides a key step in understanding the factors that give rise to this anomalous piezoresistivity and how to bring it under control for resistive sensor design.

1.1.2 Soft multi-material electronic fibers and textiles

Fabien SORIN (1)

(1) Ecole Polytechnique Fédérale De Lausanne (EPFL), Institute Of Materials, Lausanne, Switzerland

Presentation given by Dr. F. Sorin

Fibers and fabrics are becoming an important platform to seamlessly integrate functionalities highly relevant in the context of health care, robotics, energy harvesting, and sensing. It remains however challenging to integrate onto such particular substrates the materials and required micro to nano-scale architectures to achieve advanced sensing and actuation functionalities. Recently, the thermal drawing process - the same process used to make telecommunication optical fibers - has known a significant development in the type of materials, feature sizes and therefore functionalities that can be integrated within soft and thin fibers. It is now possible to draw not only optical but also electronic materials such as metals, semiconductors, nano-composites, piezo-resistive or piezoelectric systems. In this talk, I will present recent breakthroughs in the thermal drawing process in terms of fiber device design, materials, and processing to realize advanced flexible electronic systems onto soft fibers and fabrics. I will present a few examples of electronic fiber sensors for mechanical deformation, liquid flow, or shape changes. I will then show recent results in soft fiber robots that can be actuated via tendons or magnetic fields. Finally, I will show how electromechanically active polymers could be integrated using this processing platform for sensing and actuation, paving the way towards a novel approach to realize fiber-based highly integrated electronically actuated systems.

1.1.3 Leveraging electro-mechanical dynamics to improve the performance of electroactive polymer devices

Giacomo Moretti (1)

(1) Department Of Industrial Engineering, University Of Trento, Italy

Presentation given by Prof. Giacomo Moretti

The performance of EAP devices depends on an interplay of material properties, topological and geometrical features, and electro-mechanical dynamics. Understanding and leveraging electromechanical dynamics allows, on the one hand, to identify principle performance limits of EAP devices and, on the other hand, to expand their operational ranges or identify completely new working paradigms. This contribution presents an overview of our recent and ongoing works dedicated to modelling, understanding and characterizing the electro-mechanical dynamics of EAP devices. We first focus on high-frequency applications of dielectric elastomers (DE). We present models and experimental characterisations of the structural dynamics of DE loudspeakers, and the electrical dynamics induced by the electrodes resistivity, which become relevant at high frequencies. We present working principles for multi-function DE actuators, which leverage the modal response of DE membranes to embed different functionalities within a single-input actuator. We then focus on the electrical dynamics in multi-layer electrostatic transducers based on dielectric fluids. We will review the dynamics associated to leakage currents leading to charge accumulation. We will discuss models and test setups aimed at characterizing the time evolution of the blocking force in multi-layer dielectrics, and present a roadmap to extend these formulations to advanced actuator-level models.

1.1.4 **Dielectric Elastomer Transducers - Materials, Design, Fabrication and Applications**

Jürgen Maas (1),

(1) TU Berlin, Mechatronic Systems Lab, Berlin, Germany

Presentation given by Prof. Jürgen Maas

Dielectric elastomers transducers (DET) offer a number of advantages for use as soft actuators, sensors and generators. Decisive for their use is not only the structure of the transducer, but also the selection of suitable materials for their realization. The presentation will compare available materials with their advantages and disadvantages, which are suitable for the realization of elastomer layers and compliant electrodes. On this basis, two different manufacturing processes for multilayer DET will be presented. One process uses commercially available material based on industrially produced silicone films, while in another manufacturing process the silicone layers are produced by 3D printing from the two-component liquid raw materials. Silicone and electrode layers are applied alternately as usual, whereby the electrodes are responsible for the cross-linking of the multi-layer composite in addition to the properties of conductivity and flexibility. The printing of composite materials consisting of silicone-based carbon black inks has proven itself for this purpose, which can be applied in filigree structures with the developed printing process and thus guarantee many design possibilities for DET. Finally, various examples are used to show how the realized multilayer DETs perform in different applications.

Session 1.2

(abstracts are listed in the order of presentation)

1.2.1 **A large-stroke and fully-polymeric cooperative dielectric elastomer actuator matrix**

Saverio Addario (1), Alberto Priuli (1), Benjamin Zemlin (3), Sebastian Gratz-Kelly (2), Günter Schultes (3), Stefan Seelecke (1) (2), Gianluca Rizzello (1),

(1) University Of Saarland, Department Of Systems Engineering, Saarbrücken, Deutschland
(2) ZeMA - Center For Mechatronics And Automation Technology, Smart Material Systems, Saarbrücken, Germany
(3) University Of Applied Sciences, Saarbrücken, Germany

Presentation given by Mr. Saverio Addario

Dielectric elastomer actuators (DEAs) are soft transducers composed of thin, highly stretchable polymeric membranes coated with compliant electrodes. A DEA array can be coupled with mechanical biasing systems, whose force-displacement characteristics match those of the dielectric membranes, to enable a large actuation stroke. Conventional metal beams biasing mechanisms add rigidity to the system and are therefore unsuitable for integration into soft structures and wearables. A promising alternative are cross-shaped beams made of thermoplastic polymers. Those elements feature negative stiffness with low hysteresis while being fully polymer-based, thus they are particularly suitable for

miniaturized, large-stroke, and soft DEA systems. This contribution presents a multi-dimensional thermoplastic biasing mechanism designed and optimized for integration within a fully-polymeric cooperative DEA matrix. This approach ensures optimal adaptability to each DEA's operating range, considering performance variations due to position and boundary conditions acting on the membranes in the matrix. At the same time, it allows for a precise characterization of the electromechanical interactions arising from the common soft dielectric substrate. Furthermore, employing dielectric elastomer membranes as sensors enhances real-time data acquisition, improving cooperativeness and enabling complex tasks such as object manipulation and position detection in future applications.

1.2.2 Theoretical evaluation of the performance of high-pressure HASEL actuators for triggering self-healing materials in lithium-ion battery cells

Holger Boese (1), Peter Loeschke (1), Johannes Ehrlich (1),

(1) Fraunhofer Institute For Silicate Research ISC, Center Smart Materials And Adaptive Systems (CeSMA), Wuerzburg, Germany

Presentation given by Dr. Holger Boese

In order to reduce the degradation of lithium-ion battery cells and prolong their lifetime, self-healing electrode materials are a topic of development. To close eventual cracks in the material, an external pressure has to be applied. Recently, Hydraulically Amplified Self-healing ELectrostatic (HASEL) zipping actuators have received much interest due to their capability to generate pressure. They consist of two parallel polymer films partly coated with flexible electrode layers at their outer surfaces and sealed along their edges to a pouch, which is filled with an oil. When a high voltage is applied between the electrodes, the electrostatic attraction leads to a zipping effect and shifts the oil to the pouch region without electrodes. This oil shift generates a strong actuatoric deformation of the pouch. Due to the high flexibility of their pouch, these actuators are especially promising for the generation of the required pressure on the battery pouch cell for the self-healing trigger. The generated pressure of the HASEL actuator can be increased by confining the actuator in a thin rigid box. To evaluate the achievable pressure of the confined HASEL actuator, a simple calculation model was established. Calculations of the generated pressure vs. applied voltage on the HASEL actuator with various polymer materials and box dimensions were performed. Results of these calculations were compared with measurement data, which were received with a corresponding experimental setup.

1.2.3 Adept - automated dielectric elastomer actuator performance-tester

Tobias Weber (1), Bettina Fasolt (1), Tobias Willian (1), Daniel Bruch (2), Sophie Nalbach (1), Paul Motzki (1) (2),

(1) ZeMA - Center For Mechatronics And Automation Technology, Smart Material Systems, Saarbruecken, Germany
(2) Saarland University, Dept. Systems Engineering, Saarbruecken, Germany

Presentation given by Prof. Paul Motzki

The performance of dielectric elastomer actuators (DEAs) is determined by the applied electric field. While higher fields improve performance, the maximum field is limited by material properties. Local imperfections can prevent the membrane from reaching the required field, reducing yield. Previous research has introduced a repair and patching process to address this by testing DEAs up to the required field and patching early breakdown spots. Currently, this is done manually. To scale for large applications, automation is needed. This work introduces ADEPT, the first Automated Dielectric Elastomer actuator Performance-Tester, to automate breakdown tests and spot detection. ADEPT integrates a MySQL database that stores DE designs and manufacturing parameters. The process starts by importing design data from the database to ADEPT, which identifies voltage connection points. Screen-printed DEs on manufacturing frames are placed on an XYZ-stage, allowing precise positioning of a tool head to connect electrodes with a high voltage amplifier. Upon detecting a breakdown, the XY coordinates are calculated using a camera and custom algorithm. The breakdown voltage and position are uploaded to the database. A custom app controls ADEPT. The next phase involves developing a device to automatically repair detected breakdown spots using the XY coordinates.

1.2.4 **Textile integrated dielectric elastomer sensor and actuator elements with sputtered metal electrodes**

Sebastian Gratz-Kelly (1), Mario Cerino (2), Sophie Nalbach (1), John Heppe (2), Paul Motzki (1) (3),

(1) ZeMA - Center For Mechatronics And Automation Technology, Smart Material Systems, Saarbrücken, Germany
(2) University Of Applied Sciences, Saarbrücken, Germany
(3) Saarland University, Dept. Systems Engineering, Saarbrücken, Germany

Presentation given by Dr. Sophie Nalbach

Dielectric elastomer actuators (DEAs) are promising for wearable and textile-integrated applications due to their flexibility and unique properties. This contribution presents flexible DEA-based components designed for user-input sensing and tactile feedback. By integrating both sensor and actuator elements, the system enables multi-modal interactions, enhancing communication between the user and the device. A key innovation is the use of sputtered thin-film metal electrodes, reducing structural dimensions and electrode resistance compared to traditional screen-printed electrodes. This enables a compact 3x3 sensing array integrated with a single DEA-based feedback element. The DEA element consists of multiple layers of thin-film dielectric elastomers, enhancing tactile feedback, while low-resistance electrodes improve high-frequency stimulation and actuator performance. The high flexibility of these components makes them ideal for textile integration, creating a modular, textile-based user interface. A microcontroller manages interaction between the sensing array and actuator, enabling bidirectional communication. Performance validation confirms the effectiveness of these components, demonstrating their potential to create highly efficient, flexible, and durable DEA-based user interfaces. This work represents a significant step toward advancing wearable technology, offering intuitive and responsive user experiences through integrated sensing and actuation.

1.2.5 **Sensorless position control of a bi-stable dielectric elastomer soft robot**

Giovanni Soleti (1), Julian Kunze (2), Lennart Heib (1), Stefan Seelecke (1) (2), Gianluca Rizzello (1),

(1) Saarland University, Department Of Systems Engineering, Saarbruecken, Germany
(2) Center For Mechatronics And Automation Technologies (ZeMA), Saarbruecken, Germany

Presentation given by Mr. Giovanni Soleti

In this work, we present a novel sensorless control strategy for dielectric elastomer (DE)-based soft robots. The module features two rigid plates connected by a flexible beam element, whose bending is controlled via a pair of agonists DE actuators. The system is designed to be open-loop bistable, to enhance the range of motion of the system. To recover proportional regulation in the entire robot workspace while keeping the large displacement feature due to the bistable design, feedback control strategies are developed. Control of the proposed DE soft robot is challenging due to underactuation, strong nonlinearity, open-loop instability, control input saturation, and model uncertainties. To solve the problem, a passivity-based feedback control law is proposed and experimentally validated. In a first iteration, the real-time feedback of the robot state is achieved via camera measurements. Although the camera is a valid choice for a first validation, it presents different downside such as high sensitivity to the light environment, low frame rate, and increased cost for real-time applications. Subsequently, we replace the camera feedback with a system-level self-sensing architecture that, taking as inputs the voltage and current of each DE measured during actuation, estimates in real time the configuration robot of the robot. The system-level self-sensing is then employed in the control loop, allowing to achieve pose regulation without using additional sensors.

1.2.6 **Power-dense electrostatic actuators harnessing the vacuum of space**

Ion-Dan Sîrbu (1) (2), Arianna Mazzotta (3), Daniele Bortoluzzi (4), Virgilio Mattoli (3), Giacomo Moretti (4), Marco Fontana (1) (2),

(1) Scuola Superiore Sant"Anna, Institute Of Mechanical Intelligence, Pisa, Italy
(2) Scuola Superiore Sant"Anna, Department Of Excellence In Robotics & AI, Pisa, Italy
(3) Istituto Italiano Di Tecnologia, Center For Mater. Interfaces, Pontedera, Italy
(4) University Of Trento, Department Of Industrial Engineering, Trento, Italy.

Presentation given by Mr. Ion-Dan Sîrbu

Emerging space technologies, like smallsats, demand a strong focus on simplicity and minimization of both payload and volume. Conventional electromagnetic motors, however, are bulky and heavy, relying on lubrication and intricate thermal management systems, which make them less suitable for these applications. In this sense, electrostatic actuators (EA) are a promising alternative due to their lightweight and compact structures and direct-drive frictionless operation. Nevertheless, their adoption in space has been limited by the reliance on elastomeric membranes or on low-boiling-point liquids as dielectrics, which severely compromises resilience to the harsh space conditions. Herein we introduce a new class of power-dense EA that utilize the high-vacuum environment as a functional dielectric. This paradigm enables deformable high-dielectric-strength structures with negligible mass and no viscous resistance. Such devices incorporate flexible space-grade dielectric/conductive polymer layers that electrostatically zip across variable-shape vacuum gaps. The use of vacuum as a key dielectric provides exceptional agility and superior power-density compared to traditional electrostatic drives. We showcase this approach in cm-scale actuators capable of displacing over 600 times their own weight and reaching power densities in the kW/kg range. The resulting actuators are lightweight, compact and highly responsive, making them potential candidates for space missions.

1.2.7 **Wearable pneumatic tactile displays integrated with a hand exoskeleton to render softness in virtual reality**

Gabriele Frediani (1), Luisa Landi (1), Lorenzo Maggi (1), Nicola Secciani (1), Alessandro Ridolfi (1), Federico Carpi (1),

(1) University Of Florence, Department Of Industrial Engineering, Florence, Italy

Presentation given by Dr. Gabriele Frediani

Softness perception plays a key role while interacting with objects in both the real and virtual worlds. To enhance immersivity and realism in virtual reality environments, we recently described wearable compact tactile displays with pneumatic actuation. The devices were shown to be effective in delivering tactile stimuli able to simulate interactions with soft objects in virtual environments. Though very simple, such devices are inherently unable to provide kinesthetic feedback, to convey force and motion cues, which are known to serve as complementary stimuli for recognizing softness. To comparatively investigate the consequent perceptual limitations due to the lack of kinesthetic feedback, in the work presented here we integrated our wearable tactile displays with a hand exoskeleton, designed to provide that additional kind of feedback. We describe preliminary results of the integration, which, as expected, led to improvements in user performance in recognizing differences in softness between two virtual objects.

1.2.8 **Modelling and identification of dielectric elastomer systems for system analyses and controller designs**

Abd Elkarim Masoud (1), Jürgen Maas (1),

(1) Technische Universität Berlin, Mechatronic Systems Laboratory, Berlin, Germany

Presentation given by Mr. Abd Elkarim Masoud

Dielectric elastomer transducers (DETs) represent a prominent class of soft actuators capable of undergoing large deformations under applied voltage. These actuators have been widely utilized in various soft robotic applications, including grasping mechanisms, walking robots, flying robots, and humanoid systems. To further exploit the potential of such novel soft material systems, advancements in modeling and simulation are crucial for optimizing their performance. This work presents a hybrid dynamic modeling framework for complex DET systems, combining physics-based principles with data-driven techniques. The developed model is designed to be directly applicable to system analyses and controller design. A focus is placed on comparing the model's predictions with experimental data, particularly in capturing transient behavior and addressing inaccuracies in the transducer design. To enhance model accuracy and generalizability, a hybrid approach is introduced, integrating physics-informed structures with machine learning techniques. Specifically, artificial neural networks, with an emphasis on radial basis function (RBF) networks, are trained using experimental data to refine and augment the model. By systematically integrating data-driven methods into the modeling and identification of DET systems, this work provides a scalable approach to improving the predictive capabilities of soft actuator models.

1.2.9 **Miniaturization associated aspects of liquid-gas phase change actuators and their use as a phase change pump**

Rafal Ziembicki (1), Mathias Wendner (1), Ingrid Graz (1),

(1) Johannes Kepler University Linz, School Of Education, STEM Education, Linz, Austria

Presentation given by Mr. Rafal Ziembicki

Miniaturization of phase change actuators (PCAs) has been widely recognized as a promising approach for advancing soft robotics and wearable technologies. However, the comparative performance of scaled-down PCAs remains largely unexplored. In this study, we systematically examine the effects of miniaturization on PCA performance in a range of sizes relevant to wearable applications - from 7 to 28 mm diameter. Various working fluids and heating power configurations are analyzed under the assumption that both power input and actuation force should scale proportionally with liquid volume and surface area. This assumption stems from the idea that halving the surface area and volume of a PCA requires using two smaller actuators, each producing half the force of the original device with half of its power, to achieve equivalent performance. Our findings provide insights into response time, force generation, and mechanical output, enabling a direct comparison between conventional and miniaturized PCAs. Based on these results, we propose a novel application of PCAs as compact and lightweight pumps for soft robotic systems. Additionally, we demonstrate the feasibility of using our prototype in untethered McKibben muscles and worm-like robots, showcasing its potential for wearable and adaptive actuation. This study lays the foundation for further optimization of liquid-gas phase change actuators, fostering their integration into next-generation robotic and assistive technologies

1.2.10 **Variable-stiffness rehabilitative hand splints with pneumatic inverse artificial muscles**

Valentina Potnik (1), Gabriele Frediani (1), Federico Carpi (1),

(1) University Of Florence, Department Of Industrial Engineering, Florence, Italy

Presentation given by Ms. Valentina Potnik

Dynamic hand splints are rehabilitation orthoses, usually equipped with elastic bands/springs that exert passive resistance to voluntary finger movements. To make the exercise dynamically controllable, it would be advantageous to replace the elastic bands/springs with soft actuators that can generate electrically variable loads. This would allow for tailoring the rehabilitation task, not only before but also during the treatment. Here, we describe a strategy to develop dynamic hand splints that embed self-sensing pneumatic actuators functioning as "inverse artificial muscles". Prototype systems were manufactured by using off-the-shelf materials and cost-effective manufacturing processes. Unlike traditional pneumatic actuators that contract when pressurized, these actuators elongate. They comprise an airtight elastomeric tube encased by a nylon filament coil to prevent outward expansion. Self-sensing properties were achieved through an internal piezoresistive stretch sensor, made of a conductive elastomeric linear body arranged along the tube's central axis. An actuator was mounted on a forearm brace and connected at one end to a finger via a tendon, and on the other end to an on-board load cell. The latter measured the resistive force produced by the actuator at different driving pressures, as it was pulled by flexions of the finger. Psychophysical tests allowed for evaluating force perception by subjects.

1.2.11 **Investigating and optimizing lifetimes of EAP-based haptic actuators via tuning of the relevant design and operating parameters**

Tobias Stubning (1) (2), Istvan Denes (1), Reimund Gerhard (2),

(1) Robert Bosch GmbH, Corporate Sector Research And Advance Engineering, Renningen, Germany
(2) University Of Potsdam, Faculty Of Science, Institute Of Physics And Astronomy, Potsdam, Germany

Presentation given by Mr. Tobias Stubning

Screen-printed P(VDF-TrFE-CTFE)-based actuators are promising candidates for various applications, especially as haptically perceptible feedback providing human-machine interfaces (HMI). The actuators change their shape in response to externally applied electric fields. Their operating principles, as well as their dielectric and electro-mechanical properties, were extensively studied. Several approaches for improving the actuator response and a wide range of device applications have been proposed in the literature. Main challenges are sufficiently large strokes and long lifetimes as required in real-life applications for thousands and even millions of operating cycles. In order to understand the degradation behavior and its underlying mechanisms, as well as the key parameters influencing their lifetime, we built more than 150 actuators and ran them through endurance testing up to complete failure at various driving voltages, frequencies, thicknesses and numbers of stacked EAP layers, for different electrode geometries and at both polarities. The longest continuously operated actuator failed only after 225 million cycles equaling 308 h. Evaluation of the experimental results through combining voltage-based actuator-lifetime estimates with statistical (Weibull) analysis reveals that the actuator lifetime ranges between few thousands and up to hundreds of millions of operating cycles - requiring careful parameter selection and cost-benefit analysis when designing EAP actuators.

1.2.12 **High-voltage switching using silicone-based dielectric elastomer actuators and switches: performance in actuation frequency and voltage**

Carmen Perri (1), Mario Cerino (2), John Heppe (2), Paul Motzki (1) (3),

(1) Saarland University, Department Systems Engineering, Saarbrücken, Saarland, Germany.
(2) University Of Applied Sciences, Saarbrücken, Germany
(3) ZeMA - Center For Mechatronics And Automation Technology, Smart Material Systems, Saarbrücken, Germany

Presentation given by Dr. Carmen Perri

Dielectric Elastomer Actuators (DEAs) are promising for high-voltage switching due to their large deformations and excellent insulation properties. They offer a flexible alternative to rigid semiconductor-based switches, overcoming challenges like mechanical rigidity and thermal management. Dielectric Elastomer Switches (DESs), made with sputtered thin-film metal electrodes, are pre-stretched to enhance durability and electrical performance. An additional biaxial stretching step creates controlled cracks in the electrode layer, enabling resistance switching. DESs exhibit two resistance states: a high-resistance state that blocks current and a low-resistance state that allows conduction. Transitioning between these states requires an in-plane stretch of ~10%, necessitating precise DEA actuation control. This study focuses on the performance of DES coupled with DEA, specifically actuation frequency and voltage. Experimental results show that the system effectively switches high voltage by leveraging the DES's resistance-switching behaviour. The use of a silicone film enables a relatively high actuation frequency, enhancing system efficiency and applicability in high-voltage switching.

1.2.13 **Coaxial 3D printing of liquid metal-integrated dielectric elastomer fibers for soft actuation**

Inga Põldsalu (1), Christopher Daniel Woolridge (1), Robyn Ellen Worsley (1), Magdalena Skowyra (1), Anne Ladegaard Skov (1),

(1) The Danish Polymer Centre, Department Of Chemical Engineering, Technical University Of Denmark, Denmark

Presentation given by Dr. Inga Põldsalu

Due to their high deformation response under applied electric fields, dielectric elastomers (DEs) are widely explored for electromechanically active polymer (EAP) actuators. Traditional DE actuators often rely on manually assembled multilayer films, limiting design flexibility and integration. Additive manufacturing presents new opportunities for fabricating complex DE structures with improved functionality and scalability. This work presents a coaxial 3D printing approach for fabricating DE fibers with an integrated liquid metal electrode, enabling highly flexible and conductive soft actuators. Using a coaxial extrusion setup, fibers were printed with a Galinstan-based liquid metal core, a silicone-based dielectric elastomer layer, and an encapsulating outer sheath. Process optimization ensured uniform fiber morphology, stable encapsulation, and minimized metal leakage, addressing key interfacial adhesion and structural integrity challenges. The printed DE fibers exhibited sustained electrical conductivity under repeated mechanical deformations and demonstrated electromechanical actuation in response to applied voltages. These results highlight the potential of coaxial 3D printing for scalable fabrication of soft transducers, with implications for wearable devices, artificial muscles, and soft robotics. Future work will focus on integrating alternative electrode materials and refining fiber architectures to enhance actuation performance.

1.2.14 **Light-driven motion: 3D-printed liquid crystalline elastomers as smart actuators**

Giovanni Simonetti (1) (3), Ruggero Rossi (2), Caterina Credi (4), Daniele Martella (1) (2), Federico Carpi (5), Camilla Parmeggiani (1) (2) (5),

(1) European Laboratory For Non Linear Spectroscopy
(2) Department Of Chemistry - University Of Florence
(3) Department Of Physics - University Of Florence
(4) National Institute Of Optics National Research Council (INO-CNR)
(5) Department Of Industrial Engineering, University Of Florence

Presentation given by Dr. Giovanni Simonetti

4D printing, which integrates 3D printing with stimuli responsive materials, is a powerful and rapidly evolving technique that is drawing increasing interest across various fields. This innovative approach has significant potential in areas such as soft robotics, biomedical devices and optical systems, where controlled and reversible shape changing are crucial. While considerable progress has been achieved, challenges persist in enhancing response speed, improving durability, and refining actuation control to fully unlock the potential of 4D-printed materials in practical applications. Liquid Crystalline Elastomers (LCEs) offer a promising solution for developing programmable deformable structures with stimuli control. Successfully fabricating LCEs through 3D printing methods like direct ink writing (DIW) requires precise management of ink formulation, mesogens alignment, and curing process. Key challenges such as ensuring uniform molecular orientation, minimizing structural defects, and optimizing actuation efficiency remain active areas of research. Here, we present a direct synthetic method that enables large-scale ink production suitable for low-cost DIW printers, facilitating the creation of centimeter-scale liquid crystalline based objects. The resulting structures exhibit programmable deformation with activation times in the millisecond range under visible light exposure, offering a compelling alternative to conventional rigid mechanical components in optical devices.

1.2.15 **Wet-spinning of S-PEDOT yarns for stretchable e-textiles**

Yuxin Jing (1), Risa Watanuki (1), Hidenori Okuzaki (1),

(1) University Of Yamanashi, Graduate Faculty Of Interdisciplinary Research, Kofu, Japan

Presentation given by Ms. Yuxin Jing

Electronic textiles (e-textiles), representing fibers and fabrics with electronic functions, are attracting considerable attention as wearable electronics piezoelectric fabric. Here, flexible, lightweight, and inexpensive conductive fibers are the key material for the smart textiles and e-textiles. Previously, we synthesized fully soluble self-doped poly(3,4-ethylenedioxythiophene) (S-PEDOT) by chemical oxidative polymerization of a novel monomer bearing a sodium alkylsulfonate side chain. Different from PEDOT doped with poly(4-styrenesulfonate) (PEDOT:PSS), the electrical conductivity of the S-PEDOT attained as high as 1089 siemens per centimeter without the use of secondary dopants. Recently, we first reported highly conductive fibers fabricated by one-step wet-spinning of S-PEDOT aqueous solutions with different concentrations in acetonitrile used as a coagulant. However, the fracture strain of a single fiber was as low as 3%, and the fibers were brittle for use in e-textiles. In this study, S-PEDOT yarns were fabricated from wet-spun microfibers and combined with stretchable fibers to investigate their application to e-textiles. The e-textiles exhibited mechanical durability and maintained their structural integrity with nearly constant resistance even after 2000 cycles of 100% elongation, indicative of a promising candidate for stretchable e-textiles.

1.2.16 **The impact of anisotropic woven fabrics on the performance of 3D-printed PEDOT-based textile actuators**

Louise Anne Furie (1), Jose G. Martinez (1), Shayan Mehraeen (1), Edwin W. H. Jager (1),

(1) Division Of Sensors And Actuator Systems, Department Of Physics, Chemistry And Biology, Linkoping University, Linkoping, Sweden

Presentation given by Ms. Louise Anne Furie

Smart textile actuators are gaining attention for applications in soft robotics and wearable electronics. These actuators can undergo controlled, reversible deformation in response to external stimuli like temperature changes or electric potential. Recent advancements focus on integrating smart yarns, fibre actuators, and functional materials directly in/on textiles. The mechanics of the textile substrate influence the actuation performance of these devices, which can enable complex movements. By using different weave patterns in combination with different yarns, the mechanical anisotropy of the substrate can be enhanced. Additive manufacturing offers a promising approach for fabricating these actuators, allowing rapid customisation of active and passive material patterns. This study explores multi-layered PEDOT:PSS actuators 3D-printed onto various textile substrates via syringe-based extrusion. The effects of different weave patterns on bending actuation are examined, and the findings highlight the relationship between textile design, material composition, and fabrication methods in optimising smart textile actuators.

1.2.17 **Conducting polymer coated textile yarns with simultaneous actuation and sensing**

Lijin Rajan (2), Yahya A. Ismail (2), Edwin W. H. Jager (1), Jose G. Martinez (1),

(1) Linköping University, Department Of Physics, Chemistry And Biology (IFM), Division Of Sensor And Actuator Systems, Linköping, Sweden
(2) University Of Calicut, Department Of Chemistry, Calicut, India

Presentation given by Dr. Jose G. Martinez

Textiles provided with mechanical actuation are quickly acquiring relevance due to their applications in fields as haptics or assistive devices. One of the followed strategies to develop actuating textiles is to coat commercially available yarns and textiles with conducting polymers (CPs) to make CP-based textile actuators. These have been proven to be feasible and are being developed rapidly. Here, we demonstrate that CP-yarns provide simultaneously one extra functionality: sensing of different parameters. By testing the CP-yarns under different experimental conditions (different mechanical conditions, different electrolyte concentration, different electrical conditions), while actuating, the same CP coated yarn offers information about the experimental variables: it is possible to use it as different sensors. This paves the way to textile actuators with embedded multifunctionality, without the need of extra new elements.

1.2.18 **Flexible conductive polymer electrodes for soft actuators**

Daiki Ozawa (1), Daito Goto (1), Hidenori Okuzaki (1),

(1) University Of Yamanashi, Graduate Faculty Of Interdisciplinary Research, Kofu, Japan

Presentation given by Mr. Daiki Ozawa

Flexible and highly conductive electrodes are crucially important for fabrication of small, lightweight, noiseless, soft sensors and actuators for the applications to artificial muscles and electromechanical power generators. In this study, we have developed soft and flexible self-doped poly(3,4-ethylenedioxythiophene) (S-PEDOT) electrodes by modifying the counterion of sulfonic acid groups. It was found that Young's modulus and tensile strength significantly decreased from 1.2 GPa and 52 MPa to 0.04 GPa and 1.6 MPa, respectively, by replacing the protons of sulfonic acid groups with organic cations. Notably, elongation at break attained as high as 17.9%, which was much higher than the PEDOT:PSS film (6%). Furthermore, we fabricated electroactive polymer (EAP) soft actuators composed of ionic liquid-polyurethane (IL-PU) gel with soft and flexible S-PEDOT electrode films on both sides of the gel. Upon application of an electric field through the electrodes, the EAP actuator showed quick bending toward anode, the mechanism of which was associated with the electric double layer caused by polarization of ionic liquid. The results allowed us to conclude that mechanical properties of the electrodes were more important than the electrical conductivity for the performance of EAP soft actuators.

Session 1.3
(abstracts are listed in the order of presentation)

1.3.1 **HASEL engines for achieving efficient continuous rotation with electrostatic actuators**

Yasunori Toshimitsu (1) (2), Robert Katzschmann (2), Christoph Keplinger (1),

(1) Max Planck Institute For Intelligent Systems, Robotic Materials Department, Stuttgart, Germany
(2) ETH Zurich, Soft Robotics Lab, Zurich, Switzerland

Presentation given by Mr. Yasunori Toshimitsu

Electrostatic actuators offer high force generation with minimal stall current, combined with inherent compliance and backdrivability, making them highly attractive for robotic applications. Despite these advantages, existing electrostatic artificial muscles, such as HASELs and DEAs, are limited by their short stroke length, restricting their effectiveness in robotic systems as they require a large range of motion. To overcome this limitation, we introduce the "HASEL engine," an actuator system that integrates multiple HASEL actuators into a radial crankshaft mechanism, effectively converting their linear contraction into continuous rotational motion and thus achieving unlimited stroke. We present a detailed radial design featuring six independently controlled high-voltage channels. Additionally, we propose a comprehensive theoretical model derived from empirical characterization of individual HASEL actuators, demonstrating the optimization process for design parameters aimed at maximizing torque consistency and output. Our results indicate that the HASEL engine achieves competitive specific energy and torque outputs compared to existing electrostatic rotational actuators, significantly outperforming traditional electromagnetic motors in terms of energy dissipation at stall conditions. This makes the HASEL engine particularly suitable for low-power, low-rpm robotics applications.

1.3.2 A multiphasic chemo-electro-mechanical model for hydrogel-based chemical sensors

Martin Sobczyk (1), Boyu Yuan (1), Thomas Wallmersperger (1),

(1) TU Dresden, Institute Of Solid Mechanics, Dresden, Germany

Presentation given by Dr. Martin Sobczyk

Polyelectrolyte polymers can be used as transducers for in-situ ethanol concentration measurements using plasmonic sensors. It is expected that their multi-sensitivity can be tuned to use them as transducer for a wide variety of substances other than ethanol, e.g. specific ionic species. A numerical model is developed to describe the behavior of a water-saturated polyelectrolyte polymer on the basis of multiphase continuum mechanics. The developed model is formulated as variation-based model using an energy functional to ensure thermodynamical admissibility of the formulated material laws. The multiphase continuum is described as a superposition of the two material bodies fluid and solid phase. The solid phase comprises fixed ionic charges whereas in the fluid phase mobile ions are present. The chemo-electro-mechanical behavior of a functionalized plasmonic sensor based on polymer gels is described taking into account electrostatics, mass fluxes of the fluid and the ions and finite deformations of the solid phase.

1.3.3 Role of adhesion layer between dielectric elastomer actuator and human cells

Simon Holzer (1) (2), Noe Syffrig (1) (2), Chaimae Bahou (3), Ali Hashemi Gheinani (3), Yoan Civet (1) (2), Katia Monastyrskaya (3), Yves Perriard (1) (2),

(1) Integrated Actuators Laboratory (LAI), Ecole Polytechnique Fédérale De Lausanne (EPFL), Neuchatel, Switzerland
(2) Center For Artificial Muscles (CAM), Ecole Polytechnique Fédérale De Lausanne (EPFL), Neuchatel, Switzerland
(3) Functional Urology Lab, Department For BioMedical Research (DBMR), University Of Bern, Bern, Switzerland

Presentation given by Mr. Simon Holzer

The integration of human cells with dielectric elastomer actuators is a promising approach in bioengineering, enabling advancements in the fields of personalized healthcare and tissue engineering. Previous studies have shown that an external stimulus, like mechanical stress, can stimulate human cells leading to novel insights in cell biology. Soft actuators, for example dielectric elastomer actuator, are capable of introducing such mechanical stimuli. Thereby, one key challenge is ensuring effective adhesion between the cells and the actuator surface. Adhesion layers, such as collagen I, fibronectin, poly-l-lysin, laminin and gelatin, have been explored to improve cell attachment and function. In this study, we examine the effects of these adhesion layers on TEU-2 cells, urothelial cells, by using flow cytometry, focusing on apoptosis assay and cell cycle analysis. The specific adhesion layers influence the cell cycle and apoptosis of TEU-2 cells, with collagen I providing the most favourable conditions for cell attachment and survival rate compared to poly-l-lysin leading to increased late apoptosis, meaning cell death. Our results contribute to the development of better strategies for integrating living cells into stretchable actuators, expanding the potential for future biomedical applications. These insights are used in future to enable improved applications of dielectric elastomer actuators in cell biology.

1.3.4 **Comfort meets technology: a soft medicine pump design using dielectric elastomers**

Aleksandra Sowa (1), Andreas Richter (1), E.-F. Markus Vorrath (1) (2),

(1) Institute Of Semiconductors And Microsystems, TU Dresden, Dresden, Germany
(2) Auckland Bioengineering Institute, University Of Auckland, Auckland, New Zealand

Presentation given by Ms. Aleksandra Sowa

Dielectric elastomers (DEs) are advanced materials, characterized by their flexibility and ability to generate actuation under high electric fields, making them suitable for creating lightweight, adaptive devices.This study presents the design of a novel soft, wearable medicine pump utilizing DEs, aimed at improving comfort and usability for individuals with illnesses, such as diabetes. Traditional medicine delivery systems can be bulky and uncomfortable. Our design addresses these limitations by providing a pump that conforms to the body, facilitating participation in various activities, i.e. swimming, without the discomfort associated with traditional devices. The pump is designed for temporary use. The elastic properties of the DE can enable a secure fit against the skin, enhancing both discretion and comfort. By exploiting the unique characteristics of DE, this device effectively adapts to user movements, optimizing the insulin delivery experience. This research underscores the potential of soft, wearable technologies to revolutionize diabetes management by offering users enhanced freedom and improved quality of life. We anticipate that this innovative approach will contribute significantly to advancements in wearable insulin delivery systems in the future.

1.3.5 **Microfluidic Soft Robotics: Combining Actuation and Sensing through Conductive and Dielectric Modulation**

Anirshu Devroy (1), Georgi Pashew (1), Li Guo (3), Nils-krister Persson (3), Ingrid Graz (2), Andreas Richter (1),

(1) Institute Of Semiconductors And Microsystems, Dresden University Of Technology, Dresden, Germany
(2) School Of Education, STEM Education, Johannes Kepler University Linz, Linz, Austria.
(3) Polymeric E-textiles, Smart Textiles, Swedish School Of Textiles, University Of Borås, Borås, Sweden

Presentation given by Mr. Anirshu Devroy

The integration of sensing and actuation into a single, unified system remains a significant challenge in soft robotics. Existing approaches, such as vision-based and TENG-based soft grippers, typically rely on multiple modalities to achieve both functions, increasing complexity. This work presents a novel method for developing a single processing unit capable of simultaneously performing sensory and actuation functions. Using 3D molding techniques and Sylgard 184, microchannels were fabricated to serve as a multifunctional platform. When filled with conductive fluid (e.g., salt water), the system functions as an actuator, demonstrating a driving capacity of 10 V and 300 mA current. By introducing electrodes and leveraging capacitive sensing principles, the same system detects different dielectrics passing through the microchannels, exhibiting a capacitance variation of approximately 6% when alternating between salt water and oil. This dual-functionality design reduces the need for separate sensing and actuation components, paving the way for intelligent, autonomous soft robotic systems capable of real-time decision-making based on simultaneous sensory and actuation feedback.

1.3.6 Data-driven modeling and RL-based control of musculoskeletal robots actuated by electrofluidic artificial muscle

Amirhossein Kazemipour (1), Hehui Zheng (1), Mike Y. Michelis (1), Misato Sonoda (1), Robert K. Katzschmann (1),

(1) ETH Zurich

Presentation given by Mr. Amirhossein Kazemipour

In this paper, we present a comprehensive framework and pipeline for modeling and closed-loop control of musculoskeletal robotic systems actuated by Hydraulically Amplified Electrostatic Actuators (HASELs). Our approach leverages high-fidelity, data-driven models that capture the complex nonlinear electrohydraulic dynamics and inherent hysteresis behavior characteristic of HASELs. We present both black-box neural networks (multilayer perceptrons) and interpretable symbolic regression methods to model the relation between input voltage, actuator position, and velocity to the output force generated by the artificial muscle. These models are integrated into a realistic MuJoCo simulation environment of a two-degree-of-freedom limb, where we train reinforcement learning (RL) control policies using the Soft Actor-Critic (SAC) algorithm for two tasks: precise trajectory tracking during free-space motion and robust force regulation in contact-driven scenarios. To facilitate effective sim-to-real transfer, we incorporate domain randomization techniques during policy training. Validation through simulation and hardware experiments show that our framework reliably predicts actuator behaviors and consistently achieves superior

control performance compared to conventional PID controllers. This work validates a versatile pipeline applicable to more complex musculoskeletal systems, paving the way for next-generation soft robots, prosthetics, and exoskeletons.

1.3.7 Dielectric elastomer switches for pneumatic sensing

Chen Jiao (1), Ashwani Sharan Tripathi (1), Andreas Lars Peter Hubracht (2), Albert Thelemann (2), Uwe Marschner (1), Andreas Richter (1), Juergen Maas (2), E.-F. Markus Vorrath (1) (3),

(1) Institute Of Semiconductors And Microsystems, Technische Universitaet Dresden, Dresden, Germany
(2) Mechatronik Systems Lab, Technische Universitaet Berlin, Berlin, Germany
(3) Biomimetics Lab, Auckland Bioengineering Institute, The University Of Auckland, Auckland, New Zealand

Presentation given by Dr. Chen Jiao

Collaborative multi-actuator systems are expected to play a vital role in future applications such as robotics, medical devices, and advanced user interfaces. These systems have potential uses across a wide range of scales, from macro to micro. To realize intelligent, fully soft bioinspired robots, fully soft electronic circuits are essential. Dielectric elastomers (DE) are electroactive polymers with multifunctional properties, including actuation, sensing, and energy harvesting. In this work, we developed a pneumatic DE switch (DES) prototype to sense the air pressure into an electrical signal. A stretchable conductive track is printed on a silicone membrane. When compressed air is introduced, it induces significant deformation of the silicone membrane, resulting in bulge formation. The conductive tracks attached to the silicone membrane is stretched at the same time. As a result, the number of micro conductive pathways formed by conductive particles decreased significantly, causing a sharp increase in the resistance of the DES. This is a stable multiple-cycle switching where the DES switches with resistance changes of several orders of magnitude. The resistance varies with applied pressure, demonstrating the potential of this prototype to function as a pressure sensor.

1.3.8 Combining doped conductive polymers and ionogels in separate

fibre forms via a plain weave for in-air actuation

Claude Huniade (1), Jose G. Martinez (2), Marie Ekstedt Bjersing (1), Cédric Vancaeyzeele (3), Giao T.-M. Nguyen (3), Cédric Plesse (3), Edwin W. H. Jager (2), Nils-Krister Persson (1),

(1) Polymeric E-textiles, The Swedish School Of Textiles, University Of Borås, Borås, Sweden
(2) Sensor And Actuator Systems (SAS), Department Of Physics, Chemistry And Biology (IFM), Linköping University, Linköping, Sweden
(3) CY Cergy Paris Université, LPPI, Cergy-Pontoise, France

Presentation given by Mr. Claude Huniade

The continuous production of textile muscle fibres made by continuous electropolymerisation of polypyrrole (PPy) onto multifilaments coated with poly(3,4-ethylenedioxythiophene) (PEDOT) and of surface ionofibres made by UV coating ionogels on commercial multifilaments enables the manufacturing of textile muscles. Here, plain woven fabrics combining textile muscle fibres as warp threads and ionofibres as weft threads are investigated. This study aims to understand the translation of the contractile properties of textile muscle fibres in aqueous sodium dodecylbenzenesulphonate (NaDBS) to the behaviour of the fibres in such woven fabrics. Indeed, in a plain weave, the contact of the textile muscle fibres with an ion source/sink is only done at the interlacings with the ionofibres. Compared to crude fabric coatings, this contribution opens up to a new generation of textile muscles.

1.3.9 **Fabrication and characterization of bio-friendly air-operating coiled CNT yarn actuators**

Gabriela Ananieva (1), Cedric Vancaeyzeele (1), Giao T.M. Nguyen (1), Daniel Aguilera-Bulla (1), Mathieu Pinault (2), Frédéric Vidal (1), Cédric Plesse (1),

(1) LPPI, CY Cergy Paris Université
(2) Université Paris-Saclay, CEA, CNRS, NIMBE, 91191, Gif-sur-Yvette, FRANCE
Presentation given by Dr. Cedric Vancaeyzeele

Electrochemically driven coiled yarn actuators provide fast actuation and large contractile stroke. They comprise a coiled electroactive yarn and an electrolyte, serving respectively as the electrode and the ion source. The charging of the electrochemical double layer at the interface of the yarn and the electrolyte promotes an increase in volume, as the ions swell the yarn, leading to transversal expansion and longitudinal contraction. In this work, we describe the air-operating actuators based on coiled CNT yarns gels containing deep eutectic solvents (DES) derivatives as ionic coatings. These gels offer the necessary ionic conductivity and mechanical properties and do not pose any toxicity concerns. Specifically, two oppositely charged gels were developed to promote the so-called unipolar charging of yarns. The polyanionic gel contained grafted anions, while the polycationic one contained grafted cations. This ensured that the anions and cations were respectively blocked from participation in the intercalation process at the negative and positive electrodes. This enabled unidirectional contractile stroke of 3.6% over the electrochemical window of 3V. To assess their functionality in smart wearables, the actuators were integrated into cord lap warp knits, where their stroke and strain rate remained almost unchanged from that of a single actuator. Further improvements in actuation performance are expected through optimized yarn geometry and integration into textile garments.

1.3.10 **Electroadhesive gripper with thermochromic visuo-tactile sensing**

Thomas Daunizeau (1), Herbert Shea (1),

(1) EPFL, LMTS, Neuchatel, Switzerland

Presentation given by Dr. Thomas Daunizeau

The human hand seamlessly combines dexterous grasping with acute sensitivity, allowing us to infer object properties through tactile and thermal cues. Equipping soft robots with a similarly rich sense of touch is essential for their deployment in real-world, unstructured environments. While electroadhesive (EA) grippers hold immense promise, their sensing capabilities remain limited to discrete markers or basic capacitive feedback. This work addresses that gap by augmenting EA grippers with a thermochromic sensing layer coupled with an embedded heater.

Leveraging a vision-based approach, embedded cameras monitor in real time the color changes induced by contact with objects. This enables high temporal sensitivity and allows for the identification of polymers, composites, and metals based on their distinct heat transfer properties. Additionally, the high spatial resolution supports precise mapping of the contact area during grasping, crucial for shape recognition and slip prevention. Even in its simplest form, the thermochromic layer can detect warm objects without additional sensors. Theoretical analysis and a series of experiments collectively demonstrate the multifaceted potential of our approach for advancing soft robotic manipulation.

1.3.11 **Mechanochromic Soft Robotic Skin**

Giacomo Sasso (1) (2), Alessandro Pagani (1) (2), Gianni Pedrizzetti (3), Nicola Pugno (2) (4), James Busfield (2), Federico Carpi (1) (2),

(1) University Of Florence, Department Of Industrial Engineering, Florence, Italy
(2) Queen Mary University Of London, School Of Engineering And Material Science, London, United Kingdom
(3) Department Of Engineering And Architecture, University Of Trieste, Trieste, Italy
(4) Department Of Civil, Environmental And Mechanical Engineering, University Of Trento, Trento, Italy

Presentation given by Mr. Giacomo Sasso

Advancements in robotic systems for healthcare and manufacturing require accurate monitoring of contact features during interactions with objects and/or humans. This contribution introduces a novel mechanochromic robotic skin capable of tactile sensing, which uses functional materials that encode strain information through colour changes. Unlike conventional tactile sensors that rely on dense arrays of sensing elements, this approach uses a single optical camera for high-resolution detections of 3D contact patterns and 2D contact pressure distributions, by sensing colour changes induced in a mechanochromic material. This type of mechanochromic skin, based on a strain-sensitive photopolymer, provides a scalable and cost-effective strategy to enhance robotic interactions with their environment.

1.3.12 **Laser-engraved silicon buffer layer for multi-layer dielectric**

elastomer sensors

Artem Prokopchuk (1), Arthur Ewert (2), Johannes D. M. Menning (3), Andreas Richter (1), Berthold Schlecht (2), Thomas Wallmersperger (3), E.-F. Markus Vorrath (1) (4),

(1) Technische Universität Dresden, Institute Of Semiconductors And Microsystems, Dresden, Germany
(2) Technische Universität Dresden, Institute Of Machine Elements And Machine Design, Dresden, Germany
(3) Technische Universität Dresden, Institute Of Solid Mechanics, Dresden, Germany
(4) The University Of Auckland, Auckland Bioengineering Institute, Biomimetics Lab, Auckland, New Zealand

Presentation given by Mr. Artem Prokopchuk

Dielectric elastomers (DEs) are extensively used in soft robotics, wearable electronics, and advanced sensor technologies due to their ability to endure large deformations, making them ideal for flexible and stretchable applications. A major challenge in dielectric elastomer sensors (DESs) is ensuring stable electrical contact between the electrodes and external measuring devices. Conventional methods, such as carbon grease, conductive ink, or copper films, often suffer from instability under mechanical stresses like compression and stretching, leading to contact degradation and reduced sensor performance. A more robust alternative involves using wires, conductive threads, or fabric, which offer improved stability under mechanical strain. In this study, we introduce a novel contact solution incorporating a laser-engraved elastomer buffer layer. The buffer layer, combined with conductive threads and carbon grease, enhances contact fixation, improving both durability and adaptability. The laser engraving technique enables customizable contact designs, allowing for optimization based on specific application needs. This approach presents a promising strategy for enhancing the reliability of DESs, making them more suitable for dynamic and high-deformation environments.

1.3.13 **Influence of silicone content in the electrode matrix on the**

failure of DE actuators

Bettina Fasolt (1), Benedikt Holz (2), Bruch Daniel (2), Paul Motzki (1), Stefan Seelecke (2),

(1) ZeMA - Center For Mechatronics And Automation Technology, Smart Material Systems, Saarbrücken, German
(2) Saarland University, Dept. Systems Engineering, Saarbrücken, Germany

Presentation given by Ms. Bettina Fasolt

The actuation performance of dielectric elastomers actuators (DEAs) is driven by the application of electric voltages, where the generated actuation force - originating from Maxwell stress - is directly dependent on the electric field. Due to the quadratic relationship between the applied field and actuation force, higher voltages enhance efficiency; however, the field-dependent dielectric breakdown imposes a critical limitation. Various studies have demonstrated that electrode composition significantly influences breakdown behavior, with findings indicating that an increased silicone content in the electrodes correlates with a higher breakdown voltage. For applications such as pumps, where DEAs are subjected to continuous mechanical loading, not only the magnitude of the breakdown field but also the material's endurance over repeated actuation cycles is crucial. This study investigates whether the increased silicone content in electrodes not only raises the breakdown field but also extends the operational lifetime of DEA. However, a higher silicone content also increases electrical resistance, presenting a trade-off between conductivity and breakdown strength. The results underscore the necessity of tailoring electrode compositions to specific application requirements, emphasizing the demand for customized electrode formulations optimized for different operational conditions.

1.3.14 **Improvement of textile based actuators by conductive coating**

Abd Ul Qadeer (1) (2), Daito Goto (2), Shuki Toyoshima (2), Shayan Mehraeen (1), Jose G. Martinez (1), Hidenori Okuzaki (2), Edwin W. H. Jager (1),

(1) Department Of Physics, Chemistry And Biology (IFM), Linkoping University, Sweden

(2) School Of Biomedical Engineering And Agriculture, University Of Yamanashi, Japan

Presentation given by Mr. Abd Ul Qadeer

In the fabrication of textile-based ionic EAP actuators, yarns are first coated with PEDOT by solution dip coating to make the passive yarns conductive. This is followed by PPy deposition to induce electrochemical-driven actuation. In these textile-based actuators, the performance of the actuators depends amongst others on the mechanical and electrical properties of the first conductive PEDOT coating layer. In this study 5 different PEDOT solutions were prepared by adding different additives to poly(3,4-ethylenedioxythiophene) polystyrene sulfonate solutions. Films were formed from these solutions and their electrical conductivity and mechanical strength were measured. These solutions were then coated on polyamide multifilament yarns and dried at different temperatures, and their resistance and mechanical properties were measured. The yarn coated with PEDOT:PSS-PG 90 weight percent exhibit the lowest Young's modulus 0.33 MPa at room temperature, while the yarn coated with PEDOT:PSS-PEG-DMSO exhibited the lowest resistance of 130 ohms at 180°C. This study provides valuable insights that by tailoring the PEDOT solution composition and drying temperature the conductivity and mechanical properties of the coated yarn can be improved ultimately paving the way for better actuation performance of the textile-based ionic EAP actuators.

1.3.15 **A systematic approach for overcoming actuation challenges in double coiled yarn actuators**

Shayan Mehraeen (1), Jose G. Martinez (1), Amaia B. Ortega-Santos (1), Cedric Plesse (2), Nils-Krister Persson (3), Edwin W.H. Jager (1),

(1) Sensor And Actuator Systems, Department Of Physics, Chemistry And Biology (IFM), Linkoping University, Linkoping, Sweden
(2) CY Cergy Paris Universite, LPPI, 95000 CERGY, France
(3) Swedish School Of Textiles, Smart Textiles, Polymeric E-textiles, University Of Boras, SE-501 90 Boras, Sweden

Presentation given by Dr. Shayan Mehraeen

Textile actuators based on coiled yarns coated with conductive polymers are gaining increasing attention for wearable applications. Coiled yarn actuators show superior performance due to the geometrical and mechanical effects of the coils. A typical configuration to use coiled yarn actuators in air consists of two coiled yarns coated with different conductive polymers, connected through an ionogel. One coiled yarn actuator is cation-driven, while the other is anion-driven, ensuring synchronized actuation strains. Although coiled yarn actuators generally show high actuation performance in electrolytes, developing a high performance, and stable yarn actuator that works effectively in air remains a challenge for many applications. In this study, we employed a step-by-step approach to systematically identify the limitations affecting actuation in a double coiled yarn actuator. First, each coiled yarn actuator was individually characterized in a three-electrode electrochemical system in an electrolyte. Next, the performance of the individual coiled yarns was evaluated in presence of an anion-driven coiled yarn as counter electrode. In the third step, the system was studied in a two-electrode system, and finally, the overall performance was assessed in air using an ionogel. This study offers important insights into the working principles of double coiled yarn actuators and establishes the foundation for optimized designs of such actuators in air applications.

1.3.16 **Carbon fiber-silicone prepreg for anisotropic reinforcement of dielectric elastomer components**

Junhao Ni (1) (2), Markus Koenigsdorff (1), E.-F. Markus Vorrath (2) (3), Andreas Richter (2), Gerald Gerlach (1),

(1) Institute Of Solid-State Electronics, Technische Universität Dresden, Nöthnitzer Str. 63, 01069 Dresden, Germany
(2) Institute Of Semiconductors And Microsystems, Technische Universität Dresden, Nöthnitzer Str. 67, 01069 Dresden, Germany
(3) Biomimetics Lab, Auckland Bioengineering Institute, The University Of Auckland, 70 Symonds St, Auckland, 1010, New Zealand

Presentation given by Mr. Junhao Ni

Dielectric elastomer actuators (DEA) exhibit high energy and power density while also being extremely deformable. These properties make them promising for applications in bionic robotics and artificial muscles. However, DEA require a high electric field strength (20-100 V/µm) to operate. To reduce the voltage demand, the thickness of a single DEA layer is typically on the micrometer scale. As a result, stacking dozens or even hundreds of DE layers are required to achieve sufficient displacement in the thickness direction. Utilizing displacement in the planar direction can significantly reduce the required number of DE layers. However, the in-plane strain of DEA is biaxial, which means that if uniaxial actuation is desired, the strains that occur perpendicular to the working direction are of no use. Eliminating these strains reduces the actuator's degrees of freedom, resulting in improved actuator performance. In this work, a carbon fiber prepreg was developed using a unidirectional non-crimp fabric with a soft silicone as the matrix material. The use of a soft matrix material instead of the conventional stiff resins results in a composite with a high degree of mechanical anisotropy. Multilayer DEA were fabricated using the sheet-to-sheet method and reinforced with the carbon fiber composite layer. The resulting DEA were characterized and exhibited significantly higher strains and forces than their unconstrained counterpart during uniaxial motion.

1.3.17 RF sputtered gold thin films on silicone membranes as electrodes for dielectric elastomer transducers

Benjamin Zemlin (1), Dirk Göttel (1), Marcus Koch (1), Mario Cerino (1), Jonas Hubertus (1), Günter Schultes (1), John Heppe (1),

(1) University Of Applied Sciences, Saarbruecken, Germany

Presentation given by Mr. Benjamin Zemlin

Flexible and elastic polymers capable of sensing and actuation show enormous potential for adaptive systems, such as wearable electronics, implants or hapto-acoustic devices. Dielectric elastomers (DE) are highly promising for this purpose, because their capacity changes when deformed and they generate motion upon application of a voltage. For operation, it is necessary that the electrodes comply with the stretch of the elastomer and remain sufficiently conductive. Carbon black particles embedded in polydimethylsiloxane have become widespread because of their high conformability. However, they typically have high resistance. Especially for high frequency applications this becomes an issue since charging time becomes relevant. Metals offer a lower resistivity. However, the limited intrinsic strain of most metals must be overcome. One way is to sputter metal thin films on pre-stretched silicone films. When releasing the pre-stretch, the thin film forms wrinkles and allows the electrode to be stretched up to the prior pre-stretch without significantly increasing the resistance. Gold is a promising material due to its high ductility and biocompatibility. In this work, gold is sputtered onto a silicone membrane to serve as a compliant electrode for DE. The poster presents an electrical characterization of the gold electrode, along with an analysis of the adhesion of gold on silicone and the effects of the sputtering process on the interface between silicone and gold.

1.3.18 **Synergistic Interaction of Alternating Electroadhesion and Distributed Actuation in Soft Crawling Robots**

Jian Chen (1), Jan Fredric Kreft (1), Andreas Richter (1), E.-F. Markus Vorrath (1) (2),

(1) TU Dresden, Institute Of Semiconductors And Microsystems, Dresden, Germany
(2) Biomimetics Lab, Auckland Bioengineering Institute, The University Of Auckland, Auckland, New Zealand

Presentation given by Mr. Jian Chen

While traditional rigid robots have achieved remarkable motion capabilities, their mechanical limitations in biomimetic locomotion remain evident. The development of soft robots, which exhibit behaviors like animals, has opened up new perspectives and applications in robotics. The main goal of our project is to explore a method for constructing entirely soft robots, where the robot body, control system, memory components, and so forth are all designed as soft structures. Utilizing methods such as electrical and mechanical simulations to assist in design, integrating flexible circuits based on DEAs into autonomous soft robot structures functioning as distributed networks is a current critical task. Our current work is to use switchable alternating adhesion force for climbing structures. The starting point of this research is a crawling robot made of silicone. This work will explore the integration of switchable adhesion mechanisms into bioinspired, compliant robotic structures and subcomponents. Imitating the inchworm locomotion, the silicone-based robot integrates two keys: (1) patterned electro adhesive pads enabling switchable contact interface, and (2) DEA-based artificial muscles provide the axial strain for body deformation to enable movement. The distributed DE network serves multiple functions - as actuator, and signal transmission medium - achieving fully autonomous operation through DC-powered DE- Electronic Networks.

Wednesday, 11 June 2025

Session 2.1

(abstracts are listed in the order of presentation)

2.1.1 **Mimicking haptic muscles and proprioception.**

Ivan Minev (1) (2),

(1) Leibniz Institute For Polymer Research, Dresden, Germany
(2) Else Kroener Fresenius Center For Digital Health, Medizinische Fakultaet Carl Gustav Carus, Dresden University Of Technology, Dresden, Germany

Presentation given by Prof. Ivan Minev

Bioelectronic interfaces promise to enable new medical treatments delivered by implanted sensors and actuators. As neuroprostheses they may enable restoration of functions lost through injury or disease or even brain repair. Such devices will require a seamless fit to the target biological system which is a considerable technological challenge. For example, electrode arrays implanted in the brain are made from a combination of metals, silicone and other materials used in microelectronics. These operate by exchanging electrical signals with neurons. The brain however is a soft tissue made of various cell types, extracellular matrix and small and large signaling molecules. The set of materials available to neuro-engineers is currently inadequate to capture this complexity. In this talk I will describe our efforts to design materials with functions inspired by both biology and by electronics. Broadly these fall into the class of conductive hydrogels. These may enable bioelectronic devices that resemble the function and organization of tissues and enable information exchange beyond the electrical domain.

2.1.2 **Two-photon polymerisation of microactuators**

Christine Selhuber-Unkel (1),

(1) Heidelberg University, IMSEAM, Germany

Presentation given by Prof. Christine Selhuber-Unkel

Two-photon polymerization enables the fabrication of highly precisely structured and multifunctional microsystems. For example, dynamic microfluidic systems can be achieved by integrating responsive microactuators directly into microchannels. Using this technique, we printed thermoresponsive poly(N-isopropylacrylamide) (pNIPAM) microactuators into microfluidic channels to exploit their reversible volume change at around 32 °C for microactuation, allowing temperature-controlled capture and release of particles and cells under constant flow. We demonstrate this capability with micropillar arrays that selectively trap polystyrene beads and paired microgrippers that handle single cells, confirming effective manipulation. Additionally, we are also working on further responsive materials in combination with two-photon polymerisation, e.g. on a bistable multi-responsive actuator system combining pNIPAM and a light-responsive azobenzene compound, enabling programmable switching via temperature and UV light stimuli. In my talk I will give an overview on several of our approaches to establish two-photon polymerisation based strategies for microactuation, opening up pathways for advanced applications in microfluidics and other lab-on-a-chip platforms

2.1.3 **Optimizing color rendering in electrochromic displays**

Frédéric Vidal (1), Clément Ernest (1), Sébastien Fagour (1), Pierre-Henry Aubert (1), Xavier Sallenave (1),

(1) CY Cergy Paris Université

Presentation given by Prof. Frédéric Vidal

A variety of display technologies can be employed to achieve reproduction and color change as organic light-emitting diodes and liquid crystal displays, which are based on light emission. In contrast, non-emissive technologies utilize selective absorption and diffusion of incident light to generate color. A variety of non-emissive technologies are being developed, including cholesteric liquid crystals, electrowetting, electrophoretic and electrochromic materials. These technologies offer the advantage of requiring less energy than emissive ones. Electrochromic materials, which include inorganic oxides, organic molecules and polymers, can undergo color changes in response to an electrical stimulus. These materials can be utilized in the development of a color reproduction system. We present here the design of a device with an innovative superimposed architecture that is capable of reproducing a wide range of colors. To achieve this, we have stacked three pixels based on three electrochromic polymers with the three primary cyan, magenta, and yellow (CMY) colors. We propose and discuss three new architectures in which the three CMY pixels are superimposed in a single device.

2.1.4 **Electric and ionic shape memory polymers for soft actuators and sensors**

Hidenori Okuzaki (1),

(1) University Of Yamanashi, Graduate Faculty Of Interdisciplinary Research, Kofu, Japan

Presentation given by Prof. Hidenori Okuzaki

A novel electric shape memory polymer (eSMP) was fabricated with fully soluble self-doped poly(3,4-ethylenedioxythiophene) (S-PEDOT) and SMP using solution mixing method at various S-PEDOT weight ratios (WS-PEDOT). The percolation analysis showed extremely lower percolation threshold of 0.38 vol% and critical exponent of 1.15, which was associated with the S-PEDOT conductive networks formed by phase separation in the S-PEDOT:SMP compositeselhuber. The eSMP film at WS-PEDOT = 10 wt% showed electrical conductivity (?), shape fixing ratio (Rf), and shape recovery ratio (Rr) of 29 S cm-1, 95.4%, and 90.1%, respectively. Furthermore, an eSMP soft actuator, fabricated using the eSMP film at WS-PEDOT = 10 wt%, quickly recovered from temporary bent shape to its original open shape within 5 s upon application of 6 V. On the other hand, novel ionic shape memory polymer (iSMP) gels were fabricated using SMP and ionic liquid (IL) at different weight ratios (WIL). It was found that the iSMP gel at WIL = 25 wt% showed shape memory effect with Rf and Rr of 72.7% and 72.9%, respectively. Upon bending, the iSMP gel sensor with PEDOT:PSS electrodes generated open circuit voltage of 3.3 mV and charge of 1.6 nC which linearly increased with increasing the bending displacement and velocity, respectively. Furthermore, the wearable shape memory multifunctional sensor array was demonstrated as a self-powered motion sensor for the IoT applications.

2.1.5 **The effects of humidity-induced charge accumulation on the strain performance of electrohydraulic soft actuators**

Ellen Rumley (1),

(1) Max Planck Institute For Intelligent Systems, Robotic Materials Department, Stuttgart, Germany

Presentation given by Ms. Ellen Rumley

Electrohydraulic soft actuators, while exhibiting a well-rounded mechanical performance for use in soft robotics, can display a material and time-dependent change in actuation strain when exposed to high electric fields, which poses challenges for robotic control. This strain-change behavior, a phenomena driven by charge accumulation, can be further exasperbated by changes in environmental climate. Here we elucidate the effects of climate, in particular moisture, on the strain behaviors of Peano-HASEL actuators as a model system, made from a combination of BOPP or Mylar PET polymer films and dielectric liquids of FR3 or silicone oil. Results suggest that the hydrophilicity of polymer film surfaces, as well as the absorbed moisture within liquid dielectrics, lead to actuators with increased strain change. Our results highlight the importance of storage and testing climates for benchmarking actuator performance and for producing actuators with long-term controllability. We demonstrate the use of a thin hydrophobic encapsulation as a preliminary strategy to lower the interaction of actuators with moisture, thereby improving the performance of electrohydraulic actuation for use in uncontrolled climates.

2.1.6 **Characterization and optimization of screen-printed carbon black-based silicone electrodes for dielectric elastomer transducers**

Tobias Willian (1),

(1) ZeMA - Center For Mechatronics And Automation Technology GGmbH, Smart Material Systems, Saarbruecken, Germany

Presentation given by Mr. Tobias Willian

As actuators, sensors, or generators, dielectric elastomer transducers (DET) are used in various applications. To achieve optimum performance, application-specific electrode properties are required. Electrodes need to combine several aspects such as low and strain tolerant electrical resistance, strong adhesion to the dielectric, and hysteresis-free mechanical behavior. Investigating and understanding influences on the electrode properties is necessary to optimize them. In this talk I present therefore a systematic investigation of carbon black (CB) based silicone electrodes. First, different CB and silicone variations are analyzed in terms of electrical resistance, showing that the absolute resistance and the resistance behavior under strain can be adjusted by changing CB and silicone types and ratios. Secondly, the effect of different solvents used while screen-printing electrodes for DETs is characterized, revealing significant influences on the electrodes' quality and resistance, without altering dielectric breakdown behavior. Finally, thermal imaging is used to visualize the current flow distribution in the electrodes, allowing the detection of influences on the current flow, such as inhomogeneities, the design of the electrical connections, or applied strain, which can potentially affect the charging characteristics of DETs. The results provide a broader understanding of the electrodes and allow the design and manufacturing of optimized electrodes for DET applications.

Session 2.2
(abstracts are listed in the order of presentation)

2.2.1 Experimental characterisation of a dielectric fluid energy harvester

Jo Wilson (3), Marco Riva (1), Arron Goh (3), Andy Hall (3), Marco Fontana (2), Giacomo Moretti (1),

(1) Department Of Industrial Engineering, University Of Trento, Italy
(2) Institute Of Mechanical Intelligence, Scuola Sant"Anna, Pisa
(3) 4C Engineering, Inverness, UK

Presentation given by Dr. Giacomo Moretti

Dielectric fluid generators (DFGs) are a class of electrostatic energy harvesters that allow converting mechanical energy into electrical energy, leveraging capacitance variations of multi-layer liquid-polymer capacitors. Compared to dielectric elastomer generators, DFGs feature lower mechanical stiffness (i.e., lower working forces/pressures), which makes them easier to couple with mechanical input energy sources and more suitable for downscaling and modularisation. Similar to hydraulically amplified electrostatic actuators, DFGs enjoy self-healing properties and can be implemented using tough and durable technical dielectric polymers, which make them potentially more reliable than DEGs. This contribution presents a concept of a DFG that relies on a variable volume pouch made of flexible but inextensible dielectric walls (made of BOPP). We designed a test-bench that allows inducing capacitance variations in the pouch by pumping dielectric liquid (silicone oil) in/out of the pouch, and we report electrical energy generation measurements with constant-voltage generation cycles. We present an experimental parametric analysis that evaluates the device performance against the maximum applied voltage, the magnitude of the capacitance variations and the frequency of the generation cycles.

2.2.2 **Towards efficient energy harvesting: nonwoven fibrous mats with PDA-modified piezoelectric nanofillers**

Maedeh Najafi (1),

(1) INM - Leibniz-Institut Für Neue Materialien, Strukturbildung, Saarbrücken, Germany

Presentation given by Dr. Maedeh Najafi

This study aims to create a nonwoven fibrous mat composed of biopolymer fibers for energy harvesting, integrating polydopamine (PDA)-modified carbon nanofibers (CNFs) and gallium nitride (GaN) nanoparticles. GaN exhibits robust piezoelectric characteristics, whereas CNFs enhance electrical conductivity depending on their degree of graphitization. The incorporation of these functionalized nanofillers seeks to enhance the piezoelectric response and mechanical flexibility of the composite fibrous mat. This study investigates the possible synergy of piezoelectric and conductive fillers to increase energy harvesting efficiency, motivated by recent developments in using PDA for improved dispersion and interfacial bonding of functional nanomaterials. As shown in comparable systems for piezoelectric and strain-sensing applications, PDA modification is expected to resolve issues with agglomeration and interfacial compatibility. Additionally, PDA functionalization improves filler distribution and interfacial bonding, further mitigating common agglomeration challenges in nanocomposites. This contribution reports results on the examination of potential of PDA-modified nanostructures in nonwoven biopolymer-based fibrous mats for energy harvesting applications. The findings may contribute to the development of next-generation sustainable smart materials for wearable electronics and human-machine interaction systems.

2.2.3 **Broadband energy harvesting from ocean waves and river flow using bi-stable electrostatic generators**

Lennart Heib (1), Gianluca Rizzello (1), Giacomo Moretti (2),

(1) Saarland University, Department Of Systems Engineering, Saarbruecken, Germany

(2) University Of Trento,Department Of Industrial Engineering,Trento, Italy

Presentation given by Mr. Lennart Heib

Extracting energy from new renewable sources, like sea or river currents, is becoming increasingly important for sustainable power generation. However, energy harvesting in such applications is challenging mainly due to the low frequencies at play, where traditional electromagnetic generators become inefficient. Electrostatic generators represent a promising alternative due to their ability to operate efficiently at low frequencies and direct drive capabilities. Many existing harvester solutions (electromagnetic or electrostatic) rely on a resonant principle and are tuned to work at specific frequencies, experiencing a sharp drop in performance outside of resonance. To enable broadband and efficient energy harvesting in realistic (i.e., stochastic) sea state and river flow scenarios, the potential of integrating bi-stable dynamics in electrostatic energy harvesters is investigated in this work. We perform simulations to compare optimally tuned mono and bi-stable electrostatic harvesters, representative of dielectric elastomer/fluid generators, considering excitation profiles from realistic resource data. The harvesters are tuned to maximize the expected long-term power output for a given excitation profile and it is found that bi-stable biasing can increase the harvesting power by up to 20 percent in both wave and current energy harvesting applications, compared to harvesters relying on resonant designs.

2.2.4 **Design and validation of a tensegrity soft robot with rolled dielectric elastomer actuators**

Julian Kunze (1), David Herrmann (2), Julian Kobes (3), Paul Motzki (1) (3), Stefan Seelecke (3), Gianluca Rizzello (3), Valter Böhm (2),

(1) ZeMA - Zentrum Für Mechatronik Und Automatisierungstechnik GGmbH, Saarbrücken, Germany
(2) Ostbayerische Technische Hochschule Regensburg, Germany
(3) Saarland University, Department Of Systems Engineering, Saarbrücken, Germany

Presentation given by Mr. Julian Kunze

The combination of tensegrity structures with dielectric elastomer actuators (DEAs) remains largely unexplored. By leveraging nonlinear kinematics and minimizing internal friction through the omission of joints, new approaches to locomoting soft robots become possible. On this poster we present a soft robot that achieves locomotion using rolled DEAs (RDEAs), which serve as the tensional members of a planar tensegrity structure. Each RDEA consists of two spirally wound 50?µm-thick silicone films with screen-printed electrodes. The robot comprises two V-shaped rigid components connected by four RDEA groups under tensile load. When cyclical high voltage is applied alternately to front and rear groups, the components oscillate, and angled bristles convert this motion into forward locomotion. Operating at the system's resonant frequency, the robot reaches speeds up to 188?cm/s (1.18 body lengths/s). We investigate how actuation amplitude, frequency, and waveform affect locomotion, tracked via a camera-based system. We also develop a demonstrator variant for live use, along with a compact, microcontroller-based high-voltage amplifier focused on safety and serviceability. The joint-free design provides mechanical resilience and low internal friction, laying the groundwork for future DEA-driven tensegrity robots, including three-dimensional extensions.

2.2.5 **Long-endurant and agile micro-aerial-robots powered by soft artificial muscles**

Yufeng (Kevin) Chen (1),

(1) Massachusetts Institute Of Technology, USA

Presentation given by Dr. Yufeng (Kevin) Chen

Flapping-wing flight at the insect-scale is incredibly challenging. Insect muscles not only power flight but also absorb in-flight collisional impact, making these tiny flyers simultaneously agile and robust. In contrast, existing aerial robots have not demonstrated these properties. Rigid robots are fragile against collisions, while soft-driven systems suffer limited speed, precision, and controllability. In this talk, I will describe our effort in developing a new class of bio-inspired sub-gram flyers, ones that are powered by high bandwidth soft actuators and equipped with rigid appendages. Our newest design, which is driven by four independent dielectric elastomer actuators (DEAs) and equipped with four wings, could demonstrate a 1000-second hovering flight. In addition, our robot can recover from in-flight collisions, follow dynamic trajectories, and perform somersaults within 0.10 seconds. This work demonstrates for the first time that soft aerial robots can achieve agile and robust flight capabilities absent in rigid-powered micro-aerial vehicles, thus showing the potential of a new class of hybrid soft-rigid robots. On this new platform, we further demonstrated preliminary results on sensing-autonomous flight with onboard IMU, time of flight, and optical flow sensors.

2.2.6 **Wearable electrohydraulic actuation for expressive fingertip haptic feedback**

Alona Shagan Shomron (1), Yitian Shao (1) (2), Bernard Javot (1), Christoph Keplinger (1) (3), Katherine J. Kuchenbecker (1),

(1) Max Planck Institute For Intelligent Systems, Stuttgart, Germany
(2) TU Dresden
(3) University Of Colorado, Boulder, Colorado, USA

Presentation given by Dr. Alona Shagan Shomron

Touch feedback is essential for an immersive experience in extended reality (XR), but delivering expressive and versatile feedback remains challenging. Existing prototypes hinder hand movements with bulky structures, rely on tethered power sources for actuation, or output vibrations with limited expressiveness. This study introduces a design strategy for compact, lightweight, untethered haptic feedback centered on a 30-μm-thick inflatable chamber that naturally conforms to the fingertip. To minimize fluidic losses and enable high bandwidth, a soft electrohydraulic pump mounted on the hand actuates the chamber via a mechanically transparent fluidic channel. A 15.2-mm-diameter prototypical actuation chamber achieves 8 N peak force, 3 N steady-state force, stroke up to 5 mm, and bandwidth from 0 to 500 Hz. The hydraulic system succeeds at delivering these salient fingertip cues while weighing less than 8 g and being thinner than 2 mm. Additionally, a commercial fingertip sensor validates that the fingertip device imitates touch signals from typical hand interactions like pressing and grasping. This design strategy and validation method support a broad range of haptic applications in XR, including medical training, online shopping, and social interactions.

2.2.7 **Low driving voltage and high output dielectric elastomer actuators driving soft machines**

Junbo Peng (1), Jiangshan Zhuo (1), Ye Shi (1),

(1) College Of Mechanical Engineering, Zhejiang University, Hangzhou, China

Presentation given by Mr. Junbo Peng

Dielectric elastomers (DEs) have been widely investigated as an "artificial muscle" with large actuation strain, high energy density, fast response, and mechanical compliancy, which reproduce or in some aspects exceed the performance of natural muscles. However, scalable fabrication of dielectric elastomer actuators (DEAs) with low driving voltages (100 s of volts) and high mechanical outputs remains challenging, which significantly limits their wider applications. Here, processable, high-performance dielectric elastomer (PHDE) ultra-thin film based multilayer DEAs (PUT-MDEAs) through an optimized dry-stacking process are fabricated. The obtained PUT-MDEAs deliver a blocked force of 0.7 N and an energy density of 50 J/kg at 700 V. In addition, large-area PUT-MDEAs are fabricated using the scalable dry-stacking method, and adopted to build low-driving-voltage soft pumps and robotic fish, showing their potential for practical applications.

2.2.8 **Cellulose-derived ionogel actuators to enable soft actuation under feedback and control constraints**

Alvo Aabloo (1), Janno Torop (1), Veiko Vunder (1),

(1) University Of Tartu, IMS Lab, Tartu, Estonia

Presentation given by Prof. Alvo Aabloo

Electroactive polymers (EAPs), mainly ionic EAPs (iEAPs), show great promise for biomimetic actuation due to their large deflection at low voltages. Their potential spans soft robotics, wearable electronics, and medical tools like steerable guidewires. However, achieving precise feedback and position control remains a significant hurdle, limiting their integration into complex robotic systems. This

study presents a regenerated cellulose-ionogel actuator (CEL-iGEL) made entirely from biocompatible components. Cellulose was combined with confined ionic liquid [EMIm][OAc] to form an ion-conductive membrane sandwiched between carbon-assisted ionogel layers. Fabricated via a phase inversion method, the actuator operates efficiently at ±1V, showing significant bending deformation. We implemented a position feedback loop using real-time video-based image tracking to evaluate performance. A PID controller regulated voltage within ±1V, achieving a 0.5 s deflection response for a step input. The actuator could maintain position for up to five minutes until control voltage saturation. CEL-iGEL actuators demonstrate strong potential for bioinspired systems, especially in medical robotics. Applications like robotic endoscopy could benefit from their soft, precise, and minimally invasive actuation. Overcoming control challenges remains key for broader deployment in future biomedical and robotic platforms.

2.2.9 **Control of a marx generator for charge and discharge of a tubular dielectric elastomer actuator**

Maribel Cáceres Rivera (1) (2), Morgan Almanza (3), Alexis Boegli (1) (2), Yoan Civet (1) (2), Yves Perriard (1) (2),

(1) Ecole Polytechnique Fédérale De Lausanne (EPFL), Integrated Actuators Laboratory (LAI), Neuchâtel, Switzerland
(2) Ecole Polytechnique Fédérale De Lausanne (EPFL), Center For Artificial Muscles (CAM), Neuchâtel, Switzerland
(3) Université Paris-Saclay, ENS Paris-Saclay, CNRS, SATIE, Gif-sur-Yvette, France

Presentation given by Ms. Maribel Cáceres Rivera

Tubular dielectric elastomer actuators (DEAs) used in cardiac assist devices have demonstrated reliable performance in biomedical applications due to their ability to achieve large displacements. However, their application in medical devices requires a compact and efficient power supply capable of harvesting energy during long cycles. DC-DC bidirectional converters have shown good performance in this context. Therefore, this work presents a Solid-State Marx generator power supply capable of operating a real tubular DEA for cardiac assist devices. The motivation for using the Marx generator lies in its compact topology and high efficiency, achieving up to 88%. Compared to other topologies, the Marx generator offers better control over the stepped voltage, depending on the control strategy, and enables energy recovery during the discharge phase. This work validates the Solid-State Marx generator by addressing the non-linearity of the load (DEA), in contrast to other works that are limited to ideal loads. By focusing on the non-linearity effect of the DEA, this research provides new insights into the complete DEA model and power supply through simulations and experiments for cardiac assist devices. Additionally, the control of the stepping voltage for each stage of the Marx generator allows more precise control of voltage and frequency during the charging and discharging phases. Finally, the Marx generator operates within a range of 0-10 kV with a maximum current of 1 mA.

2.2.10 Finite-element and control-oriented modeling of cooperative dielectric elastomer actuator arrays

Alberto Priuli (1), Saverio Addario (1), Guenter Schultes (2), Stefan Seelecke (1) (3), Giacomo Moretti (4), Gianluca Rizzello (1),

(1) Saarland University
(2) HTW Saar
(3) ZeMA GGmbH
(4) University Of Trento

Presentation given by Mr. Alberto Priuli

Dielectric elastomer actuators (DEAs) are highly stretchable polymeric membrane transducers capable to convert an applied electric voltage to a controllable deformation. Recent approaches leverage on clustering several DEAs in multidimensional configurations, to allow for global cooperative tasks. Design optimization of the DEA array requires the availability of computationally efficient finite element models and simulation tools. At the same time, lumped-parameter dynamic models are required for an effective design of closed-loop cooperative control strategies. The work presents two different modeling approaches for a matrix of DEAs, supported by experimental validation on a 1x3 prototype of the system. A nonlinear finite element model is first proposed to capture the full state of the system in detail. Its accuracy and level of detail can be employed in design and optimization phases, such as worst-case loading

scenarios, actuation range, and topological optimization. A reduced order control-oriented lumped-parameter model is subsequently presented, to allow for real-time implementation of closed-loop strategies and algorithms. The lumped-parameter model isolates and separates each DEA's contribution on its own behavior as well as the interaction with adjacent ones, allowing for a network-like representation of the system that can be exploited in decentralized or distributed control architectures.

2.2.11 An accurate and efficient finite element model for electro-active polymer membranes including viscous effects at finite strain

Mario Kunzemann (1), Sebastian Platzer (1), Astrid Pechstein (1),

(1) Johannes Kepler Univserity, Institute Of Technical Mechanics, Linz, Austria

Presentation given by Mr. Mario Kunzemann

This contribution is concerned with the modeling and subsequent simulation of the behavior of electroactive polymer membranes. Mathematical models based on the assumptions of continuum physics contain not only hyperelastic characteristics and viscosity of the material, but also dielectric and electrostrictive effects in a coupled manner. The simulation of thin membranes is not straightforward, dimensional reduction with respect to the thickness coordinate must be carried out carefully. While reduction of elastic continua to membrane, plate or shell formulations is well understood, it is essential to choose a consistent set of degrees of freedom for the electric field, the internal polarization and the viscous strains through the thickness when considering electro-active polymers. We present a corresponding model and its realization within a multi-purpose open-source python finite element package. We explore the capabilities of this approach for VHB4910, for which we extract the necessary characteristic parameters from various sets of measurement data available in the literature. A comparison to measurements published by Wissler and Mazza (2005) shows the accuracy of the model as well as the efficiency of the computational method.

2.2.12 **High dielectric permittivity polysiloxanes for solvent-free industrial processing**

Jana Wolf (1) (2), Patrick M. Danner (1) (2), Dorina M. Opris (1) (2),

(1) EMPA - Swiss Federal Laboratories For Materials Science And Technology, Functional Polymers Laboratory, Duebendorf, Switzerland
(2) ETH Zurich, Departement Of Materials, Zurich, Switzerland

Presentation given by Ms. Jana Wolf

High-dielectric-permittivity polysiloxanes hold great potential for applications in batteries and dielectric elastomer transducers (DET). Despite their promising performance in DET, large-scale production remains unestablished due to processing challenges. These materials tend to dewet on standard industrial substrates like stainless steel, and their thiol-ene cross-linking is incompatible with platinum catalysts commonly used for polydimethylsiloxane thermal curing. In this work, we present a composite of cyano-propyl-functionalized polysiloxane and Elastosil, designed to enhance processability while increasing dielectric permittivity. We successfully produced this ink at a 40-gram scale and utilized epoxy-based curing to eliminate catalyst poisoning. The composite's mechanical and electrical properties were systematically evaluated, and actuator prototypes were fabricated and tested. Our results demonstrate improved manufacturability and performance, advancing high-permittivity polysiloxanes toward industrial integration.

2.2.13 **Post-cure functionalization of silicone elastomers: enhancing the dielectric properties for soft actuators**

Cristina Nedelcu (1), Frederikke Bahrt Madsen (1), Anne Ladegaard Skov (1),

(1) Danish Polymer Centre, Department Of Chemical And Biochemical Engineering, Technical University Of Denmark, Kgs Lyngby, Denmark

Presentation given by Ms. Cristina Nedelcu

In recent years, there has been growing interest in developing polydimethylsiloxane (PDMS) elastomers that combine mechanical stability, softness, and elasticity, mimicking human muscles, for stretchable electronics and soft actuators. However, a major challenge is their low dielectric permittivity (~2-3), leading to high operational voltages. To overcome this and increase dielectric permittivity, the PDMS polymer backbone can be chemically modified by introducing molecules with dipoles or incorporating high permittivity fillers. This work presents a novel class of PDMS elastomers with improved dielectric permittivity, characterized by a network of cyclic polymers with carbon-carbon (C=C) double bonds. These bonds allow for post-curing functionalization through thiol-ene click chemistry. To enhance dielectric permittivity, three different thiol-functional dipolar molecules were used to functionalize the C=C bonds: one with an amino group and two with chlorine atoms. The method increased dielectric permittivity by up to 39% without significantly altering mechanical properties. The prepared PDMS elastomers, distinguished by their cyclic-polymer network and C=C bonds, exhibit softness, stretchability, and functionalization potential. These properties make them suitable for mimicking the flexibility and movement of natural tissues for more precise and adaptable mechanical performance.

2.2.14 **Towards improved electromechanical properties in soft silicone films using two-dimensional materials**

Robyn Worsley (1), Anne Ladegaard Skov (1),

(1) Technical University Of Denmark, The Danish Polymer Centre, Department Of Chemical Engineering, Lyngby, Denmark

Presentation given by Dr. Robyn Worsley

Soft silicone polymers, with their low, tuneable elastic moduli, are promising candidates for dielectric elastomer actuator fabrication, with uses found in artificial muscles and soft robotics. To further increase applicability in such devices, many attempts have been made to enhance the relatively low dielectric constant of silicone through the addition of high-permittivity fillers. For many commonly-used fillers, permittivity improvements are observed to the detriment of other key performance parameters, with rigid particles leading to unfavourable elastomer stiffness increases, and conductive particles typically reducing dielectric breakdown strength. Platelet-shaped fillers have shown promise for

improving electromechanical properties in polymer composites. Two-dimensional crystals offer a huge range of ultra-thin nanoplatelets with complementary, often exceptional characteristics; they may be micron-sized in lateral dimensions, but only a few nanometres thick, and are widely-known for their flexibility. In this work, graphene, a conductive two-dimensional honeycomb carbon lattice, and its insulating analogue, hexagonal boron nitride, are investigated as flexible nanoplatelet fillers in an attempt to improve silicone breakdown strength and permittivity without compromising elastomer softness. A focus is placed on achieving well-dispersed nanoplatelets at low loadings; where necessary due to compatibility issues, functionalisation using silane coupling agents is explored.

2.2.15 **Inorganic bottlebrush and comb polymers as a platform for supersoft, solvent-free elastomers**

Edip Ajvazi (1), Felix Bauer (3), Oliver Brüggemann (1), Milan Kracalik (3), Rene Preuer (2), Ingrid Graz (2), Ian Teasdale (1),

(1) Institute Of Polymer Chemistry, Johannes Kepler University Linz, Linz, Austria
(2) Christian Doppler Laboratory For Soft Structures For Vibration Isolation And Impact Protection (ADAPT), School Of Education, STEM Education, Johannes Kepler University Linz, Linz, Austria
(3) Institute Of Polymer Science, Johannes Kepler University Linz, 4040 Linz, Austria

Presentation given by Mr. Edip Ajvazi

Bottlebrush polymers, known for their distinctive rheological and mechanical behavior, are key components in both biological analogues (e.g., cartilage) and synthetic ultrasoft elastomers. However, their material diversity remains limited, as most systems rely on aliphatic carbon-based backbones. In this study, we introduce a new class of inorganic bottlebrush polymers based on a hybrid platform of polydimethylsiloxane (PDMS) and polyphosphazene (PPz). This architecture enables tunable structural parameters, including backbone and side-chain lengths, as well as grafting densities, and allows for the synthesis of supersoft, solvent-free elastomers through PDMS-PPz grafting strategies in both directions. We systematically investigated how architectural design influences the rheological behavior of the materials. Significantly, these hybrid elastomers demonstrate significantly enhanced energy dissipation compared to conventional PDMS-based systems, attributed to increased molecular mobility and the presence of dangling chain ends. Our findings offer a versatile and scalable route toward biomimetic damping materials, suitable for applications in soft robotics, wearable actuators, and vibration isolation systems.

2.2.16 Influence of solvent on the piezoresistive properties of carbon particle-filled elastomers

Carola Böhmer (1), Markus Koenigsdorff (2), Joyappa Paradanda Somaiah (1), Johannes Mersch (1), Gerald Gerlach (1),

(1) TUD Dresden University Of Technology
(2) Ecole Polytechnique Federale De Lausanne

Presentation given by Ms. Carola Böhmer

Carbon particle-filled elastomers are widely studied materials, valued for their flexibility and conductivity in applications such as dielectric elastomer actuator electrodes and resistive strain sensors. Solvents are often used in manufacturing processes to reduce the viscosity of uncured elastomer mixtures. While previous research has investigated the effect of these solvents on processing techniques such as inkjet and screen printing, their direct effect on the resistivity of the bulk material remains largely unexplored. In addition, it is generally assumed that solvents evaporate completely during curing, leaving no effect on the final material properties. To address these knowledge gaps, the solvent evaporation of carbon particle-filled silicones is tracked during curing. The parameters studied include curing temperature, solvent type and mixing technique. The evaporation rates vary significantly depending on the solvent type. The samples are characterized electromechanically with and without residual solvent to assess the influence of the type and amount of solvent remaining. In addition, static impedance spectroscopy measurements are performed to analyze the frequency-dependent resistivity after curing and the influence of the solvent. It is concluded that the piezoresistive effect of the material differs depending on the choice and

amount of solvent present, making the type and presence of solvents an important parameter to consider.

2.2.17 Multilayer screen-printed P(VDF-TrFE) energy harvester for a durable self-powered tire pressure monitoring in a bicycle tube

Jonas Groten (1), Matthias Hammer (1), Elisabeth Schreck (1), Andreas Tschepp (1), Barbara Stadlober (1),

(1) Joanneum Research Forschungsgesellschaft MbH

Presentation given by Dr. Jonas Groten

The piezoelectric polymer P(VDF-TrFE) has raised a lot of interest for application in energy harvesting as the polymer can be processed on various substrates using low-cost and scalable printing technology while its flexibility allows for the seamless integration in versatile environments. The use of energy harvesting in rotating tires could avoid the use of toxic batteries that are currently used to power pressure monitoring systems in millions of cars worldwide. However, due to the harsh mechanical conditions in a tire and the economic competition with low-cost and widely spread batteries, self-powered tire pressure monitoring systems (TPMS) have not yet entered the market. In this work, we present a fully integrated and self-powered bicycle tire pressure monitoring system powered by energy harvesting based on P(VDF-TrFE) fabricated in a multilayer screen printing process. We have adapted the design of the harvester to adjust the output voltage in order to optimize the energy transfer to the measurement electronics. In addition, the long-term durability of the system was examined up to 5000 km according to the standard for bicycle inner tube tests. The durability tests show that a compromise must be found between energy output and durability for real applications, as the two factors depend in opposite ways on the mechanical load on the piezoelectric transducer.

2.2.18 Electrically tuneable Fresnel lens concept

Giacomo Sasso (1) (2), Alessandro Pagani (1), Gabriele Frediani (1), Valentina Potnik (1), James Busfield (2), Federico Carpi (1) (2),

(1) University Of Florence, Department Of Industrial Engineering, Florence, Italy
(2) Queen Mary University Of London, School Of Engineering And Material Science, London, United Kingdom

Presentation given by Mr. Giacomo Sasso

Fresnel lenses are known for their ability to replace the traditional curved surface of an optical lens with concentric refracting elements, significantly reducing thickness and material usage while preserving the lens’s focusing power. Electrically tuneable versions of Fresnel lenses have been demonstrated using electrowetting and liquid crystal-based lenses, whose performance can be limited by thermal instability and vibrations. The only all-solid-state tuneable Fresnel lenses described so far exploit the fact that an elastomeric Fresnel template can be deformed by external motors or annularly-shaped dielectric elastomer actuators (DEAs), which make the device significantly bulky. In this study, we present a novel design for a DEA-based tuneable Fresnel lens. It consists of a dielectric elastomer membrane, coated on one side with a continuous transparent electrode and on the other side with a mesh electrode enabling Fresnel-like optical functions. The continuous electrode was made of spray-coated PEDOT:PSS, while the mesh electrode consisted of concentric rings made of inkjet-printed silver nanoparticles. This presentation will describe ongoing developments of this new type of tuneable lens.

Session 2.3

(abstracts are listed in the order of presentation)

2.3.1 NEXIPAL® - Industrial manufacturing of electroactive polymer actuators

Johannes Neuwirth (1), Andreas Köllnberger (1),

(1) WACKER Chemie AG, Munich, Germany

Presentation given by Dr. Johannes Neuwirth

WACKER's NEXIPAL® is the next step in the value chain of electroactive polymer (EAP) based transducers (sensors and actuators) based on silicone elastomers: electrically conductive and compliant electrodes are printed in a digital process on ELASTOSIL® Film, a thin and precise film consisting of crosslinked silicone rubber. Wacker has developed a scalable roll-to-roll process including in-line process controls to produce alternating layers of dielectric and conductive material on each other to form functional and manageable semi-finished goods. The production process for EAP is taking place in a clean room and allows the formation of different layer thicknesses in the range of 20 µm to 400 µm of dielectric layer. All materials and processes have been developed by Wacker and will be produced in their own production facilities in Burghausen, Germany. Regarding an industrial production of electroactive polymer transducer, this step enables the development of a plurality of products.

2.3.2 Direct Generation: Building the community to take electroactive polymer wave energy to the next stage

Ieuan Collins(1), Jonathan Hodges (1)

(3) Wave Energy Scotland, Inverness, United Kingdom

Presentation given by Ieuan Collins

Wave Energy Scotland (WES) has been investigating a novel method of harvesting energy of the waves through the use of flexible electroactive polymeric structures within a programme named *'Direct Generation'* (DG). In a down-selection process, WES determined that variable capacitance technologies, which inimum the flexible properties of elastomers and polymers to drive variable capacitance, hold the greatest potential currently. These materials can form a structure which can *'directly'* transform the wave energy motion through stretching, twisting, bending of a material, into electrical energy. The two technologies of interest are Dielectric Elastomer Generators (DEGs) and Dielectric Fluid Generators (DFGs). The simplicity of this approach could result in scalable architectures with fewer components with the potential for reduced cost centres over conventional architectures. To investigate these technologies further WES has inimum a two-prong approach balancing both research and development. On the development side, WES has kickstarted concept creation through a design competition. The first phase, spanning 14 weeks, involved five teams launched in September 2023. The second phase lasting 9 months, involved a down-selection to two teams which has recently finished in March 2024. The first round was used as means of concept generation, demonstrating the feasibility and benefits and identification of R&D requirements for further technology progression. The second round was a more in-depth analysis of a particular concept, involving further refinement to inform future research directions. Concurrent with the competition, WES is funding fundamental research in key areas to support the development of these promising technologies. WES is building a suite of enabling R&D projects which focus on addressing these needs, starting with two 12-month Supergen ORE Impact Hub FlexFund projects and one 4-year PhD, covering material, metamaterial and module development. Looking to the future, WES is interested in the synergies and learnings from the sensor and actuator sectors, since these are the necessary stepping stones to get to large-scale generators. For example, one of the emerging themes from DG is the importance of longevity both from a mechanical and electrical point of view. Can a DG technology achieve a long fatigue life with an adequate energy density? Can innovations such as self-healing or fully recyclable polymers enhance the life-cycle? These are just some of the many questions emerging from the programme which need to be answered before progressing to later stages of development. WES plans on disseminating the findings of this two-year study to the wider community through a public report. WES would now like to discuss these findings with experts within the EuroEAP community to develop partnerships and coordinate research activities for the next stages of Direct Generation.

EuroEAP Society Challenge

Project title	Team leader	Institution
ElastoSwitch: Dielectric Elastomer-Driven Transistors with Thin-Film Metal Electrodes	Carmen Perri	University of Saarland
Demo of a Tensegrity Soft Robot with Rolled DEAs	Julian Kunze	ZeMA – Zentrum für Mechatronik und Automatisierungstechni k gGmbH
Large Stroke Multi-Dimensional Fully-Polymeric Cooperative Dielectric Elastomer Actuator Array	Stefan Seelecke	University of Saarland
Electroadhesive Gripper with Thermochromic Visuo-Tactile Sensing	Thomas Daunizeau	École Polytechnique Fédérale de Lausanne (EPFL)
Electroadhesion Suction Cups	Fabio Caruso	École Polytechnique Fédérale de Lausanne (EPFL)
ElectroFluidic Fiber Muscles with Self-Sensing Ability	Vito Cacucciolo	Politecnico di Bari

Best Poster Award

The Best Poster Award 2025 is sponsored by IOP Publishing.

Thursday, 12 June 2025

Session 3.1

(abstracts are listed in the order of presentation)

3.1.1 **Electro gels and liquid metal droplets – exploring the world of morphing matter robots and soft matter artificial muscles**

Jonathan Rossiter (1),

(1) University Of Bristol, Bristol Robotics Laboratory, Bristol, UK

Presentation given by Prof. Jonathan Rossiter

The transduction of energy to mechanical forms is at the heart of robotics. In soft robotics, this can be achieved by the application of myriad fields, from magnetic and thermal to electrical and chemical. Here we will explore new developments in soft morphing matter and soft robotics which respond to remote electrical fields and coupled electrical-magnetic fields. This will include novel electro gel morphing matter which can bend and twist on command, and morphing liquid metal fluidic systems which exploit field-induced instabilities to generate autonomous fluid motions. Potential applications of these morphing systems range from space exploration and power clothing to microfluidic actuators and lab-on-a-chip devices.

3.1.2 **Insect-scale biomimetic machines**

Florian Hartmann (1),

(1) Biomimetic Materials And Machines Group, Max-Planck-Institute For Intelligent Systems, Stuttgart, Germany

Presentation given by Dr. Florian Hartmann

Nature has evolved remarkably intricate designs at small scales, enabling insects

and other organisms to perform complex movements with efficiency and agility. Replicating such functionality in miniature robots remains a significant challenge, particularly in actuation, where conventional motors face severe limitations when miniaturized. To address this, we explore materials and fabrication processes for multilayer electronic thin films that function as artificial muscles at the millimeter scale. By combining flexible electrodes with dielectric liquids, we create soft electrohydraulic actuators that offer high bandwidth (0-150 hertz) and low power consumption (35 milliwatts). We demonstrate the monolithic integration of these actuators into centimeter-scale swimming robots (25-45 millimeters body length), which propel themselves across the water surface using undulating fin propulsion. Independent control of each actuator enables versatile maneuvering, including forward, backward, sideways, and turning motions. Integrated miniature power electronics and control systems allow untethered, autonomous operation in cluttered environments, such as grassy aquatic landscapes. These robots can navigate obstacles, seek out light sources, and execute rapid maneuvers, opening up applications in environmental monitoring, agriculture, and search-and-rescue operations.

3.1.3 **Tuning conductive polymer composite microstructures for dielectric actuators and sensors**

Tobias Kraus (1) (2),

(1) INM – Leibniz-Institute For New Materials, Structure Formation Department, Saarbruecken, Germany
(2) Saarland University, Colloid And Interface Chemistry, Saarbruecken, Germany

Presentation given by Prof. Tobias Kraus

Dielectric actuators and sensors require stretchable electrical conductors. For optimal performance, their piezoresistive response should be high in dielectric elastomer sensors (DES) and low in dielectric elastomer actuators (DEA). Conductive polymer composites (CPCs), which incorporate conductive particles as fillers, are the standard materials for such electrodes. By tuning the microstructure of CPCs, we can adjust their electrical and mechanical properties to enhance DEA and DES performance. This talk will explore how the microstructure of CPCs develops during processing, and how it can be systematically tuned through particle shape, interfacial interactions, and fabrication methods. The fractal nature of conventional carbon black fillers will be introduced and compared to anisotropic carbon-based alternatives. I will present recent results showing how confinement and alignment of graphite sheets can dramatically increase gauge factors. Conversely, we combine metal and carbon particles to create hybrid composites with reduced piezoresistance. They enable stretchable electrodes that maintain conductivity under strain. I will discuss screen-printable electrode pastes suitable for DEA applications. Finally, I will touch on the structure of conductive networks within CPCs and discuss how network analysis can provide insight into the complex microscale coupling between mechanical deformation and electrical behavior in these materials.

Session 3.2
(abstracts are listed in the order of presentation)

3.2.1 **Soft tactile sensors with super-resolution force sensing for robotics**

Natalia Sanchez-Tamayo (1) (2), Arekh Tiwari (1), Philipp Rothemund (3), Hosam Alagi (4), Christoph Keplinger (2) (5) (6), Katherine J. Kuchenbecker (1),

(1) Max Planck Institute For Intelligent Systems, Haptic Intelligence Department, Stuttgart, Germany
(2) Max Planck Institute For Intelligent Systems, Robotic Materials Department, Stuttgart, Germany
(3) Institute For Control Engineering Of Machine Tools And Manufacturing Units University Of Stuttgart, Germany
(4) Proxception GmbH, Germany
(5) Paul M. Rady Department Of Mechanical Engineering University Of Colorado, Boulder USA
(6) Materials Science And Engineering Program University Of Colorado, Boulder USA

Presentation given by Ms. Natalia Sanchez-Tamayo

Dexterous robotic manipulation requires precise tactile sensing distributed through soft artificial skin, yet existing solutions are costly, difficult to integrate, or unreliable in real-world environments. While sensors developed in materials science often offer exceptional sensitivity and/or spatial resolution, their specialized fabrication methods hinder reproducibility and real-time deployment. Vision-based sensors typically provide high spatial resolution but require extensive calibration for force quantification, and manually fabricated sensors suffer from low precision, poor reproducibility, and high noise. We present a soft capacitive tactile sensor with super-resolution force sensing across its surface. Designed for easy fabrication and real-time integration, it consists of a parallel-plate capacitor array made of a soft dielectric elastomer, stretchable electrodes, and onboard capacitance-to-digital conversion. The sensor achieves high sensitivity, detecting forces as low as 10 mN, with a signal-to-noise ratio up to 60 dB. Machine learning enables real-time contact localization with sub-millimeter

accuracy, increasing the sensor's native spatial resolution by a factor of 4.5. Transfer learning allows force prediction on new sensors without additional calibration, ensuring reproducibility and straightforward adoption. This approach provides an accessible, high-performance solution for integrating functional tactile sensing into real-world robotics applications.

3.2.2 **Electric field driven soft morphing matter**

Ciqun Xu (1), Charl Faul (1), Majid Taghavi (2) (3), Jonathan Rossiter (1),

(1) University of Bristol, UK
(2) Imperial College London, UK
(3) Queen Mary University Of London, UK

Presentation given by Dr. Ciqun Xu

Manipulating soft morphing robots using external electric fields for wireless control is challenging. To address the challenge, we introduce electro-morphing gel, a type of electric field-driven soft morphing matter, that exhibits complex multi-modal large-scale deformation and locomotion under external electric fields applied using compact and lightweight electrodes. The morphing behaviours, including rotating, translating, stretching, spreading, bending, and twisting, are presented. The complex morphing patterns enable various bio-inspired applications, such as frog tongue-inspired grippers and snail-like jumping over a gap. The electro-morphing gel provides morphing capabilities beyond the current limitations in wireless control for a wide range of applications in soft robotics.

3.2.3 **Shapeshifting liquid metal droplets for soft fluidic machines**

Saba Firouznia (1), Christian Romero (1), Hemma Philamore (1), Andrew Conn (1), Martin Garrad (1), Jonathan Rossiter (1),

(1) University of Bristol, UK

Presentation given by Dr. Saba Firouznia

Controlling droplet dynamics is crucial for microfluidics, materials science and soft robotics. Electric and magnetic fields enable precise droplet handling for drug delivery and diagnostics, but high-energy inputs trigger droplet instabilities and explosive breakup. Here we leverage these instabilities for high energy transduction, focusing on liquid metal droplets with high surface tension and conductivity. We introduce liquid metal shapeshifting, a method for fluidic power generation that uses Lorentz forces and surface tension. Demonstrated in a low voltage (<100 mV), soft, bidirectional pump, it features a simple design with two electrodes, one liquid metal drop, and a small magnet, and can be driven directly from an AAA battery, outperforming previous pumps. Integrated into a watch, it powers a wearable photoprotection skin and we demonstrate the shapeshifting principle driving soft robotic actuators and colour-changing chromatophores, showcasing potential for fluidic power in applications from laboratory-on-a-chip and macro/micro robots to environmental and wearable robotics.

3.2.4 **Investigation of different non-metallic conductive polymers for in-situ sensors for flexible wave devices**

Alexandra Perryman (1),

(1) Swansea University, Mechanical Engineering, Swansea, United Kingdom

Presentation given by Ms. Alexandra Perryman

Structural health monitoring is an important area that requires new methods for constant monitoring as traditional methods are expensive, prone to failure over long term periods. Many areas such as flexible wave devices require the use of in-situ sensors that can withstand large strain volumes 100% plus, and more than unidirectional strain. The design of flexible sensors uses the mechanical deformation of dielectric elastomer, and the voltage applied to move with displacement. The output is displacement, force and area. This work covers inimum zing different conductive materials in combination of non-conductive soft polymeric materials and fully conductive electrodes to make highly stretchable and flexible electrodes. In this case, the aim is to prepare polymer electrodes that will have good bonding with the same base of polymers. For the conductive medium, different conductive materials, carbon grease, carbon black paint and carbon black particles being added to the base polymer of silicone rubber, Ecoflex 00-50, for comparison. Running testing for cycles over 500 and above, with the aim of creating long term sensing capabilities for fatigue life applications. Determining whether the conductive material is suitable for stretching for a minimum for 100% strain. Results show that carbon grease polymer is not a suitable conductive material due to a lack of elastic properties, it cannot hold its shape. Carbon black paint polymer can be conductive and retain elastic properties.

3.2.5 **Analysis and improvement of dielectric elastomer inimum energy structure for soft-finger like robots**

Mario De Lorenzo (1), Junhao Ni (1), Uwe Marschner (1), Andreas Richter (1), Markus Vorrath (1),

(1) TU Dresden, Institute Of Semiconductors And Microsystems, Dresden, Germany

Presentation given by Mr. Mario De Lorenzo

Dielectric elastomer actuators (DEA) are an ideal alternative to muscles due to their ability to elongate similarly while offering unique properties such as silent, rapid, lightweight and tunable actuation in a compact and cost-effective format. These characteristics make DEA highly suitable for the next generation of robotic hand. Research is needed to be conducted in order to find the optimal dielectric elastomer minimum energy structure (DEMES) for actuation and force output. In this study, we investigate two bio-inspired DEMES aimed to mimic a real human finger by either joint DEMES (JDEMES) structure or a ligament DEMES (LDEMES) structure. The JDEMES features a silicone frame, Mold Star 30 by Smooth-On, and a minimal bone structure in order to facilitate actuation while maintaining a soft and lightweight design. Actuation is achieved by three multilayer DEAs connected in parallel mimicking the joints of a human finger. The LDEMES incorporates a minimal silicone frame and a fully 3D printed bone structure to increase the stiffness. A single long multilayer DEA bends the entire structure resembling a human ligament with the bone structure rotating alongside the frame to replicate human finger bending. Finite Element Analysis on ABAQUS have been performed to optimize design parameter and minimize physical testing. These novel DEMES structures exhibit the flexibility and stiffness required to replicate a human finger movement and demonstrate basic grasping skills.

3.2.6 Finite element model for the study and optimization of thin-film electro-adhesive devices

Amir Komijani (1), Irene Fassi (2), Lorenzo Molinari Tosatti (2), Rocco Vertechy (1),

(1) Department Of Industrial Engineering, University Of Bologna, Italy
(2) Institute Of Intelligent Industrial Technologies And Systems For Advanced Manufacturing – National Research Council Of Italy

Presentation given by Mr. Amir Komijani

Thin-film electro-adhesive devices (TFEADs) are flexible electrostatic systems that can be used as clutches or as grippers for object catching and manipulation. Originally conceived with the main purpose of enhancing the locomotion of people and machines, TFEADs are currently receiving significant interest from the automated packaging industry and the space sector. The performances of TFEAD heavily depend on the electrodes' geometry and on the electrical properties of the materials of both the device and the grasped object. In this context, the poster describes a finite element model to simulate the electrical response of TFEAD and, specifically, to compute the adhesion force. Besides comparing it with other simulation models frequently used in the literature, results are presented to show its adoption to optimize the architecture of a TFEAD for specific grasped objects.

3.2.7 Bio-inspired fluid networks integrating cardiovascular, neural, and endocrine functions for advanced robotics

Saba Firouznia (1), Christian Romero (1), Lihaoya Tan (1), Andrew Stinchcombe (1), Martin Garrad (1), Andrew Conn (1), Hemma Philamore (1), Jonathan Rossiter (1),

(1) University Of Bristol
Presentation given by Dr. Saba Firouznia

Soft robotics holds great promise for enabling safe, adaptable human-machine interactions while addressing challenges in environmental, wearable, and healthcare applications. Among the various actuation methods-fluidic, thermal, chemical, and bioinspired-fluidic soft actuators are widely adopted but often constrained by portability and system complexity. To overcome these limitations, we introduce an embeddable soft displacement pump for soft robotics, harnessing the potential of E-GaIn liquid metal to act as the mobile charge carrier at the core of a pump. We highlight the versatility of this technology by presenting three LIMA-driven embodiments: powering a macroscale actuator, transferring chemical energy to actuate a soft haptic actuator through a dual-colour display bracelet, and generating diverse code patterns based on its frequency for simultaneous communication. This unique combination of information encoding and fluid propulsion within a compact soft design positions the LIMA pump as an important new enabler for advanced soft robotic systems**.**

3.2.8 Additive manufacturing technologies – a comparison between inkjet printing and aerosol jet printing in depositing conductive inks for strain sensors applications

Federico Bertolucci (1), Miriam Seiti (4), Vito Basile (2), Irene Fassi (1), Emilio Sardini (5), Rocco Vertechy (1) (3), Lorenzo Molinari Tosatti (1),

(1) National Research Council, STIIMA Institute, Milan, Italy
(2) National Research Council, STIIMA Institute, Bari, Italy
(3) University Of Bologna, Industrial Engineering Department, Bologna, Italy
(4) University Of Brescia, Mechanical And Industrial Engineering Department, Brescia, Italy
(5) University Of Brescia, Information Engineering Department, Brescia, Italy

Presentation given by Dr. Federico Bertolucci

Additive Manufacturing (AM) techniques are gaining increasing popularity in both research field and industry. In a highly dynamic environment, they offer the advantage of producing shapes without geometric constraints, utilizing materials of any chemical-physical nature for rapid prototyping or proof-of-concept applications. They are also of great interest in the context of Europe's green transition due to their wasteless nature and low energy consumption. Among all AM techniques, Inkjet Printing (IJP), particularly in Drop-on-Demand (DoD) mode, and Aerosol Jet Printing (AJP) stand out for their versatility and high precision in depositing conductive or dielectric ink lines. These methods are widely used in research on flexible electronics and electrostatic transducers. Few studies have conducted an in-depth comparison of these two printing techniques, focusing on aspects such as the resistance of the deposited tracks and their morphology. This study presents an experimental plan based on the Design of Experiment (DoE) to compare conductive lines made of different metallic materials. For printing factors are varied and the electrical resistance is evaluated as an output parameter. A morphological analysis of the tracks is performed using confocal microscopy techniques, aimed at assessing line uniformity and thickness. The best result for both technologies is employed in the prototyping and testing a resistive strain sensor.

3.2.9 **Assessing digitally printed silver electrodes for thin-film electrostatic transducers**

Chiara Scagliarini (1), Rocco Vertechy (1) (2),

(1) Alma Mater Studiorum University Of Bologna, Department Of Industrial Engineering, Bologna, Italy
(2) National Research Council, Institute Of Intelligent Industrial Systems And Technologies For Advanced Manufacturing, Milan, Italy

Presentation given by Ms. Chiara Scagliarini

Digital printing techniques offer cost-effective, low-waste methods for fabricating conductive elements on flexible substrates. Inkjet and screen printing are especially attractive for soft robotics and electrostatic transducers. Silver nanoparticle inks are preferred for their excellent electrical conductivity, chemical stability, and low melting point, enabling printing on heat-sensitive materials like polymers. In thin electrode systems, achieving effective electrical conductivity can be challenging. Unreliable contact at the dielectric interface can even lead to reduced device performance. Such issues worsen with polymer compliance,

surface texture, air gaps, or moisture. This work assesses inkjet-printed electrodes based on commercial silver inks as alternatives to conventional contacts. After defining optimal strategies and printing parameters, electrodes are fabricated via drop-on-demand inkjet-printing on polyimide and polyester substrates. Their sheet resistance is first determined for different printing parameters. Then, the relative permittivity of the substrates is measured on samples with inkjet-printed circular electrodes. Comparing results from different printing settings allows us to identify the process which minimizes issues faced by conventional electrodes. We present results from the different printing processes as a practical alternative to conventional contacts, allowing on-site measurement of electrical properties of polymer films.

3.2.10 **Enhanced dielectric pressure sensor by laser ablation assisted manufacturing process for highly optimized sensor components**

Johannes Ziegler (1), Detlev Uhl (1), Johannes Ehrlich (1), Holger Boese (1),

(1) Fraunhofer ISC, Center Smart Materials And Adaptive Systems CeSMA, Wuerzburg, Germany

Presentation given by Mr. Johannes Ziegler

Silicone rubber (PDMS)-based 3D structures serve as mechanically supportive sensor components, enabling highly sensitive compression load sensors utilized on dielectric elastomers. These components function as mechanical converters, translating vertical forces into bidirectional strain within the dielectric film. They also enhance the electroactive surface area and sensitivity to compression loads, as the air gap between dielectric and supportive structure acts as part of the dielectric medium, responding to minimal forces. This study presents a laser ablation-assisted manufacturing process for the rapid and flexible production of these 3D structured sensor components, facilitating various sensor designs for research and development. A CO2 laser was employed to ablate material from a PDMS film, creating cylindrical structures. A moulded and lasered reference (structures with 1 mm diameter, 0.5 mm in height) and a structure with a reduced aspect ratio (0.25 mm in height) were fabricated. Ablation accuracy was assessed using laser scanning (LSM) and light microscopy, the resulting dielectric sensor

were electromechanically characterized. The lasered sensor exhibited a more linear sensitivity to pressure, while capacity change was only decreased by 17 % compared to the moulded reference. The sensor height was reduced by 52 %. Laser processing of compression load sensor components yields thinner sensors while maintaining exploitable sensitivity.

3.2.11 **In-situ on-surface polymerization of electrochemically active polyaniline: synthesis and application**

Atirah Atirah (1), Soumyo Mukherji (2), Saurabh Lodha (3),

(1) Center For Research In Nanotechnology And Science, Indian Institute Of Technology Bombay, Maharashtra, India
(2) Department Of Bioscience And Bioengineering, Indian Institute Of Technology Bombay, Maharashtra, India
(3) Department Of Electrical Engineering, Indian Institute Of Technology Bombay, Maharashtra, India

Presentation given by Ms. Atirah Atirah

This work introduces a novel, facile, and single-step method of polyaniline film synthesis on Si/SiO2 substrates. In this, we report a unique preparation method for polycrystalline structured, 2D thin polyaniline film on Si/SiO2 produced by the “stir coat method.” The presented approach helps resolve the existing drawbacks of less yield, time-consuming synthesis processes, low uniformity and crystallinity, lesser surface coverage, stability, and conductivity. Polyaniline (PANi) is an electrically conducting polymer. Thin flakes and films are opening up new possibilities for the material applications. Our proposed process is simple, low cost, yield effective with feasibility, at the expense of a minimal number of initial components. The film has a minimum thickness of 20 nm and a polyaniline flake of a minimum thickness of 2 nm with good electrical properties. The process is compatible with clean rooms, hence seeing its future in IC technologies. The conductivity shown is around 6 Scm-1. This is the first report showing the covalently bonded in-situ polymerization of polyaniline and its direct patterning over pre-treated Si/SiO2 substrates. PANi 2D flakes are, for the first time, reported by our proposal to be used as an electronic channel. The application of the work involves pH sensing using PANi films and electronic devices using

PANi flakes.

3.2.12 **Electrocaloric polymer multilayers for heat pump application**

Daniel Pinkal (1), Michael Wegener (1),

(1) Fraunhofer Institute For Applied Polymer Research, Department Of Sensors And Actuators, Potsdam, Germany

Presentation given by Mr. Daniel Pinkal

Electrocaloric polymers like the terpolymer P(VDF-TrFE-CFE) can exhibit adiabatic temperature differences of several Kelvin when exposed to an electric field of about 100 MV/m. To make use of the temperature change in the form of a heat pump system, different principles were suggested to create directional heat transport. These include electrostatic movement, liquid medium pumping or evaporation and condensation within a heat pipe, synchronized with the electrocaloric switching. However, one major obstacle for developing market-friendly devices is the need for relatively high voltages of several kilovolts for film thicknesses sufficient to provide a certain thermal mass for efficient operation. Here, we present a possible solution to this problem by the development of multilayer structures that are designed to meet the specific demands of heat-transferring systems, such as good thermal contact between the layers and a minimal use of passive materials. We processed electrocaloric components consisting of 10 layers of 9 μm single layer thickness, reducing the required voltage well below 1 kV without requiring bonding layers. The electrocaloric and electrical properties remain comparable to those of single layers, enabling temperature changes of about 5 K at 100 MV/m. As a further step to industrial integration, we also developed an encapsulation to protect the components from possible heat transfer media while miminizing the electrocaloric performance losses.

3.2.13 **The concept of pneumatic magnetorheological elastomer actuator with permanent magnet rolling effect.**

Pawel Czopek (1), Jakub Bernat (1), Agnieszka Marcinkowska (2), Piotr Gajewski (2),

(1) Poznan University Of Technology Institute Of Automatic Control And Robotics, Poznan, Poland
(2) Poznan University Of Technology, Institute Of Chemical Technology And Engineering, Poznan, Poland

The soft robotics system requires novel actuation methods to improve and extend its possibilities. This work presents the novel geometry of the actuator with a combination of magnetorheological elastomer, permanent magnet, and pneumatic system. The actuator is a soft strip made of three layers: the first is magnetorheological elastomer, the second is free space, and the last is pure silicone. The strip is attached to a permanent magnet to stabilize movement. The input of the presented actuator is variable pressure, and the output is the variable curvature of the strip. The strip without pressure is rolled around the permanent magnet, while the strip under pressure is unrolling from it and thus is straight. This paper shows the fabrication steps and the experimental validation in various configurations. The authors believe that the actuator with the presented geometry can find applications in the construction of practical devices of soft robotics, like fin, gripper or valve and many more.

3.3.14 **Swelling with purpose: bioinspired phase-change actuation in soft robotics**

Mathias Wendner (1), Rafal Ziembicki (1), Ingrid Graz (1),

(1) Johannes Kepler University Linz, School Of Education, STEM Education, Linz, Austria

Presentation given by Mr. Mathias Wendner

Soft robotics aims to revolutionize robotics by replacing rigid components with soft-bodied actuators that respond to electric, magnetic, or pneumatic stimuli. Among these, pneumatic systems offer promising capabilities due to their ability to produce complex deformations through simple inflation. However, they often require bulky external hardware such as compressors, valves, and tubes that tether the robot and limit mobility. In this study, we explore phase-change actuation as a compact, untethered alternative. By heating a low-boiling-point

liquid encapsulated within a soft elastomeric shell, a liquid-to-gas transition drives volume expansion and shell inflation. Inspired by plant tissues that swell or shrink with water uptake, we assess this approach across different actuator sizes, focusing on power consumption and permeation resistance. Finally, we demonstrate simple proof-of-concept devices including a gripper and a phase change McKibben actuator highlighting the potential of this strategy for future autonomous soft robotic systems.

3.3.15 **Squeezing the most out of HASEL generators: exploring the limits of energy harvesting**

Sophie Kirkman (1), Ingemar Schmidt (1), Steven Zhang (1), Lawrence Smith (1), Soo Jin Adrian Koh (1), Philipp Rothemund (1) (4), Christoph Keplinger (1) (2) (3) (5),

(1) Max Planck Institute For Intelligent Systems, Robotic Materials Department, Stuttgart, Germany
(2) University Of Colorado, Paul M. Rady Department Of Mechanical Engineering, Boulder, USA
(3) University Of Colorado, Materials Science And Engineering Program, Boulder, USA
(4) University Of Stuttgart, Institute For Adaptive Mechanical Systems, Stuttgart, Germany
(5) University Of Stuttgart, Engineering Design, Production Engineering And Automotive Engineering, Stuttgart, Germany

Presentation given by Ms. Sophie Kirkman

Renewable energy has the dual benefit of mitigating climate change and reducing dependence on fossil fuels. However, many energy sources remain untapped due to limitations in current technology. Hydraulically Amplified Self-healing Electrostatic (HASEL) transducers, which consist of dielectric pouches filled with a dielectric fluid and coated with electrodes, use electrostatic 'zipping' to deform and are a promising energy harvesting technology. In this work, we develop and validate a quasi-static model to predict the energy harvesting capabilities of HASEL generators. We analyze two different load cases and perform a parametric study to optimize the design geometry of the generator as well as the experimental

conditions. The experimental energy harvesting results align well with the model, demonstrating mechanical-to-electrical efficiencies up to 40% and specific energies reaching 12 J/kg. Furthermore, we confirm that for practical operation, HASEL generators yield significantly better performance in one of the tested loading cases. Finally, we exercise the model to lay a roadmap for further HASEL generator development, thus providing insights for future work in electrostatic energy harvesting.

List of participants EuroEAP 2025

N.	Last name	First name	Organization	Country
1	Aabloo	Alvo	University of Tartu	Estonia
2	Addario	Saverio	University of Saarland	Germany
3	Ajvazi	Edip	Johannes Kepler University	Austria
4	Atirah	Atirah	IIT BOMBAY	India
5	Aubert	Vivian	CNRS	France
6	Bertolucci	Federico	National Research Council	Italy
7	Boese	Holger	Fraunhofer Institute For Silicate Research ISC	Germany
8	Böhmer	Carola	TUD Dresden University Of Technology	Germany
9	Cáceres Rivera	Maribel	École Polytechnique Fédérale De Lausanne (EPFL)	Switzerland
10	Carpi	Federico	University of Florence	Italy
11	Caruso	Fabio	EPFL	Switzerland
12	Castellaneta	Andrea		Italy
13	Chen	Yufeng (Kevin)	MIT	United States
14	Chen	Jian	TU Dresden	Germany
15	Contreras	Consuelo	Max Planck Institute For Intelligent Systems	Germany
16	Czopek	Pawel	Poznan University Of Technology	Poland
17	Daunizeau	Thomas	EPFL	Switzerland
18	De Lorenzo	Mario	Technische Universität Dresden	Germany
19	Devroy	Anirshu	TU Dresden	Germany
20	Eller	Klaus	Wacker Chemie AG	Germany
21	Fang	Yuan	Max Plank Institute For Intelligent Systems	Germany
22	Fasolt	Bettina	ZeMA Zentrum für Mechatronik und Automatisierungstechnik gGmbH, Germany	Germany
23	Firouznia	Saba	University Of Bristol	United Kingdom

24	Frediani	Gabriele	University of Florence	Italy
25	Furie	Louise Anne	Linköping University	Sweden
26	Gao	Hongyan	Max Planck Institute	Germany
27	Gerhard	Reimund	University of Potsdam, Faculty of Science	Germany
28	Grasso	Giulio	Max Planck Institute for Intelligent Systems	Germany
29	Graz	Ingrid M.	Johannes Kepler University (JKU)	Austria
30	Groten	Jonas	Joanneum Research Forschungsgesellschaft MbH	Austria
31	Hartmann	Florian	Max Planck Institute For Intelligent Systems	Germany
32	Heib	Lennart	Saarland University	Germany
33	Holzer	Simon	École Polytechnique Fédérale De Lausanne (EPFL)	Switzerland
34	Hosovský	Alexander	Technical University Of Kosice	Slovakia (Slovak Republic)
35	Huniade	Claude	University of Borås	Sweden
36	Iacob	Mihail	Datwyler	Switzerland
37	Jager	Edwin	Linköping University	Sweden
38	Jiao	Chen	TU Dresden	Germany
39	Jing	Yuxin	University Of Yamanashi	Japan
40	Kazemipour	Amirhossein	ETH Zurich	Switzerland
41	Keplinger	Christoph	Max Planck Institute for Intelligent Systems	Germany
42	Kim	Kwang	University Of Nevada, Las Vegas	United States
43	Kirkman	Sophie	Max Planck Institute for Intelligent Systems	Germany
44	Komijani	Amir	University Of Bologna	Italy
45	Kraus	Tobias	INM - Leibniz-Institute For New Materials	Germany
46	Kunze	Julian	IMSL - ZeMA gGmbH	Germany

47	Maas	Jürgen	TU Berlin	Germany
48	Macari	Daniela	Max Planck Institute For Intelligent Systems	Germany
49	Martinez	Jose G.	Linköping University	Sweden
50	Masoud	Abd Elkarim	Technische Universität Berlin	Germany
51	Mehraeen	Shayan	Linköping University	Sweden
52	Minev	Ivan	Leibniz Institute For Polymer Research And TU Dresden	Germany
53	Mitchell	Shane	Artimus Robotics	United States
54	Moretti	Giacomo	University of Trento	Italy
55	Motzki	Paul	Saarland University - ZeMA gGmbH	Germany
56	Nalbach	Sophie	IMSL - ZeMA gGmbH	Germany
57	Naris	Mantas	Artimus Robotics	Lithuania
58	Nedelcu	Cristina	Technical University of Denmark	Denmark
59	Neuwirth	Johannes	Wacker Chemie AG	Germany
60	Ni	Junhao	Technische Universität Dresden	Germany
61	Okuzaki	Hidenori	University of Yamanashi	Japan
62	Opris	Dorina Maria	EMPA	Switzerland
63	Ozawa	Daiki	University Of Yamanashi	Japan
64	Pagani	Alessandro		Italy
65	Peng	Junbo	Zhejiang University	China
66	Perri	Carmen	Saarland University	Germany
67	Perryman	Alexandra	Swansea University	United Kingdom
68	Pinkal	Daniel	Fraunhofer Institute For Applied Polymer Research IAP	Germany
69	Põldsalu	Inga	Technical University of Denmark	Denmark
70	Potnik	Valentina	University Of Florence	Italy
71	Priuli	Alberto	Saarland University	Germany
72	Qadeer	Abd Ul	Linköping University	Sweden

73	Riva	Marco	Università Di Trento	Italy
74	Rizzello	Gianluca	Saarland University	Germany
75	Rossiter	Jonathan	University Of Bristol	United Kingdom
76	Rothemund	Philipp	University of Stuttgart	Germany
77	Sasso	Giacomo	Queen Mary University of London	Italy
78	Scagliarini	Chiara	Alma Mater Studiorum University Of Bologna	Italy
79	Seelecke	Stefan	Saarland University	Germany
80	Selhuber-Unkel	Christine	Heidelberg University	Germany
81	Shagan Shomron	Alona	Max Planck Institute For Intelligent Systems	Germany
82	Shea	Herbert	EPFL	Switzerland
83	Simonetti	Giovanni		Italy
84	Sîrbu	Ion-Dan	Scuola Superiore Sant'Anna	Italy
85	Skov	Anne Ladegaard	DTU	Denmark
86	Sobczyk	Martin	TU Dresden	Germany
87	Soleti	Giovanni		Germany
88	SORIN	Fabien	Ecole Polytechnique Fédérale De Lausanne (EPFL)	Switzerland
89	Stubning	Tobias	Bosch / University of Potsdam	Germany
90	Toshimitsu	Yasunori	ETH Zurich	Switzerland
91	Vancaeyzeele	Cedric	CY Cergy Paris Université	France
92	Vidal	Frédéric	CY Cergy Paris Université	France
93	Viovy	Jean-Louis	IPGG	France
94	Wegener	Michael	Fraunhofer IAP	Germany
95	Wendner	Mathias	JKU	Austria
96	Willian	Tobias	ZeMA - Center for Mechatronics and Automation Technology	Germany
97	Wirges	Werner	UPtransfer GmbH	Germany
98	Wolf	Jana	EMPA	Switzerland

99	Worsley	Robyn	Technical University Of Denmark	Denmark
100	Xu	Ciqun	University of Bristol	United Kingdom
101	Zemlin	Benjamin	Hochschule für Technik und Wirtschaft des Saarlandes	Germany
102	Zheng	Hehui	ETH Zurich	Switzerland
103	Ziegler	Johannes	Fraunhofer Institute for Silicate Research	Germany
104	Ziembicki	Rafal	Johannes Kepler Universität Linz	Austria