# EuroEAP 2024

**12th international conference on Soft Transducers and Electromechanically Active Polymers**

**Stuttgart, Germany**
**11-13 June, 2024**

# Technical programme

# Book of abstracts

# List of participants

# EuroEAP 2024 supported by

# Contents

# Conference venue

Max Planck Insitute for Intelligent Sytems
Heisenbergstr. 3, Stuttgart, Germany
Email: info@is.mpg.de

# Conference chairpersons

EuroEAP 2024 is chaired by
Philipp Rothemund
Junior Professor
Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW)
University of Stuttgart

EuroEAP 2024 is co-chaired by
Christoph Keplinger
Director
Robotic Materials Department
Max Planck Institute for Intelligent Systems

# Local organization

Max Planck Institute for Intelligent Systems
Robotic Materials Department

# Contact information

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# 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.

Cedric Plesse
*Conference Committee President*

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Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

# Programme Overview

## Monday 10 June 2024

| | | |
|---|---|---|
| **Arrival** | 17:00 – 19:00 | **Registration** |

## Tuesday, 11 June 2024

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|---|---|---|
| **Opening** | 08:45 – 09:00 | Welcome & introduction to the conference<br>**Philipp Rothemund**<br>University of Stuttgart, Germany |
| | Session 1.1 part I<br>*Chair: Ingrid Graz, Johannes Kepler University, Austria* | |
| **Keynote Lecture** | 9:00 – 9:30 | **Barbara Stadlober**<br>JOANNEUM RESEARCH Forschungsgesellschaft mbH, Austria |
| **Invited Lectures** | Session 1.1 part II<br>*Chair: Ingrid Graz, Johannes Kepler University, Austria* | |
| | 09:30 – 09:50 | **Masaki Fuchiwaki**<br>Kyushu Institute of Technology, Japan |
| | 09:50 – 10:10 | **Sabine Ludwigs**<br>University of Stuttgart, Germany |
| **Break** | 10:10 – 10:25 | Coffee break |
| **Interactive Talks Presentations** | Session 1.2<br>*Chair: Florian Hartmann, Max Planck Institute for Intelligent Systems, Germany* | |
| | 10:25 – 11:30 | **Oral presentations**<br>21 presentations of research activities<br>(3 minutes each) |
| **EuroEAP Society Challenge** | 11:30 – 12:05 | **Video projection**<br>11 Challenge videos (3 minutes each) |

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|---|---|---|
| **Interactive Talk poster presentations** | 12:05 – 13:15 | **Posters & exhibitions**<br>21 posters |
| **Lunch break** | 13:15 – 14:20 | Lunch |
| **Keynote Lecture** | Session 1.3<br>*Chair: Jose G Martinez, Linköping Univeristy, Sweden* | |
| | 14:20 – 14:50 | **Xuanhe Zhao**<br>Massachusetts Institute of Technology, USA |
| **Industry Talk** | 14:50 – 15:05 | **Nicholas Kellaris**<br>Artimus Robotics Inc. |
| **Interactive Talks** | Session 1.4<br>*Chair: Paul Motzki, Saarland University, Germany* | |
| | 15:05 – 16:15 | **Oral presentations**<br>22 presentations of research activities<br>(3 minutes each) |
| | 16:15 – 17:15 | **Posters & exhibitions**<br>22 posters<br>Coffee served during the session |
| **EuroEAP Society meeting** | 17:15 – 18:15 | **Annual meeting of the EuroEAP Society** |
| **Dinner** | 19:00 | Dinner at Alte Kanzlei, Stuttgart |

# Wednesday 12 June 2024

| | | |
|---|---|---|
| **Invited Lectures** | Session 2.1<br>Chair: *Chair: Herbert Shea, EPFL Lausanne, Switzerland* | |
| | 09:00 – 09:20 | **Min-Hui Li**<br>Université Paris Sciences & Lettres, France |
| | 09:20 – 09:40 | **Ye Shi**<br>Zhejiang University, China |
| | 09:40 – 10:00 | **Giacomo Sasso**<br>Queen Mary University of London, UK |
| | 10:00 – 10:20 | **Patrick Danner**<br>EMPA, Switzerland |
| **Break** | 10:20 – 10:35 | Coffee break |
| **Interactive Talks** | Session 2.2<br>*Chair: Federico Carpi, University of Florence, Italy* | |
| | 10:35 – 11:55 | **Oral presentations**<br>26 presentations of research activities<br>(3 minutes each) |
| | 11:55 – 13:00 | **Posters & exhibitions**<br>26 posters |
| **Lunch break** | 13:00 – 14:00 | Lunch |
| **Industry Talks** | Session 2.3<br>*Chair: Marco Fontana, Scuola Superiore Sant'Anna, Italy.* | |
| | 14:00 – 14:15 | **Alexander York**<br>mateligent iDEAS |
| | 14:15 – 14:30 | **Umesh Gandhi**<br>Toyota Research Institute North America |
| **Social event** | 14:30 – 18:00 | **Visit Schloss Ludwigsburg** |
| **Gala dinner** | 18:00 | Dinner at Württemberger Hof, Ludwigsburg |

# Thursday 13 June 2024

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|---|---|---|
| **Keynote Lecture** | Session 3.1 part I<br>*Chair: Cedric Plesse, CY Cergy Paris University, France* | |
| | 09:00 – 09:30 | **Virgilio Mattoli**<br>Istituto Italiano di Tecnologia, Italy |
| **Invited Lectures** | Session 3.1 part II<br>*Chair: Cedric Plesse, CY Cergy Paris University, France* | |
| | 09:30 – 09:50 | **Marco Fontana**<br>Scuola Superiore Sant'Anna, Italy |
| | 09:50 – 10:10 | **Vanessa Sanchez**<br>Rice University, USA |
| **Break** | 10:10 – 10:30 | Coffee break |
| **Interactive Talks** | Session 3.2<br>*Chair: Alona Shagan, Max Planck Institute for Intelligent Systems, Germany* | |
| | 10:25 – 11:25 | **Oral presentations**<br>20 presentations of research activities |
| | 11:25 – 12:20 | **Posters & exhibitions**<br>20 posters |
| **Best Poster & Society Challenge Awards** | 12:20 – 12:30 | Final collection and counting of votes |
| | 12:30 – 12:50 | **Announcement of the first three classified teams of the EuroEAP Society Challenge award and of the winner of the best poster awards** |
| **Closing ceremony** | 12:50 – 13:00 | Conference closure, handover to the next year's chairperson and presentation of the next year's conference venue. |
| **Lunch** | 13:00 – 14:30 | Lunch |
| **Optional: Lab Tours** | 14:30 – | Lab tour through Robotic Materials Department |

# Tuesday, 11 June 2024

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

### 1.1.1 Ferroelectric polymers for electronic skin, industrial sensing and energy harvesting

A. Petritz (1), J. Groten (1) O. Werzer (1), K. Krawczyk (1), P. Schäffner (1), A. Alvarez (1), M. Zirkl (1), M. Adler (1), E. Schreck (1), M. Hammer (1), A. Tschepp (1), H. Gold (1), T. Uemura (2), T. Araki (2), T. Sekitani (2), G. Domann (3), and B. Stadlober (1)

(1) JOANNEUM RESEARCH Forschungsgesellschaft mbH, Weiz, Austria
(2) Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka, Japan
(3) Fraunhofer-Institut für Silicatforschung ISC, Würzburg, Germany

Presentation given by Dr. Barbara Stadlober

In the development of modern society, many aspects of daily life revolve around communication and interaction between us and our environment. In the near future, not only will people and smart machines communicate with each other, but objects themselves will also constantly exchange information with their surroundings, supporting and making our daily lives more secure and convenient. This requires such smart objects to be equipped with sensitive, interactive and communicative components, such as a seamlessly integrated electronic skin (e-skin) on the objectsurface, which offers distributed sensing of multiple parameters, certain input/output (I/O) and data processing functions. In addition, a lightweight e-skin capable of multimodal sensing is also interesting as a wearable, non-obstructive medical device that can monitor human vital parameters at the point of care/living. Finally, slim free-format sensors for industrial production and mobility are in high demand.
Consequently, sensor technologies for the above application scenarios should (i) be easy to integrate on versatile materials over large areas and 3D formats, (ii) be slim and lightweight, (iv) support multi-parameter sensing with high spatial and temporal resolution, (v) be able to be manufactured using scalable, environmentally friendly and cost-effective methods, (vi) contain small format electronics with wireless data transmission and (vii) have very low energy

consumption. Ferroelectric polymers from the class of PVDF materials are ideally suited as multimodal sensors in such e-skins, as their ferroelectric properties allow them to be used for multiparameter sensing of strain, pressure, touch, vibration, temperature, IR radiation and vital parameters, as well as for the conversion of mechanical to electrical energy (energy harvesting). In particular, if fabricated by a scalable technique like screen or inkjet printing, ferroelectric polymer devices can easily be integrated on flexible substrates like plastic foils, paper, textile, leather, rubber, metal foils and so on. This is very important since energy autonomy and conformability are essential elements in the next generation of wearable and flexible electronics. In the talk I will summarize the state of the art of flexible ferroelectric polymer devices with respect to materials, processing and applications and will then present recent developments of our PVDF-TrFE based PyzoFlex® technology with novel material combinations, innovative integration concepts and more sophisticated demonstrators for sensing and energy harvesting.

### 1.1.2 Asymmetric bilayer artificial muscles based on conducting polymer, Polypyrrole

Masaki Fuchiwaki (1)

(1) Kyushu Institute of Technology, Department of Intelligent and Control Systems, Iizuka, Japan

Presentation given by Dr. Masaki Fuchiwaki

Many researchers are developing a trying to produce zoomorphic and anthropomorphic robots working in a similar way as natural muscles do. Conducting polymers constitute the base for the development of zoomorphic and anthropomorphic soft actuators and are attracting attention for its application as artificial muscles in recent years. The mechanism is extremely simple, it is expansion or contraction of conducting polymers due to the electrochemical oxidation and reduction, that is, electrochemomechanical deformation (ECMD). A number of researchers have already reported the artificial muscles based on the conducting polymers, such as polyaniline, (PAn), poly(o-methoxyaniline), (PmAn), poly(3-alkylthiophene)s and polypyrroles, (PPy). In particular, polypyrroles, are constructed from high-quality film and the electrochemical activity range of polypyrroles films is found to be wide. In case of single layer conducting polymer (PPy , anion drive actuation) attached with insulating tape in electrolyte solution, as shown in Fig. 1, the artificial muscle describes anticlockwise and clockwise angular displacement during oxidation and reduction, respectively. Similarly in case of the cation drive actuation, the artificial muscle describes clockwise and counter-clockwise angular displacements in reduction and oxidation, respectively. In order to make a large and high responsiveness bending movement, an asymmetric bilayer conducting polymer artificial muscles have been proposed and it consists of anion-driven (left side) and cation-driven (right side) films, as shown in Fig. 2. The asymmetric bilayer artificial muscle describes a clockwise and counter-clockwise bending movement during oxidation and reduction, respectively. The amplitude of the described movement is now over a few times that of the single layer conducting polymer attached with insulating tape in the same electrolyte solution. Because the anion-driven film swells by entrance of anions and water and, at the same time, the cation-driven film shrinks by expulsion of cations and water. In this study, the author investigates the dynamic behavior of the bending actuation of the asymmetric bilayer artificial muscles based on polypyrroles, the effect of the thickness ratio between the anion-driven and the cation-driven layers and their mechanical applications.

### 1.1.3 From multifunctional polymer materials design to soft robotics applications

Sabine Ludwigs (1)

(1) University of Stuttgart, IPOC – Functional Polymers, Institute of Polymer Chemistry, Functional Soft Materials Lab (FSM), Stuttgart, Germany

Presentation given by Dr. Sabine Ludwigs

Polymers are well-integrated into our daily life, just to name wearables, household equipment and flexible devices as examples. Synthetic polymers can exhibit an unlimited range of different and multifunctional physical and chemical properties. Particularly useful is their variety in mechanical properties from being rigid to soft or stretchable. Stimuli-responsive polymers are particularly exciting as they can change and adapt their structure to external stimuli, resulting for example in volume and stiffness changes. For the interfacing of novel smart devices with the human body - one major challenge of soft robotics - soft and flexible materials are desirable which match the mechanical properties of the skin and are able to adapt and follow the various forms of motion of the human body. My presentation will highlight two recent studies of our group on smart multifunctional polymer

design, using temperature, relative humidity and electric fields as external stimuli for switchable devices.
The first example is based on novel functional hydrogel patches which reversibly react to environmental conditions and show high stretchability.1 With strains at break of over 200% in dry state, the patches are compliant with human skin. Dynamic- mechanical analysis shows a huge dependence of the mechanical properties on temperature and humidity: The glass transition temperature shifts from around 60 °C at dry conditions to below 0 °C for 75% relative humidity and higher. The storage modulus is tunable over more than four orders of magnitude from 0.6 up to 400 MPa. Applications of the patches in skin wound therapy are proposed.
The second material class involves mixed conducting polymers with their ability of electrical conduction upon (electro)chemical doping and ionic conductivity when exposed to water vapor or liquid. Among various self-synthesized materials we study the blend poly(ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) which is commercially available as aqueous suspension. The humidity dependence of the PSS polyelectrolyte phase together with the electroactive nature of the PEDOT can be used to create multiresponsive surfaces and actuating devices.2 A recent research highlight includes the preparation of "intelligent" humidity-triggered bilayer actuators with an elastomer as passive layer. Their bending behavior (curvature) can be modelled by the humidity-dependent mechanical behavior of the layers3, opening pathways for prediction of more complex architectural designs.

# Session 1.2

(abstracts are listed in the order of presentation)

### 1.2.1 Carbon nanotube yarns and biofriendly electrolytes as building blocks for electrochemical artificial muscles

Gabriela Ananieva (1), Cedric Vancaeyzeele (1), Giao Nguyen (1), Daniel Aguilera-Bulla (1), Mathieu Pinault (2), Frederic Vidal (1), Cedric Plesse (1)

(1) CY Cergy Paris University, LPPI, Neuville-sur-Oise, France
(2) CEA Saclay, LEDNA, Fontenay-aux-Roses Cedex, France

Presentation given by Gabriela Ananieva

Electrochemically driven yarn actuators providing fast actuation and large contractile stroke are promising soft transducers, and are considered as precursors of artificial muscles for applications in smart textiles, prosthetics, soft robotics or exoskeletons. Among them, electrochemically driven coiled carbon nanotube (CNT) yarn actuators operate by the means of low voltage electrical stimulation, where the accumulation of ions during charge and discharge of their electrochemical double layer capacitance (EDLC) provides stable reversible tensile stroke. Air-operation of such yarn muscles requires the combination of two coiled CNT yarns, acting respectively as anode and cathode, and an ionic coating, acting as an ion source. The optimization of coiled CNT yarn performances and the development of highly ionically conducting, non-toxic and air-stable gels are of primary interest for the integration of these actuators into practical applications. Therefore, this work presents a systematic study on maximizing the electromechanical response of coiled CNT yarns obtained from commercially available yarns, the elaboration of easily synthesizable, environmentally- and biofriendly electrolytes, and the first results on their association into functional devices.

### 1.2.2 Adaptation of a solid-state marx modulator for electroactive polymer

Morgan Almanza (1), Christophe Baron (1)

(1) Université Paris-Saclay, ENS Paris-Saclay, CNRS, SATIE, 91190 Gif-sur-Yvette, France

Presentation given by Christophe Baron

Electroactive polymers show promising characteristics, such as lightness, compactness, flexibility, and large displacements, making them a candidate for application in cardiac assist devices, robotics and other compact applications. This revives the need for quasi-square wave voltage supply switching between 0 and several kilovolts. It must be efficient in both the charge and discharge phases, to limit the heat dissipation, and compact in order to be implanted. The high access resistance, associated with compliant electrodes, represents an additional difficulty. Here, a solid-state Marx modulator is adapted to cope with electroactive polymer characteristics, taking advantage of an efficient energy transfer over a sequential multistep charge/discharge process. To ensure compactness, efficiency, as well as the needs of an implanted device, a wireless magnetic field-based communication and power transfer system has been implemented. This work demonstrates the benefit of this design through simulations and experimental validation on a cardiac assist device. At a voltage of 7 kV, an overall efficiency of up to 88% has been achieved over a complete charge/discharge cycle.

### 1.2.3 Assessing the optimal combination of interdigital geometry characteristics in electro adhesion performance through design of experiment method

Federico Bertolucci (1), Lara Rebaioli (1), Irene Fassi (1), Lorenzo Molinari Tosatti (1), Rocco Vertechy (1) (2)

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

Presentation given by Dr. Federico Bertolucci

In the past decade, numerous studies have proposed optimization strategies targeting components of electro-adhesive devices (EAD) to enhance their performance in terms of normal or shear grasping force. Notably, the comb-shaped interdigital geometry, widely utilized in EAD grasping applications, has demonstrated superior performance in terms of shear force on dielectric objects as well as the suitability to grasp electrically floating conducting objects. While much of the literature has focused on determining the optimal electrode geometry for specific applications by means of theoretical models and finite element method (FEM) simulations, only a few have conducted a systematic exploration of the optimal combination of electrode gap and width through empirical evaluation. This work presents a study aimed at optimizing the geometry parameters of EAD interdigital electrodes to maximize the shear force of the device. This optimization is achieved through a proper experimental campaign developed using the statistical Design of Experiment (DoE) methodology. The EAD samples are fabricated by inkjet printing Ag electrodes, of different comb-shaped geometries, on the same PET film, and their breakaway force on a dielectric object is evaluated using a custom test-bench.

### 1.2.4 Enhanced Test Bench for Statistical Assessment of Electromechanical Characteristics and Failure Mechanisms of Dielectric Elastomer Transducers

Daniel Bruch (1), Sophie Nalbach (2), Paul Motzki (1) (2), Stefan Seelecke (1)

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

Presentation given by Daniel Bruch

Reliability and lifetime are critical factors in assessing the market competitiveness of DET technology, alongside with general properties, i.e. sensor accuracy, actuator performance, or generator efficiency. These attributes are influenced across all product levels and development phases. Their assessment and improvement require comprehensive electromechanical testing, including both short-term and long-term experiments within various operational and environmental conditions, and simultaneous testing of various test objects for accelerated statistical evaluation. In previous work, a comprehensive modular test rig has been proposed that enables simultaneous long-term testing of numerous DETs within controlled environments, and under the specification of mechanical and electrical control parameters. However, this test rig has limitations in providing synchronized electromechanical control, and enabling simultaneous measurement of electrical properties, i.e. electrode resistance or dielectric permittivity during high voltage actuation. These functionalities are crucial to provide more realistic testing conditions for DET-based systems, investigate their self-sensing properties, and to be able to access statistical relevant data with respect to short-term testing conditions. Therefore, this poster presents an upgraded test rig version incorporating these functions, demonstrated through comprehensive electromechanical tests conducted on a representative DET type.

### 1.2.5 Electromechanical investigation of DE transducers printed with different electrodes

Ozan Çabuk (1), Jürgen Maas (1)

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

Presentation given by Mr. Ozan Çabuk

Electrodes are of great significance regarding the softness and response time of dielectric elastomer (DE) transducers. Moreover, electrodes provide an adhesive function between prefabricated DE layers, especially in multilayer structures. However, electrodes are often not given sufficient consideration when investigating the behavior of DE transducers. On the one hand, the electrical capacitance is a measurable parameter that can be used to describe the storable energy, taking the driving voltage into account. On the other hand, the electrical resistance of the electrode material causes dissipation of supplied energy. This contribution investigates the effect of the different electrode materials on the capacitance and resistance of multilayer DE transducers produced with various printed electrode materials. An automated test rig is designed to measure the DE transducers' capacitance and resistance under mechanical stretching, and depending on the actuation cycles. Measurements are conducted using varying electrical actuation cycles and stretching cycles. Results regarding the DE transducers' material choice and their performance impairments are discussed.

### 1.2.6 Direct generation: a paradigm shift in wave energy harvesting

Ieuan Collins (1), Jonathan Hodges (1)

(1) Wave Energy Scotland

Presentation given by Dr. Ieuan Collins

With the ongoing climate crisis and UN goals of achieving net-zero by 2050, there is growing need for innovative, cost-effective renewable energy solutions. Wave energy could supply up to 10% of Europe's total energy demand. Wave Energy Scotland (WES) has been at the forefront of pioneering wave energy research, funding over 50 million GBP of projects through a series of competitive-funded programs since 2014. There are real indications of commercialisation for several devices around the world, but there are opportunities to reduce costs even further. Novel electrostatic generation technologies based on Dielectric Elastomer Generators (DEGs) and Dielectric Fluid Generators (DFGs) can directly transform movement (stretching, twisting, bending) of a material into electrical energy, i.e., Direct Generation (DG), leading to fewer structural cost centres compared to conventional devices. WES currently has a suite of enabling R&D projects which focus on addressing the R&D needs of DG, starting with two 12-month Supergen ORE Impact Hub FlexFund projects and one 4-year PhD. The University of Oxford will be investigating origami inspired DFGs, Manchester University will be investigating novel soft transducers for DEGs, and Swansea University will be will performing electromechanical fatigue life experiments for DEG and DFG systems. WES now wants to engage with academics and industry leaders at EuroEAP for the next stages of DG development.

### 1.2.7 Design of a soft robotic hand driven by multilayer DEAs for minimal energy consumption

Mario De Lorenzo (1), Makara Lay (2), Lingyu Liu (2), Thomas Kister (2), Uwe Marschner (1), Tobias Kraus (2), Andreas Richter (1), E. -F. Markus Henke (1) (3)

(1) TU Dresden, Institute Of Semiconductors And Microsystems, Dresden, Germany
(2) INM-Leibniz Institute For New Materials, Saarbrücken, Germany
(3) Biomimetics Lab, The University Of Auckland, Auckland, New Zealand

Presentation given by Mario De Lorenzo

Dielectric elastomer actuators (DEAs) offer lightweight, resilient, cheap, and fast-response capabilities ideal for soft robotics applications. The goal of DEA robots is to interact with their environment in a new save bio-inspired way. DEAs are limited by small actuation and force output, but stacking multiple layers of DEAs can increase the actuation force and deformation. In this study, we propose a novel design for a soft robotic hand based on multilayer DEAs that mimics the human hand. The individual soft fingers are fabricated by bonding multilayer DEAs to a soft silicone body possessing embedded bone structures, to maintain the necessary pre-stretch, to ensure optimum performance of the individual DEAs. The finger design possesses hinge like structures with non-isotropic bending stiffness, as human fingers. We here present first design, optimized by finite element analyses (FEA) , done with Abaqus and compare obtained FEA designs with first experimental studies. The aim of this contribution is, to introduce a new bio-inspired design paradigm for soft continuum robotic structures, combining the advances soft continuum structures, non-isotropic bending structure in minimum energy dielectric elastomer actuators and the biological approach of integrating stiff bones in soft tissue.

### 1.2.8 Soft electrochemical actuators enabling minimally invasive nerve interfaces

Chaoqun Dong (1)

(1) Electrical Engineering Division, Department Of Engineering, University Of Cambridge

Presentation given by Dr. Chaoqun Dong

The use of electrode arrays to interface with peripheral nerves is attracting significant interest for the diagnosis and treatment of various neurological disorders. Existing electrodes, however, require complex placement surgeries that carry a high risk of nerve injury. Here, we leverage recent advances in soft robotic actuators and flexible electronics to develop highly conformable nerve cuffs that allow for extensive and reprogrammable shape morphing into complex three-dimensional (3D) geometries. These devices combine electrochemically driven conducting polymer-based soft actuators with low impedance microelectrodes. They enable controlled shape reconfiguration of the electrode arrays into predesigned 3D architectures with applied voltages as small as a few hundreds of millivolts, allowing active grasping or wrapping around delicate nerves. We validate this technology in in vivo rat models, showing that the cuffs form and maintain a self-closing and reliable bioelectronic interface with the sciatic nerve of rats without the use of surgical sutures or glues. Moreover, they provide the flexibility to adjust the fit or release the electrode array as required. This seamless integration of soft electrochemical actuators with neurotechnology offers a path toward minimally invasive intraoperative monitoring of nerve activity and high-quality bioelectronic interfaces.

### 1.2.9 Detection of damages in fiber-reinforced dielectric elastomer actuators

Anett Endesfelder (1) (2), Carl David Wildemann (1), Markus Koenigsdorff (3), Gerald Gerlach (3)

(1) Institute Of Institute Of Materials Science, Faculty Of Mechanical Science And Engineering, TUD Dresden University Of Technology
(2) Fraunhofer Institute Of Material And Beam Technology IWS
(3) Institute Of Institute Of Solid-State Electronics, Faculty Of Electrical And Computer Engineering, TUD Dresden University Of Technology

Presentation given by Anett Endesfelder

Dielectric elastomer actuators (DEAs) offer a promising avenue for the development of soft, flexible, and highly adaptable systems. They consist of a thin dielectric membrane between two compliant electrodes. When the actuator is electrically activated the structure compresses and expands in plane. Due to different desired application scenarios, research is also concentrating on the development of new variants. For this, the evaluation of composites, damage detection methods must be tested and evaluated. Generally, for higher functionality and a longer lifetime, the relationship between the structure of dielectric elastomer actuators and their damage behavior must be known. Therefore, the identification of structural damage is crucial to prevent future failures or more serious accidents. In addition to the well-known failure criterion of electrical breakdown, which has already been analyzed more frequently, other types of damage, including those that occur during manufacturing must be addressed. Therefore, the goal of this work is to identify other fundamental defects that occur. A uniaxial strip actuator reinforced with carbon fiber fabric is investigated. To characterize the DEAs and to detect the damage, different analysis methods, which are already established for other materials, will be tested. Methods such as classical microscopy and less-known lock-in thermography are presented.

### 1.2.10 Modeling of conducting polymer soft actuators: A first principle

**approach**

Saswath Ghosh (1), Sitikantha Roy (1)

(1) Indian Institute Of Technology Delhi, Department Of Applied Mechanics, New Delhi, India

Presentation given by Dr. Saswath Ghosh

In recent times, there has been a growing interest in ionic electroactive polymer soft actuators owing to their capacity to operate effectively with low voltage input. Conducting polymer (CP) soft actuators exhibit functionality akin to natural muscles, enabling multimodal actuation by applying a small voltage. On applying a potential difference, the redox reaction initiates the charge transport across the actuator, resulting in its mechanical deformation. The complex multiphysics phenomena involved in actuation make its accurate modeling interesting to study. The present study deals with modeling a CP soft actuator following a continuum mechanics approach for an applied voltage. The electrochemomechanical model predicts the mechanical deformation in the actuator due to ion diffusion from the surrounding electrolyte. The electrochemical model depicts charge transport using the Nernst Planck Poisson equation. Further, the charge stored in CP is coupled to a nonlinear mechanical deformation model using the free energy density function. The free energy density function includes a combination of energy functions due to the stretching of the network and chemomechanical coupling, including ion mixing and the interaction between ion concentration and mechanical deformation. The findings of the derived model are also validated with existing experimental results for a trilayer bending CP actuator.

### 1.2.11 Fully additive fabrication of stretchable zipping actuators with embedded liquid

Giulio Grasso (1), Samuel Rosset (2), Herbert Shea (1)

(1) EPFL, Soft Transducers Laboratory (LMTS), Neuchatel, Switzerland
(2) University Of Auckland, Biomimetics Laboratory, Auckland, New Zealand

Presentation given by Giulio Grasso

Soft systems with embedded incompressible fluids are used as tuneable lenses, hydraulic actuators, and are at the heart of hydraulically amplified electrostatic actuators including HAXELs, Peano-HASELs and EBMs. These multi-material devices generally require manual filling with a liquid, for instance using a needle. Such processes are not readily scalable to industrial manufacturing. In this work, we present an inkjet-based process in which the working liquid is directly embedded in the actuator during device fabrication. We print the working liquid after printing the bottom of the device. We then freeze the droplets, and finally encapsulate them. We use this method to fabricate hydraulically-amplified taxels (HAXELs) using inkjet-printed silicone dielectric layers, carbon electrodes, and encapsulated oleic acid having a freezing point between 11 and 14 degrees Celsius. The 5 millimetre-wide devices generate up to 400 micrometres out-of-plane displacement at 3 kilovolts. The absence of filling channels allows high density arrays of 5 millimetre-wide actuators with only 0.5 millimetre gap between devices. These results open the door to an upscaled industrial fabrication of customized fluid-filled soft systems.

### 1.2.12 Electroadhesive DEA for a vibration experiment of a cylindrical shell

Toshiki Hiruta (1), Junya Ohno (1), Kentaro Takagi (1)

(1) Toyohashi University Of Technology

Presentation given by Dr. Toshiki Hiruta

This study proposes a vibration excitation technique using a dielectric elastomer actuator (DEA) applied an electro adhesion technique. Vibration responses of mechanical structures are experimentally analyzed through the vibration experiment for evaluation of their mechanical characteristics. These days, the vibration experiment are required for quality assessment of fruits and vegetables. The vibration excitation method should be non-destructive and adapt to fruits' complex surface. Therefore, conventional excitation technique (e.g. impulse hammers, lead zirconate titanate actuators) are not suitable for them. Herein, a DEA can be applied to the vibration excitation. The DEA can fit to the structure with curved surface and excite vibrations owing to its features of high flexibility, stretchability, and fast response. Here, conventional DEAs are attached to the target structures by adhesives. To compose automated experiment systems for quality assessment of fruits and vegetables, DEAs without adhesives should be applied. In this study, the electro adhesion technique, which can generate an electrical attraction force was applied to the DEA. The proposed DEA was fabricated by stacking two different layers composed of elastomers and electrodes. Then, a preliminary vibration experiment for an aluminum cylindrical shell was conducted using the proposed DEA. Finally, the effectiveness of the proposed method was evaluated based on vibration responses of the target structure.

### 1.2.13 Polypyrrole-coated wire actuators: A tool for the mechanostimulation of cells

Amaia Ortega (1), Satoru Hayano (2), Emilio S. Hara (2), Hiroshi Kamioka (2), Jose G. Martinez (1), Edwin W. H. Jager (1)

(1) Linköping University, IFM, Linköping, Sweden
(2) Okayama University, Graduate School Of Medicine, Dentistry And Pharmaceutical Sciences, Okayama, Japan

Presentation given by Dr. Edwin W. H. Jager

The study of mechanotransduction signals in cells is of great interest because of their implications on the onset of various diseases such as cancer, osteoporosis, or asthma. One way of studying such signals is by applying external mechanical stimuli that affect cellular functions. To date, these stimuli have been performed using magnetic or electrical fields that do not resemble real biophysical stimulation. Polypyrrole-coated wires are easy-to-handle, biocompatible microactuators to induce mechanical stress to study the mechanotransduction pathways of single-cells. In addition, their small size makes them easy to use inside a small cell culture dish. Here, we present the characterization of the actuation of PPy-coated wires with a novel non-contact optical method and its viability in cell-compatible media in three- and two-electrode cell configurations. The wire actuators are prepared by electrodepositing PPy on a 500 ?m diameter gold substrate and then actuated in NaDBS or cell culture media. The electrochemical variables are synchronously recorded with the radial actuation of the PPy using a laser scanner. The difference in the thicknesses of PPy, as well as the effect of two-electrode or three-electrode system configurations on the absolute radial actuation, strain, and consumed charge, are investigated. These results will lay the groundwork for future mechanostimulation experiments on cells and cell signalling analysis.

### 1.2.14 Buckling instabilities in fiber-reinforced DEAs

Markus Koenigsdorff (1), Stefania Konstantinidi (2), Amine Benouhiba (2), Yoan Civet (2), Yves Perriard (2), Gerald Gerlach (1)

(1) TU Dresden, Institute Of Solid-State Electronics, Dresden, Germany
(2) Ecole Polytechnique Fédérale De Lausanne (EPFL), Integrated Actuators Laboratory (LAI), Neuchâtel, Switzerland

Presentation given by Markus Koenigsdorff

Artificial muscles, mimicking natural biological movements, show promise in robotics and prosthetics and recent advancements include fiber-reinforced actuators inspired by biological tissues. Enhancing uni-axial deformation in DEAs is possible by applying pre-stretch to the actuator membrane, achieved through uni-directional fibers. However, combining pre-stretch and fiber reinforcement may cause instabilities like fiber buckling due to compressive loads or wrinkling during actuation, which can affect performance. In this work, a novel model aresses these instabilities. The validation of the model presented along with an extensive experimental investigation allow for a comprehensive analysis to explore the impact of fiber buckling on the performance and the force of uni-axial DEAs.

### 1.2.15 Scalable and modular system of flexible phase change actuation modules for soft robotics elements and functional clothes

Rafal Ziembicki (1), Ingrid Graz (1)

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

Presentation given by Rafal Ziembicki

Soft actuators utilize many different ways of actuation that often require not only power supplies, but also devices converting its energy into different forms, such as high pressure or voltage output. Therefore many soft robotic elements remain tethered to bulky hardware, making it difficult to integrate them into wearables. One concept that offers autonomy in this field is using liquid-gas phase change actuation. This quite simple in principle technology, based on evaporation of the

working fluid in enclosed, yet elastic structures, requires only portable power supplies with no need to convert its energy, while allowing to achieve numerous and unique motion types limited only by imagination. This technology has a potential to bridge the gap between emerging, but not yet fully developed concepts and the realistic, present needs of the functional clothes industry. To demonstrate this, we present our results on a concept of flexible, scalable and modular system of elements utilizing phase change phenomena. These small phase change actuation modules created by us are ideal for fashion and functional clothes owing to the fact of their compliance, simplicity of attachment to garments and moderate energy demand. Modules operation is presented in numerous setups including artificial muscle, hinge opener, mechanical instability and functional clothes demonstrator inspired by fish scale granting both protection and smart clothing features proving versatility of our concept.

### 1.2.16 A novel silver/carbon black polydimethylsiloxane composite for soft robotic actuators

Lingyu Liu (1), Makara Lay (1), Thomas Kister (1), Tobias Kraus (1) (2)

(1) INM-Leibniz Institute For New Materials, Saarbrücken, 66123, Germany
(2) Saarland University, Colloid And Interface Chemistry, Saarbrücken, 66123, Germany

Presentation given by Lingyu Liu

Dielectric elastomer actuators (DEA) are suitable for soft robotic systems because they offer sufficient forces and rates, are compliant, and remain functional after large deformations. Such actuators require electrodes with high electrical conductivity and electro-mechanical properties that remain constant upon deformation. Carbon grease has been used for DEA fabrication, owing to its adhesion properties, for devices such as grippers. Its conductivity is low, however, fabrication and use are hampered by the remaining liquid nature, and long-term stability suffers from drying or diffusion. Soft and conductive composites can solve many of these issues. In this study, we discussed a conductive soft composite that is suitable for use in DEA, characterized by high electrical conductivity and stable electro-mechanical properties. Composites containing conductive silver particles (AgP) and carbon black in liquid silicone were blended using a speedmixer. The resulting paste was screen-printed onto silicone film (Wacker). The electro-mechanical properties and durability of the composites were assessed under 10% strain for 4000 cycles. The resistance change of the AgP-CB-Ecoflex composites in response to loading is less significant than that of two other commercial pastes, even when subjected to strains of up to 190%. Furthermore, the cycling stability of the composites is enhanced by the presence of carbon black, which improves the connectivity of the conductive network.

### 1.2.17 Development of a yarn actuator working in air for wearables

Shayan Mehraeen (1), Amaia Beatriz Ortega Santos (1), Jose G. Martinez (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), Linköping University, Linköping, Sweden
(2) CY Cergy Paris Universite, LPPI, 95000 CERGY, France
(3) Swedish School Of Textiles, Smart Textiles, Polymeric E-textiles, University Of Boras, Boras, Sweden

Presentation given by Dr. Shayan Mehraeen

Wearable technologies have made significant progress in recent decades. Wearables utilizing electroactive yarns have emerged and developed as a prominent technology in this respect. However, a key challenge in utilizing ionic electroactive polymer-based actuators for wearable technology lies in operation in air without the need for a liquid electrolyte. This challenge can be addressed by developing an ionogel containing an ionic liquid with mobile ions. In this study, we have investigated a two-electrode system based on ionic electroactive polymer actuators that operates effectively in air. The actuator comprises of two coiled commercial yarns coated with poly(3,4-ethylenedioxythiophene) (PEDOT)-based conducting polymers, connected through an ionogel. To evaluate the actuator's performance, we investigated isotonic and isometric tests in air by applying a ±1V potential. The latest results of the linear isotonic strain and isometric force will be presented. These findings suggest that the introduced two-electrode system holds promise for the advancement of actuator devices based on ionic conducting polymers.

### 1.2.18 Ultrathin film based highly conformable capacitive pressure sensors via two-photon polymerization and focused-ion beam approach

Rishabh B. Mishra (1) (2), Andrea Ottomaniello (1), Virgilio Mattoli (1)

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(2) The BioRobotics Institute, Scuola Superiore Sant"Anna (SSSA), Viale Rinaldo Piaggio, 34, 56025 Pontedera (PI), Italy

Presentation given by Rishabh B. Mishra

Developing pressure sensors on curved surfaces with conventional micromachining fabrication techniques is critically challenging. Consequently, the fabrication of standalone conformal pressure sensors is necessary for transferring the sensing modules on arbitrary small bending radii surfaces. Here, we present a novel strategy to fabricate conformable pressure sensors with two different approaches using polymeric ultrathin nanofilms (<100 nm) both as substrate and mechanical element. The dielectric of the sensing element is patterned onto or into the polymeric nanofilm using two-photon polymerization printing (as shown by V. Mattoli et al., Adv. Funct. Mater., vol. 33, p. 2214409, 2023) or by focused-ion beam milling, respectively. Afterwards, the patterned dielectric area is encapsulated between a couple of metallized polymeric thin films via Van der Waals adhesion to provide a capacitor-like structure with air-trapping in the patterned hollow region. The trapped air deforms the freestanding metallized nanofilm at these hollow locations upon pressure variation. This allows pressure difference to be detected by measuring the change of capacitance. The extensive characterization of ultrathin pressure sensors as suspended and transferred on the rigid substrate has been performed. The pressure sensors with both approaches are aimed to wrap around peripheral venous catheters of 5 to 10 mmHg pressure variation in real-time.

### 1.2.19 A tri-modal dielectric elastomer actuator with self-sensing capability

Sebastian Gratz-Kelly (2), Tim Felix Krüger (2), Stefan Seelecke (2), Gianluca Rizzello (2), Giacomo Moretti (1)

(1) Department Of Industrial Engineering, University Of Trento, Italy
(2) Department Of Systems Engineering, Saarland University, Germany

Presentation given by Dr. Giacomo Moretti

Dielectric elastomer actuators (DEAs) have gained a high popularity in wearable and user interaction units. We propose a multi-modal DEA concept that leverages a single voltage input to concurrently work as linear actuator and loudspeaker, while also integrating self-sensing capabilities. Low-frequency linear actuation is obtained by inducing tangential stretching of the DEA membrane surface, whereas sound generation is achieved through structural vibrations of the DEA membrane surface. Multi-mode actuation is combined with a new self-sensing paradigm: measuring the current signal arising from the acoustic excitation (including highly polychromatic driving voltages) and processing it in real-time with capacitance estimation algorithms, the actuator stroke can be reconstructed with no need for additional transducers or probing signals. The proposed self-sensing approach is evaluated in terms of the correlation between capacitance estimates and the low-frequency stroke of the device. Concurrent self-sensing and multi-mode actuation are demonstrated in a number of application scenarios, in which the DEA acoustic output is adjusted in closed-loop as a function of externally induced deformations, such as impacts with obstacles, or interactions with a user. This multi-modality paradigm paves the way to new applications, such as multi-sensory user interfaces or integrated sensor-actuator units able to sense their state during operation and provide feedback accordingly.

### 1.2.20 Vitrimer ionogel for self-healing flexible ionotronics

Giao T. M. Nguyen (1), Khoa V Bui (1) (2), Cedric Vancaeyzeele (1), Frederic Vidal (1), Chaoying Wan (2), Cedric Plesse (1)

(1) Laboratoire De Physicochimie Des Polymères Et Des Interfaces, CY Cergy - Paris Université, 5 Mail Gay Lussac 9500 Neuville-sur-Oise (France)
(2) IINM, Warwick Manufacturing Group, University Of Warwick, CV4 7AL, Coventry (United Kingdom)

Presentation given by Dr. Giao T. M. Nguyen

Ionogels are organic materials consisting of ionic liquids (ILs) immobilized in a polymer network. Being conductive, flexible and even stretchable, ionogels have attracted attention in the field of flexible ionotronics such as ionic strain sensor, ionic cable... For such applications, ionogels are subjected to repeated deformations and susceptible to damage. Healability is thus required to improve their durability, sustainability and life-span. Here, we propose the introduction of dynamic exchangeble bonds to these materials to enable their healability via vitrimer chemistry such as dynamic beta-hydroxyester (beta-HE) linkages. Vitrimer ionogels were obtained by the step-growth polymerization in IL between and diacide oligomer, diglycidylether oligomer using an triglycidylether as crosslinker via carboxylic acid-epoxy addition. The resulting ionogels are soft, stretchable, conductive and exhibits sensing ability with a great correlation between strain and resistance variation at high sensitivity, and low hysteresis. The healed ionogel exhibits full recovery of their functional properties thanks to rearrangement of beta-HE linkages. Besides, by combining with a vitrimer elastomer containing beta-HE crosslinks, a trilayer ionogel/elastomer/ionogel can be fabricated. Thank to beta-HE functions on the both materials, large adhesion between the ionogel and elastomer has been observed. The trilayer can function as a stretchable ionοnic cable even after healing.

### 1.2.21 Feedback-controlled high voltage driving circuit for dielectric elastomer actuators

Carmen Perri (1), Paolo Roberto Massenio (2), David Naso (2), Paul Motzki (1), Gianluca Rizzello (1)

(1) Saarland University, Department Systems Engineering, Saarbrücken, Saarland, Germany.
(2) Polytechnic Of Bari, Department Electrical And Information Engineer (DEI), Bari, Italy

Presentation given by Carmen Perri

Dielectric Elastomer Actuators (DEAs) require high driving voltages (typically in the order of kV) to generate meaningful displacements. As DEA technology becomes more spread, the availability of small, inexpensive, lightweight, and low-power driving electronic circuits becomes an essential requirement for real-life applications. In attaining rapid and precise voltage regulation for DEAs, the formulation of model-based control algorithms is of fundamental importance. This work presents the development and validation of feedback control techniques of a high voltage electronic for capacitive loads. The electronic is small (13 cm × 5 cm), lightweight (5 g), cheap (~20 $ based on off-the-shelf components), and generates voltages within 0-3 kV in response to a 0-6 V input signal. The circuit consists of 2 main stages, namely charging and discharging stages, which are driven by 2 complementary PWM signals. The goal of the control algorithms is to generate a proper PWM control signal, such that the output voltage follows a desired trajectory with high closed-loop bandwidth and accuracy. Finally, the control techniques are validated through numerical simulations and experimental campaigns.

## EuroEAP Society Challenge
(listed in the order of presentation)

| Project title | Team Leader | Institution |
|---|---|---|
| DE-HaptoSkin: a real touch into the virtual world | Sipontina Croce | Smart Material Systems, Center for Mechatronics and Automation Technology – ZeMA gGmbH, Saarbrücken, DE |
| Reproduction and suppression of human wrist tremor | Alona Shagan Shomron | Max Planck Institute for Intelligent Systems, DE |
| DEAP-Pressure: Efficiency too low? Pump it up! | Matthias Baltes | Smart Material Systems, Center for Mechatronics and Automation Technology – ZeMA gGmbH, Saarbrücken, DE |
| The Circle - A New Thin Tunable Lens for Soft Opto-Mechatronics | Giacomo Sasso | Queen Mary University of London, School of Engineering and Material Science, London, UK |
| Cutaneous Electrohydraulic (CUTE) Wearable Devices for Expressive and Salient Haptic Feedback | Natalia Sanchez-Tamayo | Max Planck Institute for Intelligent Systems, DE |
| Hexagonal electrohydraulic (HEXEL) modules for rapidly reconfigurable high-speed robots | Ellen Rumley | Max Planck Institute for Intelligent Systems, DE |
| Stretchable light-emitting devices based on polar | Johannes von Szczepanski | Empa / ETH Zürich, CH |

| | | |
|---|---|---|
| silicone elastomers | | |
| A modular and accessible tool for multi-channel high-voltage control | Zachary Yoder | Max Planck Institute for Intelligent Systems, DE |
| Design of a soft robotic hand driven by multilayer DEAs for minimal energy consumption | Mario De Lorenzo | TU Dresden, DE |
| A versatile robotic leg powered by electrohydraulic actuators traverses various natural terrains | Toshihiko Fukushima | Max Planck Institute for Intelligent Systems, DE |
| HipHop Band - Smart Hip Band with Stretchable Piezoresistive Sensors for Monitoring Activities and Postures | Yutong Sun | Queen Mary University of London, School of Engineering and Material Science, London, UK |

The EuroEAP Society Challenge 2024 is sponsored by mateligent iDEAS.

## Best Poster Award

The Best Poster Award 2024 is sponsored by IOP Publishing.

## Social Event

The social event of the conference is sponsored by Toyota.

# Session 1.3

(abstracts are listed in the order of presentation)

## 1.3.1 Merging Humans and Machines with Soft Materials

Xuanhe Zhao (1)

(1) Massachusetts Institute of Technology (MIT), USA

Presentation given by Dr. Xuanhe Zhao

Whereas human tissues and organs are mostly soft, wet and bioactive, machines are commonly hard, dry and abiotic. Merging humans, machines, and their intelligence is of imminent importance in addressing grand societal challenges in health, sustainability, security, education, and joy of living. However, merging humans and machines is extremely challenging due to their fundamentally contradictory properties. At MIT Zhao Lab, we exploit soft materials to form long-term, robust, non-fibrotic, and high-efficacy interfaces between humans and machines. This talk will focus on the innovations and translations of soft materials and systems for merging humans and machines. I will conclude the talk with a vision for future human-machine convergence – aided by and synergized with modern technologies such as artificial intelligence, synthetic biology, and precision medicine.

## 1.3.2 Progress towards the commercialization of electrohydraulic actuators

Eric Acome (1), Nicholas Kellaris (1), Shane K Mitchell (1)

(1) Artimus Robotics, Boulder CO, USA

Presentation given by Dr. Nicholas Kellaris

Artimus Robotics has developed a revolutionary soft actuator technology based on an electrohydraulic actuation principle. These actuators - often referred to as Hydraulically Amplified Self-healing ELectrostatic (HASEL) actuators - offer the benefits of both dielectric elastomer actuators and fluidic actuation for muscle-like performance. HASELs (pronounced ‘hazel’) offer many benefits over existing electromechanical actuators including wide frequency bandwidth (DC to

100's of Hz), high force-to-weight (>1,000 N/kg), high power-to-weight (>300 W/kg), high actuation strain (>50%), and capacitive self-sensing. Importantly, these devices can be made from a wide array of materials using industrially amenable fabrication processes. Instead of metals, magnets, or lead-based ceramics, HASEL actuators make use of thin film polymers, liquid dielectrics, and carbon-based conductors - all materials with low embodied energy.

HASEL actuators are an emerging technology that was first published in Science and Science Robotics by the Artimus founders in 2018, with full-time commercialization efforts beginning in 2020. Since 2020, Artimus has leveraged non-dilutive SBIR/STTR funding to de-risk the HASEL technology. We have achieved key milestones including a 20x increase in operating lifetime (1M+ cycles to failure); substantially improved unipolar operation; consistent small-scale fabrication processes with >95% yield; and development of full hardware, software, and electronics stack. Thanks to these improvements, Artimus has been gaining traction in several commercial markets, providing direct sales of development kits and performing development projects with corporate partners. Our customers have spanned many industries including defense, medical, automotive, and consumer electronics.

As a platform actuation technology, there are many potential applications and thus development avenues for HASEL actuators. In this talk, we will discuss our perspective on promising applications for HASELs, based on current/near-term capabilities and market needs. In addition, we will outline important metrics for actuator performance as well as developments needed for improving these metrics; this includes the need for new dielectric materials, high voltage electronics, and control strategies to produce high forces, stable actuation, and high reliability. Finally, we will pose key questions to the academic community, whose answers will be critical for long-term commercial viability of this technology.

With growing academic and industry investment, the future of this technology will depend on sustained interest and continual improvements. This talk aims to direct development towards the largest and most relevant hurdles to commercial adoption, with the hopes that it will result in novel and productive scientific discovery that will move electrohydraulic actuation technology towards mainstream adoption.

# Session 1.4
(abstracts are listed in the order of presentation)

## 1.4.1 Synthesis of highly conductive polyelectrolytes towards 3D printed piezoionic all-solid-state touch sensors

Vladislav Shevtsov (1) (2), Juan Guerrero Teran (3), Jeremy Odent (3), Daniel Schmidt (1), Jean-Marie Raquez (3), Alexander Shaplov (1)

(1) Luxembourg Institute Of Science And Technology (LIST), Esch-sur-Alzette, Luxembourg
(2) University Of Luxembourg, Esch-sur-Alzette, Luxembourg
(3) University Of Mons (UMONS), Laboratory Of Polymeric And Composite Materials (LPCM), Mons, Belgium

Presentation given by Vladislav Shevtsov

Poly(ionic liquid)s (PILs) are expected to become the next generation materials for assembling various electrochemical devices. Owing to the combination of ionic transport properties with the mechanical stability and processability of polymer materials, these polyelectrolytes became ideal candidates for creating all-solid-state devices and touch sensors, in particular. Such sensors operate on the principle of the piezoionic effect, wherein the diffusion of ions within the PIL matrix induces a variation in potential, thus enabling the detection of applied force. This work aims to create a new subclass of efficient piezoionic sensors by means of synthesizing highly conductive ionic liquid like monomers (ILMs with conductivities of 1.0x10?4 Sxcm?1 at 25 °C) and their further photopolymerization with 2-acetoxyethyl methacrylate (AAEM) and poly(ethylene glycol) dimethacrylate (PEGDM, crosslinker). Optimization of the photopolymerization conditions, including nature and amount of solvent (isopropanol:water mixture), quantity of initiator (TPO, 1 wt.%), ratio of monomers (ILM:AAEM:PEGDM=10:85:5 by wt.%) enabled the preparation of self-standing films with high conversion (95±1 %, by gel fraction) in short time (50.9±0.7 s, by gel point) displaying good mechanical properties (2.6±0.6 kPa, by DMTA). Piezoionic tests of the films revealed the liner response with increase in the applied pressure with a maximum of 51.4 mV responding to 60 kPa stress.

## 1.4.2 Model-based design, proprioception, and motion-control of an articulated soft-robot actuated by rolled dielectric elastomers

Giovanni Soleti (1), Julian Kunze (1) (2), Johannes Prechtl (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 Giovanni Soleti

In this work, we present recent advances on modeling, design, and control of a soft robot driven by rolled DEAs. The module exhibits a T-shaped structure made by two plates connected by a flexible backbone, compressed by two pre-tensioned rolled DEAs. When actuated via high voltage, the DEAs expand and the soft structure bends toward the desired direction. By optimizing the system geometry via a model-based design approach, we trigger by the DEA activation the buckling instability of the beam, resulting in a bi-stable actuation with large bending angles. Despite bi-stability improves the system motion range, proportionality of regulation is lost. To recover it, control strategies based on a passivity framework are adopted. The method is validated experimentally on a real-life prototype based on camera feedback. Experimental results confirm the effectiveness of the stabilizing control approach. While the adoption of a camera feedback is an acceptable choice for initial controller validation, it is not a suitable sensing method to integrate the system in an unstructured environment. To overcome this limitation, a real-time self-sensing scheme is proposed. Based on a real-time processing of voltage and current, the proposed architecture allows estimating the configuration of the soft structure without requiring additional sensors. Finally, first steps towards the model-based design and validations of a three-dimensional version of the DE soft robotic system are presented.

### 1.4.3 Balancing energy conversion and long-term reliability of dielectric elastomer generators

Emmanuel Taine (1) (2), Thomas Andritsch (2), Istebreq A. Saeedi (2), Peter H. F. Morshuis (3)

(1) SBM Offshore, R&D Laboratory, Le Broc, France

(2) University Of Southampton, The Tony Davies High Voltage Laboratory, Southampton, UK
(3) Solid Dielectric Solutions, Leiden, The Netherlands

Presentation given by Dr. Emmanuel Taine

Dielectric elastomer generators (DEGs) are soft transducers capable of converting mechanical energy into electrostatic energy. Increasing the mechanical stretch amplitude and the electric field applied to the DEG leads to higher energy conversion, but at the cost of reduced lifetime. Here, we assess the mechanical fatigue and electrical ageing of a silicone-based DEG, and use the findings to build an electro-mechanical reliability model. The operating parameters (stretch amplitude and electric field) that maximize energy conversion are obtained through a 2-dimensional optimization approach, which considers the antagonistic relationship between energetic cycles and long-term reliability. Energy densities reported in the literature are often obtained by pushing the DEG on the knife-edge of their intrinsic capabilities for a limited number of cycles. In contrast, our approach presents more realistic values in the endurance domain, leading to a substantial reduction of the practical performance that can be achieved.

### 1.4.4 Novel 3D-imaging methods for electromechanical characterization of dielectric elastomers

Tobias Weber (1), Daniel Bruch (2), Sophie Nalbach (1), Stefan Seelecke (1), Paul Motzki (1) (2)

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

Presentation given by Tobias Weber

Dielectric elastomer transducers (DETs) have gained significant interest due to their promising applications in various fields such as sensors and actuators. Characterization and electromechanical analysis of DETs is crucial in research and development to evaluate and optimize their properties. In previous work, a versatile testbench had been presented including a confocal sensor system delivering thickness measurements along one axis. Thickness measurements are of relevance for the characterization of film quality on the one hand, but they also

enable an electric field estimation based on applied voltage. Non-contact measuring of thin, highly flexible films is a key challenge, especially due to variations in transparency, reflection, or light absorption. This poster presents a new setup, which enables increased precision with low-vibration operation, allowing for enhanced automatic screening to yield thickness . Additionally, a camera system aimed at the film surface with a digital image correlation algorithm provides the possibility to obtain planar strain fields. Based on these data and using an incompressibility assumption, the calculation of local thickness strains for an entire sample becomes possible. The confocal measurement of a single profile line can then be used to calibrate and subsequently calculate average thickness distribution without having to screen line by line.

### 1.4.5 Modification of polydimethylsiloxane films to improve electrical characteristics for their incorporation into dielectric electrostatic actuators.

Christopher Woolridge (1), Anne Ladegaard Skov (1)

(1) Technical University Of Denmark, Danish Polymer Centre, Kgs Lyngby, Denmark

Presentation given by Christopher Woolridge

In the emerging field of soft robotics, silicone films are a useful base material for dielectric actuators due to their flexibility and stability. However, PDMS electrical properties have some limitations in comparison to other materials such as PVDF. This study focuses on modifying the PDMS electrical characteristics through the inclusion of choline based ionic liquids. In addition to this , the films are also subjected to an external electric field while curing the elastomeric network, to add an extra level of control to the structure and position of the charged moieties.

### 1.4.6 A modular and accessible tool for multi-channel high-voltage control

Zachary Yoder (1), Jonathan Fiene (2), Christoph Keplinger (1)

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

(2) Max Planck Institute For Intelligent Systems, Robotics Central Scientific Facility, Stuttgart, Germany

Presentation given by Zachary Yoder

High voltage is a powerful mechanism for driving soft electrostatic transducers with a variety of behaviors, such as high-speed actuators, energy-efficient generators or controllable adhesives. Off-the-shelf high-voltage amplifiers are bulky, expensive and have only one output - rendering them unsuitable for driving and controlling multi-channel systems, and imposing cost-limitations on developing such systems. Existing multi-channel solutions used open-loop control or were embedded within larger systems, limiting their functionality and versatility. Here we present an accessible, modular tool for splitting any constant-output high-voltage power supply into a user-defined number of independently-controllable output channels, each with closed-loop voltage control, enabling simultaneous tracking of arbitrary, reversing polarity voltage waveforms over multiple channels. Each independent channel is controlled by one low-cost module (~250 Euro); modules are stacked together vertically and share a single high-voltage power supply, and a single USB connection controls all modules in the stack. Each module can provide up to 1 mA current at 10 kV, enabling a 1 W electrical workspace sufficient for driving a variety of electrostatic transducers. Altogether, our modular architecture enables controlled delivery of high voltages to a wide variety of electrostatic devices, providing researcher with an accessible and versatile tool for driving multi-component electrostatic robotic systems..

### 1.4.7 High stroke, fully polymeric dielectric elastomer actuator systems based on negative-stiffness thermoplastic polymer biasing elements

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

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(2) Smart Material Systems, Center For Mechatronics And Automation Technology - ZeMA GGmbH, Saarbrücken, Germany.
(3) University Of Applied Sciences , Sensors And Thin Films, Saarbrücken, Germany.

Presentation given by Saverio Addario

Dielectric elastomers actuators (DEAs) are particularly lightweight, stretchable, flexible, and soft transducers, thus they are suitable for the development of wearable smart skins. To increase the actuation stroke, DEAs are commonly combined with negative-stiffness mechanical biasing mechanisms, such as pre-compressed metal beams. These beams are subjected to high inherent stresses, and thus they are not well suited for miniaturization and integration into soft structures. Alternative negative-stiffness solutions based on buckling silicone domes, on the other hand, are affected by limited reproducibility, complex manufacturability, and large hysteresis. To overcome these issues, this work proposes novel biasing mechanisms based on thermoplastic polymers, which exhibit negative stiffness and thus are well suited to develop miniaturized, fully-polymeric, and large stroke DEA systems. In comparison to silicone-based domes and metal beams, they exhibit less hysteretic losses while maintaining high softness and flexibility. Their mechanical characteristics can be arbitrarily shaped by changing the thermoforming process parameters, as well as the biasing element layout and geometry. This poster explains the thermoforming manufacturing process, and demonstrates its reproducibility by experimentally characterizing and comparing the force-displacement behavior of several biasing elements with various geometries.

### 1.4.8 Membrane flutter of capacitive flow sensors

Iain Anderson (1), Arne Bruns (1)

(1) Biomimetics Lab, Auckland Bioengineering Institute

Presentation given by Dr. Iain Anderson

Elastic membranes aligned in a fluid flow can suffer from a hydroelastic instability called flutter. This is characterized by large amplitude membrane displacements that are of a periodic nature and that occur above a speed when hydrodynamic forces are comparable with elastic forces. For capacitive sensors this can be a problem because these sensors work through capacitance change associated with flow induced membrane-stretch. Periodic sensor membrane stretch exaggerated by a flutter phenomenon will cast doubts on the veracity of the flow/force measurement. Membrane flutter can be mitigated through stiffening and tensioning the membrane. The bat wing, for instance, employs directional stiffening of its flight membranes. While developing membrane sensors for a fish-like robot we have encountered membrane flutter. This has been manifest on two sensor types: one for measuring pointing direction of the robot (rheotaxis) and the other for measuring the force developed in a bionic fin. In this presentation we will show how we have mitigated this problem for both sensor types.

### 1.4.9 Artificial muscles based on shape memory electrospun nanofibers functionalized with conducting polymers and gold nanoparticles

Mihaela Beregoi (1), Adrian Enache (1), Ana Maria Ignat (1) (2), Ionut Enculescu (1)

(1) National Institute Of Materials Physics, Laboratory Of Functional Nanostructures, Magurele, Romania
(2) University Of Bucharest, Faculty Of Physics, Magurele, Romania

Presentation given by Ds. Mihaela Beregoi

Bioinspired devices such as artificial muscles, have gained increasing attention in academic research and industrial development with the aim of improving the patient's quality of life. Materials used for designing artificial muscles should meet various requirements like high flexibility, fast response time, low power consumption, low manufacturing costs and straightforward procedures, light weight, long life time, etc. Electroactive polymers, especially conducting polymers (CPs) in the form of fibre morphology meet the mentioned requirements due to the high active area, high flexibility, fast response time under low applied voltages, revealing impressive actuation properties and even sensing capabilities during movement. In this context, a novel material configuration based on shape memory polymer (SMP) electrospun nanofibers and a CPs which can perform mechanical motion by applying an external stimulus is proposed. Thus, free standing SMP meshes were metalized in order to make them conductive and then the metalized nets were functionalized with a CP film with dispersed gold nanoparticles. The prepared material was morphologically, structurally, mechanically analyzed and from biocompatibility and actuation point of view. The shape memory behavior and addition of gold nanoparticles should improve the actuation performances by increasing the conductivity of the material and therefore improving the stimulus distribution along the fibres.

### 1.4.10 Heat engine driven by twisted and coiled actuator

Burhan Bin Asghar Abbasi (1)

(1) University Of Wollongong, Mechanical, Wollongong, Australia

Presentation given by Burhan Bin Asghar Abbasi

In this talk, exciting possibilities of utilizing twisted and coiled actuators in heat engines to generate mechanical work will be discussed. Nylon 6,6 stands out as the most suitable material for these actuators because of its high thermal expansion ratio, high softening point, and stiffness, allowing it to withstand significant twisting. An established engine design has been remodeled that previously used shape memory alloys with a higher expansion ratio and replaced it with Nylon fibres. A theoretical framework has been developed to establish a connection between the mechanical output of the engine and the characteristics of the actuator material, enabling the comparison of the performance of this artificial muscle. Material properties required to maximize engine output and speculate on potential material structures that could further enhance engine performance are identified. Further discussed will be the making of these nylon fibres and how the actuation generates the energy required to not only run the engine but also, maximize the output by lifting different masses attached through the pulley.

### 1.4.11 Exploring the influence of polypyrrole layer thickness on the actuation properties of PEDOT:PSS/PPy core-sheath fiber actuators

Mathis Bruns (1), Shayan Mehraeen (2), Jose G. Martinez (2), Edwin W. H. Jager (2), Chokri Cherif (1)

(1) TUD Dresden University Of Technology, Institute Of Textile Machinery And High Performance Material Technology, Dresden, Germany
(2) Linköping University, Department Of Physics, Chemistry And Biology, Linkoping, Sweden

Presentation given by Mathis Bruns

Intelligent fiber-elastomer composites and intelligent textiles are both active research areas in the fields of soft robotics and wearables. Tailored properties for these applications can be obtained by tailoring textile structures and fiber functionalities, such as integrated sensor or actuator properties. This work focuses on developing filamentary conductive polymer actuators for use in soft robotics or wearables. The actuators are based on wet-spun poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) fibers, with Polypyrrole (PPy) electropolymerized onto the PEDOT:PSS fibers surface. By varying the duration of PPy electropolymerization, and thus the thickness of the PPy coating, this study investigates its effect on the mechanical and actuation properties of the fibers. The developed actuator fibers achieve a repeatable high linear contractile elongation of up to 1.7%, tensile forces of about 100 mN, and mechanical stresses of about 1 MPa. Such properties make these fibers a compelling choice as a base material for textiles to be integrated into soft robotics and wearables.

### 1.4.12 Wearable pneumatic tactile display of softness for virtual reality

Gabriele Frediani (1), Federico Carpi (1) (2)

(1) Department Of Industrial Engineering, University Of Florence, Florence, Italy
(2) IRCCS Fondazione Don Carlo Gnocchi ONLUS, Rehabilitation Centre, Florence, Italy

Presentation given by Dr. Federico Carpi

Multi-sensory human-machine interfaces are currently challenged by the lack of effective, comfortable and affordable actuation technologies for wearable tactile displays of softness in virtual-reality environments. They should provide fingertips with tactile feedback mimicking the tactual feeling perceived while touching soft objects, for applications like virtual reality-based training, tele-rehabilitation, tele-manipulation, tele-presence, etc. Displaying a virtual softness on a fingertip requires the application of quasi-static (non-vibratory) forces via a deformable surface, to control both the contact area and the indentation depth of the skin. The state of the art does not offer wearable devices that can combine simple structure, low weight, low size and electrically safe operation. As a result, wearable displays of softness are still missing for real-life uses. This presentation shows ongoing developments of a technology consisting of fingertip-mounted small deformable chambers, which weight about 3 g and are pneumatically driven by a compact and cost-effective unit. The technology has been used to conduct psychophysical tests with virtual-reality environments, aimed at elucidating how the tactile sensitivity to softness in virtual reality can vary depending on the interplay between visual expectation and tactile feedback.

### 1.4.13 Enhancing the dielectric properties of silicone elastomers via gelatin incorporation

Florina-Elena Comanici (1), Anne Ladegaard Skov (1)

(1) Danish Polymer Centre, Technical University Of Denmark, Denmark

Presentation given by Florina-Elena Comanici

Dielectric elastomer actuators are utilized in soft robotics and biomedical applications. Among these, polydimethylsiloxane elastomers are distinguished by their remarkable elasticity (up to 5000%) and biocompatibility. However, their low dielectric constant requires the application of high voltages (> 500 V) for actuation. To address this challenge, the incorporation of gelatin, a protein fragment derived from collagen, into silicone elastomers is explored. In this study, the facile incorporation of gelatin into silicone elastomers was proposed, and the impact of gelatin morphology on the dielectric properties of silicone elastomers was investigated. Silicone-gelatin blends showed an increase in dielectric permittivity, from 3,5 to 4,5, when 2 % wt. gelatin was incorporated into the sample, while the gelatin temperature upon mixing was shown to influence the morphology of the mixtures and dielectric properties of the elastomers.

### 1.4.14 Interpenetrating liquid crystal elastomer and ionogel as tunable electroactive actuators and sensors

Yakui Deng (1), Gaoyu Liu (1), Annie Brûlet (2), Giao Nguyen (3), Daniel Dudzinski (2), Frédéric Vidal (3), Cédric Plesse (3), Cédric Vancaeyzeele (3), Min-hui Li (1)

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(3) CY Cergy Paris Université, Laboratoire De Physicochimie Des Polymères Et Des Interfaces (LPPI), Cergy-Pontoise Cedex, France

Presentation given by Yakui Deng

Electroactive liquid crystal elastomers (eLCEs) have been used to make actuators and soft robotics. However, most eLCEs are monofunctional with one type of deformation (bending or contraction). Recently, we have reported a trilayer eLCE by combining ion-conducting LCE and ionic electroactive polymer device (i-EAD). This i-EAD-LCE is bifunctional and performs either bending or contractile deformation by controlling low-voltage stimulation. Nevertheless, it has a Young's modulus of only 1.63 MPa. To improve the mechanical performance, the i-EAD-IPN-LCE is prepared here, whose central membrane is composed of interpenetrating LCE and ionogel (i-IPN-LCE) instead of a single ion-conducting LCE. This i-EAD-IPN-LCE with a typical thickness of 0.5 mm can function not only as linear and bending actuators, but also as a sensor. As a linear actuator, its Young's modulus, actuation stress and actuation strain are 51.6 MPa, 0.14 MPa and 9%, respectively, reaching skeletal muscles' values. As a bending actuator, its bending strain difference is 1.18% with 3 mN output force. It can also operate as a sensor producing 0.4 mV Open-Circuit-Voltage to respond to bending deformation (bending strain difference = 9%). Therefore, this i-EAD-IPN-LCE is a promising system for the fabrication of robust electroactive devices and sensors with multiple degrees of freedom.

### 1.4.15 High performance unimorph bending actuators with stacked dielectric elastomer actuators without pre-stretch

Johannes Ehrlich (1), Peter Löschke (1), Michael Wegener (2), Daniel Pinkal (2), Lukas Heydecker (1), Holger Böse (1)

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(2) Fraunhofer-Institut Für Angewandte Polymerforschung, Funktionale Polymerforschung - Sensoren Und Aktoren, Potsdam, Germany

Presentation given by Dr. Johannes Ehrlich

Dielectric Elastomer (DE) actuators are under research since more then 20 years and the first DE actuators found their way to commercial applications as stack actuators. The performance of DE actuators can be dramatically improved by a pre-stretch of the DE film while manufacturing, which usually results in a high production effort. The authors of this poster present a DE bending actuator based on the unimorph working principle, without pre-stretch while manufacturing. The DE actuator was manufactured with single films of Wacker Elastosil (100 µm thickness), coated by 1k-dispensing with electrodes with an area of 30 mm width and 50 mm or 80 mm length. Eight of such DE films with electrodes were laminated to a stack. In the following step, the DE stack were laminated to a passive stiffening layer of Kapton with a thickness of 25 µm or 50 µm or Dynacode with a thickness of 70 µm. Finally stiffening bars were applied to the DE surface to prevent an additional bending of the DE actuator perpendicular to the intended axis. The DE actuators were tested in terms of their bending performance with up to 50 kV/mm electrical field strength. For the DE actuators with Dynacode stiffening layer, a bending angle of 54° and a tip displacement of 20 mm could be reached, as predicted by additional calculations. For further developments, the combination of unimorph DE actuators with an electroadhesion layer was successfully tested and offers a huge potential for soft robotics applications.

### 1.4.16 PELE: Musculoskeletal robotic leg for agile, adaptive, and energy-efficient locomotion

Toshihiko Fukushima (1), Thomas Buchner (2), Amirhossein Kazemipour (2), Stephan-Daniel Gravert (2), Manon Prairie (2), Pascal Romanescu (2), Philip Arm (2), Yu Zhang (1) (2), Xingrui Wang (1), Steven Zhang (1), Johannes Walter (1), Christoph Keplinger (1), Robert Katzschmann (2)

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

Presentation given by Toshihiko Fukushima

Robotic locomotion in unstructured terrain demands an agile, adaptive, and energy-efficient architecture. To traverse such terrains, legged robots use rigid electromagnetic motors and sensorized drivetrains to adapt to the environment actively. These systems struggle to compete with animals that excel through their agile and effortless motion in natural environments. We propose a bio-inspired musculoskeletal leg architecture driven by antagonistic pairs of Peano-HASEL artificial muscles. Our leg mounted on a boom arm can adaptively hop on varying terrain without using joint angle feedback in an energy-efficient yet agile manner. It can also detect obstacles through capacitive self-sensing. The leg performs powerful and agile motions up to 10 Hz and high jumps up to 40 % of the leg height. Our leg's tunable stiffness and inherent adaptability allow it to hop over grass, sand, gravel, pebbles, and large rocks using only open-loop force control. Our leg features a low cost of transport (0.73), and while squatting, it consumes only a fraction of the energy (1.2 %) compared to its conventional electromagnetic leg. Its agile, adaptive, and energy-efficient properties would open a roadmap toward a new class of musculoskeletal robots for versatile locomotion and operation in unstructured natural environments.

### 1.4.17 Modelling of multistable states in an interconnected dielectric elastomer actuators system

Sanjeet Patra (1), Shreesh Mahapatra (2), Hareesh Godaba (3)

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(2) Indian Institute Of Technology Kharagpur, Department Of Mechanical Engineering, Kharagpur, India
(3) University Of Sussex, School Of Engineering And Informatics, Brighton, UK

Presentation given by Dr. Hareesh Godaba

In recent years, snap-through instabilities in inflated dielectric elastomer actuators have been harnessed to enable large voltage induced deformation. Similarly, snap-through instabilities in interconnected inflated dielectric elastomer actuators have been shown to enable achieve ultrafast actuation and programmable multistable states. Due to the non-material behaviour and complex interplay in interconnected dielectric elastomer actuator systems, it is difficult to analytically model them. Addressing this challenge, we have developed an analytically model for a system of three interconnected dielectric elastomer spherical actuators and devised graphical and numerical approaches to solve for the equilibrium states. The results show a rich landscape of different snap-through instabilities and multistable behaviours that can be achieved in such system. A locus of initial stable states has been identified and the initial conditions can be adjusted to realize a system with multiple states. Analyses shows that in certain conditions, switchable stable states can be realized through selective actuation of a specific actuator in the interconnected systems. Furthermore, a new behaviour of cascading instability in which an actuator undergoes successive snap-through instabilities with monotonic increase of actuation voltage has been identified. We hope this work will propel programmable design of multistable soft systems for soft robots and stretchable electronics.

### 1.4.18 Integrating machine learning with soft capacitive e-skins for scalable and efficient sensing

Masoumeh Hesam Mahmoudinezhad (1), Eric Chang (1), Iain Anderson (1)

(1) Biomimetics Laboratory, Auckland Bioengineering Institute, University Of Auckland, Auckland, New Zealand.

Presentation given by Dr. Masoumeh Hesam Mahmoudinezhad

Recent advancements in electronic skins (e-skins) have significantly improved the ability of robots to interact delicately with objects and ensure safe human-robot interactions. However, the broad adoption of e-skins in robotics is impeded by the complexities associated with their integration, particularly at higher resolutions. Traditional capacitive tactile sensors, while simple and robust, require extensive wiring and complex electronics as they scale, which increases cost and complicates manufacturing. Addressing this challenge, our study introduces an innovative approach by integrating a multifrequency method with supervised machine learning to enhance the functionality of e-skins without the need for complex sensor wiring. We present a novel soft capacitive monolithic sensor that is straightforward to manufacture and uses only two sensor wires. By leveraging machine learning algorithms, our models accurately localize touch interactions within a 5-zone area and quantify both the force and location of touch within a 3-zone area. In live tests, the models demonstrated over 90% accuracy in predicting button presses. This high level of precision indicates that combining soft capacitive sensors with machine learning not only resolves the issue of scalability but also significantly reduces the complexity and cost of e-skin technology, paving the way for more widespread implementation in advanced robotic systems.

### 1.4.19 Key design parameters for hollow fiber dielectric elastomer actuators

Sina Jafarzadeh (1), Anne Ladegaard (1)

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

Presentation given by Dr. Sina Jafarzadeh

Hollow fiber dielectric elastomer actuators (HFDEAs) offer distinctive capabilities in soft robotics due to their unique structure and electromechanical performance. This research focuses on how specific design parameters, including the shape and material properties, such as the inner diameter and elasticity (Young's modulus), impact the electromechanical properties of HFDEAs. These parameters were chosen due to their measurable influence on actuator performance and their relative simplicity for experimental verification. By employing finite element method simulations in COMSOL Multiphysics, we explored the interplay between electrical and mechanical forces within the actuators. We found that differences in surface charge density between the external and internal electrodes not only cause the actuators to stretch but also to widen, a characteristic effect of the hollow fiber structures. Additionally, our simulations offer insights into the actuator's holding force-a metric traditionally difficult to quantify-highlighting how strategic parameter tuning can significantly boost performance. Ultimately, our findings pave the way for a systematic design strategy for HFDEAs, combining experimental insights with computational predictions to optimize the designs. Keywords: Dielectric Elastomer Actuators, Finite Element Method, Electro-Mechanical Modeling, Hollow Fiber Dielectric Elastomer Actuators.

### 1.4.20 Ionic liquid grafted silicone fillers for high permittivity dielectric elastomers

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

Presentation given by Leo Kershaw

Silicone-based dielectric elastomers have emerged as promising devices for a variety of sensing and actuation applications. Their primary drawback is the requirement for high driving voltages for actuation due to their relatively low dielectric permittivity. Enhancing the permittivity of silicones can be achieved through the incorporation of fillers such as: metal oxides, metal nanoparticles, and carbon nanoparticles. However, traditional filler materials often exhibit rigidity and inherently lack compatibility with silicone elastomers. Utilizing functionalized silicone oils as soft fillers offers a means to enhance the dielectric permittivity of the material whilst reducing the adverse effects associated with rigid fillers. By synthetically modifying the functional groups grafted to the silicone chain, the properties of the filler can be tailored to the required application. A novel, high-permittivity soft filler was synthesized by grafting an ionic liquid to a silicone chain. The synthesis process was monitored, and the final product characterized using H1 NMR and FT-IR techniques. Upon incorporation into an elastomer, the filler exhibited more than a twofold increase in dielectric permittivity compared to its pure elastomer counterpart. Notably, the breakdown strength remained high while the tan? remained low in comparison to other high-permittivity silicone elastomers.

### 1.4.21 Smart waistband with stretchable piezoresistive sensors for monitoring activities and postures

Yutong Sun (1), Giacomo Sasso (1), Charlotte Southam (1), Federico Carpi (2), James Busfield (1)

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

Presentation given by Yutong Sun

This poster introduces a novel wearable device: a waistband equipped with an array of low-cost piezoresistive sensors, made of carbon black and commercially available stretchable wound dressing materials. Optimally positioned around the waist, these sensors detect variations in strain caused by movements of the pelvis and hips. As such, the device is capable of monitoring changes in resistance to accurately identify a variety of activities, including walking and running, as well as distinguishing between movements of the legs. This poster outlines the current progress in the development of this technology, highlighting its potential applications in activity and posture monitoring.

### 1.4.22 Hexagonal electrohydraulic modules for rapidly reconfigurable high-speed robots

Zachary Yoder (1) (2), Ellen Rumley (1) (3), Ingemar Schmidt (1) (2), Christoph Keplinger (1) (2) (3) (4)

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Presentation given by Ellen Rumley

Reconfigurable modular robots are versatile and sustainable design options compared to fixed robotic designs. When driven by soft actuators, their modular units offer additional features like adaptability and design freedom - but current soft-actuated modules are limited in stroke, speed, and ease of reconfigurability. We introduce hexagonal electrohydraulic (HEXEL) modules - soft electrohydraulic actuators contained in a stiff exoskeleton - which generate high stroke (49% strain), high-speed (4,618%/s) actuation and offer a versatile platform for hosting magnetic, rapidly reversible electrical and mechanical connections between neighboring modules. These modules are additionally capable of untethered operation, allowing for new avenues of reconfigurable robot design.

# Wednesday 12 June 2024

## Session 2.1

(abstracts are listed in the order of presentation)

### 2.1.1 Liquid crystal elastomers as tunable electroactive actuators and mechanoelectrical sensors

Yakui Deng (1), Gaoyu Liu (1), Annie Brûlet (2), Daniel Dudzinski (2), Giao T. M. Nguyen (3), Frédéric Vidal (3), Cédric Vancaeyzeele (3), Cédric Plesse (3), Min-Hui Li (1)

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(3) CY Cergy Paris Université, Laboratoire de Physicochimie des Polymères et des Interfaces (LPPI), Cergy-Pontoise, France

Presentation given by Dr. Min-Hui Li

The stimuli-responsive smart materials that actively undergoes a predetermined change in their geometry or dimensions upon external stimulations are the focus of the research of many scientists and engineers. Liquid crystal elastomers (LCEs) belong to these smart materials, which can have promising applications in the field of actuators and soft robotics. Nematic LCEs generally exhibit reversible linear negative thermal expansion (1D NTE) along the direction of orientation with negative coefficient of thermal expansion. With special material design, LCEs can also perform other kind of shape changes like ending
deformation. However, as actuators, most LCEs are activated by external heating or light illumination, because the principle of LCE actuation resides in the chain conformation change of LC polymer induced by LC phase transition. The examples of electroactive LCEs are still limited. In addition, the same piece of LCE often remains monofunctional with only one type of deformation like bending or contraction. Here, we first report on a trilayer electroactive LCE by combining ion-conducting main-chain LCE and ionic electroactive polymer
device (i-EAD). This i-EAD-LCE is bifunctional and performs either bending or contractile deformation by controlling low-voltage stimulation at low or high frequency (± 2V, 0.1 Hz or ± 6V, 10 Hz). Nevertheless, this i-EAD-LCE has a

Young’s modulus of only 1.63 MPa. To improve the mechanical performance, the i-EAD-IPN-LCE is then prepared, whose central membrane is composed of interpenetrating LCE and ionogel (i-IPN-LCE) instead of a single ion-conducting LCE. This i-EAD-IPN-LCE with a typical thickness of 0.5 mm can function not only as linear and bending actuators under low-voltage stimulation (< 10V), but also as a mechanoelectrical sensor. As a linear actuator, its Young’s modulus, actuation stress and strain are 51.6 MPa, 0.14 MPa and 9%, respectively, reaching skeletal muscles’ values. As a bending actuator, its bending strain difference $\Delta\varepsilon$ is 1.18% with 3 mN output force. It can also operate as a sensor producing 0.4 mV Open-Circuit-Voltage to respond to bending deformation ($\Delta\varepsilon$ = 9%). Therefore, this i-EAD-IPN-LCE is a promising system for the fabrication of robust electroactive devices and sensors with multiple degrees of freedom.

### 2.1.2 Toward dielectric elastomer actuators with low driving voltages and high mechanical outputs

Ye Shi (1) (2), Junbo Peng (3), Lvting Wang (2), Jiangshan Zhuo (1)

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(2) Zhejiang University, Department Of Polymer Science And Engineering, Hangzhou, China
(3) Zhejiang University, School Of Mechanical Engineering, Hangzhou, China

Presentation given by Dr. Ye Shi

As one of the most promising artificial muscle materials, dielectric elastomers (DEs) have been widely studied and applied. In recent years, a variety of high-performance dielectric elastomers have been developed, especially the bimodal networked elastomer (PHDE) which has achieved energy and power densities superior to those of natural muscles. However, it remains a challenge to significantly reduce the driving voltage of dielectric elastomers while maintaining their high mechanical output. This talk will introduce the recent progress from our group on developing multilayer structured dielectric elastomer actuators (DEAs) with low driving voltages and high mechanical outputs. These high-performance DEAs are enabled by simultaneously tuning the mechanical/dielectric properties of PHDE, developing new ways to prepare uniform ultra-thin elastomer films, and modifying the dry-stacking method to fabricate large-area dielectric elastomer stacks. The potential of newly developed DEAs for applications in wearable devices and soft robots will also be demonstrated.

### 2.1.3 A new thin tuneable lens for soft opto-mechatronics

Giacomo Sasso (1,2), James J. C. Busfield (1), Federico Carpi (2)

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

Presentation given by Dr. Giacomo Sasso

Research on electrically tuneable optical lenses for various applications, including machine vision, microscopy, and mobile devices, has experienced significant growth in recent decades. Effective adaptive lenses have been demonstrated through the adoption of innovative actuation technologies, including electrowetting effect, liquid crystal actuation, dielectrophoretic effect, piezoelectric/electrostrictive actuation, external pumpshydraulic/pneumatic driving, electromagnetic driving, electrostatic zipping, electro-thermal activation and dielectric elastomer actuation. Some of them have been demonstrated with fluid lenses, while others with elastomeric lenses. The latter are particularly attractive, as they are less sensitive to thermal variations, mechanical vibrations and gravitational sagging. To date, most of the actuation technologies that have been demonstrated to tune the focal length of elastomeric lenses with compact driving (thereby excluding hydraulic and pneumatic actuation) critically limit the achievable range of focal length variation, owing to a limited ability to vary the lens curvature. Especially, they make it difficult to switch between a curved surface (close- distance focus) and a flat surface (far-distance focus). Here, we present a new concept for a dielectric elastomer actuation- based tuneable lens that is capable of large variations of focal length. The lens uses a dielectric elastomeric layer as both actuation and optical medium, resulting in a thin structure, capable of a large tuning range. Illustrated in Fig. 1 is a demonstration of the optical focal range variation of the device. The tunable lens is positioned in front of a web camera, which is already equipped with its own lens. To showcase its close-distance focusing capabilities, a pencil is positioned 7 cm away from the tunable lens, while the background (depicted as Big Ben) is situated at a distance of over 300 meters from the setup. In its non-actuated state, the camera's focus is naturally set to infinity to capture distant scenery. Upon actuating the tunable lens with a voltage of 3.5kV, the focus seamlessly shifts to the 7cm object, demonstrating its adjustable focusing capability.

### 2.1.4 Polar polysiloxane material and engineering opportunities beyond dielectric permittivity

Patrick M. Danner (1,2), Tazio Pleij (2), Jan Vermant (2), Dorina M. Opris (1,2)

(1) Empa, Department for Functional Polymers, Duebendorf, Switzerland
(2) ETH Zurich, Department of Materials, Zurich, Switzerland

Presentation given by Mr. Danner

Polar polysiloxanes are a class of polymers that carry an organic dipole side-group on a polysiloxane backbone. These polymers can be cross-linked into dielectric elastomers, analogous to polydimethylsiloxane (PDMS). However, the addition of polar groups side-group to polysiloxane increases the relative permittivity of the elastomer. While many polar polysiloxanes have been explored in recent years, we further explore the limits of this approach. By synthesizing polymers carrying two different dipoles, we could reach the highest relative permittivity of 32 ever reported in a neat elastomer. We answer how high the relative permittivity of a neat elastomer can be reached, what the limiting factors are, and how they can be turned into useful materials for actuators, sensors, and energy harvesting.
Polar polysiloxanes exhibit an increased relative permittivity, but the dipolar interaction leads to significant changes in various physical properties compared to PDMS. While these changes present many challenges, they offer new opportunities for applications and engineering elastomers. We showcase that by mixing polar polysiloxanes with PDMS in the presence of filler, capillary-type inks exhibiting strong shifts in the rheological properties are formed. The inks can be tuned to match different processing techniques, such as the multi-material 3D printing of a 23-layer stacked high-permittivity dielectric elastomer actuator.
While 3D printing gives a high degree of freedom, the production speed is limited. The developed inks can be used for other extrusion processes, such as fibre extrusion. We can make high-permittivity DEA fibres at unprecedented speeds, creating one meter of DEA fibre in under two minutes. We discuss how ink behavior, material properties and processing requirements are interdependent characteristics and how we are achieving high throughput and a low-cost process for scalable DEA fibre production. This process allows the creation of DEAs without the need for tedious layer-by-layer processes and significantly changes

the ink requirements compared to traditional thin film processing techniques.

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

## 2.2.1 Tuning snapping inflatable actuators with Lorentz force

Hugo de Souza Oliveira (1), Edoardo Milana (1)

(1) University Of Freiburg, LivMatS, Freiburg, Germany

Presentation given by Dr. Edoardo Milana

Elastic inflatable actuators (EIAs) are widely used in soft robotic applications due to their low cost, ease of fabrication, and fast response. Moreover, harnessing the structural and material nonlinearities of EIAs enables mechanical programmability. Nonlinear EIAs have been utilized to create fluidic controllers for soft robots, embodying fluidic logic, sequential actuation, and self-oscillators. However, the nonlinear response is predetermined by the design, resulting in an equivalent pre-programmed control scheme. In this work, we demonstrate how the introduction of an additional degree of actuation in snapping soft shells allows for the control of snapping pressure points and, thus, provides a means of online re-programmability of the nonlinear response. The additional degree of actuation consists of an electromagnetic force exerted by a PCB coil, on a permanent magnet embedded in the buckled shell. The PCB coil is placed in the inextensible base of the actuator.

## 2.2.2 Energy recovery for highly-capacitive cycles by efficient power electronics, exemplified for electrocaloric loads

Stefan Mönch (1) (2)

(1) University Of Stuttgart, Institute Of Electrical Energy Conversion (iew)
(2) Fraunhofer IAF

Presentation given by Dr. Stefan Mönch

This work discusses power electronics to drive highly-capacitive loads while recovering most of the stored energy in closed cycles. As power electronics, half-bridges and multilevel topologies are reviewed, which are based on gallium nitride semiconductor transistors and zero-voltage-switching by closed-loop

hysteretic current control. High electrical energy recovery efficiencies are reported for ideal (almost lossless) capacitive loads. For emerging solid-state heat pumps, electrocaloric ceramic capacitors are driven and experimental results are shown. Here, the electrical field change causes an almost fully reversible temperature change, and in closed cycles the stored energy in the capacitive component is recovered efficiently. The shown power electronics approach is also applicable to polymer-based electrocaloric capacitors, or other electromechanical components in future. For load capacities above 1 microfarad, charged and discharged by the power electronics up to around 400 volts, with a cycle frequency in the range of 1 to 1000 Hertz, high energy recovery efficiencies beyond 99% are experimentally demonstrated.

### 2.2.3 An investigation of the electrical dynamics in electroactive polymer transducers with resistive electrodes

Davide Vignotto (1), Antonello Cherubini (1), Ion-Dan Sîrbu (2), Marco Fontana (2), Giacomo Moretti (1)

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

Presentation given by Dr. Giacomo Moretti

An ideal electrode for EAP would posses negligible stiffness, near-perfect conductivity and adhesion, while being resistant to stretching or dessication. So far, achieving all these properties simultaneously remains beyond reach. Acceptable strains and compliance, coupled with ease of manufacturing, often come at the expense of conductivity. Resistive electrodes reduce both the EAP efficiency and operational bandwidth, which is particularly relevant for large capacitors (with resulting large RC time constants), such as large-scale energy harvesters, or for high frequency applications, like loudspeakers. Herein we describe a continuum time-domain model that predicts the electrical dynamics of EAPs by considering the electrode resistance. The model describes the non-uniform distribution of the electric potential over the EAP electrodes during fast supply voltage variations. Model results closely align with the voltage distributions measured in silicone-carbon composite electrodes via multiple electrical contacts integrated directly into the bulk of the electrode. The validated model allows performing estimates of the electrical time constants and maximum working frequencies of EAP transducers based on their dielectric properties, size and electrode resistivity. The outputs of our analysis can be used as an electrical design tool to establish electrode resistivity limits based on target application dynamics.

### 2.2.4 Low-cost tactile sensor array with anti-ghosting capabilities

Junhao Ni (1), Andreas Richter (1), E.-F. Markus Henke (1) (2)

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

Presentation given by Junhao Ni

As the population ages, the demand for home and care robots is growing. For safe interaction with humans, tactile information is indispensable. Flexible tactile sensor arrays allow robots to safely interact with their environment via touch and reduce the possibility of injuries when humans interact with machines. Many tactile sensor arrays for robotic applications have been presented in the past. However, most of them are complex in design, require complicated processes and expensive materials to manufacture and place high demands on circuit devices. In this paper, we present the design of a fully soft, flexible and stretchable tactile sensor array that can be produced using low-cost materials and widely available devices, has low requirements on circuitry, and is free of ghost signals. The sensor is stretchable, due to its mechanical compliance, it can fit on irregular surfaces and can have customized shape, spatial resolution, and detection thresholds. The sensor's measurement and communication module measures only 35 x 25 mm can be wired or battery-powered and enables Bluetooth communication. Thus, this sensor has broad potential for commercial applications. We present the fundamental functionality of the sensor, the applied production technology and an experimental study on its performance in several applications.

### 2.2.5 Variable-stiffness rehabilitative hand splints with self-sensing pneumatic actuators

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

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

Presentation given by Valentina Potnik

Dynamic hand splints are rehabilitation orthoses equipped with elastic bands, which exert a passive resistance to voluntary movements of fingers. In order to make the exercise dynamically adjustable, it would be beneficial to replace the elastic bands with soft actuators, so as to make the load electrically controllable. Such actuators should be able to produce large displacements at moderate forces, with a compact size, low specific weight and electrically safe operation. Moreover, the possibility of combing self-sensing properties would be beneficial to reduce the complexity of the system, for control purposes. Here, we present a dynamic hand splint equipped with a self-sensing pneumatic soft actuator, serving as an 'inverse artificial muscle', as, upon pressurisation, it elongates instead of contracting. The actuator was made of an elastomeric tube surrounded by a plastic coil, which constrained radial expansions. The self-sensing ability was obtained with a piezoresistive stretch sensor shaped as a conductive elastomeric body along the tube's central axis. The self-sensing pneumatic actuator was mounted onto a forearm brace and was connected, on one side, to the finger (via a tendon), and, on the other side, to an on-board load-cell. The latter was used to measure the force produced by the actuator as it was stretched when the finger was bent. The presentation will describe the design, fabrication and characterisation of the system.

### 2.2.6 Maximizing sensitivity: the promise of stacked capacitive dielectric elastomer sensors for strain detection

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

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(3) Institute Of Solid Mechanics, Dresden University Of Technology, Dresden, Germany
(4) Biomimetics Lab, Auckland Bioengineering Institute, The University Of Auckland, Auckland, New Zealand

Presentation given by Artem Prokopchuk

Flexible and stretchable electronics, such as multi-layer capacitive strain sensors utilizing dielectric elastomers, have garnered substantial interest owing to their inherent sensitivity, extensive deformation capabilities, and adaptability to intricate geometries. This contribution endeavors to propel the development of dielectric elastomer strain sensors by exploring novel methodologies aimed at enhancing stability, sensitivity, and manufacturability. A comprehensive classification of dielectric elastomer sensor structures, incorporating four electrode layers, including a novel 50µm-capacitor configuration, is introduced to optimize capacitance and sensitivity. Additionally, the study scrutinizes electrode pin designs, evaluating their technological effectiveness and mechanical stability through simulations and validation processes. A novel upside-down fabrication technique is introduced to streamline production processes and bolster reliability. Furthermore, finite element simulations are employed to elucidate the deformation behavior and capacitance variance of stacked sensor structures under diverse loading conditions. This research advances the flexible sensor technology field, particularly benefiting applications in soft- and micro-robotics, sensor-integrated machine elements, and related domains.

### 2.2.7 Electrostatic 3-phase actuators for high power density soft actuators

Martijn Schouten (1), Herbert Shea (1)

(1) EPFL, LMTS, Neuchâtel, Switzerland

Presentation given by Dr. Martijn Schouten

Electrostatic 3-phase actuator consists of two flexible printed circuit boards with 3-phase electrodes that slide over each other. The actuators have been around since 1990's and have generated forces up to 300N. Our 3-phase electrodes consist of 60 ?m wide parallel traces placed 130 ?m apart are coated by a 40 ?m thin dielectric to prevent breakdown. Because of this thin dielectric fringe fields are generated. When two actuators are placed on top of each other with silicone oil in between them these fringe fields interact and make it move one step. Each time the 3-phase actuation signal changes the actuator moves another step. Because of the potential difference between the electrodes on the top and bottom slider, there is a blocking force that pulls them together. To get motion the force moving the two PCBs must exceed the friction force between them. When designed with a high permittivity dielectric like P(VDF-TrFE-CTFE) the actuator acts like an electrostatic clutch creating more forces blocking forces than moving forces; this is generally solved by using small glass beads to reduce the friction. With a very low permittivity Parylene HT dielectric we were able to fabricate an 8 cm2 electrostatic 3-phase actuator that can produce 1.5N at 5 kV without using glass balls. By in the future rolling up the actuators, integrating fuses, and encapsulating them we will aim at fabricating self-supporting reliable electrostatic actuators with tens of newtons of force.

### 2.2.8 Silicone fiber dielectric elastomer actuator for artificial muscles

Magdalena Skowyra (1), Romisa Fakhari (1), Florina-Elena Comanici (1), Christopher Daniel Woolridge (1), Anne Ladegaard Skov (1)

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

Presentation given by Dr. Magdalena Skowyra

A silicone fiber dielectric elastomer actuator, which mimics the fibular properties of natural muscles and provides stable linear strains up to 9% at 50V/µm in both wet and dry conditions, is being developed. The hollow fiber is prepared by employing a fast UV thiol-ene cross-linking reaction using a wet spinning technique, resulting in long thin fibers of an average diameter of 500 µm and variable wall thickness of approximately 80 µm. The fiber actuator utilizes ionic liquid as an internal electrode and ionogel or ionic liquid as an external electrode, in dry and wet state conditions, respectively. In this work, we studied multiple possibilities of the fiber preparation technique by adjusting the silicone formulation, UV light intensity, and flow rates to further enhance the actuation performance and improve the fiber robustness.

### 2.2.9 A novel method for developing a tubular IPMC actuator

Nadia Triki (1), Daniel Bruch (2), Sophie Nalbach (1), Stefan Seelecke (2), Paul Motzki (1) (2)

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

Presentation given by Nadia Triki

The outstanding design versatility of IPMC technology enables the creation of a tubular continuum structure with an actively moving outer skin and an inner hollow space. Therefore, it can guide a variety of functional elements such as solids, gases, and liquids. This structure has the potential to significantly impact a wide array of fields ranging from medical engineering to micro-manipulator applications. This work introduces the development of a novel segmented tubular ionic polymer metal composite (IPMC) actuator design. This configuration allows for large bidirectional movement, paving the way for the creation of intelligent and adaptable structures. The tubular IPMC actuator is fabricated from a 40-mm long prefabricated Nafion polymer tube with an inner diameter of 1.5 mm and an outer diameter of 1.8 mm. The outer surface is plated using an electroless-plating process. The proposed tubular IPMC design incorporates an additional inner electrode and two isolated outer segments, setting it apart from existing approaches. Preliminary experimental investigations were conducted to characterize the electromechanical performance of the actuator and quantify its maximum angular bending. The results demonstrate the improved performance of this innovative tubular IPMC design compared to conventional IPMC configuration, validating the proof-of-concept, and establishing the operational principles of this novel approach.

### 2.2.10 Work loop testing of dielectrophoretic liquid zipping actuators

Reece White (1), Martin Garrad (1), Jonathan Rossiter (1)

(1) University Of Bristol, SoftLab, Bristol Robotics Laboratory, Bristol, United Kingdom

Presentation given by Reece White

Work loop testing is a commonly used test for biological muscles however, it is rarely applied to artificial muscles. This paper shows that work loop testing provides useful information beyond the standard isotonic and isometric tests that

are commonly used to evaluate the performance of an artificial muscle. A dielectrophoretic liquid zipping actuator (DLZ) was subjected to both work loop testing and conventional isotonic and isometric tests, the results from these different tests were then compared. It was found that the power calculated through work loop testing is smaller than that found from isotonic testing. Work loop testing better simulates the conditions an artificial muscle would be subjected to in an application, thus giving a better approximation of the sustained power that would be available in such a real-world application.

### 2.2.11 Electromechanical modeling and material insights for high-performance electrostatic flexible actuators

Yuejun Xu (1), Etienne Burdet (1), Majid Taghavi (1)

(1) Imperial College London, Department Of Bioengineering, London, Unite Kindom

Presentation given by Yuejun Xu

In the broad domain of soft robotics, electrostatic actuators utilizing compliant materials like electro-ribbon actuators, stand out for their promising capabilities. These actuators offer useful features, including light weight, high efficiency, extensive scalability, and direct electrical control, positioning them at the forefront of advancements in soft robot application. Despite their potential, a thorough understanding of their underlying mechanics has not been fully developed. We introduce an electromechanical model that integrates large deformation beam theory and then validated by experimental results. This model elucidates the actuation mechanism and forecasts the quasi-static behavior of electro-ribbon actuators, thereby contributing valuable insights into their operation. Additionally, we explore the role of various insulation materials in enhancing actuator performance, offering guidance for optimizing design and material selection in soft robotic applications.

### 2.2.12 Dielectric elastomer - shape memory alloy hybrid multi-material smart actuator technology

Benjamin Zemlin (1), Julian Kunze (1), Bobby Cozzette (3), Sabrina Curtis (3), Daniel Bruch (2), Sophie Nalbach (1), Eckardt Quant (3), Stefan Seelecke (2), Paul Motzki (1) (2)

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(3) Universität Zu Kiel, Institute For Materials Science, Kiel, Germany

Presentation given by Benjamin Zemlin

Dielectric elastomer actuators (DEAs) are known for their lightweight, softness, and rapid actuation capabilities, and shape memory alloys stand out for the shape memory effect and their superelastic property. This poster presents the first hybrid multi-material actuator technology using both smart materials. The superelasticity and the structurability of SMA thin films can be exploited to realize a flexible and highly conductive electrode for a hybrid smart material DEA system. This work examines the potential synergy between dielectric elastomers and SMAs, demonstrating the feasibility of the novel technology by utilizing a superelastic, auxetic structured TiNiCuCo thin film on a silicone elastomer as an actuator. The hybrid system can potentially improve the performance of actuators, by overcoming limitations of individual materials and providing new opportunities for enhanced actuation efficiency, speed and longevity.

### 2.2.13 Electroactive 4D scaffolds based on porous PEDOT:PSS cryogels

Daniel Aguilera Bulla (1), Safia Bourji (1) (2), Cédric Vancaeyzeele (1), Rémy Agniel (2), Johanne Leroy-Dudal (2), Cédric Plesse (1)

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Presentation given by Dr. Daniel Aguilera Bulla

The development of "4D" materials represents a promising area of research for the coming years, as these materials have the ability to change shape, volume or morphology in response to various external stimuli such as mechanical, electrical,

chemical, thermal or photochemical stimulation. In this work, we explored the fabrication of electroactive 4D macroporous materials derived from a suspension of poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS), an electroactive polymer. Different formulations, gelling and drying methods were first explored to select the best candidates for the elaboration of these materials, in particular for their stability in aqueous media. The selected materials were obtained by gelation in the presence of lithium bis(trifluoromethanesulfonyl)imide (LiTFSI) and CaCl2, in the presence or absence of chemical crosslinker, and dried by freeze-drying. The porosity of the resulting materials was characterized using scanning electron microscopy (SEM) revealing pore sizes ranging from 100 to 200 micrometers. Under electrical stimulation in a PBS electrolyte, the materials showed an electrochemical and electromechanical response with a size variation of up to 13.5%. These findings suggest the potential of these materials for the development of electromechanically active 4D scaffolds.

### 2.2.14 Dynamic design approach for resonance optimized self-sense based dielectric elastomer pumps

Matthias Baltes (1), Sipontina Croce (1), Daniel Bruch (2), Sophie Nalbach (1), Paul Motzki (1) (2)

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

Presentation given by Matthias Baltes

This work presents a dynamic design method for pumps based on dielectric elastomers (DEs), integrating resonance optimization and self-sense capabilities. Dielectric elastomer pumps offer numerous advantages but face challenges in achieving energy-efficient control and optimized operation across varying load conditions. Therefore, they are not used in everyday applications, despite their potential advantages. To address this, we propose a novel model-based design approach leveraging the dynamic behavior especially resonance optimization of the pump system. A prototype is developed, operating at resonance under maximum load conditions for consistent pressure delivery. However, lower load pressures lead to resonance shifts due to pressure-dependent stiffness changes, impacting efficiency. To overcome this, we integrate a self-sense-based frequency control depending on the load pressure inside the pump chamber. Thus, the pump can operate across its entire operating range with maximum efficiency.

### 2.2.15 Magnetorheological elastomer actuator with dielectric electroactive polymer sensor

Jakub Bernat (1), Pawel Czopek (1), Szymon Szczesny (2), Agnieszka Marcinkowska (3), Piotr Gajewski (3)

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

Presentation given by Dr. Jakub Bernat

Magnetic and electric fields are interesting physical phenomena. Modern manufacturing methods have allowed us to fabricate transducers that exploit these two phenomena. Our actuator is a round membrane consisting of a magnetorheological elastomer and dielectric electroactive polymer. In our actuator we use the magnetic field to move the membrane, and varying capacitance gives us information about the position of the membrane. We propose to use our actuator with an integrated sensing system to give information about membrane position. In this poster, we present the results of changing actuator capacity from actuator position. This poster aims to show how significant is capacity change in real membrane and the correlation between membrane position and membrane capacity.

### 2.2.16 A simple calculation model for a robotic gripping finger driven by zipping actuators

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

(1) Fraunhofer Institute For Silicate Research ISC

Presentation given by Dr. Holger Boese

Hydraulically Amplified Self-healing ELectrostatic (HASEL) zipping actuators have received much interest due to their high performance in terms of actuation strain and force. HASEL actuators 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 displaces the oil to the pouch region without electrodes. This oil displacement generates a strong actuatoric deformation of the pouch. A series of HASEL actuators can be used to cause a bending displacement of a flexible and soft robotic gripping finger. The performance of the single HASEL actuator and the gripping finger depends on various geometrical and material parameters. In order to optimize the actuation performance, a simple mathematical model was established to calculate the dependence of the stroke and force of the HASEL actuator as well as the bending angle and blocking force of the gripping finger on the applied voltage. This model was used to predict the performance of HASEL actuators consisting of different polymer materials. The calculated data was compared with the results of experimental investigations on corresponding HASEL actuators and related bending finger structures giving valuable information on the requirements on the actuator materials and the finger structure.

### 2.2.17 Development of soft actuators based on polydimethylsiloxane and electrospun fiber networks for biomimetic applications

Mihaela-Cristina Bunea (1), Mihaela Beregoi (1), Alexandru Evanghelidis (1), Andrei Galatanu (2), Ionut Eculescu (1)

(1) Functional Nanostructures Group, National Institute Of Materials Physics, Magurele, Romania
(2) Electronic Correlations And Magnetism Group, National Institute Of Materials Physics, Magurele, Romania

Presentation given by Dr. Mihaela-Cristina BUNEA

Development of artificial muscles based on dielectric elastomers for biomimetic implants evolved steadily thanks to their adaptability and high flexibility. Dielectric elastomers present an important interest for various applications due to their lightweight and large deformation through the conversion of the electrical energy into mechanical work. The dielectric based actuators are electrically driven actuators which need electrodes in order to transform the external electrical energy into mechanical's one. It is rather straightforward to fabricate high quality contacts onto flexible or rough substrates such as plastics, paper, or textiles. This becomes even more difficult when constant, long term mechanical motion is added. For such applications, high electrical conductivity and flexibility are both important prerequisites since the device is expected to perform thousands of movements during its lifetime. Withal, electrospun fibers are an excellent reinforcement material, useful for manufacturing soft actuators due to their features like good flexibility, high specific area, good mechanical stability and easy to be obtained. The aim of this study is to develop a new architecture of artificial muscles based on nylon 6/6 metalized microfibers attached to a thin PDMS membrane as possible candidates for biomimetic applications. The prepared materials were analyzed from morphological, electrical and mechanical stability point of view and some actuator skills were highlighted.

### 2.2.18 Autonomous soft robotic structures with distributed de-electronic networks

Jian Chen (1), Andreas Richter (1), E.-F. Markus Henke (1) (2)

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

Presentation given by Jian Chen

Traditional robotics has focused on enhancing the range of motion and functionality of machines, with most of their mechanical structures being made from rigid materials. The rigid robots have always faced mechanical limitations, such as the difficulty in achieving motions similar to biological models. The development of soft robots, which exhibit behaviors like animals, has opened up new perspectives and applications in robotics. This contribution aims to investigate soft robot structures based on multi-functional Dielectric Elastomer (DE) that can be used as actuators, sensors and signal processors. Our goal is to explore a method for constructing entirely soft robots, where the robot body, control system, power supply system, memory components, and so forth are all designed as soft structures. We have designed an inchworm like soft robot structure, capable of creeping forward under the drive of DEO (DE Oscillator). The inchworm-like soft robot features integrated control components and soft actuators composed of DEAs, without any traditional hard electronic parts. Through an external DC voltage, the robot autonomously generates all signals required to drive its dielectric elastomer actuators and converts planar electromechanical oscillations into creeping motion. This demonstration highlights the potential of soft robotics, providing practical experience for the development of more complete, complex, and intelligent soft robots in the future.

### 2.2.19 Novel haptic feedback armband based on dielectric-elastomers

Sipontina Croce (1), Lukas Roth (2), Matthias Baltes (1), Sophie Nalbach (1), Paul Motzki (1) (2)

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

Presentation given by Sipontina Croce

Smart wearables, increasingly popular due to technological advances, have diverse applications in medical, industrial, and gaming fields. However, they must be wearable, adaptable, flexible, lightweight, and intuitive. This necessitates the integration of flexible sensors and actuators into clothing fabrics, a challenge addressed by Dielectric Elastomer (DE). DEs are lightweight, highly stretchable transducers capable of simultaneous sensing and actuation. This work introduces a DE-based wearable device providing haptic feedback. The device comprises an air-inflated pouch, pre-stretching both passive and active DE membranes. Activation softens the DE, altering the actuator's internal pressure and the force exerted on the skin. The device's advantages include the ability to change internal air pressure without an external pump, adjust actuation intensity and speed, and reduce production costs by using the active membrane as both sensor and actuator. Future developments aim to create a self-sensing system that achieves desired performance by sensing its own internal pressure while actuated, via a suitable control algorithm.

### 2.2.20 Hybrid soft matter computing mechanism for soft robotics application

Anirshu Devroy (1), Georgi Paschew (1), Rafal Andrejczuk (1), Ingrid Graz (2), Andreas Richter (1)

(1) Institute Of Semiconductors And Microsystems, Dresden University Of Technology, Dresden, Germany
(2) Division Of Soft Matter Physics, Institute For Experimental Physics, Johannes Kepler University Linz, Linz, Austria

Presentation given by Anirshu Devroy

Soft robotics technologies have been recently growing with a lot of focus in developing better functional soft robot. However, to improve the performance of the soft robot, soft matter computation is very important to achieve the next level competence. The ability to integrate computational properties using soft materials, would come in a long way of achieving the goal of fully functional soft robot. Hence the current work focuses on soft material mechanism for the integration of logic by sending a digital or analog signal to the soft robot. Two liquid phases, a conducting and a non-conducting phase where used. The conductive liquid phases and the nonconductive liquid phases acts like an on/off switch. Depending on the size of each phase and how fast the phases are flowing, the setup can be also imagined as a function generator sending a PWM signal. The conducting phase is considered a high signal and the non-conductive phase a low signal. The signal is sent and amplified to an soft robot/actuator using Surface Mount Device (SMD) transistor circuit. The actuation occurs due to the change in voltage or current. The results obtained is promising for a possibility of building such a hybrid soft matter computers. Such hybrid soft matter computers would come a long way in development of electronics free fully autonomous soft robots and actuators.

### 2.2.21 HASEL actuators in soft structures for robot gripping applications

Johannes Ehrlich (1), Peter Löschke (1), Marie Richard-Lacroix (1), Thomas Gerlach (1), Holger Böse (1)

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Presentation given by Dr. Johannes Ehrlich

HASEL (Hydraulically Amplified Self-healing ELectrostatic) actuators are a new class of smart actuators with a unique weight to power ratio driven by an electric field. The HASEL actuator consists of two polymer films (PET, TPU etc.), sealed to a pouch and filled with an insulating oil. The polymer films of the sealed pouch are partially coated with a pair of electrodes on the outer sides. The zipping effect moves the insulating oil inside the pouch to the area without electrodes and deforms the pouch macroscopically. The authors of this paper present HASEL actuators with the area size of 20 mm x 30 mm, fabricated with a semi-automated sealing technology, where four of these actuators are manufactured as a serial chain in one manufacturing step. The HASEL chains are inserted into a flexible 3D printed TPU support structure with a Shore A hardness of 95, which reflects the structure of a flexible finger of a robot gripper. Overall, 20 single HASEL actuators, split into 5 chains, are activated in series with a maximum driving voltage of 9 kV. They bend the flexible support structure with an angle of 43° and an overall displacement of the finger tip of 21 mm. The gaps for the HASEL actuators inside the flexible finger structure were optimized in their geometry to improve the bending behaviour and to reduce unwanted pre-bending. The so created flexible finger structure with integrated HASEL actuators is directly usable for soft grippers and other soft robotics applications.

### 2.2.22 Modelling and self-sensing of cooperative dielectric elastomer actuator arrays

Alberto Priuli (1), Sipontina Croce (2), Saverio Addario (1), Giacomo Moretti (3), Stefan Seelecke (1) (2), Gianluca Rizzello (1)

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Presentation given by Alberto Priuli

Dielectric elastomer (DEs) are highly stretchable polymeric transducers that are used to convert an applied electric voltage to a controllable deformation. In most applications, DEs are used as independent actuator/sensor systems. New research interests encompass cooperative systems, leveraging on the self-sensing abilities of DE Actuators (DEAs) for lightweight, compact, and flexible solutions.

Differently from the stand-alone actuator case, cooperative self-sensing paradigms allow multiple interconnected actuators to estimate not only their own displacement but also that of their neighbours, based on electrical measurements only. This information can then be used to execute complex tasks through the cooperative control of multiple actuators. To effectively develop and optimize cooperative DEAs, however, numerical tools and simulation models are required. This work focuses on a 1-by-3 array of DEAs sharing a common flexible membrane. The goal is to understand the relationship between the capacitive states of the DEAs and the array deformation, enabling the reconstruction of deformation patterns for different actuation scenarios. Moreover, a non-linear finite element model of the DE array accounting for large deformation, electro-mechanical coupling, and geometry is proposed to describe and capture the actuation and sensing features of the system. These results will pave the way for the future development of cooperative control algorithms for interconnected DE array systems.

### 2.2.23 Evaluation of thin polymer dielectric films for high voltage capacitive transducer applications

Chiara Scagliarini (1), Federico Bertolucci (2), Lorenzo Agostini (1), Rocco Vertechy (1) (2)

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Presentation given by Chiara Scagliarini

Dielectric thin films of polymeric materials are very popular for mechatronics applications; in particular, for the realization of capacitors, printed electronics, and flexible transducers. For these purposes, they are frequently employed as base substrates on which patterns of conductive and, eventually, other insulating materials are deposited to manufacture multilayer devices, where the dielectric thin films typically act not only as a supporting structure but also as an energy-storing and -converting element. There is strong evidence that the performances of the final manufactured devices, whose operation often requires exposure to high voltages, are significantly affected by the electrical and tribological properties of the dielectric thin films involved in their fabrication. This work presents the results obtained from the characterization of the dielectric constant, dielectric strength, surface roughness and static friction of commercial polymeric thin films, having a thickness comprised between 12 and 25 micrometers and made of different plastic materials. Subsequently, the implications of the identified electrical and tribological properties on the performances of electro-adhesive devices (EADs) are experimentally investigated by correlating them with the shear-stress results measured on EAD specimens manufactured with the same dielectric thin films and featuring inkjet-printed electrodes.

### 2.2.24 Artificial muscles for facial reanimation

Stefania Konstantinidi (1), Pierre-Jean Martin (1), Amine Benouhiba (1), Yoan Civet (1), Yves Perriard (1)

(1) Ecole Polytechnique Fédérale De Lausanne (EPFL), Integrated Actuators Laboratory, Neuchâtel, Switzerland

Presentation given by Stefania Konstantinidi

Facial paralysis is a highly burdening condition, resulting in a patient's inability to move his musculature on one or both sides of his face. This condition compromises the patient's communication and facial expressions, and thus dramatically reduces his quality of life. The current treatment for chronic facial paralysis relies on a complex reconstructive surgery. The use of DEAs is proposed as a less invasive approach for dynamic facial reanimation, thus avoiding the traditional two-stage free muscle transfer procedure and allowing for a faster recovery of the patient. A study of the facial muscles and neural interfaces is performed, in order to implement a realistic setup and restore movement in the corner of the mouth, the eyebrows and blinking.

### 2.2.25 Artificial sphincter muscle for incontinence treatment

Beate Lyko (1), Stephan-Daniel Gravert (2), Robert Katzschmann (2), Bert Müller (1)

(1) University Basel, Department Of Biomedical Engineering, Biomaterials Science Center, Allschwil, Switzerland
(2) ETH Zürich, Department Of Mechanical And Process Engineering, Soft Robotics Lab, Zurich, Switzerland

Presentation given by Beate Lyko

Both urinary and fecal incontinence are common conditions in the general population that place a high degree of physical and psychological stress on those affected. For example, pads or transurethral urinary catheters are used to manage the disease, but these still considerably restrict the patient's activities. For more severe cases, there are implant-based therapies including artificial sphincters. The existing models including the AMS 800T show high revision rates due to complications such as tissue erosion. To address these challenges, we propose an approach utilizing Hydraulically Amplified Self-healing Electrostatic (HASEL) actuators to develop an advanced artificial sphincter. We aim to demonstrate the feasibility of this approach through testing on porcine urethrae, which yielded promising results with a HASEL cuff effectively stopping water flow at a hydrostatic pressure of 20 centimeters water column. Further research is needed to optimize device force, reduce actuation voltage, and ensure safety for clinical application.

### 2.2.26 Lifetime studies of EAP based tape yarn actuators for textile haptic devices

Jose G. Martinez (1), Carin Backe (2), Nils-Krister Persson (2), Edwin W. H. Jager (1)

(1) Linköping University, Department Of Physics, Chemistry And Biology (IFM), Linköping, Sweden
(2) University Of Borås, Swedish School Of Textiles, Borås, Sweden

Presentation given by Dr. Jose G. Martinez

Wearable textiles with mechanical actuation are of great interest for their use in haptics or assistive devices. During the last years we have been developing soft actuators based on ionic electroactive polymers (polypyrrole) in form of tape yarns that have been integrated into textiles through textile processing techniques such as weaving to obtain actuating fabrics. Tape yarns were produced by electropolymerizing Polypyrrole in both sides of an Au coated polyvinylidene fluoride (PDVF) membrane which is then soaked in the ionic liquid choline acetate forming a trilayer tape yarn polypyrrole/choline acetate soaked PVDF membrane/polypyrrole. Thus, when an electrical charge is passed through the trilayer, it produces a bending motion in air, outside of any liquid electrolyte. One of the key aspects for their applicability is their lifetime, an aspect that has not been properly studied before. Here we present the latest results about the lifetime (number of cycles) of such EAP based tape yarn actuators, when different potentials are applied.

# Session 2.3
(abstracts are listed in the order of presentation)

### 2.3.1 Industrial Developments of Dielectric EAP Sensor Technology and its Wearable Applications.

Dr. Alexander York (1)

(1) mateligent iDEAS

Presentation given by Dr. Alexander York

There have been many challenges over the past 20 years to bring Dielectric EAP technology to commercial viability. Aside from the exhaustive R&D efforts, manufacturing at reasonable costs and market adaptation are two of the biggest. In other words: How do we take new to the world technology, mass produce it with high quality and low cost, and then market it effectively in the current world's very complicated economy. This presentation will explore this history from the original start of Artificial Muscle Inc. through Bayer's commercial launch of the ViviTouch haptics product line and Parker's first sensor products to the technology's current commercial landscape. This review will give an inside look at where markets rejected the technology and how it eventually became successful with Dielectric Elastomer (DE) sensors.
The DE sensors presented are soft, thin, conformable devices that can take accurate measurements and readings while being strained up to 100% for millions of cycles. Made of tough silicone, they can withstand the harshest environments from heat, cold, and shock to dust, vibration, and moisture. The DE sensor is a flexible capacitor that acts as a displacement-to-capacitance transducer. The dielectric polymer exists between two stretchable electrodes. As the dielectric film is strained, it thins and expands within the area, increasing its capacitance.
These sensors characterized by their flexibility, lightweight nature, and responsiveness to electrical stimuli, present a unique opportunity for creating smart, comfortable, and unobtrusive wearable devices. At Mateligent we customize and produce these DE sensors that bring wearable tech solutions to life. Our sensors are very well suited for precise, fast measurement of human body movement in health care, athletics, and industry. Several examples of our sensors being used in products include measuring musculoskeletal (MSK) movement of the human body, measuring breathing during athletic training, and assessing gait and balance for reducing accidental falling in the elderly.
The presentation will give a view into the innovative materials and designs that

underpin Dielectric EAP sensors, highlighting their adaptability for various sensing functions such as strain and pressure. It also addresses challenges and prospects in the commercialization of DE sensors, including manufacturing scalability, reliability, and integration with existing systems. Furthermore, it gives an overview of current wearable applications and products pushing to market and it explores potential future directions for DE sensor technology and its role in shaping the industry's future.

### 2.3.2 Development of soft actuators to improve performance in future mobility

Umesh Gandhi (1)

(1) Toyota Research Institute North America

Presentation given by Dr. Umesh Gandhi

At Toyota, there is a growing interest in advancing mobility for all, characterized by future mobility solutions capable of accommodating occupants of varying sizes and diverse needs. Achieving this objective necessitates highly adaptive designs capable of reconfiguring and adapting to occupant size, environmental conditions, and performance criteria. One facet of this endeavor is the development of safety enablers, such as airbags, energy-absorbing pads etc. that are capable of adopting to occupant size and position to optimize protection. We are actively pursuing innovative solutions, including reconfigurable and programmable soft energy-absorbing surfaces. These solutions integrate various concepts such as origami structures, electrostatic clutches, shape memory polymers, and other smart materials and sensors into inflatable structures to provide occupant protection during impacts. We are also looking into how such soft inflatable and actuators can help robots that can work with humans. We plan to share our current research interests, the technology under development and examples of such systems already developed to enhance safety and comfort. We will also share key challenges in developing such reconfigurable features in the vehicles.

# Thursday 13 June 2024

## Session 3.1

(abstracts are listed in the order of presentation)

### 3.1.1 Ultra-thin soft electronics for soft sensing and actuations

Virgilio Mattoli (1)

(1) Istituto Italiano di Tecnologia, Center for Materials Interfaces, Pontedera (PI), Italy

Presentation given by Dr. Virgilio Mattoli

In recent years, the intersection of ultra-thin electronics and soft robotics has catalysed an increase surge of interest and innovation, propelling the development of conformable electronic systems with unprecedented capabilities, with the potential to seamlessly integrate electronic components onto non-rigid, non-planar, and complex 3D surfaces. The conformability of ultra-thin materials is a cornerstone of their functionality, enabled by their ability to adhere and conform spontaneously to surfaces, including human skin. This remarkable characteristic arises from the low bending stiffness – decreasing dramatically with thickness - and physical phenomena such as dispersive forces and Van der Waals interactions, facilitating intimate contact and unlocking a variety of applications ranging from wearable electronics to human-machine interfacing. One powerful strategy to enhance conformability involves the utilization of ultrathin free-standing polymeric films (with thickness ranging from tens to hundreds of nanometers) as substrate, offering conformal adhesion on diverse surfaces, including skin. Ink-jet printing enables the creation of circuit patterns directly on these nanofilms, paving the way for unobtrusive human-device interfaces.
Several examples of the practical application of ultra-thin soft electronics for sensing and actuation have been investigated by our group in the last 10 years. Conductive nanofilms, applied as temporary tattoos, boast unparalleled conformal adhesion, and have demonstrated their efficacy as dry electrodes for surface electromyography (sEMG), showcasing their potential for physiological signal monitoring and human-machine interaction.
Additionally, soft actuators, leveraging the synergy between electrical conductivity and hygroscopic properties, demonstrate electric- and humidity-driven actuation alongside touch and humidity sensing, paving the way for

multifunctional smart structures.
Furthermore, the versatility of conformable electronics allows its applications to be extended beyond sensing, reaching the possibility to actively stimulate the human skin to elicit tactile sensations. Utilizing localized electro-thermo-pneumatic transduction, ultra-thin tattoo devices have been developed producing discernible tactile feedback, showcasing the potential for developing wearable tactile displays with inkjet printing techniques and off-the-shelf materials.
In conclusion, ultra-thin soft electronics represent a paradigm shift in the realm of electronic systems, offering unparalleled conformability and functionality. From enabling seamless integration onto complex surfaces to revolutionizing human-machine interaction and tactile feedback, the applications of these technologies holds immense potential for transformative applications in healthcare, human-machine interaction, and beyond.

### 3.1.2 Materials for fluid gap polymeric electrostatic transducers

Marco Fontana (1)

(1) Scuola Superiore Sant’Anna , Institute of Mechanical Intelligence , Pisa, Italy

Presentation given by Dr. Marco Fontana

Electrostatic actuators and generators have long been regarded as potentially game-changing technologies for robotics, wearable systems, and energy harvesting. However, they have been confined to small-scale applications due to limitations that arise from the use of air gaps. In response to these limitations, in the early 2000s, the first examples of polymeric gap electrostatic transducers, known as dielectric elastomers, were introduced, marking a significant advancement in electrostatic technologies. These new classes of actuators and generators rely on solid state, lightweight materials and feature no rigid moving parts. Despite these innovations, their applicability has been limited by performance and reliability issues. Recently, multilayer transducers based on fluid gaps have shown significant advancements. This class of transducers uses dielectric fluids in combination with flexible, insulating polymer-based thin films that deform when subjected to high electric fields [1-4].These devices have demonstrated high power density, rapid responsiveness, cost efficiency, and enhanced lifetime prospects. This talk will introduce different architectures of fluid gap electrostatic transducers, employing various combinations of materials as dielectric layers and as the variable volume gap. It will focus on the performance and operation of these devices and how these aspects are influenced by the characteristics of the employed materials [5,6], highlighting promising new applications in environments such as space, underwater, and other harsh conditions.

### 3.1.3 Active Textiles as a Platform for Actuating Soft Robotic Devices

Vanessa Sanchez (1)

(1) Rice University, Department Of Mechanical Engineering, Houston, USA

Presentation given by Dr. Vanessa Sanchez

Wearable robots and devices-garments with embedded elements that actuate to change shape or apply forces to the wearer-offer promise for assistive and augmentative applications including rehabilitative gloves, haptic devices, and dynamically thermoregulating clothing. Early iterations of wearables from the 1950s and 60s took the form of rigid exoskeletons; however, in the past twenty years, a growing subset of this field has transitioned to the use of soft components and materials to improve portability, fit, and comfort, guided in part by advances in the related field of soft robotics. Based on the unique requirements for wearables, including personalization for varied bodies and low cost of production for wide accessibility, automated and highly customizable textile-compatible manufacturing strategies must be developed to support fabrication and integration of all the necessary components (sensors, actuators, control components, interconnections). Considering actuation, shape changing yarn mechanisms including those employing electroactive polymers (EAPs), are especially promising due to their ability to support a low profile, light weight, and the potential for seamlessly integrated devices. This talk will discuss the intersection of knowledge from the field of textiles with the needs of soft robots, focused on wearable applications, including performance metrics, architected material designs, and fabrication strategies, considering opportunities in utilizing EAPs.

# Session 3.2

(abstracts are listed in the order of presentation)

## 3.2.1 Mechanics of textile-based PEDOT:PSS soft actuators

Louise Anne Furie (1), Shayan Mehraeen (1), Jose G. Martinez (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 Louise Anne Furie

Smart textile actuators have been of growing interest due to their applications in soft robotics, exoskeletons, and assistive garments, and can deform controllably and reversibly under application of an external stimulus such as temperature or electric potential. This next generation of smart textiles integrate smart yarn and fiber actuators, and/or the deposition of smart materials in/on textile substrates. The mechanics of the textile substrate used for these actuators has an effect on the performance of the devices, and can be used advantageously to achieve complex actuation modes. Additionally, additive manufacturing processes can be used to fabricate the actuators, providing a means to quickly modify and adapt the patterning of both active and passive materials to further enhance performance. In this study, multi-layered PEDOT:PSS actuators were 3D printed on different woven textiles via syringe-based extrusion to explore the effects of the weave pattern on actuation performance. Furthermore, passive materials were printed in different patterns, utilizing selective compliance to program the movement capabilities of the devices.

## 3.2.2 Simultaneous sensing of force and displacement in an untethered dielectric elastomer actuator through an integrated piezoresistive element

Dip Kumar Saha (1), Hareesh Godaba (1)

(1) University Of Sussex, School Of Engineering And Informatics, Brighton, United Kingdom.

Presentation given by Dr. Hareesh Godaba

Dielectric elastomer actuators are excellent contenders for the development of terrestrial and underwater mobile robots due to their silent operation and full electric control. However, sensorizing untethered dielectric elastomer actuators for future autonomous capabilities faces challenges due to their high voltage requirement and nonlinear mechanics. To tackle this challenge, we developed a novel sensing technique by embedding a piezoresistive sensor track to simultaneously estimate the actuator displacement and external interaction force through the measurement of track resistance and feedback voltage. We have characterized the voltage-force-displacement characteristics of the actuator as well as their influence on track resistance. Through a data-driven regression model, Gaussian Process Regression (GPR) was built from the measured data for accurate estimation of force and displacement based on voltage input and feedback resistance. Validation tests were performed on three actuators in different operating conditions which demonstrate promising results, achieving low RMSE values of 29.736 mN for force estimation and 0.023 mm for displacement estimation under no-voltage conditions. Furthermore, we realized an actuator with fully untethered operation capable of force and displacement feedback to a remote computer by integrating a power source, mini voltage amplifier, microcontroller, and wireless connectivity module into a compact form-factor.

### 3.2.3 Soft actively-tuneable dampers with sensing capabilities

Ingrid M. Graz (1) (2), Rene Preuer (1) (2), Edip Ajvazi (1) (3), Ian Teasdale (3), Stefan Halama (1) (2)

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

Presentation given by Dr. Ingrid M. Graz

Soft elastomer materials due to their inherently dissipative nature are the materials of choice for dampers. Damping plays a vital role in our modern society, spanning a wide range of application from shoe soles to wheels, with dampers within vehicles, in bridges and buildings or seals within appliances. Taking inspiration from living systems soft multilayered protective structures such as bones, skin or fruit peel that can not only sustain high dynamic, but also quasi-static mechanical loads while being built-up by a small range of basic materials, we present simple approaches to damping structures with adjustable stiffness based on novel silicone elastomers and their foams. We highlight their fabrication, characterization, applicability as adjustable dampers along with their sensing abilities.

### 3.2.4 A multi-functional glove based on compliant metal thin film electrodes - concept study, innovative manufacturing methods and characterization

Jonas Hubertus (3), Sebastian Gratz-Kelly (1) (4), Mario Cerino (2) (3), Dirk Göttel (2), John Heppe (3), Günter Schultes (3), Paul Motzki (1) (4)

(1) Smart Material Systems, Center For Mechatronics And Automation Technology, ZeMA GGmbH, Saarbrücken, Germany
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(3) University Of Applied Sciences, Sensors And Thin Film Group, Saarbrücken, Germany
(4) Intelligent Materials Systems Lab, Department Of Systems Engineering, Department Of Materials Science And Engineering, Saarland University, Saarbrücken, Germany

Presentation given by Dr. Jonas Hubertus

Polymers that can change their shape and at the same time act as their own sensor may become important systems of tomorrow. Due to their multifunctionality, they are also referred to as smart materials. Dielectric elastomers (DE) combine these properties perfectly as they can be used as both actuators and sensors. Over the years, Carbon Black has become the preferred electrode material for DEs. Besides their well-known good properties, a high initial resistance and a limited spatial resolution due to the applied manufacturing processes makes it disadvantageous to use these electrodes in some types of applications. Especially when high excitation frequencies are required, metal based compliant electrodes take advantage of their low electrical resistance. Sputter deposited onto a pre-stretched silicone membrane, the 10 nm thick nickel-based electrode exhibits a wrinkled surface after the relaxation of the membrane giving the structure the required compliance. In addition, with a laser structuring process the spatial resolution is in the range of 20 micrometers. In the presented work, the idea of a functional glove, equipped with DEs based on metallic electrodes is presented. A hapto-acoustic element as well as a sensor matrix are to be integrated in the glove. The concept of the glove is shown together with a new manufacturing process for the creation of reliable electrical contacts through a stack of DE membranes. In addition, first acoustic characterizations are presented.

### 3.2.5 Dielectric elastomer multiactuator networks as cooperative systems

Chen Jiao (1), Ashwani Sharan Tripathi (1), Uwe Marschner (1), Andreas Richter (1), Ernst-Friedrich Markus Henke (1) (2)

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

Presentation given by Chen Jiao

Collaborative multi-actuator systems will become important in future applications such as robotics, medical devices, and advanced user interfaces. Potential uses for such devices range from macro to micro scales. To obtain smart, entirely soft bio-inspired robots, fully soft electronic circuits are required. Combining several multi-functional dielectric elastomers with Hydraulically Amplified Self-Healing Electrostatic actuators (HASELs), enable multi-actuator networks that combine HASEL's performance and DE's multifunctionality. This approach enables soft structures that implement basic logic computation and memory functions. We here present the application of complex DE-circuitry, to combine and intrinsically control multiple DEA-HASEL unit cells. We present a mathematical model for such unit cells and networks capable of complex actuation tasks. Drawing from our research on DE sensors and actuators, we have developed a model that integrates DE components to simulate multi-actuator networks. Multiple DE switches are interconnected through logic unit designs to achieve complex electro-mechanical behaviors. We predict the multiple outputs of a single input pulse voltage for a highly integrated inverter system through simulation. It opens more possibilities in the application field of cooperative multi-actuator systems.

### 3.2.6 Investigation of two types of fiber reinforcement for uniaxial DEAs

Markus Koenigsdorff (1), Stefania Konstantinidi (2), Yoan Civet (2), Yves Perriard (2), Gerald Gerlach (1)

(1) TU Dresden, Institute Of Solid-State Electronics, Dresden, Germany
(2) Ecole Polytechnique Fédérale De Lausanne (EPFL), Integrated Actuators Laboratory (LAI), Neuchâtel, Switzerland

Presentation given by Markus Koenigsdorff

Dielectric elastomer actuators (DEAs) are composed of a thin dielectric elastomer membrane that is sandwiched between two compliant electrodes. When an electrical voltage is applied, the film compresses in the thickness direction and expands in-plane. However, many technical applications require uniaxial deformation. For this purpose, the introduction of mechanical anisotropy by unidirectional fiber reinforcement is commonly used. State of the art publications utilize evenly spaced stiff fibers that are bonded to the dielectric film. These fibers inhibit the deformation of the actuator in the fiber direction, which ideally keeps the width of the actuator constant, leading to increased electro-active forces and strains. However, they also constrain the actuator lengthwise because the material below the fibers can hardly deform. Therefore, the fiber coverage ratio is an important parameter when designing actuators with this kind of reinforcement. As an alternative approach, a composite layer consisting of unidirectional fabric with a soft elastomer matrix can also be used. These reinforcement layers lead to comparable mechanical anisotropy. However, as the stiff fibers are not directly bonded to the dielectric, the actuator's lengthwise stiffness is not significantly increased. This work investigates the effect of these two types of reinforcement on the actuator properties.

### 3.2.7 Optimising sodium borohydride reduction of platinum onto nafion-117 in the electroless plating of ionic polymer-metal composites

Eyman Manaf (1), John G. Lyons (1)

(1) Technological University Of The Shannon: Midlands Midwest, Faculty Of Engineering & Informatics, Athlone, Ireland

Presentation given by Eyman Manaf

Ionic polymer-metal composites (IPMCs) have a wide variety of applications as they can act as both sensor and/or actuator. The effects of process parameters on the electroless plating of IPMCs were studied in this work. Specifically, sodium borohydride (NaBH4) reduction of platinum onto Nafion-117 was characterised. The effects of concurrent variation of NaBH4 concentration, stir time and temperature on surface resistance were studied through a full factorial design. The 3 factor 3-level factorial design resulted in 27 runs. Surface resistance was measured using a four-point probe. The fitted responses resulted in a regression model with an R2 value of 97.45%. Temperature was found to have the most significant effect on surface resistance. Generally, surface resistance was found to decrease with increasing stir time (20 minutes to 60 minutes) and temperature (20°C to 60°C). Surface resistance decreased going from 1% to 5% NaBH4 concentration, but increased from 5% to 10% NaBH4 concentration. Maximum tip displacement, measured through a computer vision system, was obtained for all 27 samples. Highest displacement obtained was 65.9mm at 10% NaBH4 concentration, 60 minutes stir time and a temperature of 40°C.

### 3.2.8 A hybrid dynamical framework for simulation, optimization, and control of SMA wire-based continuum robots

Michele Mandolino (1), Paul Motzki (1), Francesco Ferrante (2), Gianluca Rizzello (1)

(1) Saarland University, Department Of System Engineering, Saarbrücken, Germany
(2) University Of Perugia, Department Of Engineering, Perugia, Italy

Presentation given by Michele Mandolino

Continuum robots are an innovative class of semi-soft robots that overcome some limitations of the conventional rigid ones. The main characteristic of continuum robots is represented by a flexible spine-like structure capable of performing complex bending patterns. To achieve precise bending and motion, continuum robots employ different soft actuation solutions which are generally based on tendon-driven, pneumatic, and hydraulic principles. These technologies are typically noisy and require a significant amount of installation space compared with the robotic structure itself, posing an obstacle to its portability and practical use. A possible solution comes from the use of unconventional actuators such as Shape Memory Alloy (SMA) wires. These transducers, commonly consisting of Nickel and Titanium, can undergo a contraction in length when heated. Being metal and shaped as wires, they can be activated thermically through an electric current due to the Joule effect. Some SMA advantages are high flexibility, lightweight, high energy density, and the ability to act simultaneously as actuator and sensor. In this work, we present a model-based framework for the design, simulation, and control of SMA continuum robot. The robot concept involves the use of an elastic backbone made of superelastic SMA to replace the outer flexible tube. A port-oriented hybrid modeling framework enables efficient modeling and simulation of complex SMA structures in a modular and physics-oriented way.

### 3.2.9 Simulations and characterization of wearable thermo-pneumatic vibrotactile displays

Arianna Mazzotta (1), Silvia Taccola (2), Russell A. Harris (2), Virgilio Mattoli (1)

(1) Italian Institute Of Technology, CMI, Pontedera, Italy
(2) University Of Leeds, Future Manufacturing Processes Research Group, School Of Mechanical Engineering, Leeds, UK

Presentation given by Dr. Arianna Mazzotta

Soft actuators are of paramount importance in wearables, offering superior performance in terms of comfort and portability compared to rigid counterparts, being lightweight and compact. They find wide application in wearable tactile displays, where the actuation system should be carefully evaluated to avoid bulky devices that hinder user comfort and mobility. Here, flexible and conformable electronics play a fundamental role, as they can adhere to non-flat surfaces and make direct contact with human skin, ensuring reliable tactile sensations. We propose a new thermo-pneumatic actuation strategy only based on a closed volume of air ("air pocket") enclosed between thin membranes, locally heated via Joule Heating and causing the air volume to expand so as to deform an upper flexible membrane. First, the proposed principle is demonstrated via finite element simulations, in which easily available materials, such as Kapton and PDMS, were used, with the aim of obtaining a reproducible, accessible, and scalable strategy. After evaluating achievable pressures and displacements, a real prototype of a Braille display was implemented (air enclosed between a laser-cut Kapton film and thin PDMS film on top) for device characterization. The presented working principle and fabrication strategy allow the realization of light, flexible, and low-voltage devices, paving the way for the development of fully portable haptic displays in the next future.

### 3.2.10 Dielectric actuators for underwater vessels

Robin Milward Cooney (1), Masoumeh Hesam (1), Iain Anderson (1)

(1) Biomimetics Lab, Auckland Bioengineering Institute, Auckland, New Zealand

Presentation given by Robin Milward Cooney

The exploration and monitoring of underwater environments, such as coral reefs, present unique challenges due to their delicate nature and the biodiversity they support. Traditional underwater robotic systems often rely on propeller-driven motion, which can be disruptive to marine life and potentially harmful to the fragile coral ecosystems. This underscores the need for innovative approaches that ensure silent operation and minimal environmental impact. Soft artificial muscle propulsion solutions, such as Dielectric Elastomer Actuators (DEAs) and Hydraulicly Amplified Self-healing ELectrostatic (HASEL) actuators, into underwater vehicles have the potential to achieve superior maneuverability, energy efficiency, and adaptability in various aquatic conditions compared to conventional rigid-bodied solutions. Here, in partnership with industry, we consider the manufacturing processes and implementation of dielectric actuator muscle technology for use in medium scale underwater vehicles. To move this vessel, intend to use HASEL actuators and explore potential types of movements, including: (a) fish-like (side-to-side tail); (b) dolphin-like (up-and-down tail fin); (c) cuttlefish (undulating fin); (d) sea-snake (swimming form). These different designs have advantages and disadvantages. In this research, we are going to analise the actuator topologies and discuss means of operating them for compact underwater applications.

### 3.2.11 Towards wearable dielectrophoretic liquid zipping actuators

Visva Moorthy (1), Rejin John Varghese (1), Dario Farina (1), Majid Taghavi (1)

(1) Department Of Bioengineering, Imperial College London, London, United Kingdom

Presentation given by Visva Moorthy

E-textiles are part of an exciting research avenue which merges technologies such as sensing and actuation with the textile industry. Despite the substantial progress made in recent years, there has been little work on incorporating electrostatic actuators into fabrics. Dielectrophoretic Liquid Zipping (DLZ) actuators are a type of electrostatic actuator which show promise for use in wearables, owing to their lightweight construction, silent operation, and high efficiency. However, the design is yet to be optimised for use in wearables. Currently, DLZ actuators use two thin steel electrodes which are held together at one point and separated by solid and liquid dielectrics. When a potential is applied, the two electrodes zip together, starting from their point of convergence. In this work we explore incorporating e-textiles in DLZ actuators. We compare the performance of each material and develop a proof of concept textile-based DLZ actuator. This work paves the way to embedding DLZ actuators into clothing in the future.

### 3.2.12 A new class of silicone elastomers with a network of concatenated rings

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 Cristina Nedelcu

Silicone elastomers have received vast attention for their use in products such as stretchable electronics, implants, and medical devices. In recent years, there has been a growing interest in developing elastomers that possess mechanical stability, softness, and elasticity similar to human muscles for integration into soft robotic devices. The incorporation of silicone elastomers with actuation properties into textiles could, for example, revolutionize the production of soft wearables and lightweight exoskeletons. A new class of silicone elastomers, characterized by a network composed of concatenated (interlocked) polymer rings, has recently emerged. These elastomers demonstrate interesting characteristics such as extreme softness and stretchability compared to traditional covalently crosslinked elastomers. In this work, two telechelic hydride- or vinyl-functional polydimethylsiloxane polymers with reactive double bonds in the main chain were prepared. The synthesized polymers were utilized to prepare silicone elastomers with a concatenated ring network structure. The presence of the carbon-carbon double bonds inside the soft ring network allows for further functionalization to, e.g., increase the dielectric permittivity with dielectric moieties, introduce self-healing properties, or create conductive silicone elastomers.

### 3.2.13 Photothermal detection of terahertz light in freestanding ultrathin polyvinylidene fluoride-based capacitors

Andrea Ottomaniello (1), Rishabh B. Mishra (1) (2), Alessandro Tredicucci (3), Virgilio Mattoli (1)

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(2) Scuola Superiore Sant"Anna, The Biorobotics Institute
(3) Dipartimento Di Fisica "E. Fermi", Università Di Pisa

Presentation given by Dr. Andrea Ottomaniello

Polyvinylidene fluoride (PVDF) has garnered significant attention for its sensing capabilities owing to their piezo-responsive and piezoelectric properties. Thin films of PVDF in the micrometer scale present challenges due to the need for macroscopic alignment through a poling procedure. In this study, we developed ultra-thin freestanding (>100 nm thick) PVDF-based capacitors by Van der Waals assembling PVDF thin films carrying Au electrodes, where PVDF serves as a thin dielectric layer. Remarkably, without the need for poling, these capacitors exhibit a static thermal response, where the base capacitance varies upon heating or illumination with infrared (IR) radiation, demonstrating their potential as thermometers. Furthermore, by integrating an optical absorber developed using the approach demonstrated by Ottomaniello et al. (Nanophotonics, vol. 12, no. 8, 2023), the fabricated device can work as a light detector. Specifically, depending on the engineering of the optical absorber coupled to the PVDF-based capacitor, these devices can target the terahertz (THz) frequency range with either narrow or broadband sensitivity. This novel approach opens avenues for the development of room temperature ultra-thin conformable detectors capable of operating from THz to MIR frequencies.

### 3.2.14 Self-sensing pneumatic inverse artificial muscles

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Presentation given by Valentina Potnik

Wearable mechatronic devices such as powered orthoses, exoskeletons, and prostheses require advanced soft actuation devices that function like 'artificial muscles'. These actuators should be capable of large strains, high stresses, rapid reaction, and integrated self-sensing, while also ensuring electrical safety, low weight, and high compliance. Soft pneumatic actuation has seen a resurgence in the past two decades, thanks to technological progress driven by applications in soft robotics. As of now, quite a few solutions are available to create pneumatic devices with linear actuation and self-sensing properties, using readily available materials and cost-effective manufacturing techniques. Here, we describe a straightforward process to create self-sensing pneumatic actuators that act as 'inverse artificial muscles'. Unlike traditional pneumatic actuators that contract when pressurized, these actuators elongate. They consist of an elastomeric tube encased by a plastic coil to prevent outward expansion. The innovation here is the self-sensing feature, achieved through a piezoresistive stretch sensor, which was made from a conductive elastomeric material and was arranged along the center of the tube.

### 3.2.15 Investigation the effect of PPy thickness on yarn actuation performance

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Presentation given by Abd Ul Qadeer

Smart Textile is a branch of functional textiles with a built-in ability to respond to various stimuli like chemicals, light, or electricity. The key component of these textiles is "smart yarn" which is engineered to respond the external stimuli. Traditionally, smart textiles focused on textile-based sensors. Now the focus is shifting to the development of yarn and fabric actuators. Yarn coated with Poly-3,4-ethylenedioxythiophene: Polystyrene sulfonate (PEDOT: PSS) and polypyrole (PPy) acts like a soft actuator. When these smart yarns are exposed to an electrochemical potential, the PPy coating contracts and expands, like an artificial muscle. The thickness of the PPy coating impacts the actuator's performance. A thicker coating can generate greater force but might be less responsive (slower contraction/expansion). This paper investigates the effect of PPy thickness on the performance of yarn actuators. The passive yarns were dip-coated with a conductive Poly-3,4-ethylenedioxythiophene: Polystyrene sulfonate (PEDOT: PSS), Dimethyl sulfoxide (DMSO) and Polyethylene glycol 400 (PEG 400) mixture to make them electrically conductive yarns. Then PPy with different thicknesses were deposited using an electro-polymerization process. The resulting yarn actuators were then evaluated for three key properties: strain, speed of movement, and force generation, using a lever arm setup.

### 3.2.16 Accelerating the development of innovative wearable soft robotic devices for the suppression of human tremor

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Presentation given by Dr. Alona Shagan Shomron

Almost 80 million people worldwide live with tremor, involuntary movements of body parts. Wearable soft robotic devices are potentially a major practical solution for active tremor suppression, instead of traditional treatments. However, current prototypes face limitations in actuation performance and complex clinical testing procedures. Here we introduce a comprehensive approach for rapid evaluation of emerging tremor suppression technologies; this method combines reproduction of patient-recorded tremor episodes in a robotic test-bed ("mechanical patient"), with validation of achieved suppression performance of novel soft actuators via biomechanical modeling, avoiding time-consuming clinical testing in early stages of development. This approach highlights that an antagonistic pair of slim (1 mm) and lightweight (15 gr) HASEL actuators is fast and strong enough to suppress clinically relevant tremors of frequencies between 2-8 Hz by 76-94%. Using recordings of natural tremor amplitudes from patients, we show that a PID controller successfully adapts the response of these actuators, despite their non-linearity. The biomechanical model confirms that a single pair of these lightweight actuators generates adequate suppression forces for suppression across all tested tremors. Hence, this comprehensive approach confirms the potential of electrohydraulic actuation for further development in assistive devices, that may improve the quality of life for individuals living with tremor.

### 3.2.17 Soft and stretchable piezoresistive devices fabricated with inkjet-printed carbon black

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Presentation given by Jianan Yi

Inkjet printing is a remarkably versatile and promising technique for crafting functional materials. Its ability to precisely dispense minuscule ink droplets (measured in picoliters) at the target positions empowers it to achieve high-resolution and thin-layer depositions, offering great potential for the miniaturization of flexible and stretchable electronics. In this study, we developed a novel carbon black (CB) ink and tailored it for compatibility with the small cartridge nozzles (17x17 μm) of inkjet printers. Extensive characterizations were conducted to evaluate the ink, including surface tension, viscosity, stability, conductivity, and particle size distribution. With this ink, we printed a precise pattern onto a dielectric elastomer membrane (VHB). By combining a dielectric elastomer actuator (DEA) next to the printed CB pattern, its resistance could be significantly changed accompanied with actuation and non-actuation of the DEA. More than three orders of magnitude in resistance change have been obtained at frequencies of up to 3 Hz. Thanks to its excellent piezoresistive performance, we have successfully applied this dielectric elastomer-based device as a "switch" for controlling soft grippers and as a multiplexer for signal processing.

### 3.2.18 Distributed de-electronics for interfacing and collaboration

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Presentation given by Aleksandra Sowa

This research investigates the integration of Distributed DE-Electronics at the interfaces of soft robotic structures, particularly focusing on enhancing collaboration between robots and humans in various domains including industrial and medical applications. By embedding soft DE sensors and electronics, this study aims to create safer and more intuitive human-machine interfaces while advancing the capabilities of soft robotics.

### 3.2.19 Integration of HASEL Actuators with Dielectric Elastomer-Based Switches for Stretchable Membrane Deformation

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Presentation given by Ashwani Sharan Tripathi

This contribution proposes a novel integration of Hydraulically Amplified Self-Healing Electrostatic actuators (HASELs) with dielectric elastomer switches (DESs) to create versatile and adaptive systems, capable of precise deformation and actuation in multi actuator systems. DES possess the ability to integrate signal processing capabilities directly into soft multiactuator systems, enabling complex actuation patterns, without or with minimum external control signals. The integration involves HASEL actuators to deform and stretch a stretchable membrane made of silicone elastomer possessing DESs printed on top of it. This innovative approach capitalizes on the unique properties of both HASEL actuators and dielectric elastomers, enabling digital signal processing embedded in soft actuator networks. HASEL actuators, known for their high force output, rapid response, and self-healing capabilities, serve as the driving force behind the deformation of the silicone membrane. The precise and localized deformations of the stretchable membrane holding the DES generates the control signals for neighboring actuator units. This combination of HASEL and DES forms digital unit cells that are used to directly control the actuation of connected DEAs, enabling the set-up of basic digital logic functionality in multi-actuator arrays.

### 3.2.20 Investigation of electrical charging characteristics of dielectric elastomer actuators by thermal imaging

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Presentation given by Tobias Willian

Dielectric elastomer actuators (DEAs) are used in various applications. To achieve the high performance, homogeneous charging and discharging properties are indispensable and depend on various aspects, such as the homogeneity of the electrode resistance or the design of the electrical connection. This poster provides a new approach, in which thermal imaging is used to characterize these aspects for DEAs. It utilizes an artificial increase in the charging current by applying high frequency sinusoidal voltage signals, resulting in relatively low actuation response along with high joule heating. This heating is particularly pronounced in areas of inhomogeneous current distribution and can be visualized by conducting thermographic methods. Analyzing corresponding temperature gradients can be used to make statements about the homogeneity of the charging. In a first study, different geometries of electrical contacts are examined. The DEAs are set to different strain levels, while varying excitation frequencies and voltage amplitudes. Poor contacting leads to inhomogeneous charging characteristics. Improving the contacting geometry significantly reduces the measured temperature and leads to a more homogeneous current flow in the DEAs, thus a more homogeny charging behavior of the DEAs. The results of this work provide an initial insight into the charging behavior of DEAs by means of thermal imaging and will enable to optimize charging processes in the future.

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