EuroEAP 2023

11th international conference on Soft Transducers and Electromechanically Active Polymers

Bristol, United Kingdom
6-8 June 2023

Technical programme

Book of abstracts

List of participants

EuroEAP 2023 sponsors

Contents

Conference venue

Mercure Bristol Grand Hotel
Broad St, Bristol, United Kingdom
Phone: +44 117 929 1645

Conference chairperson

EuroEAP 2023 is chaired by
Andrew Conn
Associate Professor of Robotics
Department of Mechanical Engineering
University of Bristol

Local organization

University of Bristol
Bristol Robotics Laboratory

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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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Anne Skov, Technical University of Denmark (Denmark)

Programme Overview

Monday 05 June 2023

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

Tuesday, 6 June 2023

Opening	8:45 – 9:00	Welcome & introduction to conference **Andrew Conn** University of Bristol, UK
EAPlenary	Session 1.1 part I *Chair: Herbert Shea, EPFL Zurich, Switzerland*	
	9:00 – 9:30	**Michael Dickey** North Carolina State University, USA
Invited Lectures	Session 1.1 part II *Chair: Herbert Shea, EPFL Zurich, Switzerland*	
	9:30 – 9:50	**Philipp Rothemund** Max Planck Institute for Intelligent Systems, Germany
	9:50 – 10:10	**YuFeng Chen** Massachusetts Institute of Technology, USA
Break	10:10 – 10:30	Coffee break
Interactive Talks	Session 1.2 part I *Chair: Jonathan Rossiter, Bristol University, UK*	
	10:30 – 11:50	**Oral presentations** 20 presentations of research activities (3 minutes each + 1 minute to change speaker)
	11:50 – 12:50	**Posters & exhibitions** 20 posters Coffee served during the session
Lunch break	12:50 – 14:00	Buffet lunch
Interactive	Session 1.3	

Talk presentations	*Chair: Anne Skov, Technical University of Denmark*	
	14:00-15:15	**Oral presentations** 18 presentations of research activities (3 minutes each + 1 minute to change speaker)
EuroEAP Society Challenge	15:15 – 15:30	**Video projection** 6 Challenge videos (3 minutes each)
Sponsor Talk	15:30 – 15:45	**Umesh Gandhi** Toyota Motor Engineering & Manufacturing North America, USA
Interactive Talk poster presentations	16:45 – 17:45	**Posters & Challenge exhibitions** 18 posters + challenge exhibition Coffee served during the session
EuroEAP Society meeting	17:45 – 18:45	**Annual meeting of the EuroEAP Society**
Social event	18:45	Appetisers at Mercure Bristol Grand Hotel

Wednesday 07 June 2023

EAPlenary		Session 2.1 part I *Chair: Edwin Jager, Linköping University, Sweden*
	9:00 – 9:30	**Alexander Kuhn** University of Bordeaux, France
Invited Lecture		Session 2.1 part II *Chair: Alexander Kuhn, University of Bordeaux, France*
	9:30 – 9:50	**Nils-Krister Persson** University of Borås, Sweden
	9:50 – 10:10	**Anne Skov** Technical University of Denmark
Break	10:10 – 10:30	Coffee break
Interactive Talk presentations		Session 2.2 *Chair: Cedric Plesse, CY Cergy Paris Université, France*
	10:30 – 11:45	**Oral presentations** 19 presentations of research activities (3 minutes each + 1 minute to change speaker)
Sponsor Talk	11:45 – 12:00	**Jonathan Hodges** Wave Energy Scotland, UK
Interactive Talk poster presentations	12:00 – 13:00	**Posters & exhibitions** 19 posters Coffee served during the session
Lunch break	13:00 – 14:00	Buffet lunch
Invited Lectures		Session 2.3 *Chair: Federico Carpi, University of Florence, Italy*
	14:00 – 14:20	**Dorina Opris** EMPA, Switzerland
	14:20 – 14:40	**Luca Ciarella** TU Dresden, Germany
	14:40 – 15:00	**Petko Bakardjiev** TU Dresden, Germany
Break	15:00 – 15:20	Coffee break
Social event	15:20 – 18:00	River boat cruise
	18:30	Gala dinner

Thursday 08 June 2023

EAPlenary	Session 3.1 part I *Chair: Ingrid Graz, Johannes Kepler University. Austria*	
	9:00 – 9:30	**Fabrizio Scarpa** University of Bristol, UK
Invited Lectures	Session 3.1 part II *Chair: Ingrid Graz, Johannes Kepler University. Austria*	
	9:30 – 9:50	**Marc Miskin** University of Pennsylvania, USA
	9:50 – 10:10	**Martin Kaltenbrunner** Johannes Kepler University, Austria
Break	10:10 – 10:30	Coffee break
Interactive Talks	Session 3.2 *Chair: Edwin Jager, Linköping University, Sweden*	
	10:30 – 11:45	**Oral presentations** 18 presentations of research activities (3 minutes each + 1 minute to change speaker)
	11:45 – 12:45	**Posters & exhibitions** 18 posters Coffee served during the session
Best Poster & Society Challenge Awards	12:45 – 13:00	Final collection and counting of votes
	13:00 – 13:15	**Announcement of the first three classified teams of the EuroEAP Society Challenge award**
	13:15 – 13:30	**Announcement of the winner of the best poster award**
Closing ceremony	13:30 – 13:40	Conference closure, handover to the next year's chairperson and presentation of the next year's conference venue.
Lunch break	13:40 – 14:00	Buffet lunch

Tuesday, 6 June 2023

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

1.1.1 Liquid metals and tough gels for soft devices

Michael Dickey (1),

(1) NC State University, Chemical And Biomolecular Engineering, Raleigh, USA

Presentation given by Prof. Michael Dickey

This talk will discuss recent progress in utilizing liquid metals as conductors for stretchable, soft, and reconfigurable components for electroactive polymeric devices. Alloys of gallium are noted for their low viscosity, low toxicity, and near-zero vapor pressure. Despite the large surface tension of the metal, it can be patterned into non-spherical 2D and 3D shapes due to the presence of an ultra-thin oxide skin that forms on its surface. Because it is a liquid, the metal is extremely soft and flows in response to stress to retain electrical continuity under extreme deformation. By embedding the metal into elastomeric or gel substrates, it is possible to form soft, flexible, and conformal electrical components, stretchable antennas, and ultra-stretchable wires that maintain metallic conductivity up to ~800% strain. Thus, these materials are well-suited for soft actuators and stretchable electronics because they can maintain metallic properties during deformation. In addition to introducing the advantages of these materials for such applications (e.g. conductive and self-healing electrodes in electroactive polymers), this talk will focus on new encasing materials, such as ionogels, that have record breaking mechanical properties. The gels form very easily by simply polymerizing common monomers in appropriately selected ionic liquids. These advances have implications for soft machines and robots that have ultra-soft mechanical properties.

1.1.2 Electromechanical modeling of electrohydraulic HASEL actuators

Philipp Rothemund (1) (2)

(1) Max Planck Institute for Intelligent Systems, Robotic Materials Department,

Stuttgart, Germany
(2) University of Stuttgart, Faculty 7: Engineering Design, Production Engineering and Automotive Engineering, Stuttgart, Germany

Presentation given by Dr. Philipp Rothemund

Today's robots rely predominantly on rigid metallic components and electromagnetic motors, which make them heavy, expensive, and ill-suited to unstructured environments. By contrast, biological organisms use predominantly soft materials, and many outperform robots in terms of agility, dexterity, and adaptability. Hydraulically amplified, self-healing, electrostatic (HASEL) actuators are an interesting class of soft actuators with muscle-like behavior, which outperform the human skeletal muscle in many metrics and overcome some of the limitations of traditional hard robotic hardware. HASEL actuators consist of deformable, dielectric shells that are filled with liquid dielectrics and that are partially covered with of deformable electrodes. When a high voltage is applied between the electrodes, the resulting electric field causes a Maxwell stress, which displaces the liquid dielectric and deforms the pouch. In this lecture I describe how basic thermodynamic principles and scaling analyses can be used to analyze the interaction between electric fields, the mechanical behavior of the dielectric shell and the viscous behavior of the liquid dielectric and to derive accurate models for their electromechanical behavior. I will show examples, in which we successfully applied these tools to derive accurate models for the quasistatic and dynamic behaviors of HASEL actuators with different modes of deformation. The models show how geometrical and material parameters, as well as applied voltages and loads influence the performance of HASEL actuators and point towards pathways to drastically improve the performance of future designs of electrohydraulic soft actuators.

1.1.3 Agile and resilient micro-aerial-robots powered by soft artificial muscles

Yufeng (Kevin) Chen (1),

(1) Electrical Engineering And Computer Science, Massachusetts Institute Of Technology, Cambridge, USA

Presentation given by Dr. Yufeng (Kevin) Chen

Recent advances in microrobotics have demonstrated remarkable locomotive capabilities such as hovering flights, impulsive jumps, and fast running in insect-scale robots. However, most microrobots that are driven by power-dense rigid actuators have not achieved insect-like collision resilience. In this talk, I will present our recent effort in developing a new class of microrobots - ones that are powered by high bandwidth soft actuators and equipped with rigid appendages for effective interactions with environments. The robot's maximum lift is comparable to that of the best rigid-driven sub-gram robots, and it can demonstrate a 40-second hovering flight. In addition, the robot is resilient against in-flight collisions and severe damage caused by piercing or burning. Furthermore, the robot can demonstrate acrobatic maneuvers such as a somersault in 0.16 seconds. This work demonstrates for the first time that soft aerial robots can achieve agile and robust flight capabilities absent in rigid-powered micro-aerial vehicles, thus showing the potential of a new class of hybrid soft-rigid robots.

Session 1.2

(abstracts are listed in the order of presentation)

1.2.1 Development of soft wearable pneumatic actuators for variable-stiffness rehabilitative hand splints

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

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

Presentation given by Dr. Valentina Potnik

Developing new types of rehabilitation systems requires new kinds of wearable soft actuators. As an example, so-called dynamic hand splints are used to perform rehabilitations of the hand, by applying forces that oppose voluntary movements of fingers. These systems consist of wearable structures equipped with springs or elastic bands, which exert passive resistance to voluntary movements. They enable self-rehabilitation exercises, for patients affected by motor disorders of the hand but still having residual ability to move fingers. This approach is limited by the impossibility of controlling the counteracting action in real-time, which could improve the rehabilitation efficacy, by tailoring the resistance according to different strategies and the actual performance of the patient. This need can be addressed by replacing the passive elastic components with soft actuators. In order to address this issue with a solution relying on compact and lightweight devices, this presentation shows ongoing developments in our lab on soft wearable pneumatic actuators. The devices are linear elongating actuators based on the so-called inverse McKibben configuration. The presentation will describe the fabrication and characterization of the actuators, as well as their use in combination with dielectric elastomer-based capacitive strain sensors, so as to continuously monitor their deformation and implement suitable control strategies.

1.2.2 Characterizations and inkjet printing of carbon black electrodes for dielectric elastomer actuators

Jianan Yi (1), Frank Babick (2), Carsten Strobel (1), Samuel Rosset (3), Luca Ciarella (1), Dmitry Borin (4), Katherine Wilson (5), Iain Anderson (3) (5) (6), Andreas Richter (1), Markus Henke (1) (5) (6),

(1) TU Dresden, Institute Of Semiconductors And Microsystems (IHM), Dresden, Germany
(2) TU Dresden, Institute Of Process Engineering And Environmental Technology, Dresden, Germany
(3) The University Of Auckland, Auckland Bioengineering Institute, Auckland, New Zealand
(4) TU Dresden, Institute Of Mechatronic Engineering, Dresden, Germany
(5) PowerON Group, Auckland, New Zealand
(6) StretchSense Ltd., Auckland, New Zealand

Presentation given by Mr. Jianan Yi

Dielectric elastomer actuator (DEA) has been proposed as a promising technology for developing soft robotics and stretchable electronics due to its large actuation. Among available fabrication techniques, inkjet printing is a digital, mask-free, material-saving, and fast technology, making it versatile and appealing for fabricating DEA electrodes. However, there is still a lack of suitable materials for inkjet-printed electrodes. In this study, multiple carbon black (CB) inks were developed and tested as DEA electrodes inkjet-printed on acrylic membranes (VHB). Triethylene glycol monomethyl ether (TGME) and chlorobenzene (CLB) were selected to disperse CB. The inks' stability, particle size, surface tension, viscosity, electrical resistance, and printability were characterized. The DEA with Ink-TGME/CLB (mixture solvent) electrodes obtained 80.63% area strain, a new benchmark for the DEA actuation with CB powder electrodes on VHB. The novelty of this work involves the disclosure of a new ink recipe (TGME/CLB/CB) for inkjet printing that can obtain stable drop formations with a small nozzle (17 µm), high resolution (~25 µm, approaching the limit of drop-on-demand inkjet printing), and the largest area strain of DEAs under similar conditions, distinguishing this contribution from previous work, which is important for the fabrication and miniaturization of DEA-based soft and stretchable electronics.

1.2.3 Mimicking the dynamics of the cell microenvironment via electromechanically active and microporous polyHIPE-PEDOT scaffolds

Franziska Hahn (1) (2), Ana Ferrández Montero (1) (2), Cédric Vancaeyzeele (1), Rémy Agniel (2), Johanne Leroy-Dudal (2), Cédric Plesse (1),

(1) CY Cergy Paris Université, Laboratoire De Physicochimie Des Polymères Et Des Interfaces (LPPI), Neuville Sur Oise, France
(2) CY Cergy Paris Université, Equipe De Recherche Sur Les Relations Matrice Extracellulaire-Cellule (ERRMECe), Neuville Sur Oise, France

Presentation given by Ms. Franziska Hahn

In vivo, cells are surrounded by an extracellular matrix (ECM). Signals from the ECM such as biochemical or biophysical cues regulate cell behavior significantly. Although, 3D cell cultures offer biologically superior structures, there is still a lack in the transmission of dynamic mechanical signals that exist in the microenvironment of cells in vivo. The aim of this work is to develop a 4D microporous and electroactive scaffold as an innovative cell culture platform that enables the in situ electromechanical stimulation of cells and monitoring of the cell behavior. For this purpose, a 3D microporous scaffold is obtained from the polymerization of a high internal phase emulsion template. This so called polyHIPE is characterized by a high interconnectivity and a suitable porosity for a rapid cell colonization. In a further step the polyHIPE-scaffold is functionalized with a conducting polymer, the poly(3,4-ethylenedioxthiophene) (PEDOT). The functionalization leads to a 4D electroactive polyHIPE-PEDOT scaffold with stimuli-responsive properties such as changes in shape, morphology and pore size under external stimulation. Our results show that the stimulation process is reversible, stable and generates volume variations up to 10% on the scaffolds. Furthermore, the polyHIPE-PEDOT scaffolds support cell adhesion, spreading, migration and the cell viability is not affected by 5h of electromechanical stimulation.

1.2.4 Harnessing the fringe capacitive field to enhance perforated electrostatic 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 Mr. Visva Moorthy

Electrostatic zipping actuators are synonymous with microelectromechanical systems (MEMS) but recently they have been realised as dielectrophoretic liquid zipping actuators (DLZ). These bring the high efficiency, fast response times and high power density of MEMS electrostatic actuators to the macro-scale. However, for DLZ actuators to achieve their maximum contractile force a bead of liquid dielectric must be present at the zipping point, where the anode and cathode converge, and must move as this point 'zips' along the length of the electrodes when a voltage is applied. With their current design, DLZ actuators cannot prevent this liquid leaking out which diminishes their long-term performance and prevents their use in medical and wearable applications. In this work we present a scalable general solution for liquid retention in DLZ actuators of all geometries. Our solution uses a thin reservoir placed beneath an electrode which has a perforated surface. Experimentally, we found that the dielectrophoretic force was sufficient to move droplets of a high-breakdown strength liquid from the reservoir up to the electrode surface. We harnessed the fringe capacitive field to minimise the loss of force caused by the reduced conductive electrode area from the perforations: Our results show a negligible reduction in force (0.1-1%) compared to the control (4-33%) despite a significant reduction in conductive area (4-33%) by optimising the size and spacing of the holes.

1.2.5 Dielectric elastomer sensors adapted for monitoring expansion of clamped battery cells

Johannes Ziegler (1), Detlev Uhl (1), Holger Böse (1),

(1) Fraunhofer ISC

Presentation given by Mr. Johannes Ziegler

Condition monitoring of Li-ion cells in battery packs for electric vehicles is becoming increasingly important, not only in terms of safety, but also with respect to predictive maintenance and recycling applications. In addition to measuring pack temperature and electrical properties of the cell, monitoring cell expansion in a stacked battery pack provides critically valuable information about the health condition of the cell. Indeed, the cell volume effectively changes during charging and discharging, but also gradually does so irreversibly due to the cell aging. This work shows the development of a dielectric elastomer sensor (DES) system specifically adapted for monitoring the expansion of clamped Li-ion cells. By attaching special elastomer-based structures on both sides of an elastomer film, a thin and soft deformation sensor is realized. Different sensors composed of different elastomer structures were investigated and compared in order to guide the development of the optimal configuration leading to the requested deformation range of the battery cell. The sensor characterization was performed by applying a controlled deformation and by simultaneously recording the sensor signal. Cycling experiments using a sensor array in a clamped setup with the battery cell showed that its expansion could be monitored with high precision during charging and discharging, thereby exposing the great potential of such approach in the field of condition monitoring of Li-ion battery cells.

1.2.6 Design of advanced solid polymer electrolyte for soft actuators and sensors

Cedric Vancaeyzeele (1), Khoa Bui (1) (2), Fengdi Li (1), Bin Ni (1), Giao T. M. Nguyen (1), Chaoying wan (2), frederic vidal (1), cedric plesse (1),

(1) Laboratoire De Physicochimie Des Polymères Et Des Interfaces (LPPI), I-Mat, CY Cergy Paris Université, 95000, Neuville Sur Oise Cedex, France.
(2) International Institute For Nanocomposites Manufacturing (IINM), WMG, University Of Warwick, CV4 7AL, UK

Presentation given by Dr. Cedric Vancaeyzeele

Healable, reprocessable and weldable solid electrolytes were designed thanks to vitrimer chemistry. They were integrated as components of ionic actuators, dielectric actuators (DEA) or used as piezoionic strain-sensors. For ionic actuators, they play the role of ion reservoir during the redox process of the electronic conducting polymer to ensure electroneutrality or are coated on carbon nanotube (CNT) yarn electrodes to finally transduce these electrochemical driven processes into device volume variations. For this application, we have designed Ionogels and polymeric ionic liquid (PIL). Ionogels consist of an ionic liquid confined in a crosslinked polymer network whereas PILs rely on either ionic liquid-like anions or cations fixed to the polymer backbone. We especially take advantage of an intrinsic feature of PILs in the case of in open air working CNT actuator. The grafted ions turn them de facto into ion selective and conductive materials. A wise combination of PILs and ionic liquid resulted in CNTs actuators with a large linear contractile stroke of around 10%. In the framework of DEA, the vitrimer ionogel showed excellent conductivity, flexibility and appeared as promising electrodes. It could also be used as piezoresistive strain sensor as it shows a fast, linear and repeatable correlation between resistance variation and strain ratio.

1.2.7 Carbon nanotube yarn/eutectogel artificial muscles for electroactive textiles

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

(1) LPPI, Science And Engineering/Cergy Paris University, Neuville-sur-Oise, France
(2) CEA Saclay, Fontenay-aux-Roses, France

Presentation given by Ms. Gabriela Ananieva

In the field of soft transducers, there is a strong demand for electrochemically driven artificial muscles that provide fast actuation and a large contractile stroke. These muscles can be integrated into textiles and used for prosthetics, soft robotics, wearables, and exoskeletons. Their working mechanism relies on the combination of an electroactive yarn and an ion source. When stimulated under low voltage, ions charge the surface of the yarn leading to large, reversible tensile deformation. Coiled yarns spun from carbon nanotubes (CNTs) are commonly used due to their high electronic conductivity, large contractile stroke, high surface capacitance, mechanical robustness, and commercial availability. On the other hand, ionogel coatings provide the ionic conductivity and mechanical properties, required for open air actuation, but their toxicity raises concerns. Gels containing deep eutectic solvents (DES) as electrolytes (eutectogels) are an excellent alternative, as they have properties analogous to these of ionogels, but are more environmentally friendly. In this work, eutectogels are synthesized in a one-step photopolymerization process, and have an average ionic conductivity of 0.6 mS cm-1, as well as high stretchability. These properties can be tuned based on the selection of hydrogen bond donors and acceptors. The gels are to be coated on coiled CNT yarns with variable morphologies to establish the most optimal structure-property relationship for the application.

1.2.8 Silicone based electroadhesion actuators with various electrode geometries and a modified non-sticky surface

Johannes Ehrlich (1), Lukas Heydecker (1), Marie Richard-Lacroix (1), Gerhard Domann (1), Tetjana Shinkar (1), Holger Böse (1),

(1) Fraunhofer-Institut Für Silicatforschung, CeSMA, Würzburg, Germany

Presentation given by Mr. Johannes Ehrlich

In recent years, electroadhesion has become a prominent branch of the field of electro-active polymer (EAP) actuators. Based on stretchable silicone substrates, it supplements conventional dielectric actuators (DEA) by acting as a simple add-on to generate large holding or grasping forces on an object. As the DEA itself provides displacement possibilities, the combination of movements and adhesion inherently paves the way for soft robotic applications. Here, investigations of the electroadhesive shear force of stretchable silicone-based structures interacting with different flat objects (paper-based, metallic conductive and polymer-based objects) are presented. For each, various oscillation frequencies of the applied voltage and interdigital electrode geometries have been tested. The electrode structures on the silicone substrate are created from laser-ablating flat electrode material and subsequent coating of a 120 µm thick silicone layer, which acts as a dielectric. Surfaces have been further modified to reduce the intrinsic stickiness of silicone materials (which is detrimental to objects release) to a minimum while maintaining the electroadhesion effect. All tests are performed with a constant horizontal movement of the object from the fixed electroadhesive surface. With an overall electroadhesive electrode area of 40 x 50 mm and an applied voltage of up to 5 kV, relatively high shear forces of 3 N (polymer), 5 N (paper-based) and 12 N (metallic conductive) are reached.

1.2.9 Polypyrrole coated wet-spun pedot: pss fibres and their electromechanical performance

Mathis Bruns (1) (2), Andreas Nocke (1) (2), Iris Kruppke (1) (2), Chokri Cherif (1) (2),

(1) ITM TU Dresden
(2) RTG 2430 Interactive Fiber Rubber Composits

Presentation given by Mr. Mathis Bruns

Electromechanically Active Polymers (EAP) offer great potential as alternative driving and sensing concepts for various applications like soft-robotics, exoskeletons or active prostheses. Due to the similarity to natural muscles, fibre shaped EAP are of great interest for flexible and tailored incorporation in various actuating devices. Conductive Polymer (CP) Actuators work by migration of ions in and out of the polymer network, which is induced by reduction or oxidisation of the CP. These redox processes depend, among other parameters, on the CP's electron conductivity. Since the electrical conductivity of wet-spun PEDOT: PSS fibres has been significantly improved by post-treatment with concentrated sulphuric acid in recent years, these fibres are even more promising for reasonable actuation performance. This work therefore covers the production of highly conductive PEDOT: PSS fibres via an automated wet-spinning process and post-treatment of the fibres with concentrated sulphuric acid. Furthermore, polypyrrole is electrodeposited on the PEDOT: PSS fibres. The electromechanical performance of the coated and pristine PEDOT:PSS fibres is compared and evaluated.

1.2.10 Optically reconfigurable electrode architectures for shape morphing dielectric elastomer actuators

Gino Domel (1), Ehsan Hajiesmaili (1) (2), David Clarke (1),

(1) Harvard University, School Of Engineering And Applied Sciences, Cambridge, United States
(2) Meta, Reality Labs, Redmond, United States

Presentation given by Mr. Gino Domel

By careful design of electrodes in multilayer dielectric elastomer actuators (DEAs), a variety of 3D shape morphing geometries can be achieved by applying a voltage. The shape morphing depends on local internal electric fields, is fully reversible, and can also be achieved in arrays of individual DEAs. These morphing functionalities extend the capabilities of DEAs but at the expense of complexity of the physical wiring. In this work, we describe a novel reprogrammable and optically addressable electrode architecture for DEAs and DEA arrays based on embedding photoconductive zinc oxide nanowires in combination with carbon nanotubes (CNTs). Normally, the network of zinc oxide nanowires is electrically insulating but becomes conducting in the presence of UV light. Taking advantage of this, we create an addressable electrode design, in which stripes of non-overlapping CNT regions are covered with, and electrically connected to, sheets of photoconductive zinc oxide nanowires. When a voltage is applied, the multilayer actuator responds in a deterministic manner that depends on the permanent electrode structure. When, in addition, areas of the zinc oxide nanowires are illuminated by UV, the local electrode structure is modified creating overlapping conductive regions and new local capacitor structures. In this way, novel DEA structures and actuator responses can be created, and the electrode architecture can be optically reconfigured enabling local control of the DEA actuation.

1.2.11 Design and Evaluation of a Novel Soft Capacitive Sensor for Accurate Tactile Sensing in Robotic Applications

Masoumeh Hesam Mahmoudinezhad (1), Derek Orbaugh (1), Antony Tang (1), Iain Anderson (1),

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

Presentation given by Ms. Masoumeh Hesam Mahmoudinezhad

This paper proposes a novel soft capacitive sensor design for robotic applications that require tactile sensing capabilities, such as the manipulation of fragile objects. The sensor is based on an interdigitated electrode patterned on a commercial printed circuit board and a deformation-sensitive composite, which makes it easy to fabricate and highly sensitive to low-range compression loads. Unlike traditional dielectric elastomer sensors, this design does not require a compliant electrode or complex fabrication methods. The proposed sensor has a fast response and can measure different compression load ranges with high sensitivity, making it versatile for use in various robotic applications. Experimental results confirm the high sensitivity of the proposed sensor to low-range compression loads, demonstrating its effectiveness in accurately measuring different compression load ranges. This design has great potential for use in robotic applications that require accurate and sensitive tactile sensing capabilities.

1.2.12 Pyroelectricity in polar polynorbornenes-based stretchable elastomer composites

Thulasinath Raman Venkatesan (1), Francis Owusu (1) (2), Frank A. Nüesch (1) (2), Dorina M. Opris (1) (3),

(1) EMPA Swiss Federal Laboratories For Materials Science And Technology, Laboratory Of Functional Polymers, Dübendorf, Switzerland
(2) EPFL, School Of Engineering, Lausanne, Switzerland
(3) ETH Zürich, Department Of Materials, Zürich, Switzerland

Presentation given by Dr. Thulasinath Raman Venkatesan

The currently available pyroelectric devices are mostly based on ceramic materials, which limits their flexibility and applicability to large and non-uniform surface areas. On the other hand, fluorinated polymers such as polyvinylidene fluoride and its co-polymers, which show pyro- and piezoelectricity, are environmentally unfriendly and suffer from limited stretchability. Composites prepared by introducing polar amorphous polynorbornene filler particles in a PDMS matrix exhibit piezoelectric behaviour with a quasi-stable transverse piezoelectric coefficient (d31). By poling the filler particles above their glass-transition temperature and cooling down the composites to room temperature (RT) under the influence of the field, the polarization in the filler particles can be frozen within the PDMS matrix. Hence, when subjected to sinusoidal temperature variation at RT, they show pyroelectric behaviour. For a maximum applied electric field of 30 V/micrometer, a dynamic pyroelectric coefficient of 0.54 microC/m2 was obtained. The polynorbornene particles, in comparison, showed a higher pyroelectric coefficient of 1.5 microC/m2 for an applied electric field of 25 V/micrometer. These novel pyro- and piezoelectric elastomers could be used as pyroelectric energy generators or as sensors taking advantage of their stretchable nature in combination with flexibility and easy processing.

1.2.13 Multi-layer capacitive strain sensor based on dielectric elastomers

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Presentation given by Mr. Artem Prokopchuk

In recent years, traditional machine elements have been enhanced with new capabilities through the integration of sensors. One of the core components of machines are couplings. To transform couplings into "smart" machine elements, sensor integration is necessary. Due to the requirement for high deformation in the built-in sensors, a dielectric elastomer sensor (DES) concept was implemented in a deformable elastic cam ring gear. In this work, we present the manufacturing process and layout of stacked multi-layer capacitive strain sensor (ML-DES), in the form of an electric multi-layer capacitor. The ML-DES design includes an elastomeric substrate with alternating layers of silicone-based conductive ink as capacitor plates, and an elastomeric film as dielectric and electrical insulation. To assess the stacking process, various thin ML-DESs with four electrode layers were fabricated and tested using a tensile testing machine and an LCR meter. The study reveals that the viscoelasticity of the dielectric elastomer material impacts the behavior of capacitance change. Comparing stacked and non-stacked sensors, it was observed that the capacitance change of the stacked sensor is more stable.

1.2.14 Millimeter-scale swimming robots powered by soft electrohydraulic actuators

Florian Hartmann (1), Herbert Shea (1),

(1) EPFL, Soft Transducers Laboratory (LMTS), Neuchatel, Switzerland

Presentation given by Dr. Florian Hartmann

Undulating fin and tail propulsion-used by marine animals across many size scales-represents an efficient locomotion method, both on and underwater. It is silent and enables a variety of maneuvers. Robotic swimmers can achieve such life-like locomotion using soft actuators but typically measure several tens of centimeters, preventing applications that benefit from smaller scales. Here we present the design, material approaches, and fabrication processes of soft millimeter-scale electrohydraulic actuators. Our actuators use zipping of metalized polymer films to displace a dielectric fluid, which generates the bending of fins, creating a periodic undulation. We developed a fabrication strategy based on multilayer lamination to enable actuators that operate reliably when submerged in water at 500 Volts to 2000 Volts. The actuators are fast, capable of operation up to 100 Hertz, and provide suitable amplitudes for swimming, with bending angles up to 15 degrees. With these actuators, we demonstrate flatworm-inspired robots, only a few tens of millimeters long, that locomote both on or under water.

1.2.15 Biodegradable electrohydraulic actuators for sustainable soft robots

Ellen Rumley (1) (2), David Preninger (3) (4), Alona Shagan Shomron (1), Philipp Rothemund (1) (2), Florian Hartmann (3) (4), Melanie Baumgartner (3) (4), Nicholas Kellaris (2) (5), Andreas Stojanovic (3) (4), Zachary Yoder (1), Benjamin Karrer (1) (3) (4), Christoph Keplinger (1) (2) (5), Martin Kaltenbrunner (3) (4),

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Presentation given by Ms. Ellen Rumley

Mitigating environmental pollution requires a sustainability-minded approach, in particular from emerging technologies with wide applicability in modern societies. Soft robotics is one such technology that may replace conventional rigid machines where adaptability and dexterity are essential. For key components of soft robots, such as soft actuators, it is important to seek sustainable options like bio-derived and biodegradable materials. Here, we introduce systematically-determined and compatible materials systems for the design of fully biodegradable, high-performance electrohydraulic soft actuators, based on biodegradable polymer films, ester-based liquid dielectric, and sodium chloride-infused gelatin hydrogel. Biodegradable actuators can operate at high electric fields of 200 V/µm, perform comparably to non-biodegradable counterparts, and survive over 100,000 actuation cycles, proving that biodegradability does not inhibit actuation performance. Lastly, we use biodegradable actuators to actuate a robotic gripper that is readily compatible with commercial robot arms, demonstrating the wide applicability of biodegradable materials systems in soft robotics.

1.2.16 A system architecture for modular high-speed electrohydraulic soft continuum robots

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Presentation given by Mr. Ingemar Schmidt

Continuum arms, like an elephant trunk or octopus limb, are among the natural world's most effective appendages, owing to their speed, strength, dexterity, and versatility. These advantageous properties also make them difficult to replicate with robots. Continuum robots made with traditional rigid hardware have demonstrated high strength, but fall short in efficiency and compliance. Soft robotic systems including pneumatics and other novel soft technologies have achieved various combinations of strength, speed, and high strain, but require bulky driving systems to achieve high performance. Hydraulically Amplified Self-healing Electrostatic Actuators (or HASELs) are artificial muscles with high power, efficiency, and compliance, and may be an effective solution for continuum arms. We have developed a soft, efficient, and high-speed continuum arm actuated by HASELs. The robot arm is composed of modular units for rapid reconfiguration and repair, and achieves high strain and rapid movement with low power draw. It is manufactured with materials and methods accessible to a typical robotics lab. Via modularity, an accessible fabrication pipeline, and desirable performance, we aim to provide the scientific community with an effective dynamic testbed for novel control approaches for soft robotic systems and robotic applications.

1.2.17 A multifunctional soft robotic shape display with high-speed actuation, sensing, and control

Brian Johnson (1) (2), Mantas Naris (1), Vani Sundaram (1), Angella Volchko (1), Khoi Ly (1), Shane Mitchell (1) (3), Eric Acome (1) (3), Nicholas Kellaris (1) (3) (4), Christoph Keplinger (1) (2) (4), Nikolaus Correll (5), Sean Humbert (1), Mark Rentschler (1),

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Presentation given by Dr. Brian Johnson

Shape displays are an expanding robotics domain with applications to haptics, manufacturing, and aerodynamics. Existing displays often lack high-fidelity shape morphing, high-speed deformation, and embedded state sensing, limiting their potential uses. Here, we present a multifunctional soft shape display driven by a 10x10 array of scalable cellular units combining electrohydraulic actuation, magnetic-based sensing, and control circuitry. We report high-performance metrics including actuation speeds up to 50 Hz, sensing of surface deformations with 0.1 mm sensitivity, and sensing of external forces with 50 mN sensitivity in each cell. We demonstrate applications in user interaction, image display, sensing of object mass, and dynamic manipulation of solids and liquids, showcasing the high-performance multifunctionality that arises from tightly-integrating large numbers of actuators, sensors, and controllers at a previously undemonstrated scale in soft robotics.

1.2.18 Yarn actuators powered by electroactive polymers for wearables

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(3) Department Of Management And Engineering (IEI), Solid Mechanics, Linköping University, Linköping, Sweden

Presentation given by Dr. Shayan Mehraeen

Electroactive polymer coated yarns have shown a great promise in preparation of textile actuators for applications in smart wearables. The efficiency of the textile actuators is governed by the effectiveness of the individual coated yarn actuators. The current challenge in textile actuators is the limited force or strain of the individual yarns. One key player here is the core yarn. In this study, we have investigated how the strain of individual yarn actuators is affected by the properties of the core yarn. Four commercial yarns were coated with conducting polymers including poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) and polypyrrole (PPy). Then their isotonic and isometric actuation performances were investigated in a liquid electrolyte. The results showed actuation strain and force as great as 1 % and 95 mN, respectively. Finally, a mechanical model was developed to explain the relationship of observed isotonic strain with isometric force according to the yarn's mechanical properties.

1.2.19 A method to measure and optimize full cycle electrostatic-mechanical efficiency of soft electrostatic actuators

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Presentation given by Dr. Steven Zhang

Actuators are a key component of all robotic systems, which have potential to improve human lives. Energy Efficiency is a critically important metric for soft mobile robotic systems. The field of soft electrostatic actuators is missing an universal, easy-to-implement tool and a standard that allow measurement and analysis of an actuator's intrinsic electrostatic-mechanical performance. Thus, in this work, a method to measure and optimize the efficiency of soft actuators are developed, where the four work conjugate parameters: voltage, charge, force, and displacement, can be monitored in real time. The full cycle efficiency of electrostatic actuators can be calculated by dividing the area enclosed in the force-displacement plane and the area enclosed in the charge-voltage plane. We demonstrate our method using HASEL Actuators as a model system, and both the intrinsic electrical loss, and intrinsic mechanical loss were studied, and these two losses are a key in understanding the full cycle electrostatic-mechanical efficiency. The full cycle efficiency was then calculated at different voltages, forces, cycle speed, and different material combinations for HASEL, such as different plastic films and oils. It was found that there is an optimal force for high efficiency, and based on the results, full cycle efficiency of 58% was reported, which is the highest reported for HASEL Actuators.

1.2.20 Design, modeling, and control of a high voltage driving circuit for dielectric elastomer actuators

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Presentation given by Ms. 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. Moreover, to achieve fast and accurate control of the voltage delivered to the DEA, the development of dynamic models capable of accurately describing the response of the driving circuit is of fundamental importance. This work presents on design, modeling, and control of a novel high voltage driving circuit for DEAs. The developed electronic consists of a combination of a charging stage (i.e., a cascade of a resonant converter and a rectifier Greinacher circuit) and a discharging stage. The circuit 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 PWM signal. Experimental validation of the model is carried out based on a variety of sine and square wave input signals. The results show a good agreement between experiments and dynamic model, with an accuracy not lower than 80% up to a driving frequency of 100 Hz. In addition, to achieve fast and accurate control of the output voltage delivered to the DEA, a model-based feedback law is developed and preliminarily validated through numerical simulations

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

1.3.1 A bi-stable soft robotic bendable module driven by silicone dielectric elastomer actuators: design, modeling, self-sensing, and position control

Giovanni Soleti (1), Johannes Prechtl (1), Matthias Baltes (2), Julian Kunze (2), Stefan Seelecke (1) (2), Gianluca Rizzello (1),

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(2) Center For Mechatronics And Automation Technologies (ZeMA) GGmbH, Saarbrücken, Germany

Presentation given by Mr. Giovanni Soleti

In this work, we present on design, modeling, control, and self-sensing of a soft robotic module actuated by dielectric elastomer actuators (DEAs). The structure consists of a flexible backbone capable of continuously bending along a plane, having a rigid plate connected to its top. When actuated via high voltage, the rolled DEAs expand and the structure bends along a desired direction. The structure is able to achieve large bending displacement thanks to a bistable design concept, whose optimal design is guided by means of a physics-based model of the system. The bistability, however, causes the system to exhibit an unstable behavior in open-loop. To keep the advantage of bistability without losing proportional positioning, an energy-based position control approach has been developed. The proposed control law permits to stabilize the position of the structure in every admissible position, while accounting for the structure strong nonlinearities, underactuation, and limited control input. Furthermore, to estimate the configuration of the soft-robotic module without additional position sensors, a system-level self-sensing has been developed. The self-sensing algorithm uses as input the lengths of the DEAs, estimated with voltage and current measurements via actuator-level self-sensing, and provides as output the robot configuration of the robot by means of an extended Kalman Filter. Such method will enable future self-sensing based control of DEA-driven soft robotic systems.

1.3.2 Empty slot

1.3.3 A multi-mode dielectric elastomer user interface with self-sensing capability

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Presentation given by Dr. Giacomo Moretti

We recently proposed a principle to control dielectric elastomer (DEs) actuators in a way that a multi-mode operation is possible. Applying a multi-harmonic voltage to a DE actuator allows generating a separate linear motion of an end-effector (at low frequencies - LFs), and a structural vibration of the active membrane (at high frequencies - HFs - in the acoustic range). This principle allows building multi-mode user interfaces that can be controlled through a single input voltage. We present a concept and an experimental demonstration of an audio-tactile interface (push button) that leverages the abovementioned principle. The interface consists of a multi-layer DE membrane pre-stretched against a nonlinear spring, and it makes use of LF voltage components to generate tactile stimuli on a user's finger, and HF components to produce an acoustic feedback. The interface also bears the ability to recognise deformations impressed by users during operation via self-sensing. In contrast with classical self-sensing approaches, where an additional HF signal is superimposed to the main actuation signal, we propose an approach that directly makes use of current measurements associated to the HF component of the actuation signal. The results and concept presented here might allow the development of smart buttons that adapt their tactile or acoustic feedback depending on the user input, and textile-integrated multi-functional elements for guidance or virtual reality applications.

1.3.4 Electro-ribbon actuators with controllable stiffness variation

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

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

Presentation given by Mr. Yuejun Xu

Muscles in biological systems routinely modulate their stiffness to achieve specific functions. Such stiffness variations are essential in real-world applications, such as extending the loading capabilities of artificial muscles. Electrically-activated artificial muscles inspired by biological muscles have been extensively exploited in robotics due to their deformability and inherent compliance. However, developing artificial muscles with the variability and controllability of stiffness equivalent to their biological counterparts remains a challenge. We present a concept for electrostatic zipping actuators integrated with controllable stiffness variation, which expands the muscles' functionalities and improves their static and dynamic response. By independently controlling the actuation and stiffness components, we can vary the actuator's force, stiffness, and damping. This technology offers new versatile and interactive functionalities for applications in various environments, ranging from rehabilitation to grippers.

1.3.5 Valveless Impedance-driven Pump via DEAs

Amine Benouhiba (1), Yoan Civet (1), Yves Perriard (1),

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Presentation given by Dr. Amine Benouhiba

Impedance pumps are simple systems that allow the generation or amplification of flow. They are fluid-filled systems based on elastic tubing connected to tubing with different impedances. A periodic off-center compression of the elastic tubing causes the fluid to move and generate a flow. Wave reflection at the impedance mismatch is the primary driving mechanism of the flow. Here we present an approach to bladeless, valveless soft pumping via dielectric elastomer actuators (DEAs). The design of the soft pump is based on the embryonic heart mechanism, also known as an impedance pump. It consists of three parts: an active DEA tube (pressure wave generator), a passive tube (pressure wave damper), and a decoupling ring connecting the two tubes. The decoupling ring ensures that the motion transfer between the two subsystems is only through the fluid. Furthermore, by adjusting the input signal parameters (frequency, amplitude, etc.), the flow properties can be controlled and adapted to the requirements of the desired application. The high performance of the proposed approach (up to 1.35 litres per minute) has been demonstrated theoretically and experimentally.

1.3.6 Electric field-driven dielectrophoretic elastomer actuators

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Presentation given by Mr. Ciqun Xu

Dielectrophoresis is the electro-mechanical phenomenon where a force is generated on a dielectric material when exposed to a non-uniform electric field. It has potential to be exploited in smart materials for robotic manipulation and locomotion, but to date it has been sparsely studied in this area. Here we describe a new type of dielectrophoretic actuator exploiting a novel electroactive polymer, termed a dielectrophoretic elastomer (DPE), which undergoes electric field-driven actuation through dielectrophoresis. Unique deflection and morphing behavior of the elastomer induced by controlling the dielectrophoretic phenomenon, such as out-of-plane deformation and independence of electric field polarity, are illustrated. The dielectric and mechanical properties of the DPE are studied to gain insight into the influence of materials composition on deformation. Actuation performance using different electrode parameters is experimentally investigated with supplementary analysis through finite element simulation, revealing the relationship between electric field inhomogeneity and deflection. We demonstrate the applications of DPE actuators in a range of robotic devices, including a pump, an adjustable optical lens, and a walking robot. This diverse range of applications illustrates the wide potential of these new soft-and-smart electric field-driven materials for use in soft robotics and soft compliant devices.

1.3.7 Novel soft materials for damping

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Presentation given by Dr. Ingrid M. Graz

Damping plays a key role in our modern society, spanning a wide range of application from shoe soles to wheels and dampers within vehicles, seals in appliances and dampers in bridges and buildings. A similar wide range of damping solutions offers a perfect fit for every application, ranging from hydraulics to structural dampers (such as springs) and rubber with its inherent dissipative nature. Rubber and other soft materials due to their viscoelastic nature are considered perfect dampers - however, even in novel field such as stretchable electronics, damping in form of strain reduction is still not ideal causing mechanical failure due to rigid-soft transitions. Similarly, the plethora of soft materials used in soft actuators seem perfectly suited for energy dissipation, however, also here highly elastic materials prevail. We present some novel approaches for soft damping materials and their characterization based on chemical synthesis or macroscopic structure.

1.3.8 A high throughput in vitro platform for traumatic brain injury

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Presentation given by Mr. Sahan Jayatissa

Mild Traumatic Brain Injury (mTBI) is a leading neurological injuries worldwide, and New Zealand has one of the highest rates among developed countries. While the immediate injury is considered 'mild', the results can include persistent neurological dysfunction and long-term neurodegeneration. The nature of mTBI makes it difficult to study in human patients; hence, an in vitro mechanical assay has been explored as a potential way to study mTBI. We present a high throughput platform (HTP) that utilises an Dielectric Elastomer Actuator (DEA) as a deformable cell culture substrate to provide high strain with fast response times, recapitulating the characteristic strains experienced during an mTBI event. Our HTP conforms to a standard 12-well plate, allowing it to be used in a variety of pre-existing biological apparatus. We conducted experiments using cultured human brain cells isolated directly from patient biopsy specimens to validate the platform. We characterised the strain homogeneity of a culture well by mapping the strain levels induced onto the cells using a registration algorithm with sub-pixel resolution. Our HTP is capable of applying controlled amounts of mechanical insults directly to human brain cells in a high-throughput manner, making it an attractive device for drug and biomarker researcher for TBI.

1.3.9 Equibiaxial cell stretcher based on dielectric elastomer actuator

Simon Holzer (1), Yoan Civet (1), Yves Perriard (1),

(1) Ecole Polytechnique Federale De Lausanne (EPFL), Integrated Actuators Laboratory (LAI), Neuchatel, Switzerland

Presentation given by Mr. Simon Holzer

Cell culture is an important method to understand cells, tissues and their interactions. In addition, they are used to study the effects of drugs on healthy and pathological cells and are thus an alternative to animal experiments. Unfortunately, different drawbacks like cell dedifferentiation can occur in cell culture making research and observation over a longer period of time impossible. Regarding to recent studies, additional stimuli like mechanical stimulus or electrical stimulus can prevent these effects. Therefore, an equibiaxial cell stretcher based on a dielectric elastomer actuator is designed to apply a mechanical stimulus to cells. A characterization of the cell stretcher is given together with a comparison of the influence of the pre-stretch on the maximum strain. The cell stretcher can be actuated by an electrical potential and reaches a maximum equibiaxial strain of 30.5 % at 8 kV. These properties make the device a promising alternative for future cell stretching applications, especially in the case where a uniaxial stimulation is not sufficient. In addition, both sides of the cell stretcher are freestanding and can be used to apply cells, which enables the usage of the device for co-cultures.

1.3.10 Practical insights from transient analysis of layered composite dielectrics

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Presentation given by Dr. Adrian Koh

Our electrohydraulic Peano-HASEL actuators strain-relax under a DC voltage. This is peculiar. More intriguingly, when the voltage is turned off after a while, the actuator re-actuates in the absence of voltage. More than a hundred years ago, James Clerk Maxwell and Karl Willy Wagner studied charge transport through lossy dielectric multilayers, using capacitor-resistor representations for the dielectrics, known as the Maxwell-Wagner (MW) model. They demonstrated that electric charges accumulate at the interfaces between dielectric layers. The rate and amount of accumulated charge depends on the relative dielectric properties of the layers. We adopt this model framework to understand strain-relaxation and re-actuation in our actuators, and identified conditions under which such phenomena will take place. Our model agrees well with our experiments, which provided us with some fundamental understanding required to guide future developments of our actuators and electrostatic-based multilayer transducers in general.

1.3.11 Self-sensing approach based on pure DC current measurement for dielectric elastomer actuators

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Presentation given by Ms. Carmen Perri

Dielectric Elastomer Actuators (DEAs) are soft electro-mechanical transducers with the ability to deform when subjected to an applied voltage. A special feature of DEAs is their self-sensing capability. Classical (AC) impedance measurement requires high precision and dynamics of the amplifier. In order to reduce these requirements, this work investigates the extent to which pure (DC) current measurement is combined with feature detection. In particular, an exemplary system is examined, which is based on in-plane working rectangular-shaped DEAs, that perform uniaxial motion and collide with a mechanical hard stop. Changes in the current flowing through the DEA during deformation, are detected, that indicate the presence of this hard stop. Different experiments, investigating different amplitudes and frequencies of the applied high voltage, as well as different bias mechanisms, are carried out, which demonstrate the effectiveness of this current sensing technique in detecting mechanical stops. The results of this work show that it is generally possible to detect hard stops in a uniaxially actuated DEA system with pure current measurement rather than requiring more sophisticated impedance measurement. It is likely that this measurement method could be applied to further DEA designs in the future and could be used to detect various other features.

1.3.12
Empty slot

1.3.13 Investigating pre-stretch dependent blocked force and capacitive self-sensing in strip DEAs with anisotropic carbon fiber-reinforced electrodes

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(2) Technische Universitaet Dresden, Institute Of Control Theory, Dresden, Germany

Presentation given by Mr. Markus Koenigsdorff

Anisotropic fiber reinforcement was shown to be a way to increase the uniaxial electro-active strain of planar strip DEAs. However, the influence of the anisotropic layer on the blocked force has not been extensively investigated yet. Within this work, strip DEAs with a highly anisotropic carbon fiber composite electrode are manufactured and a measurement regime to investigate the pre-stretch dependent blocked force is carried out. Furthermore, the capacitive self-sensing capabilities of the structure are investigated. Capacitance is measured by an MPR121 capacitance board connected to an Arduino, which allows miniaturized electronics for portable, autonomous applications. Due to the high stiffness of the carbon fibers, the silicone film additionally can be pre-stretched uniaxially before the electrode is bonded to the material. The stretch is then supported by the fiber-reinforced electrode. Accordingly, there are two independent pre-stretches - the constant in-fiber pre-stretch applied during manufacturing and the variable pre-stretch perpendicular to the fiber direction, both of which have influence on the blocked force. The measured forces are then compared to a simple analytical model, allowing the evaluation of the actual anisotropic properties present in the dielectric. The presented concepts are of importance for the development of complex biomimetic systems, as they provide necessary tools to successfully integrate planar strip DEAs as artificial muscles.

1.3.14 Optimisation of EAP based tape yarns

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Presentation given by Dr. Jose G. Martinez

Actuating wearable textiles are of great interest in fields such as haptics or assistive devices. Soft actuators based on electroactive polymers are being merged with yarn and fabric technology to obtain actuating fabrics. Here we present the latest optimisation on polypyrrole-based actuators that can be incorporated into textile processing. The processes involved there impose extra requirements to the actuators such as the required size, improved mechanical and electrochemical stability, actuation in air or the use of low/non-hazardous materials so they can be worn safely. The optimisation of tape yarn actuators composed of polypyrrole/ionically conducting layer/polypyrrole regarding applied potential, ionic liquid/electrolyte used, electropolymerisation conditions or frequency of movement will be presented.

1.3.15 The effect of enzyme immobilization methods in polypyrrole-based soft actuators driven by glucose and O2

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Presentation given by Dr. Jose G. Martinez

Electroactive polymer-based actuators are of great interest for small implantable and wearable devices due to their low power consumption. To date, these actuators have been driven by external power sources. Enzymatic biofuel cells are great candidates for wirelessly powering such small devices by integrating them one to another. Glucose oxidase and laccase enzymes embedded in the actuator and in presence of glucose and O2 have been proven to enable actuating these artificial muscles. The immobilization method of the enzymes plays an important role in the power generated by biofuel cells and therefore in the motion of the actuator, yet it has not been investigated. Here, we present the effect of the enzyme immobilization methods on polypyrrole-based trilayer actuators driven by glucose and O2. The glucose oxidase and laccase enzymes are immobilized with the following techniques: surface adsorption, chitosan entrapment, crosslinking with bovine serum albumin (BSA) protein, poly(carbamoylsulfonate) (PCS)-based hydrogel encapsulation, and entrapment in the polypyrrole matrix during the electropolymerization. The immobilized enzymes in contact with glucose and O2 will provide the polymer with the electron flow needed to reduce and oxidize, resulting in the shrinking and swelling of the opposing sides, creating the bending movement. The latest results will aid the development of more complex biofuel-embedded artificial muscles for implantable and wearable devices.

1.3.16 Electro-adhesive performance comparison of commercially available dielectric films

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Presentation given by Dr. Federico Bertolucci

As demonstrated in the literature of the past decade, Electro-adhesion (EA) could provide significant benefits as a grasping technique in industrial production lines. Due to its low power consumption, adaptability in grabbing a lot of different materials and the low-cost manufacturing procedure, EA is a promising candidate to substitute vacuum suction and mechanical prehension mechanisms, especially when dealing with soft and fragile objects and porous materials. The easy and low-cost production process is a key factor in the realization of a gripping device for industrial applications and the choice of the material, in the first instance, plays a crucial role. This work proposes a comparison of the electro-adhesive performances of three different commercially available dielectric film materials. To do so, two comb-shaped

Ag-based electrodes (interdigital geometry) are inkjet printed on the target dielectric film material and isolated with a thin layer of blade-casted PDMS. The comparison focuses on the electro-adhesive shear stress performance, dielectric strength resistance and energy consumption. For each material, pros and cons are highlighted and some suitable applications are given, based on the costs, mechanical and electrical properties, and hypothetical environmental conditions.

1.3.17 3D printing soft microrobot

Si-Qi Wang (1) (2), Shayan Mehraeen (1), Edwin Jager (1)

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(2) Northeastern University, School of Material Science and Engineering, Shenyang, China

Presentation given by Siqi Wang

Three-dimensional (3D) printing is an additive manufacturing process, which can fabricate sophisticated and complex geometries without subsequent cutting process, with advantages of material saving and shape freedom. 3D printing of soft microrobot is a strategy to combine soft actuator materials and 3D printing technique together, which may integrate the actuating part and unactuating part in one device, no need to assemble different parts together. In addition, it has potential to scale down to millimeter and even micrometer scale to access complex and narrow areas in the human body in a minimally invasive manner. Herein, we designed and fabricated a fully 3D printed microrobot with multiple materials by using a direct writing 3D printer. The micro robot is made of soft body and six individually controlled actuating legs, with printed circuits embedded inside. Under the programmed low voltage stimulation of 1-3V, it performs different actions like standing up, getting down, push-up action, dancing and walking on the table.

1.3.18 PDMS fiber actuator with ionic liquid-based electrodes

Zhaoqing Kang (1), Liyun Yu (1), Anne Ladegaard Skov (1),

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Presentation given by Mr. Zhaoqing Kang

Due to the linear response to an external electrical stimulus, dielectric elastomers show great potential as artificial muscles. In this work, we demonstrate a continuous preparation of polydimethylsiloxane (PDMS) hollow fibers through a coaxial spinning method utilizing a rapid thiol-ene photocuring reaction. The developed PDMS fiber with an external diameter of ~460 µm and uniform wall thickness of ~80 µm, shows significantly increased tensile strain of ~600 % and strength of 0.62 MPa compared to these of the planar film (86 % tensile strain and 0.14 MPa strength). To assemble the fiber actuator, an ionic liquid core electrode is injected and then coated with ionogel or carbon grease as the outer electrode. The fiber actuator with ionogel presents a high transparency of ~90 % in a visible light spectrum. The fiber actuator exhibits a sizeable linear strain of 9 %, and repeatable and stable linear actuation strain over 1000 cycles. Moreover, the fiber actuator is employed in weight-lifting systems constructed using Lego models. The loading weight and displacement are regulated using suitable fiber lengths and bundles. Additionally, when actuated in an ionic liquid electrolyte, the PDMS fiber actuator exhibits remarkable actuation strain (10 %) and fast response (0.1 s). Furthermore, the PDMS fiber actuator can also serve as a microfluidic pump, displaying remarkable pumping capabilities.

EuroEAP Society Challenge and Toyota Innovation Award Projects

(listed in the order of presentation)

Project title	**Team Leader**	**Institution**
The digital sense of touch as the key to automation	Steffen Hau	Delfa Systems GmbH
A versatile jellyfish-like robot powered by electrohydraulic actuators	Christoph Keplinger	Robotic Materials Department, Max Planck Institute for Intelligent Systems
Wave field synthesis for spatially individual sound using dielectric elastomer loudspeakers	Michael Gareis	Technical University of Berlin
3D soft touch pad enabled by vision-based mechanochromic sensing	Giacomo Sasso	Queen Mary University of London
Technology Demonstrator of Dielectric Elastomer Actuator Systems with Different Shapes and Preload Configurations	Paul Motzki	Saarland University, Department of Systems Engineering
Hybrid soft-rigid joint with inherent sensing and actuation capabilities based on rolled dielectric elastomers"	Paul Motzki	Center For Mechatronics And Automation Technologies (ZeMA) GGmbH, Department Systems Engineering

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Wednesday 07 June 2023

Session 2.1
(abstracts are listed in the order of presentation)

2.1.1 Hybrid electroactive polymers for wireless actuation, pumping and sensing

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Presentation given by Prof. Alexander Kuhn

Actuation of electroactive materials is potentially interesting for several applications, from analysis to soft robotics. Here we propose the wireless actuation of conducting polymers triggered by bipolar electrochemistry. In bipolar electrochemistry, a global electric field induces opposite electrochemical reactions at the two extremities of a freestanding conducting polymer layer located in an electrolyte. This results in its controlled deformation due to localized swelling and shrinking. We use this concept in for a large variety of applications, ranging from the electromechanical readout of analytical information to microfluidic pumping and controlled release. Thus the concept of bipolar actuation of conducting polymers opens up interesting new scientific opportunities due to its wireless nature.

2.1.2 Fundamental concepts of textiles and opportunities for actuation

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Presentation given by Dr. Nils-Krister Persson

Actuation based on electroactive polymers offers low weight, electrical control, high degree of integrability and a doorway towards all-polymeric-devices. However, still the achieved exerted forces and strains are small which is a drawback for many potential applications, not least from a wearable technology

point of view. We identify textiles as an interesting strategy to scale up both forces and strains. We discuss a number of fundamental characteristics of textiles and textile processes that are of relevance for actuation. Textile fabric making is inherently an additive manufacturing technology built upon the defining building blocks of any textiles, which are yarns. Different functionalization of individual yarns facilitates the creation of complex patterns in both parallel and serial arrangement. This, in turn, enables making actuating devices directly in the loom, minimizing post-processing, highly contributing to both large area and efficient production of actuators. We show how textile assembly can amplify forces. As textiles typically are polymer-based, the vision of all-polymeric-devices can be given support. By employing textile processes for actuation and introducing actuation for textile community, a novel scientific, technological and industrial field emerge.

2.1.3 Silicone Dielectric Elastomer Artificial Muscle Fibers

Anne Ladegaard Skov (1),

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

Presentation given by Prof. Anne Ladegaard Skov

Natural human skeletal muscle fibers, the basic functional unit of the muscular system, provide soft linear motion, enabling humans to achieve excellent mobility. We developed a highly flexible silicone dielectric elastomer fiber inspired by skeletal muscle fibers. The silicone fibers present significant linear actuation and were prepared based on a continuous coaxial spinning method using a photocurable thiol-ene reaction. The fiber has a consistent diameter of 460 µm and uniform wall thickness of 80 µm over multiple meters, and it demonstrates a 7-fold increase in tensile strain and a 5-fold increase in tensile strength compared to a planar film of the same composition. Silicone fiber and bundle actuators are created by using ionic liquid as the core electrode and ionogel or carbon grease as the outer electrode. The actuator presents a strain of around 10 %. Moreover, the linear actuation strain is reproducible over 1000 cyclic actuations. Large actuation displacement (3 cm) and lifting weight (14 g) are achieved by increasing the fiber length to 50 cm and winding up one fiber into a bundle with 22 fibers, respectively. A weight-lifting system with Lego beams demonstrates the high potential of the fiber actuator as an artificial muscle. Additionally, the silicone fiber actuator can also be applied in a liquid condition, such as actuating in an ionic liquid, where actuation strain of 10 % and fast response time of 0.1 s are obtained.

Session 2.2

(abstracts are listed in the order of presentation)

2.2.1 In-vivo experiments of a DEA based cardiac assist device

Thomas Martinez (1), Silje Ekroll Jahren (2), Francesco Clavica (2), Armando Walter (1), Paul Philipp Heinisch (3), Eric Buffle (4), Thierry Carrel (5), Jürgen Hörer (3), Dominik Obrist (2), Yoan Civet (1), Yves Perriard (1),

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(5) University Hospital Zurich, Departement Of Cardiac Surgery, Zurich, Switzerland

Presentation given by Dr. Thomas Martinez

In the domain of cardiac assist devices, classic solutions may consist of pneumatic counterpulsation devices inserted in the aorta that actuates in sync with the heart to decrease its load. We propose an alternative to this pneumatic devices by taking advantage of the assets of dielectric elastomer actuators. They are soft actuators that require no pneumatic line as they are electrically driven and ,contrary to the first solution, they do not block the flow of blood when actuated. The proposed augmented aorta consists of a prestretched multilayer tubular DEA implanted as a replacement of the aorta. When passive, the device mimics the natural behaviour of the aorta. However, when actuated in sync with the heart, the DEA expands and lowers the aortic pressure by storing more blood. When deactivated, the tube releases the stored blood thus increasing the coronary pressure and flow. In this work, we present the in vivo experiments realized on acute pigs to study and quantify the effect of the device on the hemodynamic parameters. We especially focus on the activation timing compared to the opening of the aortic valve. The device provides up to 50 mJ to the cardiovascular system and helps reduce the aortic pressure up to 15 %.

2.2.2 Contractile dielectric elastomer actuators with embedded structured fibres

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(1) Ecole Polytechnique Federale De Lausanne (EPFL), Integrated Actuators Laboratory, Neuchatel, Switzerland

Presentation given by Dr. Thomas Martinez

Implementing dielectric elastomer actuators (DEAs) that mimic natural muscles has been proven difficult, as DEAs provide in-plane expansion when actuated, while natural muscles contract upon stimulation. Multiple solutions can be found in literature, namely stack DEAs and fibre reinforced DEAs. Currently, the fibres used for DEAs to achieve contractile motion rely on a fishnet design, where the angle between the fibres, the spacing, mechanical properties as well as the fibre dimensions can be set by establishing a fibre analytical model. An optimization of the fibre structure is proposed in this study. The use of structured fibre sheets embedded in DEAs is an innovative approach allowing to explore more complex configurations. Structured sheets can be described as materials whose microstructure is controlled in order to achieved a desired macroscopic mechanical and deformative behaviour. Their design is very complex and interesting, and can be performed by mapping the meso-scale mechanical behaviour to the macro-scale behaviour. This work will attempt to introduce a design method for contractile DEAs by embedding soft structured fibres sheet in the actuators. To that end, a computational design known as Topology optimisation (TO) can be used, which is a powerful design approach aiming at an objective by investigating the distribution of the material inside a discretised design space.

2.2.3 A versatile jellyfish-like robot powered by electrohydraulic actuators

Tianlu Wang (1) (2), Hyeong-joon Joo (3), Shanyuan Song (1) (4), Wenqi Hu (1) (4), Christoph Keplinger (3) (5) (6), Metin Sitti (1) (2) (7),

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Presentation given by Mr. Hyeong-joon Joo

Submarine devices are in high demand for underwater scientific studies including exploration, monitoring, footage taking, and sampling. However, typical existing devices are bulky and noisy, resulting in severe interference with their surroundings. Here, we present a soft and noise-free prototype of a jellyfish-like robot enabled by strong yet silent electrohydraulic actuators. The locomotion of this robot generates fluid flow that allows the robot to efficiently propel its body while manipulating objects without contact. The resulting against-gravity speed reaches 6.1 cm/s, which is substantially faster than other reported jellyfish-like robots, while consuming only around 100 mW. The effective actuation mechanism further allows this robot to readily achieve various functions, and several examples are demonstrated including direction changing and grasping of objects. We finally show that several robots can cooperate to accomplish further tasks, and a wireless prototype carrying its own driving electronics is developed. This study introduces key techniques for noise-free underwater propulsion and operation of a versatile jellyfish-like robot, which shows promise for various underwater tasks.

2.2.4 A pilot line to functionalise textile fibres for textile actuators

Claude Huniade (1), Tariq Bashir (1), Nils-Krister Persson (1),

(1) The Swedish School Of Textiles, Polymeric E-textiles, University Of Boras, Boras, Sweden

Presentation given by Mr. Claude Huniade

Textile actuators are at their infancy within the field of electromechanically active polymers. Crude fabric coatings as well as coated pieces of yarns can certainly perform actuation. However, they do not fully consider the capabilities of textiles processes and structures. To allow for such possibilities, it is required to have a sufficient supply of processable functional fibres. The presented pilot line is designed to produce said functional fibres from commercial textile yarns. The three continuous processes composing the pilot line are: the layered dip coating using a PEDOT:PSS based solution, the electrodeposition of polypyrrole (PPy) onto the PEDOT coated fibres, and the ultraviolet cured dip coating of ionogels (i.e. dipping followed by UV curing). The continuous aspect of the processes is a key element for fabric manufacturing. Indeed, even the smallest usable fabric requires a substantial length of yarn. This is one of the reasons why the produced fibres were tested on an industrial knitting machine, the other reason being to test their processability. Additionally, a series of tests have been done on the fibres to obtain their conductive, tensile and, if applicable, actuative properties. Therefore, we present a pilot line producing knittable PEDOT coated fibres, textile muscle fibres and ionofibres.

2.2.5 High-strain honeycomb-HASEL actuators for fast and reconfigurable robots

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Presentation given by Mr. Zachary Yoder

Muscle-like materials enable robots which display capabilities not possible with conventional components. In particular, soft electrostatic actuators show strong potential for use in lifelike robots due to their high performance and efficient, electrical driving mode; however, it is still challenging to achieve rapid, large contractions (~50% strain). Using a design strategy that combines soft and stiff materials, we introduce Honeycomb-HASEL (hydraulically-amplified self-healing electrostatic) actuators which use a hexagonal array of stiff plates to transform the shape change generated by soft electrostatic zipping pouches into large and fast contractions. A standard Honeycomb-HASEL demonstrates 49% free contractile strain (over 20mm of stroke), peak strain rates over 4600%/s and a bandwidth over 15Hz while remaining back-drivable and semi-conformal. We present a model which predicts the force-strain curve when varying key parameters such as geometry and pouch material. As these actuators contract they also expand laterally (up to 130%), enabling jumping and crawling robots. Inspired by natural honeycomb, we introduce a modular design based on rapidly reconfigurable magnetic connectors that allows us to combine many individual Honeycomb-HASELs into multi-modal, active arrays. This rapid reconfigurability combined with the high-speed, large stroke output of individual Honeycomb-HASEL actuators opens up new opportunities for designing highly dynamic, lifelike robotic systems.

2.2.6 Biomimetic Robots autonomously driven by Dielectric elastomers (BROADCAST)

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

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(3) PowerON Ltd., Auckland, New Zealand

Presentation given by Mr. Mario De Lorenzo

Dielectric elastomers (DE) have been investigated as compliant and bioinspired actuators since 1998. They are mainly used as actuators (DEA), sensors, energy harvesters or signal processors due to their electromechanical structures with multiple functions, compliance and high deformability. They typically include a non-conductive elastomer component and flexible conductor electrodes. Since the dielectric elastomer switch was discovered, they gained popularity largely because of its variety of applications. DE circuits are the next frontier for material-integrated soft robotics. They draw inspiration from the distributed nervous systems of organisms. The lack of guidelines and knowledge is limiting the outcome of soft robots today. The collaboration between material scientists and soft robotics engineers is the key for the development of this technology. Project BROADCAST aims to provide this link in order to deliver a new class of potent soft biomimetic systems that can interact safely with their environment. The strategy is based on significant advancements in the manufacturing of DE circuitry, new soft electronic materials and novel signal processing techniques. BROADCAST researches multi-functional DEs that power robotic structures based on electro-mechanical control methods that are inspired by biological processes. This necessitates the development of new materials for flexible electrodes and sensors that have limited Young's modulus, conductivity and piezo-resistivity.

2.2.7 Materials for liquid-gap electrostatic actuators

Ion-Dan Sîrbu (1) (2) (3), David Preninger (4) (5), Doris Danninger (4) (5), Lukas Penkner (4) (5), Reinhard Schwödiauer (4) (5), Giacomo Moretti (1), Nikita Arnold (4) (5), Marco Fontana (2) (3), Martin Kaltenbrunner (4) (5),

waiting

Presentation given by Mr. Ion-Dan Sîrbu

The field of soft robotics has witnessed an increase in interest in a new class of electrostatic actuators based on fluidic gap, which exhibit high power density, fast response, and low cost. Various actuation concepts have been developed under different names such as hydraulically amplified self-healing electrostatic (HASEL) actuators, electrostatic ribbon actuators, dielectric fluid transducers (DFT), hydraulically amplified taxel (HAXEL), and electrostatic bellow muscles (EBM). These architectures employ dielectric liquids combined with flexible thin-films made of insulating polymers that are operated by applying controlled high electric fields. Previous theoretical and experimental works have shown that the performance of such actuators is heavily influenced by the properties of the employed materials. In this contribution, we present a comparative study of different combinations of solid dielectric films and dielectric liquids to evaluate their performance and potential for implementing novel high-performance actuators that are easy to control and energetically efficient. Our results provide insights into the influence of dielectric materials on the actuator's performance and can guide the design of optimized liquid-gap electrostatic actuators for various soft robotic applications.

2.2.8 Static and dynamic electro-mechanical coupling effects in a dielectric elastomer membrane array

Sipontina Croce (1), Julian Neu (1), Jonas Hubertus (2), Stefan Seelecke (1) (3), Guenter Schultes (2), Gianluca Rizzello (1),

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(3) Center For Mechatronics And Automation Technologies (ZeMA) GGmbH, Saarbruecken, Germany

Presentation given by Ms. Sipontina Croce

Dielectric elastomer (DE) transducers are commonly used in soft robotics and wearables due to their unique properties like large deformation and lightness. If many independently controllable DE actuators (DEAs) are closely arranged in array-like configuration, novel form of cooperative and soft actuator/sensor systems can be obtained. On one hand, cooperative DE systems achieve complex actuation tasks via several units by physically work together. On the other hand, intrinsic self-sensing feature of the elastomer permits to embedded intelligence into the system without introduce external components. When DEs are placed on a single elastic substrate, however, the actuation (i.e., force, displacement) and sensing (i.e., capacitance, current) response of each transducer is strongly dependent on the state of its neighbors due to spatial coupling effects. In this work, we perform an experimental and simulation study on a fully polymeric 1-by-3 array of DEAs. We investigate how the static and dynamic response of each DE unit (i.e., mechanical and electrical outputs) undergo changes when its neighbors are subject to different types of electro-mechanical loads. The obtained results provide guidelines for the systematic design of cooperative actuator/sensor systems based on DE with desired performance and functionality. Furthermore, by integrating distributed self-sensing control algorithms, complex tasks will be achieved while keeping the overall system highly compact and soft.

2.2.9 Wearable pneumatic tactile displays of softness for virtual reality

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

(1) University Of Florence

Presentation given by Dr. Gabriele Frediani

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- or augmented-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 contribution will present 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. We will describe results of various psychophysical tests aimed at elucidating the perceptual responses generated on users by this technology, when it is employed with virtual-reality environments to explore the softness of various kinds of objects, either visually recognizable or not.

2.2.10 Dielectric elastomer unimorphs with anisotropic bending stiffness: a simple and cost-effective manufacturing approach using thermoplastic dielectric and 3d-printed electrodes

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Presentation given by Ms. Zhenbi Wang

Dielectric elastomer actuators (DEAs) have shown great potential for various research applications, but due to the fragility of the commonly used dielectric films the manufacturing process of DEAs remains challenging and often requires expensive specialized equipment. In this work, a simple manufacturing approach for unimorph bending actuators is presented. The employed dielectric is a commercially available TPU film with a stiffness significantly higher than that of typically used silicones or acrylics. However, as demonstrated in recent works, the stiffness of the dielectric film has only a minor impact on the achievable deformation of unimorphs as the strain in the active layer is low. The use of a thermoplastic dielectric layer allows to circumvent manufacturing challenges associated with silicone dielectrics, such as electrode adhesion and the handling of the thin fragile films. Therefore, we propose the use of 3D-printed electrodes made of commercially available conductive TPU on a standard FDM-printer. This allows the creation of complex patterns on the electrode to achieve locally variable bending stiffness. Within this work three different bending actuators are presented to showcase the viability of the approach for future applications such as shape-conforming grippers. Our method offers a simple and cost-effective solution for manufacturing DEAs and it has the potential to open up new possibilities for their use in various fields.

2.2.11 3D soft touch pad enabled by vision-based mechanochromic sensing

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Presentation given by Mr. Giacomo Sasso

We describe a 3D touch pad made of an elastomeric membrane with mechanochromic transduction properties. It consists of a box that encloses a video camera and a diffused light source, and is closed by the membrane. The video camera monitors chromatic changes of any portion of the membrane that is touched with a variable extension and indentation, so as to track not only the position of fingertips or objects in contact with the membrane, but also the contact shape and pressure. The latter can be considered as a third dimension of information, besides conventional 2D spatial information. The membrane is a three-layers structure, consisting of a 500?m-thick layer of a carbon loaded PDMS, coupled to a 16?m-thick layer of a structurally coloured material, coupled to a 2mm-thick layer of a soft transparent elastomer (e.g. PDMS or VHB acrylic film by 3M). The structurally coloured material is obtained by applying the Lippman photographic technique to a commercial photopolymer (C-RT20 holographic film, Litiholo, USA) and is able to change its colour in response to stretch. The membrane rests on a 3mm-thick glass plate, acting as a support against which the membrane is squeezed upon touching. The use of a video camera advantageously overcomes the need for dense arrays of mechanoelectric sensing elements. Although this strategy increases the system's size and weight, it conveniently reduces complexity and enhances resolution, which is limited only by the camera's number of pixels.

2.2.12 Thickness measurements for a field driven DE actuation

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Presentation given by Ms. Bettina Fasolt

Actuation performance of dielectric elastomers (DE) is achieved through the application of electric voltages. The actuation force, the result of the so-called Maxwell stress, however, is determined by the electric field, which in addition to the voltage also depends on the current thickness of the DE membrane. As the original membrane thickness is typically well-known within certain tolerances, the thickness decrease during actuation contributes an additional unknown increase of the electric field. As the field-dependence is quadratic, higher voltage leads to more efficient actuation; on the other hand, the limiting factor is the field-dependent dielectric breakdown. A safer way of efficient operation of DEA systems would hence be an electric-field controlled method rather than mere voltage control. The purpose of the presented work is a systematic study of thickness decrease during actuation of a 50µm membrane. To this end, two different pre-stretches and two different electrode geometries are prepared and the thickness change during actuation measured using two confocal optical sensors. The voltage is ramped up in defined steps until breakdown, and the thickness continuously measured in order to determine the actual electric field rather than taking the original thickness, leading to a nominal field value only. Furthermore, a camera records changes of the electrode area during the voltage application.

2.2.13 Technology Demonstrator of Dielectric Elastomer Actuator Systems with Different Shapes and Preload Configurations

Stefan Seelecke (1), Daniel Bruch (1), Marius Jank (1), Julian Kobes (1), Paul Motzki (1),

(1) Saarland University

Presentation given by Prof. Stefan Seelecke

Dielectric Elastomer Actuators (DEAs) which utilize surface expansion during actuation, can be realized in various shapes. They are usually equipped with various mechanical preload mechanisms that directly affect the characteristics of the resulting combined actuator system. In this poster, the design of a technology demonstrator is presented, in which five different uniaxial deflecting DEA system designs are implemented side-by-side in a common enclosure and can thus be directly compared in their stroke response during actuation. In addition to the visual effects, the user can feel the output force of each individual actuator system via rods that are led out of the enclosure. Widely used DEA shapes are utilized for this purpose, namely strip-in-plane DEA, rolled DEA, and circular-out-of-plane DEA. Three of the realized actuator systems feature the same DEA shape, but different biasing mechanisms, namely constant mass, positive biasing coil spring, and negative biasing beam spring. In addition, three of the systems are implemented with a similar preload mechanism, whereas each is coupled with a different DEA shape. The systems are driven by custom made high voltage circuits providing signals with configurable amplitude and frequency, which can be controlled via graphical user interface. This demonstrator is well suited to illustrate the general potential of DEA technology and explain the influence of design variations in terms of actuator shape and biasing mechanism

2.2.14 A study on active vibration control using dielectric elastomer actuators for membrane space structures in a vacuum environment

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(2) Shibaura Institute Of Technology
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(4) Hokkaido University

Presentation given by Mr. Toshiki Hiruta

This paper proposes a vibration suppression technique using a dielectric elastomer actuator (DEA) for a lightweight and flexible membrane structure in a vacuum environment. Membranes are suitable to compose large space structures such as solar sails and large reflectors. However, vibrations on the membrane structures caused by disturbances in space are scarcely eliminated in a vacuum environment due to their flexibility leading to degradation of their maneuverability. Thereby, active vibration control technique using a DEA is required to ensure the membrane structures' stability. DEA is composed of soft polynomial material. Features of DEA are their high stretchability, lightweight, and fast response. Its advantages include easy application to the membrane structures and vibration suppression over a wide frequency band. For a vibration control experiment, a laminated DEA was fabricated and attached to the membrane surface. The target membrane structure was fixed in a vacuum chamber during the experiment. An experimental setup including a digital control system was constructed with a non-contact laser excitation system. The target structure was modeled based on an experimental modal analysis and a controller was designed by H-infinity control theory with the identified model. The vibration control experiment was conducted for the target membrane structure and effectiveness of the proposed method is demonstrated.

2.2.15 Piezoelectric-ionic liquid network for smooth stiffness-graded muscle

Caterina Azais Tatistscheff (1), Visva Moorthy (1), Krunal Ladwa (1), Majid Taghavi (1),

(1) Imperial College London

Presentation given by Ms. Caterina Azais Tatistscheff

Inspired by nature, the hierarchical stiffness-graded structure has emerged as an efficient solution for interfacing rigid and soft materials. These structures exhibit a gradual change in the stiffness of the material, which allows for improved load transfer and reduced stress concentration. Incorporating this concept into stimuli-responsive materials enables the development of monolithic active structures which mimics the behaviour of bone-tendon-muscle. The stiffness-graded pattern can be programmed into multiple morphologies such as linear, and radial patterns, allowing for pre-programming of the actuation behaviour in the muscle. This approach has already been demonstrated using a PVC (polyvinyl chloride)-plasticizer composite which exhibits anodophilic actuation behaviour. The stiffness gradient is achieved through a diffusion process, where a mixture of polymer powder and plasticizer is crosslinked under a temperature treatment. Within this study we show a new graded stiffness material made of PVDF(Polyvinylidene fluoride) and ionic liquid, highlighting how this fabrication method can be extended to different materials while enabling low-voltage actuation achievable through piezoelectricity.

2.2.16 A bio-inspired gripping system driven and controlled by flexible dielectric elastomer components

Junhao Ni (1) (2), Moritz Scharff (2), Dorsa Mosadegh Mehr (2), Katie Wilson (2), Delwin Tanto (2), Morgen King (2), Hui Zhi Beh (2), Gonzalo Cervetti (2), Andreas Richter (1), E.-F. Markus Henke (1) (2),

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

Presentation given by Mr. Junhao Ni

This work presents a comprehensive bio-inspired demonstrator platform, consisting of dielectric elastomer actuators, a dielectric elastomer switch, a soft tactile sensing skin, and a soft gripper. The gripping system is controlled by a dielectric elastomer switch. By applying mechanical deformation to the flexible piezoresistive electrode, printed on a flexible DE-membrane the. electrical circuit is opened and closed, which is powering the dielectric elastomer actuators. The gripper is 3D-printed of soft material and possesses flexible continuum-hinges creating a compliant mechanism. The sensing skin covers the gripper "fingertips". Its sensing matrix allows to feel touch, as well as to recognize features of contacted area of an object. The gripper is driven by a DEA unit. The DEA consists of eight parallel DEAs artificial muscles, made up of four layers each, and a nonlinear biasing spring. A high voltage power supply capable of delivering up to 4 kV is embedded in the system to power the DEA. Tests have shown that the gripper can be opened 40 degrees and grip sensitive objects like strawberries or cherry tomatoes without damage.

2.2.17 Serially connected EAP based tape yarns for in-air actuation using textile structures

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

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

Presentation given by Ms. Carin Backe

Smart textiles that have the capability for actuation are of great interest for creating wearables and haptic devices. Through the use of textile fabric production processes electroactive polymeric materials in the form of film-based yarns can be integrated and combined with passive yarns to create soft, actuating fabrics. This way single EAP materials can be transformed into segments consisting of multiple EAP yarns working together. Furthermore, these segments can be positioned within a fabric to work individually or simultaneously in different patterns by use of incorporated conductive yarn paths. While the chase for additivity in force is a long-standing part of developing new actuator structures, so is the need for additivity in displacement motion. Here we construct an actuating textile fabric through the process of weaving that is able to operate in-air using trilayer polypyrrole tape yarns with choline acetate ionic liquid. Finding balance between weaving parameters turned out to be a central key. We found that in a vertically suspended arrangement, a three-segment serially connected fabric assembly demonstrate a transfer in displacement and a joint-like motion behaviour. This opens up for more complicated motion patterns to be created through textile processing of EAP materials.

2.2.18 Dumbbell lifting Dielectric Elastomer Actuator Demonstrator

Daniel Bruch (1), Sebastian Becker (2), Sophie Nalbach (1) (2), Paul Motzki (1) (2),

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(2) Center For Mechatronics And Automation Technologies (ZeMA) GGmbH, Saarbrücken, Germany

Presentation given by Ms. Sophie Nalbach

Dielectric Elastomer Actuators (DEAs) are known for their softness, light weight and high design variability. As a result, they are often considered in the context of low-power applications, that are relatively compact, and also lightweight and soft. The fact that this is not essential for loads driven by DEAs is demonstrated in this work by presenting a demonstrator capable of lifting the weight of a 10 kg dumbbell over a range that is on the same order of magnitude as the height of the drive system itself. The design is based on a multilayer configuration of DEAs with circular diaphragms operating out-of-plane (COPs). To achieve a large stroke yield, the COPs are preloaded with a cascaded spring mechanism consisting of linear coil springs with positive slope characteristics and nonlinear buckled beam springs with negative slope characteristics. The preload mechanism is optimized to compensate for a large portion of the load, so that the actual mechanical work, that the DEA system must perform to displace the dumbbell through the full lifting range, is relatively small. Thus, only a minimal number of active COP layers is required, making the application compact and particularly efficient, but also limited in dynamic operation due to acceleration forces. Therefore, the lifting capacity of the demonstrator is investigated by laser deflection measurements at different frequencies and shown as stroke over time and stroke over voltage curves.

Session 2.3

(abstracts are listed in the order of presentation)

2.3.1 The dream of artificial muscle operated at low voltages

Dorina Maria Opris (1), Yauhen Sheima (1), Patrick M. Danner (1), Johannes von Szczepanski (1), Elena Perju (1), Mihail Iacob (1), Frank A. Nüesch (1), Thulasinath Raman Venkatesan (1),

(1) Swiss Federal Laboratories For Materials Science And Technology Empa, Laboratory For Functional Polymers, Dübendorf, Switzerland

Presentation given by Dr. Dorina Maria Opris

High dielectric permittivity elastomers can reduce the actuation voltage and increase the actuation pressure of dielectric elastomers. The most promising approach to increasing elastomers' dielectric permittivity is the chemical modification with polar groups of the elastic network. For a strong increase in permittivity, the polar group content should be as high as possible. This, however, negatively affects the glass transition temperature, which increases. This presentation will give an overview of the dielectric and thermal properties of over 70 polar polysiloxanes synthesized in our lab. The polysiloxanes that show the most promising properties were further cross-linked into thin films and their mechanical, dielectric, thermal, and electromechanical properties were investigated. While novel materials are tested in single membrane actuators, it became necessary that promising materials are also tested in stack or roll actuators. The processability and compatibility of both dielectric and conductive materials are crucial. This presentation will also show our strategies for such materials and how we used them to manufacture stack actuators using standard equipment.

2.3.2 Dielectric elastomer robots with integrated logic

Luca Ciarella (1), Andreas Richter (1), Markus Henke (1) (2),

(1) Institute Of Semiconductors And Microsystems, TU Dresden, 01062 Dresden, Germany
(2) PowerON Ltd., Auckland, New Zealand

Presentation given by Mr. Luca Ciarella

This work presents integrated logic circuits to control soft robotic structures based on dielectric elastomers (DEs). DE logic circuits and sensors can partially replace conventional, non-polymeric components and can be embedded into structures made of DEs. Soft logic is used to program the behavior of DE robots. Soft sensors can provide a response to external stimuli. The final goal is autonomous, soft, and smart structures with minimal external control. One of the challenges of soft robotics is to shift a control problem to a material problem, reducing the need for complex control loops and the number of sensors and electronics. This lowers the cost and simplifies the operation of the device. A classic example is the need to precisely program hard grippers versus the natural compliance of soft grippers, which makes them more suited to grasp unknown and fragile objects. This work follows the same approach by trying to provide the bulk polymeric material with basic logic functions that can autonomously guide the operation of the soft machine.

2.3.3 Small-signal modelling of dynamic dielectric elastomers

Petko Bakardjiev (1), Uwe Marschner (1), Ercan Altinsoy (2), Andreas Richter (2),

(1) TU-Dresden IHM
(2) TU-Dresden AHA

Presentation given by Mr. Petko Bakardjiev

The establishment of the DEA technology requires an efficient and easily manageable design methodology. Current designs are mostly top-down based on high-level models, require a high level of expertise, a large number of predefined parameters, and are not easily adaptable. Such a methodology already exists for dynamic electromechanical systems based on a variety of technologies in the form of electromechanical and acoustic networks. However, it has not yet been adapted for DEA. It requires lossless and passive transducer models in the form of two-port networks that describe the interactions of physical domains and subsystems. In this work, these are presented for DE longitudinal and thickness oscillators and extended to account for waveguide behaviour. This approach can greatly improve access to this technology for application developers, accelerate the design evaluation process, and improve comparability with other technologies. It enables the derivation of fundamental design and general operational considerations for dynamic and acoustic DEA. Using axially vibrating roll actuators as an example, the modelling procedure and its advantages are presented and possible and necessary future developments are discussed. The aim is to contribute to the development of DE-based acoustic sources in particular and dynamic DE actuators in general.

Thursday 08 June 2023

Session 3.1

(abstracts are listed in the order of presentation)

3.1.1 Biobased composites and metamaterials: a route for sustainable robotics and smart structures

Fabrizio Scarpa (1)

(1) University of Bristol, UK

Presentation given by Prof. Fabrizio Scarpa

Sustainability and low carbon footprints are becoming increasingly important in the design of future generations of adaptive structures and robotics applications. This talk will describe new approaches to developing metasurfaces and metastructures using biobased materials, such as hygromorph composites made with epoxies (standard and shape memory) and flax/hemp fibers. Hygromorphs are materials that change shape when exposed to moisture, and this hygroscopic strain can be used to provide programmable actuation authority in metasurfaces made with these biobased composites. By stacking the composites in specific sequences, we can create metasurfaces with a wide range of programmable actuation properties. In addition to the shape memory effects of the matrix and the hygroscopic behavior of the natural fibers, we can also add other smart materials to create even more versatile metasurfaces. These metasurfaces can be used for a variety of applications, such as soft robotics handling and adaptive and shape morphing antennas. We will also demonstrate how metastructures and biomimicking actuators can be produced using 3D/4D printing, and we will discuss modeling and design techniques for achieving optimal deposition of the hygromorph biobased materials for specific actuation authority targets.

3.1.2 Electronically Integrated Microscopic Robotis

Marc Miskin (1), Maya Lassiter (1), Will Reinhardt (1), Lucas Hanson (2), David Blaauw (3), Jungho Lee (3), Li Xu (3),

(1) University Of Pennsylvania, Electrical And Systems Engineering, Philadelphia, USA
(2) University Of Pennsylvania, Dept. Of Physics, Philadelphia, USA
(3) University Of Michigan, Electrical Engineering Computer Science, Ann Arbor, USA

Presentation given by Dr. Marc Miskin

After 50 years of Moore's law, it's now possible to pack nearly 1 million transistors in the space of a paramecium, enabling tiny systems for sensing, communication, and computation. This radical miniaturization of electronics has brought with it the incredible opportunity to make robots too small to see with the naked eye. This talk is about building microscopic robots. First, I'll show how electrochemical actuators can be used to build mechanical components that are controllable with electronic signals, opening the door to integrating silicon electronics with small-scale moving parts. As proof of concept, I'll show a simple robot that walks using on-board silicon photovoltaics for power. Each step in fabricating these robots is carried out massively in parallel, allowing millions of electronically integrated robots to be built on a single 4-inch wafer. Next, I'll present ongoing work in our lab to build robots that propel themselves using self-generated fluid flows. Finally I'll show a programmable robot just over a hair's width in size, complete with memory, a controller, sensors, and on-board power. Looking forward, I'll argue that tiny robots offer a new platform to explore collective behaviors and emergent phenomena with swarms containing nearly 1 million robots.

3.1.3 Materials and methods for sustainable soft robotic system - from biodegradable tough gels to mycelium based elektronik skins

Martin Kaltenbrunner (1) (2),

(1) Johannes Kepler University, Soft Matter Physics, Linz, Austria
(2) Johannes Kepler University, Soft Materials Lab, Linz, Austria

Presentation given by Prof. Martin Kaltenbrunner

Modern societies rely on a multitude of electronic and robotic systems, with emerging stretchable and soft devices enabling ever closer human machine interactions. These advances however take their toll on our ecosystem. Mitigating some of these adverse effects, this talk introduces materials and methods for soft systems that biodegrade. Based on highly stretchable biogels and degradable elastomers, our forms of soft electronics and robots are designed for prolonged operation in ambient conditions without fatigue, but fully degrade after use through biological triggers. Enabling autonomous operation, stretchable and biodegradable batteries power wearable sensors. 3D printing of biodegradable hydrogels enables omnidirectional soft robots with multifaceted optical sensing abilities. Going beyond, we introduce a systematically-determined compatible materials systems for the creation of fully biodegradable, high-performance electrohydraulic soft actuators. They reliably operate up to high electric fields, show performance comparable to non-biodegradable counterparts, and survive over 100,000 actuation cycles. Pushing the boundaries of sustainable electronics, we demonstrate a concept for growth and processing of fungal mycelium skins as biodegradable substrate material. Mycelium-based batteries allow to power autonomous sensing devices including a Bluetooth module and humidity and proximity sensors, all integrated onto mycelium circuit boards.

Session 3.2

(abstracts are listed in the order of presentation)

3.2.1 Hybrid soft-rigid joint with inherent sensing and actuation capabilities based on rolled dielectric elastomers

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

Presentation given by Mr. Andreas Meyer

Traditionally the tension structures are built by passive wires unable to give information about the state of the system or to excite an actuation from within. Using dielectric elastomers (DEs) to distribute tension forces, both can be achieved within the structure itself. DEs are thin silicone membranes that are printed with a flexible, conductive electrode on both sides, resulting in a capacitor with variable geometry. To integrate slim DEs that can not only be used as actuators and sensors but also assume the role of passive tension elements, the membrane is being rolled up to be used as a stiffer, centrical elastomer beam which is called a rolled dielectric elastomer (RDE). These smart elements are characterized by capacitance-displacement and force-displacement measurements. Especially the linearity of the sensor signal in relation to the applied stretch allows for a good displacement reconstruction, while this work concentrates on the first design and feasibility investigation. Here a first table like tensegrity structure has been designed based on RDEs as soft displacement elements. The structure has been built and tested with an integrated sensing electronic for simultaneous sensor monitoring.

3.2.2 Rapid responsive behaviour of electro-chemically driven coiled yarn actuators

Manikandan Ganesan (1), Shayan Mehraeen (1), Jose G. Martinez (1), Nils-Krister Persson (2), Edwin Jager (1),

(1) Division Of Sensor And Actuator Systems, Department Of Physics, Chemistry And Biology, Linkoping University, Linkoping, Sweden.
(2) Smart Textiles Technology Lab, Swedish School Of Textiles, University Of Boras, Boras, Sweden.

Presentation given by Mr. Manikandan Ganesan

Complex three-dimensional movements with time constants ranging from fractions of a second to a few minutes exist in nature. Inspired by human muscle fibres, electrochemically driven actuators made up of conducting polymers and textile fibres are attaining more focus. These possess great potential in haptic and exoskeleton applications. Our work demonstrates the rapid electrochemical responsive behaviour of a coiled yarn actuator comprising of PEDOT:PSS coated polyamide yarns in a liquid electrolyte (sodium dodecylbenzenesulfonate). Coiled yarn actuators were fabricated through a facile protocol consisting of a brush coating method, conventional twisting technique and heat setting. Interestingly, these actuators exhibit a substantial reversible actuation strain of 1.5 percentage at an actuation cycle speed of 0.5Hz. Further, actuation repeatability, the influence of the yarn plying, the mechanism behind the actuation and proof of concepts will be presented in detail.

3.2.3 Technology demonstrator of dielectric elastomer sensors with different design variants and sensing quantities

Sebastian Gratz-Kelly (2), Daniel Philippi (2), Andreas Meyer (2), Daniel Bruch (2), Sophie Nalbach (2), Paul Motzki (1) (2),

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

Presentation given by Prof. Paul Motzki

Dielectric Elastomer Sensors represent a promising capacitive sensing technology that is particularly well suited for detecting large deflections. Due to their high mechanical and geometric flexibility, many variations of sensors can be realized, which can detect simple uniaxial and even more complex multidimensional deformations. This contribution presents the design of a technology demonstrator that illustrates exemplary Dielectric Elastomer Sensor types of different complexity, namely a uniaxial position sensor, a uniaxial force-sensor, a two-dimensional touch pad, and a three-dimensional joystick. The sensors are installed in a common demonstrator housing but freely accessible to the user and can be operated by hand. Customized electronics detect the change in capacitance of the dielectric elastomers associated with their deformations, and model-based signal processing is performed with microcontrollers. The overall demonstrator is equipped with a large screen on which the sensor signals are displayed in various graphical representations that can be configured and scaled by the user via a touch screen. This allows the sensors to be virtually visualized in various application scenarios, making the demonstrator ideal for presenting the technology in a wide variety of domains.

3.2.4 Influence of the active-to-passive coverage ratio on electro-active strain in dot actuators

Hans Liebscher (1), Markus Koenigsdorff (1), Johannes Mersch (1), Gerald Gerlach (1),

(1) Technische Universität Dresden, Faculty Of Electrical And Computer Engineering, Institute Of Solid-State Electronics, Dresden, Germany

Presentation given by Mr. Hans Liebscher

There is an increasing interest to use novel elastomers with inherent or modified advanced dielectric and mechanical properties as components of dielectric elastomer actuators (DEAs). This requires suitable techniques to assess their electro-mechanical performance. Often this is carried out by manufacturing simple dot-actuators, which consist of an equi-biaxially pre-stretched dielectric film fixed to a circular frame. The applied pre-stretch significantly influences the performance of the DEA. However, the additional influence of the ratio between active electrode area and passive area is mostly neglected. Within this work, we experimentally investigate said influence, and propose a simple linear model for the dot actuator behavior. The results show that, in general, electrodes covering about 50% of the overall radius of the film will lead to the largest deformation, but not to the largest strain. This has implications for the optimization of measurement accuracy for the characterization of dielectric films, which are discussed in this work.

3.2.5 Machine embroidery provides mechanical support for electroactive components in wearable robots

Mona Küüts (1), Indrek Must (1), Alvo Aabloo (1),

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Presentation given by Prof. Alvo Aabloo

Modern health and care technologies in contact with human skin must be safe, soft, flexible, breathable, and light in weight. Textiles intertwined with electroactive components are a promising material-level platform in wearable robotics. One approach for defining actuators from active textiles is cutting from a fabric sheet to allow for off-plane displacement. However, this interrupts mechanical force chains in threads and compromises the textile's structural integrity. Therefore, a method for combining active and load-supporting functions in the same textile is needed. We demonstrate machine embroidery as an exclusive method to program actuation modes already in the textile fabrication phase, preserving thread integrity. The embroidering method was demonstrated on a leaf-inspired tunable-transpiration textile suggesting the uninterrupted threads to be functional in structural strength, similar to veins that support a leaf lamina. We demonstrate the program-defined alignment of individual threads to support off-plane actuation and provide longitudinal stiffness simultaneously. Consequently, the fibrous support results in the engagement of soft electroactive components in a mechanically robust platform. The capability for thread placement in arbitrary patterns via embroidery allows for designing complex actuation patterns on a conformable surface, enabling new wearable technologies.

3.2.6 Evaluation of two carbon black-based electrodes in terms of the printing and electromechanical behavior

Ozan Çabuk (1), Jana Mertens (1), Andreas Hubracht (1), Jürgen Maas (1),

(1) Technical University Of Berlin, Mechatronic Systems Laboratory/Institute Of Machine Design And Systems Technology, Berlin, Germany

Presentation given by Mr. Ozan Çabuk

Electrodes for dielectric elastomer (DE) transducers are still challenging concerning the material choice and fabrication method. In general, electrodes enable the electrical charging of DE transducers and ensure the adhesion between elastomer layers, especially when using prefabricated elastomer sheets for multilayer DE transducers. In detail, electrode parameters should be optimized according to specific requirements of different DE transducer application types, e.g., sensors, high displacement generators, or high dynamic actuators. Particularly, electrical resistance, mechanical stiffening, and lifetime are the significant electrode parameters that characterize the transducer behavior and limit the application. The electrode layer's fabrication should also be considered specifically for the electrode material and other fabrication requirements, such as thickness and precision. In this contribution, two electrode materials based on carbon black filled elastomer are experimentally investigated, evaluated, and compared concerning electromechanical behavior, as well as their applicability in the printing process. As a result, an overview of the comparison of electrodes in terms of material choice and the printing process regarding the DE transducer application will be shown.

3.2.7 A simple calculation model for dielectric elastomer unimorph bending actuators

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Presentation given by Dr. Holger Boese

Unimorph bending actuators based on dielectric elastomers (DE) are promising components for soft robotic grippers. In a simple manufacturing process of the unimorph actuator, a bendable, but not stretchable passive film is laminated with an active DE film, which expands in the electric field and generates a large bending deformation. The actuation performance in terms of bending angle, actuator tip displacement and blocking force depends not only on the geometrical design of the unimorph actuator, but also on the properties of the used materials such as the Young's moduli of the passive film and the elastomer film as well as the elastomer's permittivity. To evaluate the influence of the relevant geometrical and material parameters on the actuation performance, a simple calculation model

was developed. Additionally, DE unimorph actuators were manufactured and their performance was experimentally investigated. The results of calculations are compared with those of the corresponding measurements and exhibit satisfying agreement. Furthermore, the dependence of the actuator performance on various material parameters (Young's modulus and permittivity) as well as on geometrical parameters is predicted with the calculation model. The calculation results clearly indicate that a dielectric elastomer material with high permittivity and large Young's modulus is preferable for high performance unimorph bending actuators. This result is in agreement with experimental investigations.

3.2.8 Mechanisms of magnetorheological elastomer actuators

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

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

Presentation given by Dr. Holger Boese

Magnetorheological elastomers (MRE) are mechanically soft composite materials consisting of soft-magnetic particles in an elastomer matrix. When a strong magnetic field is applied, the Young's modulus of the material is increased due to magnetic particle-particle interactions. Besides this reversible controllability of the mechanical properties, MRE materials exhibit also distinct actuation capabilities. In a magnetic field, the particles are magnetized and attracted by the magnetic field source, which causes a deformation of the MRE composite. When the magnetic field is removed, the elastic matrix material causes the relaxation of the composite to the original shape. Depending on the mechanical properties of the MRE body, its elongation reaches about 10 %. Different kinds of material deformations can be generated by this way. If the magnetic field lines are linearly oriented, the deformation of a MRE body occurs in the same direction. This linear actuation can be exploited for the generation of haptic feedback. In a radially oriented magnetic field, a corresponding deformation of a ring-shaped MRE body is possible as well. As an example, this radial actuation can be used for proportional valves, where the flow rate of a gaseous or liquid medium is continuously controlled by the magnetic field strength. The basic mechanisms of linear and radial MRE actuation are explained and possible applications of these soft magnetic polymer actuators are presented.

3.2.9 Wave field synthesis for spatially individual sound using dielectric elastomer loudspeakers

Michael Gareis (1), Jürgen Maas (1),

(1) Technical University Of Berlin, Mechatronic Systems Lab, Berlin, Germany

Presentation given by Mr. Michael Gareis

Wave field synthesis (WFS) is a technology for creating arbitrary wave fields by using multichannel audio systems. To fully satisfy the theory, an infinite number of channels over a closed surface of the space is required. To put WFS into practice, the theory is discretized to a finite number of loudspeakers on a finite-sized array. Yet, a large number of closely spaced loudspeakers is required. High cost, size, and weight of conventional systems prevent widespread application, and WFS remains a niche technology. The Buckling Dielectric Elastomer Transducer (BDET) loudspeaker concept promises a solution to these technical challenges. The loudspeaker consists only of a 3D printed frame and a DE-membrane that buckles up under voltage-induced area extension. An AC voltage, superimposed on a DC voltage, causes vibration and sound radiation. No mechanical bias by magnets, springs, or air-pressure is required, resulting in an extremely lightweight and thin setup. A WFS system including loudspeakers, electronics, and software has been developed to demonstrate the structural advantages of the BDET. 480 loudspeakers are built and installed into an array of 48 individual channels. A HV amplifier supplies both the DC offset and the audio voltage. Different scenarios have been implemented in the software, to demonstrate WFS. The WFS is not only suitable for sound reinforcement in rooms, but also in vehicles where different individual audio content is required in a confined space.

3.2.10 Electronic soft sensors for deep ocean swimmers

Iain Anderson (1), Arne Bruns (1), Masoumeh Hesam (1), Antony Tang (1),

(1) Biomimetics Lab Auckland Bioengineering Institute

Presentation given by Prof. Iain Anderson

Fish have hydrodynamic situational awareness: the ability to point into the flow (rheotaxis), hold station behind bluff bodies (flow refuging) and sense their surrounds in dark environments without touching. To sense and exploit small changes in water flow, fish have sensor arrays along their bodies (i.e. the lateral line), surface sensors (superficial neuromasts) and fins, that they can use to sense what the water is doing around them and to process this data in real time. We wish to emulate this capability for unmanned underwater vehicles (UUVs) through the deployment of electronic electroactive polymer (EAP) sensor arrays, that will give UUVs underwater situational awareness. Sensors under development include a capacitive fringe-field bending sensor for measuring transverse flows across a fish-like UUV body (Finlet sensor) and a head-mounted capacitive membrane sensor pair for rheotaxis. We have demonstrated that both types can work in the deep ocean by testing functionality in a pressure vessel device to an equivalent depth of 1.5 km. We have also demonstrated their ability to operate at moderate to high flow speeds (up to 1.2 m/s) in a water tunnel. Improvements will include optimizing sensor elements for flows of order 0.1 m/s or less and putting the information together to provide a fish-like mind-map of the situation. Our recent results and future plans towards these ends will be presented along with our vision to make UUVs think and feel like fish.

3.2.11 Analysing the influence of the electrode layer properties on dielectric elastomer transducer behaviour

Jana Mertens (1), Ozan Çabuk (1), Jürgen Maas (1),

(1) Technical University Of Berlin, Mechatronic Systems Laboratory/Institute Of Machine Design And Systems Technology, Berlin, Germany

Presentation given by Ms. Jana Mertens

Dielectric elastomer (DE) transducers basically consist of a thin DE film coated on both sides with stretchable and conductive electrodes, often using carbon black-filled elastomers as the electrode material. Thinning the DE film has the advantage of lower voltage requirements, but results in greater electrode layer influence on DE transducer behavior, since the electrode layer thickness is limited by the manufacturing process. Therefore, in this contribution the DE material ELASTOSIL®2030 (EL 2030) and the electrode material ELASTOSIL®LR 3162 (EL 3162) are first characterized with respect to their static mechanical properties. Compared to EL 2030, EL 3162 exhibits a higher elasticity value, a higher degree of non-linearity in the elastic behavior and a significant static hysteresis. As a result, the elastic material model needs to be extended to include the static hysteresis for the electrode material EL 3162. In this study, a static rheological model is parameterized by comparing two different hyperelastic models and considering the static hysteresis by so-called Prandtl elements, modeled with one elastic and one plastic element in series. The analysis and model parameter identification of the DE materials and electrode materials is completed by an experimental and simulative analysis of multilayer DE transducers under variation of the electrode thickness.

3.2.12 Set-up for electromechanically testing and evaluating of multilayer dielectric elastomer submodules

Tim Krüger (1), Jürgen Maas (1),

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Presentation given by Mr. Tim Krüger

Dielectric elastomer transducers (DETs) consist of a thin elastomer film and compliant conductive electrodes on each side. Using a sheet-to-sheet thin film-based manufacturing process enables producing multilayer DE laminates being processed into a high number of DE transducers within a reasonable period of time. After cutting the laminate, small DE submodules can be stacked, e.g. in order to produce DE multilayer stack transducers. However, processing only few deficient submodules can cause failure of the stack transducer. To ensure that no deficient submodules are processed, a suitable test procedure can be beneficial. This work presents an alternative, ex-situ test set-up for DE submodules, which facilitates an electromechanical characterisation of thin and small DE specimens. The presented set-up enables the reversible electrical contacting and mounting of variable submodule sizes, so it is possible to reliably measure both electrical properties and mechanical deformation for quantitatively describing the transducer's characteristics. Comparing measurement results with expected values, DE submodules can be categorised or sorted out. Furthermore, conclusions about the upstream manufacturing process can be drawn. Thus, this work contributes to quality improvements of DEs and related manufacturing processes.

3.2.13 Fabrication and characterization of polymer-based layers for dielectric elastomer transducers using a 3D printing system

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Presentation given by Mr. Andreas Hubracht

Dielectric elastomer transducers (DET) have been a topic of research for several years and are constantly being improved. In the basic composition, they consist of a polymer as dielectric sandwiched between two compliant and electrically conductive electrodes. Exemplarily applications are grippers, valves or membrane-based speakers. Besides advantages over conventional transducers, such as the simultaneous usability as actuator and sensor or their low weight, the production is still challenging. One way to produce DET is the usage of industrially prefabricated elastomer films. Another method to build the polymer layer yourself is by dispensing a liquid two-component silicone rubber. Using this technique, shape and layer thickness can be variably adjusted, which enhances the flexibility and enables rapid prototyping. For this purpose, a new system with multiple printing technologies is available at TU Berlin. The goal is to print a multilayer DET by applying the polymer layer using Direct-Ink-Writing and the electrode layer by a droplet-based process. This article deals with the production of multilayer DET with the 3D printing system. Therefore, the influence of different materials and process parameters (e.g. printing speed or process temperature) on the polymer is analyzed as well as printing results of combined polymer and electrode layers are investigated. The evaluation focuses on geometric parameters (e.g. layer thickness) and the breakdown field strength.

3.2.14 Fully printed micro-patterned electrochemical actuators

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Presentation given by Mr. Ji Zhang

Submillimetre or micrometre scale electrically controlled soft actuators have immense potential in microrobotics, haptics, and biomedical applications. However, the fabrication of miniaturised and micro-patterned open-air soft actuators has remained challenging. In this study, we demonstrate the microfabrication of trilayer electrochemical actuators through aerosol jet printing (AJP), a rapid prototyping method with 10 micrometre lateral resolution. A fully printed 1 mm by 5 mm, 12 micrometre-thick PEDOT:PSS/Nafion/PEDOT:PSS actuator was successfully actuated in air under voltages from 0.1 V to 0.8 V in amplitude; its deflection angle was proportional to the applied voltage, reaching a peak-to-peak deflection of 0.246 rad (14.1 degrees) under a 0.8 V amplitude 0.1 Hz square wave. The low thickness of the AJP actuator reduced the proton transport length and flexural rigidity, hence causing relatively fast response and large deflection under low voltages. Next, we fully printed an actuator with two individually controlled submillimetre segments and demonstrated its multimodal actuation. The convenience, versatility, rapidity, and inexpensiveness of our microfabrication strategy promise exciting future developments in integrating arrays of intricately patterned individually controlled soft microactuators on compact stretchable electronic circuitries.

3.2.15 Tuneable lens based on a thickness-mode dielectric elastomer actuator

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Presentation given by Mr. Giacomo Sasso

This presentation describes a new electrically tuneable optical lens based on the architecture of so-called thickness-mode dielectric elastomer actuation. The device is made of an annular dielectric elastomer actuator (circular actuator with a central hole), coupled to a passive transparent elastomeric layer. The actuation membrane consists of an acrylic elastomer, coated with carbon-loaded silicone elastomer electrodes. The passive layer consists of a spin-coated silicone elastomer. When a volage is applied, the attraction of the two compliant electrodes causes a bulging of the dielectric material in the central region, amplified by the passive coating. This effect is used to electrically change the lens' curvature and therefore also its focal length. The presentation shows ongoing developments of this device.

3.2.16 Beyond classical viscoelastic models: a unified physics-based framework for rate-independent and -dependent hysteresis in dielectric elastomer actuators

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Presentation given by Mr. Giovanni Soleti

It is well known that dielectric elastomer (DE) transducers exhibit a strongly rate-dependent hysteresis in their force-displacement response, which is typically attributed to the viscoelasticity of the material. In case of DE materials exhibiting low mechanical losses (e.g., silicone), however, a practically rate-independent hysteresis is generally observed when loading the DE mechanically in the sub-Hz range, while rate-dependent hysteretic effects start to become relevant at higher deformation rates. Being able to accurately describe such complex hysteretic losses in a wide frequency range is essential to accurately predict the performance of DEs in a wide variety of real-life applications. In this work, we propose a new unified modeling framework for both rate-independent and rate-dependent hysteresis occurring in uniaxially-loaded DE actuators. The model is grounded on a physics-based approach, combining classic thermodynamically-consistent modeling techniques for DEs with an energy-based Maxwell-Lion description of the hysteretic process. The resulting dynamic model consists of a set of ordinary differential equations compatible with the first and second laws of thermodynamics, and describes at the same time large deformation nonlinearities, electro-mechanical coupling, as well as rate-independent and rate-dependent hysteretic effects. After presenting the theory, the model is validated via experiments conducted on silicone-based rolled DE actuators.

3.2.17 Direct ink writing of high-permittivity dielectric elastomer transducers

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Presentation given by Mr. Patrick Marcel Danner

3D printing of dielectric elastomer transducers (DET) would significantly accelerate their application in soft robotics. Even though facile printable DETs are highly desirable, the number of printed DET is very limited. Printability is hindered by multiple factors, such as the need for a multi-material printing of dielectric and compliant electrodes and the relatively large thickness, high stiffness, and poor mechanical properties of elastomers printed by direct ink writing (DIW). In this work, we present polar polysiloxanes as a key multi-purpose component in DIW printable DETs. We found that polar polysiloxanes not only increase the permittivity of the materials but also improve the printability of the ink, dielectric and mechanical properties of the printed and cross-linked elastomer and enable high frequency actuation at low electric fields. We explore how all these material parameters can be tuned simultaneously, focusing on interdependencies between ink requirements and final material performance. Here, the significant impact of ink formulation on the elastomer electro-mechanical properties is highlighted. The facile printing of these high-permittivity dielectrics with standard 3D printers is demonstrated. Combined with multi-material printing high-permittivity DET are successfully printed into stacked devices. Lastly, the performance of the printed DETs is analyzed in sensor and actuator prototypes.

3.2.18 3D printing soft microrobot

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Presentation given by Ms. Siqi Wang

Three-dimensional (3D) printing is an additive manufacturing process, which can fabricate sophisticated and complex geometries without subsequent cutting process, with advantages of material saving and shape freedom. 3D printing of soft microrobot is a strategy to combine soft actuator materials and 3D printing technique together, which may integrate the actuating part and unactuating part in one device, no need to assemble different parts together. In addition, it has potential to scale down to millimeter even micrometer scale to access complex and narrow areas in the human body in a minimally invasive manner. Herein, we designed and fabricated a fully 3D printed microrobot with multiple materials by using a direct writing 3D printer. The micro robot is made of soft body and six individually controlled actuating legs, with printed circuits embedded inside. Under the programed low voltage stimulation of 1-3V, it performs different actions like standing up, getting down, push-up action, dancing and walking on the table.

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