EuroEAP 2021

International conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles

Online
1-3 June 2021

Technical programme

Book of abstracts

List of participants

Contents

Conference Chairperson

EuroEAP 2021 is chaired by
Assoc. Prof. Edwin Jager
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Presentation of the EuroEAP conference series

Electromechanically Active Polymers (EAPs) are a young and rapidly growing research area. Applications are being explored in many fields, while fundamental research in novel materials and device architectures promises new capabilities.
EAPs are 'smart materials', capable of changing dimensions or shape in response to electrical stimuli, thus transducing electrical energy into mechanical energy, and vice-versa. They can be used as actuators, sensors, and as energy harvesters
EAPs have unique and appealing attributes, including large electrically-driven actuation strain, high mechanical flexibility, structural simplicity, ease of processing and scalability, and high energy and force density, and low-coast materials. Owing to their functional and structural properties, electromechanical transducers based on these materials are usually referred to as EAP 'artificial muscles'.
The two main EAP classes, ionic and electronic, enable applications in a braod range of fields, including haptics, optics, acoustics, microfluidics, automation, orthotics, artificial organs, energy harvesting and soft robotics.
The rapid expansion of the EAP research in Europe led to the creation of the EuroEAP Society as a non-profit Association. The Society's main purpose is to promote the scientific and technological advancement of Transducers and Artificial Muscles based on EAPs. In an effort to disseminate the latest advances and to bring together experts from around the world, the Society organises and supports the annual EuroEAP conference, driven by both scientific quality and industrial impact.
I wish to express my sincere gratitude to the conference Chairperson Prof. Jager and his team for the organization of this 2021 edition.
I am sure that you will enjoy this event.

Herbert Shea
EuroEAP Society President

Conference committees

Organizing committee

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

Edwin Jager, Linköping University (Sweden) - President
Federico Carpi, University of Florence (Italy)
Ingrid Graz, Johannes Kepler University (Austria)
Cedric Plesse, University of Cergy-Pontoise (France)
Frédéric Vidal, University of Cergy-Pontoise (France)

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Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
Anne Ladegaard, Technical University of Denmark (Denmark)
Peter Sommer-Larsen, Danish Technological Institute (Denmark)

Programme Overview

Tuesday, 1 June 2021

Opening	9:00-9:10	Welcome & introductory remarks **Edwin Jager** Linköping University, Sweden **Herbert Shea** EPFL, Switzerland
Invited Lectures	Session 1.1 *Chair: Herbert Shea, EPFL Zurich, Switzerland*	
	9:10-9:30	**Anne Ladegaard** DTU, Denmark
	9:30-9:50	**Cedric Plesse** University of Cergy Paris, France
	9:50-10:10	**Federico Carpi** University of Florence, Italy
Break	10:10-10:20	Break
Interactive Talks	Session 1.2 *Chair: Herbert Shea, EPFL Zurich, Switzerland*	
	10:20-10:40	**Pre-recorded videos** streamed by ZOOM 13 presentations of research activities
	10:40-12:00	**Interactive slide presentations** over WONDER 13 presentations
Break	12:00-14:00	Break
Plenary talk	Session 1.3 *Chair: Federico Carpi, University of Florence, Italy*	
	14:00-14:30	**Michael Dickey** NC State University, USA
Invited lecture	14:30-14:50	**Gianluca Rizzello** Saarland University, Germany
EuroEAP Society challenge	Session 1.4 *Chair: Federico Carpi, University of Florence, Italy*	
	14:50 - 15:20	**Pre-recorded videos streamed** by ZOOM
Break	15:20-15:30	Break

Interactive Talks	15:30-15:50	**Pre-recorded videos** streamed by ZOOM. 13 presentations of research activities
	15:50-17:00	**Interactive slide presentations** over WONDER 13 presentations

Wednesday, 2 June 2021

EAPlenary	Session 2.1 *Chair: Cedric Plesse, University of Cergy Paris, France*	
	9:00-9:30	**Il-Kwon Oh** Korea Advanced Institute of Science and Technology, Korea
Invited Lectures	9:30-9:50	**Xiaoming Tao** The Hong Kong Polytechnic University, Hong Kong
	9:20-9:40	**Takeshi Sugino** AIST, Japan
Break	10:00-10:20	Break
Interactive Talks	Session 2.2 *Chair: Cedric Plesse, University of Cergy Paris, France*	
	10:20-10:40	**Pre-recorded videos** streamed by ZOOM. 13 presentations of research activities
	10:40-12:00	**Interactive slide presentations** over WONDER 13 presentations
Break	12:00-14:00	Break
EuroEAP Society meeting	14:00-15:00	Annual meeting of the EuroEAP Society open to everyone
Social Event	15:00-17:00	**Virtual social event** over WONDER

Thursday, 3 June 2021

EAPlenary	Session 3.1 *Chair: Anne Ladegaard, DTU, Denmark*	
	9:00-9:30	**Barbara Stadlober** Joanneum, Austria
Invited lectures	9:30-9:50	**Geoff Spinks** University of Wollongong, Australia
	9:50-10:10	**Jonathan Rossiter** Bristol University, United Kingdom
Break	10:10-10:20	Break
Interactive Talks	Session 3.2 *Chair: Ingrid Gratz, Johannes Kepler Uiversity. Austria*	
	10:20-10:40	**Pre-recorded videos** streamed by ZOOM. 10 presentations of research activities
	10:40-12:00	**Interactive slide presentations** over WONDER 10 presentations
EuroEAP society challenge awards	12:00-12:20	Announcement of the first three classified teams of the EuroEAP Society Challenge
Closing ceremony	12:20-12:40	Conference closure, handover to the next year's chairperson and presentation of the next year's conference place

Tuesday, 1 June 2021

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

1.1.1 Invited Lecture

Anne Ladegaard (1),

(1) DTU, Denmark
Presentation given by Anne Ladegaard (1),

1.1.2 All solid-state ionic actuators based on polymeric ionic liquids and electronic conducting polymers

Braz Ribeiro Frederic (1), Giao T.M. Nguyen (1), Soyer Caroline (2), Eric Cattan (2), Frederic Vidal (1), Cedric Plesse (1),

(1) CY Cergy Paris Université, LPPI - Chemistry Department, Cergy-Pontoise, France
(2) Univ. Polytechnique Des Hauts De France - IEMN, Lille, France

Presentation given by Dr. Cedric Plesse

Electronically conducting polymers (ECP) are promising candidates for the development of flexible microelectromechanical systems (MEMS) and electroactive textiles due to their ability to change dimensions in response to electrochemical stimulation, but also to generate an electrical signal following mechanical stimulation. However, these electroactive polymers require the presence of an ion source, generally in the form of a liquid electrolyte phase, which can limit their range of applications due to leakage and toxicity issue. Turning such "wet" ionic EAPs into "dry" ionic EAPs is then of primary importance to make possible their transfer to practical applications. We describe here the elaboration and characterizations of all-solid-state ionic EAPs, containing no liquid-based electrolyte and behaving both as actuators and sensors. These "dry" ionic EAPs are prepared by using linear polymeric ionic liquids (PIL) associated with a poly(ethylene oxide) (PEO) network and highly conducting poly(3,4-ethylenedioxythiophene) :poly(styrene sulfonate) (PEDOT:PSS) electrodes. The results showed that the use of ECP electrodes and highly conductive PLI-based membranes resulted in actuators and sensors with performances equivalent to similar systems containing a liquid electrolyte phase.

1.1.3 Monitoring flexions and torsions of the trunk: dielectric elastomer stretch sensors vs inertial sensors

Gabriele Frediani (1), Leonardo Bocchi (2), Federica Vannetti (3), Giovanni Zonfrillo (1), Federico Carpi (1),

(1) University Of Florence, Department Of Industrial Engineering, Florence, Italy
(2) University Of Florence, Department Of Information Engineering, Florence, Italy
(3) Don Gnocchi Foundation IRCCS, Florence, Italy

Presentation given by Prof. Federico Carpi

Continuously monitoring flexions and torsions of the human trunk via wearable sensors could help various types of workers to reduce risks associated to incorrect postures and movements. Dielectric elastomer (DE) stretch sensors have been described as a wearable, lightweight and cost-effective technology to monitor human kinematics. Their stretching causes an increase of capacitance, which can be related to angular movements. Here, we describe a wearable wireless system to detect flexions and torsions of the trunk, based on such sensors. In particular, we present: i) a comparison of different calibration strategies for the sensors, using an accelerometer and a gyroscope; ii) a comparison of the DE sensors' performance with that of the accelerometer and gyroscope; to that aim, the three types of sensors were evaluated relative to stereophotogrammetry. Findings show that DE stretch sensors are attractive as a complementary, rather than alternative, technology to inertial sensors.

Session 1.2

(abstracts are listed in the order of presentation)

1.2.1 Multi-stimuli responsive core-shell nanorods for artificial skin applications

Taher Abu Ali (1) (2), Barbara Stadlober (1), Anna Maria Coclite (2),

(1) Joanneum Research Forschungsgesellschaft, Institute For Surface Technologies And Photonics, Weiz, Austria
(2) Graz University Of Technology, Institute Of Solid State Physics, Graz,Austria

Presentation given by Mr. Taher Abu Ali

This work presents a multi-stimuli responsive sensor for artificial skin applications. The sensor can detect surrounding changes in force, temperature and humidity. The proposed design consists of a hydrogel core, responsive to temperature and humidity changes; and a piezoelectric shell for force/pressure sensing. Swelling of the hydrogel core when stimulated, mechanically strains the piezoelectric shell, which results in a measurable electrical output. The two active materials are combined into core-shell nanorods, using vapor-based deposition techniques, namely, plasma-enhanced atomic layer deposition (PEALD) and initiated chemical vapor deposition (iCVD). These deposition techniques provide control over material's mechanical, optical and electrical properties as well as deposition conformity and uniformity. . Fabrication of hydrogel core: humidity (14.2 nC at 96% RH) and temperature (2.1 nC at 30°C) responsive hydrogel, Poly-N-vinylcaprolactam (pNVCL), is deposited using iCVD. The technique gives control over the lower critical solution temperature (LCST).(1) . Fabrication of piezoelectric shell: piezoelectric zinc oxide shell is deposited using PEALD. In PEALD, substrate temperature defines the preferential crystallographic orientation of the deposited material.(2) In this work, piezoelectric zinc oxide with (100) and (002) crystallographic orientation is deposited at 35°C, with piezoelectric charge response of 340 pC at F= 20 N.

1.2.2 Spider-inspired electrohydraulic soft-actuated joints

Philipp Rothemund (1) (2), Nicholas Kellaris (2), Yi Zheng (2), Shane K. Mitchell (2), Garret M. Smith (2), Kaushik Jayaram (2), Christoph Keplinger (1) (2),

(1) Max Planck Institute For Intelligent Systems, Robotic Materials Department, Stuttgart, Germany
(2) University Of Colorado Boulder, Paul M. Rady Department Of Mechanical Engineering, Boulder, USA

Presentation given by Dr. Philipp Rothemund

Traditionally, articulated robots are driven by electric motors giving them strength, speed, and precision, which make them ideal for applications in controlled environments. However, in unstructured environments and in the vicinity to humans these robots often lack the necessary adaptability and can even be dangerous. Replacing electric motors with soft actuators may alleviate this problem by limiting the maximum output force and making the joints backdrivable. This poster presents spider-inspired electrohydraulic soft-actuated (SES) joints that use an electrohydraulic mechanism for actuation that was inspired by the mechanics of spider legs. In SES joints a flexible, dielectric shell is attached to a rotary joint and filled with a liquid dielectric. The liquid dielectric is pressurized with an electric field, which causes deformation of the shell and thus rotation of the joint. We demonstrate actuation angles up to 70°, blocking torques up to 70 mN?m, and specific torques up to 21 N?m/kg. These results are rationalized with an electromechanical model. SES joints also exhibit roll-off frequencies up to 24 Hz and specific powers as high as 230 W/kg. We demonstrate their use in a bidirectional joint, a multisegmented artificial limb with independently addressable joints, and a compliant gripper. Their low profile and weight in combination with their good performance make SES joints ideal actuators for mobile articulating robots for applications in which space is constrained.

1.2.3 Lifetime of silicone-based dielectric elastomer actuators under DC actuation

Fabio Beco Albuquerque (1), Herbert Shea (1),

(1) Ecole Polytechnique Federale De Lausanne (EPFL), Soft Transducers Laboratory (LMTS), Neuchatel, Switzerland

Presentation given by Mr. Fabio Beco Albuquerque

We report an experimental study of the effect of relative humidity, temperature and electric field on the lifetime of silicone-based dielectric elastomer actuators (DEAs) under DC voltage. We then show that lifetime can be increased by up to 300x by using thin passivation layers, with negligible effect on actuation strain. Our DEAs consist of equibiaxially prestretched 50 mm diameter silicone membranes (Elastosil 2030/20, 20 um initial thickness, 12 um thick after prestretch) sandwiched between 4 um thick carbon black - PDMS composite circular electrodes, 5 mm in diameter. A constant DC voltage is applied to the DEAs, whose lifetime is measured under different environmental conditions and electric fields. Relative humidity is an important accelerating factor for dielectric breakdown failure of DEAs. At 90 V/um and at 85°C, the median lifetime drops from 117 hours at 20%RH to 2.8 hours at 85%RH. A similar strong RH dependence is seen at 80 V/um and 100 V/um, as well as at 50°C and 20°C. We demonstrate that adding a 4 um thick soft silicone encapsulating layer on both sides of the DEA yields an improvement in DC lifetime at 85°C - 85% RH of 25x at 90 V/um and of 20x at 100 V/um, leading to much more robust DEAs.

1.2.4 Smart 4d scaffolds based on polyhipe structure and electroactive pedot for cell culture application

Ana Ferrandez Montero (1) (2), Melodie Culot (1) (2), Remy Agniel (2), Johanne Leroy-Dudal (2), Cedric Vancaeyzeele (1), Cedric Plesse (1),

(1) CY Cergy Paris University, LPPI, 95000 Cergy, France
(2) CY Cergy Paris University, ERRMECe, 95000 Cergy, France

Presentation given by Dr. Ana Ferrandez Montero

Recently electronic conducting polymer (ECP) materials have received a critical interest in several applications. Their electromechanical properties are especially interesting in biomedical applications since these biocompatible soft materials can present volume changes under low voltage stimulation in a physiological electrolyte. Thus, they open the possibility of both electrical and mechanical stimulation of cell or biological tissues when implemented in 3D porous materials, providing them with a 4th and time-resolved dimension. The purpose of the project is to develop poly(3,4-ethylenedioxythiophene) (PEDOT) based 4D electrostimulable scaffold as innovative cell culture platform that will combine controlled biochemical, topographical, mechanical and electrical cues, along with tunable actuation. The smart electrostimulable scaffolds are developed through PEDOT functionalization of passive porous polyHIPE structures. These porous polymers are processed by the polymerization of an external phase in a high internal phase emulsions (HIPEs). The final materials present spherical and highly interconnected pores usually ranging from 1 to 100 µm. The electroactive 4D polyHIPE/PEDOT scaffolds present an excellent electroactivity response with a modulated volume variation response. Additionally these scaffolds show promising cells viability and proliferation as well as adhesion of fibroblast cells.

1.2.5 Polysiloxanes modified with different types and contents of polar groups: synthesis, structure, thermal and dielectric properties

Yauhen Sheima (1) (2), Yulia Yutz (3), Holger Frauenrath (2), Dorina M. Opris (1),

(1) EMPA, Laboratory For Functional Polymers, Dübendorf, Switzerland
(2) EPFL, EDMX, Lausanne, Switzerland
(3) ETH, Zürich, Switzerland

Presentation given by Mr. Yauhen Sheima

Over the last 20 years, dielectric elastomers have drawn the attention of scientists due to their versatile properties. They found applications in many areas, including robotics, pumps, valves, sensors, generators, and solid-state electrolytes, to name just a few. Polydimethylsiloxanes are among the best materials for such applications, however, their low permittivity value (around 3) is too low. Here, we report the synthesis, the glass transition temperature (Tg), and the dielectric properties of polysiloxanes with different polarities. For this, we set out from poly(dimethyl-co-methyvinyl)siloxanes with different vinyl group content. The vinyl groups were then transformed into polar groups of various nature by an efficient one-step thiol-ene addition post-polymerization modification. The synthesized polymers were used to establish structure-property relationships. Our results show that the Tg increases with the polar group content and the strength of the polar group. A similar trend is observed for the dielectric permittivity as long as the Tg of the polymer is well below 0°C. Our findings guided us to design polysiloxanes with a permittivity as high as 27.7 and a Tg of -18.2 °C. To the best of our knowledge, this is the highest dielectric permittivity of a polymer with a Tg well below room temperature.

1.2.6 Modeling and simulation of soft robots driven by rolled dielectric elastomers

Johannes Prechtl (1), Julian Kunze (1), Gianluca Rizzello (1), Stefan Seelecke (1) (2),

(1) Intelligent Materials Systems Lab, Department Of Systems Engineering, Department Of Materials Science And Engineering, Saarland University, Saarbrücken, Germany
(2) Intelligent Materials Systems Lab, Center For Mechatronics And Automation Technologies, ZeMA GGmbH, Saarbrücken, Germany

Presentation given by Mr. Johannes Prechtl

In recent years, soft robots have received increasing attention due to the growing needs in human-robot collaboration. Due to their large deformation, high compliance, and lightweight, Dielectric Elastomer (DE) transducers are suitable for actuation and self-sensing applications in the field of soft robotics. While mathematical models for simple DE actuators configurations have been widely explored in the literature, up to date only few authors have attempted to model complex and multi-degree-of-freedom DE soft robotic structures. In this work, we present a dynamic model for a DE soft robotic system, which can be used for system simulation, design optimization, as well as for the development of control systems and self-sensing algorithms. The structure under consideration consists of a flexible T-shaped backbone with two tendon-like DE roll actuators mounted at the tips, resulting in a multi-degree-of-freedom bending motion. Such a system is intended to be used as a building block for a modular soft robotic tentacle arm. The developed model accounts for both DE material behavior and elastic properties of the flexible structure, as well as for the interaction between the two, by means of a free-energy approach grounded on Lagrangian mechanics Actuation performance of the soft robotic structure, quantified in terms of angular deflection, is compared for different backbone stiffnesses, actuator mounting positions, and DE membrane dimensions.

1.2.7 Development, operation, and modeling of a polyurethane-based dielectric elastomer actuator

Hans Liebscher (1), Muhammad Tahir (2), Sven Wießner (2) (3), Gerald Gerlach (1),

(1) Technische Universität Dresden, Faculty Of Electrical And Computer Engineering, Institute Of Solid State Electronics, Dresden, Germany
(2) Leibniz-Institut Für Polymerforschung Dresden E.V., Research Division Elastomers, Dresden, Germany
(3) Technische Universität Dresden, Faculty Of Mechanical Science And Engineering, Institute Of Materials Science, Dresden, Germany

Presentation given by Mr. Hans Liebscher

In recent years, dielectric elastomer actuators (DEA) have gained an increasing importance in research and development studies. Especially in the field of soft robotics, there are many applications at the prototype stage. DEAs consist of a thin electroactive elastomer layer between two compliant electrodes. When an electric field is applied to the elastomer layer, the attractive electrostatic force between the electrodes causes a reduction in thickness and hence an extension in the free spatial directions. In literature, mostly experiments on silicone- and acrylic-based DEAs are reported. However, better actuator performance can be expected with materials that have a higher relative permittivity. This makes unconventional electroactive polymers, such as polyurethane, chloroprene or nitrile rubber, interesting. This poster presents a polyurethane-based planar actuator with respect to its mechanical, dielectric and actuation properties. The hyperelastic material behavior of crosslinked polyurethane elastomer is represented by a nine-parameter Mooney-Rivlin model. A simulation approach for FEA software is shown for the prediction of voltage-induced deformations and compared to the experimental operation of the DEA.

1.2.8 Electromechanically active yarns for textile exoskeletons

Sujan Dutta (1), Jose Gabriel Martinez Gil (1), Shayan Mehraeen (1), Edwin Jager (1),

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

Presentation given by Dr. Sujan Dutta

Recently, electrically driven conductive polymer (CP) coated yarn has shown a great effect to develop soft wearable actuators with synergetic actuation. To address these issues in this work, we introduced and demonstrated a lightweight and flexible actuator technology that can be integrated into fabrics. For this, nonconductive KDK and intrinsically conducting Ag plated KDK commercial yarns were used, and a range of electroactive conductive yarn was prepared by dip-coating with poly (3,4-ethylene dioxythiophene) polystyrene sulfonate (PEDOT: PSS) followed by polypyrrole (PPy) electro-polymerization. Moreover, using one nonconductive and one intrinsically conducting yarn, to understand the voltage drop mechanism during the electro-chemo-mechanical actuation, two different approaches also applied. In the first approach, after applied preload, the actuation behavior of active yarns length was measured by adding the required amount of sodium dodecylbenzene sulphonate (NaDBS) electrolyte in the electrochemical cell. In the second approach, a requisite length of active yarn was cut, and actuation behavior was measure after applied a pre-load. The resultant electroactive yarn exhibit low electrical resistance, high strain (0.64%), and superior electrical stability in NaDBS electrolytes. The new highly conductive yarns will shed light on the development of next-generation textile-based exoskeleton suits, assistive devices, wearables, and haptics garments.

1.2.9 Is a tapered design of dielectric elastomer finger good for grip strength?

Fa-Yi Chen (1), Shu Huang (2), Gih-Keong LAU (1),

(1) Department Of Mechanical Engineering, National Yang-ming Chiao-tung University, Taiwan 30010
(2) Mechanical And Mechatronics System Research Labs, Industrial Technology Research Institute, Taiwan 31057

Presentation given by Prof. Gih-Keong LAU

Is a tapered design of dielectric elastomer finger good for grip strength? A dielectric elastomer finger can flex a large angle to grasp an object but the earlier design was flimsy using a single layer of dielectric elastomer actuator and a weak base flexure. How dielectric elastomer fingers can be designed with increased strength to carry at least an apple? It remains a design challenge because multiplying the dielectric elastomer layers or thickening the base flexure are at the great expense of reduced actuation stroke. Interestingly, the anatomy of tendon-driven finger provides some useful design tips. It is known that playing musical instrument or typing a typewriter can blunt the finger tips. This inspires a strengthened design of dielectric elastomeric fingers by having a tapered base flexure but a blunt (heightened) tip. With this optimized finger design, the three-finger grippers of 22.5-gram total weight can carry a 181 gram apple without giving way.

1.2.10 Characterization and modeling of polymeric domes as large-stroke biasing elements for dielectric elastomer membrane actuators

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

(1) Saarland University, Department Of Systems Engineering, Department Of Materials Science And Engineering, Saarbruecken, Germany
(2) University Of Applied Sciences Of Saarland, Department Of Sensors And Thin Films, Saarbruecken, Germany
(3) Center For Mechatronics And Automation Technologies (ZeMA) GGmbH, Saarbruecken, Germany

Presentation given by Ms. Sipontina Croce

Dielectric elastomer actuators (DEAs) have gained a significant popularity in application fields such as soft robotics and wearables, due to their unique mix of large deformation, lightweight, and high compliance. In order to produce a significant actuation stroke, a membrane DEA must be coupled with a mechanical biasing system. Commonly used spring-like bias elements, however, are generally made of rigid materials such as steel, and thus they do not meet the compliance requirements of soft robotic and wearable applications. To overcome this issue, in this work we propose a novel type of compliant mechanism as biasing elements for DE actuators, namely a three-dimensional polymeric dome. When properly designed, such types of mechanisms exhibit a region of negative stiffness in their force-displacement behavior. This feature, in combination with the intrinsic softness of the polymeric material, ensures large actuation strokes and high compliance at the same time. After presenting the novel biasing concept, a physics-based finite element model of the biasing dome is derived and experimentally validated. A model-based design algorithm is developed to optimize the dome geometry, in such a way to maximize the overall DEA stroke. Finally, the optimized soft actuator is designed, manufactured, and assembled, and its experimental characterization is conducted. The developed concept will be used, in future research, to develop small-scale and flexible arrays of cooperative DEAs.

1.2.11 DE-unimorph membrane headphone driver

Petko Bakardjiev (1) (2), Markus Franke (2), Andreas Richter (2), Uwe Marschner (2), Ercan M. Altinsoy (1),

(1) TU-Dresden, Chair Of Acoustics And Haptics, Dresden, Germany
(2) TU-Dresden, Chair Of Microsystems, Dresden, Germany

Presentation given by Mr. Petko Bakardjiev

Dielectric elastomers (DE) are often referred to as being suitable for acoustic applications. Nevertheless, only few concepts have been developed and realized so far, which can hardly compete with conventional electrodynamic loudspeakers. The most prominent examples are vibrating DE-diaphragms that are inflated by a bias pressure. However, adding support or other mechanical systems (pressure pump, magnets, springs, etc.) usually prevents achieving the desired technological advantage using DE and can be further detrimental to broad frequency behavior. We realized and investigated an alternative approach to sound sources based on DE using unimorph membrane configurations. These consist of a circular multilayer stack of a substrate PET-membrane, coated on one side with a metal film and on the other side with a silicone film, with a compliant electrode on top, clamped in a ring structure. Due to the different mechanical properties of the materials, the application of a voltage induced Maxwell stress results in an out-of-plane bending motion and thus a volume displacement. The unimorph membranes were installed as replacement drivers in conventional on-ear headphones, where they showed promising frequency response, sound pressure levels and linearity. Compared to conventional electrodynamic drivers, the DE unimorph membranes are lightweight, free of magnets and magnetically permeable materials, can potentially be manufactured at very low costs and achieve outperforming efficiency.

1.2.12 Development and characterization of core-free, silicone-based rolled dielectric elastomer actuators

Julian Kunze (2), Johannes Prechtl (1), Daniel Bruch (1), Bettina Fasolt (2), Sophie Nalbach (1) (2), Paul Motzki (1) (2), Stefan Seelecke (1) (2), Gianluca Rizzello (1),

(1) Intelligent Materials Systems Lab, Department Of Systems Engineering, Department Of Materials Science And Engineering, Saarland University, Saarbrücken, Germany
(2) Intelligent Materials Systems Lab, Center For Mechatronics And Automation Technologies, ZeMA GGmbH, Saarbrücken, Germany

Presentation given by Mr. Julian Kunze

In this work, we develop a coreless rolled dielectric elastomer actuator (CORDEA) to be used as artificial muscles in soft robotic structures. The new CORDEA concept is based on a 50 µm silicone film, with screen-printed electrodes made of carbon black suspended in polydimethylsiloxane. Two printed silicone films are stacked together and then tightly rolled in a spiral-like structure, which is suitable to be used as tendon-like actuators in soft robotic applications. Readily available off-the-shelf components are used to implement both electrical and mechanical contacts. A novel manufacturing process is developed to enable the production of rolled actuators without a hollow core, with a focus on simplicity and reliability. In this way, actuator systems with high energy density can be effectively achieved. After presenting the design, an experimental evaluation of the CORDEA electromechanical behavior is performed. Actuator experiments in which the CORDEA is pre-loaded with a mass load and subsequently subject to cycling voltage are illustrated, and the resulting performance is discussed. In addition, we observed a repeatable and linear relationship between the strain and the capacitance, which make the CORDEA highly suitable for future implementation of self-sensing concepts.

1.2.13 Modeling of IEAP based actuator using a linear model with localized parameters

Vadim Becquer (1), Hélène Arena (1), Sofiane Ghenna (1), Eric Cattan (1), Sébastien Grondel (1),

(1) Université Polytechnique Hauts-de-France, CNRS, University Of Lille, YNCREA, Centrale Lille, UMR 8520-IEMN, DOAE, 59313 Valenciennes, France

Presentation given by Mr. Vadim Becquer

Currently, ionic electro-active polymers (IEAP) using increases due to their interesting characteristics i.e., large strain response, soft actuation, similarities to biological muscles, . However, IEAP actuators have a complex behavior. This work presents a study on the modeling of an IEAP based trilayer actuator [PEDOT:PSS-PEO/NBR-PEO/PEDOT:PSS-PEO] using the bond-graph method which is a graphical approach based on energetic exchanges. As power is a universal currency in physical systems, it allows taking into account the electro-chemo-mechanical phenomena and the interactions between them. The proposed model is able to predict the electro-chemical (current, voltage) and chemo-mechanical (force, displacement) behaviors of the actuator. Most relevant, with this model, simulation results are in good keeping with experimental ones. In addition, this model can be used to estimate physical values that could not directly be measured. This work is illustrated with simulation results and experimental validations.

Session 1.3

(abstracts are listed in the order of presentation)

1.3.1 Liquid metals for electroactive polymers and soft devices

Michael Dickey (1),

(1) NC State University, Department Of Chemical And Biomolecular Engineering

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 robotics, stretchable electronics, and actuators 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 recent work to utilize liquid metal for energy absorbing / harvesting materials, stretchable sensors, electrodes for electroadhesion, and soft materials logic. These advances have implications for soft machines and robots that have ultra-soft mechanical properties.

1.3.2 From smart materials to smart systems - modeling, control, and self-sensing of dielectric elastomers

Gianluca Rizzello (1),

(1) Saarland University, Saarbrücken, Germany

Presentation given by Prof. Gianluca Rizzello

Dielectric Elastomers (DEs) are flexible capacitors consisting of a highly deformable membrane coated with compliant electrodes. A DE can be operated as an actuator, by converting applied stimuli into motion, or as a sensor, since its electrical capacitance can be related to the membrane geometry. Eventually, actuation and sensing can be performed simultaneously, achieving the so-called self-sensing mode. Despite their many attractive features, the practical use of DE transducers is currently limited by several factors, such as the high amount of voltage required for achieving a significant deformation (on the order of kV), or the strong input-output nonlinearities which significantly complicate design, modeling, and control. To truly embody smartness into smart materials such as DEs, intelligent control algorithms need to be developed and used to compensate their nonlinearities. In this talk, recent advances on smart algorithms for DE systems will be presented. Topics related to model-based design optimization, motion control paradigms, position/force self-sensing, and sensorless control will be discussed, with a special emphasis on engineering applications in the fields of actuators and soft robotics. Such methods represent a fundamental step towards the development of the next generation of smart material systems.

Session 1.4

EuroEAP Society Challenge Projects

Project Title	Team Leader	Affiliation
Augmenting a Dielectric Elastomer Sensor Glove with Vibrotactile Feedback	Antony Tang	University of Auckland
DE Shaker – Unconfined Fluid Mixing Device	Giacomo Sasso	Queen Mary University
App controlled, credit card sized DE-Actuator	Matthias Balter	Intelligent material systems lab, Saarland
DE-Unimorph-Membrane-Headphone-Driver	Petko Bakardjiev	TU Dresden
TOFI – Digital Tongue fitness trainer	Tino Toepper	Bottmedical
An off-the shelf High Voltage Signal Generator	Markus Henke	PowerOn
TouchDetect	Markus Henke	PowerOn

The EuroEAP Society Challenge is generously supported by **Bürkert Fluid Control Systems**. https://www.burkert.com/en

Augmenting a Dielectric Elastomer Sensor Glove with Vibrotactile Feedback

EuroEAP Society Industry Challenge Projects

Project Title	Team Leader	Affiliation
DE Shaker – Unconfined Fluid Mixing Device	Giacomo Sasso	Queen Mary University
An off-the shelf High Voltage Signal Generator	Markus Henke	PowerOn
EAP-Pump	Metin Giousouf	Festo
DE-Unimorph-Membrane-Headphone-Driver	Petko Bakardjiev	TU Dresden
DextrES: electrostatic clutch for wearable haptics	Ronan Hinchet	LMTS,EPFL
Clearing the Way for DEAs	Steffen Hau	Desaar
Omnigrasp soft gripper	Vito Cacucciolo	LMTS,EPFL
TouchDetect	Markus Henke	PowerOn

The EuroEAP Society Industry Challenge is generously supported by **Bürkert Fluid Control Systems**. https://www.burkert.com/en

(abstracts are listed in the order of presentation)

1.4.1 Study of pressure and strain distribution in parquet tiles with integrated p(vdf-trfe) sensors for smart floor applications

Asier Alvarez Rueda (1), Philipp Schäffner (1), Andreas Petritz (1), Jonas Groten (1), Andreas Tschepp (1), Martin Zirkl (1), Barbara Stadlober (1),

(1) Joanneum Research Forschungsgesellschaft MbH,MATERIALS, Weiz, Austria

Presentation given by Mr. Asier Alvarez Rueda

In recent years, many different concepts of smart floors have been presented, which aim to track movement of people or trigger functions in smart home environments. Usually, they are realized by integrating pressure sensitive elements distributed in the area of the floor. In order to minimize costs and thus making these designs commercially attractive as well as reduce crosstalk, the position of the individual units and their shape needs to be optimized, which requires a detailed understanding of how a localized pressure load on top spreads over the floor into the sensitive layer. In this study, we present a multiphysics finite element model of a piezoelectric strain sensor array integrated in a parquet floor tile. The model, which is implemented in COMSOL Multiphysics, takes as input the applied pressure distribution on the topside of the floor. Based on the predefined material parameters we are able to predict the signal of each individual sensor unit in the sensor layer. This takes into account the distribution of strain along the floor tile and thus allows predicting the response of different sensor designs before prototyping. In order to validate this model we have equipped a parquet tile with a screen-printed P(VDF-TrFE) sensor array. Then, we performed a controlled pressure loading with a circular stamp, while simultaneously reading out the signals of all sensor pixels. The comparison of the experimental values and the modelled output shows an excellent agreement.

1.4.2 Modular pump design for DE based membrane pumps

Matthias Baltes (1), Sophie Nalbach (1), Gianluca Rizzello (2), Stefan Seelecke (1),

(1) Intelligent Materials Systems Lab, Center For Mechatronics And Automation Technologies, ZeMA GGmbH, Saarbrücken, Germany
(2) Intelligent Materials Systems Lab, Department Of Systems Engineering, Department Of Materials Science And Engineering, Saarland University, Saarbrücken, Germany

Presentation given by Mr. Matthias Baltes

The working principle of membrane pumps is based on linear displacements, which are commonly generated by converting rotational motion of electric motors through mechanical transmissions. A more efficient way to generate such motion patterns consists of using linear actuators, e.g., based on dielectric elastomer (DE) transducers. DE technology is known for its advantages concerning weight, energy efficiency, and driving strategies. Membrane pumps consist of three main components: the pump chamber containing the pump membrane, the valves, and the actuator system. All three parts exhibit a different working principle, and have a strong influence on the performance of the pump. In order to use a DE transducer as actuator system for membrane pumps, the influence of the individual components on the load force has to be properly accounted for. First, commonly used working principles are compared and rated according their performance and suitability in conjunction with DEs, with the aim to optimize the system performance. After choosing the most efficient combination of pump chamber and valves, it is possible to determine the load force for different pressures. Based on this analysis, a DE system is designed accordingly. Finally, the functionality of the design method is verified experimentally, based on a custom-developed system prototype.

1.4.3 Ultra-high voltage, compact and energy recovering electronics for dielectric elastomer actuators

Raphael Mottet (1), Alexis Boegli (1), Yves Perriard (1),

(1) EPFL, LAI, Neuchatel, Switzerland

Presentation given by Mr. Raphael Mottet

Powering DEAs has always been a challenging aspect of the technology due to the voltages required. Especially when the aim of the application is to be portable, compact and efficient. It is for this reason that we developed an electronics system capable to not only supply the necessary high voltages but also recover parts of the electrical energy stored in a DEA that is fully charged. Our device, based on the DC/DC flyback converter topology, is capable to take as input a voltage of only 12V and charge to at least 8kV (and potentially more) a capacitive load. It is also capable to discharge an actuator back through itself, thus recovering energy without any additional electronics. With the current design, we were able to charge a 2.4nF DEA in as little as 10ms to 8kV and discharge it equally fast. The overall efficiency was estimated at around 55% for both the charge and discharge when using a standard capacitor as a load. A drop in efficiency is to be expected when used with a DEA due to the access resistance. During the conference, we plan to present in detail the converter and its various components, as well as show how it performs with various loads going from the basic capacitor to multilayer DEA tubes.

1.4.4 Non linear behavior in IEAP based actuator from electrical point of view

Sofiane Ghenna (1), Iman Dadras (2), Sébastien Grondel (1), Éric Cattan (1), Saoni Banerji (2), Jaan Raik (3), Alvo Aabloo (2),

(1) Université Polytechnique Hauts-de-France, CNRS, University Of Lille, YNCREA, Centrale Lille, UMR 8520-IEMN, DOAE, 59313 Valenciennes, France
(2) Intelligent Materials And Systems Laboratory (IMS Laboratory), Institute Of Technology, University Of Tartu, 50411 Tartu, Estonia
(3) Department Of Computer Engineering, Tallinn Technical University, 12618 Tallinn, Estonia

Presentation given by Dr. Sofiane Ghenna

In this work, the mechanical deformation of ionic electroactive polymer (IEAP) based tri-layer micro-actuator subjected to an electrical excitation and mechanical payload is presented. A detailed study on the electrical response of the micro-actuator during charging and discharging process is investigated. Electrical charges, capacitance and resistance of the simplified equivalent electrical circuit are analyzed. The results have shown that, the micro-actuator exhibits a linear behavior for applied voltage lower than 1V. Beyond that, non-linearities appear and are related to the discharging process, especially the corresponding electrical resistance which increases in a non-linear way. Moreover, accumulated electrical charges depend on the previously applied voltage and are not totally restored during the discharging process. The results of this study are illustrated with experimental and theoretical results.

1.4.5 The Beauty of Breakdown

Bettina Fasolt (1), Felix Welsch (2), Sophie Nalbach (1), Gianluca Rizzello (2), Stefan Seelecke (1) (2),

(1) Intelligent Materials Systems Lab, Center For Mechatronics And Automation Technologies, ZeMA GGmbH, Saarbrücken, Germany
(2) Intelligent Materials Systems Lab, Department Of Systems Engineering, Department Of Materials Science And Engineering, Saarland University, Saarbrücken, Germany

Presentation given by Ms. Bettina Fasolt

Dielectric Elastomers represent an attractive technology for the realization of low-cost actuators and sensors. The transduction performance of such systems strongly depends on the material properties of the membrane, especially permittivity and breakdown field strength. To properly characterize these properties, a reproducible testing method is required. In an ongoing study the electrical breakdown in dielectric elastomer thin films subject to voltage application via different electrode shapes - ranging from small spherical and large flat ones to hollow cylindrical shapes - is investigated. A scientific test stand facilitates the exchange of gold-plated electrode tips and thus enables the investigation of different electrical field distributions induced by various electrode geometries. A laser is additionally attached to the setup to provide information about membrane thickness changes during voltage application. The main focus of this presentation, however, is not the illustration of these test results but the depiction of unique enlarged photos, showing amazing geometrical formations and indentations of the silicone film right after breakdown. Additionally, photos and movies were taken over the course of the voltage application until breakdown showing the electro-mechanical effect on the silicone film. These beautiful pictures are intended to make amends to the frustrated researcher, when early breakdown takes place after a carefully assembled experiment.

1.4.6 Characterization of energy dissipation in silicone blends by a simple ball drop test

Rene Preuer (1) (2), Umut Cakmak (3), Ingrid Graz (2),

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

Presentation given by Mr. Rene Preuer

Soft materials, such as elastomers, are the materials of choice for dampers due to their inherent energy dissipation. Their dissipative nature results from the entangled network structure formed by long chain polymers connected by chemical crosslinks. We explore silicone-based elastomers blends for their dissipation by using a ball drop test. This offers a simple and quick way to determine the dissipative properties by monitoring the rebound of a steel sphere dropped onto the samples. The steel sphere`s motion is monitored with a high-speed camera and provides information on quantities such as trajectory, acceleration and velocity of the ball before and after impact. We not only evaluated the dissipated energy by rebound resilience, but also calculated work of deformation. To complement the ball drop experiment, the materials were characterized by conventional measurement methods such as dynamic thermo-mechanical analysis and uniaxial tensile testing, with the results obtained being evaluated by theoretical models in conjunction with the results of the ball drop experiment. Both the experimental and theoretical data show excellent agreement and prove that the ball drop test is indeed a simple but effective alternative to conventional measurement approaches.

1.4.7 Piezoresistive behavior study of the soft inverter based on dielectric elastomer

Jianan Yi (1), Luca Ciarella (1), Moritz Scharff (2), Junhao Ni (1) (2), Katherine Wilson (1) (2) (3), Andreas Richter (1), Markus Henke (1) (2),

(1) TU Dresden, Institute Of Semiconductors And Microsystems (IHM), Dresden, Germany
(2) PowerON Ltd., Dresden, Germany
(3) The University Of Auckland, Auckland Bioengineering Institute, Auckland, New Zealand

Presentation given by Mr. Jianan Yi

Dielectric elastomer (DE) has been extensively studied and considered as a critical component for soft robotics due to its high flexibility and stretchability. However, implementing the integration and fabrication of multi-functional structures on the same DE substrate still remains challenging. In this work, an actuator and square wave patterns with alternative inks were successfully integrated and fabricated on the dielectric elastomer, yielding a soft inverter. The highly electrically conductive carbon nanotube-polydimethylsiloxane (CNT-PDMS) composites were prepared for the dielectric elastomer actuator (DEA) and horizontal patterns, while the vertical patterns (dielectric elastomer switch, DES) were made from piezoresistive carbon black-polydimethylsiloxane (CB-PDMS) nanocomposites. All inks were applied to the dielectric elastomer film (3M VHB) through spray painting. The results indicated that the electrical resistance change of the dielectric elastomer switch could be up to three orders of magnitude when 2500V voltage was applied to the actuator. This entirely soft inverter structure can be potentially applied to develop biomimetic robotics in terms of driving, controlling, monitoring, sensing, and self-regulation.

1.4.8 The role of yarn on the actuation of textile yarn actuators

Shayan Mehraeen (1), Milad Asadi (2), Jose G. Martinez (1), Nils-Krister Persson (2), Jonas Stalhand (3), Edwin Jager (1),

(1) Bionics And Transduction Science, Department Of Physics, Chemistry And Biology (IFM), Linkoping University, Linkoping, Sweden
(2) Swedish School Of Textiles, Smart Textiles, Polymeric E-textiles, University Of Boras, Boras, Sweden
(3) Department Of Management And Engineering (IEI), Solid Mechanics, Linkoping University, Linkoping, Sweden

Presentation given by Dr. Shayan Mehraeen

Textile actuators are a class of wearable technologies that convert electrical energy to mechanical movement through electrochemical reactions by means of conducting polymers. The main merits of textile actuators over the current commercial actuator technologies are that they are light-weight, flexible, and not bulky which all together make them attractive candidates for wearable applications. We have shown that by knitting or weaving actuator yarns into a fabric, it is possible to intensify the total force or strain created by individual yarns which signifies the importance of the performance of individual textile yarn actuators. In this work, we have investigated the effect of the core yarn on the linear actuation of conducting polymer-coated textile yarns. Different yarns, viscose multifilament, viscose Rotorspun, polyamide bulky, and polyamide knit-de-knit were coated with PEDOT:PSS as the first coating layer to make them electrically conductive. Next, PPy was electropolymerized on the PEDOT:PSS coated yarns as the electromechanically active layer. Then, linear strain, as well as blocking force of the different actuator yarns, were investigated as a response to an electrical potential in the range of -1.2 to +0.2 V in an aqueous solution of NaDBS. The actuation results depict that the yarn actuator with viscose core yarn can show linear isotonic strain up to 0.99 % or equivalently linear isometric blocking force of 95 mN.

1.4.9 Crosstalk issues in addressing arrays of dielectric elastomer actuators

Ehsan Hajiesmaili (1), David Clarke (1),

(1) Harvard University, School Of Engineering And Applied Sciences

Presentation given by Mr. Ehsan Hajiesmaili

Two-dimensional grids of dielectric elastomer actuators (DEAs) are central to the development of reprogrammable DEA-based shape-morphing devices. A multilayered two-dimensional grid of DEAs can be created by depositing one-dimensional arrays of rectangular electrodes on each layer, placed perpendicularly to the ones on the adjacent layers. In this design, n2 actuators can be addressed using only 2n high-voltage switches, simplifying the control circuitry of high-resolution DEA matrices. The challenge with such a design, however, is to minimize the crosstalk between the individual DEAs. Two types of crosstalk will be described in this presentation. The first type is inherent because all the electrodes in the system act as floating electrodes, resulting in activation of all DEAs in the system but with lower charge. The second type of crosstalk occurs when the DEAs on row r1 and column c1 and row r2 and column c2 are activated simultaneously. In this case, two other DEAs will also be activated inadvertently, one on row r1 and column c2 and the other on row r2 and column c1. It will be shown that this type of crosstalk can be resolved by addressing one DEA at a time and using the fast charging and slow discharging of the low-leakage DEAs.

1.4.10 Soft, electrohydraulic actuators for a new generation of life-like prosthetic devices

Zachary Yoder (1), Nicholas Kellaris (1) (2), Christina Chase-Markopoulou (1) (3), Devon Ricken (4), Shane K. Mitchell (1), Madison B. Emmett (1), Richard F. ff. Weir (3), Jacob Segil (3) (4), Christoph Keplinger (1) (2) (5),

(1) Paul M. Rady Department Of Mechanical Engineering, University Of Colorado Boulder, Boulder, United States
(2) Materials Science And Engineering Program, University Of Colorado Boulder, Boulder, United States
(3) Biomechatronics Development Laboratory, Rocky Mountain Regional VA Medical Center, Aurora, United States
(4) Engineering Plus Program, University Of Colorado Boulder, Boulder, United States
(5) Department Of Robotic Materials, Max Planck Institute For Intelligent Systems, Stuttgart, Germany

Presentation given by Mr. Zachary Yoder

Powered prosthetic devices promise to restore the functionality of lost limbs. However, the design of these devices is limited by the nearly exclusive use of DC motors. The heavy weight, heat generation and slow speed of these motors are significant drawbacks that often lead to abandonment of the device. The field of soft robotics has demonstrated new types of muscle-like actuators, thereby opening up new design opportunities for prosthetic devices that more closely resemble the neuromuscular systems they are designed to replace. Hydraulically amplified self-healing electrostatic (HASEL) actuators are a new type of soft, electro-hydraulic actuator that demonstrates fast actuation speed and high specific energy. This poster presents an evaluation of the first attempt to drive a prosthetic finger with linearly contracting Peano-HASEL actuators. A kinematic model is used to inform the design of a finger that better utilizes the force-strain characteristics of the Peano-HASEL actuator. When compared to a weight-matched DC motor, the Peano-HASEL system consumes 8.7 times less electrical energy to grasp, and is 10.6 times faster with 11.1 times higher bandwidth. However, the DC motor produces 10 times the pinch force at a relevant grip position. We discuss ways to increase the force of the Peano-HASEL actuators, and show how this type of soft actuator allows for prosthetic devices that deliver improved capability to the user.

1.4.11 Self-healable all-solid electrolytes for electroactive devices designed from polymeric ionic liquids and vitrimer chemistry

Fengdi LI (1), Giao T. M. NGUYEN (1), Cédric VANCAEYZEELE (1), Frédéric VIDAL (1), Cédric PLESSE (1),

(1) LPPI, Laboratory Of Physico-Chemistry Of Polymers And Interfaces, CY Cergy Paris University, Cergy-Pontoise Cedex, France

Presentation given by Ms. Fengdi LI

Ionic electroactive polymers are promising materials for actuation and sensing due to their unique benefits such as flexibility, low driving voltage, and large displacement. Their electromechanical behaviour relies on ion exchanges between electroactive electrodes and a surrounding electrolyte under low voltage stimulation (few volts), and opens promising applications in soft (micro)robotics, biomedical devices and recently into electroactive textile muscles. While air-operation of such devices requires an ion source that can be provided by ionogels (combining properties of crosslinked polymer networks and those of ionic liquids), leakage and toxicity issues can arise from the presence of embedded liquid electrolyte. In this work, "dry" and easily processable ionically conducting materials based on polymeric ionic liquid are presented for truly all-solid-state electroactive devices. Besides, the recent progress of vitrimers inspired us to introduce dynamic covalent bonds to endow the all-solid electrolyte with reprocessability and self-healing ability. These materials can be processed through classical coating methods compatible with textile production on classic yarn. Hence, they appear as promising materials for developing actuators integrated in active and haptic clothe.

1.4.12 Auxetic textured soft strain gauges

Han Liu (1), Simon Lafamme (1) (3), Matthias Kollosche (2),

(1) Department Of Civil, Construction, And Environmental Engineering, Iowa State University, Ames, IA, United States Of America
(2) Harvard John A. Paulson School Of Engineering And Applied Sciences, Harvard University, Cambridge, MA, 02138, United States Of America
(3) Department Of Electrical And Computer Engineering, Iowa State University, Ames, IA, United States Of America

Presentation given by Mr. Matthias Kollosche

Soft stretchable dielectrics and sensor designs with so called self-sensing capabilities have facilitated the development of large-area electronics (LAE) used for sensing, enabling the deployment of dense compliant sensor networks mimicking sensing skin to allow cost-effective monitoring. A sensing skin based on a soft elastomeric capacitor (SEC) technology was developed in prior work. The SEC is as thin-film, highly compliant, and scalable polymer sensors that transduces geometric variations into a measurable change in capacitance. In this contribution, we proposed a new generation of the SEC sensor equipped with a corrugated surface to provide the sensor with higher sensitivity and sensing directionality. We have selected multiple patterns, inspired by auxetic structures, and designed a set of numerical simulations to predict the functionality of surface textured SECs. These simulations are used to evaluate the performance of textured SECs under composite effect, and to determine the effect on stress re-distribution when fully glued onto biological skin. Results show that the auxetic patterns can yield a significant increase in the overall gauge factor and also decrease the stress experienced by the biological skin located under the SEC. It is shown that a hexagonal honeycomb pattern allows the best performance compared to the other selected patterns.

1.4.13 Micro- and nano-structured camouflage surfaces inspired by cephalopods

Yinuan Liu (2), Zhijing Feng (1), Chengyi Xu (3), Atrouli Chatterjee (1), Alon Gorodetsky (1) (2) (3),

(1) University Of California, Irvine, Department Of Chemical And Biomolecular Engineering, Irvine, USA
(2) University Of California, Irvine, Department Of Chemistry, Irvine, USA
(3) University Of California, Irvine, Department Of Materials Science And Engineering, Irvine, USA

Presentation given by Ms. Yinuan Liu

Wrinkled materials are widespread in the natural world and underpin the functionality of a variety of emerging modern technologies. Indeed, the implementation of wrinkles can improve the performance of various devices such as photovoltaics and dielectric elastomer actuators. However, despite tremendous progress to date, the reversible post-fabrication tuning of wrinkle sizes across multiple length scales has remained quite challenging, and the development of comprehensive relationships between structure and function for optically-active wrinkled surfaces has often been fraught with difficulties. Herein, by drawing inspiration from natural micro- or nano-structured cephalopod skin components and leveraging methodologies established for artificial adaptive infrared-reflecting and infrared-transmitting soft actuators, we engineer camouflage surfaces with dynamically-reconfigurable morphologies and concomitant tunable visible-to-infrared spectroscopic properties, while also developing an enhanced understanding of the relationship between their local surface structures and global functionalities. When mechanically actuated, our systems can reconfigure their height frequency distributions by around 180-fold and root-mean-square roughnesses by around 215-fold; When electrically actuated, our systems maintain their highly-desirable visible and thermal functionalities and feature competitive figures of merit and good stabilities upon repeated actuation.

Wednesday, 5 June 2021

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

2.1.1 Plenary talk

Il-Kwon Oh (1),

(1) Korea Advanced Institute of Science and Technology, Korea

Presentation given by Il-Kwon Oh

2.1.2 Invited Talk

Xiaoming Tao (1)

(1) The Hong Kong Polytechnic University, Hong Kongù

Presentation given by Il-Kwon Oh

2.1.3 Actuation and sensing properties of CNT/ionic polymer composites

Takushi Sugino (1),

(1) Nanomaterials Research Institute, National Institute Of Advanced Industrial Science And Technology (AIST), Osaka, JAPAN

Presentation given by Dr. Takushi Sugino

In the IoT (Internet of Things) society, electrically activated polymers (EAPs) are promising key materials as soft actuators [1] and sensors [2] because of their light weight, flexibility, and processability. From the viewpoint of human interaction applications, ionic EAP actuators have been receiving much attention because of low driving voltages (~3V). On these backgrounds, we have studied on ionic EAP actuators consisting of carbon nanotubes (CNTs), ionic liquids (ILs), and a base polymer (BP) called as nanocarbon polymer (NCP) actuators [3-6]. NCP actuators have a three-layered structure where a gel electrolyte layer is laminated by two electrode layers as shown in Fig. 1. The three-layered NCP actuators show a bending motion to the anode side (electromechanical response) when voltages are applied to the actuators. On the contrary, the same three-layered NCPs generate sensing voltages (~mV) when they are bended mechanically from outside (mechanoelectrical response). In this presentation, we will present our research results on the actuation and the sensing properties of NCP composites. Furthermore, we will introduce our application trials with NCP actuators [7-8].

Session 2.2

(abstracts are listed in the order of presentation)

2.2.1 Bimodal resistance behavior of strip dielectric elastomer membranes

Tobias Willian (1), Bettina Fasolt (1), Sophie Nalbach (1), Gianluca Rizzello (2), Stefan Seelecke (1) (2),

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

Presentation given by Mr. Tobias Willian

Dielectric Elastomers (DEs) show several advantages compared to alternative actuator and sensor technologies, e.g., in terms of large deformation, low production cost, and energy efficiency. DEs mainly consist of two elements, i.e., the dielectric membrane and the conductive electrodes. Both of them play a key role in determining the performance of a DE. In particular, the electrical conductivity is attractive, since it allows furthering the bandwidth and the energy efficiency of DE actuators. At the same time, a monotonic, hysteresis-free, and rate-independent relationship between electrode resistance and membrane stretch is attractive for a DE sensor. In our previous research, a bimodal behavior of the electrode resistance w.r.t. the stretch of a strip DE was observed. In this study, the influence of the electrode composition on the behavior of the resistance is investigated. The electrodes composition is based on silicone as matrix material, in which conductive Carbon Black (CB) is used as filler to ensure a conductive behavior. Different CBs, silicones, and CB-to-silicone ratios are investigated. The absolute resistance value, as well as the shape of the resistance-stretch curve, are shown to be strongly dependent on the electrode composition. After showing experimental results, a possible explanation for the bimodal behavior is also presented.

2.2.2 Automated electrical characterization setup for aerosol-jet-printed dielectric elastomer tansducers

Sina Martin (1), Sebastian Kaßner (1), Arne Bruns (1), Paul Schärfe (1), Sebastian Reitelshöfer (1), Jörg Franke (1),

(1) Friedrich-Alexander University Erlangen-Nürnberg, Institute For Factory Automation And Production Systems, Erlangen, Germany

Presentation given by Ms. Sina Martin

or the production of stacked and individually shaped dielectric elastomer (DE) transducers the aerosol-jet-printing had been chosen and further developed at our institute. This printing technology allows the alternating direct deposition of thin layers of either silicone dielectrics or reduced graphene particle electrodes. As the layers are deposited line-wise the surface quality is an issue which has to be considered to obtain constant and predictable electro mechanical parameters. Typically the characterisation of those material systems is performed following the standards for DE testing by Carpi, et al.. Based on this established standard we built up our test bench for mechanical and electrical multi-analysis of the printed DE. Furthermore, the setup has been automated to make DE characterization more precise and to facilitate the comparison of a large number of samples in order to create a validation routine to optimize the production process. To allow precise positioning of the specimen the four axis have been motorized and the program interfaces are used to align the generated information with other measurable parameters such as environmental conditions or timestamps.

2.2.3 Improvement of a soft electrostatic generator: addition of a triboelectric function

Simon-emmanuel Haim (1), Claire Jean-mistral (2), Alain Sylvestre (1),

(1) Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, Grenoble, France
(2) Univ Lyon, INSA-Lyon, CNRS, LaMCoS, Villeurbanne, France

Presentation given by Mr. Simon-emmanuel Haim

Soft electrostatic generators (SEG), typically made of electroactive polymers, represent an efficient way to power up devices widely used in the IoT, including smart clothes, biomechanical energy harvesters or sensors. The working principle of these generators is to use the variation of capacitance to convert mechanical energy into electrical one. Our team demonstrated that an electret can be used to replace the external voltage supply needed for these SEGs leading to an energy self-sufficient soft generator. The goal of our work is to extend the performance of our electrostatic generator by adding a sliding-mode triboelectric function. Both the electret and the triboelectrification contribute to biasing the electrostatic generator made of silicone. We modelled by finite elements the electrical power generated during the mechanical deformation (50% of strain) of our centimeter-scale generator coupling these electrostatic, triboelectric and electret modes. We will compare those results with analytical simulations performed with Matlab, as well as with some preliminary tests of a pure sliding mode triboelectric nanogenerator.

2.2.4 Electrical and mechanical parameters variation in IEAP actuators as a function of payload mass and voltage

Iman Dadras (1), Sofiane Ghenna (2), Sébastien Grondel (2), Éric Cattan (2), Saoni Banerji (1), Jaan Raik (3), Alvo Aabloo (1),

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(2) Université Polytechnique Hauts-de-France, CNRS, University Of Lille, YNCREA, Centrale Lille, UMR 8520-IEMN, DOAE, 59313 Valenciennes, France
(3) Department Of Computer Engineering, Tallinn Technical University, 12618 Tallinn, Estonia

Presentation given by Mr. Iman Dadras

This work justifies the nonlinearity errors in ionic electroactive polymer actuator lumped-parameter models. The errors are traced back into the model parameters variations as functions of voltage and payload mass. Six experiments with different voltages and payload masses were carried out. Experiments showed that a linear lumped-parameter model with corrected parameters accurately predicts actuator's behaviors as a linear second-order system. Therefore, nonlinearities are mapped to lumped parameter variations. The changes in resistance, capacitance, mechanical pole, and mechanical gain according to the voltage and payload mass are calculated and illustrated. Mechanical pole and mechanical gain are functions of mechanical parameters, namely, second moment of inertia, Young's modulus, and viscosity. Geometrics and electrical transitions due to actuator movement and voltage are responsible for the changes in parameters. The results are promising for a linear and straightforward but accurate loaded and unloaded actuator model.

2.2.5 Actuator and sensor elements based on dielectric elastomers for mobile assisting tools in Industry 4.0 environment

Sebastian Gratz-Kelly (1), Bettina Fasolt (2), Sophie Nalbach (1) (2), Giacomo Moretti (1), Paul Motzki (1) (2), Stefan Seelecke (1) (2), Gianluca Rizzello (1),

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Presentation given by Mr. Sebastian Gratz-Kelly

Due to the high demand for human-machine-interaction, especially in the industry 4.0 environment, a flexible and safe interaction between the working tools and the worker, for example through haptic feedback, is very important. Actual systems to facilitate force feedback to a user are mostly very bulky and expensive and the classic actuator and sensor principles are not suitable for integration into textiles. Dielectric Elastomers (DEs) are highly stretchable transducers suitable for a number of application, which allow, in particular, integrating sensor and actuation capabilities into a single soft unit. Due to their lightweight, high energy density, and large deformation, they are particularly suitable to develop user-interface textiles and integrated applications. However, despite the great potential of DEs in the haptic field, the topic has received only little attention so far. This poster shows first results of the development of an intelligent glove prototype based on DE elements. DE elements are used for gesture recognition, haptic feedback to the worker, and potentially combined vibro-acoustic feedback. A DE element with 8 DE Sensors, which is fully integrated into a Glove, is presented. The concept for the integration of haptic and acoustic feedback elements into the Glove, as well as a strategy to embed the driving electronic into the system, is shown. Finally, some possible use- and demonstration scenarios for the envisaged glove prototype are presented.

2.2.6 Novel silicone-spin crossover composites with multi-stimuli response

Codrin Tugui (1), Valeria Harabagiu (1), George Stiubianu (1), Sergiu Shova (1), Aurelian Rotaru (2),

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(2) Faculty Of Electrical Engineering And Computer Sci. & Research Center MANSiD, Stefan Cel Mare University, Suceava, Romania

Presentation given by Dr. Codrin Tugui

Silicones represent one of the best-performing dielectric elastomers, exhibiting excellent long-term stability and reliability, low creep, scalability, fast response and biocompatibility. However, finding new silicone dielectric elastomers capable to respond to multiple stimuli has attracted the interest of many researchers. Therefore, this work reveals the possibility of extending the applicability of silicone-based dielectric materials by combining the excellent properties of silicone elastomers with those of spin-crossover complexes (SCO). Spin-crossover materials (SCO) are capable of undergoing reversible switching between two electronic configurations (low spin - LS and high spin - HS) upon application of external stimuli, such as temperature, pressure, light, pH, electric and magnetic field. SCO material plays a dual function when incorporated into the silicone elastomer: enhance the dielectric permittivity and induce sensitivity to new stimuli. The results obtained on these composites may contribute to the development of a new generation of materials capable to enlarge the applicability of conventional elastomers.

2.2.7 Novel dielectric elastomer sensor design for high pressure loads

Holger Boese (1), Jinchao Liu (1), Thomas Gerlach (1),

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

Presentation given by Dr. Holger Boese

Besides actuation and energy harvesting, dielectric elastomers exhibit also high potential for sensor applications. Dielectric elastomer sensors (DES) are mostly used for strain monitoring, where simple thin elastomer films with stretchable electrode layers are convenient. When the DES is stretched, the capacitance between the electrode layers is enhanced due to the increase of the area and the decrease of the thickness of the capacitor. However, for compression measurements modified sensor designs are necessary, because the known strain sensors are very insensitive to pure pressure loads due to the inherent volume incompressibility of elastomers. Therefore, a new sensor design with enhanced sensitivity for pressure loads is presented. The new sensors consist of a DES film in multi-layer configuration with several dielectric and electrode layers, which is covered on both sides by plates with a pattern of openings. When this sensor composite is compressed, the DES film can locally deform and shift the elastomer material into the neighbored openings, which relieves its compression and the corresponding increase of the capacitance. In contrast, if the plates exhibit no openings or the sensor exhibits no plates, the expansion of the DES film is hindered due to friction. The plates with openings can be made either stiff or flexible. The performance of such compression sensors evaluated in experiments is described and compared with the results of corresponding simulations.

2.2.8 Strain dynamics under DC voltage of PEDOT:PSS-based micro-actuators

Lauréline Seurre (1), Hélène Arena (1), Sofiane Ghenna (1), Caroline Soyer (1), Sébastien Grondel (1), Cédric Plesse (2), Giao T.M. Nguyen (2), Frédéric Vidal (2), Eric Cattan (1),

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(2) LPPI, EA2528, Institut Des Materiaux, Universite De Cergy-Pontoise

Presentation given by Ms. Lauréline SEURRE

Conducting polymer actuators exhibit large strain in response to an external stimulation, thus representing promise materials for MEMS. Presented as a trilayer structure composed of an ion reservoir membrane sandwiched between two electronically conducting polymers (ECP) as electrodes, the actuator exhibits bending deformation as a result of ions movements between the two electrodes during their redox process. We recently reported on the development of micro-actuators based on PEDOT:PSS, a commercially available ECP. Although micro-actuators are very often characterized by applying an AC voltage, many applications require subjecting the actuators to a DC voltage for several seconds or minutes. Some of these applications are the closing of a micro-gripper and the actuation of a cochlear implant during a surgery. With the aim of developing a micro-gripper, the dynamics strain of PEDOT:PSS-based trilayer micro-actuators have been studied by applying DC voltages in order to reach the maximum strain and force. The application of a DC voltage for an extended time shows that the actuator does not go back to its initial position after switching off the power supply. This study reveals the appearance of a memory effect, which is directly related to the intrinsic operation of the ECP-based actuator. These results allow a better understanding of the actuation process and are needful for the modelling and future control of integrated ECP actuators in microsystems devices.

2.2.9 Experimental characterisation and modelling of continuum voltage-driven vibrations in dielectric elastomer membranes

Giacomo Moretti (1), Gianluca Rizzello (1), Marco Fontana (2), Stefan Seelecke (1),

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(2) TeCIP Institute, Scuola Superiore Sant"Anna, Italy

Presentation given by Dr. Giacomo Moretti

Although dielectric elastomers (DEs) typically make use of simple deformation patterns to perform actuation task, in the presence of high-frequency excitation they exhibit higher-order structural modes and complex structural dynamics. Predicting and controlling the voltage-driven continuum dynamics of DEs might pave the way to new applications such as morphing structures, and tunable optic and acoustic devices. We carried out an experimental campaign aimed at the characterisation of the voltage-driven vibrations in a cone DE actuator (C-DEA) layout. By using a 3D laser vibrometer, we measured the complex structural mode shapes and velocity spectra generated applying a broadband excitation on the C-DEA. We were able to explain the observed mode shapes and their natural frequency resorting to a multi-physics model. In particular, we observed that the air pressure loads generated by the DEA vibrations are able to significantly affect the natural modes' frequency. We hence set up a model accounting for the electro-elastic and aero-elastic coupling contributions, and validated it against the data. The model is able to predict the profiles of the different velocity components at different points of the C-DEA surface, within a broad frequency range. The development modelling framework might be used, in the future, for the design of multi-function C-DEAs capable of exploiting different vibration regimes to concurrently accomplish different actuation tasks.

2.2.10 Submerged dielectric elastomer generator for wave energy harvesting with tuneable stiffness compensation

Marco Fontana (1), Giacomo Moretti (3), Michele Righi (1), Rocco Vertechy (2), Lorenzo Agostini (1), David Forehand (1),

(1) Scuola Superiore Sant"Anna
(2) University Of Bologna
(3) University Of Saarland
(4) University Of Edinburgh

Presentation given by Prof. Marco Fontana

Dielectric elastomer generators (DEGs) are a promising option for the implementation of sea wave energy converters (WECs). This contribute introduces a concept of a novel pressure differential WEC equipped with a DEG power take-off operating in direct contact with sea water. The device consists of a closed submerged air chamber, with a fluid-directing duct and a deformable DEG power take-off mounted on its top surface. The DEG is cyclically deformed by wave-induce pressure, thus acting both as the power take-off and as a deformable interface with the waves. This layout allows the partial balancing of the stiffness due to the DEG's elasticity with the negative hydrostatic stiffness contribution associated with the displacement of the water column on top of the DEG. This feature makes it possible to design devices in which the DEG exhibits large deformations over a wide range of excitation frequencies. We propose a modelling approach for the system that relies on potential-flow theory and electro-elasticity theory. This model makes it possible to predict the system dynamic response in different operational conditions and it is computationally efficient to perform iterative and repeated simulations, which are required at the design stage of a new WEC. We performed tests on a small-scale prototype in a wave-tank with the aim of investigating the fluid-structure interaction between the DEG membrane and the waves in dynamical conditions and validating the numerical model.

2.2.11 Dielectric elastomer array: Manufacturing, characterization, and modelling

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

(1) Saarland University
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Presentation given by Mr. Julian Neu

Most of currently available dielectric elastomer actuators (DEAs) operate by using a single membrane, whose stroke ranges on a macroscopic scale (several cm). Alternatively, many small DEA elements can be arranged in an array configuration, thus allowing the development of flexible, energy efficient, and self-sensing cooperative actuator systems. Despite being highly attractive, only few preliminary examples of cooperative DEA systems have been presented up to date. In a DEA array, the closely packed actuators may exhibit a strong electro-mechanical coupling with their neighbours. Such interactions have a strong effect on the overall array performance, and depend on several design parameters. In order to properly design and optimize cooperative DEA arrays, these coupling effects have to be systematically understood first. In our poster, we present on development and modeling of a first prototype of DEA array system. The considered system consists of a 3-by-1 matrix of individually controllable DEA elements, deployed on a single silicone membrane clamped at its outer edges. After describing the system, experimental characterization results are shown. The collected data are then used to validate a physics-based model of the device, which is subsequently used to study the influence of the design parameters (e.g., geometry, pre-stretch) on the spatially-coupled system response. These findings will serve as a first steps towards the development of cooperative DEA arrays.

2.2.12 Preparation of dry ionic coatings containing cationic or anionic polymeric ionic liquid for the electro-responsive fabrics

Bin Ni (1), Fengdi Li (1), Cédric Vancaeyzeele (1), Tran-minh-giao Nguyen (1), Frédéric Vidal (1), Cédric Plesse (1),

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Presentation given by Dr. Bin Ni

Flexible wearable fabrics have attracted the researcher's attention due to the widely promising applications in real-time display, health monitoring, active and haptic devices, etc. The recent development of electrochemical textile muscles based on conducting polymer is now pushing the demand of ionic coatings combining processability, stretchability and high ionic conductivity for their in-air operation. Additionally, ideal ionic coating must be dry to solve toxicity/leakage issue, with precursors presenting low viscosity and ultra-fast polymerization speed for homogenous coating on textile. Polymeric ionic liquid (PIL) has become one of the excellent candidates for dry ionic coatings. Meanwhile, PEO network has been proved with self-standing ability and good ion-pair dissociation. Therefore, in this work, we described the synthesis of semi-interpenetrating polymer networks based on PEO network and entangled linear polyanion/polycation-type PILs. Their ionic precursor has a low initial viscosity (< 1min), which is suitable for yarn coating. The fabricated materials exhibit good stretchability (up to ~100 % of the original length) and high ionic conductivity (up to 10-5 S/cm), which is even maintained after dry washing process. These materials coatings will be evaluated in a near future as ionic coating on electroactive yarns for haptic textile application incorporated as part of the WEAFING project.

2.2.13 PEDOT:PSS coated twisted and coiled yarn actuators

Shazed Aziz (1), Jose G. Martinez (1), Bidita Salahuddin (2), Nils-Krister Persson (3), Edwin W. H. Jager (1),

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(3) Smart Textiles Technology Lab Swedish School Of Textiles University Of Borås Borås SE-501 90, Sweden

Presentation given by Dr. Jose G. Martinez

Commercial yarns can be functionalized with conducting polymers (CPs) to develop yarn and textile actuators. Here we show a method of functionalization of commercial polyamide yarns by poly-3,4-ethylenedioxythiophene:polystyrenesulfonate (PEDOT:PSS) coating. After coating, while PEDOT:PSS is drying, it is possible to twist and coil the yarns, resulting in a major improvement of their linear strain and speed of movement. By using a potential window between +0.6 V and -1.2 V vs Ag/AgCl it was possible to obtain a fully reversible actuation of a coiled yarn providing up to 1.62% strain. A strain higher than 1% was achieved in less than 1 second. Compared to the untwisted, regular yarns, the twisted and coiled yarns produce >9× and >20× higher strain, respectively. These results are a step forward towards the development of soft, silent and compliant smart textile exoskeletons.

Thursday, 3 June 2021

Session 3.1

(abstracts are listed in the order of presentation)

3.1.1 Ferroelectric polymer devices on flexible and ultraflexible substrates

Barbara Stadlober (1), Andreas Petritz (1) (2), Esther Karner-Petritz (1) (2), Philipp Schäffner (1), Jonas Groten (1), Martin Zirkl (1), Andreas Tschepp (1), Manfred Adler (1), Takafumi Uemura (2), Teppei Araki (2), Tsuyoshi Sekitani (2),
(1) Joanneum Research Forschungsgesellschaft MbH, MATERIALS-Institute For Surface Technologies And Photonics, Austria
(2) Institute Of Scientific And Industrial Research, Osaka University, Japan.

Presentation given by Barbara Stadlober

Abstract: Ferroelectric polymers like PVDF-TrFE are very versatile and can be deployed for multi-parameter sensing of strain, pressure, touch, vibration, temperature, IR radiation and vital parameters as well as for the harvesting of waste energy. Through fabrication by screen printing, ferroelectric polymer devices can easily be integrated on large areas of flexible substrates and different materials like plastic foils, paper, textile, leather, rubber, metal foils etc... This makes them very attractive for a wide range of applications as energy autonomy and flexibility are essential elements in the next generation of wearable and flexible electronics. Recently we have demonstrated various applications of flexible ferroelectric polymer devices in sectors like Industry 4.0, Condition Monitoring, Smart City, Smart Living, Smart Mobility, Smart Wearables and Consumer Electronics. In these examples, the PVDF-TrFE sensors compel not only with their mechanical flexibility, but also with the reproducibly high performance, the fast response time and the zero energy consumption. For a next generation of medical devices we have integrated ferroelectric polymer sensors on ultrathin parylene substrates and combined that with organic rectifier diode circuits and capacitor storage elements to realize imperceptible pulse wave sensors and biomechanical energy harvesters.
Barbara Stadlober (1),

3.1.2 Supercoiling artificial muscles

Geoffrey Spinks (1),

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

Presentation given by Prof. Geoffrey Spinks

Supercoiling of double-stranded DNA is a fascinating molecular phenomenon implicated in vital cellular functions such as gene expression, DNA folding and replication. Supercoiling is a response to torsional strain imposed on topologically constrained DNA segments such that any change in the double helix twist is represented as a concomitant change in molecular shape known as writhe. For example, intercalation of small molecules into the double helix can generate plectoneme structures where the DNA wraps around itself rather like a twisted telephone cord. Plectoneme formation draws distant parts of the DNA molecule into close proximity enabling specific protein interactions that trigger processes such as transcription. While DNA supercoiling is not known to be involved in cellular mechanical functions, our analysis of tensile experiments on single DNA molecules shows a work per mass exceeding skeletal muscle. Intercalation of non-tethered DNA leads to unwinding of the double helix in a process similar to the swelling-induced torsional actuation in macroscopic twisted fibres and yarns. Indeed, we were able to demonstrate supercoiling in twisted composite yarns made from polyester sewing thread infused with a pH-sensitive hydrogel. The supercoiling transition generated actuation strokes of 90% and with work capacities exceeding 1 J/g. Coiling the composite yarns by over-twisting produced coiled coils when swollen with simultaneously high strokes and high work capacities.

3.1.3 Invited Talk

Jonathan Rossiter (1)

(1) Bristol University, United Kingdom

Presentation given by Jonathan Rossiter

Session 3.2

3.2.1 Fully automatic multi-characterization setup for systematic long-term investigation on dielectric elastomers

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

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(2) Intelligent Materials Systems Lab, Center For Mechatronics And Automation Technologies, ZeMA GGmbH, Saarbrücken, Germany

Presentation given by Mr. Daniel Bruch

Dielectric Elastomers (DEs) represent an emerging electromechanical transduction technology which enables a variety of new sensor and actuator applications. Features such as low weight, inexpensive materials and high design flexibility make it particularly attractive and competitive compared to traditional solutions. To further develop the technology towards market readiness, there is a growing interest on systematic quantification of its long-term performance in order to obtain a deeper understanding of aging and fatigue behaviour as a function of material, design, manufacturing and load conditions. This work introduces an electromechanical multi-characterization setup on a modular base, which enables this systematic long-term investigation on DEs. Each module permits to arbitrarily program mechanical stroke and electrical voltage, and enables simultaneous testing of five samples. Three modules are placed inside of a climate chamber, which provides reproducible environmental testing conditions. Investigated quantities are force and displacement as well as electric current, voltage, capacitance and resistance. A table control interface enables high flexibility in programming different test routines which are executed sequentially. Extensive safety facilities enable fully automatic 24/7 operation without interruption. First test results are given and evaluated in terms of change of the reaction force, capacitance and resistance over number of fatigue cycles.

3.2.2 Dielectric elastomers based on 3D printed silicone

Codrin Tugui (1), Maria Cazacu (1), George Stiubianu (1), Manole-Stelian Serbulea (2), Alin Stefan (3),

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Presentation given by Dr. Codrin Tugui

Current methods of manufacturing dielectric elastomer transducers (DETs) are developed from spin-coating and spray coating technologies. The spin coating method is suitable for thin silicone elastomer film with good uniformity, while the spray coating method is advantageous on fabricating stacked DETs. Also, other silicone objects can be produced traditionally through injection molding, a mature technology developed specifically for large series production. However, for the prototyping of small series of customized products, the process may be expensive. This has motivated the development of advanced manufacturing methods, such as 3D printing technologies, which allows the construction of three-dimensional objects layer by layer following a digital model. Silicone materials such as thermoplastics or metal composites cannot be thermally processed, and to make it possible to use silicones for this purpose, we have had to develop a completely different process. Our technology based on UV-activated curing process requires low energy consumption and is not polluting. In addition, the process is very fast and generates materials with excellent properties for DET technologies.

3.2.3 Study on the strain and mechanism of polypyrrole-based yarns for the development of linear textile actuators

Amaia Ortega (1), Jose G. Martinez (1), Edwin Jager (1),

(1) Linkoping University, Physics Chemistry And Biology, Linkoping, Sweden

Presentation given by Ms. Amaia Ortega

Conducting polymer-based textile actuators are promising devices that have shown great features, e.g., processability, flexibility, and stretchability. The actuation of these materials is based on the mass transfer from the surrounding electrolyte to the polymer matrix and vice versa. The dopant incorporated during electropolymerization establishes the actuation mechanism of these actuators. Small or mobile anions lead to the anion motion, whereas big anions that cannot move lead to the exchange of cations. So far, most of the developed yarn-based actuators were doped with immobile anions in liquid solutions. However, little is known about the anion exchange in yarns. Here, we present a study on the effect of the dopants, solvents, and polymers on single yarns' strain and actuation mechanism. This work will help understand and develop electrically conductive yarns that can be used to build wearable smart textiles.

3.2.4 New actuation modes of dielectric elastomer composite devices

Massimiliano Gei (1), Roberta Springhetti (2),

(1) DIA, University Of Trieste, Italy
(2) DICAM, University Of Trento, Italy

Presentation given by Prof. Massimiliano Gei

For a usual Dielectric Elastomer (DE) actuator, the attraction between the electrodes owing to Maxwell forces entails a reduction of thickness with an expansion of in-plane area. However, the overall response also depends on the local effects induced by polarization, which can be macroscopically accounted for assuming the dielectric constant as a function of the strain. In this case, actuators can exhibit the remarkable theoretical property of CONTRACTING and THICKENING under an electric stimulation. In this work, we show that such counterintuitive behaviours can be achieved by tuning the electric input on tailored hierarchical dielectric composites whose phases obey an ideal dielectric behaviour. Our study concerns laminates for which we highlight the main design parameters, i.e. the shear modulus-- and dielectric constant-ratios as well as the lamination angle, to achieve the new modes. The effect of the layout in limiting, suppressing or promoting electromechanical instability under voltage control is also presented; in some cases, where the instability is suppressed, the maximum in-plane stretch orthogonal to the laminae can increase considerably with respect to a homogeneous actuator. On the basis of our results, hierarchical DE composite materials can be conceived, whose counterintuitive properties can be taken advantage of in the design of innovative actuators, sensors and energy harvesters.

3.2.5 Comparative study of different dielectric materials for the implementation of electrostatic bellow muscle (EBM)

Ion-Dan Sirbu (1), Giacomo Moretti (4), Rocco Vertechy (3), Sandra Dirè (1), Luca Fambri (1), Marco Fontana (2),

(1) University Of Trento
(2) Scuola Superiore Sant"Anna
(3) University Of Bologna
(4) University Of Saarland

Presentation given by Prof. Marco Fontana

Here, we present a novel electrostatic actuator that combines the use of thin films, liquid dielectric and stiffening rings, assembled to form circular actuation units that undergoes to out-of-plane expansion/contraction. Prototypes of these actuation units have been tested showing a contraction of up to 40%, a maximum power density during contraction of 100 W/kg, a maximum strain rate of 1000% per second, a bandwidth of approximately 10 Hz, and the ability to lift hundreds of times their weight. Additionally, these units resulted easy to manufacture in different dimensions and can be assembled in arrays and stacks to form electrostatic bellow muscles (EBM) that can be effectively employed as a contractile artificial muscle, as pump and as electrostatic generator. EBM demonstrated their flexibility in matching a wide range of requirements and scales in terms force-displacement combinations and bandwidth. The compact 2-D shape, the low-cost of components, the simple assembling procedure, the high level of reliability and the relevant performance make the EBM a possible enabling technology for a variety of high-performance robotic and mechatronic systems. In this contribution we compare the performance EBM devices implemented with different dielectric materials including biaxially oriented polyethylene, polymide and Polyvinylidene fluoride.

3.2.6 Biofriendly ionogel coatings for electroactive textile muscles

Loris Gelas (1), Tran-Minh-Giao Nguyen (1), Frédéric Vidal (1), Cédric vancaeyzeele (1), Cédric Plesse (1),

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Presentation given by Mr. Loris Gelas

Textile muscle is an important part of the new field of soft electronics since they open new perspectives in promising applications such as robotics or medicine. In order to operate in open-air, yarns or textile actuators employing ionic electroactive-active polymers require an ionic source. This can be provided by the development of ionic coating combining low initial viscosity and fast polymerization for the coating process, good stretchability and ionic conductivity for their operation and no toxicity for contact with user skin. In this work we describe the synthesis of photopolymerizable and biofriendly ionogel coatings, made of UV polymerized poly(hydroxyethylacrylate) networks percolated with Choline Acetate as biocompatible ionic liquid. The low viscosity precursor solution (0.739Pa/s) jellifies in 1 second and present ionic conductivity of 0. 5 mS/cm with stretchability of 85%. In order to improve further the mechanical properties of these ionogels, double network architecture is also explored and demonstrated significant improvement of toughness while maintaining ionic conduction. These coatings appear as a promising candidate for electroactive textile coatings and will be evaluated in a near future for in-air textile muscles.

3.2.7 Experimental and analytical investigation of the viscous-elastic behavior of elastomer and electrode materials

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

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

Presentation given by Mr. Ozan Çabuk

For dielectric elastomer (DE) transducers, the elastic and viscous behavior of both elastomer and electrode materials have significant influence on the actuation performance. Whereas the elastic stiffness affects against the electrostatic pressure depending on the stretch ratio, viscose effects are time-dependent and occur only by changing the stretch ratio. Therefore, not only the stiffness but also the viscosity of materials plays an important role by the material choice, especially for DE-transducers when providing high dynamic actuation. In this contribution, a model based on a combination of a Kelvin-Voigt element and Maxwell element for the viscous-elastic behavior is introduced and subsequently the quasi-static and the dynamic compression tests with an elastomer and two electrode materials are conducted. The dynamic behavior is analyzed by step function responses and sine sweep excitations in order to estimate the model's parameters by an appropriate fitting method. Besides the DE's hyperelasticity, the obtained parameters describe the viscosity-dependent hysteresis, frequently observed in DE-transducers. Finally, the mechanically characterized materials are compared and the results are discussed regarding to the actuation performance of DE-transducers.

3.2.8 Test approach to prove and characterize the proper functioning of dielectric elastomer transducers during manufacturing process

Andreas Hubracht (1), Tim Krüger (1), Jürgen Maas (1),

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

Presentation given by Mr. Andreas Hubracht

Dielectric elastomer transducers (DETs) progressively attract attention in research and industry. One major reason is their diverse use as actuators, sensors or even generators. Basically, DETs consist of a dielectric elastomer coated with compliant electrodes. By stacking several of these layers, multilayer transducers can be realized. When electrical voltage is applied to the electrodes, the electrostatic pressure leads to an actuation of the stacked films. With regard to manufacturing, submodules with a small number of layers are produced and DETs can be created by stacking multiple of these submodules. In order to minimize the scrap rate, increase the productivity and monitor the manufacturing process, testing of multilayer composite during manufacturing process could be favorable. The proposed test is capacitance-based and applied on submodule level whereby the composite is placed between two capacitor plates. An electrical voltage is applied to the capacitor plates, so the multilayered composite between the two plates is exposed to an electric field, e.g. 50 V/µm. If two electrode layers are conductively connected due to a defect in production, a breakdown may occur. In this way, faulty submodules can be detected. Methodologically, an analytical approach and FEM simulation are used to design the set-up. Finally, a test procedure to reduce the scrap rate and to improve the production quality is presented and validated by conducting experiments in a laboratory scale.

3.2.9 Toward micro-transducers based on conducting polymer for biomedical devices

Anta THIAM (1), Tran Minh Giao NGUYEN (1), Frederic VIDAL (1), Cedric PLESSE (1),

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Presentation given by Ms. Anta THIAM

The project ROBOCOP (ROBOtization of COchlear imPlant) aims at creating a new prototype of cochlear implant with active and sensing part to better control its insertion process, in order to facilitate the work of surgeon, to increase the success ratio, and to decrease the probability of trauma. Such robotization can be provided by the development of low voltage ionic actuators based on conducting polymers. Previous works from LPPI/IEMN demonstrated the possibility to fabricate PEDOT:PSS based trilayer microactuators according to microsystem processes. However, this proof of concept relies on materials and chemical no suitable with biomedical application, more specifically containing and potentially releasing toxic substances. In this work, first results are presented on the fabrication of the micro-transducers. First the composition and synthesis of the PEDOT:PSS electrodes and of the ionic conducting membranes are optimized to limit the presence of any extractible compound. In a second step, two solutions are proposed to avoid the use of toxic ionic liquids: i) using a non-toxic electrolyte such as Saline solution, choline aqueous solution or choline based biocompatible ionic liquid; ii) synthesis of all-solid-state micro-transducers containing no liquid phase able to leak by the use of polymeric ionic liquid. Synthesis, characterization and first actuation results will be described.

3.2.10 Matlab/simulink model for dielectric elastomer circuits

Luca Ciarella (1), Katherine Wilson (1) (2) (3), Andreas Richter (1), Iain Anderson (2) (3) (4) (5), Markus Henke (1) (3),

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Presentation given by Mr. Luca Ciarella

Dielectric elastomers (DEs) are electroactive polymers, capable of realizing multiple functionalities. They are used as soft actuators, sensors and energy harvesters. In recent years, also soft electronic circuits have been successfully built with DE components. This circuitry has the advantage of being intrinsically compatible with other DE devices because they are made of the same materials and with the same processes. An easy-to-use model that can simulate the behaviour of these structures accurately in short times would be an important tool that could support the development of new and more complex circuits. DE devices possess a complex electro-mechanical behaviour. Many models exist for studying DE properties like actuation, leakage current and time-dependent viscoeleastic response. However, they usually rely on complex and time-consuming multi-physics finite element simulations and they usually take into account a single aspect of the device (e.g. actuation, leakage current or viscoelasticity). Here, we present a Matlab/SIMULINK model that takes into account the full electro-mechanical behaviour of DE devices and interconnects multiple units in a circuit network. The model shows a correct prediction of the circuits behaviour and it can be used to study the effectiveness of DE circuit networks before physically building them.

3.2.11 2D positioner driven by a double-cone dielectric elastomer actuator

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Presentation given by Mr. Giacomo Sasso

This presentation describes a 2D positioner made of a double-cone dielectric elastomer actuator. The device consists of two conically-shaped VHB membranes forming a 3D hyperbole. Each membrane is spray-coated on either side with carbon black-silicone electrodes, forming four independent radial actuation segments. The two conical membranes support a central end effector. Via image processing-based motion tracking, we show how, by modulating the activation of the actuation segments, the end effector can be finely positioned in two dimensions. The direction and the amplitude/speed of motion of a central dot are tuned via a custom-made, Arduino-driven, multichannel, high-voltage control unit. Different trajectories forming geometrical shapes (e.g. figure of eight, star, square, cross, circle) are shown, so as to demonstrate the accuracy of the device.

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