WorldWide ElectroActive Polymers

EAP

(Artificial Muscles) Newsletter

Vol. 20, No. 1 (39th issue) **WW-EAP Newsletter** **June 2018**

http://eap.jpl.nasa.gov

FROM THE EDITOR

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This Newsletter issue reports the latest progress in the fields of Electroactive Polymers (EAP) and Biomimetics.

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ABOUT THE EXPERTS

Herbert Shea was promoted to Full Professor

In December 2017, Herbert Shea was promoted to Full Professor of Microtechnology in the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. Over the course of his successful scientific career, Herb has conducted research in a wide range of fields relating to applied physics and microtechnology. Since joining the EPFL in 2004, he has led research in Dielectric Elastomer Actuators, with pioneering work in miniaturized high-speed DEAs and in compliant electrode technology. His current research at EPFL focuses on polymer-based transducers for soft robotics, haptics, and cell biology.

GENERAL NEWS

The WW-EAP Webhub http://eap.jpl.nasa.gov is periodically being updated with information regarding the EAP activity worldwide. This

Webhub is a link of the JPL's NDEAA Webhub of the Advanced Technologies Group having the address: http://ndeaa.jpl.nasa.gov

Standard for EAP

A paper about a standard for EAP materials is posted on the internet and can be read at http://dx.doi.org/10.1088/0964-1726/24/10/105025

UPCOMING CONFERENCES

2019 SPIE EAPAD Conference

The SPIE's EAPAD conference is going to be held again in Denver, Colorado, from March 3 thru 7, 2019. This conference, which is part of the Smart Structures Symp., is going to be the 21st annual one and is going to be chaired by Yoseph Bar-Cohen, JPL, and Co-chaired by Iain A. Anderson, The Univ. of Auckland (New Zealand) and Nancy L. Johnson, General Motors Co., USA. The Conference Program Committee consists of representatives from 32 countries. The call for papers is posted at: http://www.spie.org/eap

The papers will focus on issues that help transitioning EAP to practical use thru better understanding the principles responsible for the electro-mechanical behavior, analytical modeling, improved materials and their processing methods, characterization of the properties and performance as well as various applications.

In the 2019 EAPAD Conf., a Special Session is going to be "3D Printed EAP Materials: Progress and Challenges" and its Session Chair is Geoff M. Spinks, Univ. Wollongong, Australia.

There are going to be two Keynote Speakers and they are:

1. Ray H. Baughman, NanoTech Institute at the Univ. of Texas in Dallas, who will present "Science and Technology Contributions and Accomplishments", in honor of his 75th birthday.
2. Douglas A. Litteken, NASA Johnson Space Ctr. (JSC) will present the paper "Inflatable Technology: Using Flexible Materials to Make Large Structures".

On the record of the EAPAD conferences archive, the following is the list of the Co-chairs since the start in 1999 at Newport Beach, CA.

Year	Co-chair	Country
1999	Mohsen Shahinpoor, U. of New Mexico	USA
2000	Steve Wax, DARPA	USA
2001	Danilo De Rossi, Univ. degli Studi di Pisa	Italy
2002	Yoshihito Osada, Hokkaido University	Japan
2003	Geoff Spinks, University of Wollongong	Australia
2004	Peter Sommer-Larsen, Risoe National Lab.	Denmark
2005	John D. Madden, U. of British Columbia	Canada
2006	Jae-Do Nam, Sung Kyun Kwan University	S. Korea
2007	Gabor Kovacs, EMPA	Switzerland
2008	Emillio P. Calius, Industrial Res. Limited	New Zealand
2009	Thomas Wallmersperger, Univ. Stuttgart	Germany
2010	Jinsong Leng, Harbin Institute of Tech.	China
2011	Federico Carpi, Univ. of Pisa	Italy
2012	Keiichi Kaneto, Kyushu Inst. of Tech.	Japan
2013	Siegfried Bauer, Johannes Kepler U.	Austria
2014	Barbar J. Akle, Lebanese American Univ.	Lebanon
2015	Gal deBotton, Ben-Gurion U. of the Negev	Israel
2016	Frédéric Vidal, U. de Cergy-Pontoise	France
2017	Jonathan Rossiter, University of Bristol	England
2018	Iain A. Anderson, The Univ. of Auckland	New Zealand
2019	Iain A. Anderson, The Univ. of Auckland Nancy L. Johnson, General Motors Co.	New Zealand USA

TECHNOLOGY DEVELOPMENT CHALLENGES

Seeking concepts of autonomous fully controllable "endoscope"

Studor, George F. (LARC) [TEAMS3 NESC Affiliate] george.f.studor@nasa.gov

NASA Engineering and Safety Center, NDE Technical Discipline Team's lead for in-space inspection, George Studor, is looking for technologies that can enable the development of a fully controllable "endoscope" that is operational at zero-gravity onboard the ISS. This advanced endoscope is sought for inspection applications for reaching hardware areas that are difficult to access directly. The scope should be able to be inserted through existing (1/4") gaps in between racks of equipment or small (3/8") holes in the front of the racks normally used for fire suppression and controlled to inspection targets 3 to 4 feet behind the panel. It must sense contact and thermal hazards and be able to avoid creating a hazard during crew-based insertion or retraction. It must not rely on a pre-determined model of the physical interior, but build the model that it be guided through as it is inserted, with classification of fixed and moving objects as appropriate. Shape-following technology will be used to ensure the rest of the snake follows where the head went for insertion and that the entire snake follows the same path on extraction. As a minimum, an LED-illuminator will support the high res camera at the tip.

George is also looking for examples from Nature to apply to fully autonomous inspection methods Autonomous in that the inspection platform and sensors are able to complete a survey of a given surface for certain features and conduct characterization inspections of identified features of interest (such as MMOD damage) with no involvement of crew or other external controls. The platform will generate and process raw image/data on-board. The inspection base is initially though of as a free-flying platform(UAV, SUV or inspection satellite), crawling robot, endoscope(such as above) or manipulator arm. Considerations of how Natural systems perform similar functions should be considered to ensure that efficiency and effectiveness are optimized for sensing, navigation, control, processing, communication, etc..

RECENT CONFERENCES

2018 SPIE EAPAD Conference

The SPIE's Electroactive Polymers Actuators and Devices (EAPAD) Conference continues to be the leading international forum for presenting the latest progress, challenges and potential future directions for the EAP field. This year, the conference was Chaired by Yoseph Bar-Cohen, JPL/Caltech, and Co-Chaired by Iain A. Anderson, The Univ. of Auckland (New Zealand). The Conference was held in Denver, Colorado, and it has been the 20th since its start in 1999. The invited talks focused on reviewing the accomplishments, challenges and potentials of the various types of EAP known today. Some of the EAPAD Conf. Session co-Chairs are shown in **Figure 1**.

The Conference included 94 presentations and was well attended by internationally leading field experts including members of academia, industry, and government agencies from the USA and overseas. The presented papers reported the significant progress that has been made in the theoretical modeling and analysis of EAP mechanisms; improved EAP materials, processes, fabrication (e.g., 3D printing) and characterization techniques; emerging EAP actuators (e.g., ionic, shape memory polymers, and dielectric EAP); applications of EAP materials including power generation and energy harvesting, robotics, haptic, tactile, and various sensors.

Figure 1: Some of the Session co-Chairs of the EAPAD Conf. From left to right: Ji Su, NASA Langley Research Ctr. (United States), Iain Anderson, The Univ. of Auckland (New Zealand), Gabor Kovacs, EMPA (Switzerland), Qibing Pei, Univ. of California, Los Angeles (United States), Ron Pelrine, SRI International (United States); Yoseph Bar-Cohen, Jet Propulsion Lab. (United States), Qiming M. Zhang, The Pennsylvania State Univ. (United States), Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland), John D. W. Madden, The Univ. of British Columbia (Canada) and Jonathan M. Rossiter, Univ. of Bristol (United Kingdom)

The efforts described in the presented papers are showing significant improvements in understanding the electromechanical principles towards better methods of dealing with the challenges to the materials applications. Researchers are continuing to develop analytical tools and theoretical models to describe the electro-chemical and -mechanical processes, non-linear behavior as well as methodologies of design and control of the activated materials. EAP with improved response were described including dielectric elastomer, hydraulically amplified self-healing electrostatic, IPMC, conducting polymers, gel EAP, carbon nanotubes, and other types. Specifically, there seems to be continuing trend towards using dielectric elastomers as practical EAP actuators for commercial applications.

The Keynote speaker has been Brian Trease, (**Figure 2**), the Univ. of Toledo, United States. Brian Trease spent eight years working at JPL/NASA, Pasadena, CA, after he graduated from the University of Michigan,. His specialties include mechanism design, optimization, flexible systems, and deployable structures. At JPL, Brian was a research technologist in compliant mechanisms, printable spacecraft, rover mobility, and solar sail development. His current research interests at the University of Toledo include origami inspired design, biomimicry, swarm robotics, and autonomous robotics for environmental remediation.

According to Brian, the engineering world has exploded with recent interest in the craft of origami. This traditional art form, most often associated with Japan, has become fertile ground for inspiration of devices with applications ranging from medicine to aerospace. In his talk, Brian presented an overview of the prominent figures and applications that are currently driving innovation in the field. He pointed out that engineers and artists alike have come together to develop new techniques that take the practice from paper curiosities to practical engineered devices and systems. Foldable tools are now entering the human body during minimally invasive surgery, and foldable optical structures are being designed for the next generation of space-based telescopes. Mathematicians, material scientists, roboticists, architects, and mechanical designers are all investigating classical origami patterns and inventing new ones, benefiting from the insights and craftsmanship of partnering artists. The resulting software tools are accessible by engineers, tinkerers, and artists alike, some of who then leverage laminated manufacturing techniques to fabricate fully-operational systems with embedded electrical components and smart material actuation. While engineering is often influenced by external disciplines, such as biology or aesthetics, the melding of engineering and origami has been uniquely synergistic. The interaction of scientists and artists has mutually benefited both sides: beyond the novel advancements in engineering, the artists themselves are taking back the numerical tools and material innovations, using them to produce revolutionary pieces of balanced complexity and elegance.

The invited papers in the 2018 EAPAD Conference were:

- John D. W. Madden, The Univ. of British Columbia (Canada), "25 years of conducting polymer actuators: History, mechanisms, applications and prospects" Paper 10594-2
- Qiming M. Zhang, The Pennsylvania State Univ. (United States), "Molecular machine: how ferroelectric polymers generate giant electrostriction", Paper 10594-3
- Ron Pelrine, Roy D. Kornbluh, SRI, International (USA); Qibing Pei, Univ. of California, Los Angeles (USA), "Dielectric Elastomers past, present and potential future", Paper 10594-4
- Ray H. Baughman, The Univ. of Texas at Dallas (United States), "Stronger, faster, and more powerful artificial muscle yarns and fibers" Paper 10594-6
- Gabor M. Kovacs, EMPA (Switzerland), "Manufacturing polymer transducers: opportunities and challenges", Paper 10594-7
- Kwang Jin Kim, Univ. of Nevada, Las Vegas (United States), "Last twenty-five years of effort in developing fabrication-methods of IPMCs", Paper 10594-9

Figure 2: The Keynote Speaker, Brian Trease, the Univ. of Toledo (United States).

- Minoru Taya, Univ. of Washington (USA); and Kevin Kadooka, Pacific Northwest National Laboratory (USA), "Review talk on viscoelastic behavior of dielectric elastomer actuators", Paper 10594-19
- Ji Su, NASA Langley Research Ctr. (United States), "A review of electrostrictive graft elastomers: structures, properties, and applications", Paper 10594-23
- Jian Zhu, and Hareesh Godaba, National Univ. of Singapore (Singapore), "Review on soft robots using dielectric elastomer actuators", Paper 10594-26
- Nicholas Kellaris, Vidyacharan Gopaluni-Venkata, Garrett Smith, Shane K. Mitchell, Eric Acome, Christoph Keplinger, Univ. of Colorado Boulder (United States) , "The Peano-HASEL actuator: a versatile electrostatic actuator that linearly contracts on activation", Paper 10594-80

The EAP-in-Action Session of the EAPAD Conference/SPIE Smart Structures/NDE Symposia is highlighting some of the latest capabilities and applications of Electroactive Polymer (EAP) materials where the attendees are given demonstrations of these materials in action. In the 2018, EAP-in-Action Session 14 demonstrations were presented by teams from China, Germany, New Zealand, Singapore, Switzerland, and USA.

The presenters consisted of professors and their students as well as engineers from industry. This Session continues to highlight the latest capabilities and applications of Electroactive Polymer (EAP) materials where the attendees have been shown demonstrations of these materials in action. At this Session, the attendees are given an opportunity to interact directly with the presenters as well as have been given "hands-on" experience with the presented technology. The first Human/EAP-Robot Armwrestling Contest was held in 2005 during this session.

Best EAP-in-Action Demonstration Award - As of 2017, as part of the EAP-in-Action Session a selection is made of the "Best EAP-in-Action Demonstration". This selection is intended to encourage excellence in developing EAP materials and accelerate the transition of EAPs to practical and commercial technologies. A judging committee, consisting of leading EAP experts, selects the award winner(s) among the presenters of the demonstrations at the EAP-in-Action Session. The judges assess the presenters' performance as well as the quality and content of the demos. The top ranked three are recognized and are being awarded with a certificate during the Symposium.

<u>Evaluation criteria</u>: The demo presenters are ranked based on the following criteria:

1. Originality/creativity
2. Use of EAP to drive the demo
3. Performance of the demo
4. Potential impact

Scores: 4 excellent; 3 Good; 2 Fair; 1 Reasonable; 0 no show

The 2018 judges were:

1. Gabor Kovacs, EMPA (Switzerland)
2. John D Madden, The Univ. of British Columbia (Canada)
3. Qibing Pei, University of California, Los Angeles (UCLA), (USA)
4. Jonathan Rossiter, Univ. of Bristol (United Kingdom)
5. Brian Trease, University of Toledo, Ohio (USA)

The top three best demonstration presentations (**Figure 3**) were:

- **<u>First Place (Figure 4)</u>:** "HASEL: Hydraulically amplified self-healing electrostatic actuators with muscle-like performance". The recipients are Eric Acome, Shane K. Mitchell, Timothy G. Morrissey, Nicholas Kellaris, Vidyacharan Gopaluni Venkata, Madison B. Emmett, Claire Benjamin, Madeline King, Garrett Smith, Miles Radakovitz, and Christoph Keplinger, University of Colorado (USA).
- **<u>Second Place (Figure 5)</u>:** "Haptic feedback demonstrators based on strip dielectric elastomer actuators", Philipp Loew (on the left

in the photo), and Daniel Bruch, Univ. des Saarlandes, Lehrstuhl für Intelligente Materialsysteme, Intelligent Material Systems Lab (Germany). -

- **Third Place:**
  1. "Dielectric elastomer energy harvester autonomously primed by piezo- and tribo-electricity", Koh Soo Jin Adrian (shown in the photo on the left), Liu Chong, Ahmed Haroun, Anup Teejo Mathew, National University of Singapore (Singapore) - **Figure 6**
  2. "An untethered swimming robot powered by dielectric elastomer actuators" Mihai Duduta (shown in the photo on the left), Florian C. Berlinger, Hudson Gloria, Radhika Nagpal, Robert J. Wood, and David R. Clarke, Harvard University (USA) - **Figure 7.**

Figure 3: The recipients of the top three places of the best 2018 EAP-in-Action Demonstrations.

Figure 4: The recipients of the 1st place Best EAP-in-Action Demo – "HASEL: Hydraulically amplified self-healing electrostatic actuators with muscle-like performance". The recipients are Eric Acome, Shane K. Mitchell, Timothy G. Morrissey, Nicholas Kellaris, Vidyacharan Gopaluni Venkata, Madison B. Emmett, Claire Benjamin, Madeline King, Garrett Smith, Miles Radakovitz, and Christoph Keplinger, University of Colorado (USA)

Figure 5: The recipients of the 2nd place Best EAP-in-Action Demo - "Haptic feedback demonstrators based on strip dielectric elastomer actuators", Philipp Loew (on the left in the photo), and Daniel Bruch, Univ. des Saarlandes, Lehrstuhl für Intelligente Materialsysteme, Intelligent Material Systems Lab (Germany).

Figure 6: The recipient of one of the two 3rd place EAP-in-Action Demo - "Dielectric elastomer energy harvester autonomously primed by piezo- and tribo-electricity", Koh Soo Jin Adrian (shown in the photo on the left), Liu Chong, Ahmed Haroun, Anup Teejo Mathew, National University of Singapore (Singapore)

Figure 7: The recipient of the second of the two 3rd place EAP-in-Action Demo - "An untethered swimming robot powered by dielectric elastomer actuators" Mihai Duduta (shown in the photo on the left), Florian C. Berlinger, Hudson Gloria, Radhika Nagpal, Robert J. Wood, and David R. Clarke, Harvard University (USA)

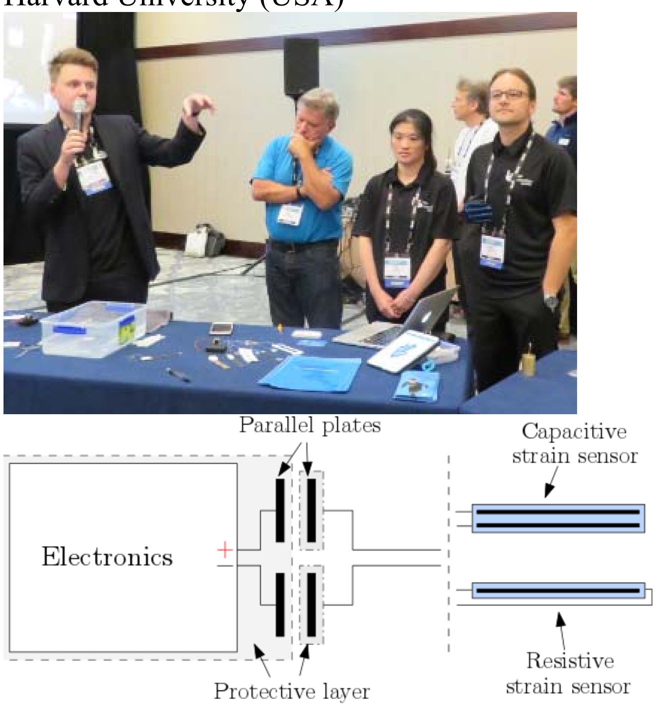


Figure 8: The demonstration of the Capacitive coupling as an underwater signal transmission interface

2. E.-F. Markus Henke, Katherine E. Wilson, and Iain A. Anderson, Biomimetics Lab., The Univ. of Auckland (New Zealand) – "Autonomous soft robots without electronics" (**Figure 9**): Multifunctional dielectric elastomers possess outstanding characteristics for future developments in soft robotics. Large actuation combined with piezo-resistive switches enables new fast elements of dielectric elastomer logic that can directly drive soft robotic structures. Combining soft DE electronics with silicone skeletons enables the design of entirely soft, autonomous robots. This The 2018 EAP-in-Action demonstrations included innovative devices and potential new products that are driven by EAP and they were as follows:

1. Christopher R. Walker, Samuel Rosset, and Iain Anderson, The Univ. of Auckland (New Zealand) – "Capacitive coupling as an underwater signal transmission interface" (**Figure 8**): Capacitive coupling was showcased as a signal transmission method to interface a capacitive strain sensor with electronics underwater. This signal transmission interface has the potential to simplify strain sensor integration into underwater wearables. The demonstration technology could be useful in diver health monitoring, human-interaction, and performance sport coaching applications.

demo presented the design of soft skeletons (see example below) that is able to undergo large actuations and simultaneously maintaining necessary pre-strains in DE membranes. It allows integration of multifunctional DE electronics for autonomous signal generation using integrated DE oscillators and design that uses DE electronics, soft skeletons and electro static adhesion for locomotion.

3. Samuel Rosset, Biomimetics Lab, The Univ. of Auckland (New Zealand) and Ecole Polytechnique Fédérale de Lausanne (Switzerland); Patrin Illenberger, Biomimetics Lab, The Univ. of Auckland (New Zealand); Samuel Schlatter Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland); Iain Anderson, Biomimetics Lab, The Univ. of Auckland (New Zealand) – "Single channel high voltage power supply with integrated touch screen" (**Figure** 10): Completely independent high-voltage power supply was demonstrated to drive dielectric elastomer actuators. It can generate a user-programmable voltage between 0 V and 5 kV, either continuously or as a square signal

between 1 mHz and 1 kHz. It integrates a large 7'' LCD touch screen and a user-friendly graphic user interface. Its integrated battery makes it possible to use the power supply.

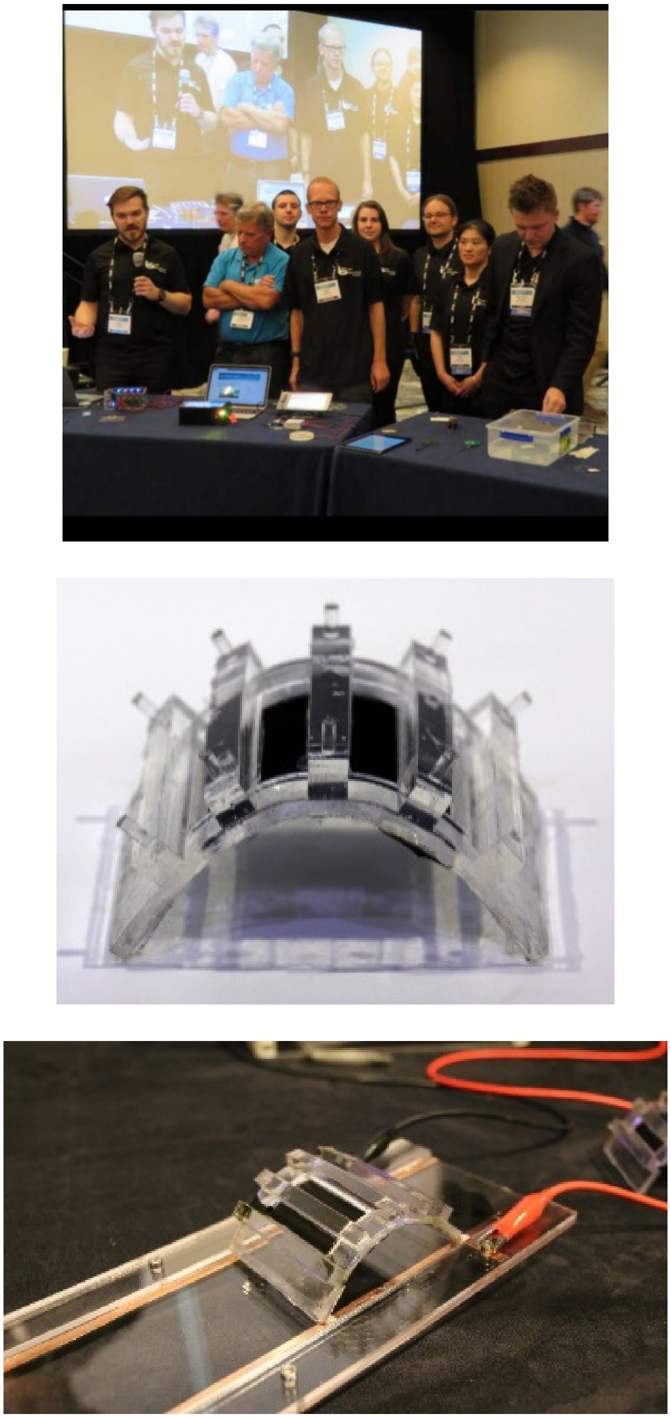


Figure 9: The demo of the autonomous soft robots without electronics

Figure 10: The demo of a single channel high voltage power supply with integrated touch screen

4. Eric Ambos, Iain Anderson, StretchSense Ltd. (New Zealand) – "The latest offerings in wearable electroactive polymer technology from StretchSense Ltd." (**Figure 11**): This will include a glove that transmits via Bluetooth to phone or computer hand kinematic data from embedded stretch sensors with on-board inertial measurement. Uses include gaming, virtual reality and good old fashioned air guitar (or violin). The new application software can depict a live 3D rendering of your hand.

5. Mihai Duduta, Florian C. Berlinger, Hudson Gloria, Radhika Nagpal, Robert J. Wood, and David R. Clarke, Harvard University (USA) – "An untethered swimming robot powered by dielectric elastomer actuators" (**Figure 12**): DEAs are rarely used in untethered robots because their force output is too small to enable locomotion via crawling or swimming. A multilayer assembly technique was developed to fabricate stronger bimorph actuators capable of outputting 20 mN of thrust when flapping in water at 1-8 Hz. A 10 cm long robot encapsulating the high voltage power supply that

swims at 0.2 body lengths / second was demonstrated (***<u>Tie in 3rd place</u>***).

Figure 11: The demo of a wearable electroactive polymer technology.

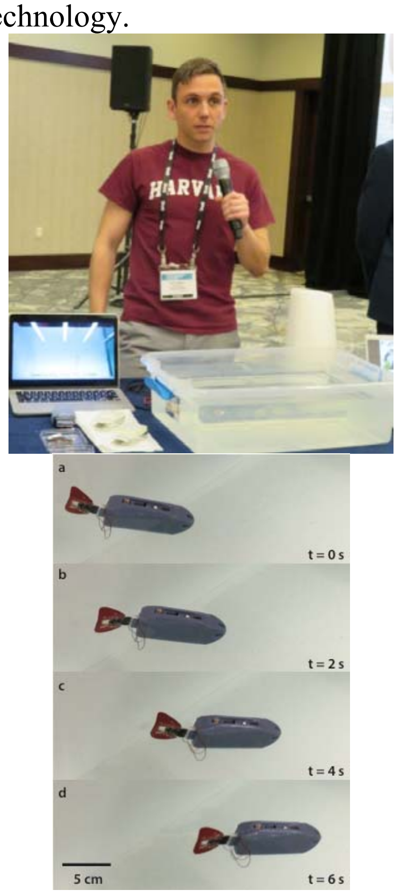


Figure 12: An untethered swimming robot powered by dielectric elastomer actuators

6. Tim Helps, Majid Taghavi, University of Bristol (United Kingdom) – "Towards electroactive gel artificial muscle structures" (**Figure 13**): Electrostatic phenomenon has been used for decades in the form of variable capacitors to build electro-active actuators. Dielectric elastomers are an example of electrostatic actuators and can produce high forces and specific energies. However, can only be created using soft materials and are strain-limited because of dielectric breakdown at high compression. The presenters are investigating the opportunity for improved performance and alternative actuator arrangements, which could allow for real world applications.

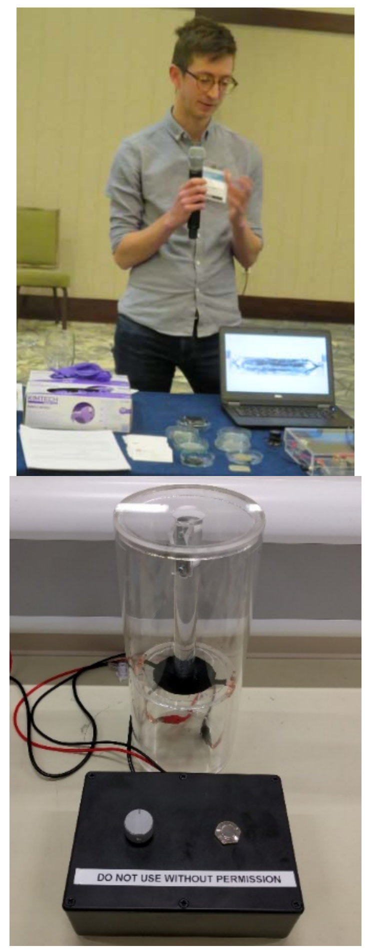


Figure 13: The demo of electroactive gel towards becoming artificial muscle structures

7. Eric Acome, Shane K. Mitchell, Timothy G. Morrissey, Nicholas Kellaris, Vidyacharan

Gopaluni Venkata , Madison B. Emmett, Claire Benjamin, Madeline King, Garrett Smith, Miles Radakovitz, Christoph Keplinger, Univ. of Colorado (USA) - HASEL: Hydraulically amplified self-healing electrostatic actuators with muscle-like performance (Figure 14): Soft electrostatic actuators that provide muscle-like performance was demonstrated. These electrically controlled devices are based on a new class of soft actuators, termed hydraulically amplified self-healing electrostatic (HASEL) actuators, which recover from electrical failure while also combining the benefits of pneumatic and dielectric elastomer actuators. Key attributes were presented including the ability to deliver large actuation force, achieve large actuation strain, output high power, and self-sense deformation for controlled actuation (***1st place***).

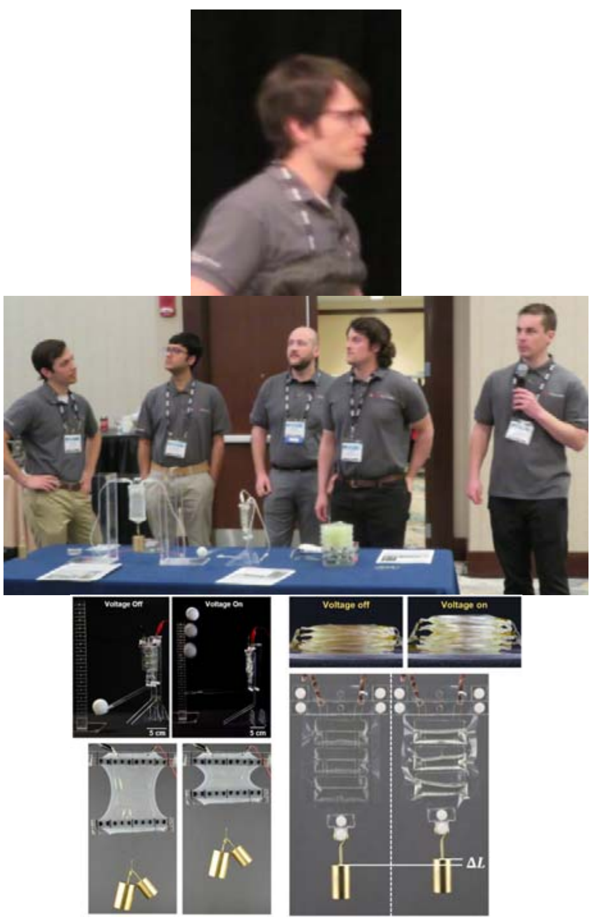


Figure 14: The demo HASEL: Hydraulically amplified self-healing electrostatic actuators with muscle-like performance

8. Sarah Trabia, Robert Hunt, Taeseon Hwang, Qi Shen, Zachary Frank, Justin Neubauer, Zakai Olsen, Tyler Stalbaum, Blake Naccarato, Kwang Kim, "Active Materials and Smart Living Lab., Univ. of Nevada Las Vegas (USA) – "Multiple mode ionic polymer-metal composite array for the use in travelling wave actuators and sensing" (Figure 15): In nature, there are teams of actuator-like limbs that move together (such as cilia). By producing a travelling wave effect, they can transport items, generate flow, and act as sensors. It would be ideal for researchers to be able to reproduce something similar to create more biomimetic systems. Presented was an Ionic Polymer-Metal Composite (IPMC) array that has the ability to work as a team of actuators moving in a travelling wave or a team of sensors, being able to give a reading of the flow across the surface of the array. In this demo an IPMC array that works as an actuator and sensor was presented.

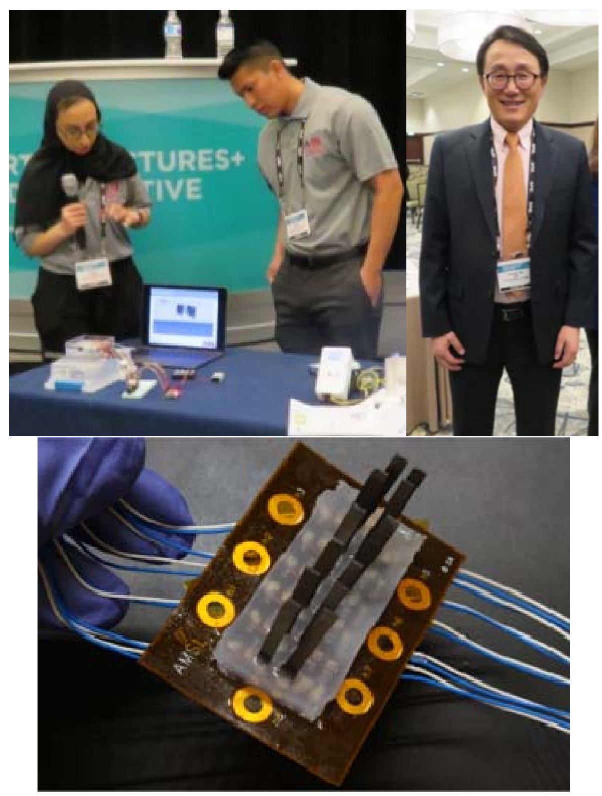


Figure 15: The demo of multiple mode ionic polymer-metal composite array for the use in travelling wave actuators and sensing

9. Liwu Liu, Xiongfei Lv, Qinghua Guan, Jinrong Li, Yanju Liu and Jinsong Leng, Harbin Institute of Technology (China) – "Applications of smart polymers and their structures" (**Figure 16**): This demonstration will show smart polymers and their structures in action taking advantages of their being light weight, fast response, and large deformation. The demonstration will include the applications of EAP, shape memory polymer (SMP) and other smart structures. Specifically, a smart gripper, based on EAP and SMP materials, will be presented. Different soft actuators with various structures could achieve bend, elongation, contraction and other types of movements.

Figure 16: The demo of applications of smart polymers and their structures

10. Lenore Rasmussen, Simone Rodriguez, and Matthew Bowers, Ras Labs, Inc. (USA) – "Synthetic Muscle™: Shape-morphing EAP based materials and actuators" (Figure 17): Ras Labs Synthetic Muscle™ is a class of electroactive polymer (EAP) based materials and actuators that contract, and with reversed electric input polarity, expand. Several actuators and sensors will be presented including a thick shape-morphing EAP pad that controllably contract or expand and is being used to prototype self-adjusting extremely comfortable prosthetic socket liners and other void-filling continual-fit applications, such as ear buds.

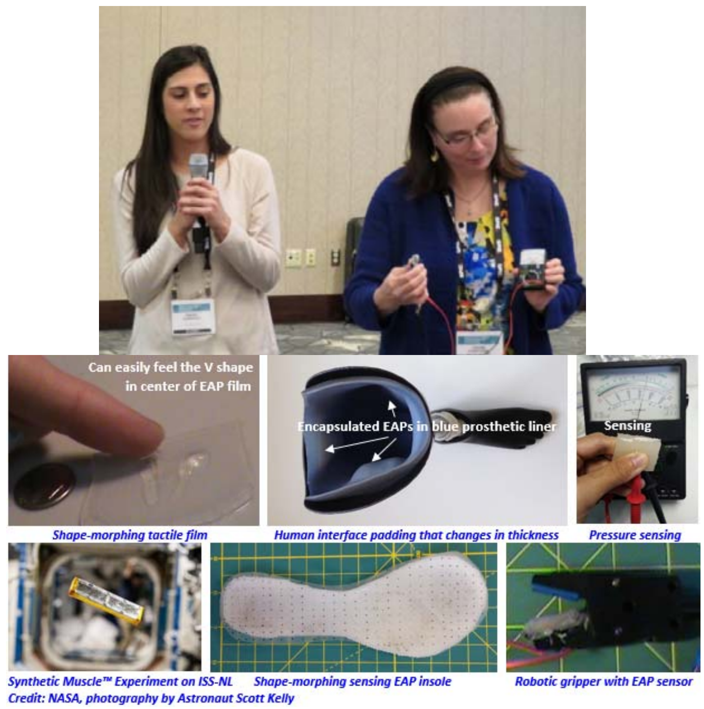


Figure 17: The demo of the Synthetic Muscle™: Shape-morphing EAP based materials and actuators.

11. Philipp Loew, and Daniel Bruch, Univ. des Saarlandes, Lehrstuhl für Intelligente Materialsysteme, Intelligent Material Systems Lab (Germany) – "Haptic feedback demonstrators based on strip dielectric elastomer actuators" (**Figure 18)**: Touchscreens are more and more part of our daily lives. Using haptic feedback based on the image that is being received from the screen is helpful to operate a touch device without looking at it. The

haptic feedback demonstrator, which is based on strip dielectric elastomer actuators is, is designed to perform this task, especially simulating buttons and rough surfaces. (***2nd place***)

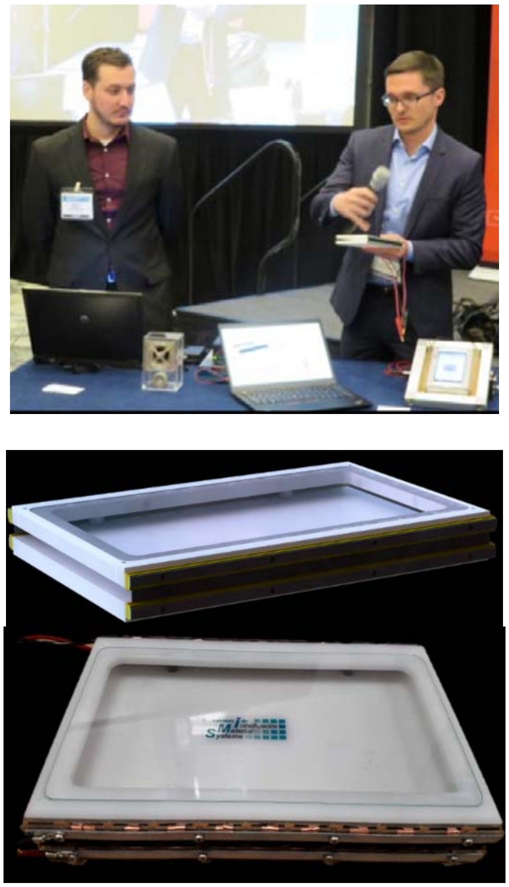


Figure 18: Haptic feedback demonstrators based on strip dielectric elastomer actuators

12. Philipp Loew, and Daniel Bruch, Univ. des Saarlandes, Lehrstuhl für Intelligente Materialsysteme, Intelligent Material Systems Lab (Germany) – “Loudspeaker based on cone shaped out-of-plane dielectric elastomer actuators” (**Figure 19**): Due to their advantages, such as lightweight, energy efficiency, low cost, compactness and freedom in design, dielectric elastomers are suited to substitute commercial loudspeakers. The presented demonstrator supplies the overall driving motion by an out-of-plane biased cone shaped dielectric elastomer actuator. In contrast to conventional loudspeakers, sound is generated by the active membrane surface.

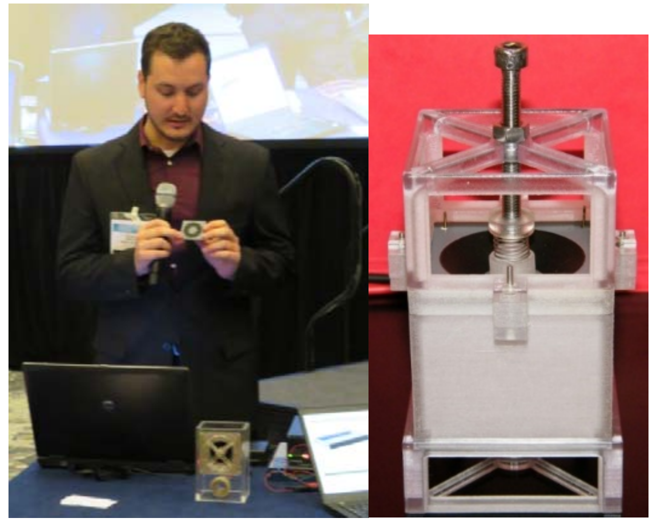
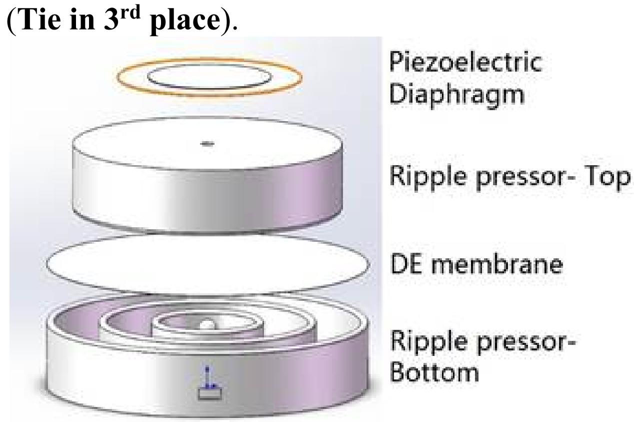


Figure 19: The demo of loudspeaker based on cone shaped out-of-plane dielectric elastomer actuators

13. Koh Soo Jin Adrian, Liu Chong, Ahmed Haroun, Anup Teejo Mathew, National Univ. of Singapore (Singapore) – “Dielectric elastomer energy harvester autonomously primed by piezo- and tribo-electricity” (**Figure 20**): A Dielectric Elastomer (DE) Energy Harvester that is autonomously-primed with a piezo- and a tribo-electric source will be demonstrated. The similar nature of piezo- and tribo-electric primers with DE allows a DEG to operate autonomously without the need of an external source of electricity. We present an assembly of a piezo-DEG and tribo-DEG energy harvester. The piezo- and tribo- sources will provide a voltage prime of about 100 V. The DE film then takes over the electrical charges from the piezo- and tribo- source, and amplifies the voltage (**Tie in 3rd place**).



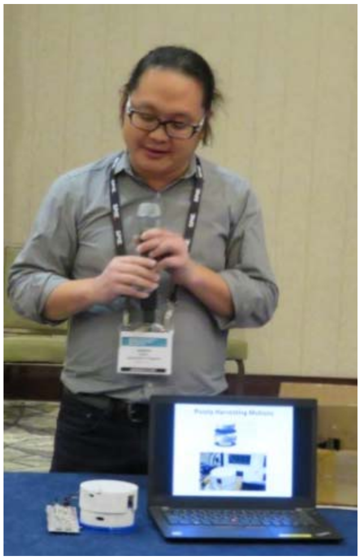


Figure 20: The demo of dielectric-elastomer energy harvester autonomously primed by piezo- and tribo-electricity

14. Tino Töpper[a], Bekim Osmani[a], Sebastian Buchmann[a], Matej Siketanc[a], Dominik Bachmann[b] and Bert Müller[a]

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[b] Transport at Nanoscale Interfaces, EMPA, 8600 Dübendorf, Switzerland

"Enhancing the capabilities of artificial muscle implants using low-voltage dielectric elastomer sensors" (Figure 21): The Swiss BRIDGE Proof-of-Concept initiative aims for dielectric elastomer sensors (DES) operated at battery voltages. The DES prototype was equipped with electronics built by EMPA. The capacitive sensor is based on a polydimethylsiloxane (PDMS) elastomer layer covered by flexible electrodes. The high-vacuum-based thin-film technology reliably enables the fabrication of sub-micrometer-thin elastomer and nanometer-thin conducting films. Compression is resolved with a sensitivity better than 4 kPa-1, which can be adjusted to the physiological pressures of interest, i.e. from Pa to MPa. The resting capacitance of hundreds of pF/cm2 only requires conventional electronics. The total DES thickness of maximal 20 μm opens the path for a wide variety of applications in medical implants and devices. An energy consumption below 1 nW and the self-healing capabilities enable long-term stability and reliability.

Fabricated on flexible polymer substrates the DES can be directly attached to the skin or implant surface for monitoring with millisecond response. In particular, the team is going to integrate the DES to an artificial muscle implant for incontinence treatments, which is under development at the Wayne State University in Detroit, Michigan. The leading medical expert Nivedita Dhar envisions a reliable force feedback for a substantially improved and biomimetic urinary incontinence treatment.

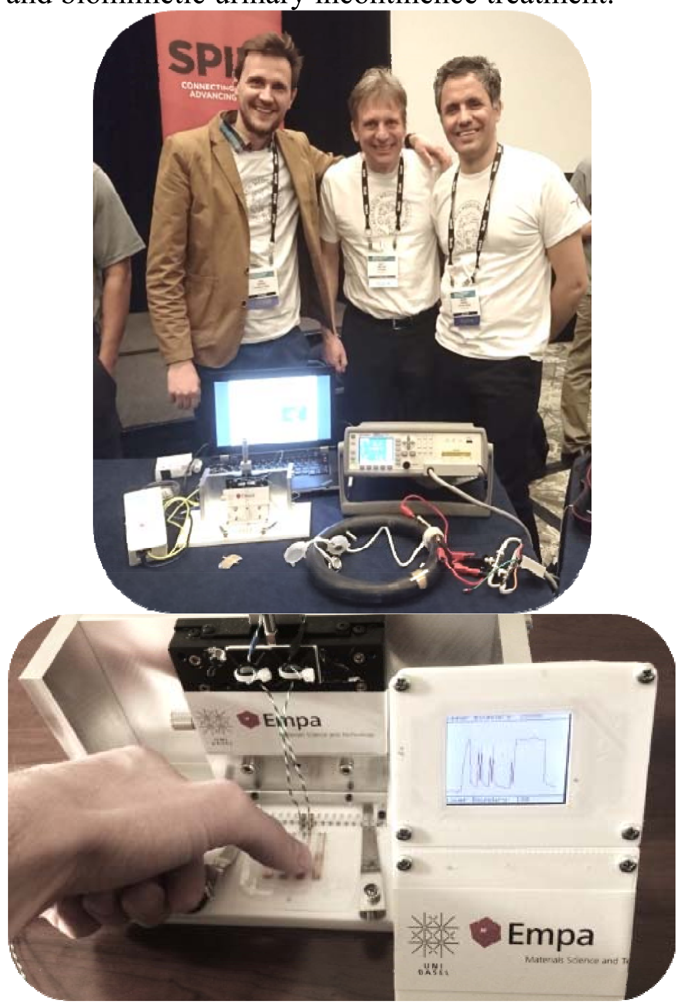

Figure 21: Top - the team from the Biomaterials Science Center at the University of Basel T. Töpper, B. Müller and B. Osmani. Bottom - The dielectric-elastomer sensor prototype on flexible substrates.

ADVANCES IN EAP

Aerospace Engineering-Propulsion/MEMS

DEA Compressor and Its Key Role to Regulate PDTurboDEA Engine Performance Toward Optimum Operation

Babak Aryana, Independent Researcher/
Inventor Babak.Aryana@Gmail.com

Pulse Detonation TurboDEA is a conceptual pulse detonation aeroengine that is configured based on special characteristics of DEA compressor [1]. In the previous Newsletter issues, I introduced TurboDEA [2] and PDTurboDEA and briefly explained how DEA compressor specification allows designing aeroengines with exceptional performance in a wide working envelope.

DEA compressor construction allows implementing an air intake in PDTurboDEA that can help engine to operate in hypersonic flight Mach numbers. Air intake of a DEA compressor can be designed to keep compressor entrance aside from usual losses crated by high speed airflow. Additionally, special configuration of DEA compressor makes turbine and exit nozzle seclude from inlet airflow condition, which is advantageous for generating thrust particularly in high flight Mach numbers **Figure 22**. In fact, input flow to turbine and direct channel toward exit nozzle is influenced just by condition of detonation chamber, and then turbine and exit nozzle entrances can be regulated separately for the optimum performance when nozzle is supplied by a mixed flow of detonation chamber direct exit flow and bypassed turbine exit flow. Moreover, DEA compressor operation can be regulated considering working condition and environmental elements (context-awareness) that helps optimization of engine performance (**Figure 23** and **Figure 24**).

Aforementioned conditions at compressor intake and detonation chamber exit as well as ability to adapt to environmental element create unique area to design aeroengines that can operate in a wide working condition with the best available performance. However, such a compressor needs dielectric elastomers with very short response time and very high working durability (**Figure 25** and **Figure 26**).

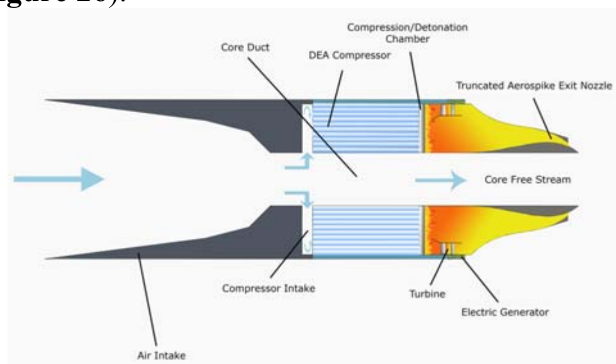

Figure 22: Schematic cutaway of PDTurboDEA illustrating engine components

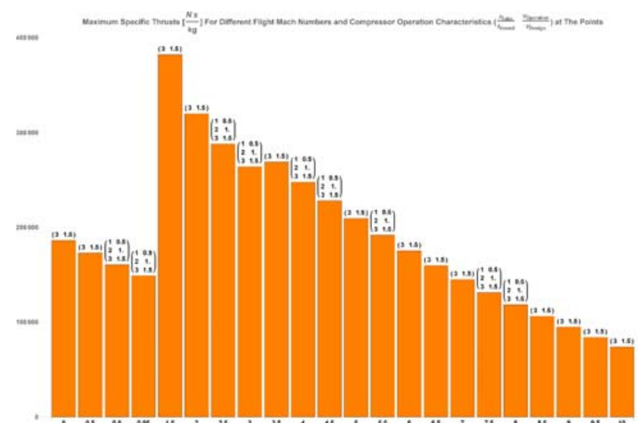

Figure 23: Maximum specific thrust in each flight Mach number collected based on compressor operation characteristic at the point. This categorization helps designer to collect the best compressor configuration for the optimum engine operation.

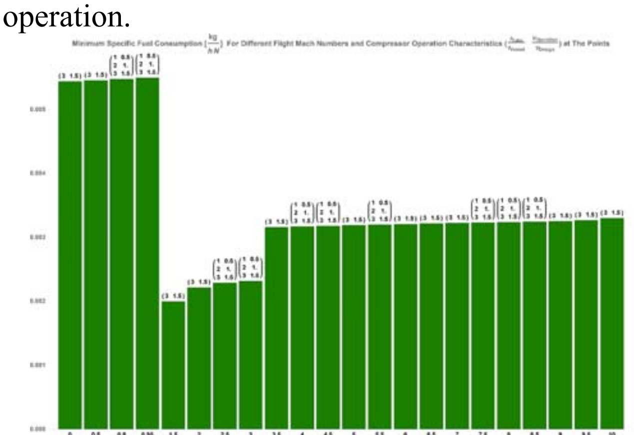

Figure 24: Minimum specific fuel consumption in each flight Mach number collected based on

compressor operation characteristic at the point. This categorization helps designer to collect the best compressor configuration for the optimum engine operation.

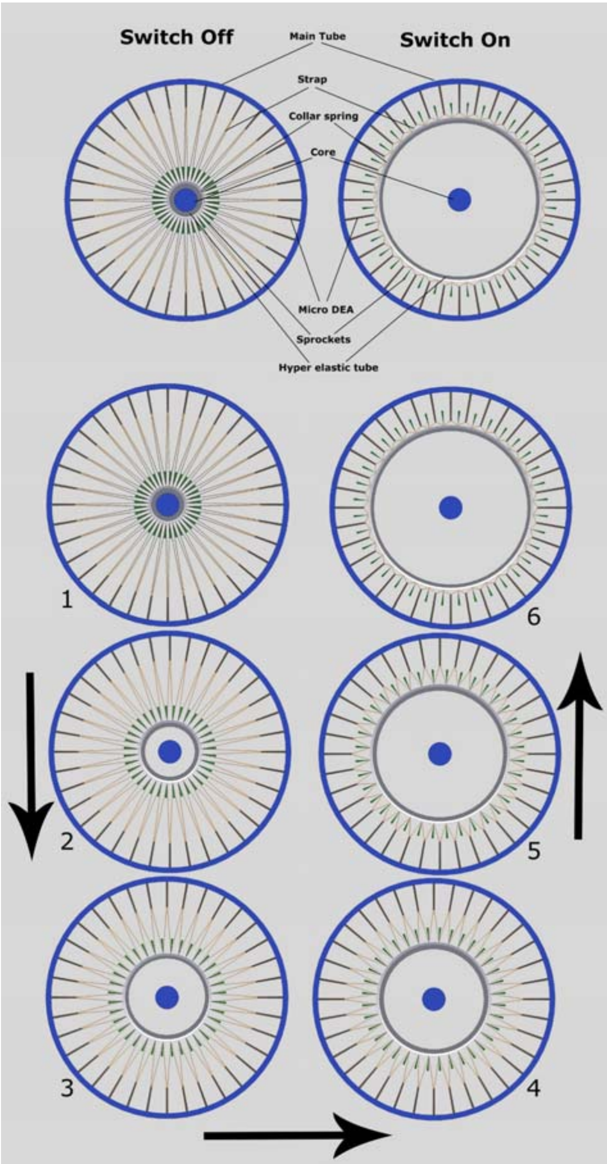

Figure 25: Actuator mechanism in a cell of DEA compressor to push air into vessel for pressurizing

<u>References</u>

[1] B. Aryana, "Implementing DEA to create a novel type of compressor," *Materials Science and Engineering C,* p. 30 42–49, 2010.

[2] B. Aryana, "New version of DEA compressor for a novel hybrid gas turbine cycle: TurboDEA," *Energy*, pp. 111 676-60, 2016.

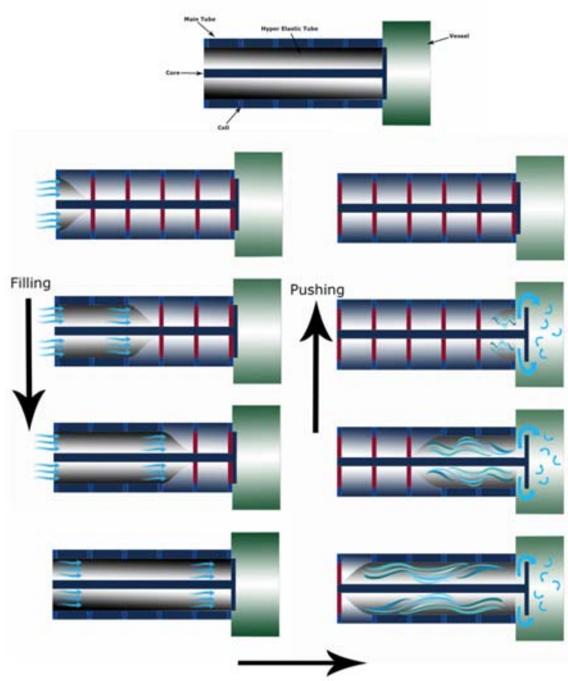

Figure 26: Frequency of filling/pushing air into vessel and frequency of detonation of pressurized air and fuel mixture are key parameters that can be regulated toward optimum operation based on environmental element. Response time of dielectric elastomer is a crucial factor in this point. In fact, the shorter response time, the higher engine working frequency. As a result, reliability of dielectric elastomer to endure acceptable time under such a tough working condition is essential.

ElastiSense ApS, Denmark

Industrial EAP Product – on the market now

Rahim Sarban, rahim@elastisense.com

ElastiSense has developed the first CE certified (the European Standard that is equivalent to the United State's UL) EAP sensor product for industrial applications. The product portfolio contains displacement sensors of different variants (**Figure 27**) for universal use in industrial applications.

The patent-pending design of these sensors enable precise measurements in micro-meter level even in the most aggressive applications. This key advantage is inherited from the unique characteristics of the utilized EAP technology as core sensing component.

Due to the flexible and highly robust nature of the underlying EAP technology, the sensor can withstand high degrees of shocks, vibrations, and installation misalignment. These effects can be detrimental to piston-based displacement sensors such as LVDTs, Potentiometers, and Encoders (https://www.youtube.com/watch?v=SnlxEvc2iPU).

Figure 27: ElastiSense displacement sensors for industrial applications.

The sensors are already in active use in one of world-leading pump manufacturing company Grundfos. Here the sensors together with ElastiSense proprietary controllers and software provide inline quality control and predictive maintenance of their metal forming machines (**Figure 28**).

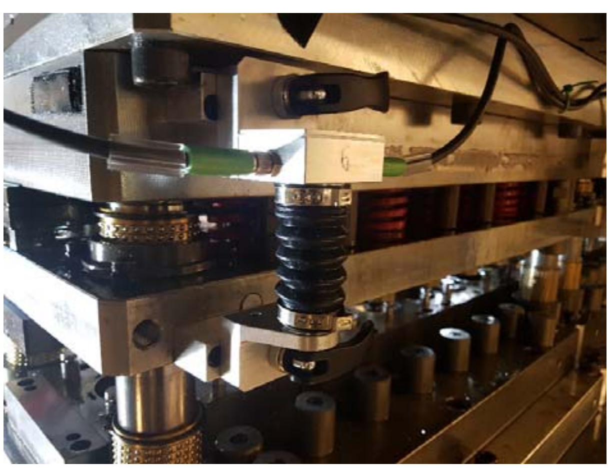

Figure 28: ElastiSense displacement sensor monitoring stamping process at Grundfos.

The use of these sensors is not limited to metal forming process. ElastiSense is currently working with many industrial partners in implementation of the product in other industrial applications. **Figure 29** shows a few examples of the applications in which these sensors have demonstrated competitive advantage over existing solutions.

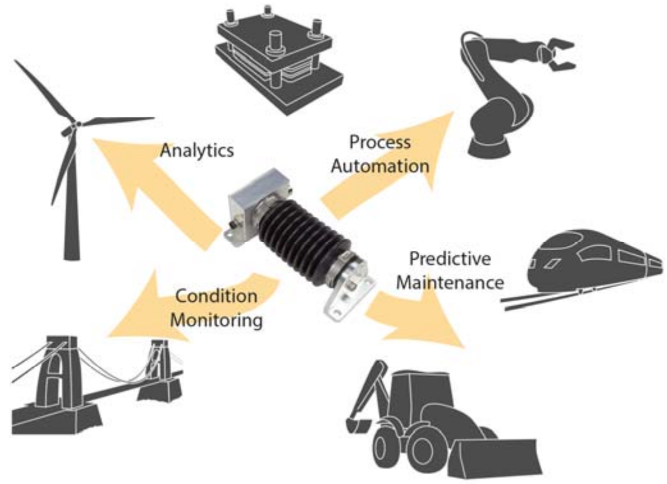

Figure 29: Few applications where the sensors will soon be implemented.

With these advancements, the EAP technology can no longer be regarded as a "researched" technology but more as a technology undergoing accelerated commercialization.

Embry-Riddle Aeronautical University, Orlando, FL

Self-folding origami inspired dielectric elastomer actuator

Jang Ho Park Parkj9@my.erau.edu

Studies in active material and on acceptable kinematic folds have provided new possibilities for designing various structures. Through experimental and computational investigation, characterization and design of advanced structures and active material concepts, utilization of origami inspired structures to solve real world problems has emerged. Origami inspired engineering combines the ancient Japanese art with studies of modern materials and engineering principles to find solutions in various field such as aerospace, medical, and robotics as well as various engineering applications by benefiting the manufacturing, storage and deployment process as well as reduction in material consumption.

Self-folding is a capability of a structure to actively fold and/or unfold in response to external stimulus. Based on different active materials, electro active polymers is a very favorable candidate for self-folding structures. Electroactive polymers (EAPs) are polymers where electric stimulus is applied to generate mechanical response. The concept of self-folding materials require various attributes such as high strain, stress and fast response. Among the family of EAPs, dielectric elastomer actuators (DEA) seem to be a promising active material for self-folding applications.

Previous studies have shown that there is a growing demand of self-folding origami structures and developing dielectric elastomer actuators capable of localized deformation that allows folding behavior along the predetermined crease pattern. **Figure 30** shows the crease pattern called 'Kresling pattern', which is a deployable cylindrical based origami structure that was studied for the actuation using dielectric-elastomer actuator placement through mathematical studies as well as numerical simulation.

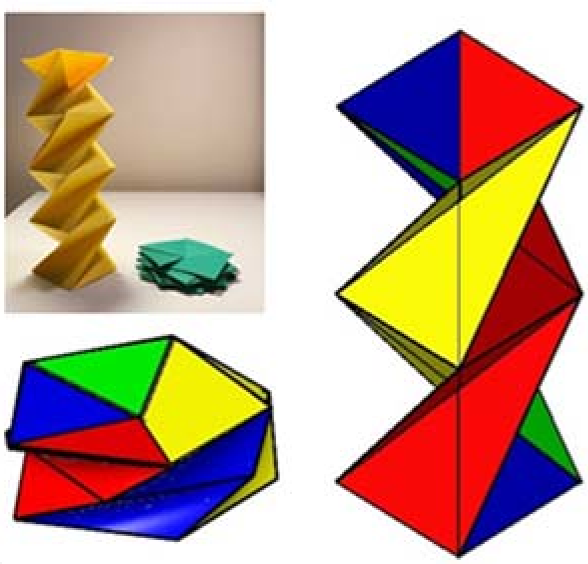

Figure 30: Actual and numerical simulation model of the origami actuator

Imperial College London

Electroactive Polymer-Electrolyte-Composite Artificial Muscles of Greatly Enhanced Strength

Zachary Goodwin zachary.goodwin13@imperial.ac.uk, *Michael Eikerling, Hartmut Löwen, and Alexei A. Kornyshev*

Electro-actuators, composed of polymer-electrolyte films impregnated with bulky mobile cations confined between electrodes, curve in response to applied voltages (forward actuation). Alternatively, upon forced bending an output voltage or current can be produced (reverse actuation). Both forward and reverse actuation, involve redistribution of mobile cations and solvent molecules. To further understand and develop these much-desired devices, we present a unified theory that describes forward and reverse actuation with flat and porous electrodes, as seen in **Figure 31**.

Forward actuation with flat electrodes has limited response to applied voltages because stressful regions develop only in minor parts of the ionomer.[2] To overcome this limitation, one can use 'volume-filling', porous electrodes. We develop a theory for such systems to give a foundation for engineering such devices.[3] We found that the electroactive response, see **Figure 32**, is dramatically enhanced, potentially orders of magnitude, as compared to flat electrodes. However, the actuator response time, which for most applications should not be longer than 1 s, imposes constraints on the pore length, as **Figure 33** shows.

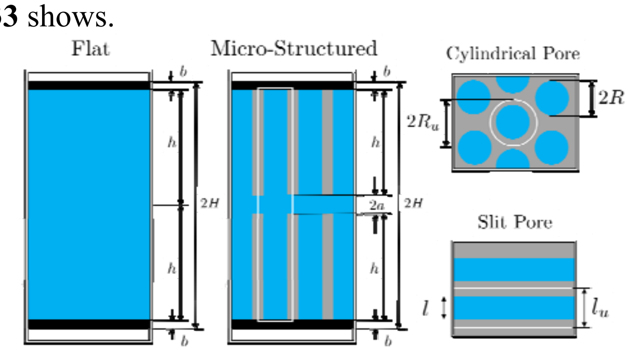

Figure 31: Sketch of the studied electrode architectures.[2,3,5]

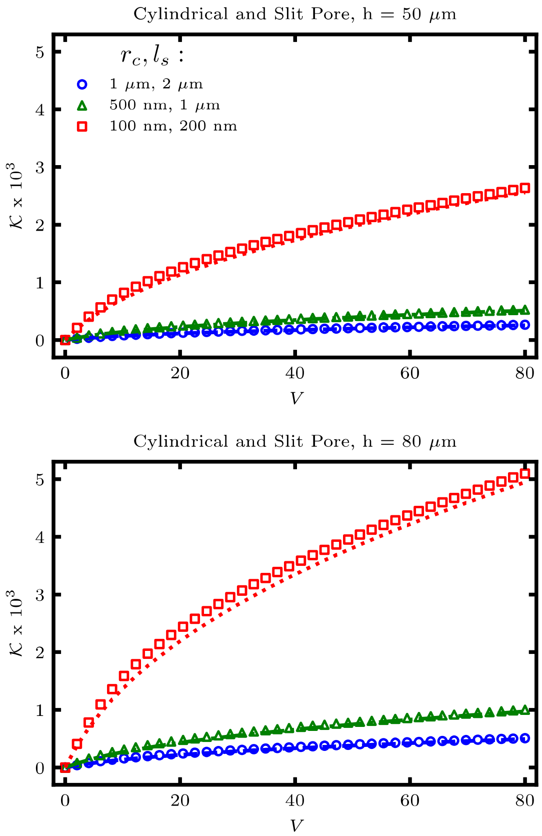

Figure 32: Increasing the 'pore length' increases the electroactive response. Dimensionless curvature as a function of applied voltage.[3]

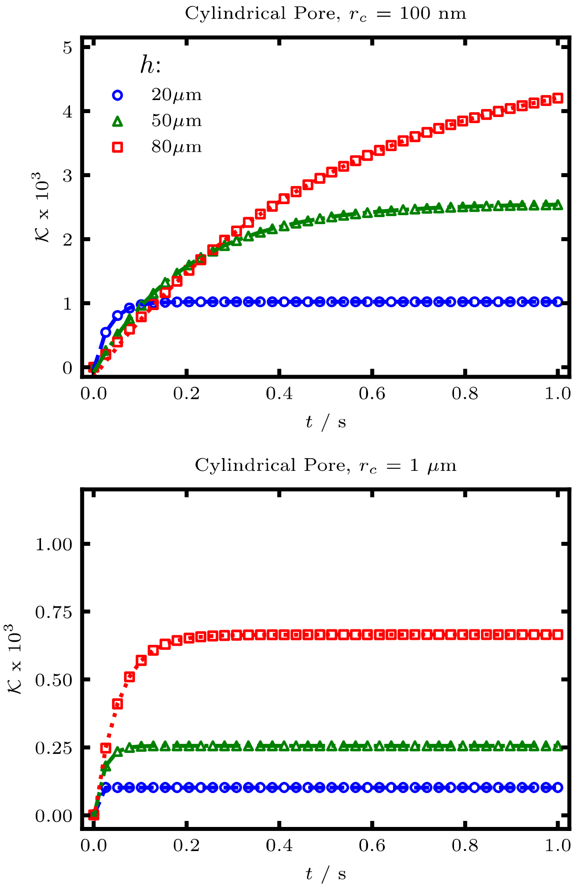

Figure 33: 'Longer pores' result in slower charging times. Dimensionless curvature as a function of time.[3]

It is well known that reverse actuation produces significantly smaller voltage than the one applied to produce the same curvature in forward actuation. This practically limits reverse actuation to sensing applications.[4] We develop a theory, the underlying basis of which is similar to that of forward actuation, in which ions are treated as volumetric defects.[5] The signal generated by bending the actuator depends on the volume of mobile ions, in agreement with experiments. Cases of open and short-circuit operation modes were investigated separately. The results suggest two options for self-sensing artificial muscles: (i) open-circuit sensing – bundles of microstructured actuators for forward actuation, should include flat electrode actuators which are substantially thicker for sensing; (ii) short-circuit sensing – the design can be based only on microstructured electrodes.

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3 Z Goodwin, M Eikerling, H Löwen, A Kornyshev, Theory of microstructured polymer-electrolyte artificial muscles, Smart Mater. Struct. https://doi.org/10.1088/1361-665X/aac291 (2018, In press)

4 Y Cha, M Porfiri, J. Mech. Phys. Solids, 71 (2014) 156

5 Z Goodwin, A Kornyshev, Theory of sensing for polymer-electrolyte-composite artificial muscles with flat or volume filling electrodes, submitted to Soft Matter (2018)

PolyK Technologies, LLC; State College, PA

PolyK offers low cost EAP materials and test instruments to support academic EAP R&D

Shihai Zhang, energy@polyktech.com

PolyK Technologies (www.polyk-lab.com) is located in State College, PA, USA with over 17,000 sf lab and production space. PolyK is specialized in high voltage polymer dielectric, ferroelectric, piezoelectric, and smart materials, test instrument, and applications. In addition to our high energy density polymer film capacitor products, PolyK provides various PVDF homopolymer, copolymer, and terpolymer resins, films, and test instruments to characterize PVDF. We have a collection of over 50 different PVDF-related compositions and grades from major suppliers around the world.

PolyK has in-house roll-to-roll solvent casting machine, film extruder, machine-direction orientation machine (MDO) to produce customized PVDF and its copolymer film, as well as other polymer film such as electroactive polymer film, actuator film, and electrocaloric film with uniform thickness and with length from <1 m to >1000 m, thickness from <5 um to >500 um, and width up to 600 mm. More recently, PolyK also successfully commercialized piezoelectric PVDF and PVDF-TrFE copolymer film with high piezoelectric coefficient > 30 pC/N in large rolls.

In addition, during its commercialization process, PolyK also developed several low-cost test instruments related to EAP technologies, such as turnkey dielectric test system to measure dielectric constant and loss as a function of temperature, frequency, and DC bias voltage, ferroelectric polarization loop and dielectric breakdown test system to measure charge density as a function of electric field, frequency, and temperature, pyroelectric current and TSDC (thermally stimulated depolarization current) test system, and table-top zone stretching machine to prepare stretched EAP film.

During the past two years, PolyK has helped over ten young scientists build their first high voltage dielectric and ferroelectric test laboratory around the world. PolyK is looking forward to working with scientists in the EAP technologies to develop and commercialize advanced EAP technologies.

University of Colorado Boulder

HASEL Artificial Muscles – Versatile High-Performance Actuators for Next-Generation Robotics

Eric Acome, Nicholas Kellaris, Timothy Morrissey, Shane K. Mitchell and Christoph Keplinger (Christoph.Keplinger@colorado.edu)

Soft actuators are a critical component in soft robotic systems. Currently, two classes of soft muscle-mimetic actuators dominate the literature – soft fluidic actuators (predominantly based on pneumatic operation) and electrically powered dielectric elastomer actuators (DEAs) – both of which have advantages and drawbacks. Fluidic actuators readily feature diverse modes of actuation such as bending and twisting, but require complex and inefficient systems of tubes, valves, and sources of pressurized fluid. DEAs excel with muscle-like performance of actuation and are controlled and powered electrically, but they face hurdles towards large scale applications due to susceptibility to catastrophic failure from dielectric breakdown and electrical aging.

The Keplinger Research Group recently published a pair of papers in *Science* [1] and *Science Robotics* [2] introducing a new class of artificial muscles termed Hydraulically Amplified Self-healing ELectrostatic (HASEL) actuators. HASEL actuators harness an electrohydraulic mechanism to drive shape change of soft active structures. By directly applying electrostatic forces to an insulating hydraulic fluid, HASEL actuators combine the versatility of soft fluidic actuators with the muscle-like and self-sensing performance of dielectric elastomer actuators. In contrast to soft fluidic actuators, where inefficiencies and losses arise from fluid transport through systems of long tubes and channels, HASEL actuators generate hydraulic pressure locally via electrostatic forces acting on liquid dielectrics distributed throughout the system [**Figure 34**]. In contrast to DEAs, where dielectric breakdown through elastomeric membranes limits lifetime and reliability, we show that the use of liquid dielectrics in HASEL actuators enables self-healing attributes with immediate and full recovery of actuation performance even after tens of breakdown events.

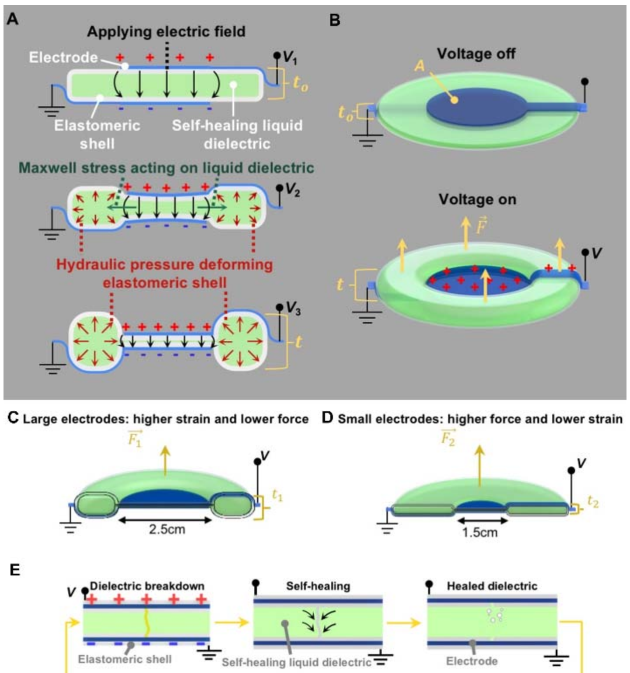

Figure 34: (A) Schematic of a donut HASEL actuator shown at three different applied voltages, where V1 < V2 < V3. (B) The actuator deforms into a donut shape with application of voltage. This voltage-controlled deformation can be used to apply force F onto an external load. (C and D) Strain and force of actuation can be tuned by modifying the area of the electrode to harness hydraulic scaling. (E) The use of a liquid dielectric confers self-healing capabilities to HASEL actuators.

Using a deformable structure containing a liquid dielectric gives HASEL actuators significant design freedom for both materials and manufacturing methods. In contrast to DEAs, *HASEL actuators do not have to rely on elastomers and stretchable electrodes*, and can instead use inextensible materials as shells as well as low resistance, thin films of metal as electrodes. The resulting flexibility in material selection enables HASELs to be high performance, low cost, versatile, and compatible with roll-to-roll industrial fabrication processes such as heat sealing and vacuum-deposition of low-resistance metal electrodes.

In our recently published papers, we I) discuss fundamental physical principles of HASEL actuators, II) demonstrate the robust and muscle-like performance of HASEL using prototypical designs and geometries, and III) illustrate the wide potential and versatility of HASEL actuators by demonstrating exemplary applications such as soft grippers, self-sensing artificial muscles powering a robotic arm, and the ability to scale actuators up to exert large forces [**Figure 35**] - all using only widely available, low-cost materials and industrially-amenable fabrication techniques. We believe there is a wide range of potential applications for HASEL that are still untapped as a plethora of geometries, materials and more advanced fabrication strategies remain unexplored.

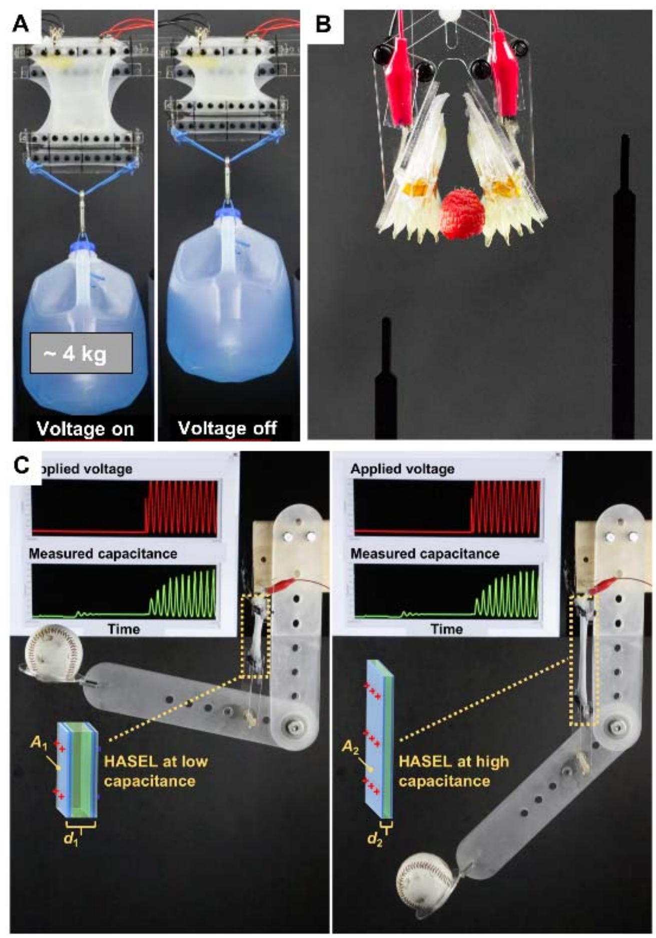

Figure 35: (A) HASEL actuators scaled up to exert large forces. (B) Soft HASEL gripper lifting a

raspberry. (C) A robotic arm powered by self-sensing HASEL actuators.

Videos:

Overview of planar and donut HASEL actuators [1]: https://youtu.be/M4qcvTeN8k0

Overview of Peano-HASEL actuators [2] https://youtu.be/-TKjJBZEZe4

References:

[1] E. Acome, S. K. Mitchell, T. G. Morrissey, M. B. Emmett, C. Benjamin, M. King, M. Radakovitz, C. Keplinger, *Hydraulically amplified self-healing electrostatic actuators with muscle-like performance*. **Science** 359.6371 (2018): 61-65. https://doi.org/10.1126/science.aao6139

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University of Hong Kong

Electroactive ceramic actuated by low voltage and light

K. W. Kwan kkwkwan@connect.hku.hk, S. J. Li, N. Y. Hau, Wen-Di Li, S. P. Feng, Alfonso H. W. Ngan hwngan@hku.hk

For making artificial muscles, electroactive polymers that actuate with high strain and fast response have been developed. However, each EAP has its limitation; for example, a high excitation voltage is required for dielectric-elastomer actuators and conducting polymers have a low actuating stress. Therefore, a continuous search for new actuation materials that might be used together with or as alternatives to EAP is needed. Recent examples including carbon nanotubes [2] and nanoporous metals [3] have shown great potentials as artificial muscles.

Ngan's research group at the University of Hong Kong is introducing a new electroactive ceramic material that actuates via a volume-changing redox reaction between the hydroxide and oxyhydroxide forms of Ni (i.e. $Ni(OH)_2 \leftrightarrow NiOOH$). This material is cheap and easy to fabricate through electrodeposition, and only requires an electrical potential of <1 V in an alkaline electrolyte to fully actuate. Actuating strains close to 1% can be achieved, and although these are lower than the EAPs, mechanical amplification of the actuation can be easily achieved through proper engineering design, such as depositing the active material onto a passive layer to form a "skin-effect" cantilever actuator. In this case, the redox reaction triggered by the applied potential creates a reversible and fast-responsive strain of the active material, causing the bi-layered actuator to bend (**Figure 36**). The corresponding actuating stress of $Ni(OH)_2$-NiOOH is in the order of 10 MPa, which is comparable to that in EAP and is greater than skeletal muscles.

In addition to electrochemical actuation, $Ni(OH)_2$-NiOOH can also actuate reversibly by light, due to rapid water desorption under illumination. Selected-area electrodeposition of the active material onto a substrate allows the fabrication of interesting devices, such as the mini robotic arm as shown in **Figure 37**. Here, the active material is deposited selectively to form two actuating hinges on a passive substrate, enabling the device to lift an object ~50 times heavier than the active material when illuminated by light. The light-induced actuation here offers the possibility of wireless powering of micro robotic devices.

From the electrochemical and light-induced actuating performance shown, we believe that $Ni(OH)_2$-NiOOH is a promising material for artificial muscles. These findings are published in: Science Robotics, 2018 10.1126/scirobotics.aat4051

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[2] Sugino, T., Shibata, Y., Kiyohara, K., & Asaka, K. (2012). CNT/conductive polymer

composites for low-voltage driven EAP actuators. doi: 10.1117/12.914759
[3] Detsi, E., Onck, P., & De Hosson, J. T. M. (2013). Metallic muscles at work: high rate actuation in nanoporous gold/polyaniline composites. doi: 10.1021/nn400803x

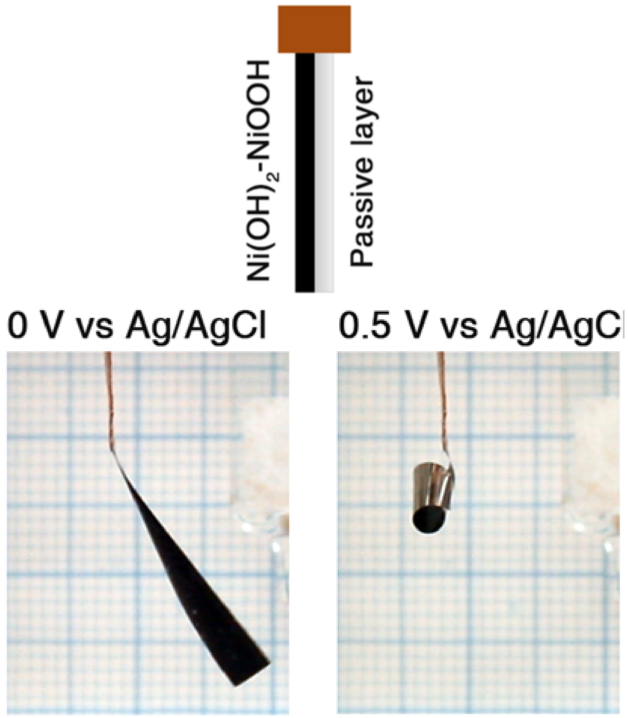


Figure 36: Electroactive ceramic Ni(OH)2-NiOOH actuating under <1 V, causing large bending of a bi-layered actuator.

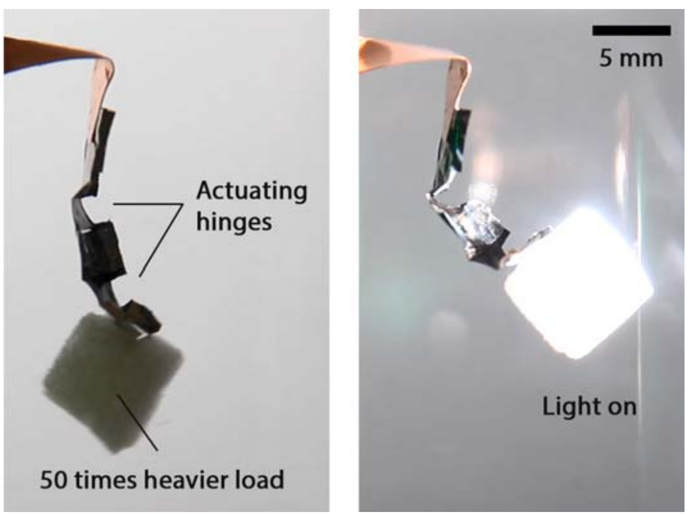


Figure 37: Light-induced actuation of a "mini arm" lifting an object ~50 times heavier than the active material.

FUTURE CONFERENCES

Date	Conference/Symposium
June 5-6, 2018	The EuroEAP 2018, which is the 8th international Conf. on EAPs, will take place in Lyon, France, on 5-6 June 2018 and was chaired by Claire Jean-Mistral (INSA Lyon, France). Detailed information about this conference is available at www.euroeap.eu/conference
June 25-27, 2018	The Actuators 18, International Conference and Exhibition on New Actuators and Drive Systems is going to be held at Bremen, Germany. Further details are available at www.actuator.de and thru e-mail: actuator@messe-bremen.de
October 14-16, 2018	2nd International Biotechnology Congress (IBC-2018) will be held in Fukuoka, Japan. For more details please see the following: http://www.bitcongress.com/ibc2018/programlayout.asp as well as http://www.bitcongress.com/ibc2018 or contact Sophie Yu Tel: 0086-411-84799609-839 Email: sophie@mol-cell.com
March 3 - 7, 2019	The 2019 SPIE's EAPAD Conf. is going to be held again in Denver, Colorado. This Conf. will be the 21th annual one and is going to be chaired by Y. Bar-Cohen, JPL, and Co-chaired by I. A. Anderson, The Univ. of Auckland (New Zealand) and Nancy L. Johnson, GM Motors Co., USA. The call for papers is posted at: http://www.spie.org/eap

EAP ARCHIVES

Information archives and links to various websites worldwide are available on the following (the web addresses below need to be used with no blanks):

Webhub: http://eap.jpl.nasa.gov

Newsletter: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/WW-EAP-Newsletter.html

Recipes: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-recipe.htm

EAP Companies: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-material-n-products.htm

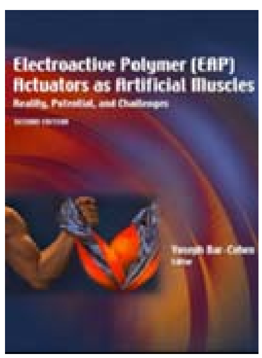
Armwrestling Challenge: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

Books and Proceedings: http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

2nd Edition of the book on EAP

Y. Bar-Cohen (Editor)

In March 2004, the 2nd edition of the "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges" was published.



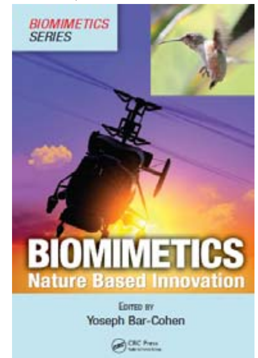
This book includes description of the available materials, analytical models, processing techniques, and characterization methods. This book is intent to provide a reference about the subject, tutorial resource, list the challenges and define a vision for the future direction of this field. Observing the progress that was reported in this field is quite heartwarming, where major milestones are continually being reported.

Biomimetics books series

Biomimetics – Nature Inspired Innovation

Yoseph Bar-Cohen (Editor)

This book contains 20 chapters covering various aspects of the field of biomimetics including Nature as a source for inspiration of innovation; Artificial Senses & Organs; Bio-mimicry at the Cell-Materials Interface; Multiscale modeling of plant cell wall architecture and tissue mechanics for biomimetic applications; Biomimetic composites; EAP actuators as artificial muscles; Refreshable Braille Displays Actuated by EAP; Biological Optics; Biomimicry of the Ultimate Optical Device: Biologically Inspired Design: a tool for interdisciplinary education Enhancing Innovation Through Biologically-Inspired Design; Self-reproducing machines and manufacturing processes; Biomimetic products; Biomimetics for medical implants; Application of biomimetics in the design of medical devices; Affective Robotics: Human Motion and Behavioral Inspiration for Safe Cooperation between Humans and Humanoid Assistive Robots; Humanlike robots - capabilities, potentials and challenges; Biomimetic swimmer inspired by the manta ray; Biomimetics and flying technology; The Biomimetic Process in Artistic Creation; and Biomimetics - Reality, Challenges, and Outlook. Further information is available at: http://www.crcpress.com/product/isbn/9781439834763



Architecture Follows Nature - Biomimetic Principles for Innovative Design

Authored by Ilaria Mazzoleni ***www.imstudio.us*** *info@imstudio.us in collaboration with Shauna Price* http://www.crcpress.com/product/isbn/9781466506077

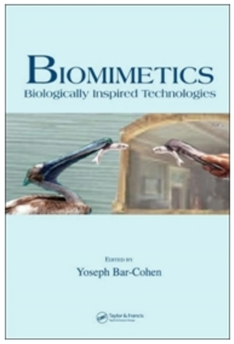
The book entitled "Architecture Follows Nature - Biomimetic Principles for Innovative Design" has been published by CRC Press as part of the book series on Biomimetics for which Y. Bar-Cohen is the editor. The homepage of this book series is:

http://www.crcpress.com/browse/series/?series_id=2719

Biomimetics - Biologically Inspired Technologies

Y. Bar-Cohen (Editor)
http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

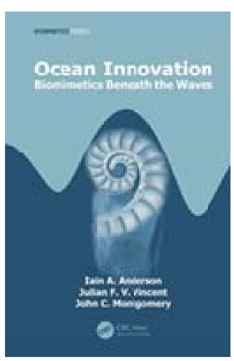
This book about Biomimetics review technologies that were inspired by nature and outlook for potential development in biomimetics in the future. This book is intended as a reference comprehensive document, tutorial resource, and set challenges and vision for the future direction of this field. Leading experts (co)authored the 20 chapters of this book and the outline can be seen on http://ndeaa.jpl.nasa.gov/ndeaa-pub/Biomimetics/Biologically-Inspired-Technology.pdf



Ocean Innovation: Biomimetics Beneath the Waves

Authored by Iain A. Anderson i.anderson@auckland.ac.nz, Julian Vincent, and John Montgomery
https://www.crcpress.com/Ocean-Innovation-Biomimetics-Beneath-the-Waves/Anderson-Vincent-Montgomery/p/book/9781439837627

Generally, biomimetics is the idea of creating new technologies abstracted from what we find in biology. The book "Ocean Innovation: Biomimetics Beneath the Waves" seeks that technological inspiration from the rich biodiversity of marine organisms. Bringing both a biological and engineering perspective to the biomimetic potential of oceanic organisms, this richly illustrated book investigates questions such as:



- How can we mimic the sensory systems of sea creatures like sharks, sea turtles, and lobsters to improve our ability to navigate underwater?
- What can we do to afford humans the opportunity to go unnoticed by marine life?
- How can we diffuse oxygen from water to enable deep diving without the risk of decompression sickness?

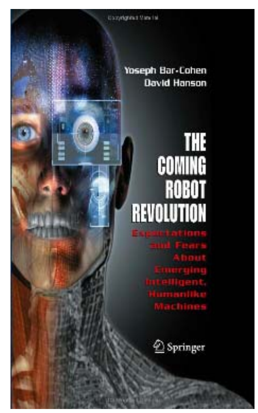
Each chapter explores an area where we, as divers and technologists, can benefit from understanding how animals survive in the sea, presenting case studies that demonstrate how natural solutions can be applied to mankind's engineering challenges.

Books about robotics

The Coming Robot Revolution - Expectations and Fears about Emerging Intelligent, Humanlike Machines

Yoseph, Bar-Cohen and David Hanson (with futuristic illustrations by Adi Marom), Springer, ISBN: 978-0-387-85348-2, (February 2009)

This book covers the emerging humanlike robots. Generally, in the last few years, there have been enormous advances in robot technology to which EAP can help greatly in making operate more lifelike. Increasingly, humanlike robots are developed for a wide variety of applications. These "smart" lifelike robots are designed to help with household chores, as office workers, to perform tasks in dangerous environments, and to assist in schools and hospitals. In other words, humanlike robots are coming and they may fundamentally change the way we live, even the way we view ourselves.

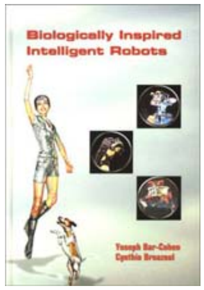


Biologically Inspired Intelligent Robots

Y. Bar-Cohen and C. Breazeal (Editors)

The book that is entitled "Biologically-Inspired Intelligent Robots," covering the topic of biomimetic robots, was published by SPIE Press in

May 2003. There is already extensive heritage of making robots and toys that look and operate similar to human, animals and insects. The emergence of artificial muscles is expected to make such a possibility a closer engineering reality. The topics that are involved with the development of such biomimetic robots are multidisciplinary and they are covered in this book. These topics include materials, actuators, sensors, structures, control, functionality, intelligence and autonomy.



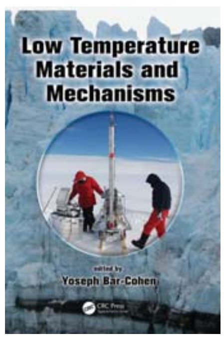
Other books

Low Temperature Materials and Mechanisms

Yoseph Bar-Cohen (Editor)

https://www.crcpress.com/Low-Temperature-Materials-and-Mechanisms/Bar-Cohen/p/book/9781498700382

Published on July 1, 2016, this book addresses the growing interest in low temperature technologies. Since the subject of low temperature materials and mechanisms is multidisciplinary, the chapters reflect the broadest possible perspective of the field. Leading experts in the specific subject area address the various related science and engineering chemistry, material science, electrical engineering, mechanical engineering, metallurgy, and physics.

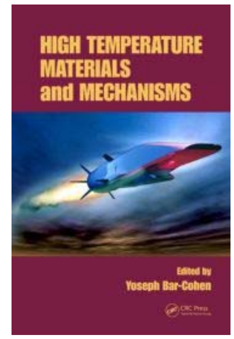


High Temperature Materials and Mechanisms

Yoseph Bar-Cohen (Editor)

http://www.crcpress.com/product/isbn/9781466566453

This book is addressing the growing interest in high-temperature technologies. This book covers technology related to energy, space, aerospace, electronics, metallurgy, and other areas. While some applications involve the use of materials at high temperatures, others require materials processed at high temperatures for use at room temperature.



Reflecting the multidisciplinary nature of the subject of high-temperature materials and mechanisms, the chapters bring as broad a perspective to the field as possible and are authored by leading experts in the specific subject. The book addresses the various related science and engineering disciplines, including chemistry, material science, electrical and mechanical engineering, metallurgy, and physics.

WorldWide Electroactive Polymers (EAP) Newsletter

EDITOR: Yoseph Bar-Cohen, http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi.htm

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