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Yoseph Bar-Cohen
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Introduction

The SPIE Electroactive Polymers Actuators and Devices (EAPAD) conference remains the leading international forum for presenting the latest progress and information exchange among the attendees regarding the advances, capabilities, challenges and potential future directions. The conference this year was chaired by Yoseph Bar-Cohen, Jet Propulsion Laborotary/California Institute of Technology (United States), and co-chaired by Jonathan M. Rossiter, University of Bristol (United Kingdom). Hani E. Naguib, a notable award recipient within the Smart Structures symposium, University of Toronto, Canada (Figure 1) received the 2017 SPIE Fellow Award for his contributions to multifunctional materials development and characterization including EAP materials.

Figure 1: Hani E. Naguib (on the left) receiving the 2017 SPIE Fellow Award from Chris Lynch, University of California, Los Angeles.

Photos from the conference were posted at the SPIE website: http://spie.org/about-spie/press-room/spie-smart-structures/nondestructive-evaluation-2017-news-and-photos

The conference included 122 presentations and was well attended by internationally leading experts in the field including members of academia, industry, and government agencies from the United States and overseas. This year, two plenary speakers made EAP-related presentations at the symposium. David Hanson (Figure 2), Hanson Robotics, presented "Electroactive polymers for healthcare and biomedical applications". His presentation included a demonstration of his robot, Sophia, conversing with him and making facial expressions. Hanson pointed out that bio-inspired intelligent robots are coming of age in both research and industry, and are propelling market growth for robots and AI.

Figure 2: David Hanson and Yoseph Bar-Cohen next to a toy robot Prof. Einstein

However, conventional motors limit the capability of bio-inspired robotics. EAP actuators and sensors could improve the simplicity, compliance, physical scaling, and offer bio-inspired advantages in robotic locomotion, grasping, manipulation, and social expressions. For EAP actuators to realize their transformative potential, further innovations are needed. The actuators must be robust, fast, powerful, manufacturable, and affordable. In his presentation, Hanson reviewed the progress, opportunities, and challenges in his latest work with social robots and EAP actuators, and he proposed a roadmap for EAP actuators in bio-inspired intelligent robotics.

In addition, Chiara Daraio, California Institute of Technology (United States), presented a plenary presentation entitled "Plant nanobionic materials for thermally active, soft, artificial skins". In her paper, she described bionic materials as a class that aims to preserve, enhance, and exploit properties of living systems for engineering purposes. In most cases, however, creating synthetic materials that reproduces or surpasses the performance of natural materials has been elusive. In her lab, Daraio fabricated synthetic materials that combine carbon nanoparticles in a matrix of plant cells to create new temperature sensors with record-breaking responsivity. She had extracted the active molecule, pectin (responsible for the temperature sensitivity in plants), to create ultra-sensitive, flexible membranes that can map temperature changes from a distance. These materials augment properties of synthetic skins for robotics and prosthesis, and can find applications in consumer electronics or NDE.

Figure 3: From left to right – Gabor Kovach, Yoseph Bar-Cohen, and Siegfried G. Bauer

In the EAPAD conference, the keynote speaker was Siegfried G. Bauer (Figure 3), Johannes Kepler Universität, Linz (Austria) with a paper titled "Electroactive polymers for healthcare and biomedical applications". In his paper, he noted that electroactivity has been noticed in biological substances; including proteins, polynucleotides and enzymes. In addition, piezo- and pyro-electricity were found in wool, hair, wood, bone and tendon. He stated that there is still a strong debate about the physiological importance of electroactive effects in biological materials, but it is interesting that electroactive phenomena are widespread in natural materials. According to Bauer with the currently available science and technology, we are at the verge of witnessing the demonstration of truly complex bionic systems and the future of EAP materials remains bright.

Overall, the presented papers reported the significant progress made in each of the topics of the EAP field infrastructure. The topics included: theoretical modeling and analysis of EAP mechanisms; improved EAP materials, processes, fabrication (including 3D printing) and characterization techniques; emerging EAP actuators (including ionic, conducting, shape memory polymers, CNT and dielectric EAP); applications of EAP materials including power generation and energy harvesting, robotics, haptic, tactile, and other sensors. Of significant interest, Gabor M. Kovacs, EMPA (Switzerland), (Figure 3) presented a paper entitled "From research to production" in which he described his company efforts to create a commercial EAP actuator at mass production scale and the related issues.

The efforts described in the presented papers show significant improvements in understanding the electromechanical principles towards better methods of dealing with the challenges to the materials applications. Researchers continue to develop analytical tools and theoretical models to describe the electro-chemical and mechanical processes, nonlinear behavior as well as methodologies of design and control of the activated materials. EAP with improved response were described including dielectric elastomer, IPMC, conducting polymers, gel EAP, carbon nanotubes, and other types. Specifically, there seems to be a significant trend towards using dielectric elastomers as practical EAP actuators. The invited papers in the 2017 EAPAC Conference were as follows:

> Gabor M. Kovacs, EMPA (Switzerland), "From research to production" [10163-2];
>
> John D. W. Madden, Yuta Dobashi, Mirza S. Sarwar, Eden C. Preston, Justin K. M. Wyss, The Univeristy of British Columbia (Canada); Vincent Woehling, Tran-Minh-Giao Nguyen, Cédric Plesse, Frédéric Vidal, Université de Cergy-Pontoise (France); Sina Naficy, Geoffrey M. Spinks, University of Wollongong (Australia), "Proximity and touch sensing using deformable ionic conductors" [10163-3];
>
> Stoyan Smoukov, University of Cambridge (United Kingdom), "Bottom-up approaches to multi-functional materials and artificial morphogenesis" [10163-8];
>
> James D. Carrico, Kam K. Leang, The University of Utah (United States), "Fused filament 3D printing of ionic polymer-metal composites for soft robotics" [10163-16];
>
> William S. Oates, Paul Miles, Wei Gao, Jonathan Clark, Somayeh Mashayekhi, Mohammad Y. Hussaini, Florida State University (United States), "Rate dependent constitutive behavior of dielectric elastomers and applications in legged robotics" [10163-40];
>
> Christoph Keplinger, University of Colorado Boulder (United States), "Reliable, robust, electrically powered soft actuators that self-heal from mechanical and electrical damage" [10163-55];
>
> Seon Jeong Kim, Shi Hyeong Kim, Hanyang University (Korea, Republic of); Ray H. Baughman, The University of Texas at Dallas (United States), "Artificial muscles for electrical energy harvesting" [10163-60];
>
> Gih-Keong Lau, Yao-Wei Chin, Nanyang Technological University (Singapore); Thanh-Giang Lau, Nanyang Technological University

(Singapore), "Development of elastomeric flight muscles for flapping wing micro air" [10163-69];

Mohammad Vatankhah-Varnosfaderani, William F. M. Daniel, Alexandr P. Zhushma, Qiaoxi Li, Benjamin J. Morgan, The University of North Carolina at Chapel Hill (United States); Krzysztof Matyjaszewski, Carnegie Mellon University (United States); Daniel P. Armstrong, North Carolina State University (United States); Andrey V. Dobrynin, The University of Akron (United States); Sergei S. Sheyko, The University of North Carolina at Chapel Hill (United States); Richard J. Spontak, North Carolina State University (United States), "Bottlebrush elastomers: a promising molecular engineering route to tunable, prestrain-free dielectric elastomers" [10163-72];

Ramona Mateiu, Liyun Yu, Anne L. Skov, Technical University of Denmark (Denmark), "Electrical breakdown phenomena of dielectric elastomers" [10163-77];

Vy Khanh Vo Tran, Anup Teejo Mathew, Adrian Koh, National University of Singapore (Singapore), "Stackable configurations of artificial muscle modules that is continuously-tunable by voltage" [10163-88];

The EAP-in-Action Session included 13 demonstrations with presenters from China, Germany, Japan, New Zealand, Singapore, Switzerland, and the United States. The session was opened by Dr. Hanson's robot Sophia, who welcomed the attendees of the session and gave general introductory words. Then, Dr. Hanson presented the new toy robot, Prof. Einstein, and demonstrated its capabilities (Figure 2). This year SPIE started giving awards for the best EAP-in-Action Demonstrations (see Appendix for the details).

A notable accomplishment of the students who participated and made a presentation at the EAPAD conference was winning the Best Student Paper Award. The winner this year, Caleb Christianson, University of California, San Diego, (Figure 4) with his paper titled "Fluid electrodes for submersible robotics based on dielectric elastomer actuators" [10163-57].

Figure 4: Caleb Christianson, University of California, San Diego, the winner of the Best Student Paper Award

In closing, I would like to extend a special thanks to all the conference attendees, paper presenters, session chairs, EAP-in-Action Demo presenters, and the members of the EAPAD program organization committee. In addition, special thanks are extended to the SPIE staff that helped making this conference a great success.

Appendix: the 2017 EAP-in-Action program

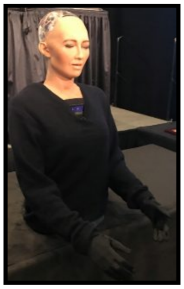

Figure 5: Hanson's robot, Sophia, greets the attendees of the EAP-in-Action Session.

The 2017 EAP-in-Action session highlighted some of the latest capabilities and applications of Electroactive Polymer (EAP) materials where the attendees have been shown demonstrations of these materials in action. In addition, the attendees were 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.

This year, the session has been opened by Dr. Hanson's robot, Sophia (Figure 5), who welcomed the attendees of the session and gave general introductory words. Then, he presented the new toy robot, Prof. Einstein, and demonstrated its capabilities (Figure 2). This participation of a humanlike robot gave great excitement to the participants with the feeling of the "future is here".

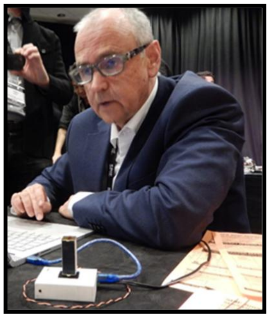

Figure 6: Gabor Kovach presenting his company's new contractile multilayered stack EAP actuator.

As part of the session, Gabor Kovacs presented his company's new contractile multilayered stack EAP actuator that they are developing towards mass production (Figure 6).

The Session included 13 demonstrations with presenters from China, Germany, Japan, New Zealand, Singapore, Switzerland, and the United States. The presenters consisted of professors and their students as well as engineers from various companies. This year, the session ran as a competition, and the top three presentations were selected by six judges. The winners were as follows:

First Place: Multilayered PVC gel artificial muscle - Minoru Hashimoto, Yi Li, Aya Suzuki, Hanako Niwa, Rina Yokotsuka, Shinshu University, Japan (Figure 7, left)

Second Place: DEA-driven vibratory feeder - Steffen Hau, Mathias Hoffmann, Stefan Seelecke, Saarland Universität, Germany (Figure 8, right)

Third Place: "Multilocation sensing on one input/output and the EAP zoo", Markus Henke, Patrin Illenberger, Andreas Tairych, Chris Walker, Katie Wilson, and Iain Anderson, Biomimetics Lab, Auckland Bioengineering Institute, Auckland, New Zealand (Figure 9, left).

The ranking evaluation criteria of the demonstration were:

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

The judges for the 2017 competition were:

- Siegfried Bauer, Johannes Kepler Universität Linz (Austria)
- David Hanson, Hanson Robotics LLC (United States)
- Gabor Kovacs, EMPA (Switzerland)
- John D Madden, The University of British Columbia (Canada)
- Qibing Pei, University of California, Los Angeles (United States)
- Jonathan Rossiter, University of Bristol (United Kingdom)

Presentations were scored as followed: 4 Excellent; 3 Good; 2 Fair; 1 Reasonable; 0 No Show

The demonstrations in 2017 included innovative devices and potential new products that are driven by EAP and were as follows (listed by the country of the leading presenters):

China

(Figure 10) Jing Dai, Bangyuan Liu, Feiyu Chen, Sukai Wang, Zhiqiang Fu, Tiefeng Li, Soft Matter Research Center of Zhejiang University, China, “Applications of smart polymers”

Figure 10: The team from Zhejiang University demonstrating their EAP actuated soft robotic mechanism.

This demonstration showed Soft robotics and smart structures that are made of multiple soft active materials, and can be fabricated by 3D printing method. Driven by dielectric elastomer, the robot shows excellent performances in large actuation and fast response. Using a common compact power and control electronics, various configurations of soft robot can be designed as actuated modules. Smart structures made of temperature active tough hydrogel will also demonstrate as actuators of bio-medical applications. The operation principles may guide the further design of soft robots for various applications.

(Figure 11) Liwu Liu, Jinrong Li, Fengfeng Li, Xiongfei Lv, Jinsong Leng, Harbin Institute of Technology, China, "Applications of smart deformable polymers"

This demonstration will show smart polymers in action taking advantage of their being light weight, fast response, and large deformation. These advantages make them attractive for applications in smart bionics, aerospace, biomedicine and other fields. The demonstration will include the applications of EAP, shape memory polymer (SMP) and pneumatic artificial muscle (PAM), such as soft robot, soft continuum manipulator, smart release device, adaptive eyewear frame and other deformable structures.

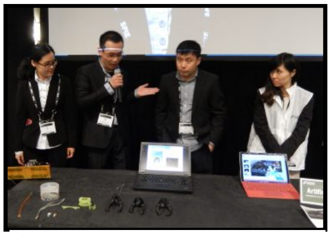

Figure 11: Hui Gao, Fanlong Chen (speaker), Liwu Liu (from left to right) (Harbin Institute of Technology), presenting the demo "Applications of smart deformable polymers"

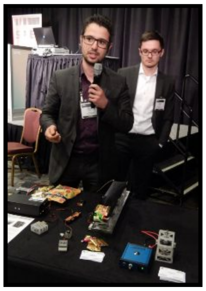

Figure 12: Steffen Hau, Saarland Univ. (Germany), presenting the DEA Driven Vibratory Feeder demo.

Germany

(Figure 12) Steffen Hau, Mathias Hoffmann, and Stefan Seelecke, Saarland Universität, Germany, "DEA Driven Vibratory Feeder"

Vibratory feeders are widely used in part handling technology for transport, aligning and/or feeding parts to a certain process. Currently they are driven by electro-magnetic actuators and unbalance motors, which do not allow arbitrary vibration profiles or changes of amplitude/frequency during operation. Dielectric elastomer actuator (DEA) show potential to overcome these drawbacks. A fully functional DEA driven vibratory feeder transporting small goods will be demonstrated, showing DEAs potential in this new field of application. This demo received the Runner-Up Best Student Paper Award.

Japan

(Figure 13) Minoru Hashimoto, Yi Li, Aya Suzuki, Hanako Niwa, Rina Yokotsuka, Shinshu University, Hashimoto-Tsukahara Laboratory, Nagano, Japan, "Multilayered PVC Gel Artificial Muscle"

Multilayered contraction type PVC gel actuator was developed using stainless mesh electrodes having many positive characteristics. This include being soft and lightweight, with stable actuation in air and with high output. It is activated by applying voltage of 400V, and the displacement of 60-layer artificial muscles is ~3.0mm, with contraction strain of ~10%, and the maximum output force is ~50kPa. The response rate is 9Hz, and the current is about 0.45mA. This demo received the Best EAP-in-Action Award.

Figure 13: The Multilayered PVC Gel Artificial Muscle being presented (from Left to Right) by Rina Yokotsuka, Minoru Hashimoto, and Yi Li.

Figure 14: Tempuu Siva (on the right) and Teruo Toyoda (on the left), Haloworld Inc., presenting their Biomimetic robot system

(Figure 14) Tempuu Siva, Teruo Toyoda, and Fujio Mine, Haloworld Inc., Fukushima, Japan, "Biomimetic robot system for plumbing tests"

A tubular inchworm robot mechanism that is driven by electroactive polymer and air pressure will be presented. This robot will be equipped with a camera to allow testing the plumbing of the decommissioned Fukushima Daiichi Nuclear Power Plant. The robot is capable of traversing thru the many elbow sections along the more than several hundred meter plumbing. The use of the EAP actuation mechanism allows for smooth operation thru the curvatures along the plumbing path.

New Zealand

(Figure 15) Patrin Illenberger, Katie Wilson, Andreas Tairych, Chris Walker, Antoni Harbuz and Iain Anderson, Biomimetics Laboratory, Auckland Bioengineering Institute, Auckland, New Zealand "Multilocation sensing on one input/output and EAP zoo"

The Biomimetics Lab presented:

1. The multisensor shirt that can measure stretch at several locations from one input/output.
2. The Electroactive polymer zoo: we present the latest self-regulating crawling caterpillars and wing flapping dragonflies fabricated from printed polymer and electrode. No need for electronics!

This demo received the Third Place Best EAP-in-Action Award.

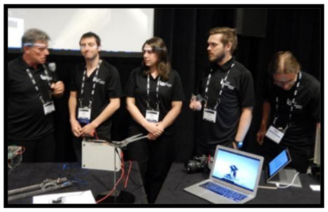

Figure 15: Iain Anderson presenting the Auckland Bioengineering Institute's Multilocation sensing on one input/output and EAP zoo. From left to right: Iain Anderson, Patrin Illenberger, Katie Wilson, Markus Henke, Andreas Tairych, and Chris Walker.

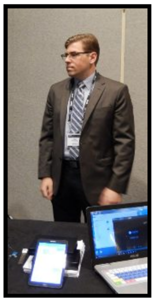

Figure 16

(Figure 16) Mark Williamson StretchSense Ltd., Auckland, New Zealand, “New EAP products”

What’s new in wearable electroactive polymer sensing and energy harvesting. This included soft sensors with soft electronics.

Singapore

(Figure 17) Jiawei Cao, Lei Qin and Jian Zhu, National University of Singapore, Singapore, “Soft untethered robots”

The soft untethered robot mainly consists of a deformable robotic body and two paper-based feet. Based on the optimal mechanical design, the robot is capable of achieving autonomous movements.

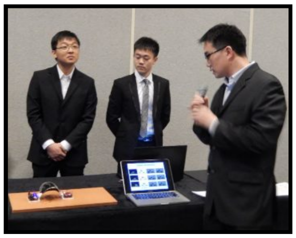

Figure 17: The team from National University of Singapore, Singapore, demonstrating their soft untethered robots.

(Figure 18) Anansa S. Ahmed and Gih-Keong Lau School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore, “Dielectric elastomer grippers using tensioned arch flexures”

The followings are going to be demonstrated

1. Versatile DEA grippers with enhanced tip angle deflection and blocked force due to tension arch flexure structure.
2. Grippers capable of grasping and lifting a variety of objects including highly deformable materials without damage.

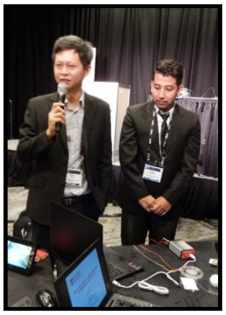

Figure 18: The Nanyang Technological University, Singapore, team presenting their electrically tuning transparency

Milan Shrestha, Anansa Ahmed, Anand Asundi, Gih-Keong Lau, Nanyang Technological University, Singapore, “Electrically tuning transparency by wrinkling of ZnO/Ag thin film”

This demonstration unit consists of transparency tunable device. It works based on wrinkling and unfolding a ZnO/Ag-coated elastomer substrate using a dielectric elastomer actuator (DEA). Initially, the membrane is at wrinkled state and the device is opaque. An object placed underneath the membrane will not be visible. When the DEA device is electrically activated, the wrinkles are flattened turning the device to a transparent membrane and the object placed behind the device becomes clearly visible. Reversible tuning between the two states can be obtained electrically for a large number of cycles.

Switzerland

(Figure 19) Samuel Rosset and Samuel Schlatter, EFPL, Switzerland "PetaPicoVoltron: an open-source portable high-voltage supply"

A portable high voltage power supply (HVPS) has been demonstrated that is specifically designed to drive DEAs. Its output DC voltages is up to 5kV with a resolution of 0.1% of full scale, and can generate square signals from 1mHz to 1kHz with a slew rate faster than 15V/µs. It has a user friendly GUI enabling easy interaction with the HVPS, and using LabView library makes it simple to integrate the power supply with other instruments. The circuit layout and the software have been released as an open-source project, for anyone to use and improve.

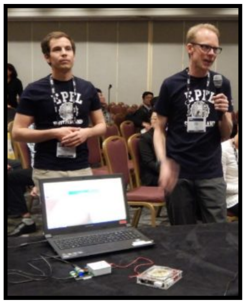
Figure 19: The EFPL, Switzerland, presenting their PetaPicoVoltron demo

United States

(Figure 20) Qi Shen, Sarah Trabia, Tyler Stalbaum, Taeseon Hwang, Robert Hunt, Zakai Olsen, and Kwang Kim, University of Nevada, Las Vegas "Development of an origami soft robot using multiple shape memory ionic polymer-metal composite"

The multiple-shape-memory ionic polymer-metal composite (MSM-IPMC) actuator is used to demonstrate complex 3D deformation. The MSM-IPMC has two characteristics, which are the electro-mechanical actuation effect and the thermal-mechanical shape memory effect. The bending, twisting, and oscillating motions of the actuator could be controlled simultaneously or separately by means of thermal-mechanical and electro-mechanical transactions. Using the MSM-IPMC, a soft biomimetic robot was developed that has origami structure. The multiple shape memory effect enables the robot to change its shape and in return enables the robot to move forward in water. This work may bring inspiration for designing new soft robotic systems with the MSM-IPMC actuators

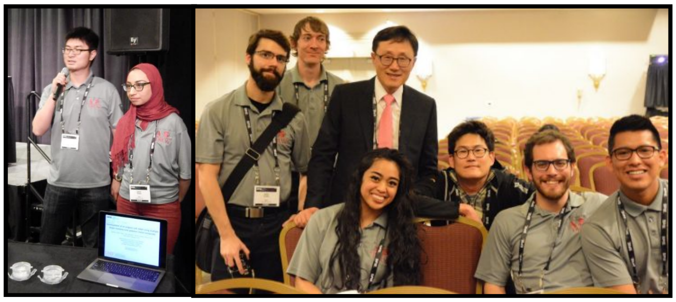
Figure 10: The team Univ. of Nevada, Las Vegas, under the lead of Kwang Kim (right) and their origami soft robot using multiple shape memory ionic polymer-metal composite (left).

Figure 11: Lenore Rasmussen, Ras Labs, demonstrating her latest Synthetic Muscle based actuator, with sensing EAP pads retrofitted to a standard EMI robotic gripper.

(Figure 21) Lenore Rasmussen, Ras Laboratories, "Synthetic Muscle"

The operation of the latest Synthetic Muscle based actuators was demonstrated. These are EAP based actuators that contract and expand, attenuate impact, and sense pressure. In addition, prosthetic liner prototype with self-adjusting EAP based pads and sensing robotic gripper was shown.

Yoseph Bar-Cohen