Electroactive Polymer Actuators and Devices (EAPAD) XXI

Yoseph Bar-Cohen
Iain A. Anderson
Nancy L. Johnson
Editors

4–7 March 2019
Denver, Colorado, United States

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Published by
SPIE

Volume 10966

Proceedings of SPIE 0277-786X, V. 10966

Electroactive Polymer Actuators and Devices (EAPAD) XXI, edited by Yoseph Bar-Cohen, Iain A. Anderson,
Proc. of SPIE Vol. 10966, 1096601 · © 2019 SPIE · CCC code: 0277-786X/19/$18 · doi: 10.1117/12.2524992

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Please use the following format to cite material from these proceedings:
Author(s), "Title of Paper," in *Electroactive Polymer Actuators and Devices (EAPAD) XXI*, edited by Yoseph Bar-Cohen, Iain A. Anderson, Nancy L. Johnson, Proceedings of SPIE Vol. 10966 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)

ISBN: 9781510625877
ISBN: 9781510625884 (electronic)

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

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Introduction

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. The conference this year was Chaired by Yoseph Bar-Cohen, JPL/Caltech (United States), and Co-Chaired by Iain A. Anderson, The Univ. of Auckland (New Zealand) and Nancy L. Johnson, General Motors Co. (United States). This Conference has been the 21st since its start in 1999. Presented papers reported the significant progress made in topics that included: theoretical modeling and analysis of EAP mechanisms; improved EAP materials, processes, fabrication (including additive manufacturing such as 3D printing) and characterization techniques; emerging EAP actuators (including ionic, shape memory polymers, and dielectric EAP); applications of EAP materials including power generation and energy harvesting, robotics, haptic, tactile, and various sensors. The 2019 EAP-in-Action Session consisted of 12 demonstrations by teams from China, Germany, New Zealand, Switzerland, Sweden, and USA (see Appendix for the details).

On a sad note, the conference was opened with a brief acknowledgement for the late Prof. Siegfried Bauer by Martin Kaltenbrunner, Johannes Kepler Univ. Linz (Austria).

The Conference included 101oral and poster presentations and it was well attended by internationally leading experts in the field including members of academia, industry, and government agencies from the USA and overseas. We are seeing significant improvements and breakthroughs in modelling, materials and applications for EAP. 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 a continuing trend towards using dielectric elastomers as practical EAP actuators for commercial applications.

Figure 1: The Keynote Speaker Ray Baughman, NanoTech Institute, the University of Texas in Dallas

At this EAPAD Conf., there were two Keynote speakers including Ray H. Baughman, The Univ. of Texas at Dallas (**Figure 1**) and Douglas A. Litteken, NASA Johnson Space Ctr. (**Figure 2**).

Ray's presentation, in honor of his 75th birthday was titled: "Sixty years of fun in science and technology". In August 2001, Ray became the Robert A. Welch Professor of Chemistry and Director of the NanoTech Institute at the University of Texas in Dallas, after 31 years in industry. Ray is a member of the National Academy of Engineering, the Academy of Medicine, Engineering and Science of

Texas, the Academia Europaea, and the European Academy of Sciences and Arts; a foreign member of the European Academy of Sciences; a Fellow of the Royal Society of Chemistry, the National Academy of Inventors, and the American Physical Society; an Academician of The Russian Academy of Natural Sciences; and an honorary professor of 7 universities in China.

Figure 2: The Keynote Speaker Douglas Litteken, NASA's Johnson Space Center (JSC) in Houston, TX

Douglas A. Litteken was the 2^{nd} Keynote speaker and the title of his presentation was: "Inflatable technology: using flexible materials to make large structures". Doug is a structural engineer at NASA's Johnson Space Center (JSC) in Houston, Texas. He is the Lightweight Structures Domain Lead at JSC and a Subject Matter Expert in the agency for softgoods structures. He is also the sub-system manager for the Orion crew cabin primary structure. His interests include inflatable habitats, parachutes, composite structures, flexible electronics, and structural health monitoring. His experience includes the design, analysis and testing of softgoods structures including lunar surface habitats, airlocks, and deep space transit vehicles. He received both his Bachelor's and Master's degrees in Mechanical Engineering from the University of Illinois at Urbana-Champaign.

The invited papers in the 2018 EAPAC Conference were:

1. Design of reliable silicone elastomers for dielectric elastomers and stretchable electronics (Paper 10966-9) - Piotr Mazurek, Liyun Yu, **Anne Ladegaard Skov**, Technical Univ. of Denmark (Denmark)
2. Manufacturing dielectric elastomer stack actuators: challenges and applications for industrialization (Paper 10966-29) - **Helmut F. Schlaak**, Technische Univ. Darmstadt (Germany)
3. From soft microrobotics to macroscopic wearables (Paper 10966-32) - **Edwin W. H. Jager**, Linköping Univ. (Sweden)
4. Soft electronic and robotic systems from biocompatible and degradable materials (Paper 10966-39) - **Martin Kaltenbrunner**, Johannes Kepler Univ. Linz (Austria)
5. Soft robotics for prosthetic devices: how dependent it is on smart materials? (Paper 10966-53)- **Gursel Alici**, Univ. of Wollongong (Australia)
6. Dielectric elastomer spring-roll bending actuators: applications in soft robotics and design (Paper 10966-56) - Yanju Liu, Liwu Liu, Jinsong Leng, Harbin Institute of Technology (China)
7. Soft hybrid generators for harvesting human kinetic energy (Paper 10966-72) - **Claire Jean-Mistral**, Institut National des Sciences Appliquées de Lyon (France); Alain Sylvestre, Lab. de Génie Électrique de Grenoble (France)

In closing, we 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 to make this conference a great success. Moreover, the Conference Chairs would like to thank Emily Power, SPIE, for providing some of the photos that were used in this Preface.

Yoseph Bar-Cohen
Iain A. Anderson
Nancy L. Johnson

APPENDIX – THE 2017 EAP-IN-ACTION PROGRAM

Moderator:
Yoseph Bar-Cohen, Jet Propulsion Laboratory

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 addition, the attendees are given opportunity to interact directly with the presenters as well as given "hands-on" experience with the presented technology. The first Human/EAP-Robot Arm wrestling 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.

Evaluation criteria: 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 2019 judges were (Figure 1):

1. Nancy L. Johnson, General Motors Co. (United States)
2. John D Madden, The University of British Columbia (Canada)
3. Qibing Pei, University of California, Los Angeles, (UCLA), (USA)
4. Geoffrey M. Spinks, University of Wollongong (Australia)
5. Ray H. Baughman, The University of Texas at Dallas (United States)

Figure 1: The judges of the EAP-in-Action best demonstrations and the audience

The 2019 EAP-in-Action Session included 11 demonstrations with presenters from China, Germany, New Zealand, Switzerland, Sweden, and USA. The presenters consisted of professors and their students as well as engineers from industry. In addition to the formal demonstration participants, presenters from the University of Colorado presented their HASEL artificial muscle actuator and a prototype that they are currently considering for commercialization (**Figure 2**).

Figure 2: Members of the University of Colorado team (Christoph Keplinger and Shane Mitchell pictured) provided an impromptu demonstration of the latest developments for HASEL artificial muscles.

The top three best demonstration award recipients were:

- **<u>First Place (Figure 3)</u>:** "Electro-ribbon actuators and electro-origami robots". The recipients were Tim Helps, Majid Taghavi, Richard Suphapol Diteesawat, and Jonathan M. Rossiter, Univ. of Bristol (United Kingdom) (USA).
- **<u>Second Place (Figure 4)</u>:** "A fast 200 mg DEA robot". The recipient was, Herbert R. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
- **<u>Third Place (Figure 5)</u>:** "Synthetic muscle in prosthetics", Lenore Rasmussen, Ras Labs., Inc. (United States)

Figure 3: Recipients of the 1st place Best EAP-in-Action Demo - The team from the University of Bristol (Jonathan Rossiter, Yosi Bar Cohen, Tim Helps and Richard Diteesawat).

Figure 4: Yosi Bar Cohen congratulates Herb Shea, one of the recipients of the 2nd place Best EAP-in-Action Demo.

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Figure 5: Yosi Bar Cohen with Lenore Rasmussen: recipient of the 3rd place EAP-in-Action Demo.

The 2019 EAP-in-Action demonstrations included innovative devices and potential new products that are driven by EAP and they were as follows:

1. **Novel dielectric elastomer membrane actuator concept for pneumatic valves** - **Steffen Hau**, Saarland University (Germany)


Despite being relatively easy to manufacture and providing large strokes, dielectric elastomer (DE) membrane actuators suffer from low force outputs (for single layer systems). This demo presents a novel design concept that permits to retune the stroke-force trade-off of DE actuators, by allowing increasing force output of the actuator at the expense of a reduced stroke. This is of particular interest for valve applications, which typically need high closing forces and low strokes in the submillimeter regime. By means of the novel design concept, the valve closing force of single DE membranes can be increased by a factor of 3 to 4. The concepts still keeps the general advantages of DEAs, e.g., light weight, and energy efficiency. The use of strip-in-plane DE actuators additionally allows staying within the typical dimension of commercial valves.

2. **DEA-based pneumatic pump** - **Philipp Linnebach**, Saarland University (Germany)


This demonstrator shows the use of circular out-of-plane dielectric elastomer actuators (COP-DEA) in a pneumatic pump application. The presented concept allows building very small and lightweight pumps. It is related to the paper with the title “Design of a dielectric elastomer actuator driven pneumatic pump”.

3. A fast 200 mg DEA robot – X. Ji, B. Aksoy, H. Shea, EPFL (Switzerland)

This team presented a DEAnsec, which is an ultra-light (0.2 g) soft robot driven by stacked dielectric elastomer actuators (DEAs) operating at 450V. The DEAnsect has a flexible silicone body and three legs, each driven independently by a DEA stack. The DEAnsect moves at four body lengths per second and can be accurately steered thanks to the independent control of each DEA. It is robust, can climb slopes of 15°, and survives being flattened with a fly swatter.

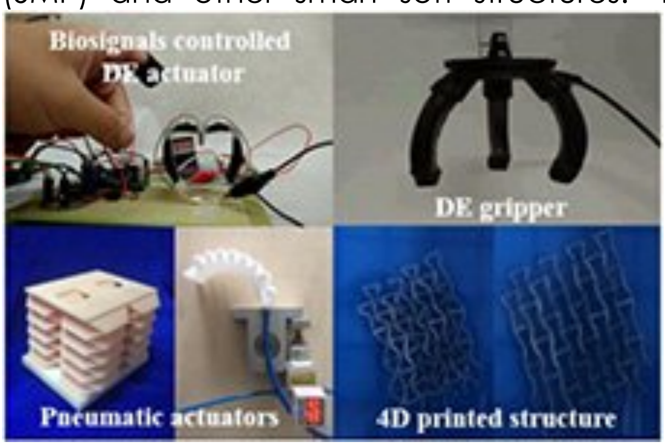
4. **Textile exoskeletons** – **Edwin W. H. Jager, Jose G. Martinez**, Linkoping Univ. (Sweden), **Nils-Krister Persson**, Univ. of Boras (Sweden)



Various diseases or aging can cause a reduction in the muscle function of a person. Robotic exoskeletons have been developed to augment or replace the movement of various limbs and thus for instance assist walking or aid rehabilitation. Current exoskeletons are rigid, heavy, stiff and non-compliant. This team is developing textile-based exoskeletons that can be worn like items of clothing being light-weight, soft, compliant and comfortable. In this EAP-in-Action, demonstrators of the prototype textile exoskeleton-arm-sleeves developed by Linköping University and University of Borås was shown. The exoskeleton arm-sleeve prototypes use small electrical motors or McKibben actuators and enable lifting the arm, including a weight, of the wearer without using the user's own muscles.

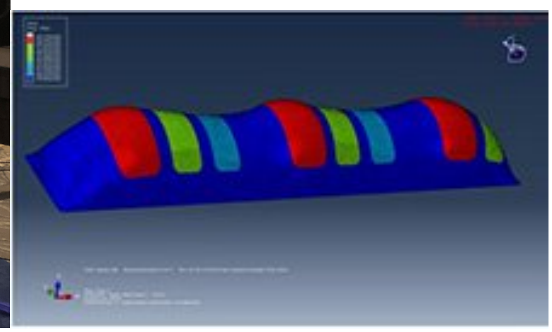
5. **Smart soft polymers and structures** - **Liwu Liu, Qinghua Guan, Jinrong Li, Yanju Liu, Jinsong Leng**, Harbin Institute of Technology (China)

These demonstrations were focus on the applications of smart soft polymers, including dielectric elastomer (DE), shape memory polymer (SMP) and other smart soft structures. The presentations included:



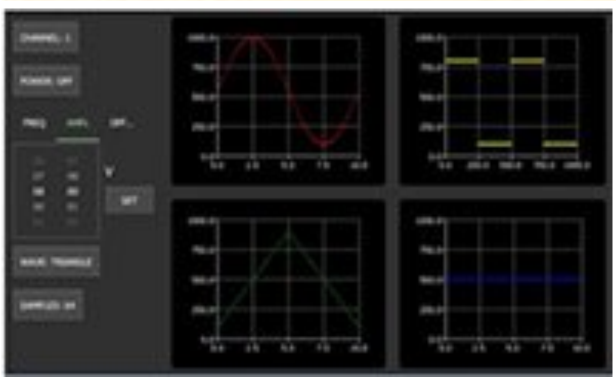
a. Biosignals controlled DE actuators - Biosignals are acquired, processed and then amplified to drive DE actuators.
b. Smart morphing structures based on DE and SMP: Structures may include deployable gripping devices or lock-release structures, etc.
c. Flexible pneumatic actuators. Multi-degree-of-freedom motions could be realized by combining multiple flexible pneumatic actuators together.
d. SMP based 4D printing technique. The 3D printable filaments with shape memory effect and some representative printed structures, which can change shape along with time, will be demonstrated.

6. **Inflatable dielectric elastomer conveyor - Joseph Ashby, E. -F. Markus Henke, Sam Rosset, Iain Anderson** , Biomimetics Laboratory (New Zealand)

This team presented an inflatable robot, created from a sheet of silicone and airbrushed electrodes, which uses out of phase segmented actuation to produce linear conveyance of a light load along its length. In addition, they presented the results of their finite element simulation of their model. This demonstration has potential application for inflatable dielectric robotics.

7. **High voltage EAP controller** - **E.-F. Markus Henke,**, Biomimetics Lab. (New Zealand) and TU Dresden (Germany), **Patrin Illenberger, Katie Wilson, Sam Rosset, Iain Anderson**, Biomimetics Laboratory (New Zealand)



This demo is a new EAP high voltage controller that is at a stage. This new controller is intended to help university labs and other research institutions to easily power their EAP actuators without the need of developing complicated driving electronics. It comes with four channels, a touch-screen user-interface, and is battery powered. The controller provides DC, rectangle, sinusoidal and triangle signals, with an amplitude having up to 5kV @ 1mA per channel. The Channels can be programmed independently.

8. **Geometric limit switches (gDES) for robotics and automation industry** - **E.-F. Markus Henke,**, Biomimetics Laboratory (New Zealand) and TU Dresden (Germany), **Patrin Illenberger, Katie Wilson, Sam Rosset, Iain Anderson**, Biomimetics Laboratory (New Zealand)


Geometric dielectric elastomer switches (gDES) have been demonstrated as a switch of both high and low voltages. They only consist of soft materials such as silicones and carbon-doped conductive silicones. Arrays of these switches can be integrated in soft robotic grippers and extend the features of those grippers by touch and shear force detection. Furthermore, gDES can act as limit switches and can be introduced in automation technology. One of the key advantages is that the switches themselves are entirely shielded and not affected by environmental influences.

9. **From StretchSense Ltd.: the latest in EAP gloves** - **Marco Tabor, Iain Anderson**, StretchSense Ltd. (New Zealand) (In the picture: Sam Rosset, Iain Anderson, Yuting Zhu)


StretchSense have demonstrated their putting EAP sensors into garments using fabric-backed sensors and combining information from different sensor types. To illustrate the technology, they presented an EAP glove that can capture and send in real-time hand-posture (rotation) and finger bending to a device with an application to visualize the data e.g. game.

10. **Synthetic Muscle in prosthetics** - **Lenore Rasmussen, Damaris Smith**, Ras Labs, Inc. (United States)



Ras Labs Synthetic Muscle™, which is an EAP based actuator that contracts, and with reversed electric input polarity, expand. Ras Labs has begun testing their EAP system on amputees to maintain continual perfect prosthetic socket fit and is going to present their prototype. These EAPs serve dual use as sensors, which can be tied in to automatic adjustment and touch biofeedback, and can determine the number of impacts (or steps) and severity of impact/pressure for protective gear and comfortable shoe wear and insoles

11. **Versatile dielectric loudspeakers** - **Florian Klug and Helmut F. Schlaak,** Technische University Darmstadt (Germany)

Electronic EAPs, such as the dielectric elastomer transducer, offer higher frequencies up to several kilohertz. This team presented an EAP loudspeaker. Due to their nonlinear behavior and high driving voltages, they suffer from poor audio quality and high costs. In this demonstration, the team presented a configuration for low cost, flexible or low distortion loudspeakers. Sound pressure levels higher than 100 dB with <10 kHz bandwidth and distortion < 2 % depending on the configuration, they can be adaptable to various shapes and produced with large surfaces.

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