PROCEEDINGS OF SPIE

Electroactive Polymer Actuators and Devices (EAPAD) 2016

Yoseph Bar-Cohen
Frédéric Vidal
Editors

21–24 March 2016
Las Vegas, Nevada, United States

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Published by
SPIE

Volume 9798

Proceedings of SPIE 0277-786X, V. 9798

Electroactive Polymer Actuators and Devices (EAPAD) 2016, edited by Yoseph Bar-Cohen, Proc. of SPIE Vol. 9798, 979801 · © 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2242836

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Author(s), "Title of Paper," in *Electroactive Polymer Actuators and Devices (EAPAD) 2016*, edited by Yoseph Bar-Cohen, Frédéric Vidal, Proceedings of SPIE Vol. 9798 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)
ISBN: 9781510600393

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.

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Contents

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

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Session Chairs

1 EAP as Emerging Actuators
Yoseph Bar-Cohen, Jet Propulsion Laboratory (United States)
Frédéric Vidal, Université de Cergy-Pontoise (France)

2 Celebrating the 10th Anniversary of the Dielectric Elastomer Minimum Energy Structures (DEMES)
Siegfried G. Bauer, Johannes Kepler University Linz (Austria)
Herbert R. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

3 Dielectric Elastomers
Elisabeth Smela, University of Maryland, College Park (United States)
Frédéric Vidal, Université de Cergy-Pontoise (France)

4 EAP Fabrication Techniques
Harold Park, Boston University (United States)
Aaron D. Price, Western University (Canada)

5 EAP Characterization
Rocco Vertechy, Universitá degli Studi di Bologna (Italy)
Reimund Gerhard, University of Potsdam (Germany)

6A Power Generation and Energy Harvesting
Jinsong Leng, Harbin Institute of Technology (China)
Marco Fontana, Scuola Superiore Sant'Anna (Italy)

6B Theoretical Modeling and Analysis
Jian Zhu, National University of Singapore (Singapore)
Vanessa Y. F. Leung, Universität Basel (Switzerland)

7A Ionic EAP Materials and Actuators I
Barbar J. Akle, Lebanese American University (Lebanon)
Richard J. Spontak, North Carolina State University (United States)

7B New EAP Materials, Processes, and Fabrication Techniques I
Edwin W. H. Jager, Linköping University (Sweden)
Lenore Rasmussen, Ras Laboratories, LLC (United States)

8A New EAP Materials, Processes, and Fabrication Techniques II
Hyacinthe Randriamahazaka, Université Paris 7-Denis Diderot (France)

8B Applications of EAP
Jonathan M. Rossiter, University of Bristol (United Kingdom)
Holger Böse, Fraunhofer-Institut für Silicatforschung (Germany)

9A Applications of EAP Materials to Robotics
Herbert R. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
Kwang Jin Kim, University of Nevada, Las Vegas (United States)

9B New EAP Materials, Processes, and Fabrication Techniques III
Adrian Koh, National University of Singapore (Singapore)
Yonas Tadesse, The University of Texas at Dallas (United States)

10A Ionic EAP Materials and Actuators II
Markus Henke, TU Dresden (Germany)
Thomas Wallmersperger, TU Dresden (Germany)

10B Haptic, Tactile, and Other Sensors
Kyle Van Volkinburg, University of California, Irvine (United States)
Miriam Biedermann, Fraunhofer-Institut für Angewandte Polymerforschung (Germany)

11A New EAP Materials, Processes, and Fabrication Techniques IV
Qibing Pei, University of California, Los Angeles (United States)
Frédéric Vidal, Université de Cergy-Pontoise (France)

Introduction

This SPIE Electroactive Polymers Actuators and Devices (EAPAD) conference is the leading international forum for presenting the latest progress and holding discussions among the attendees regarding the capabilities, challenges, and potential future directions. The conference this year was chaired by Yoseph Bar-Cohen, Jet Propulsion Laboratory/Caltech, and co-chaired by Frédéric Vidal, Université de Cergy-Pontoise (France), and it included 128 presentations.

The conference 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, the keynote speaker was Elisabeth Smela, University of Maryland, College Park (United States), and the title of her presentation was, "Nastic actuators." In her presentation, she covered the progress in developing actuators that are inspired by plants, namely the use of miniature hydraulic pumping mechanisms to deliver large forces and displacements. Devices are being developed using lamination of elastomer layers and encapsulating a fluid. Propylene carbonate has been demonstrated to be an effective fluid that does not generate gas bubbles. An example of an application that is being pursued is the development of smart stents with adjustable diameters. This topic was discussed at her presentation.

Overall, the presented papers reported the significant progress that was 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. This year, the special session was dedicated to "Celebrating the 10th Anniversary of the Dielectric Elastomer Minimum Energy Structures (DEMES)."

The efforts described in the presented papers are showing significant improvements in understanding the electromechanical principles and 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, 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. Interesting presentations include the invited paper by Markus Henke, and Iain A. Anderson, The University of Auckland (New Zealand) describing autonomous artificial muscle robots without electronics. Also, a team that was led by Federico Carpi, Queen Mary, University of London (United Kingdom) reported the formation of standards for dielectric elastomer transducers. The formation of standards for the field of EAP is an important step towards a wide commercialization of the technology.

This year, the conference included a half-day course about electroactive polymers, and the instructors were Yoseph Bar-Cohen, Jet Propulsion Laboratory/Caltech, Pasadena, California; John Madden, University of British Columbia, Vancouver, Canada; and Qibing Pei, University of California, Los Angeles. Also, an EAP-in-Action session was held and consisted of nine demonstrations with presenters from China, Germany, Great Britain, New Zealand, Singapore, Switzerland, and the United States.

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

Yoseph Bar-Cohen

THE 2016 EAP-IN-ACTION PROGRAM

Moderator:

Yoseph Bar-Cohen, Jet Propulsion Lab.

The 2016 EAP-in-Action Session highlighted some of the latest capabilities and applications of Electroactive Polymer (EAP) materials where the attendees were shown demonstrations of these materials in action (**Figure 1**). Also, 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 Arm-wrestling Contest was held in 2005 during this session. In 2017, another EAP robotic arm is expected to participate.

Figure 1: A view of the presenters and the participants of the 2016 EAP-in-Action Session.

The Session in 2016 included 9 demonstrations with presenters from China, Germany, Great Britain, New Zealand, Singapore, Switzerland, and USA. The presenters consisted of professors and their students as well as engineers from companies. The demonstrations included innovative devices and potential new products that are driven by EAP including (listed by the country of the leading presenters):

China

1. Tiefeng Li, Yuhan Xie, Guorui Li, Yiming Liang, Xuxu Yang, Yongbing Jin, Zhejiang University (China), **"**Soft robotics and smart SAM structures" (**Figure 2)** - In this demonstration, soft robotics and smart structures driven by dielectric elastomer were shown to produce large actuation, fast response and integrated actuation-sensing (**Figure 3**). The demonstrated materials

were thermally active tough hydrogel and the objective is to use them for bio-medical applications.

Figure 2: The team from Zhejiang University (China)

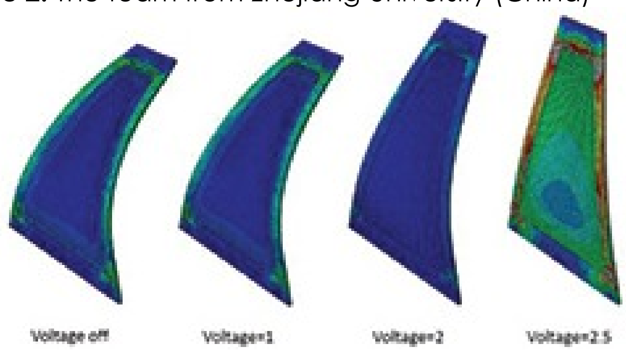


Figure 3: A model of a dielectric elastomer that produces large actuation, and fast response.

2. Liwu Liu, Jinrong Li, Fengfeng Li, Xiongfei Lv, Jinsong Leng, Harbin Institute of Technology (China), "Applications of smart polymers" (**Figure 4**) - This demonstration showed smart polymers in action taking advantage of their lightweight, fast response, and large deformation. These advantages make them attractive for applications in smart bionics, aerospace, biomedicine and other fields. The demonstration included application of shape memory polymer (SMP) and dielectric elastomer EAP as actuators and deployable structures (**Figure 5**).

Figure 4: The team from Harbin Institute of Technology (China). From left to right: Qingqing Lu, Liwu liu, Jialiang Tao and Xiongfei Lyu

Figure 5: Soft robot and soft gripping device based on DE Actuators

Germany

Steffen Hau, Alexander York, Saarland Univ. (Germany), **"**High force dielectric electroactive polymer (DEAP) membrane actuator**"**

(Figure 6) - Energy efficiency, lightweight and scalability are key features to actuation applications such as valves, pumps or any portable system. DEAP technology is able to fulfill the requirements better than commonly used technology e.g. solenoid, but it has limitations concerning force and stroke. This demo showed improvements that were made in increasing the force that is delivered by DEAP stack. Two different actuators were shown: The 1st lifted 10kg and the 2nd generate 66N force while acting against a spring load (**Figure 7**).

	
From left to right: Alexander York and Steffen Hau,	Stefan Seelecke

Figure 6: The team from Germany

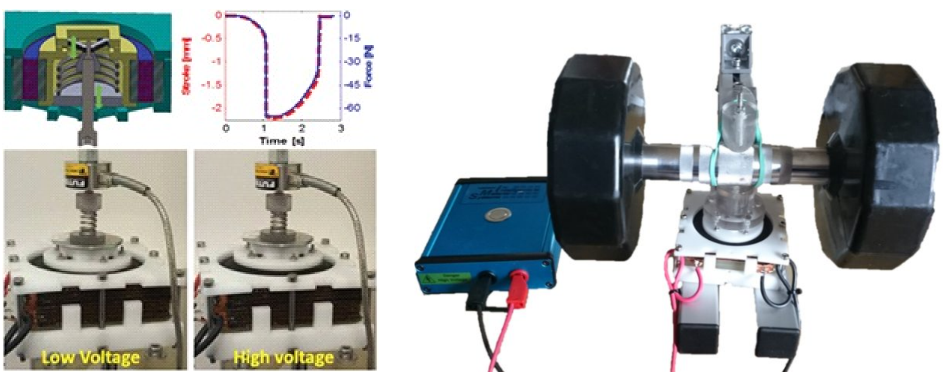


Figure 7: The two different DEAP actuators that were shown with an example of lifting 20 lbs.

New Zealand

Iain Anderson, Markus Henke, Patrin Illenberger, Andreas Tairych, Allan Veale, Chris Walker: "New technology from the Biomimetics Laboratory and StretchSense Ltd."

(Figure 8) - The Biomimetics Lab. and its spinout company StretchSense Ltd. demonstrated EAP soft autonomous robots, wearable sensors, and energy harvesters.

Figure 8: From left to right: Allan Veale, Chris Walker, Andy Tairych, Markus Henke, Iain Anderson, Antoni Harbuz and Patrin Illenberger (Biomimetics Lab. and StretchSense Ltd.)

The demos included:
1) Trevor the robot and Jule the Dragonfly – These EAP robots have no control electronics. By simply adding electric charge Trevor will crawl and Jule will flap her wings (**Figure 9**).
2) Wearable, stretch sensitive communication – An EAP glove for gesture-based communication and game control was demonstrated.
3) Wearable muscles with cyber-proprioception – Using soft wearable motion sensing, the team showed how to augment ones' strength and get machines to follow gesture based commands.
4) Generate electricity using EAP – The lab's spinoff company, Stretchsense, displayed an EAP starter kit that includes a polymer generator (that you squeeze) coupled to portable electrical charge management electronics.

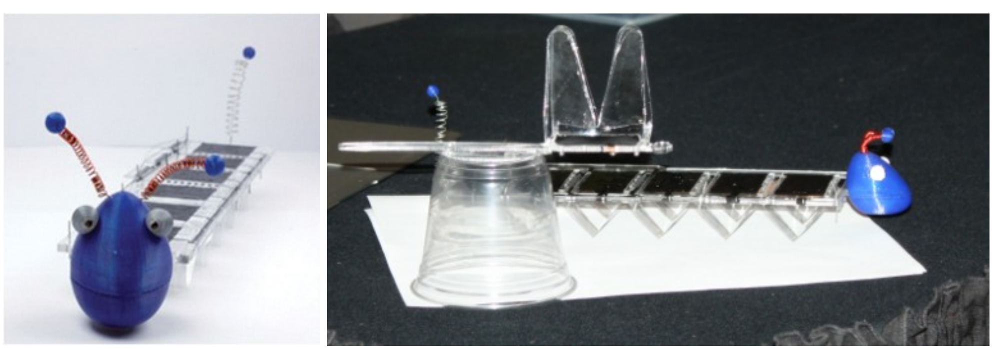


Figure 9: Trevor the robot

Singapore
Jian Zhu, Yuzhe Wang, Ujjaval Gupta, National Univ. of Singapore (Singapore), "Soft robots based on dielectric elastomer actuators"
(**Figure 10**) - Artificial muscles were developed to mimic natural masseter muscles (superficial portion), using dielectric elastomer actuators. Soft actuators were installed onto a robotic skull, and were shown moving the jaw and the mimicking natural muscles' displacement and velocity. Also, a worm-like robot driven by a dielectric elastomer actuator was shown (**Figure 11**).

Figure 10: The team from National University of Singapore.

Figure 11: A demo and a video that were shown by the National University of Singapore.

Singapore and Great Britain
Koh Soo Jin Adrian, Stoyan Smoukov*, Ang Marcelo H. Jr., Vy Khanh Vo Tran, Tan Hiok Yang, Christopher Tan, Zhang Jie, I-Ting Lin, and Tiesheng Wang, National University of Singapore (NUS) and Cambridge University, "An arm for the Arm-wrestling contest"
(Figure 12) – Capabilities that are going to be used to produce an antagonistic system of a wrestling arm were described and shown. The concept of driving the arm is the use of a pair of elastomers that work against each other are attached to a disc that forms the "shoulder" of the artificial arm, via (ideally) inextensible cords. Both elastomers are pre-tensioned by mechanical stretching. A wrestling arm is under development for potential demonstration at the 2017 EAP-in-Action Session.

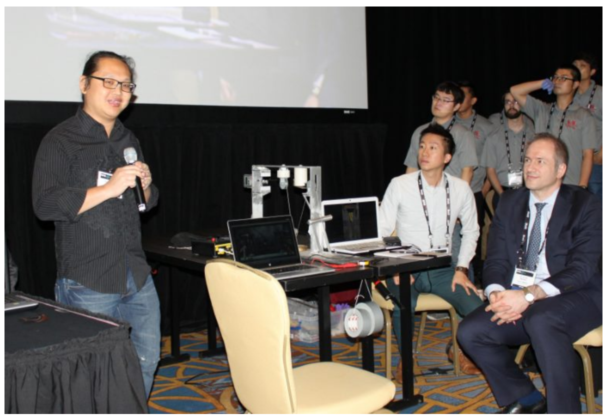
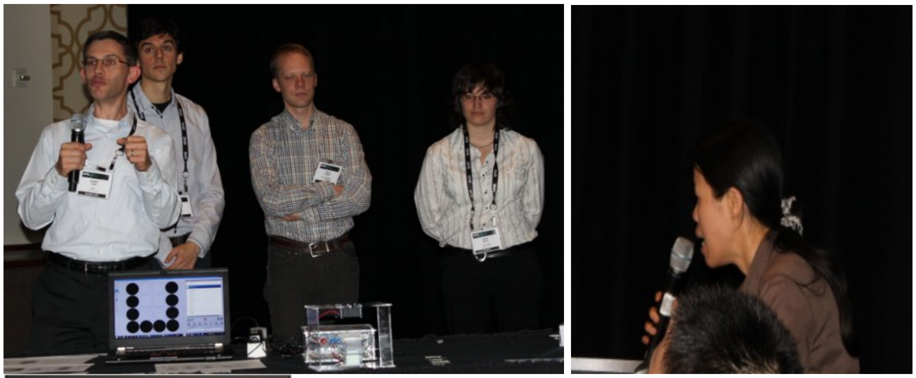


Figure 12: Koh Soo Jin Adrian, National University of Singapore (NUS) on the left and Stoyan Smoukov, Cambridge University, on the right describing their arm-wrestling EAP actuator

Switzerland
Nadine Besse, Samuel Rosset, Alexandre Poulin, and Herbert Shea, Ecole Polytechnique Fédérale de Lausanne (EPFL) (Switzerland), "Tactile display based on shape memory polymers"
(**Figure 13**) - A fully latching and scalable 4x4 tactile display was demonstrated to have 300 mN holding force and 300 μm motion per taxel (tactile pixel). The device, which is intended to provide graphical information to visually impaired users, consists of a shape memory polymer membrane, a compliant integrated heater per taxel, and a single common pneumatic actuation mechanism. Each taxel is individually addressable and the entire display can be refreshed in 5 seconds (**Figure 14**).



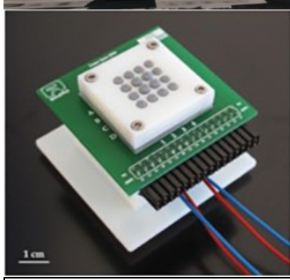


Figure 13: From left to right: Herbert Shea, Alexandre Poulin, Samuel Rosset, Nadine Besse and Vanessa Leung	**Figure 14:** The fully latching and scalable 4x4 tactile display

<u>United States</u>

1. Qi Shen, Sarah Trabia, Tyler Stalbaum, Choonhan Lee, Robert Hunt, and Kwang Kim, Univ. of Nevada, Las Vegas (United States), "Shape memory programmable and electrically controllable IPMC"
   (**Figure 15** and **Figure 16**) - Recently, the UNLV team successfully demonstrated an ionic polymer-metal composite (IPMC) actuator, having multiple-shape memory by two external inputs, electrical and thermal. This demonstration introduces a soft multiple-shape-memory IPMC actuator having multiple degree-of-freedoms that exhibited high maneuverability when controlled by two external inputs, allowing complex motions that are routine in nature.

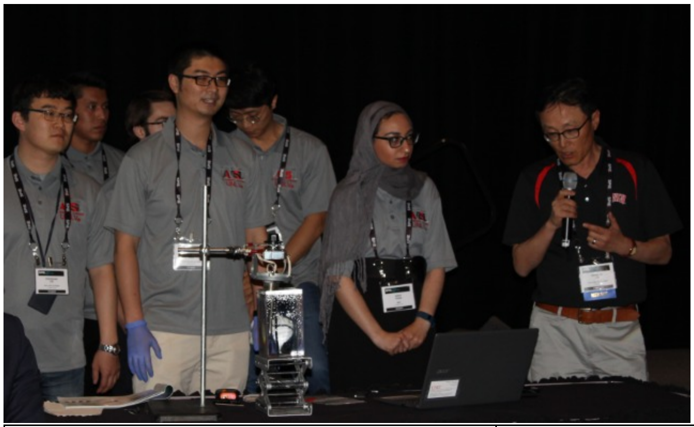


Figure 15: The team from the University of Nevada, Las Vegas (United States)	**Figure 16:** Shape memory programmable and electrically controllable IPMC

2. Lenore Rasmussen, Eric Sandberg, Leila Albers, Simone Rodriguez, Ras Labs., "Synthetic Muscle™: shape-morphing EAP based materials and actuators" (**Figure 17**) - EAP materials that contract upon activation and expand under a reversed electric input has been shown. A thin shape-morphing film of the material in the expansion mode produces raised surface zones in desired shapes. A thick shape-morphing pad can controllably contract or expand, which are being used to prototype self-adjusting prosthetic socket liners and other void-filling continual-fit applications. These EAPs can serve as sensors, which can be tied to biofeedback, and communicate impact and pressure. The material is currently being tested for radiation resistance on the International Space Center (ISS) (see **Figure 18**).

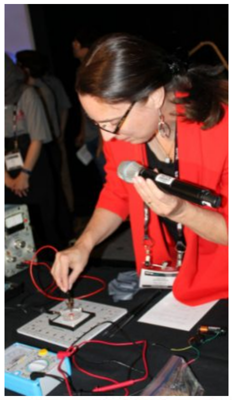


Figure 17: Lenore Rasmussen, Ras Labs.	**Figure 18: The** Synthetic Muscle™ that is on the ISS.