

# WorldWide ElectroActive Polymers



# EAP

## (Artificial Muscles) Newsletter

Vol. 14, No. 1 (27<sup>th</sup> issue)

WW-EAP Newsletter  
<http://eap.jpl.nasa.gov>

June 2012

### FROM THE EDITOR

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Parallel to the development in the field of Electroactive Polymers (EAP) there has been enormous research and development growth in the field of biomimetics. Today, there is significant number of conferences and journals that are dedicated to the latter. Among these Conferences, in March the first one was held as part of the SPIE Smart Structures Symposium in San Diego, California. Further, in the last two years individuals who are involved with the development of a biomimetic program at the San Diego Zoo gave lectures and live show of animals at part of the SPIE Smart Structures Symposium. On March 12 this year, during their Plenary Paper presentation, an owl was shown and described (**Figure 1**).

Since EAP, named as artificial muscles, is viewed as part of the field of biomimetics, the Editor of this Newsletter is increasingly including inputs related to biologically inspired technologies.

### GENERAL NEWS

The WW-EAP Webhub <http://eap.jpl.nasa.gov> is continually 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>



**Figure 1:** Sunni Robertson, Education Department, San Diego Zoo, is showing an owl as part of the plenary presentation about biomimetics.

### About the experts

In March 2012, Keiichi Kaneto has retired from the Kyushu Institute of Technology, Japan, after extensive career in developing EAP materials. Prior to retiring, his research and development has focused on EAP, Soft Actuator, Organic Molecular Devices, Optical and Electrical Properties of Organic Molecules, Electrochemistry of Conducting Polymer, and Organic transistors. After obtaining his PhD in Engineering at Osaka University, he became an Associate professor at the Faculty of Engineering of the same university. In April 1988,

he joined as a full professor the Faculty of Computer Science and Systems Engineering, at the Kyushu Institute of Technology. As part of his career, he spent several years as visiting researcher at the University of Pennsylvania and at the CEA in Grenoble. Before he retired, he worked as a Professor at the Graduate School of the Life Science and Systems Engineering, Kyushu Institute of Technology, Japan. It is interesting to note that Keiichi Kaneto co-chaired the SPIE EAPAD 2012 Conference that was held at San Diego, CA, in March this year.



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## UPCOMING CONFERENCES

### 2013 SPIE EAPAD Conference

The 15<sup>th</sup> SPIE's EAPAD conference is going to be held March 10-14, 2012, in San Diego, California.

This Conference will be chaired by Yoseph Bar-Cohen, JPL, and Co-chaired by Siegfried Bauer, Johannes Kepler University Austria. The Conference Program Committee is consisted of representatives from 26 countries. The call for abstracts has been issued and can be found at <http://spie.org/ssn02> and <http://spie.org/eap> The submittal of abstracts is due on August 27, 2013.

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

At the EAPAD 2013, the Keynote Speaker is going to be Larry Howell, Brigham Young University, and he will cover the subject of Compliant Mechanisms. Also, two Special Sessions are planned including "Electro-chemo-mechanical actuators and mechano-chemo-electrical sensors" with Invited Paper by Toribio Otero, Spain; and "Actuator for soft robotic and biomedical applications".

As in past years, a course will be given on Sunday, March 10, and the EAP-in-Action Session will be held on Monday, March 11, 2013.

### 7th World Congress on Biomimetics, Artificial Muscles and Nano-Bio (BAMN2013)

The 7th World Congress on Biomimetics, Artificial Muscles and Nano-Bio (BAMN2013) is going to be held on August 26-30, 2013 at Jeju Island, South Korea. This is a biannual conference that is held at different countries all over the world. The island Jeju is a UNESCO Heritage of Nature and one of New 7 Wonders of Nature (<http://www.n7w.com>).

The aim of this congress is to offer high-level lectures, extensive discussions and communications covering the state of the art on biomimetics, artificial muscles, and nano- & bio-materials including potential applications to industrial, biomedical and robotic fields. This conference is a platform for a dialogue between researchers from different areas including chemistry, physics, biology, medicine, engineering, robotics, etc.

The Conference is chaired by Il-Kwon Oh, Korea Advanced Institute of Science and Technology (KAIST), Korea. Information about this conference is provided at <http://www.bamn2013.org>.

#### **4th International Conference on Smart Materials and Nanotechnology in Engineering (SMN)**

From July 10 to 12, 2013, the 4th International Conference on Smart Materials and Nanotechnology in Engineering (SMN) is going to be held at Gold Coast, Australia. The conference is chaired by Jinsong Leng, Harbin Instituted of Technology, China; and Jayantha Epaarachchi, University of Southern Queensland, Australia. The conference will focus on smart materials and structure, and nanotechnology for different engineering applications ranging from nano-structural and biosensor systems to large scale structures, including smart wind turbine technology and solar energy systems for space vehicles. The conference is seeking to address the growing interest in designing materials with multi-functionality in the form of smart structures. These include magnetically-changed materials, "memory" molecules that return to their original form, and materials that generate an electric charge when pressed, twisted, or warped. Smart structures that are incorporated with sensor system can be used for aerospace, civil and mechanical engineering and other applications. Since the last decade, a significant growth took place in the development of miniature structures and systems, particularly on micro and nano electromechanical systems (MEMS and NEMs). Also, integrated biosensor systems have opened new page in the era of smart materials and nanotechnology.

Information about this conference is available at: <http://www.a-tech.hk/SMN%202013/index.html>

#### **ICEP-2012 – The 5<sup>th</sup> international Conf. on EAP in India**

From Nov. 4 thru 9, 2012, the Indian Society of Electroactive Polymer, and the Materials Research Development Fund and Department of Physics,

Banaras Hindu University, are going to hold the 5th biennial international EAP: Materials and Devices (ICEP-2012) Conf. The conference is going to be held at the Banaras Hindu University, Varanasi, India (**Figure 2**). The previous four conferences were held at Dalhousie (Nov. 2004), Goa (Feb. 2007), Jaipur (Oct 2008) and Surajkund (Nov. 2010).

The objective of the conference is to provide a discussion forum on Electroactive Polymers: Materials and Devices. The Conference will cover the following topics: Electron conducting polymers, Ion conducting polymers, Ferroelectric and ferromagnetic Polymers, Polymeric Actuators / Artificial Muscles, Polymeric Energy Storage / Generation Systems, Liquid crystalline polymers, Biopolymers and biological membranes, Nanopolymers, Polymer-nano composites, Supramolecules and Molecular Electronics.



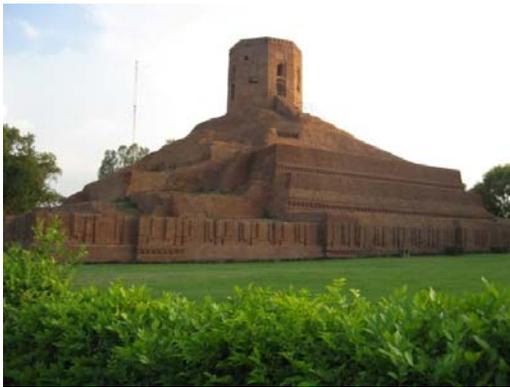
**Figure 2:** Banaras Hindu University, Varanasi.

The Banaras Hindu University, Varanasi, India, is the largest university campus in India, and Varanasi is Buddhism's holy city and it is believed to be the world oldest living city. It has several famous cultural/religious centers, and it is a major tourist destination and pilgrimage center of Buddhists. Boating in the Ganges River (**Figure 3**) offers a view of the panoramic old "Ghats" with glimpses of traditional Indian culture. It consist of narrow walkways and temples of the old city (**Figure 4**) providing a memorable experience. Varanasi is famous for silk, hand-woven carpets and handicrafts. In November, the weather is generally very pleasant and the temperature around 25-30°C.

Further details about the Conference can be seen at [www.icep2012.org](http://www.icep2012.org)



**Figure 3:** Ganga Arti Darshan on the bank of Ganges River, Varanasi.



**Figure 4:** Famous Buddhist Stupa at Sarnath, Varanasi where Buddha is believed to have delivered his first sermon.

## RECENT CONFERENCES

### 2012 SPIE EAPAD Conference

The 14<sup>th</sup> SPIE's EAPAD conference was held in San Diego, California from March 11 to 15, 2012. The Chair of this Conference was Yoseph Bar-Cohen, JPL, and the Co-chair Keiichi Kaneto, Kyushu Institute of Technology, Japan. The Conference Program Committee consisted of representatives from 26 countries.

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

was dedicated to the subject of "EAP Actuated Medical and Tactile Devices".

The conference was opened with two Keynote presentations:

- Jeff Corsiglia (**Figure 5**), Vice President of Spin Master (<http://www.spinmaster.com/>), who talked about actuation of toys and potential applications for artificial muscles.
- John Rogers (**Figure 6**), who is the Lee J. Flory-Founder Chair in Engineering and a Professor at University of Illinois at Urbana/Champaign, talked about stretchable electronics through soft lithography.



**Figure 5:** The keynote speaker, Jeff Corsiglia, talked about actuation of toys and potential applications for artificial muscles.



**Figure 6:** The keynote speaker, John Rogers, talked about stretchable electronics through soft lithography.

The invited papers were as follows:

- “Multi-functional soft smart materials and their applications,” Jinsong Leng, Harbin Institute of Technology (China)
- “Actuators, biomedicine, and cell biology,” Edwin W. H. Jager, Linköping Univ. (Sweden)
- “Applications of scanned pipette techniques for the highly localized electrochemical fabrication and characterization of conducting polymers,” Jadranka Travas-Sejdic, The Univ. of Auckland (New Zealand)
- “Patterning process and actuation in open air of micro-beam actuator based on conducting IPNs,” Cedric Plesse, Univ. de Cergy-Pontoise (France); Alexandre Khaldi, Univ. de Valenciennes et du Hainaut-Cambrésis (France); Ali Maziz, Univ. de Cergy-Pontoise (France); Caroline Soyer, Univ. de Valenciennes et du Hainaut-Cambrésis (France); Claude Chevrot, Dominique Teyssie, Frederic Vidal, Univ. de Cergy-Pontoise (France); Eric Cattan, Univ. de Valenciennes et du Hainaut-Cambrésis (France)
- “Giant torsional actuation from carbon nanotube yarns,” Javad Foroughi, Geoffrey M. Spinks, Gordon Wallace, Univ. of Wollongong (Australia); Jiyoung Oh, Mikhail E. Kozlov, Shaoli Fang, The Univ. of Texas at Dallas (United States); John D. Madden, Univ. of British Columbia (Canada); Tissaphern Mirfakhrai, Stanford Univ. (United States); Min Kyoon Shin, Seon Jeong Kim, Hanyang Univ. (Korea, Republic of); Ray H. Baughman, The Univ. of Texas at Dallas (United States)
- “Ionic EAP transducers with amorphous nanoporous carbon electrodes,” Friedrich Kaasik, Janno Torop, Inga Põldsalu, Indrek Must, Alvo Aabloo, Univ. of Tartu (Estonia)
- “Compliant electrodes for large strain actuation,” Sungryul Yun, Qibing Pei, Univ. of California, Los Angeles (United States)
- “Electroactive polymer based force sensor for robotic fingertip tactile sensing,” Baek-chul Kim, Hogyun Won, Y. Lee, Jae-Do Nam, Hyungpil Moon, Hyouk Ryeol Choi, Ja Choon Koo, Sungkyunkwan Univ. (Korea, Republic of)

- “Macro-, micro-, and nano-actuators based on liquid crystal elastomers: a bottom-up molecular design,” Patrick Keller, Min-Hui Li, Institute Curie (France)

The EAP-in-Action Session was held on Monday, March 12, 2012, and it included 9 demonstrations of the latest EAP materials, their capability, and potential for smart structures. The presentations were as follows:

### Australia and Canada

1. Geoffrey M. Spinks, University of Wollongong, Australia (**Figure 7**); and John D.W. Madden, University of British Columbia, Canada, presented “Carbon Nanotube Torsional Muscles” - This demo consisted of a rapid rotation of a plastic paddle in air driven by carbon nanotube yarn. The torsional muscle operates with part of the yarn immersed in a liquid electrolyte that is electrochemically charged by application of a small voltage. The charging of the yarn causes the yarn to partially untwist and produce rotation of the attached paddle. Discharging the yarn causes it to re-twist. The demonstration illustrated the very rapid and large rotations achievable in these simple actuator systems.



**Figure 7:** Geoff Spinks, University of Wollongong, is demonstrating Carbon Nanotube Torsional Muscles.

## France

2. Philippe Jean, Guillaume Ardoise, Ambroise Watez, SBM Offshore, (**Figure 8**) presented “Standing Wave Tube Electro Active Polymer Wave Energy Converter”. This presentation included the SBM Offshore development of a flexible EAP based Wave Energy Converter. This system consists of large EAP ring generators made of a flexible tube that are intended to be placed underwater to directly convert wave energy into high voltage DC electrical power. Large EAP ring generators having 800mm diameter with multiple layers were displayed. Also, videos of wave tank model tests were shown.



**Figure 8:** Philippe Jean (on the left) is presenting the SBM Offshore most recent development of EAP based system of energy harvesting. From left to right: Ambroise Watez, Guillaume Ardoise, and Philippe Jean.

## New Zealand

3. Iain Anderson, Emilio Calius, Todd Gisby, Andrew Lo, Thomas McKay, Ben O’Brien (**Figure 9**), Biomimetics Laboratory, Auckland Bioengineering Institute, Auckland, New Zealand, presented Dielectric elastomer (DE) technology for self-sensing, portable energy harvesting and product development. Their set of demonstrations included.



**Figure 9:** The presenters from the Biomimetics Laboratory, Auckland Bioengineering Institute, Auckland, New Zealand. From left to right: Ho Cheong (Andrew) Lo, Tom McKay, Todd Gisby, Ben O’Brien, and Iain Anderson.

- a. *Cyber-proprioception and cyber-pain:* Like natural muscles, DE-based artificial muscles can now provide in real time both positional feedback (cyber-proprioception) and condition-monitoring information (cyber-pain). These capabilities, essential for the control and performance of soft machines, were demonstrated using the lab’s Self-Sensing Unit coupled to a DE actuator.
- b. *A hand-held dielectric elastomer generator:* DE can be used to extract useful low voltage power from human movement. This was demonstrated using a device that can be held in one hand
- c. *The four channel Artificial Muscle Control Unit:* This stand-alone portable laboratory instrument simplifies the generation and control of high voltages for artificial muscle research. Features include 4 independent output channels, computer control, battery operation, and safety features that make it suitable for bench-top use.

## Switzerland

4. Samuel Rosset, Luc Maffli, Samin Akbari, B. O’Brien, Herbert R. Shea, EPFL-LMTS, Switzerland, (**Figure 10**) presented a demo of “Miniaturized EAPs based on Ion-implanted compliant electrodes: mm-size pumps, motors,

and robots.” Several miniaturized dielectric elastomer devices were demonstrated. By using metal ion-implantation compliant electrodes can be made with features as small as 50  $\mu\text{m}$ . The developed devices included micropumps, rolling robots, rotary motors, and cell-stretchers.



**Figure 10:** The presenters from the EPFL-LMETS, Switzerland. From right to left: Herbert Shea, Samuel Rosset, Luc Maffli, and Samin Akbari.

5. Pit Gebbers (EPFL/ZHAW), Optotune Inc., (**Figure 11**) presented “A Laser Speckle Reducer” actuated by DEAs. The actuators cause a diffuser to perform in-plane, resonant movements. When a laser beam is directed through the moving diffuser, its speckle noise is significantly reduced by averaging the local interferences. The demonstrated device is significantly smaller and less expensive to produce than the commercial ones.



**Figure 11:** Pit Gebbers, EPFL/ZHAW, Optotune Inc., presenting a demo of a laser speckle reducer.

## USA

6. Andy Cheng and S. James Biggs (**Figure 12**), Artificial Muscle, Inc., a Bayer Material Science Company, California, presented a demo of

“Feel the game’ with ViviTouch™ Technology”. This demo consisted of the latest ViviTouch haptic actuators integrated into consumer products for “high definition feel” in Mobile and Gaming applications.



**Figure 12:** S. James Biggs, Artificial Muscle, Inc., presenting the company latest product that is a haptic attachment of smart phones.

7. Xiaofan Niu, Paul Brochu, Sungryul Yun, Zhibin Yu, Qibing Pei (**Figure 13**) UCLA, “Improved bistable electroactive polymers (BSEP) and refreshable Braille display devices,” This demo is bistable EAP actuators with significantly improved actuation performance, and refreshable Braille display device consisting of 1 to 4x10 cells.



**Figure 13:** Qibing Pei and his student, Xiaofan Niu, presenting their improved bistable EAP (BSEP) and a refreshable Braille display device.

8. Eugene Dariush Daneshvar<sup>1</sup> (**Figure 14**), Elisabeth Smela<sup>2</sup>, Daryl Kipke<sup>1</sup>

<sup>1</sup>Department of Biomedical Engineering, University of Michigan, Ann Arbor, MI, USA

<sup>2</sup>Department of Mechanical Engineering, University of Maryland, College Park, MD

The presentation was entitled “Articulating Neural Interfaces” and covered articulating neural interfaces that can guide the trajectory as well as the proximity of electrode sites to neural tissues.



**Figure 14:** Eugene Daneshvar presenting a demo of articulating neural interfaces.

9. Shihai Zhang (**Figure 15**), Qiming Zhang and Ralph Russo, Strategic Polymer Sciences, Inc. presented “Haptics based on EAP actuators” - A high definition localized smartphone haptics device was demonstrated using EAP actuators. The actuator provides sharp and concentrated multi-touch HD haptic feedback. It is driven by voltage below 200 V allowing its activation by low cost miniature power supply.



**Figure 15:** Shihai Zhang, Strategic Polymer Sciences, Inc, presenting a haptics device using EAP actuators

## Workshop on Compliant Mechanisms for Space

From April 30 to May 1, NASA’s Jet Propulsion Laboratory (JPL) held a workshop on “Compliant Mechanisms for Space Applications” (**Figure 16**). More than 20 professors and JPL researchers got together to explore future opportunities in this field of flexible multi-functional devices. Brian Trease, JPL, hosted the event at the JPL’s “Left Field” facility, a creative environment designed to enable brainstorming and rapid exchange of innovative ideas.

Based on the paradigm of *strong and compliant*, “Compliant Mechanisms” (CMs) stem from more than 15 years of academic research that combines structure, mechanism, actuation, materials, optimization, and bio-inspiration. CMs are often defined as moveable mechanical structures that achieve their desired motion, force, or displacement by means of the deflection of flexible members and can perform a necessary function. Advantages over traditional mechanisms can include increased performance through *reduced weight, increased precision, reduced friction, elimination of lubricants, ease of miniaturization, and integration of functions* into fewer components, all leading to reduced complexity.

Participants included 11 academics from across the country, including 3 authors of textbooks on flexures and CMs. Professors presented on topics covering flexures, precision, kinematic synthesis, bio-inspiration, smart-material actuation, MEMS, and novel robotics (**Figure 17 and 18**). JPL’ers responded in turn with presentations on the unique challenges of designing mechanisms for spaceflight and the latest NASA developments in fabrication technologies, advanced metallurgy, and MEMS applications. In addition, Yosi Bar-Cohen, JPL, presented a summary on bio-inspired actuator and mechanisms, while Andrew Klesh, JPL, introduced the growing field of Cubesats: 10x10x10cm satellites that offer an unprecedented platform for demonstration of early development technologies in real space environments.

During breakout groups, many applications and challenge areas were found in four key topics: deployable structures, precision instruments,

robotics, and multifunctional materials. Both communities expressed a common interest in developing friendly design tools for ongoing work in CMs.

This workshop was sponsored by JPL's Center for Academic Partnerships.



**Figure 16:** Brian Trease opening the workshop on Compliant Mechanisms for Space Mechanisms at JPL.



**Figure 17:** Craig Lusk (U. of South Florida) presenting on morphable compliant surfaces.



**Figure 18:** Jonathan Hopkins (LLNL post-doc) introducing design tools for synthesis of compliant mechanisms.

## EuroEAP 2012 conference

*Federico Carpi, University of Pisa, Italy*

On May 29 to 30, the EuroEAP 2012 that is the Second international conference on Electromechanically Active Polymer (EAP)

transducers & artificial muscles ([www.euroeap.eu/conference](http://www.euroeap.eu/conference)) took place in Potsdam (Berlin), Germany. The conference was chaired by Reimund Gerhard, University of Potsdam, Germany, and was organized by the 'European Scientific Network for Artificial Muscles - ESNAM' ([www.esnam.eu](http://www.esnam.eu)). The event was attended by more than 120 delegates and a photo of some of the attendees is shown in **Figure 19**. The technical program and conference proceedings are available at [www.euroeap.eu/conference](http://www.euroeap.eu/conference).



**Figure 19:** Attendees of the EuroEAP 2012

The invited speakers in this Conference were Ray Baughman (University of Texas at Dallas, USA), Gerhard M. Sessler (Darmstadt University of Technology, Germany), Eiichi Fukada (Kobayasi Institute of Physical Research, Kokubunji, Tokyo, Japan), Kinji Asaka (AIST, Japan), Iain Anderson (University of Auckland, New Zealand), Yoshiro Tajitsu (Kansai University, Japan), Jim Giger (Optotune, Switzerland), and Jadranka Travas-Sejdic (University of Auckland, New Zealand).

During the event, in an informal ceremony and friendly atmosphere, the following three scientists were awarded by the ESNAM network: Ray Baughman for his pioneering work and fundamental scientific contributions to the field of Artificial Muscles based on Conjugated Polymers and Carbon Nanotubes; Gerhard M. Sessler for a long-standing career and his pioneering work to the field of electrets' physics and applications to electro-mechanical devices; and Eiichi Fukada for a long-standing career and his pioneering work to the field of the piezoelectricity of biopolymers. Photos that

were taken during the conference can be seen at [www.euroeap.eu/conference](http://www.euroeap.eu/conference).

The next edition, EuroEAP 2013, will be held in Zurich, Switzerland, on 25-26 June 2013 and will be chaired by Gabor Kovacs from EMPA. Detailed information will be made available at [www.euroeap.eu/conference](http://www.euroeap.eu/conference).

## ADVANCES IN EAP

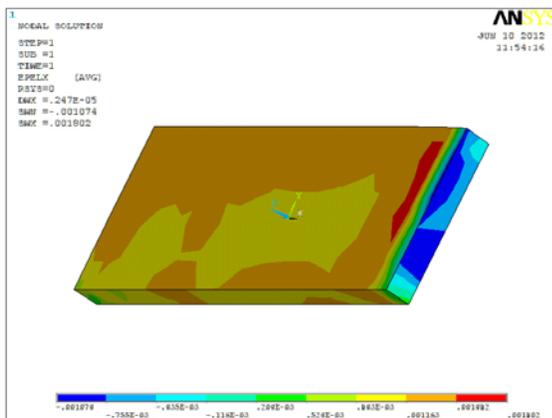
### Aerospace Engineering-Propulsion

#### Modeling DEA Compressor for Gas Turbine Engines by ANSYS

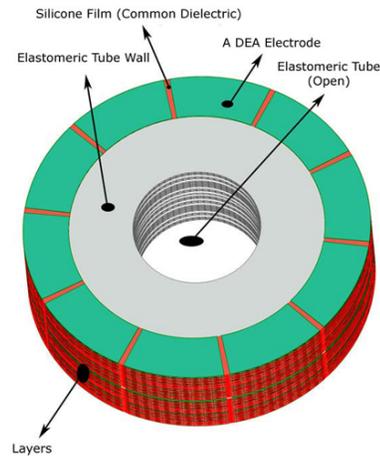
Babak Aryana (Independent Researcher)

[Babak.Aryana@Gmail.com](mailto:Babak.Aryana@Gmail.com)

Enhancing the previous work [1], the author worked on developing a computer model of DEA compressor using the finite element modeling tool ANSYS [2]. This way, he attempted to model the experimental results that he reported in [3] for Silicone Actuators. As the first steps, a sample of Silicone with characteristic similar to [3] was modeled to compare the results with experiment (**Figure 20**). Drawing out a suitable modeling specification, the second step was to model a ring (**Figure 21**) that guides the process to model a cell (**Figure 22**). The main aim of this step is to simulate the work process of a DEA compressor cell (**Figure 22**) and evaluate its performance.

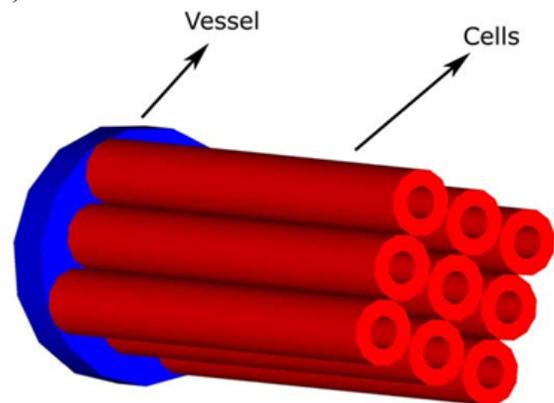


**Figure 20:** Analysis of total mechanical strain of a specimen constructed from Silicone polymer under electric field done by ANSYS Mechanical APDL.



**Figure 21:** A ring encompassing tube schematically depicted by its sections at switch on (Tube open)

The analysis by ANSYS required the use of the Multiphysics package and coupled field analysis. Selecting mesh method and other analysis specification is crucial to achieve acceptable results. Time pacing is important to model the compressor operation. Inflating the vessel (**Figure 22**) needs to be done in 1/50 second and then for the compressor with characteristic designed in [3] each ring needs 200/11 microseconds to pulse (time to open and close).



**Figure 22:** DEA compressor schematically indicated by two major parts.

Additionally, simulating air compression procedure was carried out by FLUENT package of ANSYS. A complete modeling reveals the airflow characteristic in different position of the compressor and change of swallowing process characteristics like frequency of rings pulse that influence rate of compressed airflow and should be assessed as well.

As a result, dynamics of the compressor modeling would be a challenging process.

Completing such a modeling process, assessment of DEA compressor can be done more dependably, which pushes the research a step forward to make first mockup of the DEA Compressor.

### References

1. Babak Aryana, "DEA Compressor for Gas Turbine Engines", WW-EAP Newsletter (NASA JPL lab) - Vol. 13, No. 1, June 2011 (The 25th issue) pages 9-10: [http://ndea.jpl.nasa.gov/nasa-nde/newsltr/WW-EAP\\_Newsletter13-1.pdf](http://ndea.jpl.nasa.gov/nasa-nde/newsltr/WW-EAP_Newsletter13-1.pdf)
2. Babak Aryana, "Implementing DEA to Create a Novel Type of Compressor", Materials Science and Engineering C 30 (2010) 42–49, doi: <http://dx.doi.org/10.1016/j.msec.2009.08.007>
3. Guggi Kofod, "Dielectric elastomer actuators", The Technical University of Denmark, Ph.D. thesis, September 2001.

### Artificial Muscles, Inc.

**ViviTouch<sup>®</sup> – Now Bringing a New Dimension to the Sound and Listening Experience**

Andy Cheng [andy.cheng@artificialmuscle.com](mailto:andy.cheng@artificialmuscle.com)

After launching the ViviTouch<sup>®</sup> product last summer, Artificial Muscle Inc. (AMI)\* a Bayer MaterialScience company is now applying EAP in a brand new way to the portable audio category. Rather than amplify what you hear, headphones using ViviTouch<sup>®</sup> actuators will amplify the experience of hearing (**Figure 23**). This cinematic experience bridges the senses of seeing, hearing and feeling for games, music and movies. By leveraging the sensitivity around the ears, the technology creates an augmented stimulation without pushing the actual volume to potentially harmful levels. The first headphone product that features the use of ViviTouch<sup>®</sup> actuators will arrive later this year and more information about it will be made available in the coming months.

\* Artificial Muscle, Inc. is a Silicon Valley-based company that designs and manufactures actuator and sensing components based on EAP. In haptics, ViviTouch<sup>®</sup> actuators bring High Definition feel to a world of High Definition audio and video. In audio, ViviTouch<sup>®</sup> actuators can make sounds come alive by amplifying the experience of hearing, not just what you hear. Visit [ViviTouch.com](http://ViviTouch.com) to learn more.



**Figure 23:** The new headphones using ViviTouch<sup>®</sup> actuators.

### Meggitt Sensing Systems, Denmark

**Highly active flexible piezoelectric material with ultra-low acoustic impedance**

Konstantin Astafiev

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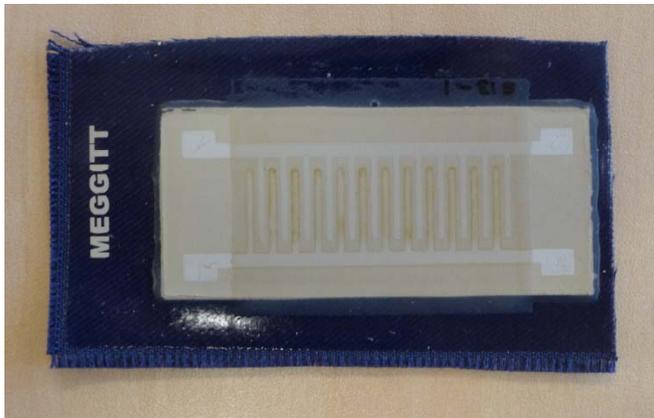
A new flexible piezoelectric material, PiezoPaint<sup>™</sup>, has been developed by MEGGITT. Key features of the material are compatibility with flexible substrates, including textile, plastic, paper, and ability to be applied to large areas (**Figure 24: Example of motion sensor printed on textile.**). PiezoPaint<sup>™</sup> is compatible with most of the commercial printing techniques available, including pad-, screen-, and stencil printing techniques and requires very low temperatures for curing (< 100 °C).

Nowadays, there are a number of piezoelectric polymer materials available (e.g. polyvinylidene fluoride family materials) that can be incorporated

into textile or deposited onto large areas. However, such polymer materials typically show relatively low piezoelectric activity, high production cost, and other technological problems such as limited suitability for commercially available printing techniques.

In addition to having significantly higher sensitivity than PVDF-type polymer materials ( $d_{33}$  is more than 40 pC/N), the PiezoPaint™ material has very low acoustic impedance and therefore can be used in underwater acoustics and other applications, where the acoustical matching is critical. PiezoPaint™ is also available in a lead-free version.

Thanks to the specific manufacturing technique developed, PiezoPaint™ combines high piezoelectric activity, flexibility in the cured state, and compatibility with most of the commercially available printing techniques. This opens new opportunities for the next generation of devices, including MEMS, for applications in a wide variety of fields, such as safety, health, non-destructive testing, structural health monitoring, and underwater acoustics.



**Figure 24:** Example of motion sensor printed on textile.

## Fraunhofer Institute, Germany

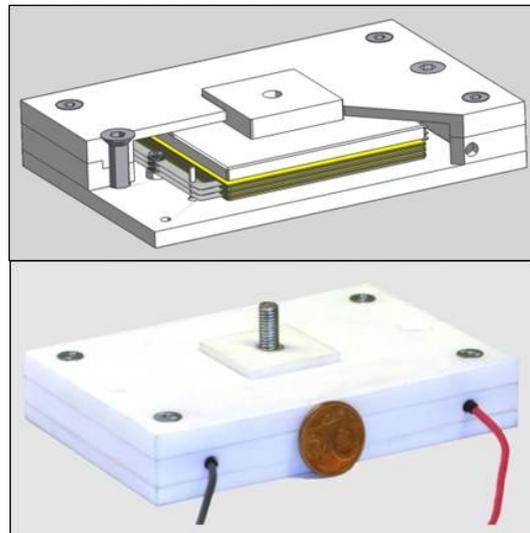
### Artificial muscles as shock absorbers

Kaal, William [william.kaal@lbf.fraunhofer.de](mailto:william.kaal@lbf.fraunhofer.de)

Dielectric elastomer stack actuators have been shown to have high potential in many applications. When a high voltage is applied, they contract in length with a strain of several percent and, due to

the material's incompressibility, expand in area. However, when connected to rigid structures, they lose much of their performance potential due to the areal constraint at the boundary layers. Especially for thin actuators with only a few layers these effects can become dominant and erase the inherent advantages completely. Extra outer passive elastomer layers may allow a homogeneous deformation of the actuator, but reduce the overall performance and absorb much of the generated force.

In order to overcome these disadvantages a new design concept was developed (Figure 25). Instead of using flexible electrodes made of carbon grease rigid metal electrodes are employed. They comprise thousands of small holes and therefore allow the elastomer to be locally squeezed into the holes when electrically activated (**Figure 26 and Figure 27**). Thus, a macroscopically compressible material laminate is achieved that can be connected to rigid boundaries without losses.



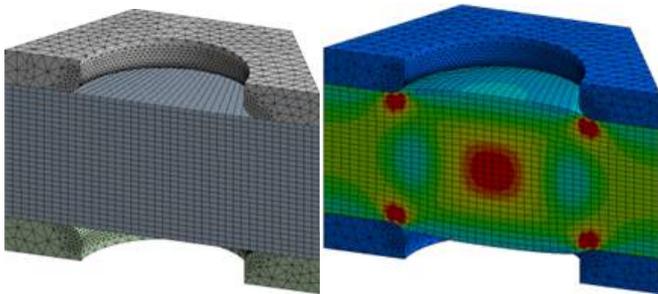
**Figure 25:** Functional demonstrator of a dielectric stack actuator with perforated electrodes with 44 layers developed and built at Fraunhofer LBF

Since the electrodes are made of pure metal sheets the electrical losses are very low, predestining the actuator for high frequency applications especially in the field of active vibration control or for haptic and acoustic devices. The nonlinear progressive stiffness makes the stack able to bear high loads and thus applicable for active shock absorber. The varying capacitance of

the stack even allows the utilization of energy-harvesting techniques for further using the kinetic energy of the vibrations that are to be reduced. Various functional demonstrators of DE actuators with this novel electrode design have successfully been built and tested. So far, the stacking process has been done manually, however a fast, reliable and efficient automated manufacturing for industrial production seems to be easily realizable.



**Figure 26:** Design configuration of elastomer layer in the background with perforated metal electrode in the front.



**Figure 27:** 3D FE Model of hexagonal cut-out element of stack actuator for numerical optimization of electrode hole size.

### Semmelweis University, Hungary

#### Novel electroactive polymer composites performing rotation in uniform DC electric field

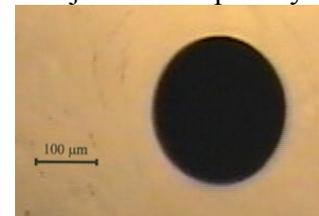
Miklos Zrinyi [mikloszrinyi@gmail.com](mailto:mikloszrinyi@gmail.com) and Masami Nakano [mnakano@fmail.ifs.tohoku.ac.jp](mailto:mnakano@fmail.ifs.tohoku.ac.jp)

Novel electroactive polymer composites have been developed that could spin in uniform DC electric field. Wide range of applications (e.g. microscopic motor) motivates researchers to find materials showing electrorotation with microfabrication possibilities.

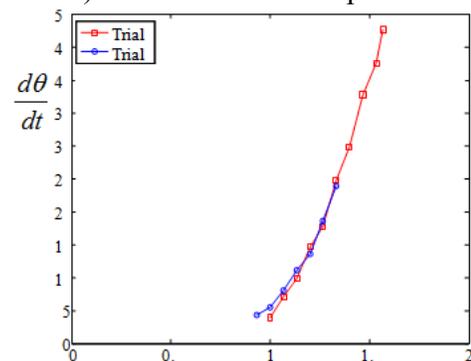
Here, we present development of novel EAP composites that are possible candidates of rotor of micro sized electro-motors, which rotate in uniform

DC electric fields. We have used orthorhombic FeO(OH) particles as filler particles in different host polymers like polyvinyl alcohol and gelatin [1-3] (**Figure 28a**). Micron sized cylindrical samples with different diameter and heights were prepared. The experiments were conducted in a specially designed cell where the electric field intensity was varied up to  $1.6 \cdot 10^6$  V/m perpendicularly to the axis of the polymer disk. The angular frequency of the rotation was determined by recording the motion of the disk by high speed camera (**Figure 28b**).

It was concluded that dynamics of the rotary motion is very complex. Above a critical value of electric field, the disk begins to rotate. With increasing field intensities, the angular velocity of rotating disk increases. Three regimes have been identified as the strength of static DC field is accounted for. It was found that disk rotor generates maximum torque of  $2.4 \mu\text{Nm}$  when an electric field intensity of  $2.00 \text{ kV/mm}$  is applied [4]. The data and video acquired during the tests show that the rotating disk acts like micro sized motor with tunable angular frequency. A microscopic motor this operated based on the principle of electro-rotation is just one step away.



a) Gelatin based composite



(b) The dependence of angular frequency

**Figure 28:** Top view of (a) the gelatin based composite, and (b) the dependence of angular frequency as a function of DC electric field. The

size of disks: diameter: 573  $\mu\text{m}$ , heights 208  $\mu\text{m}$ .  
The FeO(OH)/PVA mass ratio: 8.4

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2. M. Antal, G. Filipcsei, M. Zrinyi, Comp. Sci. and Tech. **67** (13), 2884 (2007).
3. M. Zrinyi, M. Nakano, Smart Mater. Struct. 21 (2012) 065022, doi:10.1088/0964-1726/21/6/065022
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## University of Wollongong, Australia

### Polymer actuators set to improve quality of life for breast cancer survivors

Natalie Foxon Phillips [natalie\\_foxon@uow.edu.au](mailto:natalie_foxon@uow.edu.au)

Women suffering from painful swelling of the arms as a result of breast cancer may soon feel relief, thanks to an innovative sleeve being developed by a research team at the ARC Centre of Excellence for Electromaterials Science (ACES), and funded by the Australian National Breast Cancer Foundation (NBCF).

About one third of Australian women newly diagnosed with invasive breast cancer will develop breast cancer-related lymphoedema (BCRL) or swelling of the arm. “These swollen limbs carry an extra two to three kilograms,” said Philip Clingan, Wollongong Hospital’s Director of Medical Oncology. “If you’re constantly carrying around extra weight on your arms it puts strain on your shoulder, it puts weight on your spine and you end up with shoulder pain and back pain. It is very disabling.”

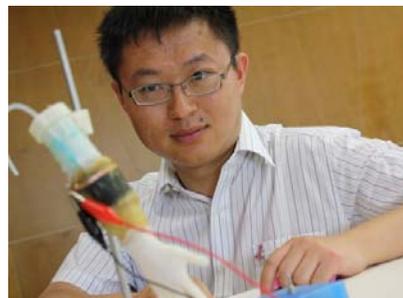
BCRL is incurable but the swelling can be managed by massage, passive compression garments, gentle exercise, and manual lymphatic drainage. These therapies often require lengthy visits to health services are expensive and may not be successful in the long term.

In the collaborative project between ACES and University of Wollongong’s School of Health Sciences and Graduate Medical School, the research team (**Figure 29**) aim to develop a ‘Lymph Sleeve’ which will be able to be worn by breast cancer-related lymphoedema patients during their daily lives.

The Lymph Sleeve will be developed using lightweight actuating fabric that will detect swelling and then respond by “squeezing” the arm to enhance lymph flow (**Figure 30**). “The dream is to produce a light weight sleeve that incorporates bands of artificial muscles along with fabric pressure sensors,” said ACES researcher Geoff Spinks.



**Figure 29:** ARC Centre of Excellence for Electromaterials Science (ACES) staff. From left: Bridget Munro, Philip Clingan, Wen Zheng, and Rosemary Paul



**Figure 30:** ACES researcher, Wen Zheng, with an early working model of how a Lymph Sleeve could work

“As the bands contract the pressure will assist in the drainage of lymphatic fluids. We also hope that relaxing the bands will make putting the sleeve on a much easier process. This project is in its infancy, but already we have developed a small prototype

consisting of a single contracting band that is able to pump fluid.”

## Technical University of Cartagena, Spain

### One muscle and several sensors embedded in one device - theoretical description

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During the last 15 years, sensing and tactile artificial muscles based on conducting polymers have been developed by our group. Position and movement rate of the artificial muscles (either exchanging anions or cations during reaction) are linear functions of the driving current ( $i_a$ ) and consumed charge ( $Q=i_a t$ ), respectively [1]. From basic principles of chemical and electrochemical kinetics the basic equation describing the actuation-sensing behavior of reactive muscles driven by constant currents was attained [2]:

$$E(t) = E_0 + \frac{RT}{(1-\alpha)nF} \left( \ln\left(\frac{i_a}{FV}\right) - a \ln[A^-] - b \ln\left([Pol^*]_{initial} - \frac{i_a t}{FV}\right) - \ln k_0 \right)$$

The evolution of the muscle potential,  $E(t)$ , is a function of (senses) the working temperature ( $T$ ), the electrolyte concentration  $[A^-]$ , or the mechanical conditions (through the film volume evolution,  $V$ ) including, simultaneously, the actuating magnitudes: current (movement rate) and charge (position). A good agreement exist between experimental and theoretical muscle potentials after different times of current flow under influence of individual variables, as temperature [2] (**Figure 31**), or electrolyte concentration.

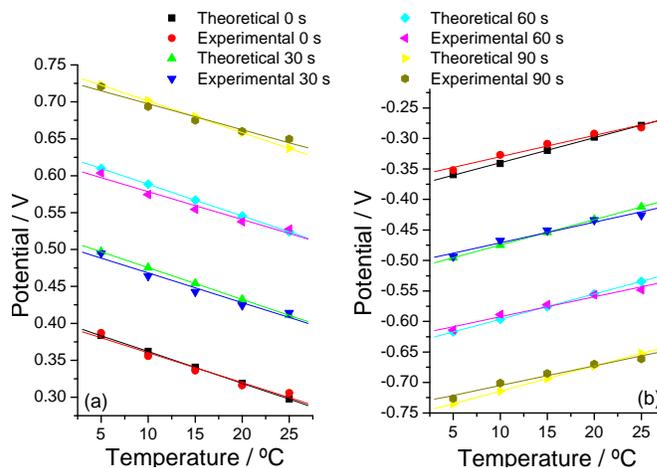
Only two connecting wires include, at any time, all the information about the actuator and the sensors followed by the computer. They mimic brain-muscles feedback communication (**Figure 32**): our brain keeps at any time a clear consciousness of the weight, position and movement rate for any object trailed by hand.

#### References

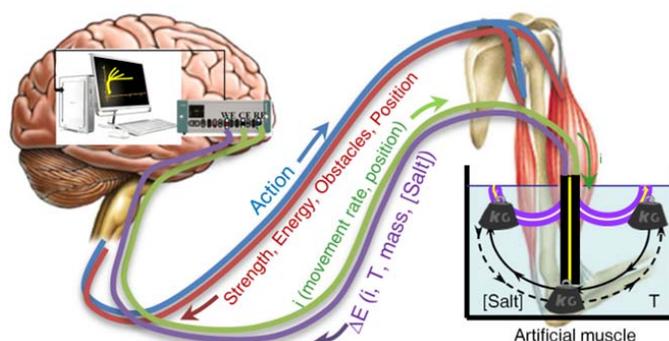
- Otero, T.F., Martínez, J. G., Arias-Pardilla, A review. *Artificial Muscles, Smart Membranes, Smart Drug Delivery and Computer/Neuron*

*Interfaces*, J. Biomimetic Electrochemistry from Conducting Polymers, *Electrochimica Acta*, DOI:10.1016/j.electacta.2012.03.097.

- Otero, T. F., Sanchez, J. J. and Martinez, J.G. *Biomimetic Dual Sensing-Actuators Based on Conducting Polymers, Galvanostatic Theoretical Model for Actuators Sensing Temperature*, *Journal of Physical Chemistry B* 2012. **116**: p. 5279–5290



**Figure 31:** Theoretical and experimental muscle potential after different times of current [0.75 or -0.75 mA] flow at different temperatures.



**Figure 32:** Brain-muscles feedback communication and scheme of the mimetic computer-generator/sensing artificial muscle system.

## Universidad Politécnica de Madrid, Spain

### Neural network approach to modeling the behavior of ionic polymer-metal composites in dry environments

Andrés Díaz Lantada [adiatz@etsii.upm.es](mailto:adiatz@etsii.upm.es)

Ionic polymer-metal composites (IPMCs) are interesting EAP materials because they generate large deformation when subjected to low voltage around 1 - 2 V and many applications have already been demonstrated. Normally, a humid environment is required for their operation, although after proper encapsulation or if a solid electrolyte is used in the manufacturing process, some IPMCs can operate in a dry environment. However, such solutions usually lead to an increased mechanical stiffness and to reduction in the actuation capability. In our study, we focused on the behavior of non-encapsulated IPMCs as actuators in dry environments. This was done in order to obtain relevant information for design tasks linked to the development of active devices based on this kind of smart material. The non-linear response obtained in the characterization tests is especially well-suited to modeling these actuators with the help of artificial neural networks (ANNs). Once trained using the characterization data, such neural networks prove to be an effective simulation tool for describing IPMC response in dry environments [Díaz Lantada et al., 2012a].

#### Reference

Díaz Lantada A., et al., “Neural network approach to modeling the behavior of ionic polymer-metal composites in dry environments”, Journal of Signal and Information Processing, 3(2), 137-145, 2012a.

## UPCOMING EVENTS

Date	Conference/Symposium
March 10 -14, 2013	15th EAPAD Conf., SPIE’s Smart Structures & Materials and NDE Symposia, San Diego, CA., For information contact: Rob Whitner, SPIE, <a href="mailto:mikes@SPIE.org">mikes@SPIE.org</a> Website: <a href="http://www.spie.org//eap">http://www.spie.org//eap</a>
Nov. 4-9, 2012	5th International Conference on Electroactive Polymers: Materials and Devices (ICEP-2012), Banaras Hindu University, Varanasi, India. For information contact Suresh Chandra <a href="mailto:sureshchandra_bh@yahoo.co.in">sureshchandra_bh@yahoo.co.in</a>
June 25-26, 2013	EuroEAP 2013 will be held in Zurich, Switzerland, and chaired by Gabor Kovacs from EMPA. Detailed

	information will be made available at <a href="http://www.euroeap.eu/conference">www.euroeap.eu/conference</a> .
July 10 to 12, 2013	The 4th International Conference on Smart Materials and Nanotechnology in Engineering (SMN) will be held at Gold Coast, Australia. The conference is chaired by Jinsong Leng, Harbin Instituted of Technology, China; and Jayantha A Epaarachchi, University of Southern Queensland, Australia. Information is available at <a href="http://www.a-tech.hk/SMN%202013/index.html">http://www.a-tech.hk/SMN%202013/index.html</a>
August 26-30, 2013	The 7th World Congress on Biomimetics, Artificial Muscles and Nano-Bio (BAMN2013) will be held at Jeju Island, South Korea. Information about it is available at <a href="http://www.n7w.com">http://www.n7w.com</a> .

## 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://ndea.jpl.nasa.gov/nasa-nde/lommas/eap/WW-EAP-Newsletter.html>

**Recipe:** <http://ndea.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-recipe.htm>

**EAP Companies:** <http://ndea.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-material-n-products.htm>

**Armwrestling Challenge:**  
<http://ndea.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm>

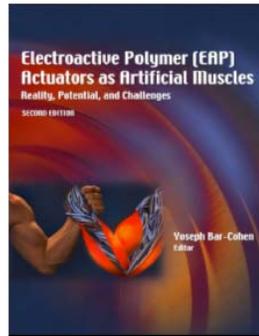
**Books and Proceedings:**  
<http://ndea.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm>

### 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.

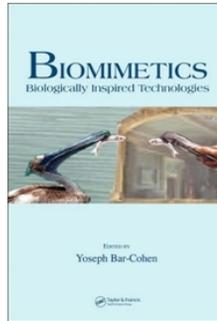


## Biomimetics - Biologically Inspired Technologies

Y. Bar-Cohen (Editor)

<http://ndea.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

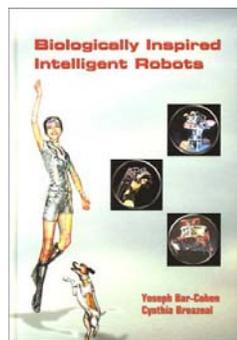


<http://ndea.jpl.nasa.gov/ndea-pub/Biomimetics/Biologically-Inspired-Technology.pdf>

## 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

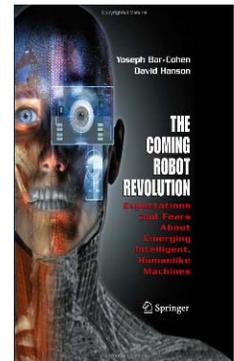


multidisciplinary and they are covered in this book. These topics include: materials, actuators, sensors, structures, control, functionality, intelligence and autonomy.

## 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.



## 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>



## **WorldWide Electroactive Polymers (EAP) Newsletter**

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