WorldWide ElectroActive Polymers EAP (Artificial Muscles) Newsletter

June 2003 | WW-EAP Newsletter | Vol. 5, No. 1

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

FROM THE EDITOR

Yoseph Bar-Cohen, *yosi@jpl.nasa.gov*

Since the last issue of this Newsletter published in December 2002, two major milestones for the field of EAP have been reached. The first one is the emergence of the first commercial product. This product is a fish-robot, which needs no maintenance or battery and it is designed with controlled buoyancy. It is driven by an IPMC type EAP and energized via electromagnetic induction from coils in the upper and lower sections of the water tank inducing power onto a coil inside the fish. The fish-robot and the water-tank were developed by Eamex, Japan, and they are manufactured by Daiichi Kogei, Japan. Examples of this EAP actuated fish-robot are shown in Figure 1. Further, a video of these fish-robots shown swimming in this water tank can be seen on: http://www.eamex.co.jp/index_e.html.

FIGURE 1: The first reported commercial EAP-based product in the form of a fish-robot. This fish is produced by Eamex, Japan.

Another major milestone is a statement from scientists of SRI International (see further information about their EAP related activity on Pages 10-12 of this Newsletter) claiming that they believe to be ready to develop the first robotic hand that has the potential to win an arm-wrestling match against a human opponent. While this is only a statement, still, reaching the level that such a self-assessment can be made about EAP related to robotic capability is an important milestone. In an effort to launch the armwrestling competition a committee was formed and plans are underway to prepare for such a match as well as seek possible award for the winner(s). Further details about this competition can be found in the General News section of this Newsletter and the following website: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

ABOUT THE EXPERTS

Mihoko Otake

In April this year, Mihoko Otake was appointed as a faculty researcher for the 21 COE Program at the Graduate School of Information Science and Technology, the University of Tokyo, Japan (see further information about this program on: http://www.kc.t.u-tokyo.ac.jp/COE/index.html. During her Ph.D. studies, she made contributions to the modeling, design and control of deformable machines consisting of actively deformable materials and EAP gels. She obtained a doctor degree in March. At her new affiliation, she is engaged with the Real World Information System project. Her research topics include simulating human sensorimotor algorithms utilizing musculoskeletal model and motion capture system, and dynamic computation of machines consisting of EAP. Mihoko Otake's new e-mail address is otake@ynl.t.u-tokyo.ac.jp and her website address is: http://www.ynl.t.u-tokyo.ac.jp/~otake/.

Guggi Kofod

As of April 1st, 2003, Guggi Kofod has transferred from the Danish Polymer Centre, Risø, Denmark, to the Department of Chemistry, Ateneo de Manila University, Philippines, where he was appointed Assistant Professor. He obtained his Ph.D. degree in Sept 2001 and his thesis entitled "Dielectric Elastomer Actuators." At the Danish Polymer Centre, Risø, Denmark, he worked under the supervision of Peter Sommer-Larsen. Further, in the spring of 2000, he had also an excursion of 5 months at SRI, where he worked under the supervision of Roy Kornbluh. In the Philippines he is going to set up an artificial muscle lab, working on the dielectric type (Maxwell stress) elastomer actuators. His primary interest is to improve the dielectric and mechanical properties of existing elastomers, as well as designing new elastomer materials. Also, he is seeking to improve the analytical modeling and the understanding of the electromechanics of dielectric elastomer actuators.

GENERAL NEWS

The WW-EAP Webhub is continuing to be updated with information regarding the EAP activity Worldwide. This webhub is a web-address link of the JPL's NDEAA Technologies Website: http://ndeaa.jpl.nasa.gov

LIST OF CONTENTS

Helpful hint against computer viruses

The following is based on the editor's personal experience receiving e-mails with attachments that were identified as virus. While it is not claimed as conclusive it is believed to be a helpful list. As a general rule, unless you receive none e-mail confirmation, it is **not** recommended to open files having the following extension (e.g., *.bat): **bat, com, exe, ink mm, pif, scr, tmp, or vsb**

The first Armwrestling Match is Getting Closer

The futuristic idea of armwrestling between a human and a robot that is actuated by EAP seems to be closer than we think. In 1999, the Editor of this Newsletter posed this challenge to the worldwide research and engineering community. Recently, researchers from SRI International announced that they believe they have the capability to meet this challenge. The first Armwrestling Match of EAP Robotic Arm against Human (AMERAH) is considered to be held as part of one of the SPIE's Annual International EAPAD (EAP Actuators & Devices) Conferences. Discussions are underway with various organizations including the United States ArmSports regarding the planning of this competition as an official international event and the raising of a prize that would be awarded to the winner. Further information is available on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

This Editor of this Newsletter would appreciate any assistance in making this competition a reality including the raising of the prize for the award.

Members of the Organization Committee (currently being formed)

L. Alfred Couvillon -Vice President, Technology Integration and Knowledge Sharing, Boston Scientific

Dave Devoto - Pioneer and leading representative of the United States ArmSports http://www.armwrestling.com/Robot.html

Joanne Pransky - World's First Robotic Psychiatrist www.robot.md

Scott Walker - Senior Event Manager, SPIE -- The International Society for Optical Engineering

2003 SPIE EAPAD Conference

The 5th EAPAD conference was held this year with about 75 papers. The conference was well attended by leading world experts in the field including members of academia, industry, and government agencies from the USA and overseas. Significant progress was reported in each of the topics of this conference sessions including applications of EAP. Overall, the reported applications covered a broad range of fields including optical devices (such as Braille displays, large scale mirrors and human eye assisting mechanisms) and robotics.

The Keynote Speaker was Anna-Maria R. McGowan, NASA Langley Research Center, and the title of her talk was "Biologically-Inspired Technologies in NASA's Morphing Project." In her talk, she described the efforts to mimic the flying of birds where the emphasis is not just on copying but rather learning from biology to make better flying capabilities. She described the considerations of EAP as actuation materials and the fabrication of an electro-spun wing that was injected to form the equivalent of the spider web. One of the points that were mentioned with regards to the efficient use of power for flying by birds and butterfly is that flapping is done at the wing's resonance frequency.

FIGURE 2: The Keynote Speaker, Anna Maria R. McGowan from NASA

The conference presentations covered progress in the various areas of the EAP infrastructure. The papers focused on issues that can lead to the transition to practical use, including improved materials, better understanding of the principles responsible for the electromechanical behavior, analytical modeling, processing and characterization methods as well as considerations and demonstrations of various applications. The sessions about EAP materials were divided into the two principal groups that the Conference Chair defined: ionic and electric EAP. The electric EAP materials are driven by electric forces, whereas the ionic EAP materials consist of electrodes and electrolytes and involve mobility/diffusion of cations or anions. Papers in this conference covered the following topics:

- Electroactive polymers (EAP) and non-electro active-polymer (NEAP) materials
- Theoretical models, analysis and simulation of the mechanism that drive EAP.
- Support technologies, including synthesis, processing, shaping and fabrication
- Methods of testing and characterization of EAP
- Small scale EAP including MEMS, micro and nano actuators
- EAP as artificial muscles, actuators and sensors
- Applications of EAP related to biomimetics, robotic, optical device, etc. that are under consideration, in progress or desired

The efforts described in the presented papers indicated significant improvements in understanding of the electromechanical principles and better methods of dealing with the challenges to the materials applications. Researchers are developing analytical 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 electrostrictive, IPMC, dielectric, liquid crystals, conductive polymers, and other types. Also, the development of composite electrostrictive polymers allowed reduction in needed high actuation voltage for the electric EAP group. Applications to biologically inspired robots and many other fields are continuing to be considered with encouraging results. Moreover, components for such devices as Braille display were showing promising results.

As in past years, the conference included an EAP-in-Action Session and the attendees were given an opportunity to see demonstrations of EAP actuators and devices. This Session continues to offer a forum of interaction between the technology developers and potential users as well as a "hands-on" experience with this emerging technology. Eight presentations were included:

1. Geoffrey Spinks, Gordon Wallace, Dezhi Zhou, Binbin Xi and William Megill, IPRI, University of Wollongong, Australia; and John Gillespie, Quantum Technologies Ltd, Australia – This team presented three EAP applications: Electronic Braille Prototype Cell; Valve and Sensor Smart Packaging System; and Remote Control Rudder for Model Aircraft.
2. Roy Kornbluh, Ron Pelrine, Qibing Pei, Jonathan Heim, Richard Heydt, Joseph Eckerle, Seajin Oh, Scott Stanford, Neville Bonwit, Philip von Guggenberg, and Don Czyzyk, SRI International, Menlo Park, California, USA – This team presented Dielectric Electro-elastomer EAP and their demo showed stretching capabilities of this EAP and its applications as actuators, generators and sensors
3. Paul Yang, Arizona State University – An EAP Based Braille Display concept with a self supporting and hydraulic (SSH) system was shown.
4. Don Leo, Rick Claus, Matt Bennett, Marten de Vries and Tingying Zeng, NanoSonic Inc., Blacksburg, VA - NanoSonics presented its EAP products including ionomeric transducers, EAP sensors, analysis methods and design software.
5. David Hanson, UT Dallas – A Humanoid Robot Head enacting facial expressions was presented representing several steps forward in making an EAP testbed ideal for demonstration of artificial muscles
6. Kazuo Onishi, and Shingo Sewa, EAMEX Corp and DAIICHI KOGEI Corp - Videos of a Fish-Robot and other applications were shown. As mentioned earlier in this issue of the Newsletter, this Fish-Robot represents a major milestone for the field with this introduction of the first commercial EAP-based product. EAP actuators (1mm x 12mm is size) are responsible for the fish swimming and they are attached between the body and fish tail and fins.
7. Edwin Jager, Micromuscle AB, Westmansgatan, Sweden - A video was presented showing several of this company EAP related products including microactuators, in-vitro surgery of blood vessel connector and implantation surgery (on laboratory rats). Hands-on non-functioning old microactuator samples were presented to give the participants a chance to appreciate the actual size.
8. Liming Dai and Prabhu Soundarrajan, University of Akron, OH – A video of a Carbon Nanotubes EAP actuator was shown. This video presented the response to $\pm$2V square wave signal where the Nanotube film changes its shape. The sample was tested using cyclic, differential, and normal signals showing a similar response. During activation bubbles are seen emitted from the film

and the presenters are concerned that the shape change is not an EAP behavior but a result of the bubbles emission. When the film is placed in a strong organic base there is no movement in the potential range of -2V (< reduction potential for electrolysis in this base). The sample consists of a gold plated Nanotube electrode in a three electrode system of a single compartment cell. The electrolyte is 2M Nano3 with platinum and an Ag/AgCl is the counter and the reference electrodes.

The conference included also an Open Discussion Session to debut the status of the field of EAP, where the conference Chair, Cochair, and the invited speakers served as the discussion panelists. Each of the panelists gave a short presentation of his views and the attendees expressed thoughts and comments. This session was intended to stimulate ideas and thought with no attempt to reach a consensus. The general views have been that the field is moving in the right direction and the progress is very encouraging. The panel Moderator was the Conference Chair: Yoseph Bar-Cohen, JPL, and the panelists included: Minoru Taya, University of Washington; Geoff Spinks, University of Wollongong, Australia; Ji Su, NASA Langley Research Center; and Keiichi Kaneto, Kyushu Institute of Technology, Japan. The topics that were discussed at this session included:

- Areas of EAP weakness/shortcoming of the EAP technology infrastructure?
- What is the gap between the needed and available EAP and how to bridge it?
- Are there other practical applications where currently available EAP materials can be used?
- Future science and engineering directions

The points that were raised included the desire to see EAP materials that simultaneously generate other changes besides mechanical change. There is a need to make materials with improved properties as well as possibly compromise properties for the sake of other more significant ones just like in motors where speed is traded for torque. Also, there is a need for more basic material science development, establishment of documented database to allow engineers to consider the use of EAP as the actuators-of-choice. Further, there is a need for EAP that can operate in extreme environments such as cryogenic temperatures. The Panel Discussion was attended by high percentage of industry attendees. The human prospective from personal experience was expressed by Paul Yang, Arizona State University, who became totally blind as a result of an accident. Paul Yang expressed his satisfaction of the development rate of the EAP technology and his hope to see devices that can enhance the capability of blind people to operate independently.

World Congress on Biomimetics

The First World Congress on Biomimetics and Artificial Muscles was a great success having more than 260 participates. The final program and the associated activities can be seen on www.world-congress.net. The proceedings is now available on a CD ROM and can be ordered by e-mail to Mary Zsigmond (biomimetics@ijecdm.com). The submittal of papers to the Biomimetics, Artificial Muscles & Nano-Bio 2004 World Congress can be done via the above website too. The third congress will be held at INSA, Lyon, France in August of 2005. A new society of "Biomimetics" is currentlty being formed and for information or becoming a member you can contact Mohsen Shahinpoor (shah@unm.edu).

Call for Papers - ACTUATOR 2004

The ACTUATOR 2004, 9th International Conference on New Actuators and 3rd International Exhibition on Smart Actuators and Drive Systems, will be held on 14 - 16 June 2004, in Bremen, Germany. As in 2002, there will be a special session on polymer based actuators. Again, the session will be chaired by Roy Kornbluh, SRI International, and Peter Sommer-Larsen, Risø National Laboratory.

Abstracts can be submitted to this conference (oral or poster presentation), preferably via e-mail to the organizer, by no later than 30 November 2003. The abstracts should be written in English, cannot exceed 500 words, and should include the name(s) of author(s) and institution(s). The name of the principal author needs to be underlined and the preferred type of presentation needs to be indicated. Further, the submittal should include a short version of the abstract containing about 10 lines (500 characters) for publication in the online version of the conference program. The conference organizer and address are as follows:

Hubert Borgmann
Division Messe Bremen, HVG Hanseatische Veranstaltungs-GmbH, 28209 Bremen, Germany, (+49 421) 35 05 347, Fax +49 421) 35 05 340, actuator@messe-bremen.de www.actuator.de

EAP ADVANCEMENTS

Denmark, Technical University of and UK, University of Reading,

Electroactive Polymer Actuators for Tremor Suppression

Steen Skaarup skaarup@kemi.dtu.dk Naja Mogensen, Denmark.
Wayne Hayes, and Nicolas Guernion, UK

Neurological tremor in human limbs is characterized by frequencies in the range 2-16 Hz. Electroactive polymers exemplify a 'soft actuator' technology that may be especially suitable for use in conjunction with limbs to suppress the effects of tremor. The development of this type of actuator comprises part of a European project funded under the Fifth Framework Quality of Life program, DRIFTS: (Dynamically Responsive Intervention for Tremor Suppression, www.gerontech.org.il/drifts/home.htm). The project involves 9 research groups in 6 countries, investigating several alternative approaches to the non-invasive mechanical control of tremor.

One approach is the use of conducting polymer actuators such as polypyrrole permanently doped with dodecyl benzene sulfonate ions. A main challenge is the ability to drive polymeric actuators of this type at the required frequencies at loads up to about 1 kg. Our results have shown that the time constants for the change of length and for the stiffness change are significantly different – the stiffness change being about 10 times faster. Using the change in stiffness may therefore be the key to reaching the higher frequencies.

Figure 3 shows the surprising result that the load capability goes through an optimum as the scan rate is increased. Results indicate that part of the reason is that the largest volume changes are associated with slow processes such as osmotic influx of water. Since the solvent saturated reduced state is also the one having the smallest strength, bypassing these processes sacrifices strength to a much smaller degree than maximum strain. The polymer is unable to change its conformation rapidly enough to track the higher frequencies – thereby reducing creep and other slow effects. The encouraging result is that the actuator seems to become both stronger and more reversible at higher frequencies, partially compensating for the less than 100% utilization of material. One kg at 0.5 Hz would require a film 30mm wide and 0.13 mm thick. The exact nature of the limiting effects in the desired frequency range will be studied further, since the diffusion limit in the film has not yet been reached.

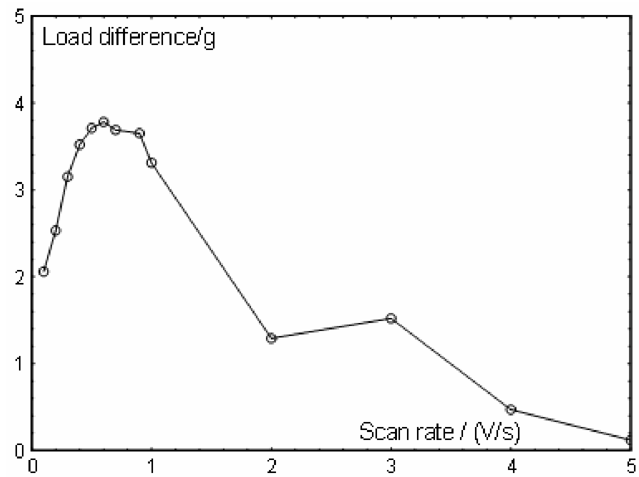


FIGURE 3: Maximum difference in measured load between oxidized and reduced states for 10 mm PPy (DBS) actuators as a function of scan rate (5 V/s corresponds to ~0.7 Hz). 0.1 M NaCl is the cycling electrolyte

When the above objective has been achieved, further improvement will require new types of polymers. Derivatives of the pyrrole ring at the β-position is a suitable approach towards EAP systems with improved conductivity characteristics. To date, a wide variety of functional groups have been appended at the β-position of the pyrrole ring (alkanes, ketones, carboxylic acids, polyethers, crown-ethers, for example) and the resulting polymers have been electropolymerised successfully. Preliminary results obtained via cyclic voltammetry indicate that the resulting polymers possess excellent overall conductivity and electroactivity. The electromechanical properties of the poly(3-substituted pyrroles) are still under investigation, with the ultimate aim of obtaining polymeric actuators with a much higher diffusion limits in comparison to poly(pyrrole).

Japan - University of Tokyo

Modeling, design and control of electroactive polymer gel robots

Mihoko Otake, otake@ynl.t.u-tokyo.ac.jp
and Hirochika Inoue

Recent progress of gel robots made of EAP can be found in the Ph.D. thesis from Mihoko Otake. The thesis studies the modeling, design and control of deformable machines consisting of actively deformable materials, which are referred to as artificial muscles.

The main focus is to propose methods for deriving a variety of shapes and motions of such machines, using a particular electroactive polymer gel, poly 2-acrylamido-2-methylpropane sulfonic acid (PAMPS) gel [1], and its co-polymer gel. Mechanisms consisting of the gel, hereafter called 'gel robots', were designed, developed, and controlled experimentally. The results demonstrate the effectiveness of the proposed methods.

This dissertation includes: (1) a mathematical model of the gel to be applied for design and control of distributed mechanisms, (2) gel robots manufacturing and their driving systems, (3) control of gel robots for dynamic deformations. The results are demonstrated for beam-shaped gels curling around an object and starfish-shaped gel robots turning over [2, 3] (see Figure 4).

Full abstract of this thesis is available on the web.
http://www.ynl.t.u-tokyo.ac.jp/~otake/gelrobot/thesis.htm

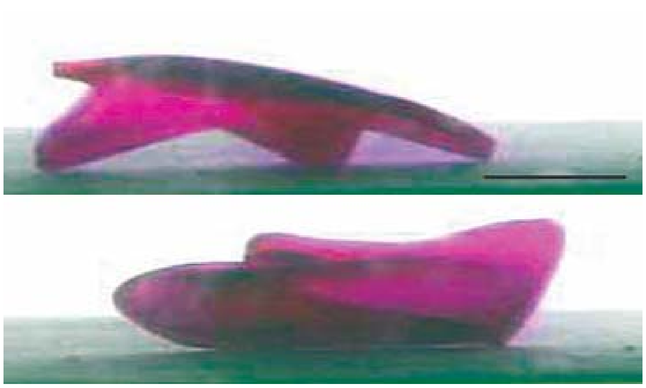


FIGURE 4: Starfish-shaped gel robot made of EAP that turns over: The scale bar is 5[mm]. Photos show gel robots 20 and 50[s] after applying the electric fields.

Reference
[1] Y. Osada et al, "A Polymer Gel with Electrically Driven Motility", Nature, vol. 355, pp.242-244, 1992.
[2] M. Otake et al, "Motion design of a starfish-shaped gel robot made of electro-active polymer gel", Robotics and Autonomous Systems, vol.40, pp.185-191, 2002.
[3] M. Otake et al, "Starfish-shaped Gel Robots made of EAP", WW-EAP Newsletter, vol. 4, no.2, pp.7-8, 2002.

South Korea - Hanyang University

Biocompatible modified chitosan hydrogels for actuators

S.J. Kim, sjk@hanyang.ac.kr
http://nbt.hanyang.ac.kr
S.J. Park, S.K. Yoon, S.R. Shin, I.Y. Kim, and S.I.Kim

Hydrogel transitions occur in response to changing environmental conditions such as temperature, pH, solvent composition and electrical stimuli. Interpenetrating polymer networks (IPNs) for hydrogels have attracted many investigations. The IPNs, by their original definition, are composed of two or more chemically distinct components held together ideally and solely by their permanent mutual entanglements. IPN hydrogels based on chitosan (CS), polyallylamine (PAA), poly(vinyl alcohol) (PVA), polyacrylonitrile (PAN) and poly(hydroxyethyl methacrylate) (PHEMA), have been prepared in our work. Due to their good biocompatibility, biodegradability, nontoxicity and availability Chitosan IPN, hydrogels have been widely studied and applied in the biomedical field.

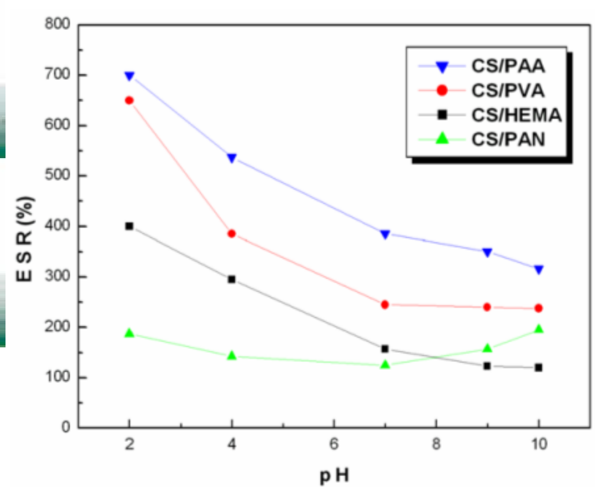


FIGURE 5: pH dependent swelling behaviors of the hydrogels at 35 ^oC

The equilibrium swelling ratio (ESR) of CS/PAA, CS/PVA and CS/HEMA hydrogels decreased with increasing pH of the buffer solution. Conversely, the ESR of the CS/PAN hydrogel decreased with increasing pH of the buffer solution, until pH 7, and the increased in the basic buffer solutions (see Figure 5) indicates the pH sensitivity of these materials.

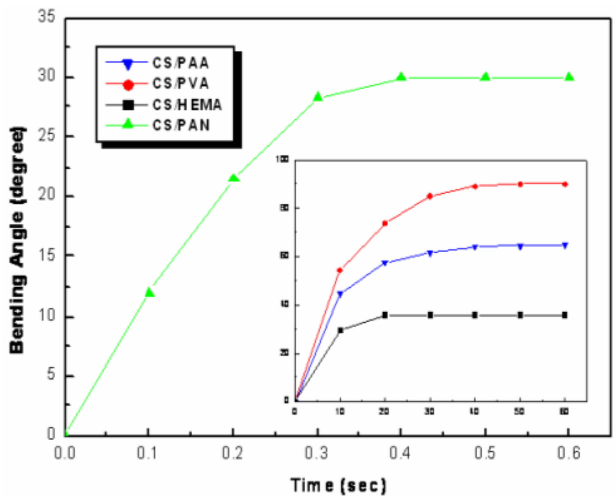


FIGURE 6: The bending angles of the hydrogels at a constant applied voltage (10 V) in a 0.8 wt% aqueous NaCl solution at 35 ^{o}C.

Bending angle measurements were carried out in a 0.8 wt% aqueous NaCl solution, as extracellular fluid contains about 0.8 wt% NaCl, under a non-contact DC electric field. When an electric field was applied to hydrogels in a 0.8 wt% aqueous NaCl solution, they showed significant and quick bending toward the cathode (see Figure 6). When the electric stimulus was removed, the hydrogels returned to their original position. Also, when the polarity of the electric field was reversed, the hydrogels bent in the opposite direction. The hydrogels also exhibited reversible bending behavior on the application, and subsequent removal of the electric field. These results suggest that the hydrogels could be useful for artificial organ components, such as actuators and switches in a body.

Sweden, France and England

BISL-AASS, Örebro University, Sweden
Paris 7 & INSERM, France
LIRIS, CNRS, France
ENST-Paris, France
Elumotion Ltd., England

Artificial Sensory Hand (ASHand) Project

S. Eskiizmirliler, P. Wide (BISL-AASS), E. Stenninger (LDAPC, Örebro University Hospital), M. Maier (Paris 7 & INSERM, France), F. Ben Ouzdou (LIRIS, CNRS, France), C. Darlot (ENST-Paris, France)

Contact Person: Selim.Eskiizmirliler@tech.oru.se

Website: http://www.aass.oru.se/Research/Sensors/

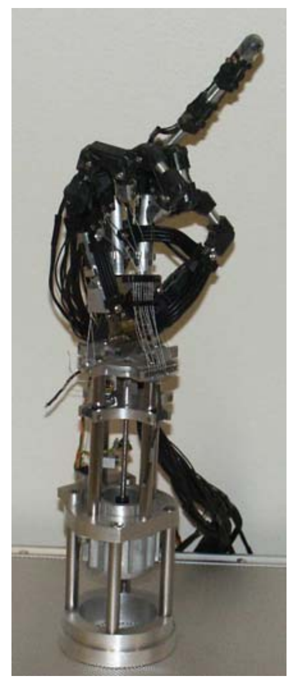


FIGURE 7: Artificial Sensory Hand (ASHand) Project

Since the beginning of the year 2003, a new project has been launched at the Örebro University, Sweden to develop a five finger artificial sensory hand which will be actuated by EAPs with the aim of studying and applying the neuropysiological sructures and processes that play a role in dexterous manipulation towards providing Dysmelia patients a more dexterous prosthesis. The project is conducted by the Biologically Inspired Systems Laboratory **(BISL)** at the Center for Applied Autonomous Sensor Sytems **(AASS)** of **Örebro University** in collaboration with the Limb Deficiency and Arm Prosthesis Centre **(LDAPC)** of Örebro University Hospital, the **University of Denis Diderot** - Paris 7, **INSERM**, **LIRIS** of **CNRS** and **ENST-Paris**. The electromechanical structure of the artificial hand has been designed and constructed by **Elumotion Ltd**. (England). The five artificial fingertips of the hand (see Figure 7) are equiped with strain-gauge sensors and except for the distal interphalangeal joints, the positions of the proximal interphalangeal and meta-carpophalangeal joints are detected by half effect sensors. Currently, different types of EAPs are being tested so that the actuation scheme could be a biologically plausible one. The research team has applied to the French delegate Ministry of New Technologies and to the Swedish Research Council (Vetenskaprådet) for two applications projects entitled "Haptic multi-modal recognition through real-world experience" and "Biologically Inspired Intelligent Control of an Artificial Hand," respectively.

Switzerland – Swiss Federal Laboratories for Materials Testing and Research (EMPA)

Current EAP related activity at the EMPA Center

G. Kovacs, gabor.kovacs@empa.ch
X. Zhang, xuequn.zhang@empa.ch
S. Michel, silvain.michel@empa.ch
P. Lochmatter, patrick.lochmatter@empa.ch
M. Wissler, michael.wissler@empa.ch

The research activities at Swiss Federal Laboratories for Materials Testing and Research (EMPA) are focused on dielectric polymers. The main efforts and tasks include

- Chemical optimization of EAP materials based on acrylic and silicon elastomers
- Building up a laboratory for the characterization of the developed EAP foils
- Performing concept studies on actuator structures
- Prototyping and optimization of EAP
- Building up a laboratory for the determination of the actuator performances
- Numerical modeling the viscoelastic material behavior and simulation of EAP actuators
- Performing feasibility studies in different fields of potential applications

The results that were achieved until end of May 2003 include

- New silicon elastomers, blended with organic compounds, were obtained, with lower percent ionic silicone or with high dielectric constants. These new elastomers sustain >8 % strain at 2 kV, which is much lower than the voltage required by non-blended silicon elastomers. A method for thin elastomer film (minimum 50 µm) preparation has been developed. To make measurements on such thin foils including monotonic tension, cyclic load, creep and relaxation tests, the required facilities is available to the team.
- Preliminary results of material characterization of the well-known acrylic material (VHB 4910) have been collected and verified with data from the literature.
- The first practical knowledge with prototyping planar and cylindrical actuators has been gained and further optimization steps have been identified.
- A feasibility study for the application of EAP actuators on wind exposed ropeway gondolas has been performed.

The team future steps that are planned include:

- Continuing chemical modifications/synthesis of silicon and acrylic elastomers
- Developing material models, design methods and tools together with university partners
- Establishing a laboratory for systematic comparison tests with various types of materials and actuators
- Prototyping various types of actuators and improving the production process
- Generate a large scale shell actuator for possible applications in lightweight structures (Figure 8).

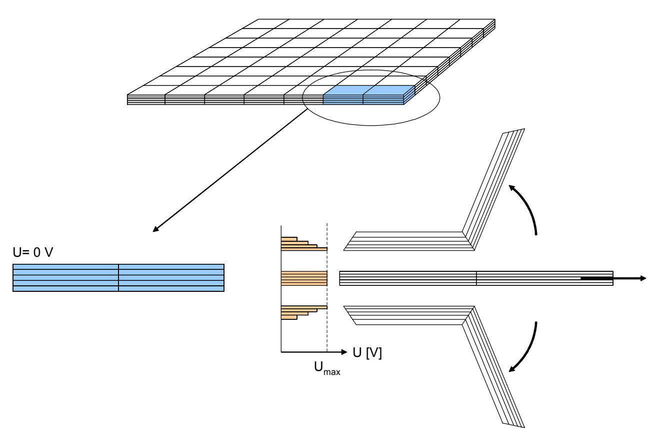


FIGURE 8: Concept of a large scale shell actuator for possible applications in lightweight structures.

USA - Jet Propulsion Laboratory (JPL)

Potential use of EAP in robotics

Y. Bar-Cohen, yosi@jpl.nasa.gov and Brett Kennedy

As the NASA center for the unmanned exploration of the universe, JPL is seeking robotic technologies to support its efforts to investigated the surface of various planets, conduct sampling and analysis and many other in-situ science and engineering tasks. The NDEAA lab at JPL, under the lead of Yoseph Bar-Cohen, has been seeking since 1995 to use EAP as potential actuators to support the development of novel robotics, gossamer structures, mechanisms and devices. The recent co-editing of the book about biomimetic robots with Cynthia Breazeal, MIT (see further information at the end of this issue of the Newsletter), was an effort to document the status of this robotic technology and examine the role and potential of EAP. EAP platforms that were prepared in the form of an android head by David Hanson, U. of Dallas, TX, and the robotic arm by Graham Whitely, England, have offered a testbed for the EAP researchers worldwide and a link between the EAP field and robotics.

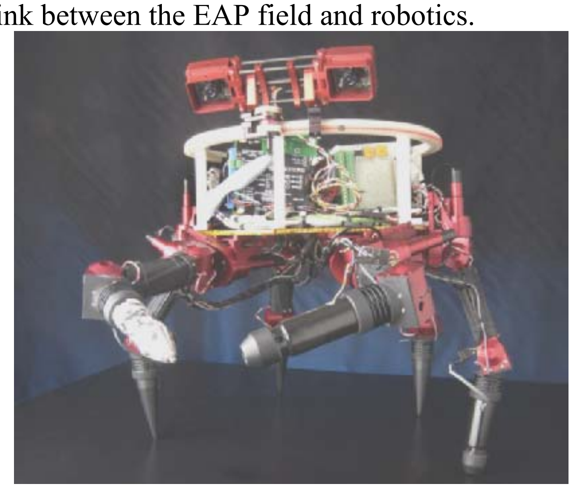


FIGURE 9: The JPL's LEMUR robot representing the new class of biomimetic robots that could be used as platforms for EPA to enhance these robots performance.

In parallel to the EAP development effort at JPL, there is a new generation of biologically inspired robots in the form of legged robots that have emerged under the lead of Brett Kennedy. One of this class of robots is the LEMUR (Limbed Excursion Mobile Utility Robot) that is shown in Figure 9.

The LEMUR is a six-legged robot that is being developed for consideration in future missions to such planets as Mars. These type of robots could strongly be enhanced by use of effectuve EAP actuators for the mobility and execution of its manipulation tasks. The LEMUR is designed to perform mobility in complex terrains, grasping and object manipulation, sample acquisition and analysis, and many other functions that are attributed to legged animals. Using such life-like robots may affect the planning of future NASA missions in profound ways. The details of such missions may be designed as a plot, commonly used in entertainment shows rather than conventional mission plans of a rover moving in a terrain and performing simple autonomous tasks. Equipped with multi-functional tools and multiple cameras, the new models of LEMUR are being designed with the task of inspecting and maintaining installations beyond humanity's easy reach in space. This spider looking robot has on its legs interchangeable end-effectors to perform the required mission. The axis-symmetric layout is a lot like a starfish or octopus, and it has a panning camera system that allows omni-directional movement and manipulation operations.

USA - SRI International

Multifunctional Electroelastomer Roll (MER) Actuators

Qibing Pei qpei@erg.sri.com

Ron Pelrine, Marcus Rosenthal, Scott Stanford, Roy Kornbluh, and Harsha Prahlad.

SRI International is developing multifunctional cylindrical roll actuators based on electroelastomers, also known as dielectric elastomers, with up to 380% actuated strain. These electroelastomer rolls can be used as robots' legs, for load bearing, electromechanical actuation, position sensing, and elastic and viscous responses, all of which are capabilities of animal legs. This development project has been funded by the Synthetic MultiFunctional Materials program of the Defense Advanced Research Program Agency (DARPA). A goal of the project is to develop the multifunctional electroelastomer roll actuators to the point where they can be integrated with robots that offer mobility and dexterity approaching those of natural creatures. SRI subcontracts to Robert Full of the University of

California, Berkeley, to study the multifunctionality of natural muscles and leg systems in order to improve the design of the synthetic systems.

MER Spring Rolls (Figure 10): Electroelastomers have exhibited high strain and moderate stress (up to 8 MPa). The response speed varies in a wide range from 1 Hz to as high as 20 kHz, depending on the type of materials and the amount of strain. This remarkable performance is obtained when the elastomer films, for instance 3M VHB 4910 adhesive, are prestrained as much as 25-fold in area. Previously, sturdy, bulky frames were needed to support such high levels of prestrain. These frames occupied significantly more space and weighed much more than the polymer films themselves. Therefore, SRI designed the multifunctional electroelastomer roll (MER, or spring roll) in which highly prestrained electroelastomer films are rolled around a compression spring. When released, the spring holds the polymer films in high circumferential and axial prestrain while allowing for axial actuation. One-degree-of-freedom (1-DOF), 2-DOF, and 3-DOF spring rolls have been demonstrated wherein the compliant electrodes are not patterned, are patterned on two, and are patterned on four circumferential spans, respectively.

1-DOF Spring Rolls: The maximum linear actuated strain is around 25%. The spring roll shown in figure 11 is 65 mm long with 45 mm active length and 10 g weight. Its achieved strain is up to 12 mm or 26%, which compares favorably with natural muscle strains in animal legs, which are typically 4–15%. The blocked force of the spring roll is 15 N; it could lift a 0.5 kg weight and exert an 8 mm stroke. Spring rolls with different sizes and blocked forces were also fabricated. The maximum strain remained roughly the same. The rolls were able to operate at over 10 Hz. However, the half-strain frequency was only 5–7 Hz, due to the slow relaxation of the acrylic films. With recently developed new materials, the half-strain frequency has been increased to over 50 Hz. The mechanical power output is consequently increased by one order of magnitude, to the level of 5 watts per roll or 400 watts per kilogram of actuator mass. With these results, we believe roll actuators could be fabricated that are large and strong enough to participate in EAP-human arm wrestling.

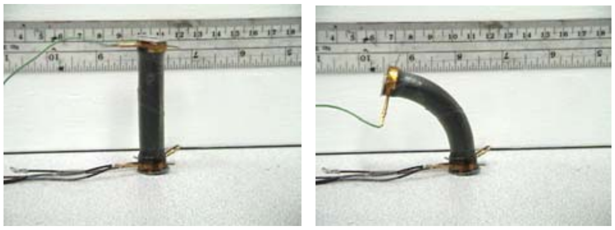
Multi-DOF Spring Rolls (Figure 10): A stroke S in the actuated span causes a 2- or 3-DOF spring roll to bend toward the non-actuated span(s). The bending angle of the roll is

$$\phi = \tfrac{2}{\pi} \bullet \frac{S}{r} \cos \frac{\pi - \theta t}{2}$$

wherein r is the roll radius, and θt the radial angle of the actuated span. The figures shown below are, respectively, a 2-DOF spring roll at rest and actuated on its right span. The maximum bending angle achieved was 90°.

FIGURE 10: Multifunctional Electroelastomer Roll (MER) Spring Roll

Biologically Inspired Robots (Figure 12): We fabricated small walking robots with a spring roll as each of their six legs. Skitter, shown below at left, is based on six 1-DOF spring rolls. The robot is about 7.5 in long and 5 in wide. Each spring-roll leg is a linear actuator with 3–6 mm strain at 1–10 Hz frequency. The speed was as high as 2.7 in or one-third of the robot's body length per second. MERbot, shown below at right, uses six 2-DOF spring rolls. It has a hexagonal frame, dimensions of 7.1 × 7.1 × 4 in, and a weight of 292 g. The robot's maximum speed was 5.4 in or two-thirds of its body length per second. We believe that both Skitter and MERbot could be optimized for much higher speeds, considering the capabilities of their legs.



at Rest Actuated state

FIGURE 11: 2-DOF Spring Roll

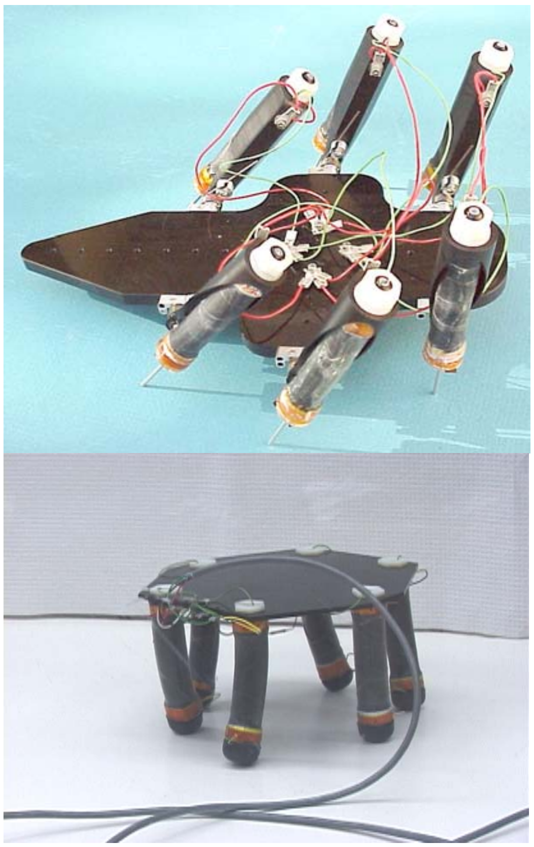


FIGURE 12: A photographic view of the Skitter

References

Pei, Q., R. Pelrine, S. Stanford, R. Kornbluh, M. Rosenthal, K. Meijer, and R. Full. "Multifunctional Electroelastomer Rolls," *Materials Research Society Symposium Proceedings*, Vol. 698, (2002), pp. 165–170.

Pei, Q., M. Rosenthal, R. Pelrine, S. Stanford, and R. Kornbluh. 2002. "3-D Multifunctional Electroelastomer Roll Actuators and Their Application for Biomimetic Walking Robots," *Smart Structures and Materials 2002: Industrial and Commercial Applications of Smart Structures Technology*, ed. A. McGowan, *Proc. SPIE*, Vol. 4698, pp. 246–253.

USA - University of Nebraska-Lincoln

Exchange coupling in all-organic composites with giant electrostriction

Jiangyu Li jli2@unl.edu

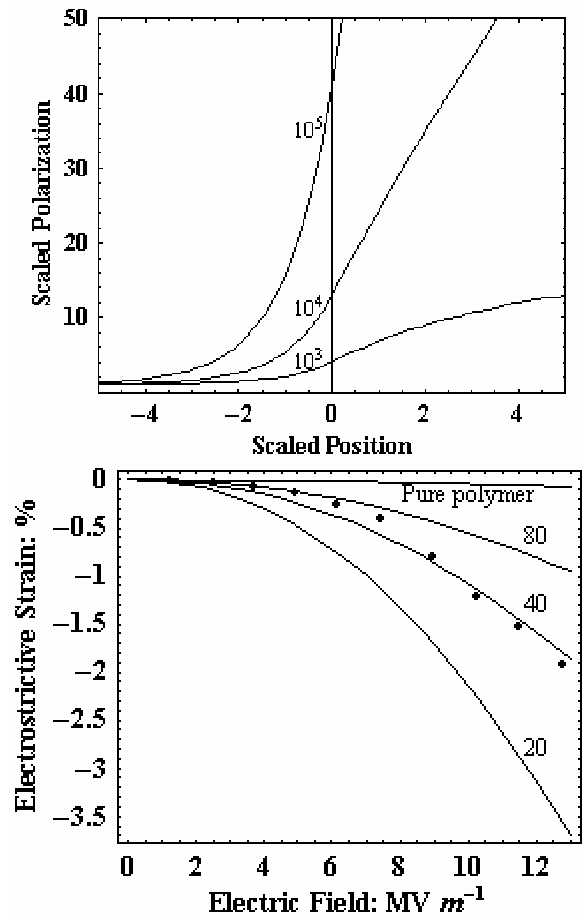


FIGURE 13: Top: the polarization profile at the composite interface for various dielectric constant of the second phase; Bottom: the strain versus electric field for various heterogeneity sizes of second phase.

At the Active Materials Lab in the University of Nebraska-Lincoln, we are working toward the analysis, design, and optimization of ferroelectric polymer based electrostrictive composites. Recently, we proposed an exchange coupling mechanism to explain the dramatically enhanced electrostriction and dielectric constant in an all-organic composite consisting of polyvinylidene fluoride trifluoroethelyne [P(VDF-TrFE)] copolymer matrix and copper-phthalocyannine (CuPc) particles reported by Q.M. Zhang's group in Penn State University, which could not be explained by traditional composite theory. We demonstrate that the dramatic property enhancement is due to the exchange coupling between the dielectrically hard P(VDF-TrFE) and dielectrically soft CuPc, which becomes dominant when the heterogeneity size of the composite is comparable to the exchange length; see Figure 13. The exchange coupling is a very effective mechanism when the heterogeneity size becomes small in composites, and could be used to enhance the piezoelectric, pyroelectric, and electrostrictive properties in ferroelectric and dielectric systems. For more information, please refer to *Physical Review Letters* **90**, article 217601, and *Applied Physics Letters* **81**, page 1860.

EMERGING EAP SUPPLIERS

Environmental Robots Incorporated

www.environmental-robots.com

Massoud Ahghar mahghar@environmental-robots.com

Complementary IPMC samples to everyone who requests

The complimentary IPMC samples program announced in the 8th issue of this Newsletter has been getting nice responses. A number of universities, research institutions and individuals have received complimentary samples of ionic polymeric metal composite (IPMC) from Environmental Robots Incorporated. The company is pleased to announce that upon request complimentary samples of IPMC will be provided to any interested researcher or institution. Inquiries can be directed to:

Massoud Ahghar
(mahghar@environmental-robots.com)
Environmental Robots Incorporated
909 Virginia Avenue, NE, Suite 205
Albuquerque, New Mexico 87108
Tel: (505) 265 4479

Educational outreach

Efforts are underway to bring the EAP technology, and in particular ionic polymer metal composites (IPMC), to the attention of the young curious minds, high school (grades 9-12), college students and researchers. For this purpose, Environmental Robots Incorporated (www.environmental-robots.com) has developed a low cost "Polymeric Artificial Muscles Science Kit®" to enable the users to learn about and manufacture IPMC based EAP and to be able to test them as a biomimetic distributed nanosensor and nanoactuator science project. Further information is available on the company website or by e-mail to mahghar@environmental-robots.com.

Network: Smart Textiles for Intelligent Consumer Products, UK

Sharon Baurley is collaborating with the textiles department at University Manchester Institute of Science and Technology [UK] to develop electroactive actuator fiber fabrics for which EAP can offer great potential. The principal aim is to develop a new genre of fabrics for fashion that can change their shape, texture, size in response to an electrical stimulus. The main challenge will be the extrusion and spinning of electroactive actuator polymers into fibers, which can then be woven or knitted. This new area of smart textiles is going to be very big in fashion, and will be driven by developments in electroactive polymers, such as EAP. She is seeking a developer of electroactive actuator and sensor polymers to join the project. Inquiries can be sent to s.baurley@csm.linst.ac.uk

In November 2003, Baurley has scheduled to launch the Network: Smart Textiles for Intelligent Consumer Products. Funded by the Engineering and Physical Sciences Research Council in the UK, this network will constitute a Think-Tank for future intelligent/smart consumer products, applications, textiles, and markets. The principal benefit will be the development of a new multidisciplinary community by bringing together all sectors that will be involved in the design, development and production chain, including designers and electroactive polymer developers. The network will generate R&D programs and will form a framework for a new research centre in intelligent products and textiles at Central Saint Martins.

Baurley is an Arts and Humanities Research Board, UK, research fellow, looking into interactive and experiential design of smart textiles. She is interested in the impact that active [smart] fabrics will have on the experience the consumer will derive from clothing and interior products, in terms of the consumer being able to express themselves through customization.

Central Saint Martins College of Art and Design is the largest of the five colleges of the London

Institute [UK], which is collectively the largest centre for art, design and communication research and education in Europe www.csm.linst.ac.uk .

BOOK REVIEWS

Biologically Inspired Intelligent Robots

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

In May 2003, the book that is entitled "Biologically-Inspired Intelligent Robots," covering this topic of biomimetic robots, was published by SPIE Press. The cover page of the book (Figure 14) presents the challenges to making such robots in terms of appearance, operation, facial expression, stability, robustness, etc. With today's technology one can quite well graphically animate the appearance and behavior of biological creatures (e.g., Shrek and other cartoon movies). Advances in biomimetics are increasingly making it feasible to emulate creatures to the point that viewers will eventually react with "gosh, this robot looks so real!" just like the reaction to an artificial flower. 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.

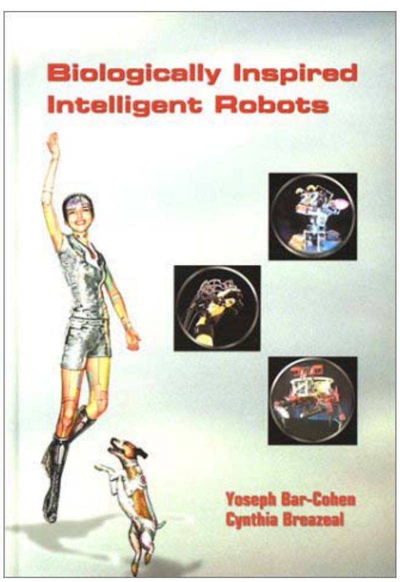


FIGURE 14: The cover page of the new book about biomimetic robots describing the state of the art and challenges to making such robots

The issues that are involved with the development of such robots are multidisciplinary and they include: materials, actuators, sensors, structures, functionality, control, intelligence and autonomy. Generally, it is interesting to address these technical issues but there are also fundamental ones that also need attention. Some of these issues include self-defense, controlled-termination and many others. Inspiration from science fiction has created very high level of public expectations. However, the reality will continue to be bound by the technology limitations that its state-of-the-art capability. Effectively, this book is about the electro-mechanical equivalence of cloning and ….who knows, as these robots become more engineering reality they may rise to become a topic of public debut similar to the topic of cloning biology.

Further information about this book is available on:
http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm
and
http://www.spie.org/web/abstracts/oepress/PM122.html

UPCOMING EVENTS

23-25 June 2003	11th International Seminar on the Technology of Inherently Conductive Polymers, Boston, MA, Matt Aldissi at: maldissi@fractalsystemsinc.com
14-18 March, 2004	EAPAD, SPIE's joint Smart Materials and Structures and NDE Symposia, San Diego, CA., Pat Wight patw@spie.org Website: http://spie.org/Conferences/Calls/04/ss/conferences/index.cfm?fuseaction=SS03
25-28 April 2004	2nd "Biomimetics and Artificial Muscles," Williamsburg, Virginia, M. Shahinpoor shah@unm.edu
14-16 June 2004	ACTUATOR 2004, Messe Bremen GMBH, Germany. H. Borgmann, actuator@messe-bremen.de Website: http://www.actuator.de

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):

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

Webhub: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-web.htm

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

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

Opportunities:
http://www.acq.osd.mil/sadbu/sbir/solicitations/sttr02/navy02.htm

Biomimetics: http://ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/bm-hub.htm

WorldWide Electroactive Polymers (EAP) Newsletter

EDITOR: Yoseph Bar-Cohen, JPL, http://ndeaa.jpl.nasa.gov

All communications should be addressed to:

Dr. Y. Bar-Cohen, JPL, M.S. 82-105, 4800 Oak Grove Dr., Pasadena, CA 91109-8099
Phone: (818)-354-2610, Fax: (818)-393-3254 or E-mail: yosi@jpl.nasa.gov