WorldWide ElectroActive Polymers


EAP

(Artificial Muscles) Newsletter

June 2004 **WW-EAP Newsletter** **Vol. 6, No.1**

http://eap.jpl.nasa.gov

FROM THE EDITOR

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

It is my pleasure to report another milestone for the field of EAP – we are planning to hold on March 2005 the 1st Armwrestling Match of EAP Robotic Arm against Human (AMERAH). We already have two committed contestants with a third one that gave a commitment pending on availability of development funding. Also, we now have a wrestler on the human side and her name is Panna Felsen, a high school student from the San Diego school district. Panna is an A student with great interest in robotics. To make the competition meet high sportsmanship standards, rules were drafted and posted on the WW-EAP webhub. Also, a formal armwrestling table was committed for the competition.

As mentioned in the previous issue of this Newsletter, SPIE is hosting this event during the EAP-in-Action Session of the EAPAD Conf., at the Town & Country Resort, San Diego, CA. The competition will be held on March 7, 2005, at 5:00 PM

Since communication and information exchange are very important to the progress in the field, I have recently formed an easy to remember alias link for our WW-EAP Webhub http://eap.jpl.nasa.gov

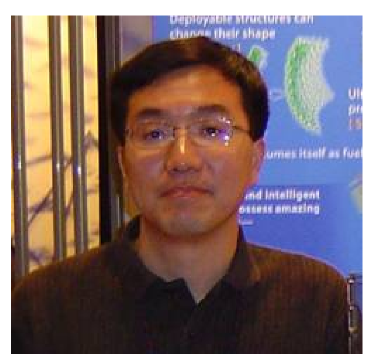
Another notable event that deserves the attention of our EAP community is the recent 50th anniversary of the American Society for Artificial Internal Organs (ASAIO). The objective of this society is to promote development and implementation of artificial organs and medical aiding devices. Some of the organs that are getting significant attention include heart, kidney, liver, and lungs. However, other devices and mechanisms are also of interest and I am hoping to see artificial muscles as one of the subjects of this society involvement.

The reported progress in this issue indicated continuing advances in the field of EAP with such exciting devices as a smart pill and a Braille display.

On March 15, 2004, the 2nd Edition of the book entitled "Electroactive Polymers (EAP) actuators as artificial muscles" was published by SPIE. This comprehensive book brings up to date information about EAP http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

ABOUT THE EXPERTS

Qibing Pei



At the beginning of July this year, Qibing Pei is leaving SRI International to join the University of California, Los Angeles, as professor of materials science and engineering.

At SRI International he worked on a variety of electronic polymers and devices including polymer light emitting diodes, polymer light emitting electrochemical cells, electroactive polymer artificial muscles, and biologically-inspired robots. His research interests include synthesis of new electronic polymers, nano-structured solar cells, electro-elastomers with large electrically-induced strain. Before joining UCLA, Pei was a senior chemist at UNIAX Corporation, which was later merged into DuPont Display, and then a senior research engineer at SRI. At his new address he can be reached by email qpei@seas.ucla.edu, phone: (310) 825-4217; fax: (310) 206-7353.

Liming Dai

In September, Liming Dai will leave his professorship at the Polymer Engineering, the University of Akron's College of Polymer Science and Polymer Engineering to build and guide a research program in nanomaterials at The University of Dayton in collaboration with the Materials and Manufacturing Directorate of the Air Force Research Laboratory. Being the first Wright Brothers Institute Endowed Chair in Nanomaterials (http://www.afrlhorizons.com/Briefs/Sept02/HQ0205.html), Dr. Dai will begin his career at UD as a full professor in The School of Engineering, with joint appointments at the Research Institute and in the College of Arts and Sciences. His new E-mail address is: Liming.Dai@udri.udayton.edu

GENERAL NEWS

The WW-EAP Webhub is continually being updated with information regarding the EAP activity Worldwide. This webhub can be reached on http://eap.jpl.nasa.gov and it is a link of the JPL's NDEAA Technologies Webhub having the address: site: http://ndeaa.jpl.nasa.gov

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50th anniversary of the American Society for Artificial Internal Organs (ASAIO)

The American Society for Artificial Internal Organs (ASAIO) is celebrating its 50th anniversary this year. ASAIO has over 1,400 Members consisting of specialists from 40 different countries with over 30 different professional degrees. They represent private hospitals, universities, government, industry, and independent research groups. The areas of Nephrology, Biomaterials and Cardiopulmonary devices are heavily represented as well as numerous other specialized interests. The Annual ASAIO Conference draws over 1,000 attendees with a broad range of primary interests to the society. This Conference provides a forum for over 400 speakers from more than a dozen countries. It provides a forum for individual researchers to present not only to fellow investigators, but also to members of industry and to government representatives who are involved in regulatory affairs as the projects are developed into the production of clinical devices.

The 1st armwrestling planned for March 7, 2005

The 1st Armwrestling Match of EAP Robotic Arm against Human (AMERAH) is now a reality. It became possible with the announcement of two committed and one on contingency organizations that they will are planning to be ready as contestants. These organizations (in the order of joining the competition) are:

1. SRI International, Menlo Park, CA, USA (Currently seeking the necessary funds to develop the required arm in order to compete)
2. Environmental Robots Incorporated (ERI), Albuquerque, New Mexico, USA. A model of the ERI's wrestling arm was presented at the 2004 EAP-in-Action Session of the SPIE's EAPAD Conf. that was held in San Diego, CA, March 15, 2004.
3. Swiss Federal Laboratories for Materials Testing and Research, EMPA, Dubendorf, Switzerland

Initially, the challenge is to win against a human (any human) using a simple shape arm. However, the ultimate goal is to win against the strongest human using as close resemblance of the human arm as possible.

Objective

Developing a winning arm will require advances in the EAP field infrastructure including: Analytical tools, materials science, electromechanical tools, sensors, control, feedback, rapid response, larger actuation forces, actuator scalability (use of small and large ones), enhanced actuation efficiency, etc. The competition will help:

- Promote advances towards making EAP actuators that are superior to the performance of human muscles.
- Increase the worldwide visibility and recognition of EAP materials.
- Attract interest among potential sponsors and users.
- Lead to general public awareness since it is hoped that they will be the end users and beneficiaries in many areas including medical, commercial, etc.

Current status

The news about the competition has reached the world of armwrestlers and it brought the attendance of armwrestling VIP at during the EAP-in-Action Session of the 2004 SPIE's EAPAD. Shown in Figure 1, these VIP included John Brzenk (the World Wrestling Champion per Guinness Book of Records), John Woolsey (ABC Wide World of Sports Wrist-wrestling Champion) and Harold Ryden (California State Champion),

These champions were introduced to the 2004 EAPAD Conference attendees to give them an idea regarding the toughness of the challenge ahead. The participation of these champions was arranged thanks to Mr. Marvin Alex Cohen, who was the Technical Advisor to Warner Bros Motion Pictures in the movie "Over The Top", which was stared by Sylvester Stallone. Cohen participated in the conference under the banner "Fox Sports Net".

Rules for the competition

In order to assure the safety of the human competitor and the fairness/sportsmanship of the Match, rules were drafted for the various parties to the competition. These rules are envisioned to be modified as advances will be made and more capable arms will be produced. The rules were posted as a link to the Armwrestling Competition website at http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/armwrestling-rules.htm. Suggestions and comments can be sent to yosi@jpl.nasa.gov.

To make the competition an official international event, the editor received the commitment of Dave Devoto to provide a standard armwrestling table (an example of such table is shown in Figure 2). Dave is the pioneer and leading representative of the United States ArmSports and he is a member of the competition committee.

FIGURE 1: The arm- and wrist- wrestling champions (from left to right J. Brzenk, J. Woolsey, and H. Ryden) who attend the EAP-in-Action Session of the EAPAD Conf. in March 2004.

Members of the Organization Committee

CHAIR: Yoseph Bar-Cohen, Senior Research Scientist, JPL

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

Robert Dennis - Expert in skeletal muscle tissue engineering at the University of Michigan and MIT, Biomechatronics Groups

Dave Devoto - Pioneer and leading representative of the United States ArmSports

Richard Landon - Stan Winston Studio, the studio that designed and created the robots and makeups for Spielberg's movie AI.

Joanne Pransky - World's First Robotic Psychiatrist

Scott Walker - Former Senior Event Manager, SPIE

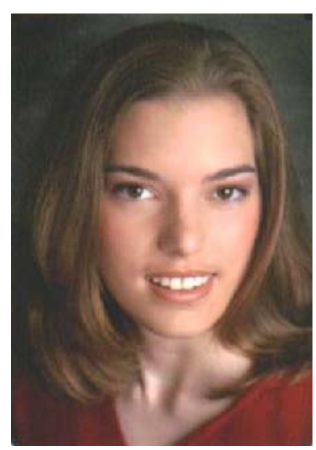
Brian Thomas - Current Senior Event Manager, SPIE

FIGURE 2: Standard armwrestling table. For a scale see the viewgraph projector on the top-right. **Acknowledgment**: This table was brought to the 2004 EAPAD Conf. by Marvin Alex Cohen and his armwrestling VIPs who accompanied him.

The Armwrestling - Support Organizations

- The hosting and logistics of the competition will be done by SPIE
- The United States ArmSports, which is an umbrella organization representing armwrestlers, armwrestling organizations and tournaments in the USA and worldwide.

The Human Opponent — Panna Felsen



Panna Felsen is a student in the class of 2005 at the La Costa Canyon High School of the San Diego School District. She is a hardworking student who mixes both education priorities and extracurricular activity ranging from recreation sports to robotics.

Panna has taken as many as six AP courses in a school year—and earned all A's in course work that included advanced calculus and physics. In her junior year, she founded an engineering club at her school for which her robotics knowledge helped the team win KISS Institute's National Research and Design Challenge. She also taught the members IC programming and led the design team that built and programmed autonomous robots for which her Botball team earned second place at Southern California Regionals. During the summer, 2004, she was selected as a NASA Sharp Apprentice to do paid research at the University of Michigan. Ultimately, she plans to enter the engineering field.

She lives in Encinitas, California, which is located north of San Diego, where she enjoys shooting hoops at the YMCA and occasional walks to the beach from her home. What was once training ground during her eight-year competitive swimming regiment, the beach is now a place where she goes only for recreation to ride her boogie board and to build extreme sand castles—when she allows herself the free time. Panna's interests began to change from athletics to academics when she was introduced to Botball robotics in middle school.

Currently, Panna is serving as the only student member of the San Diego Science Alliance Robotics Steering Committee, the group that first introduced her to robotics. She is also organizer of her school's participation in Science Olympiad, and on weekends, she works as a ballroom dance junior instructor for the San Dieguito Cotillion.

RECENT EAP CONFERENCES

2004 SPIE EAPAD Conference

The 6th 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 conference sessions including the applications of EAP

Tithe Keynote Speaker was Hugh Herr (Figure 3), MIT-Harvard Division of Health Sciences and Technology, and the title of his talk was "New horizons for orthotic and prosthetic technology: merging body and machine." In his talk, he described the progress in the development of smart artificial limbs and prosthetics, also known as Cyborgs, to which EAP can contribute enormously. He described prosthetic ankles and foots that were made in his lab allowing natural walking capability and he shared his own personal experience. He described the need for EAP as actuators that will be low mass, quiet, fast to respond and will not require high metabolism to operate.

FIGURE 3: The Keynote Speaker, Hugh Herr, MIT

The conference presentations covered progress in the various areas of the EAP infrastructure including:

- Electroactive polymers (EAP) and non-electro active-polymer (NEAP) materials
- Theoretical models, analysis and simulation of EAP and computational chemistry.
- Support technologies, including electroding, synthesis, processing, shaping and fabrication
- Methods of testing and characterization of EAP
- EAP as multifunctional materials
- EAP scalability to miniature (MEMS, micro and nano) and large dimensions
- EAP as artificial muscles, actuators and sensors
- Design, control, intelligence, and kinematic issues related to robotic and biomimetic operation of EAP
- Under consideration, in progress or desired applications of EAP

The papers focused on issues that can forge 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 Editor defined: ionic and electric EAP. The electric EAP materials are driven by electric forces and involve mostly movement of electrons, whereas the ionic EAP materials consist of electrodes and electrolytes and involve mobility/diffusion of cations or anions.

FIGURE 4: David Hanson presenting his latest Android heads during the EAP-in-Action Session.

The efforts described in the presented papers are showing significant improvements in understanding of the electromechanical principles and better methods of dealing with the challenges to the materials applications. Researchers are continuing to develop analytical tool 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.

As in past years, the EAP-in-Action Session was held on Monday, March 15, 2004. The attendees were given an opportunity to see eight 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. As mentioned earlier, this year, leading individuals from the armwrestling world have honored the conference with their attendance as shown on Page 3 (see Figures 1 and 5).

FIGURE 5: John Brzenk (the World Wrestling Champion per Guinness Book of Records) in wrestling pose with the ERI's arm model (NOTE: it was not shown active) that was presented at the EAP-in-Action Session.

The presentations in the EAP-in-Action Session included:

- David Hanson, University Texas of Dallas and Human Emulation Robotics, and Victor White, - EAP Testbench Android.
- Jawad Naciri, Amritha Srinivasan (Geo-Centers, Inc.), and Banahalli R Ratna, Naval Research Laboratory - Liquid Crystalline Elastomers as Artificial Muscles.
- Mohsen Shahinpoor and Massoud Ahghar, Environmental Robots Incorporated (ERI) - A wrestling robotic arm driven by EAP (ionic polymeric contractile PAN) and an array of their EAP products.
- Patrick Anquetil, Nate Vandesteeg, and Rachel Zimet, MIT - Polypyrrole-Based Finger Actuators in Air.

- Qibing Pei, Scott Stanford, Marcus Rosenthal, Jon Heim, Roy Kornbluh, Ron Pelrine, Harsha Prahlad, and Neville Bonwit, Philip von Guggenberg - SRI International, and Alex Beavers, CEO - Artificial Muscle Inc (AMI), - Artificial Muscles: From Creatures to Products.
- Qiming Zhang, Penn State University, Terpolymers and a micro-pump -video and sample
- Rick Claus and Sherri Box, NanoSonic, Inc. - Self-assembled membrane materials and their use as electrodes on EAP actuators
- Liming Dai, University of Akron, and prabhu Soundarrajan, Applied Nanotechnology, Texas - Carbon Nanotube EAP actuators.

FIGURE 6: Chi-Min Li, Auburn University, the winner of the Best Poster award for the 2004 EAPAD Conf.

The poster session this year included 11 papers and the presenters were asked to summarize the content of their poster. To bring visibility to the high quality of these papers and to promote excellence, an award for the Best Poster Paper was given this year. The posters were reviewed by the Conference co-Chair, Peter Sommer-Larsen, Risø National Lab, Denmark, who served as the Poster Session Chair. The award was given to Chi-Min Li, Auburn University (see Figure 6), for her paper entitled "Recrystallization study of high-energy-electron irradiated P(VDF-TrFE) copolymer," paper No. 5385-67.

The conference also included an Open Panel Discussion Session to debut the status of the field of EAP. The panel Moderator was the Conference Chair: Yoseph Bar-Cohen, JPL, and the panelist included: Peter Sommer-Larsen, Risø National Lab. (Denmark); Qibing Pei, SRI International; Jaedo Nam, Sung Kyun Kwan Univ. (South Korea); Toribio F. Otero, Univ. Politécnica de Cartagena (Spain); Keiichi Kaneto, Kyushu Institute of Technology (Japan); Elisabeth Smela, Univ. of Maryland/College Park; and Philip von Guggenberg, SRI International. 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
- Future science and engineering directions

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 and the general views have been that the field is moving in the right direction and the progress is very encouraging.

2nd Conf. on Artificial Muscles, Japan

On May 20-21, 2004, "The Second Conference on Artificial Muscles" was held at the National Institute of Advanced Industrial science and Technology (AIST), Ikeda, Osaka, Japan. This conference was organized by the Research Institute for Cell Engineering (RICE) of AIST, the Bio-mimetic Control Research Center (BMC) of RIKEN (The Institute of Physical and Chemical Institute), and the Technical Committee on Soft Material, System Integration (SI) Division, The Society of Instrument and Control Engineers (SICE). The organizers were Takahisa Taguchi (RICE), Zhi-Wei Luo (BMC), Kinji Asaka (RICE), and Yoshihiro Nakabo (BMC). More than 170 attendees participated in this conference which included 10 invited papers and 23 oral and

FIGURE 7: The organizers and the invited speakers at the 2nd Conference on Artificial Muscles that was held on May 20-21, 04, in Osaka, Japan.

poster papers. The conference objectives were to provide an integrative forum for researchers and technicians, who are interested in the technology of the artificial muscles. Also, it provides a form of information exchange, stimulation of discussion and presentation of recent advances in the following three main subjects:

1. Biomolecular systems as models for artificial systems.
2. Functional polymers as artificial soft materials.
3. Bio-mimetic robotic system integrated artificial muscles.

The invited speakers were: Y. Bar-Cohen (JPL, USA), T. Yoshikawa (Kyoto Univ., Japan), R. H. Baughman (Univ. of Texas at Dallas, USA), T. Hirai (Shinshu Univ., Japan), I. Otsuki (Jikei Medical Univ., Japan), S. Arimoto, (Ritsumeikan Univ., Japan), S. Hosoe (RIKEN, Nagoya Univ., Japan), N. Hogan (MIT, USA), K. Kaneto (KI Tech, Japan).

The conference was opened with a presentation by Y. Bar-Cohen, JPL, who reviewed the state of the art of the field of EAP and the current challenges. On the second day of the conference, Y. Osada (Hokkaido Univ., Japan) gave a keynote presentation entitled "Intelligent Gels – An Approach to Artificial Muscles". At the closing of the conference, Bar-Cohen gave the closing remarks where he pointed out that the participants well recognize the advantages and disadvantages of current EAP and the important issues that need to be solved in the near future. Further, he stated that even though EAP may have enormous potential as functional materials it is critical to see niche applications where the properties of these materials offer advantages with clear superiority over competing actuators.

A limited number of abstract books are now available from asaka-kinji@aist.go.jp or nakabo@riken.jp .

EAP COURSES & TUTORIALS

Course on EAP - EAPAD 2004

An introductory course about EAP was given during the EAPAD 2004 Conference. The course was entitled "Electroactive Polymer Actuators and Devices," and the lead instructor, Y. Bar-Cohen, presented an overview, and cover applications that are currently developed and ones that are being considered. The subject of Ionic EAP was covered by J. Madden from the University of British Columbia, Vancouver, Canada. Further, the topic of Electronic EAP was covered by J. Su from NASA Langley Research Center, USA. This course was attended by about 30 students and was intended for Engineers, scientists and managers who need to understand the basic concepts of EAP, or are interested in learning, applying or engineering mechanisms or devices using EAP materials.

Tutorial on EAP - 2004 IROS Conference, Japan

A tutorial on "Electro-Active Polymers for Use in Robotics" is planned to be given during the upcoming 2004 IROS conference, Japan (http://www.iros2004.org/). This tutorial will cover the fundamental chemistry, physics, modeling, and demonstration of EAPs and robotic applications. Specific topics will include a) Dielectric elastomer (by H. R. Choi and J.-D. Nam, Sungkyunkwan University, S. Korea), b) Ionic polymer-Metal Composite (Kwang J. Kim, University of Nevada, Reno, USA), and c) EAP applications and demonstration in robotics (S. Tadokoro, Kobe University, Japan and W. Yim of UNLV, USA).

CALL FOR PAPERS AND FUTURE CONFERENCE

2005 EAPAD Conf. – Call for papers

A call for papers was issued for the 2005 EAPAD Conf. where abstracts are due on Aug. 23, 2004 and the papers are due by Feb. 7, 2005. This conference will be held again in San Diego, CA from March 7 to 10, 2005. As in past years, the objective is to identify improvements and development of new EAP materials, enhance the understanding of the electromechanical behavior, cover effective modeling of the electro-mechanics and chemistry, processing and characterization techniques, as well as applications of these materials. Further, this conference is seeking to promote the development of high performance EAP as smart materials and to increase the recognition of EAP as viable options for use in smart structures.

2nd World Congress on Biomimetics

The second world congress on biomimetics, artificial muscles and nano-bio is scheduled to be held from December 5 to 8, 2004 at the Albuquerque Convention Center, New Mexico. The congress this year will emphasize the role of nanotechnology in biological systems and biomedical research. Abstracts can be submitted online view the congress website (www.world-congress.net) and also registration can be made via this site.

ACTIVITY IN COUNTIES WORLDWIDE

Advances in EAP are continuing to emerge worldwide and two countries seem to have a very notable level of activity that deserves special attention. During my visits to Korea and Japan in the middle of May, I was very impressed of the broad range of activity and the number of organizations that are conducting related research. In this issue I added this section that is dedicated to the progress in specific countries worldwide and this issue includes a review of the activity in Korea that Jaehwan Kim provided.

EAP R&D activity in Korea

Jaehwan Kim jaehwan@inha.ac.kr

Increasingly, Korea is becoming a leading hub for active EAP research programs and it has a growing research community that devotes its efforts to issues related to materials and devices development. The following lists the activity at some of the leading research centers in Korea (see also the section Advances in EAP later in this issue).

Korea Institute of Science and Technology (KIST, B. Kim), Korea University (J.J. Park) and Dankook University (S.-K. Lee) are jointly working on development of IPMC related technology. Thick (1mm) IPMC films were fabricated using a casting method. Fish robot, walking robot for pipe inspection without connecting wire, and micropump in MEMS were successfully demonstrated using IPMC actuators. Moreover, using polypyrrole actuator a valve was fabricated for a cell manipulator that is part of a cell processor chip. A photographic view of the micropump is shown in Figure 8 and a schematic view of the fabrication process of the valve is shown in Figure 9.

At the Sungkyunkwan University (H.R. Choi, J.D. Nam) dielectric elastomer EAP was used to develop a tube-like smart pill that is a biomimetic moving mechanism (Figure 10). The mechanism is based on an inchworm motion, and it is intended to traverse inside the gastrointestinal track. Further, a tactile stimulator of Braille display for visually impaired is being developed using dielectric elastomer EAP that does not require pretension. A photographic view of the Braille display element is shown in Figure 11. More details about these devices are given later in this issue.

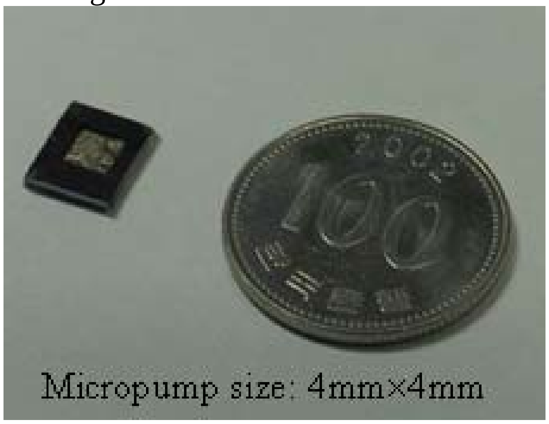


FIGURE 8: A view of the micropump

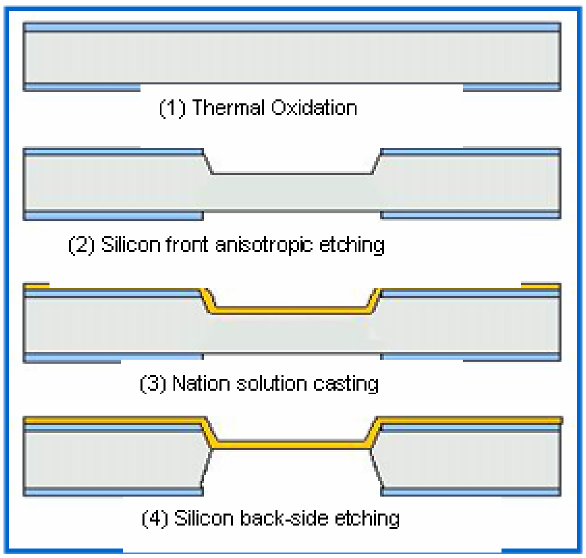


FIGURE 9: A schematic view of the valve fabrication process.

FIGURE 10: A tube-like smart pill that is a biomimetic moving mechanism.

Hanyang University (S.J. Kim, Biomedical Engineering) is investigating the development of smart system capable of Bio-MEMS & NEMS or nano-biomimetic organs using biocompatible EAPs. For this purpose, not only macroscale biomedical engineering is being studied but also the nanoscale level. The resulting research was already documented in over 60 publications in international journals.

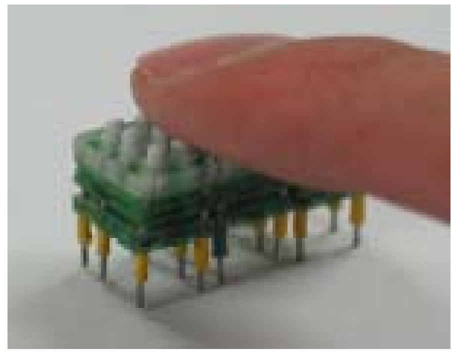


FIGURE 11: Braille display for visually impaired.

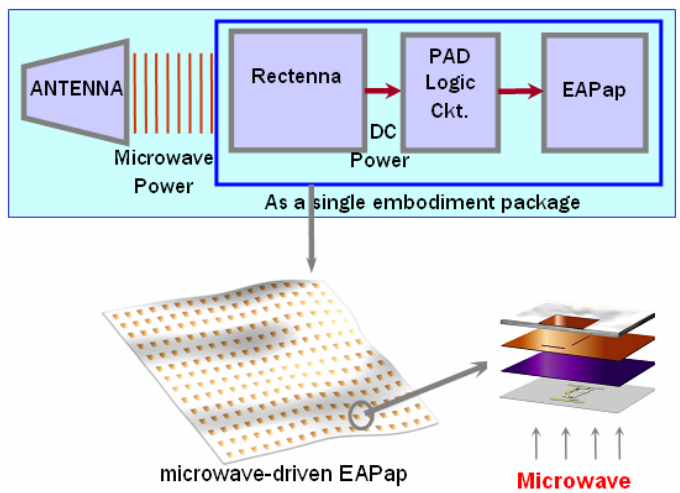


FIGURE 12: A schematic view of an EAPap based actuator and its wireless activation by microwave.

In June 2003, **Konkuk University** has launched one of its specialized research institutes, *Artificial Muscle Research Center*. This Center is led by K.J. Yoon from the Department of Aerospace Eng. (http://artm.konkuk.ac.kr). Seven professors and graduate students majoring in physiology, polymer processing, textile engineering, aerospace engineering, and electrical engineering have joined this center. Their objective is to develop EAP and Piezo-composite actuators and to apply the technology to biomimetic locomotive devices where flying/ swimming robot systems are some of the applications that are being considered. Current research topics include IPMC flapping wing for mimicking bird wing, flying robots actuated by piezo-composite actuator (LIPCA), developing shape memory polymer and controlling surfaces of micro air vehicle (MAV) using EAPs.

Inha University (J. Kim) has recently established the *Creative Research Center for EAPap Actuator* (www.EAPap.com). This center is sponsored by the Ministry of Science and Technology for the research of remotely activatable microwave-driven EAPap (Electro-Active Paper) actuators. EAPap is a paper that can be activated in the presence of electric field, and the concept of microwave-driven EAPap is very attractive for many applications since it can be made wirelessly and it does not require carrying any batteries. A schematic view of the activation of this type of actuator is shown in Figure 12. The developed actuator can be easily integrated, compact, lightweight and rugged. The Center will be devoted for the research of EAPap actuators in terms of material development, conceptualization and development of remotely-driven EAPap devices for niche applications. This research is multi-disciplinary and Korea-US collaboration is anticipated.

ADVANCES IN EAP

Jet Propulsion Laboratory, Pasadena, CA, USA

Potential bio-medical application of Cold Hibernated Elastic Memory (CHEM) self-deployable structure

Witold Sokolowski,
Witold.M.Sokolowski@jpl.nasa.gov

A number of medical applications are being considered for the cold hibernated elastic memory (CHEM) self-deployable structure technology. CHEM technology utilizes polyurethane-based shape memory polymers in open cellular (foam) structures. The CHEM structures are self-deployable and are using their shape memory plus the foam's elastic recovery to erect a structure. In practice, the CHEM foams are compacted to small volume above their glass transition temperature Tg. They may then be stored below their Tg without constraint. Heating to a temperature above their Tg restores their original shape. The CHEM technology is under development at the Jet Propulsion Laboratory (JPL) and its processing cycle is illustrated in Figure 13 below.

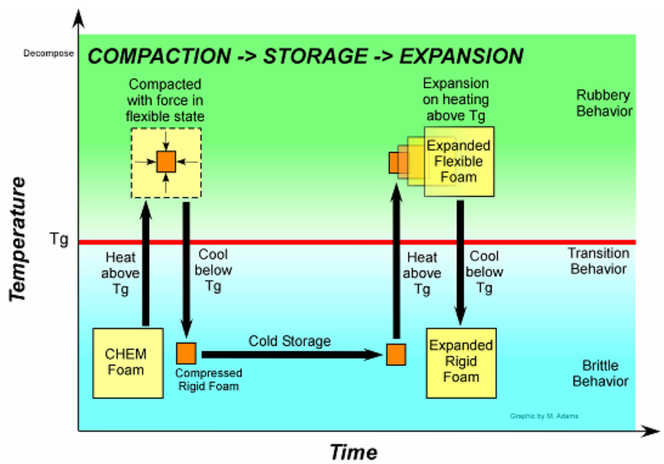


FIGURE 13: CHEM processing cycle

Biomedical and dental CHEM applications are foreseen for vascular and coronary grafts, catheters, orthopedic braces and splints, dental implants and prosthetics, just to name a few.

One of these potential applications, endo-vascular treatment of aneurysm, was experimentally investigated at the Ecole Polytechnique, Montreal. Lateral wall venous pouch aneurysms were constructed on both caroid arteries of 8 dogs. The aneurysms were occluded with CHEM blocks. The efficient vascular embolization was confirmed in the aneurysms and good neointimal formation over the neck of treated aneurysms was demonstrated at the CHEM interface. Maxillary arteries embolized with CHEM foam remained occluded during this 12 week experiment. The major conclusion of the investigation was that new embolic devices for endovascular interventions could be designed using CHEM's unique physical properties.

Kyushu Institute of Technology, Japan

Improved performance of conducting polymers actuators based on polyaniline and polypyrrole

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The linear strain of polyaniline (PANi) actuators [1] has been improved to produce more than 7% deformation by operating at high concentration of supporting electrolyte of 3M NaCl at pH2. The large strain is explained in terms of the Donnan effect. It is also found that (as shown in Figure 14) the electro activity of PANi film has shifted toward higher pH by making composite with polypyrrole (PPy) or by reinforcing the film conductivity with metal coated textile gauze, the electro activity of PANi film extended to pH 5. The result expects to expand the possible usage of PANi films to the practical applications.

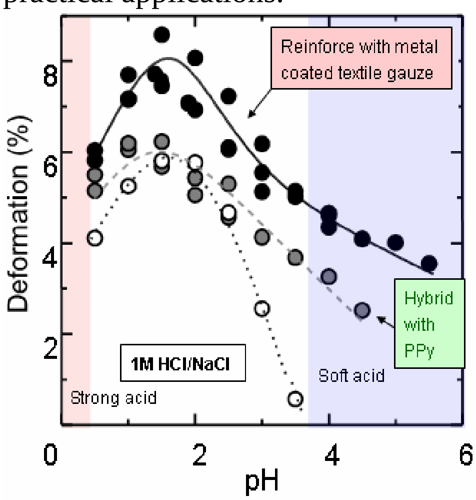

FIGURE 14: The deformation of PANi as a function of pH.

Eamex Co. has developed super polypyrrole film [2], which shows the electrochemical strain of 26.5 % and the stress of 6.7MPa. These figures are close to the natural muscle except for the response time. The film was electrochemically deposited on Ti or Pt electrode in tetrabutylammonimun bis(trifluoromethane sulfonyl)imid (TBATFSI)/ methylbenzoate solution. The film shows the macro porous morphology and gel like with the conductivity of 129 S/cm. This film and the method of preparation of conducting polymer are believed to be a new breakthrough for field of EAP.

References

[1] W. Takashima, M. Nakashima, K. Kaneto, Electrochem. Acta, 2004 in press.
[2] S. Hara, T. Zama, W. Takashima and K. Kaneto, J. Mater. Chem. 2004, 14 1516-1517

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Tabulated the properties of conductive polymers

Patrick A. Anquetil patanq@mit.edu and Ian Hunter, MIT

TABLE 1: Comparison of the properties of polypyrrole as a conductive polymer EAP and skeletal muscles.

Property	Polypyrrole v.2003.03 in 0.1 M TEAP in PC [2]	Mammalian Skeletal Muscle[1]
Activation Potential	2 V amplitude	-
Displacement (Strain)	2 % (at 10 MPa)	20 %
Max. Active Stress (Load)	40 MPa	0.35 MPa
Velocity (Strain Rate)	3 %/s (at 5 MPa)	100 %/s
Power to mass	150 W/kg	50-100 W/kg
Strain to charge	1.3×10^{-10} m³/C	-
Efficiency	0.6 % (at 4 MPa) 3 % (at 30 MPa) 18 % (with energy recovery)	30 - 35 %
Stiffness (wet)	0.2 to 0.8 GPa	0.3 to 80 MPa (contracted)
Tensile Strength (wet)	120 MPa	0.3 MPa
Conductivity	4.5×10^{4} S/m	-
Lifetime	10^{5} (at 0.3 %)	10^{9}

[1] Hunter I. et. al., *Technical Digest IEEE Solid State Sensors and Actuators Workshop*, **1992**.
[2] Madden et. al., in press.

Recently, researchers at the BioInstrumetation Lab, MIT, have documented a comparative table that shows the properties of conductive polymer EAP compared to skeletal muscles. Activation solution was 0.1 M tetraethylammonium hexafluorophosphate in propylene carbonate. This data is documented in Table 1 and it is also posted as one of the WW-EAP webhub links at the following address http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/PPY-v-2004-03-Perfromance-MIT.pdf

Ohio Aerospace Institute/Northland Scientific Inc., Cleveland, Ohio, USA

IPMC Based Solid State Aircraft Concept

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A revolutionary type of unmanned aircraft may now be feasible, due to recent advances in polymers, photovoltaics, and batteries. This is a "solid-state" aircraft, with no conventional mechanical moving parts (Figure 15). Airfoil, propulsion, energy production, energy storage and control are combined in an integrated structure.

The key material of this concept is an ionic polymeric-metal composite (IPMC) that provides source of control and propulsion. This material has the unique capability of deforming in an electric field like an artificial muscle, and returning to its original shape when the field is removed. Combining the IPMC with emerging thin-film batteries and thin-film photovoltaics provides both energy source and storage in the same structure.

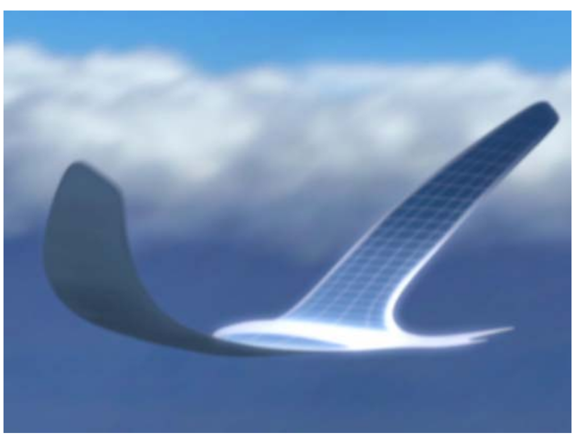

FIGURE 15: Artists drawing of the solid state IPMC based aircraft concept

Combining the unique characteristics of the materials enables flapping motion of the wing to be utilized to generate the main propulsive force. With a flight profile similar to a hawk or eagle, the Solid State Aircraft will be able to soar for long periods of time and utilize flapping to regain lost altitude. By analyzing the glide duration, flap duration, wing length and wing motion of travel it has been determined that a number of design configurations can potentially be produced to enable flight over a range of latitudes and times of the year on Earth, Venus and possibly Mars.

Sungkyunkwan University, Korea

Development of muscle actuator based on dielectric elastomer without pretension and its applications

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Recently, a series of mechanisms and devices were developed using dielectric elastomer EAP. The actuator converts the bending motion of the elastomer into the translational motions, which assures repeatable and robust performance of actuation as shown in Figure 16. The actuator that was developed does not require pretension and thus eliminate the problem of creep that degrades the performance of prestrained EAP. A photographic view of the new actuator is shown in Figure 17.

Specific applications of the new elastomer EAP that does not require pretension include a biomimetic inchworm robot that can serve as a smart pill (Figure 18) and a Braille display device (Figure 19).

The smart pill that was made as a tube-like structure that is biomimetic moving mechanism. This robot uses inchworm motion in order to move inside of the gastrointestinal track The flexible skin of the smart pill was fabricated using a 3-D molding technique.

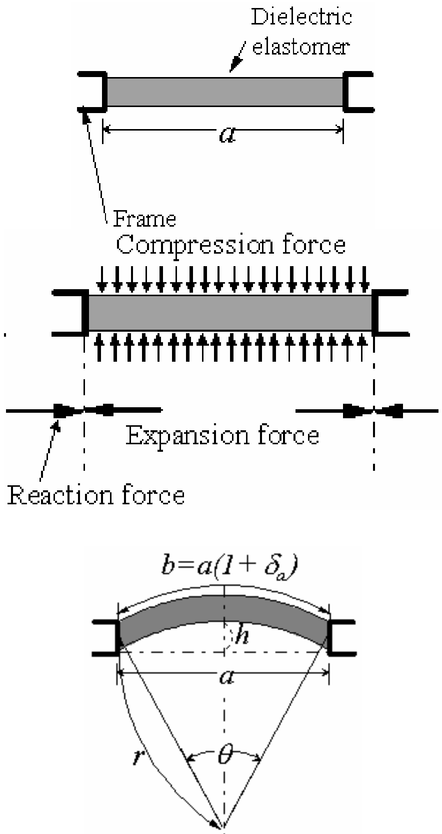

FIGURE 16: Basic principle of actuation without pretension.

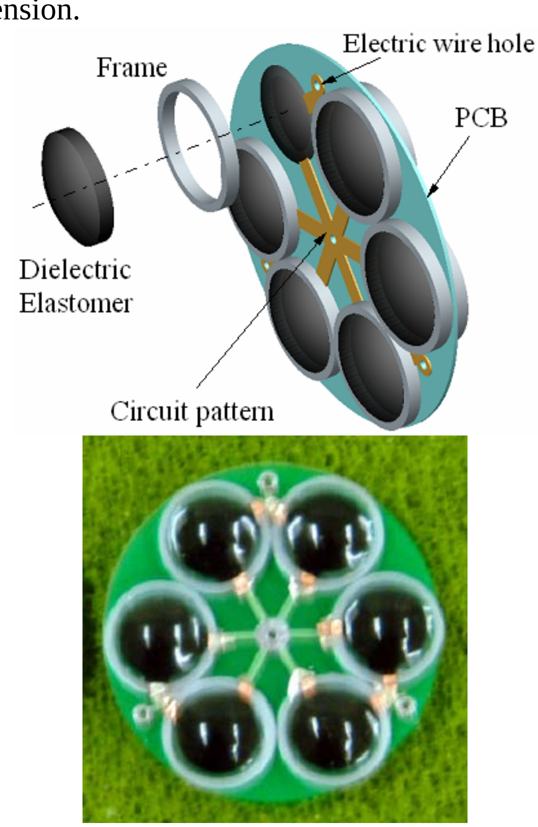

FIGURE 17: Actuator module (six actuator units are integrated)

Acknowledgement: This project is funded by 21C Intelligent Microsystem Research Program, Korea Ministry of Science and Technology

The second application of the elastomer EAP was a tactile stimulator of Braille display for visually impaired. The display was designed to be completely compatible with existing Braille devices and its performance is currently being under evaluation. A photographic view of the display and its mode of test showing a human finger on it can be seen in Figure 19. In Figure 20, a view of a blind person is shown testing the new EAP Braille display.

Acknowledgement: This project is funded by Korea Ministry of Health and Welfare.

FIGURE 18: Different views of the smart pill that is a tube-like biomimetic moving mechanism.

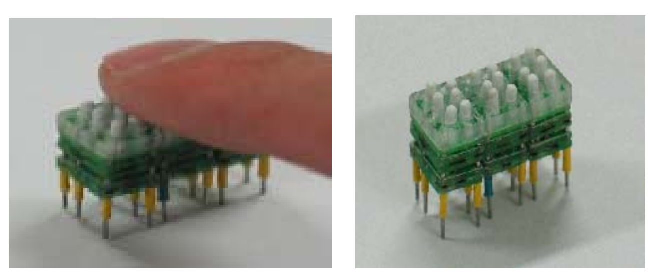

FIGURE 19: Braille display for visually impaired

FIGURE 20: Evaluation of the EAP based Braille display device for the visually impaired.

University of Nevada, Reno, USA

Self-Oscillatory Behavior of Ionic Polymer-Metal Composite (IPMC)

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The use of Ionic Polymer-Metal Composite (IPMC) based materials is attractive since they are operational in aqueous environment producing a reasonable level of forces and useful nominal strains under low voltages. Moreover, they can be operated in self-oscillatory manners without electronics. These features allow us to make an optimum chemical design and to develop useful IPMC materials with desired properties for various engineering applications. The self-oscillation of IPMCs can be achieved electrochemically via active surface electro-chemical reactions. The properly-controlled surface electrochemical reactions can lead to the controllable voltage oscillations in requisite concentrations of additives. The measured voltammograms and impedance data indicate hidden negative differential resistance and instability in front of the oscillations.

University of Pisa, Interdepartmental Research Centre "E. Piaggio", Italy

Linear Contraction Actuators

Federico Carpi, Antonio Migliore, Giorgio Serra, Danilo De Rossi, f.carpi@ing.unipi.it

Today, dielectric elastomers offer excellent materials for the electro-activation as polymer based actuators capable of high electromechanical performance [1]. At our research center we recently developed a new type of dielectric elastomer actuator that is capable of linear contraction and related radial [2]. This actuator is based on a new configuration, which we recently patented [3,4]. It consists of a hollow cylinder of dielectric elastomer, having two helical compliant electrodes integrated within its wall (Figure 21).

By applying a voltage difference between the electrodes, the interactions with the free charges causes axial contractions of the actuator, as well as related radial expansions. Our silicone-based prototype actuators (Figure 22 was made as follows:

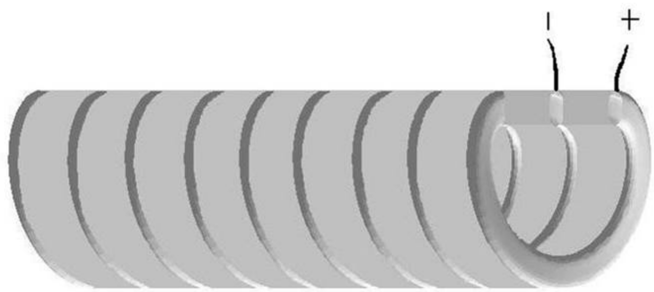

FIGURE 21: Novel actuating configuration

1. A silicone rubber was processed in the form of tubes, which were made by mold casting.
2. Helixes are cut from the tubes by using a blade, whose motion is automatically made helical by a machine that composes a motion of rotation with one of translation.
3. Two compliant electrodes (made of carbon loaded silicone or graphite spray) were fabricated onto each silicone helix that was masked.
4. The actuator is completed by alternating one naked helix to one electroded helix and sealing and coating the two with further silicone.

Figure 23 shows results of the preliminary characterization of the performances of our first prototypes linear electromechanical contraction actuator. In particular, this figure shows axial contraction strains that were obtained in response to the application of the indicated electric fields. Our current efforts are devoted to completing the fabrication setup and process, in order to improve the performances of this new type of dielectric elastomer actuator.

FIGURE 22: Photograph of a prototype of the new kind of actuator.

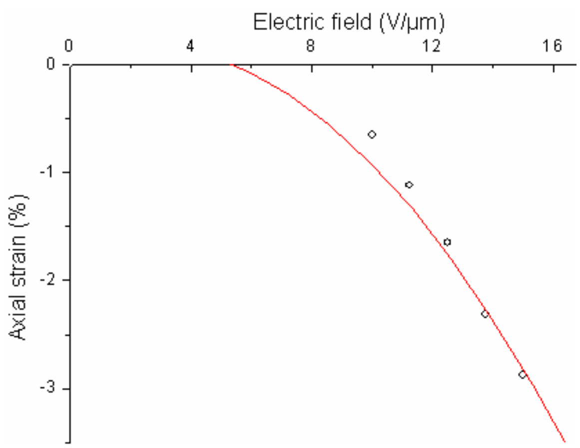

FIGURE 23: Preliminary data on axial contraction strain versus applied electric field

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[1] R. Pelrine, R. Kornbluh, Q. Pei and J. Joseph, "High-speed electrically actuated elastomers with strain greater than 100%", *Science*, Vol. 287 (2000), pp. 836-839.

[2] F. Carpi, D. De Rossi, "Theoretical description and fabrication of a new dielectric elastomer actuator showing linear contractions", *Proc. of Actuator 2004*, Bremen 14-16 June 2004, pp. 344-347.

[3] F. Carpi, D. De Rossi, "Attuatore elettromeccanico contrattile a polimero elettroattivo con elettrodi deformabili elicoidali", *Italian Patent* (2003), PI/2003/A/000043.

[4] F. Carpi, D. De Rossi, "Electroactive polymer contractible actuator", *PCT International Application* (2004), PCT/IB2004/001868.

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Towards Standardization of EAP Actuators Test Procedures

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Since the field of EAP actuators is fairly new there are no stand synthesis and testing processes for these materials. This drawback can seriously limit the scope of application of the materials since the targeted industrial sectors (aerospace, biomedical...) require high reliability. Therefore a regulation on the test process of the materials and a Unit Tester definition are required to assure the product quality.

As in the electronic engineering industry, future EAP actuators factories will require set of properties that are characterized for the manufactured actuators. Therefore, there is a need for automatic instruments that are able to record the performance of the materials under controlled conditions and environmental constraints. The UC3M EAP Unit tester v.2 is a first iteration that our lab has taken towards the design of such equipment (see Figure 24).

For this tester, the following sensors are being used:

- CCD camera - PAL. 25 fps. (Framegrabber: MATROX)
- Temperature infrared sensor - Calex Convir EL101A. (0ºC-250ºC, +-1%, 250 ms.)
- Displacement sensor - Laser Displacement meter (0.1 mm resolution)
- Load Cell: - Precision balance 0.1mg resolution.
- Precision analog break: Novel design. (mN resolution)

Analog acquisition channels are processed using a 16 bit ADC and sent to a PC through a 1

Mbps serial bus. Through a friendly Graphical User Interface (Visual C++). The EAP Unit Tester v.2 allows real-time monitoring of the following properties of the EAP actuator material specimen under test:

1. Curvature of the deformation of the EAP
2. Tip Displacements of the EAP
3. Temperature at the electrodes
4. Output Voltage of the EAP in sensing operation
5. Voltage and Current being driven to the EAP
6. Weight of the specimen.

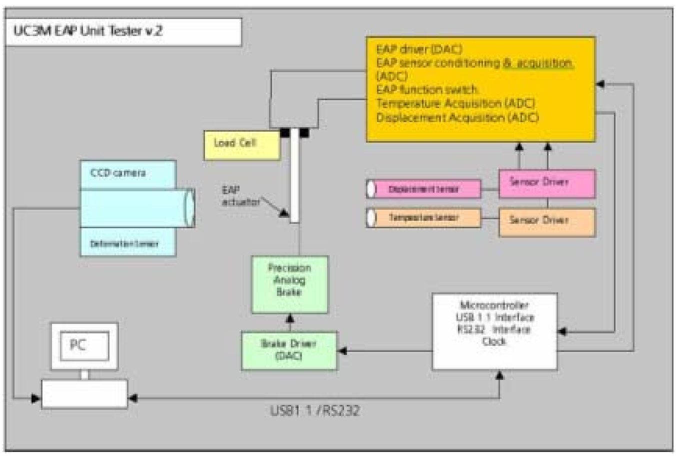

FIGURE 24: Block diagram of the UC3M EAP Unit Tester towards the development of standard testing

Data is also recorded in MATLAB compatible format for future analysis. In addition the Unit Tester allows real-time control of the following signals being applied to the EAP specimen:

1. Electrical voltage (and Current)
2. Opposing Force at the edge of the specimen.

Since the EAP specimen may act as a sensor, an actuator or as a simple structural material another function was included. This function is the switching of the sensor/actuator/none use of the EAP

In addition, the actuator/sensor control algorithms at the Unit Tester can be programmed in order to test the self-control capability of the material. Monitoring the controllability of the material is useful in order to determine the reliability of the technology for diverse applications such as vibration damping, positioning. This way not only the EAP material is under test, but also the control algorithms.

Due to the automatic testing performance, aging analysis of the material as well as failing mode can be recorded in order to understand the long time durability effects on the operation of the tested EAP actuators.

EMERGING EAP SUPPLIERS

Environmental Robots Incorporated (ERI)

Environmental Robots Inc. (ERI) is currently making a robotic arm for the armwrestling competition that will be held during the 2005 EAPAD Conference. Their EAP based robotic arm is an all plastic one and it is made of PMMA and Derlin, as required for the competition. The arm is actuated by conductive PAN fiber bundles that are electrochemical based artificial muscles. For information about ERI their website is www.environmental-robots.com.

POSTDOC OPENNINGS

2 Postdoctoral Fellowship Positions

Paul Kilmartin http://www.auckland.ac.nz/

Applications are invited for two Postdoctoral Fellowships that will be available in the Polymer Electronics Research Centre, University of Auckland, New Zealand, from July 2004. The term of each Fellowship is two years, with possible extension to three or four years. The Fellowships are offered for research on two topics in the electronically conducting polymers field, as outlined below.

Responsive membranes: The research program involves the design and development of multifunctional membranes incorporating conducting polymers. Experience in polymer synthesis and characterization and /or polymer blending and extrusion would be an advantage.

Micropumps for drug delivery: The research program involves development of novel microactuators based on conducting polymers that will be assembled into micropump devices. Experience in design and testing of actuators and device assembly would be an advantage.

For both project the following skills are required:
- PhD in materials (polymer) science and/or electrochemistry
- Excellent communications and report/ manuscript writing skills.

For both projects experience in conducting polymers, either synthesis and /or characterization, will be an advantage. The Fellows will be expected to assist in day-to-day supervision of PhD and MSc students.

Applicants should submit a statement of interest, including their CV and the names of at least three referees who can be approached for supporting comments, by email to Dr Jadranka Travas-Sejdic, Director of PERC, Chemistry Department, The University of Auckland, Auckland, New Zealand. Statements of interest should be received preferably before 15 July 2004. Email: j.travas-sejdic@auckland.ac.nz. Phone: +64-9-373 7599 ext 88272.

NEW BOOKS

2nd Edition of the book on EAP

Y. Bar-Cohen (Editor)

In March 2004, SPIE Press published the 2nd Edition of the book entitled "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges". This new edition was prepared in response to the high demand for the first edition and the fact that the available copies are starting to run out. In preparing this second edition efforts were made to update the chapters in the topic areas that sustained major advances since the first issue that was prepared over three years ago. Twelve out of the total of twenty one chapters were revised at various degrees where some like Chapters 6 and 18 were significantly rewritten. As in the first edition, this new edition of the book is reviewing the state-of-the-art of the field of Electroactive Polymers (EAP). These materials are also known as artificial muscles for their functional similarity to natural muscles. The cover page of the book (see Figure 25) was also revised where the new icon of the armwrestling challenge is used. This new icon represents the desire to see that the robotic arm will not only be driven by polymer actuators but also be made of polymer materials.

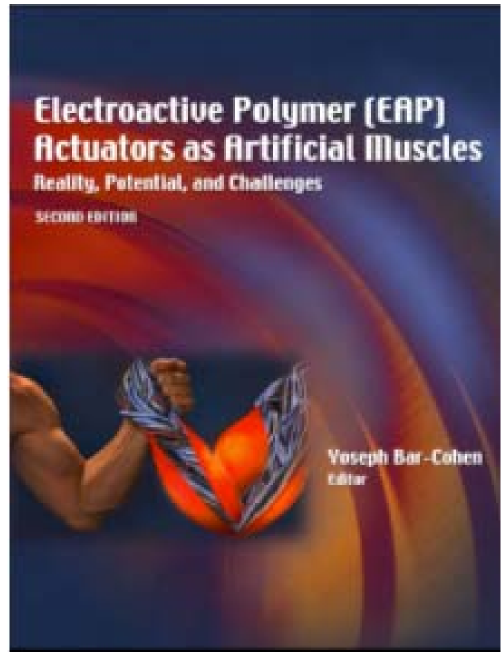

FIGURE 25: The cover page of the 2nd Edition of the book about EAP

The new edition of the book, which is identified as Volume PM136, also covers the field of EAP from all its key aspects, i.e., its full infrastructure. This includes description of the available materials, analytical models, processing techniques, and characterization methods. The intent in issuing the book is 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 heart warming, where major milestones are continually being reported. These advances are bringing the field significantly closer to the point of having EAP considered by engineers as actuators of choice. Further information about this book is available on: http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

IPMC Artificial Muscles

M. Shahinpoor, K. J. Kim and M. Mojarrad (Authors)

In April 2004, a book entitled "IPMC Artificial Muscles" was published by Environmental Robots Incorporated/AMRI Press. The authors of this book are M. Shahinpoor, K. J. Kim and M. Mojarrad (ISBN No. 1-884077-07-2, 444 pages). The book can be ordered online from the ERI web site (www.environmental-robots.com).

Biomimetics - Biologically Inspired Technologies

Y. Bar-Cohen (Editor)

A new edited book is currently being prepared covering the subjects of biomimetics and biologically inspired technologies. In this book there is a distinction between these two technologies. The book will cover the state of the art of these two technologies of biologically mimicking versus inspired. Both approaches were attempted by humans in many areas where success depended on the specific applications. For example, flying via flapping feathered wings always failed while success occurred only when the Wright brothers turned to relying on the use of aerodynamic principles and human made actuation capabilities. This success was celebrated last year as we reached the 100 years anniversary of their major aviation milestone. Using aircraft we can now fly way higher, faster and longer distances than any flying creature can ever do.

Leading experts have agreed to coauthor various chapters of this book and the topics address the key issues related to this field. These topics include Mimicking biological Mechanisms, Mechanization of Intelligence, Biologically-Inspired Design Processes, Genetic Algorithm, Mobility, Manipulation and Robotic Mechanisms, Molecular Machines, Molecular Design of Biological and Nano-Materials, Engineered Muscle Actuators: Cells & Tissues, Artificial muscles using Electroactive Polymers (EAP), Bio-sensors the equivalent of the human senses, Multifunctional Materials and Devices, Defense and attack strategies and mechanisms in biology, Biological Materials in Engineering Mechanisms, Functional surfaces in biology - mechanisms and applications, Biomimetic and biologically inspired control, Interfacing Microelectronics and the Human Body, Nastic structures as well as the Challenges and Outlook.

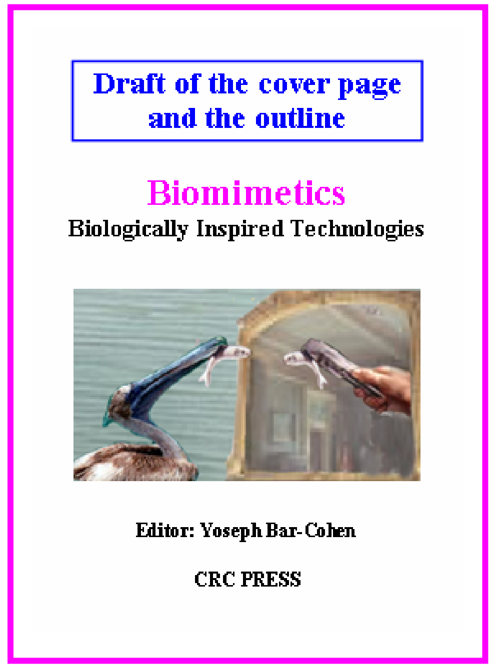

FIGURE 26: The draft of the cover page of the new book on biomimetics and biologically inspired technologies.

This book is intended to serve as a reference comprehensive document that methodically covers the subject, tutorial resource, documented challenges and vision for the future direction of this field. Figure 26 shows a draft of the book cover-page and the graphics that was prepared by David Hanson shows the editor's idea of biomimetics where human learns from nature to produce mechanisms and devices.

The draft of the outline of this book is on http://ndeaa.jpl.nasa.gov/ndeaa-pub/Biomimetics/Biologically%20Inspired%20Technology-preliminary%20outline.pdf

UPCOMING EVENTS

5-8 Dec. 2004	2nd "Biomimetics and Artificial Muscles," Williamsburg, Virginia, M. Shahinpoor shah@unm.edu
7-10 March, 2005	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/05/ss/conferences/index.cfm?fuseaction=SS03

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://eap.jpl.nasa.gov

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

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

EAP Companies: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-material-n-products.htm

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

Armwrestling Challenge: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

WorldWide Electroactive Polymers (EAP) Newsletter

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

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