WorldWide ElectroActive Polymers EAP (Artificial Muscles) Newsletter

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http://eap.jpl.nasa.gov

FROM THE EDITOR

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

Progress in the field of EAP is continuing to be made and currently the most notable milestone is the planned 1st Armwrestling Match of EAP Robotic Arm against Human (AMERAH). We already have two committed contestants with two more that are pending on making progress towards readiness by the time of the contest. 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 AMERAH competition will be held on March 7, 2005, at 5:00 PM.

The human opponent in the upcoming armwrestling competition is Panna Felsen. Panna, a high school student from San Diego, California. Information about her is available on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/amerah/the-human-opponent.htm

ABOUT THE EXPERTS

Award Winner - Toribio Fernández Otero

The Spanish Royal Society of Chemistry http://www.ucm.es/info/rsequim/ is a centennial institution. As part of its activity, it rewards chemists for making significant contributions to the fields of Physical Chemistry, Inorganic Chemistry, Organic Chemistry, Chemical Engineering and Analytical Chemistry. Every year, it makes five awards at the level of €1500 for the top contributors to these fields. Also, this society issues Research Awards at the level of €6000 to these chemists and also issues €1000 awards to four young scientist. This year the award in Physical Chemistry is shared by Toribio Fernandez Otero (Polytechnic University of Cartagena) and Francesc Illas (University of Barcelona).

Otero received the award for his contributions to the development of various electroactive polymers as artificial muscle actuators, sensors and tactile interfaces. His contribution included the development of the theoretical model entitled Electrochemical Stimulation of the Conformational Relaxation (ESCR). In this model he combined electro-chemistry and polymer science to determine the behavior and properties of conducting polymers.

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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

ERRATA

In the 11th issue of this WW-EAP Newsletter the name of the winner of the SPIE EAPAD best poster award was misspelled and it should be Zhimin Li (Not Chi-min Li).

The 1st armwrestling on Mar. 7, 2005

As mentioned earlier, the 1st Armwrestling Match of EAP Robotic Arm against Human (AMERAH) will be held on March 7, 2005. Two organizations have already committed to participate with an EAP actuated robotic arm and they include:

1. Environmental Robots Incorporated (ERI), Albuquerque, New Mexico, USA.
2. Swiss Federal Laboratories for Materials Testing and Research, EMPA, Dubendorf, Switzerland

In this first competition using a simple shape arm the challenge is to win against a human and, in this case, the high school student, Panna Felsen (see photo on Page 1). However, the ultimate goal is to win against the strongest human using as close resemblance of the human arm as possible. Success in this ultimate goal will require significant advances in the EAP field infrastructure including: Analytical tools, materials science, electromechanical tools, sensors, control, feedback, rapid response, larger actuation forces, actuator scalability, enhanced actuation efficiency, etc. The overall objectives of this competition to:

- 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 as well as scientists and engineers.

2005 SPIE EAPAD Conference

The EAPAD Conferences, which started in 1999, is continuing to be the leading international forum for the field of EAP. The next conference will be held in San Diego, California, over four days from

March 7 to 10, 2005 and with a course on Sunday, March 6. The presentations will cover a broad range of topics from analytical modeling to application. The 2005 EAPAD program is now available on: http://spie.org/Conferences/Programs/05/ss/conferences/index.cfm?fuseaction=5759. This year, 84 abstracts were submitted making it the largest number for the EAPAD Conferences. The papers will focus on issues that can help transitioning EAP to practical use thru better understanding of the principles responsible for the electro-mechanical behavior, improved materials, analytical modeling, methods of processing and characterization of the properties and performance as well as various applications.

The 2005 EAPAD conference will be opened with another interesting and exciting Keynote presentation. The speaker will be Pramod Bonde, Johns Hopkins Univ. School of Medicine and his presentation is entitled "**Artificial support and replacement of human organs.**" In this presentation he will cover the topic of artificial organs to which EAP can contribute enormously.

FIGURE 1: The Keynote Speaker, Pramod Bonde, Johns Hopkins University School of Medicine

In this EAPAD conferences, will have another EAP-in-Action Session and it will be held on Mon., March 7, 2005, where some of the latest practical implementations of EAP will be demonstrated. As mentioned earlier we will have the first armwrestling competition in this coming Session. The EAP-in-Action Session is a forum of interaction between the technology developers and potential users and it offers a "hands-on" experience with this emerging technology. During this session, the attendees are given opportunity to see demonstrations of EAP actuators and devices.

ACTUATOR 2004

Peter Sommer-Larsen, Risø National Laboratory, peter.sommer.larsen@risoe.dk; **Roy Kornbluh**, SRI International

The 9th International Conference on New Actuators that was held in on June 14 to 16 at Bremen, Germany. This conference featured for the second time in its series a session on polymer actuators [see list of references below]. This bi-annual Conference is organized by Hubert Borgmann, Messe Bremen. The speakers at the EAP session gave some excellent talks to an enthusiastic overcrowded auditorium. The speakers included John Madden, Federico Carpi, Toribio Otero, and Phillip von Guggenberg. In addition, to the oral presentations Peter Sommer-Larsen and Helmut Schlaak and M. Matysek gave fascinating poster presentations on modeling of dielectric elastomers and a tactile display based on a multilayer dielectric elastomer device that they made of over 100 layers.

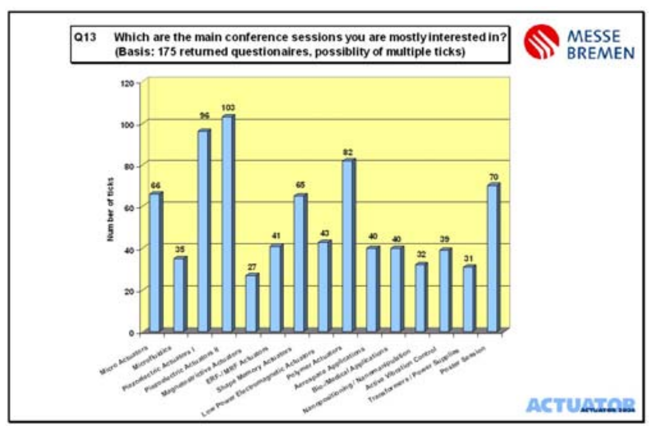

FIGURE 2: Significant interest of audience at ACTUATOR 2004 has been expressed in polymer actuators. About half of those who filled the questionnaire had been particular interest in attending the polymer actuators session.

The conference consisted of 15 sessions about actuation technologies with outstanding exhibition that featured 42 companies and institutions in the field of smart actuators and drive systems. The conference was attended by 431 participants. A little less than half of the attendees filled opinion questionnaire (see Figure 2) with 95% of them rated the conference overall as good or better than good (71%). Especially encouraging for field of EAP is the significant interest of the attendees in the topic of polymer actuators. Over half of the responding attendees stated that they have particular interest in attending the session on polymer actuators.

The EAP community is encouraged to plan attending the next conference: ACTUATOR 2006 that will be held in June 2006 again in Bremen, Germany.

Reference

J. Madden, "Properties of electroactive polymer actuators", in "Proceedings of ACTUATOR 2004, Bremen, 14-16 June 2004", Ed. H. Borgmann, Messe Bremen, pp. 338-43 (2004)

F. Carpi, D. De Rossi, "Theoretical description and fabrication of a new dielectric elastomer actuator showing linear contraction", ibid. pp. 344-47 (2004)

T.F. Otero, J. López-Cascales, G. Vázquez, MT. Cortés, "Artificial Muscle with Tactile sensing", ibid., pp. 248-51 (2004)

A. Beavers, R. Kornbluh, P. von Guggenberg, P. Marcotullio, R. Pelrine, Q. Pei, "Marketing Muscles: Towards commercial applications of dielectric elastomer artificial muscle actuators", ibid., pp. 352-57 (2004)

EAP COURSES & TUTORIALS

Course on EAP at EAPAD 2005

An introductory course about EAP is planned to be held on Sunday, March 6, 2005 as part of the upcoming EAPAD Conference. The course is entitled "Electroactive Polymer Actuators and Devices," and the lead instructor is the Editor, Y. Bar-Cohen, who will give an overview, and cover applications that are currently developed and ones that are being considered. The subject of Ionic EAP will be covered by J. Madden from the University of British Columbia, Vancouver, Canada. Further, the topic of Electronic EAP will be covered by J. Su from NASA Langley Research Center, USA. This course is 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. Also, it is intended for those who are considering research and development in EAP materials and their present and/or future applications. Details about this SPIE course are available thru:
http://spie.org/Conferences/Programs/05/ss/shortcourses/index.cfm?fuseaction=shortcoursedetail&course=SC634

CALL FOR PAPERS & FUTURE CONF.

Fall 2005 MRS - Call for papers

A call for papers is expected to be issued soon for the Fall 2005 MRS Symposium and it will include an EAP related conference entitled "Electro Responsive Polymers and Their Applications." This Symposium will be held in Boston from Nov. 28 to Dec. 2, 2005. Details about the call for papers to this conference are currently being prepared and will be announced at a later time. Generally, in the last several years, an increasing level of R&D efforts is dedicated to the field of electro responsive polymers (ERPs) including the material development and device applications. The interest in ERPs is due to the fact that these materials show remarkable charge storage and other electrical properties in addition to their exceptional physical properties and low manufacturing cost. One class of these materials is also known as EAP or smart materials and there is a great interest in potential applications of these materials including electromechanical device, air filtration, and insulation etc. The objective of this symposium is to provide a forum for the researchers from academia and industries involved in this field to exchange information and stimulate discussions to present the recent research and commercial advances to the audiences. The topics of this symposium include, but are not limited to: Class-1: Sensor and actuators; and Class-2: Dielectrics and Charge Storage. The ERPs Conference is organized by Vivek Bharti, 3M Center; Qiming Zhang, The Penn State University; John Madden, The University of British Columbia, Canada; Yoseph Bar-Cohen, Jet Propulsion Laboratory; and ZhongYang Cheng, Auburn University. The tentative list of Invited speakers includes : Mitch Thompson (MSI, USA), John Main (DARPA, USA), Jan Obrzut (NIST, USA), Geoffrey Spinks (Univ. of Wollongong, Australia), Ray Baughman (UT Dallas, USA), Mark Dadmun (University of Tennessee, USA), S. Bauer (Johannes-Kepler University, Austria), S.B. Lang (Ben-Gurion University of the Negev, Israel), Timothy Swager (MIT, USA), Mark Zahn (MIT, USA), and Zhang (Penn State).

For further information please contact: Vivek Bharti 3M Center, Saint Paul, MN vbharti@mmm.com, Ph. 651-736-8057, Fax: 651-737-5335

ACTIVITY IN COUNTRIES WORLDWIDE

Advances in EAP are continuing to emerge worldwide and, as of the last issue of this newsletter, this section was added to focus attention on activity in specific countries. In the last issue the activity in Korea was covered and in this issue we have a review of the activity in Australia, Italy, Japan and New Zealand.

EAP Activity in Australia and New Zealand

Geoffrey Spinks gspinks@uow.edu.au

The largest group working on EAP in Australia is our own Intelligent Polymer Research Institute (IPRI) based at the University of Wollongong and located about 80km south of Sydney. The group was established in the mid 1980s by Gordon Wallace who is still the Director. The Institute now employs around 30 people with about 15 graduate students, 10-12 full time research fellows (post-docs) and 5 faculty (teaching/research staff). The Institute forms one node of a recently established National Centre called the Australian Centre for Nanostructured Electromaterials and is funded by the Australian Research Council for 5 years www.uow.edu.au/science/research/nsem/]. The Centre is particularly interested in the fundamental design and testing of organic materials for electroactive applications. The application areas are very diverse, including photovoltaics and photochromics, electronic textiles, chemical and biological sensors, nerve cell communications, synthetic enzymes and (of course) artificial muscles. The other major node of the Centre is Monash University (in Melbourne) whose expertise is in ionic electrolyte materials, such as ionic liquids and plastic crystals. Together we can tailor both the electrode material and the electrolyte for virtually any electrochemical device. One particularly exciting outcome is the application of such systems in biomedical engineering at the Bionic Ear Institute (established by Graeme Clark, inventor of the Cochlear Implant). This work is exploring the use of electrochemical stimuli to promote and direct the growth of nerve cells.

IPRI's work on artificial muscles includes studies of conducting polymers (polypyrrole, polyaniline and polythiophene), carbon nanotubes and polyelectrolyte gels. Most significant outcomes achieved in recent times include the development of a helix tube actuator made from PPy (Figure 3) that has produced the highest strain rate yet achieved with these materials [1]. Our collaboration with Monash University and also Ben Mattes, Elisabeth Smela and others at Santa Fe Science and Technology led to the discovery that vastly improved cycle life could be achieved for PPy and PANi actuators operated in ionic liquid electrolytes (Figure 4) [2, 3]. More recent work has increased the cycle life to 500,000 cycles at 1% strain per cycle and with little degradation in performance.

Currently, we have been exploring the inter-relationships between the mechanical properties of the actuator material and its actuation behavior. Of particular importance is the change in elastic modulus that occurs when the polymer is oxidized and reduced. Under load this change in modulus causes length changes and so the modulus shift is an integral part of the actuation process. A full description of the theoretical development is soon to be published [4].

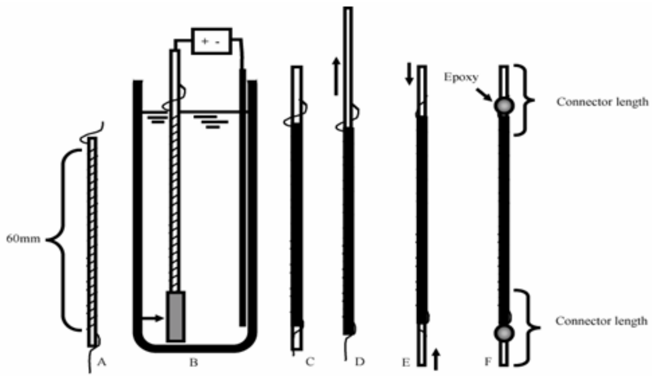

FIGURE 3: Method of preparing hollow tubes by electropolymerisation of pyrrole onto a helically wound platinum wire template. Removal of the inner platinum wire (step D) leaves a hollow tube in which a thinner platinum wire is contained within the PPy tube wall.

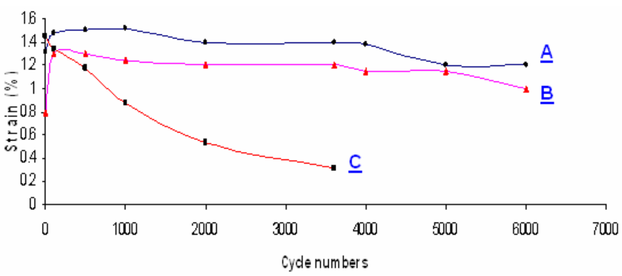

FIGURE 4: Actuator strain obtained from a PPy helix tube operated at 1Hz in 3 electrolytes: A and B are ionic liquids and C is a propylene carbonate based electrolyte.

Our most recent studies have focused on producing novel fiber actuators. In particular, we have developed methods for wet-spinning carbon nanotube reinforced polyaniline fibers [5]. Small additions of nanotubes produce significant improvements in the mechanical and electrical properties of the fibers. Improved actuation performance has also been noted. These works build on our previous studies of PANi-nanotube composites with Tan Truong at Australia's defense science organization (DSTO) [6].

Much of the work described has involved fruitful collaborations with many other researchers worldwide. Most notable are our collaborations with John Madden (now at University of British Columbia), Ray Baughman (Univ. Texas at Dallas), Danilo deRossi (Univ. Pisa) and new collaborations with Edwin Jager (Micromuscle, Sweden) and Seon Jeong Kim (Hanyang Univ, South Korea). In addition, we have been fortunate to work with a number of companies in the development of actuators. The longest collaboration has been with Quantum Technologies (Sydney, Australia) with whom we are continuing to develop an electronic Braille screen (Figure 5).

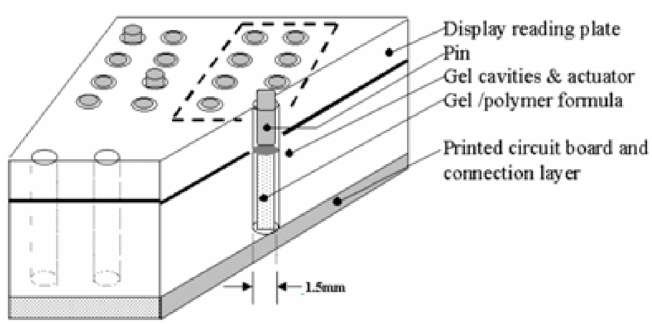

FIGURE 5: Design of an electronic Braille screen [www.quantech.com.au]

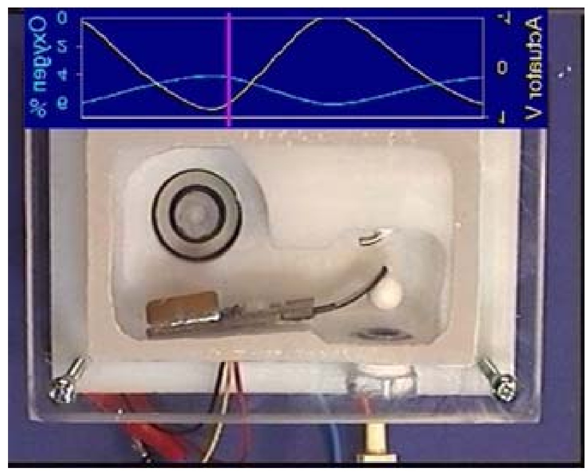

FIGURE 6: Open state of a bimorph actuator allowing air into a simulated apple box. The actuator was automatically opened when the oxygen sensor (top left) detected the oxygen content to below the target state (5%).

Another fun project was initiated by Mike Andrews and Murray Jansen at Industrial Research Limited in New Zealand. The idea was to produce a bending actuator to operate a valve for the control of oxygen content in apple boxes. The bending actuator was produced at IPRI and worked for long periods (months) in air utilizing a solid form of the ionic liquid electrolyte [7]. The actuator was coupled to an oxygen sensor (Figure 6) so that the oxygen content in a simulated apple box was maintained at the required level over time [8].

References

1. Ding, J., Liu, L., Spinks, G. M., Zhou, D. & Wallace, G. G. High Performance Conducting Polymer Actuators Utilising a Tubular Geometry and Helical Wire Interconnects. *Synthetic Metals* **138**, 391-398 (2003).
2. Ding, J. et al. Use of Ionic Liquids as Electrolytes in Electromechanical Actuator Systems Based on Inherently Conducting Polymers. *Chemistry of Materials* **15**, 2392-2398 (2003).
3. Lu, W. et al. Use of ionic liquids for .pi.-conjugated polymer electrochemical devices. *Science* **297**, 983-987 (2002).
4. G.M. Spinks and V-T. Truong, Sensors and Actuators A, IN PRESS.
5. V. Mottaghitalab, G.M. Spinks and G.G. Wallace, Synthetic Metals, IN PRESS.
6. Tahhan, M., Truong, V.-T., Spinks, G. M. & Wallace, G. G. Carbon nanotube and polyaniline composite actuators. *Smart Mater. Struct* **12**, 626-632 (2003).
7. D. Zhou et al. Solid state actuators based on polypyrrole and polymer-in-ionic liquid electrolytes. *Electrochem. Acta* **48**, 2355-2359 (2003)
8. M.K. Andrews, M.L. Jansen, G.M. Spinks, D. Zhou and G.G. Wallace, An integrated electrochemical sensor-actuator system. *Sensors and Actuators A* **114**, 65-72 (2004).

EAP Activity in Italy

Interdepartmental Research Center "E. Piaggio"

A. Mazzoldi, a.mazzoldi@ing.unipi.it
F. Carpi, f.carpi@ing.unipi.it
G. Pioggia, giovanni.pioggia@ing.unipi.it
M. Ferro, marcello.ferro@ing.unipi.it
D. De Rossi, d.derossi@ing.unipi.it

The Center "E. Piaggio" of University of Pisa is the leading center for EAP activity in Italy and it has been involved for several years in related studying covering broad range of topics. The materials that were studies initially included piezoelectric polymers, polyelectrolyte gels (Figure 7). The latter was modelled analytically [1] and was shown to be poroelastic with a response time that is proportional to the inverse of the square of the sample characteristic dimension.

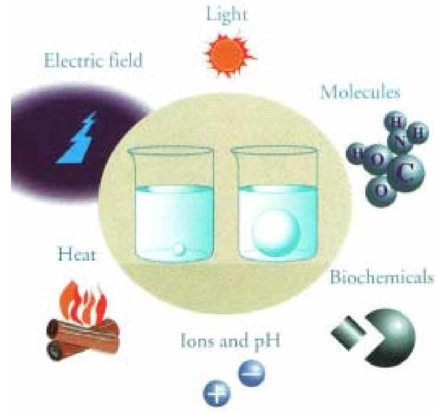

FIGURE 7: Stimuli enabling mechanical responses of polyelectrolyte gels.

More recently the work was shifted to conducting polymers [2] and focused characterization and device realization. In particular a pump [3], a dry fiber actuator (Figure 8) [4] and actuators based on radial expansion were proposed [5]. Also, a continuum model in passive condition [6] and a lumped model in active condition [7]) were developed.

In collaboration with the research group under the lead of Ray Baughman, University of Dallas, Texas and prior affiliations, the Center become involved also with carbon nanotube actuators and fibers (Figure 9). The electromechanical properties of nanotube actuators were determined and the behaviour under various levels of applied voltage were determined and ascribed to diverse origins [8, 9].

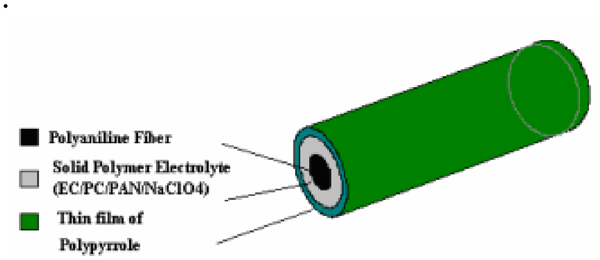

FIGURE 8: Scheme of a conducting polymer fiber actuator

Another polymer actuation technology currently under study is the dielectric elastomer EAP [10, 11]. Research efforts in this field are directed towards the following directions: improvement of material properties, design of new configurations and study of applications.

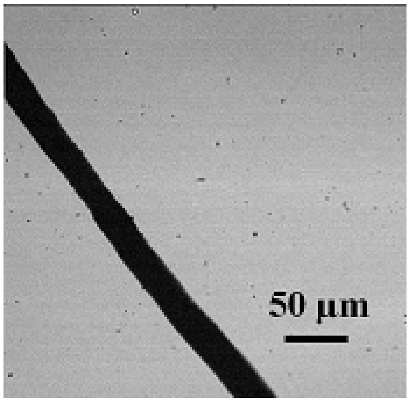

FIGURE 9: Photograph of a carbon nanotube fiber realized in our laboratory.

In order to reduce the electric field that is needed to drive dielectric elastomer actuators, new highly dielectric elastomers are being investigated by making a composite material with ceramic filler. By filling an ordinary elastomer (silicone) with titanium dioxide an effective combination of matrix elasticity and filler permittivity was obtained (Figure 10) [12]. During the last year, the use of other loading ceramics was investigated including lead magnesium niobate-lead titanate (PMN-PT), and the results are expected to be presented soon.

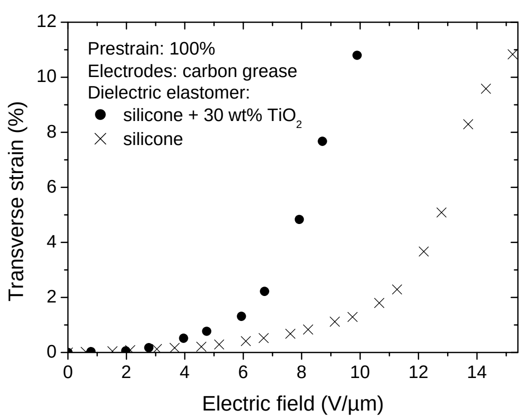

FIGURE 10: Strain-electric field curves of planar actuators made of a pure (crosses) and TiO_2-loaded (dots) silicone elastomer.

Dielectric elastomer actuators shaped in forms of tubes or rolls have been demonstrated as devices that are capable to generate linear extensions [10, 13, and 14]. A new type of dielectric elastomer actuator that exhibits electrically-induced linear contractions, has been developed and it is based on a patented configuration [15, 16] presented in Figure 11. The device consists of a hollow cylinder-like structure made of a dielectric elastomer (e.g. silicone), where the wall integrates two helical compliant electrodes. When a voltage difference is applied between the electrodes, the attraction among opposite charges causes an axial contraction of the actuator [17, 18].

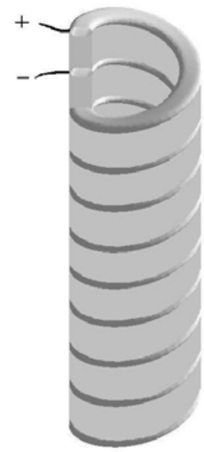

FIGURE 11: A new dielectric elastomer linear actuator.

The first prototype that was realized so far has shown axial strains of about -3% using about 15 V/µm. Higher performance is expected to result from the continued development of effective fabrication techniques that is currently under development.

The Center is also devote its efforts to studies of applications and has currently two contracts with the European Space Agency: one, already concluded (ARIADNA - "EAP-based artificial muscles as an alternative to space mechanisms"), which has been focused on a preliminary study for the application of a contractile dielectric elastomer actuator as jumping mechanism of a Mars spherical elastic rover (Figure 12) [19]; the other contract ("EAP Actuators"), just started in collaboration with RISØ Danish Polymer Centre and other partners, will investigate space applications of dielectric elastomer actuators and sensors.

A platform for the application of the Center's polymer actuators and sensors is represented by the project FACE (Facial Automaton for Conveying Emotions) [20] (Figure 13). One of the FACE models consists of an anthropomorphic head that developed by the Center is capable of expressing and modulating basic emotions in a repeatable and flexible way. It can be used to quantitatively analyze the emotional reactions of individuals through optical recognition and tracking of facial expressions. The head consists of an artificial skull covered by an artificial skin, equipped with a sensory system and actuated so far by electric motors. It aesthetically represents a copy of a human head, both in shape and texture.

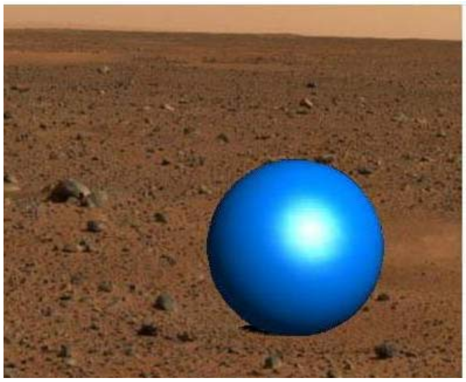

FIGURE 12: Drawing of a spherical elastic rover conceived for Mars exploration (adapted from [19]).

FIGURE 13: One model of FACE.

The eyes of FACE were made using animatronic techniques and their expressivity is achieved by dedicated actuators. FACE "feels" the world through the sensorized artificial skin and "sees" using an artificial vision device. The artificial skin of FACE is made of 3D latex foam, under which lies a sensing layer. The sensing layer responds to simultaneous deformations in different directions by means of a piezoresistive network, made of carbon/rubber mixture screen-printed onto a cotton lycra fabric. These sensors are elastic and do not modify the mechanical behaviour of the fabric. FACE adopts a stereoscopic vision in the frequency domain. The technique used for an automatic recognition of facial expressions of an interlocutor is based on the extraction of features from four facial regions, from which a neural networks classifies emotional states [21]. At present, the main aim of our work is to use FACE as a supporting therapeutic tool for autism that will enable us to verify if the system can help autistic subjects to learn, identify, interpret and use emotional information and extend these skills in a socially appropriate, flexible and adaptive context.

References

1. D. De Rossi, M. Suzuki, Y. Osada, P. Morasso, Journal of Intelligent Material Systems and Structures, vol. 3 (1992), pp. 75-95.
2. P. Chiarelli, A. Della Santa, D. De Rossi, A. Mazzoldi, Journal of Intelligent Material Systems and Structures, vol. 6, n°1, January (1995), pp. 32-37.
3. A. Della Santa, A. Mazzoldi, D. De Rossi, T. Gerlach , M. Kloepzig, ,Actuator 96 (Brema, Germania, Giugno 1996)
4. A. Mazzoldi, C. Degl'Innocenti, M. Michelucci, D. De Rossi, Materials Science & Technology C: Biomimetic Material, Sensors and Systems, v. 6 (1998), pp. 65-72
5. W. Rocchia, A. Mazzoldi, D. De Rossi, "Convenience of radial to longitudinal conversion in londucting polymer actuation", Advanced Materials, submitted.
6. A. Della Santa, A. Mazzoldi, C. Tonci, D. De Rossi, Materials Science & Technology C: Biomimetic Material, Sensors and Systems, v. 5 (1997), pp 101-109.
7. Della Santa, D. De Rossi, A. Mazzoldi, Smart Material and Structures, vol. 6 (1997), pp. 23-34.
8. R.H. Baughman, Changxing Cui, A.A. Zakhidov, Z. Iqbal, J.N. Barisci, G.M. Spinks, G.G. Wallace, A. Mazzoldi, D. De Rossi, A.G. Rinzler, O. Jaschinski, S. Roth, M. Kertesz, Science v. 284 (1999), pp. 1340-1344
9. G.M. Spinks, G.G. Wallace, L.S. Fifield, L.R. Dalton, A. Mazzoldi, D. De Rossi, I.I. Khayrullin, R.H. Baughman, Advanced Materials, vol 14, issue 23 (2002), 1728-1732.
10. E. Pelrine, R. D. Kornbluh and J. P. Joseph, Electrostriction of polymer dielectrics with compliant electrodes as a means of actuation, Sensors and Actuators A 64 (1998) 77-85.
11. 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.
12. F. Carpi, D. De Rossi, "Improvement of electromechanical actuating performances of silicone dielectric elastomer by dispersion of titanium dioxide powder", IEEE Trans. Dielectrics and Elelectrical Insulation, submitted.
13. Q. Pei, R. Pelrine, S. Stanford, R. Kornbluh, M. Rosenthal, Electroelastomer rolls and their application for biomimetic walking robots, Synthetic Metals 135-136 (2003) 129-131.

14. F. Carpi, D. De Rossi, Dielectric elastomer cylindrical actuators: electromechanical modelling and experimental evaluation, Mater. Sci. Eng. C, vol. 24 (2004) pp. 555–562.
15. F. Carpi, D. De Rossi, "Attuatore elettromeccanico contrattile a polimero elettroattivo con elettrodi deformabili elicoidali", Italian Patent (2003), PI/2003/A/000043.
16. F. Carpi, D. De Rossi, "Electroactive polymer contractible actuator", PCT International Application (2004), PCT/IB2004/001868.
17. 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.
18. F. Carpi, A. Migliore, G. Serra and D. De Rossi. Helical dielectric elastomer actuators. Smart Materials and Structures, submitted.
19. F. Carpi, Aldo Tralli, Danilo De Rossi and Paolo Gaudenzi, "Martian jumping rover equipped with electroactive polymer actuators: a preliminary study", IEEE Tran. On Aerospace and Electronic Systems, submitted.
20. Pioggia G., Ahluwalia A., Carpi F., Marchetti A., Ferro M., Rocchia W., De Rossi D., "FACE: Facial Automaton for Conveying Emotions", Applied Bionics and Biomechanics, 1(2), 2004.
21. Pioggia G., Ferro M., Kozlowski J., Marchetti A., Di Francesco F., Ahluwalia A., De Rossi D., "Automatic facial expression recognition by means of a neural approach", in Proceedings of the 2nd International Symposium on Measurement, Analysis and Modeling of Human Functions ISHF2004, Genova, Italy, 2004.

EAP Activity in Japan

There is a significant level of efforts related to EAP activity in Japan. The review in this issue represents input that was provided by Keiichi Kaneto, Kyushu Institute of Technology.

Soft Actuators based on Conducting Polymers

Keiichi Kaneto, kaneto@life.kyutech.ac.jp

Soft actuators or artificial muscles are attracting Japanese companies to seek the development of robotic technologies that model humans, medical devices, etc. This trend was evident in the first Innovation Japan that was held at the convention center of the International Forum in Tokyo, Japan, in 28-30 Sept. 2004 (Figure 14). Shown During this event were new ideas and innovations that were created by Japanese academies and could be leading to venture business. More than 250 Universities and Institutes attended to present their most outstanding accomplishments based mainly on bioscience and nano-technologies. Visitors were more than 280,000. K. Kaneto assistant by W. Takashima, Kyushu Institute of Technology, presented their recent progress in soft actuators based on conducting polymers. Visitors from various companies (more than 300) such as electronics, automobile and mechatronics expressed great interest.

FIGURE 14: The first Innovation Japan held 28-30 Sept. 2004 at the International Forum, Tokyo, Japan. K. Kaneto (left) was assisted by W. Takashima in this Forum.

"Self-organized" bending-beam actuator

The "Self-organized" bending-beam actuator was invented by Kazuya Tada and Mitsuyoshi Onoda (onoda@eng.u-hyogo.ac.jp), Himeji University. This actuator is based on polypyrrole and the inventors found that a PPy pipe can be electrochemically grown in a thin pipe of poly(tetrafluoroethylene) (PTFE) (Figure 15). The PPy pipe consists of an anisotropic PPy film, i.e., the inner and outer walls have quite different morphology and the former shows smooth and glossy texture while the latter was non-glossy. A bending-beam type actuator based on conjugated polymer is usually fabricated as a bimorph, that is, an electrochemically active conjugated polymer laminated with an inert polymer film. However, a piece of the anisotropic PPy film is readily available as an actuator because of anisotropic volume change. The anisotropy of the PPy film along the thickness apparently originates from the difference in polymerization environments. Namely, the outer wall contacts relative to the PTFE wall while the inner one is surrounded by the polymerization electrolyte. It was shown that a large size of anisotropic PPy film can be obtained in a thin slab vessel, and the performance of the actuator can be improved by replacing the supporting salt for polymerization.

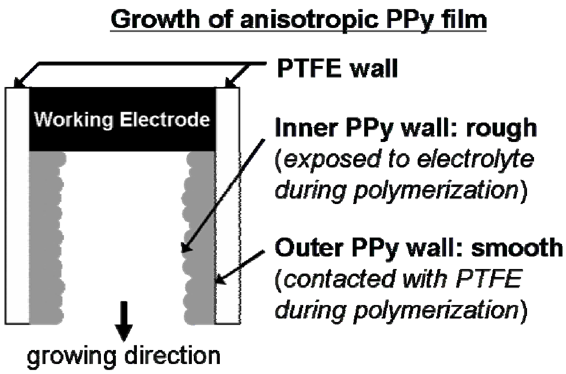

FIGURE 15: Schematic drawing of polymerization of PPy tubing.

References
1. K. Tada, Y. Kato and M. Onoda: "Preparation of sheet polypyrrole with vertical anisotropy: a self-organized bending-beam actuator," Synthetic Metals, Vol. 135-136 (2003) pp.101-102.
2. Y. Kato, K. Tada and M. Onoda: "Preparation of Large-size Anisotropic Polypyrrole Film and Its Actuation Property," Jpn. J. Appl. Phys., Vol. 42 (2003) pp.1458-1461.

Humido-responsive polypyrrole actuators

The EAP actuator Humido-responsive polypyrrole was demonstrated by H. Okuzaki, okuzaki@yamanashi.ac.jp, at the University of Yamanashi. The electrochemically synthesized polypyrrole films undergo quick and intensive bending in ambient air as a result of anisotropic dimensional change due to the sorption of water or organic vapor molecules from one side of the film. Figure 16 shows a polypyrrole motor capable of transducing the free energy change of sorption directly into a continuous rotation. The curvature of the polypyrrole belt increases by sorption of water vapor evaporated from a finger but decreases by dehydration due to the organic solvent. Thus, a net rotary moment acts on the pulleys and causes a clockwise rotation, where the belt moves at a speed of 22cm/min, corresponding to a rotation of the large pulley at 6-7rpm.

Furthermore, a combination of electrical and hygroscopic nature of the polypyrrole provides an insight into the development of a new class of electro-driven actuators or artificial muscle systems working in air. Upon applying dc 3V, the polypyrrole film contracts by 1-2%, which lies in the dehydration due to the Joule heating. Under isometric condition, the film generates contractile stress of 6MPa repeatedly in response to the electric field. Unlike in the conducting polymers based on the electrochemical doping, this system does not employ an electrolyte solution or counter and reference electrodes, where the electric field is capable of controlling the equilibrium of water vapor sorption.

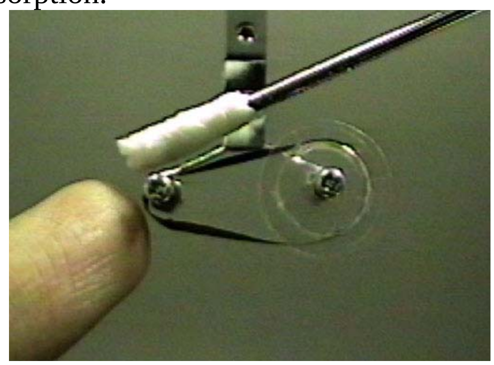

FIGURE 16: Polypyrrole motor transduces the free energy change of sorption directly into a continuous rotation.

Composite film tested for the electrochemo-mechanical properties

The electrochemomechanical properties of the composite film Polypyrrole and poly(2-methoxyaniline-5-sulfonate) tested by W. Takashima, A. Tanaka and K. Kaneto at Kyushu Institute of Technology kaneto@life.kyutech.ac.jp These researchers polymerized polypyrrole (PPy) film in aqueous solution of 0.1 M pyrrole with 0.1 M electrolyte consisting of dodecylbenzene sulfonate acid (DBS) and poly(2-methoxyaniline-5-sulfonate) (PMAS) with various ratios. The surface morphology of PPy/PMAS film (Figure 17) is corrugated, resulting from drying a gel like as grown film, which contained 95% water. The film was prepared with the PPy/(0.005M PMAS/0.095M DBS) showed also gel like polymer behavior with 71% of water content. The film shrunk upon electrochemical oxidation by more than 6% in electrolyte solution of 0.5 M TBACl/acetonitrile. The results suggested that the cation of TBA should be excluded and the self doping of sulfonate acid took place, instead of insertion of Cl^- (Figure 18). The cathodic expansion is quite interesting for the fabrication of linear actuators and the magnitude of strain is the largest so far at the present time.

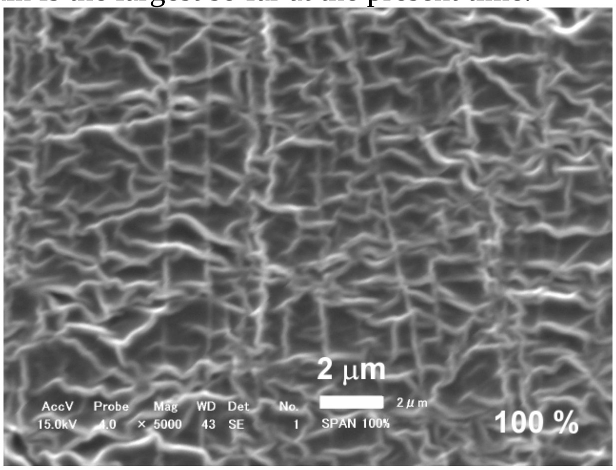

FIGURE 17: Scanning Electron Micrograph of PPy/PMAS film.

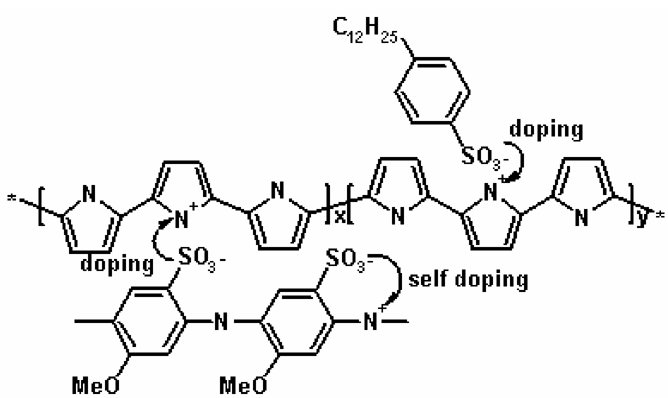

FIGURE 18: Scheme of electrochemical oxidation of PPy/(DBS/PMAS) film.

Eamex Co.

Eamex is a company in Japan that has been formed to transfer EAP related technology to commercial products. Their fish robot represents a milestone for the field of EAP. Information about this company and its products can be found on www.eamex.co.jp

ADVANCES IN EAP

Auburn University

New inexpensive electroactive polymer – P(VDF-CTFE) and its blends with (PVDF-TrFE)

Zhongyang (Z.-Y.) Cheng
chengzh@eng.auburn.edu

In an effort to significantly reduce the cost of PVDF-based high performance EAPs, P(VDF-CTFE) copolymers and its blends with P(VDF-TrFE) copolymers have been developed.

PVDF-based EAPs, such as high-energy-electron irradiated P(VDF-TrFE) copolymers and newly synthesized P(VDF-TrFE-CTFE) and P(VDF-TrFE-CFE) terpolymers, have been investigated in the last couple of years since they exhibit high electrostrictive strain response (a few percents of strain) and high elastic modulus (a few hundreds to more than one thousand MPa of Young's modulus). However, the cost of these polymers is still too high to be widely employed in various real devices.

Blending one polymer with another is an important approach to changing the polymer's structure in order to enhance its performance, create new properties, or improve its workability. Polymer blending has become an increasingly important technique for improving the cost/performance ratio of commercial plastics.

Inspired by the results of PVDF-based terpolymers and blending technology, the electromechanical performance of copolymer blends of P(VDF-CTFE) and P(VDF-TrFE) has been investigated. The electromechanical performance of the polymers is strongly dependent on the treatment of the samples. The samples treated with proper thermal and mechanical conditions exhibit a high strain response. The electrostrictive strain response of some P(VDF-CTFE) copolymers is shown in Figure 19.

It is found that the blends also exhibit very similar strain response (about 5%). More importantly, as shown in Figure 19, the electric field needed to get a strain of 5% in the blends is smaller than that in the pure P(VDF-CTFE). It is also experimentally found that the P(VDF-CTFE) and its blends with P(VDF-TrFE) have a high elastic modulus, Young's modulus about 400 MPa to 900 MPa.

To investigate the nature of electromechanical performance, the apparent piezoelectric constant of the polymers under DC bias were characterized. A high piezoelectric constant was obtained as shown in the Figure 20. The linear dependence of apparent piezoelectric constant on the DC bias indicates the electrostrictive nature for the polymers.

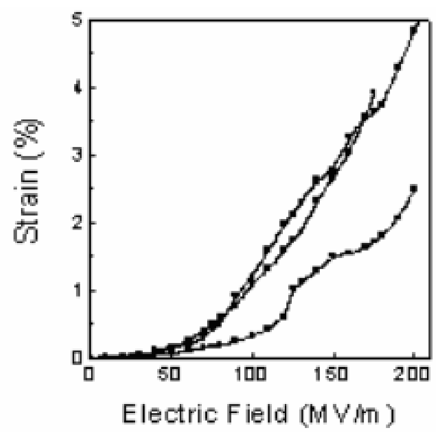

FIGURE 19: The electrostrictive strain response of some P(VDF-CTFE) copolymers

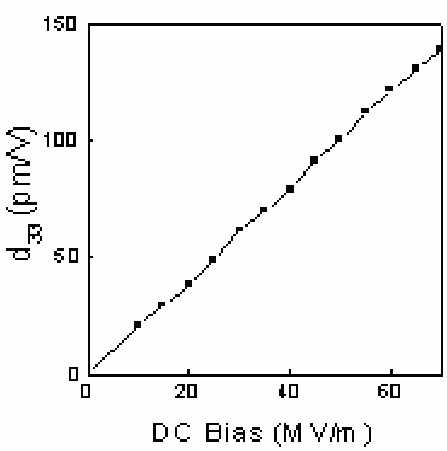

FIGURE 20: The apparent piezoelectric constant of the polymers under DC bias were characterized and a high piezoelectric constant was obtained

Acknowledgement
The graduate students who contributed to this work are Zhimin Li and Yuhong Wang.

EMPA, Mat. Science and Tech., Swiss Federal Institute of Tech., Zurich, Switzerland

Modeling of dielectric elastomer actuators

Michael Wissler, EMPA, michael.wissler@empa.ch
Gabor Kovacs, EMPA gabor.kovacs@empa.ch
Edoardo Mazza, ETH, edoardo.mazza@imes.mavt.ethz.ch

Models are required for the design and optimization of EAP actuators. This research project deals with modeling and simulation of dielectric elastomers. The challenges of modeling dielectric elastomers include the constitutive behavior of the elastomeric film and the electromechanical coupling. In particular the mechanical behavior of the elastomer is quite complex to describe due to viscous effects, anisotropy and large strains.

Hyperelastic models are used and three strain energy formulations (Yeoh, Ogden and Mooney-Rivlin) are compared in their predictive capabilities [1]. The hyperelastic model is combined with a so called quasi-linear viscoelastic model which describes time dependent effects [2]. Material parameters were determined from uniaxial experiments (relaxation tests and tensile tests).

A biaxially pre-strained circular actuator is proposed as model system for the characterization of the electromechanical behavior of the dielectric elastomer VHB 4910. In this system, like in all dielectric elastomer actuators, the deformation of the actuator for a given activation voltage depends on the three dimensional mechanical behavior of the film. A three dimensional finite element model of the circular actuator was created (figure 21) and the electromechanical activation process simulated.

The time history of the radial strain measured experimentally (assuming incompressibility) served as input of the finite element analysis, whereas the voltage needed to realize this deformation history is the output of the calculation. The results of the calculations with the three strain energy forms (figure 22) differ significantly, although all forms were successfully fitted to the same uniaxial data set. Predictions of the actuator behavior with the

Yeoh form agree to a great extent with the measurements.

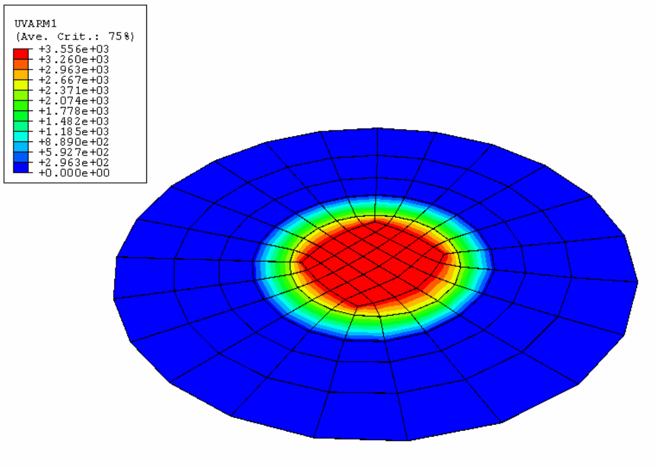

FIGURE 21: FE model of the prestrained circular actuator

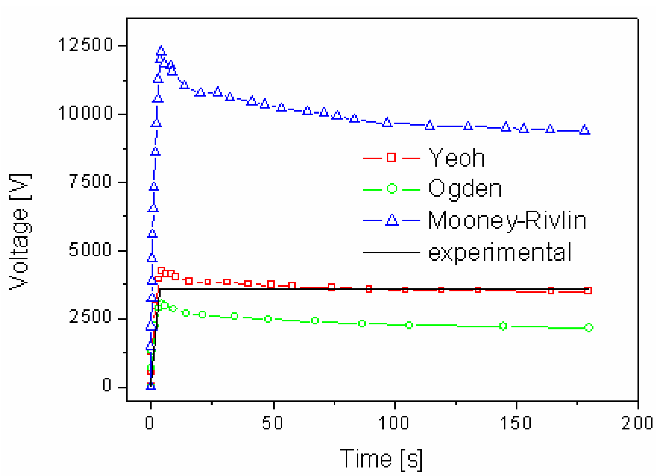

FIGURE 22: FE-calculation: time history of the voltage required to obtain the observed radial elongation history for the Yeoh-, Ogden- and Mooney-Rivlin-form.

References:

1. M. Wissler, E. Mazza, Modeling of a pre-strained circular actuator made of dielectric elastomers, accepted for publication in Sensors and Actuators
2. M. Wissler, E. Mazza, Modeling and simulation of dielectric elastomer actuators, submitted to Smart Materials and Structures

Development of Advanced Actuators for Portable Force Feedback Devices

Rui Zhang, ETH, zhang@imes.mavt.ethz.ch
Gabor Kovacs, EMPA, gabor.kovacs@empa.ch
Andreas Kunz, ETH, kunz@iwf.mavt.ethz.ch

This proposed work is to develop a force feedback device, which provides satisfying touch sensations to the operator that is portable, powerful, lightweight, and non-obstructive. The focus is on employing dielectric elastomer actuators, which were proven to have high power density, fast response and low cost [1]. Great efforts are being done to design, to manufacture, and to characterize the actuators based on acrylic elastomer films.

A chain-like actuator (Figure 23) was demonstrated. Such an actuator consisting of a sequence of several planar dielectric elastomer actuators is mounted to a rubber glove. One end of the chain is attached to a nylon band around the wrist while the other end is fixed to a ring around the fingertip. During voluntary motions of a human operator, the actuator is controlled to follow the finger movements. As soon as the operator touches a virtual object, the actuator is deactivated and tries to contract to its initial shape. Thus, it gives a resistance force via the ring onto the fingerpad, blocking the finger's motion.

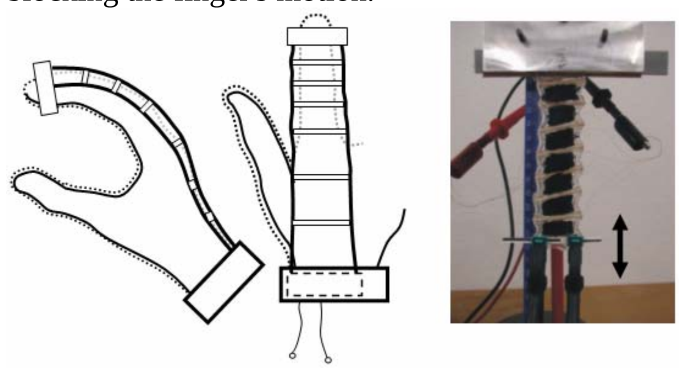

FIGURE 23: Schematic of a chain-like actuator (L.) and a demonstrator (R.)

A stable manufacturing process of the elementary actuator was developed [2]. The preliminary results from the isometric and isotonic measurements showed potentials of the actuator to meet the requirements for force feedback gloves. Current activities are the optimization of such chain-like actuators and the development of cylindric contractile dielectric elastomer actuators.

References

1. Mazzone, A., Zhang, R.: Novel actuators for haptic displays based on electroactive polymers, Virtual Reality Software and Technology Conference, Osaka Japan, 2003, pp. 196 – 204.
2. Zhang, R. Kunz, A.: Dielectric elastomer actuators for a portable force feedback device, The 4th European Conference on Haptics, Munich Germany, June 2004, pp. 300-307.

Acknowledgement

Part of National Center of Competence in Research CO-ME (Computer Aided and Image Guided Medical Intervention).

Development of a Shell-like Dielectric Elastomer (DE) Actuator

Patrick Lochmatter, EMPA, patrick.lochmatter @empa.ch; Gabor Kovacs, EMPA, gabor.kovacs@empa.ch; Paolo Ermanni, Centre for Structure Technologies, ETH Zurich

The aim of this work is to produce a large-scale, adaptive membrane actuator using the dielectric elastomer (DE) technology. This shell-like actuator must have the capability to maintain a predetermined surface shape by an automatic control system even under the influence of time variant external loads. The research activities in this project mainly focus on the investigation of diverse actuator designs, on the search for suitable actuator fabrication processes as well as on the investigation of the resulting actuator's performance.

The deformation requirements for such shell-like actuators comprise the overall ability of independent biaxial strain and curvature. The adaptive shell could either be realized by using a complex mechanical framework, which is activated by incorporated DE actuators, or by realizing an integrated structure consisting mainly of dielectric elastomer material. In order to achieve a continuous deformation of the shell, an array of many small elementary actuators could be reasonable. As feedback for the actual surface shape of the shell either the characteristic capacity behavior of deformed DE actuators or an external optical device could be employed.

As a promising field of application for shell-like actuators, a preliminary study investigated the impact of conventional and new concepts on the excursion-reduction of wind-excursed continuous ropeway gondolas. It was shown that adaptive approaches hold a large potential for drag-reduction on gondolas.

FIGURE 24: Passive (top) and activated (bottom) dielectric elastomer balloon actuator filled with air.

In a second step practical knowledge was gained by manufacturing and improving various actuator demonstrators such as circular actuators, rolled actuators or balloon actuators (Figure 24). The succeeding comparison of circular actuators coated with different electrodes showed that thin gold electrodes applied to the over-stretched dielectric film prevented the actuator's malfunction even when electrical breakdown occurred in the film.

Human Emulation Robotics, LLC

SPEM Materials Closing the Gap to EAP Applicability in Expressive Social Robots

David Hanson dayofid@hotmail.com and Victor White

Social robots are great candidates for EAP artificial muscle actuation, as the requirements can be lower than those for walking, flying or other applications. However, the materials conventionally used to emulate facial soft tissue seem to require more force and displacement to effect expressions than EAP actuators can produce at this time.

To lower the forces required for expressive robot faces, we developed materials with properties more like those of human facial soft tissues. For this purpose, we used a technique called structured porosity elastomer manufacturing (SPEM). Conventional sponge or foam elastomers create pores or cells by means of a blowing agent [Kemers et al 2000]—an expanding gas, which creates hollow pockets throughout the cellular material; but this limits cellular geometry generally to spheroid forms.

The SPEM process, on the other hand, allows the pore structure of a spongelike material to take an indeterminately large number of possible topologies. With SPEM, the possible pore geometries are unbounded—they can be spheroids, rectangular, accordian-like folds, star-shapes, or any desireable topology (see Figure 25). Thus, with accordian-shaped pores, tremendous elastic strains may be achieved, such as might be useful for aerospace, medical, or entertainment applications [Hanson and White, 2004]. By creating "fractal" pore structures recurring at diminishing orders of magnitude, the density of a spongelike elastomer theoretically may be reduced to 10^{-4} equivalent to an aerogel [ibid]. Moreover, SPEM has been employed with hybrid pore geometries—ideal for simulating human soft tissues: soft and elastic like a gel but as strong and abrasion resistant as much harder material.

To date, SPEM was demonstrated in several hybrid pore geometries made in single castings of the skin of a social robot. The material was sed to form artificial facial skin, as can be seen in the Eva robot (see Figure 26, and http://ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/Biomimetic-robot-Hanson.mov). Eva's skin consists of a single batch of silicone cross-polymerized across three layers that vary in pore size, pore geometry, and thickness. This technique better achieves the aesthetic behaviors of human skin while consuming less than 1/20th the energy relative to previous materials. The pores of Eva's skin are structured for mechanical advantage, relieving stress and increasing total elastic strain. Thus, the elongation of silicone SPEM increased from 280% to >800%—a value that is 85% of the elastic strain of the solid constituent elastomer, and an excellent value for facial expression robots [Hanson and White, 2004]. This notably betters the inadequate, 100%-300% strain exhibited by previous silicone foam and foam-latex materials.

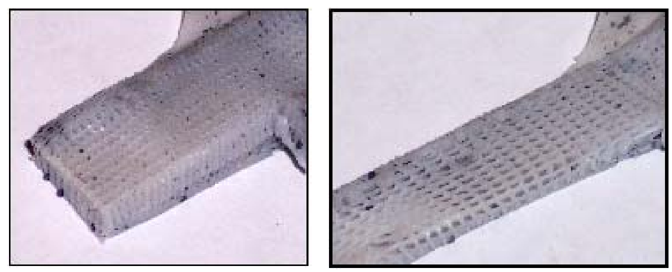

FIGURE 25: Rectangular celled SPEM made using rapid prototyping technology. Elongated state is on the right. The sample is 2 cm in width, 10 cm length, and .6 cm depth.

FIGURE 26: Eva, a social robot made of porous silicone using SPEM processes, with 36 actuated DOFs, face tracking and speech recognition. The low energy requirements of the SPEM enable Eva to run on AA batteries for 2 hours.

Using SPEM, the requirements for actuating robots' skins are well within the range of possible EAP actuation. Moreover, the materials wrinkle and bunch with unparalleled naturalism, as seen in figure 27, and in videos that is available at:

http://androidworld.com/HansonHead.wmv. The performance enhancements realized by EAP actuation could be greatly valuable to future social robots and entertainment robots—markets that are projected to expand 7-fold between 2004 and 2008, according to the U.N. [UNECE 2004].

FIGURE 27: Sociable robots demonstrating the expressive qualities of SPEM materials.

References

Hanson D. and White V, "Converging the Requirements of Facial Robotics and the Capabilities of EAP Actuators", Proceedings of the SPIE Smart Materials Conference, March 2004.

Landon, R. "Chapter 6: Character Creation - Structural Elements of Biomimetic Robots / 145" in *Biologically Inspired Intelligent Robotics,* Ed. Yoseph Bar-Cohen and Cynthia Breazeal, SPIE Press, 2003.

Kremers, A, Krusche, A, Haberstroh E "Analysis of the production of sponge rubber profiles" Macromol. Mater. Eng, 2000.

UNECE, United Nations Economic Commission for Europe, Press release ECE/STAT/03/P01, Geneva, 17 October 2004.

India – National Chemical Laboratory

Response of Conducting Polymer bi-layer Actuators

S.Radhakrishnan, srr@che.ncl.res.in and Swarnendu .B.Kar

Electroactive polymers (EAP) offer the promise of creating the flexible, low mass actuators that can form the basic building blocks of artificial muscles. Conducting polymer actuators make use of bulk material deformations that results from changes in oxidation state. Researchers already reported how bi-layer actuator in which a differential expansion between two thin, adjoining layers results in bending. However, they did not throw any light on how bending of actuator depends on mechanical property of backing layer which supported the active conducting polymer .We studied the effect of backing layer thickness and its mechanical properties on the response of conducting polymer bi-layer actuators [theoretical (Figure 28) experimental (Figure 29)].

It is evident that (Figure 30) as the backing layer thickness is decreased the bending angle increases for any modulus value. Also, the bending angle decreases with increase of backing layer modulus. There is an optimum for backing layer thickness as well as material modulus together with the thickness of the conducting polymer at which maximum bending is observed.

We have also investigated the time dependence of the bending of bilayer actuator with different applied potentials (Figure 30) Results indicate that there are two mechanisms functioning here: one ion diffusion and the other electrostatic force of electrical double layer. The exact reason is being studied further.

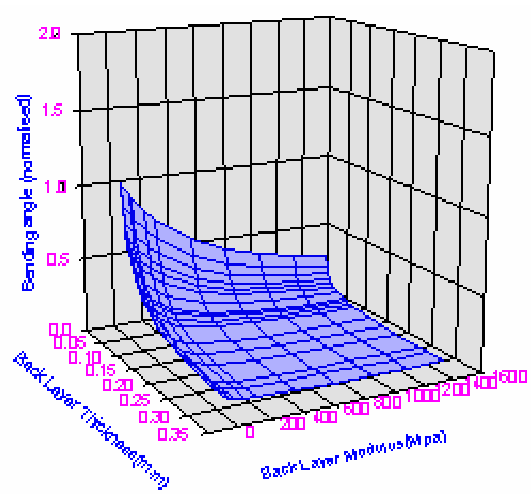

FIGURE 28: Plot of bending angle of actuators Vs. various backing layer thickness with modulus

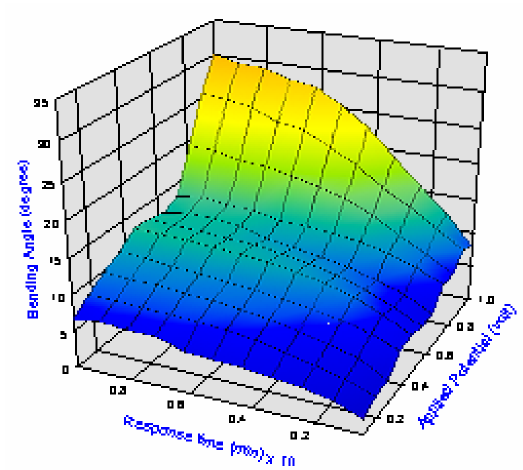

FIGURE 29: Plot of bending angle of actuators Vs. various backing layer thickness

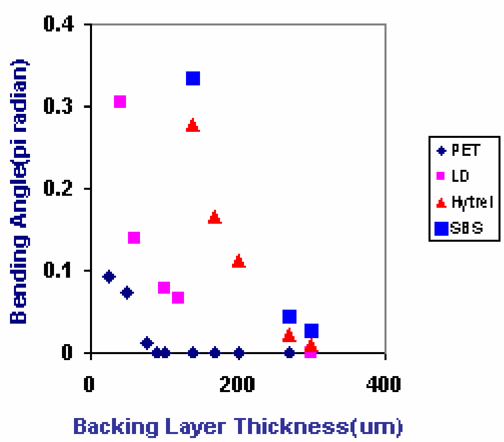

FIGURE 30: Variation of bending angle vs Response time and different applied potential

Our studies can be used for optimization of bi-layer actuator design with materials parameters. For lifting substantial weight we have to use high modulus backing layer materials but at the cost high strain or bending angle. There is an optimum thickness of backing layer as well as the EAP for best performance of the actuator.

Mesomorphic Phase Sensitivity of Polymer Microfiber to Proton Irradiation

B Mallick, T Patel and R C Behera
bmallick@iopb.res.in

An external ion beam facility was recently developed at the Institute of Physics, Bhubaneswar, India to carry out in-air Proton Induced X-ray Emission (PIXE) [1]. This source is intended for multi-elemental analysis and material modification by ion beam irradiation in air environment. For the present work proton, beam of 3-MeV energy was obtained from a 3 MV tandem type pelletron accelerator. The beam was collimated by a graphite collimator to a beam size of 3 mm diameter and was extracted into air using a Kapton^{TM} foil of 8 micron at the exit point of a vacuum (10^{-7} mbar) chamber. The external beam current measurement was performed using a rotating vane chopper [2] designed in the institute. Beam size of the external proton beam can be increased to 10-15 mm diameter circular patch by proper adjustment. Polyethylene terephthalate (PET) fiber is chosen for irradiation study because of its wide application in various fields such as textiles [3], surgical polymeric textiles [4], composites [5], nanocomposites [6], conducting polymer [7], electroactive polymer [8] etc. Again, microfibers are manufactured to replace traditional materials in application from super absorbent diapers to artificial organs. So this has been selected for the present study. Ion beam modification improves mechanical, electrical, thermal, optical and chemical properties of polymers. Polymers can be modified by proton irradiation [9]. A beam of 3MeV energy was used to irradiate the microfiber in air at normal atmospheric pressure and temperature (ranging18-22 °C) with flounce of 1×10^{11} p/cm^2. In the above study the beam is allowed to travel 3 cm in air inside the irradiation cell (an aluminum cylinder of 15mm diameter and 30mm length moving with 1Hz frequency for homogeneous irradiation during which the energy gets reduced to about 2.4 MeV before interaction with microfibers.

Calculation of projectile range in air and materials was done using "TRIM" program. PET is a two-phase material, the crystalline and amorphous. In addition to these amorphous (disordered) and crystalline (3-dimentionally ordered) there is also a mesomorphic phase consisting of a 2-dimensionally ordered structure. The diffraction patterns as shown in Figure 31 are obtained from the non-irradiated sample (each contains 30 number of fibers) and irradiated PET microfiber. Small changes were obtained in the x-ray diffraction pattern of the irradiated PET fiber as compared to the virgin one and no shifting of angle takes place. Increase in relative intensity (counts) of the diffraction peak of the irradiated sample was observed in both parallel and perpendicular alignment of fiber axes to x-ray direction. In both the cases the intensity of the diffraction peak of irradiated fiber sample were found to be unequal mainly because of non-uniform diffraction area and crystallites orientation.

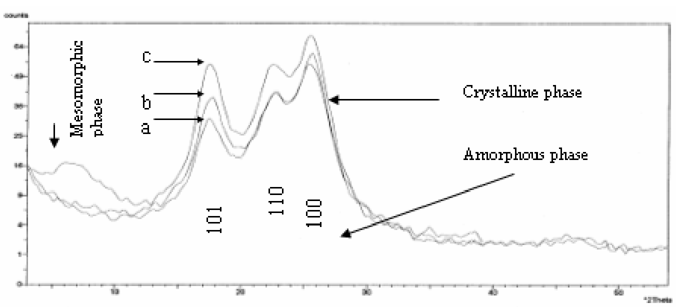

FIGURE 31: (a) X-ray diffraction pattern obtained from the non-irradiated PET microfiber keeping fiber axis parallel to x-ray beam, (b) x-ray diffraction pattern of proton irradiated microfiber keeping fiber axis perpendicular and (c) parallel to x-ray direction.

The crystallinity of non-irradiated microfiber was calculated to be 81.82%; this increases to 84.87% after irradiation. Morphological changes [9] of polymers due to proton irradiation, forming short length ordered aggregates can be studied using wide-angle x-ray diffraction. Observation of low intense broad x-ray diffraction peak from the irradiated microfiber at low angles when the fiber axis is kept parallel to the incident x-ray beam indicating the presence of mesomorphic phases. This type of peak is not observable when the fiber is perpendicular to the incident x-ray beam. The amount of mesomorphic phases enhance due to proton irradiation in the above sample was estimated to be 5.3%. The above study on mesomorphic phase may help to understand optoelectronic [10] behavior of polymer for sensor application.

References

1. V. Vijayan, R. K. Choudhury**,** B. Mallick**,** S. Sahu, S. K. Choudhury, H. P. Lenka, T. R. Rautray, P. K. Nayak, *Current Science.*, **85** (2003) 772.
2. S. Sahu, S. K. Choudhury, B. Mallick, T. R. Rautray, V. Vijayan and R. K. Choudhury, *Proc. on Indian Particle Accelerator Conference-2003, CAT, Indore, India* (2003) 695.
3. T. Patel and S. Bal, *Polym. J.*, **33**, (2001) 121.
4. L. M. Ferreira, M. H. Casimiro, C. Oliveira, M. E. Cabeco Silva, M. J. Marques Abreu and A. Coelho, *Nucl. Instr. and Meth*., B **191**, (2002) 675.
5. S. Fu, P. Wu and Z. Han, *Compos. Sci. Technol.*, **62**, (2002)3.
6. J-Hae Chang, S. J. Kim, Y. L. Joo and S. Im, *Polymer*., **45**, (2004)919.
7. R. Mishra, S. P. Tripathy, D. Sinha, K. K. Dwivedi, S. Ghosh, D. T. Khathing, M. Muller, D. Fink and W. H. Chung, *Nucl. Instr. and Meth.*, B **168**, (2000)59.
8. T. Patel and B. Mallick, *WW-EAP-Newsletter (http://ndeaa.jpl.nasa.gov/nasa-nde/, NASA, USA).*, **2**, (2000) 4.
9. M. E. Martinez-Pardo, J. Cardoso, H. Vazquez and M. Aguilar, *Nucl. Instr. and Meth*., B **140**, (1998) 325.
10. J. W. Y. Lam, C. K. LW, y. Dong, J. Ge, B. Z. Tang, *Optical Materials*, **21,** (2002), 321.

Bio-Mimetic Control Research Center, RIKEN, and AIST, Japan

Limited Angle Rotary Actuator using IPMC

K. Takagi (BMC, RIKEN), Z.W. Luo (BMC, RIKEN), K. Asaka (AIST), K. Tahara (BMC, RIKEN) takagi@bmc.riken.jp

A rotary actuator using Ionic Polymer-Metal Composite (IPMC) is developed as shown in Figure 32. It consists of three main parts: the spiral polymer strip(s), the rotor shaft and the actuator case. An IPMC strip (50[mm]x6[mm]x0.18[mm]) was fabricated from Nafion117 via electroless gold plating process. The counter ion is Na+. In Figure 33, two antagonistic polymer strips are used. One end of the spiral polymer strip(s) is connected to the output shaft and the other end is fixed on the wall of the actuator case. The rotor shaft and the case are made of acrylic resin. The actuator case can be filled with water or a solution and therefore it can act as the water reservoir.

Motivated by the mechanics of spiral spring, we have discovered that the bending motion of the

IPMC beam can be transformed to the rotary motion with limited angles. The bending motion of the polymer causes the rotary motion of the rotor shaft even without the polymer contraction. The motion of the actuator applied a voltage of 1.5[V] is shown in Figure 33.

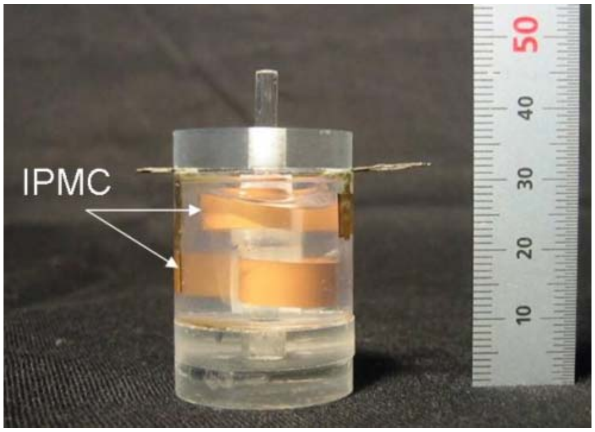

FIGURE 32: Rotary IPMC actuator

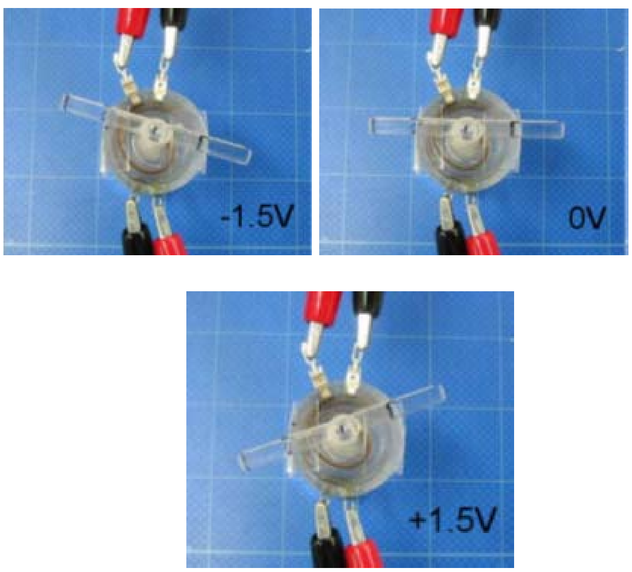

FIGURE 33: Motion of the actuator

The actuation torque presently was about 6×10^{-6}[Nm/V]. In order to develop the model based control law, we introduce an approximated linear model which consists of an electromechanical system and one degree of freedom mechanical system. The transfer function was identified experimentally as shown in Figure 34. The proposed mechanism is expected to apply to the miniature manipulators, in-water robot actuators, soft rotary joint actuators, and others.

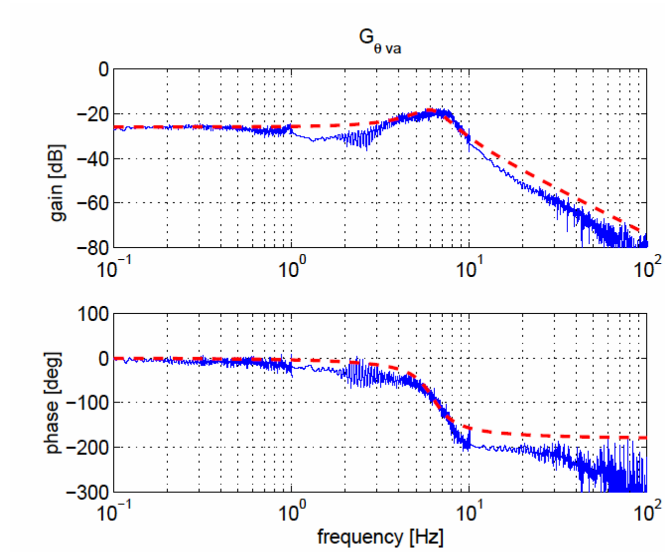

FIGURE 34: Frequency response from applied voltage to angle (solid: experimental, dashed: identified)

Acknowledgement

The tested IPMCs were fabricated and provided by Yoshihiro Nakabo. The authors greatly appreciate his kindness and his useful advice.

University of Nevada, Reno, NV, USA,

Self-Oscillating Ionic Polymer-Metal Composite

Kwang Kim and Doyeon Kim kwangkim@unr.edu

A unique Ionic Polymer-Metal Composite (IPMC) with "self-oscillation" capabilities is currently being developed. The self-oscillations of IPMC can be obtained by the potential periodicity in the Pt anode where the activation-overpotential is altered by complex surface reactions under an applied DC current. Such a self-oscillatory behavior of IPMC was highly conceivable and repeatable when it was properly prepared. IPMC's can mimic biological systems that often exhibit rhythmic phenomena at all levels. Experimental results show spontaneous and continual oscillatory motion of IPMC (in the frequency range from 0.15-0.30Hz) that is caused by the surface reactions.

NEW BOOKS

2nd Edition of the book on EAP

Y. Bar-Cohen (Editor)

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

The 2nd edition of the "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges" was released during the 2004 EAPAD Conference. 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. 12 chapters in topics that sustained major advances were revised at various degrees where some like Chapters 6 and 18 were significantly rewritten.

This book includes description of the available materials, analytical models, processing techniques, and characterization methods. This book is intent to provide a reference about the subject, tutorial resource, list the challenges and define a vision for the future direction of this field. Observing the progress that was reported in this field is quite heart warming, where major milestones are continually being reported.

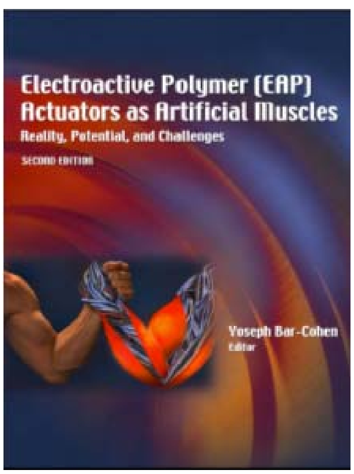

FIGURE 35: The cover page of the 2nd Edition of the book about EAP

Soft Actuators [in Japanese]

Y. Osada, Hokkaido University (Editor)

The book entitled "Soft Actuators" (Figure 36) was published in November by NTS publishing Co. Ltd. http://www.Nts.book.co.jp/item/detail/summary/bio/20040900_31html, Japan. This book covers the current statues of the areas related to soft or novel actuators, i.e. soft actuators driven by electrical stimuli, Soft actuators driven by photo stimuli, and artificial muscles driven by the other stimuli. Actuators driven by compressed air are also covered. The total number of pages in this book that is written in Japanese is 420 pages and 30 authors participated in writing its chapters. The first printed 1,200 books have been sold out in a month.

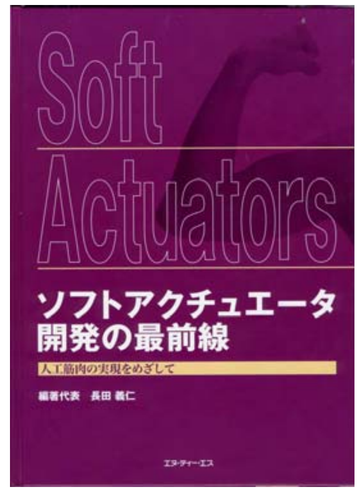

FIGURE 36: "Soft Actuators" is a review book on EAP that is written in Japanese.

Biomimetics: Mimicking & Inspired by Biology

Y. Bar-Cohen (Editor)

A new edited book is currently being prepared covering the subjects of biomimetics and biologically inspired technologies. This book is in the final draft stages describing nature as a pool of marvelous inventions that have evolved over billions of years of evolution offering numerous models for imitation. This book is intended to serve as a reference comprehensive document, tutorial resource, and set challenges and vision for the future direction of this field. Figure 37 shows a draft of the book cover-page and the graphics (prepared by David Hanson) shows the editor's idea of biomimetics where human learns from nature to produce mechanisms and devices. Leading experts (co)author the 20 chapters of this book and the draft of the outline is on http://ndeaa.jpl.nasa.gov/ndeaa-pub/Biomimetics/Biologically-Inspired-Technology.pdf

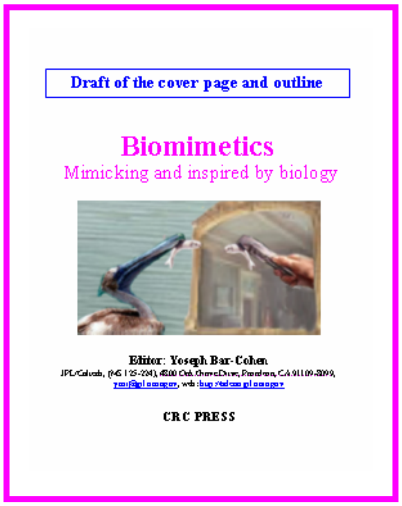

FIGURE 37: The draft of the cover page of the new book on biomimetics and biologically inspired technologies.

Robots Slither

Ryan A. Hunter and Julia Gorton

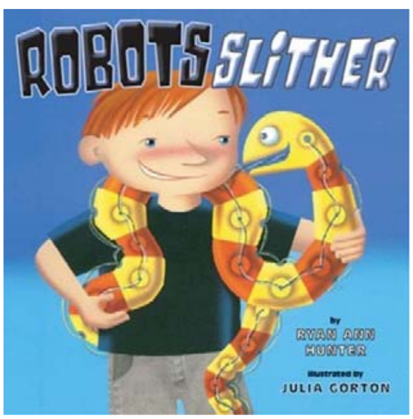

FIGURE 38: A new children book with input about EAP http://www.amazon.com/exec/obidos/tg/detail/-/0399237747/qid=1097833019/sr=1-12/ref=sr_1_12/103-5812020-2503004?v=glance&s=books

A children book for the level of Kindergarten to second Grade was recently published that includes a description of the EAP based microrobot. This robot was developed by Micromuscle AB, Sweden. The illustrations in this book amplify interest with imaginative cartoon scenes of human-robot interaction, and realistic sidebar drawings.

UPCOMING EVENTS

7 - 10 March, 2005	2005 EAPAD, SPIE's joint Smart Materials and Structures and NDE Symposia, San Diego, CA., For information Contact: Jonica Todd , SPIE, jonica@SPIE.org Website: http://spie.org/app/education/index.cfm?fuseaction=offeringdetail&offering_id=553259
Nov. 28 to Dec. 2, 2005.	2005 MRS Fall Meeting, Symposium W - "Electro Responsive Polymers and Their Applications." Boston, MA For information contact: Vivek Bharti, 3M Center, vbharti@mmm.com,
June 2006	ACTUATORS 2006. For information contact: Peter Sommer-Larsen, Risø National Laboratory, peter.sommer.larsen@risoe.dk;

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

Happy New Year

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

All communications should be addressed to:

Dr. Y. Bar-Cohen, JPL, M.S. 125-224, 4800 Oak Grove Dr., Pasadena, CA 91109-8099
Phone: (818)-354-2610, Fax: (818)-393-2879 or E-mail: yosi@jpl.nasa.gov