WorldWide ElectroActive Polymers

EAP

(Artificial Muscles) Newsletter

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http://eap.jpl.nasa.gov

FROM THE EDITOR

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Progress in the field of EAP is continuing to be made and as we are approaching the New Year it is great to mark 2005 for the major milestone that was accomplished. The first wrestling match contest of EAP actuated robotic arms and human, which took place on March 7, 2005, is now an important part of the history of this field. Looking towards 2006, at the SPIE's EAP-in-Action Session of the EAPAD Conference we are going to implement lessons learned from this first competition. In the upcoming Conference, we are going to focus on having competition of EAP actuated robotic arms that will be measured for performance rather than wrestling with a human. In a future conference, once advances in developing such arms reach sufficiently high level, a professional wrestler will be invited for the next human/EAP-actuated robot wrestling match. Further information about this challenge and information about the competition is available on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

It is interesting to note that the subject of biomimetic robots that emulate humans have now reached the level of interaction with presidents of nations. In November, the President of the USA, George W. Bush, shook the hand of an Einstein robot (Figures 1) and the Presidents of South Korea, Roh Moo-hyun, wrestled with a robotic arm that is driven by motors (Figure 7).

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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 of the Advanced Technologies Group having the address: http://ndeaa.jpl.nasa.gov

Albert Hubo meets President George W. Bush

Hanson Robotics Inc. (HRI) has built the first fully expressive humanlike robot face to be mounted on a walking robot body, demonstrating dramatic reductions in power requirements for expressive robotic faces. The "Albert Hubo" robot, with a body built by KAIST's Hubo group was demonstrated at the November 19 APEC summit in Busan, South Korea, where the robot greeted and shook hands with numerous world leaders, including President George W. Bush (see Figure 1).

FIGURE 1: President Bush is shaking the hand of the robot Albert Hubo on Nov. 19 at the APEC summit in Busan, South Korea.

To make the full range of facial expressions, Frubber materials (Hanson's patent pending) are used requiring less than 10-W and that is significantly less power than any previous robot skin materials [Hanson et al 2005]. Frubber is a structured porosity elastomer, with cellular structure designed mechanically to lower the needed forces and increase expressivity. The reductions in power requirements may make Frubber an ideal candidate for EAP actuation [Hanson, 2004]. The similarity of Frubber to human soft tissues enables new bio-inspired approaches, which could greatly benefit from the incorporation of EAP artificial muscles [Hanson and White, 2004]. Actuators, sensors, and other devices can be precisely positioned and embedded in the Frubber material, a concept HRI is developing with the microactuator group of University of Texas at Arlington (UTA) Automation and Robotics Research Institute (ARRI).

This combination of technologies promises to realize active smart composites that better emulate the multi-purpose nature of human facial soft tissues [Bar-Cohen, 2004].

Hanson Robotics was founded by David Hanson, a current PhD candidate at the University of Texas at Dallas, to commercialize social robots for elder care, education, and other applications. Hanson Robotics is also investigating Frubber's wider potential uses, including in smart active prosthetics, surgical simulation, and "smart" bandages.

Since 2002, Hanson has built 10 social robots incorporating computer vision, conversational speech software, and a layered cognitive architecture to simulate human social intelligence. The robots are being used to investigate human social perception and cognition at the University of Texas at Dallas, and the University of the West of England. HRI is working with the University of Memphis Autotutor group to test tutorial robots. Since 2002, one of Hanson's robot heads is serving as a platform for testing EAP actuators at the JPL's NDEAA lab.

The Albert Hubo will live in Korea at the KAIST Hubo Lab, Daejeon, with remote access available via the web for ongoing software/AI development.

Hanson Robotics is located in Dallas TX. The company website is www.hansonrobotics.com, and the company email is info@hansonrobotics.com

References:

Bar-Cohen, Y. (Ed.), "Applications for Electrically Actuated Polymer Actuators," in *Electrically Actuated Polymer Actuators as Artificial Muscles*, SPIE PRESS, Washington, USA, Vol. PM136, Ch. 18, 2nd ed. March 2004.

Hanson, D, Olney, A, Zielke, M, Pereira, A. "Upending the Uncanny Valley", AAAI Conference Proceedings, 2005

Hanson D., White V. "Converging the Capabilities of Electroactive Polymer Artificial Muscles and the Requirements of Bio-inspired Robotics", Proc. SPIE's Electroactive Polymer Actuators and Devices Conf., 10th Smart Structures and Materials Symposium, San Diego, USA, 2004.

Hanson D., "Chapter 18: Applications for Electrically Actuated Polymer Actuators," in Electrically Actuated Polymer Actuators as Artificial Muscles, Bar-Cohen Y. (Ed.) SPIE PRESS, Washington, USA, Vol. PM136, 2nd Edition, March 2004.

The 2006 EAP Armwrestling Competition

The first armwrestling match of EAP actuated arms and human took place on March 7, 2005 (see a photo in Figure 2) and it is now part of the history of this field. Looking towards 2006 at the SPIE's EAP-in-Action Session of the EAPAD Conference we are going to implement lessons learned from this first competition. In this Conference, we are going to focus on having competition of EAP actuated robotic arms that will be measured for performance rather than wrestling with a human. In a future conference, once advances in developing such arms reach sufficiently high level, a professional wrestler will be invited for the next human/machine wrestling match. Before the start of the 2006 EAP-in-Action Session, each of the participants in the competition will give 5-minutes description of their arm, the EAP actuation mechanism, structural materials, information about the arm performance characteristics and any other interesting information about the development of the arm.

As in the past years, the EAP-in-Action Session will be held as part of this SPIE's EAPAD conference and it intended to turn the spotlight on EAP materials and their applications as well as increase the recognition of their potential. New materials and applications are continuing to emerge and this session provides the attendees an opportunity to see a demonstration of the latest EAP materials in action. This Session offers a forum of interaction between the technology developers and potential users as well as a "hands-on" experience with this emerging technology. It is a great opportunity to see the capability of the state-of-the-art of EAP as potential actuators-of-choice.

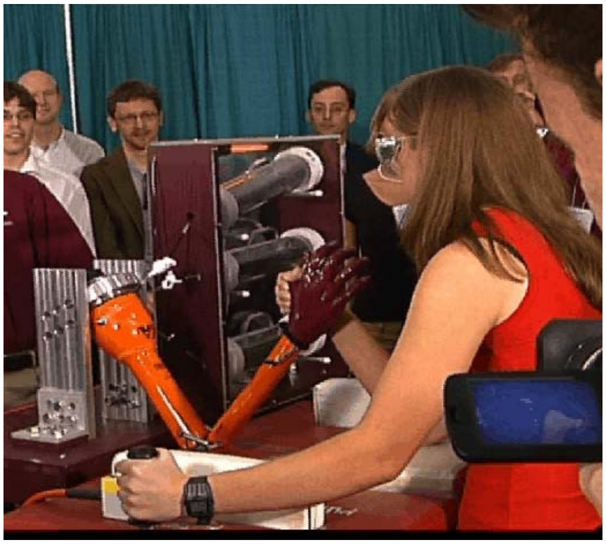

FIGURE 2: The human challenger, Panna Felsen, wrestling with the VT robotic arm.

The 2006 competition will involve measuring the arms capability and compare the data of the competing arms. The EAP actuated arm will pull on a cable that has a force gauge on its other end and is supported by a wrestling fixture (see Figure 3). A schematic diagram with the fixture dimensions is shown in Figure 4. This fixture will be strapped to a table (see Figure 5) having dimensions of: Length: 244 cm (96") x Width: 76 cm (30") x Height: 76 cm (30") and Thickness: 2.5 cm (1"). EAP actuated arms will be tested for speed and pulling force capability, and there will be a minimum weigh that will need to be lifted. The initial value for this weight we chose 0.5-kg.

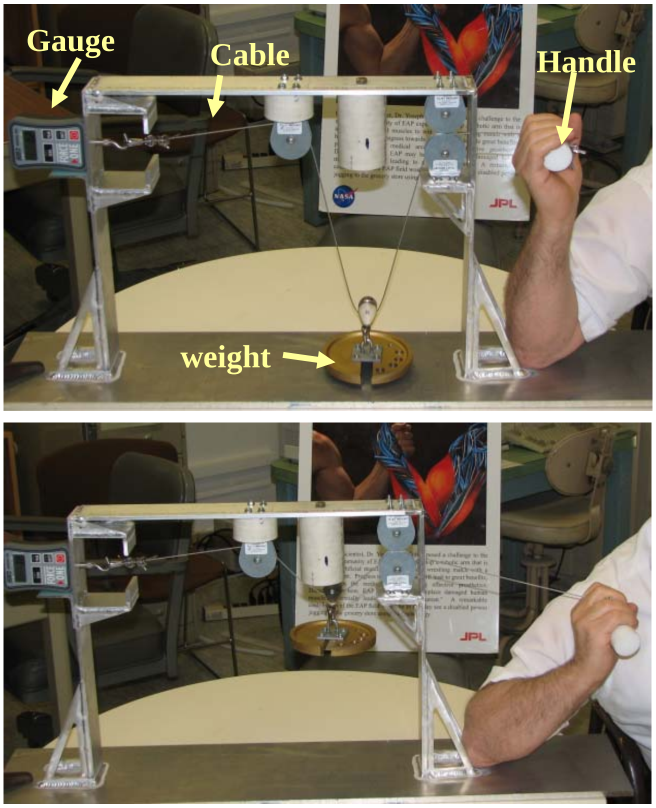

FIGURE 3: The fixture for testing the force and speed of the EAP actuated robotic arms.

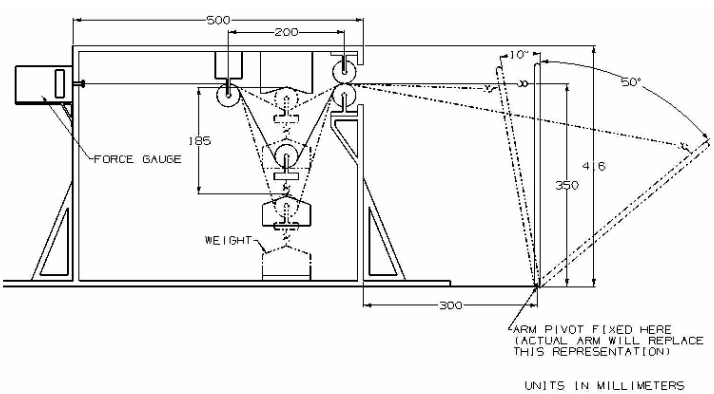

FIGURE 4: The competing arms testing fixture (see larger drawing on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm .

The competing arms (shown as a vertical rod on the left of the drawing) will be connected via a cable to a Force Gauge (see on the right of the fixture). Upon starting the test, weight that is hanged on the cable will be lifted and the time that it takes to reach the top of the fixture will be measured. Once the weight reaches the top, the cable will be fully stretched and the force will be measured by the gauge. The three strongest arms will be invited to wrestle with each other to select the winner. Three SPIE award certificates will be given recognizing the achievers in developing the wrestling arms that are the fastest, the lifter of the heaviest weight and the strongest. The rules of the contest are on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/amerah/Amerah-2006/armwrestling-rules.htm

FIGURE 5: An example of the table that will be used to support the test fixture.

The competition will start with measuring the performance of the student Panna Felsen (see Figure 5), who served at the human opponent in 2005. The measured data will be used as a baseline for comparison with the performance results of the tested robotic arms that are driven by EAP actuators.

So far, the following organizations have already announced their intent to bring an EAP actuated robotic arm for the upcoming competition:

1. DSO National Laboratories, Defense Medical & Environmental Research Institute, Centre for Human Performance, Singapore, under the lead of Kelvin Hau-Kong Chan, Chan Hau Kong, and Lee Vee Sin Peter
2. Environmental Robots Incorporated (ERI), Albuquerque, New Mexico, USA, under the lead of Mohsen Shahinpoor
3. Virginia Tech, USA: Senior Students under the lead of Don Leo, Kevin P. Granata.

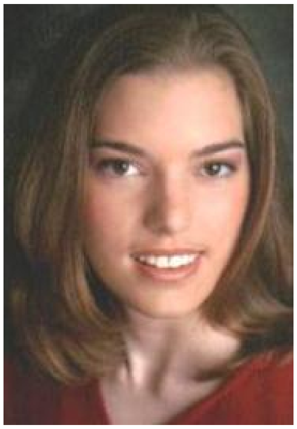

FIGURE 5: Panna Felsen, the former high school student from San Diego, who was the human opponent in the first Armwrestling Competition.

Acknowledgement
The wrestling fixture for this contest was drawn (see Figure 3) by Ayoola K Olorunsola, JPL, was constructed by Qibing Pie and his students from UCLA (Figure 4) and finalized by Chris Jones, JPL.

Cyberhand – A European Artificial Hand

A highly dexterous, artificial hand called Cyberhand is currently being developed in Europe under funded by the Future and Emerging Technologies initiative of the European Information Society Technologies (IST) program. This program parallels the development that is funded by DARPA under the title "Revolutionized Prosthetics" seeking to develop smart prosthetic hand that can operate and feel as good as the real thing (http://www.darpa.mil/ dso/solicitations/prosthesisPIP.htm).

As the DARPA objective, the Cyberhand is being developed with sensors that may provide patients with active feeling by connecting them to the nervous system. Thus sensory feedback can be provided from the hand to the brain, and instructions from the brain control the hand. The prototype uses two types of human senses: (a) sensing where parts of the body are relative to other parts, whether our fingers are open or closed; and (b) providing sense of taste, touch, sound, hearing, and sight that tell us about the external world. Each of the five fingers is articulated and has one motor dedicated to its joint flexing for autonomous control. The hand is also equipped with an opposable thumb that can perform different grasping actions. The Cyberhand is developed by researchers from Germany, Spain, Italy and Denmark. For more information, visit: http://link.abpi.net/l.php?20051201A8

Robo Arm-Wrestler Wrestles with the President of South Korea

Korea – Konkuk University, Seoul
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Web: http://konkuk.ac.kr/~cgkang

Chul-Goo Kang at the Intelligent Control and Robotics Laboratory, Dept. of Mechanical Engineering at Konkuk University has announced that his research team has developed a motors driven smart armwrestling robot named Robo Arm-Wrestler (Figure 6). The President of South Korea President, Roh Moo-hyun, arm-wrestled with this Robo Arm-Wrestler at the Future Tech Korea 2005 exhibition that was held on November 26, 2005 in Seoul (Figure 7).

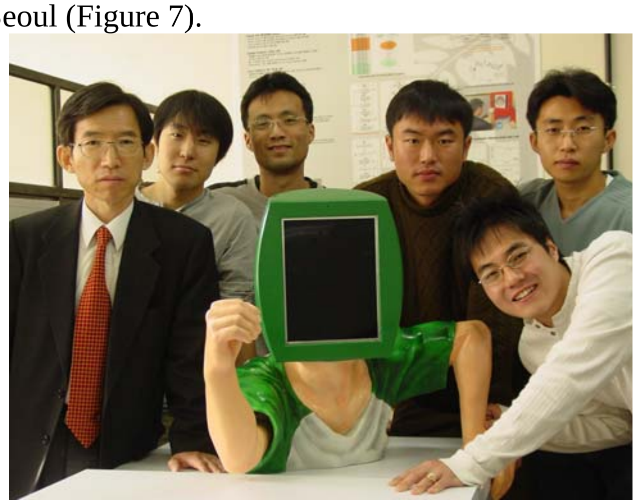

FIGURE 6: Robo Arm-Wrestler and its developers.

This robot is intended to serve as a friendly help to seniors keep their physically and emotionally health via armwrestling exercises. The Korean National Statistics Office reported that Korea is becoming an older society, as its aging population increases sharply in recent decades with the elderly index recorded as 35 percent well over the standard 30 percent for an aging society. Declining youth population brings about an acute work force shortage and burdens the society with social welfare cost excessively. Therefore, the Korean government has started recently to promote developments of various intelligent robots for the aging population.

FIGURE 7: Roh Moo-hyun, South Korea President, arm-wrestled against Robo Arm-Wrestler.

The Robo Arm-Wrestler is different from conventional armwrestling devices [1, 2] in its novel functions. The functional characteristics of the Robo Arm-Wrestler are as follows: (i) It automatically generates a force level appropriate to each person after sensing the human's arm force, and therefore all persons with large or small arm force can enjoy the armwrestling. (ii) The generated force profile varies with each match, so one person can enjoy armwrestling with the robot for a long time without being bored. (iii) The winning average of the robot is determined randomly at the starting instant of the match, but the robot measures human's will to win during the match and the result influences the winning average of the robot. That is, the robot's force is possibly becoming less and less and the winning probability of the human may increase if the human try to stand out to win the match during a prescribed time interval. (iv) When the human approaches the robot, it recognizes human's approach using ultrasonic and photoelectric sensors and begins to talk to him such as "Hello, welcome to the robotic armwrestling system. If you want to try armwrestling, please sit down on the chair", and recognizes automatically sitting on the chair, and guide human arm-wrestler how to play and enjoy armwrestling. The tone of the voices may vary from time to time in order to prevent from being tedious due to the same repeated voices. The facial expression of the avatar often changes synchronously according to the armwrestling situation.

The system concept of the Robo Arm-Wrestler is shown in Figure 8. The inference engine generates an appropriate force profile for each match, which considers human's maximum force, human's force pattern, time duration, human's will to win, and finally randomness. Then force control logic makes the robot arm to follow the generated force profile as smooth as possible. The force control logic is basically PID type, but it uses velocity and position information together with force information.

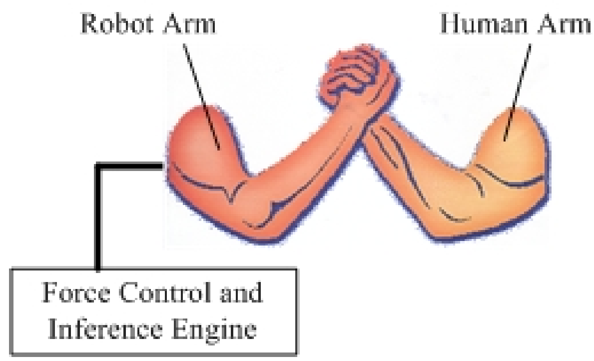

FIGURE 8: System Concept of the Robo Arm-Wrestler

The mechanism of the Robo Arm-Wrestler is composed of a servomotor, a reduction gear, a torque sensor, and three inclinometers [3]. The reduction gear is necessary for increasing torque from the servomotor. The reduction gear should have low backlash and friction for good control performance. Inclinometers are necessary for initializing the angular position of the robot arm.

Currently, this research is pursued further to add more human-like functions such as using visual information at armwrestling competitions. This technology can provide great basis for the development of EAP driven robotic arms.

Acknowledgment

The author gratefully acknowledges the financial support from 21C Frontier Project (Intelligent Robotics Development Program 6-2-3).

References

1. F. P. Rufa, Arm-wrestling device, US patent 5842958, 1998.
2. S. Toshio, Muscular force strengthening device for arm-wrestling, Japan patent JP2002017891, 2002.
3. C.-G. Kang, "Conceptual Design for Robotic Arm-wrestling," IEEE RAM, 1072-1076, Singapore, 2004.

TUTORIAL AND COURSES

Course on EAP at EAPAD 2006

An introductory course about EAP is planned to be held on Sunday, February 26, 2006 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 Qibing Pei, University of Californian at Los Angeles.

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 on: http://spie.org/Conferences/Programs/06/ss/shortcourses/index.cfm?fuseaction=shortcoursedetail&course=SC634

RECENT CONFERENCES

MRS Fall 2005

As part of the Fall 2005 MRS Symposium an EAP related conference entitled "Electro Responsive Polymers (ERP) and Their Applications," was held in Boston from Nov. 28 to Dec. 2, 2005.

The topics of this symposium included: Class-1: Sensor and actuators; and Class-2: Dielectrics and Charge Storage. The ERPs Conference was 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 Lab; and ZhongYang Cheng, Auburn University.

Invited speakers included: 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), Qiming Zhang (Penn State).S. B. Lang (Ben-Gurion University of the Negev, Israel), Timothy Swager (MIT, USA), and Mark Zahn (MIT, USA),

UPCOMING CONFERENCES

2006 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 again in San Diego, California, over four days from February 27 to March 2, 2006 and with a course on Sunday, February 26. The 2006 EAPAD will include 88 presentations from leading world experts in the field including members of academia, industry, and government agencies from the USA and overseas. The 2006 EAPAD program is now available on: http://spie.org/Conferences/Programs/06/ ss/conferences/index.cfm?fuseaction=6168

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. Papers will cover various aspects of the following topics:

- Advances in electroactive polymers (EAP) materials
- Non-electro active-polymer (NEAP) materials (e.g., activated thermally, chemically, etc.)

- Theoretical models, analysis and simulation of EAP including computational chemistry.
- Methods of EAP measurement, testing and characterization
- Manufacturing technologies, including electroding, synthesis, processing, shaping and fabrication
- Design and engineering of EAP actuators and sensors and the their integration into devices
- EAP scalability from miniature (MEMS, micro and nano) to macroscopic devices.
- In progress, under consideration, or desired EAP applications in artificial muscles, robotics, biomimetics, etc.
- EAP driving electronics, system integration and packaging
- Nonlinear control algorithms for EAP devices and their implementation in software and hardware.

The 2006 EAPAD conference will be opened with another interesting and exciting Keynote presentation. The speaker will be Rainer Stahlberg, from the University of Washington (see Figure 9) and the title of his presentation is "**What can we learn from nastic plant structures? The phytomimetic potentiality of nastic structures,** In this presentation he will cover the topic of plants as active structures the efforts to emulated them using EAP technology.

FIGURE 9: The 2006 EAPAD Keynote Speaker, Rainer Stahlberg, from the University of Washington.

As in past years, a EAP-in-Action Session will be held on Monday, Feb. 27, 2007 and in addition to the armwrestling competition, which was mentioned above, the attendees were given an opportunity to see several; demonstrations of EAP actuators and devices. 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.

MRS Fall 2006

As part of the Fall 2006 MRS Symposium an EAP related conference entitled "Smart Dielectric Polymers Properties, Characterization and Their Devices," Symposium C. The Chairs will be V. Bharti, Y. Bar-Cohen, Q. M. Zhang, Z.-Y. Cheng, and G. M. Sessler. Information about this Symposium will be made available at a later time on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/eap-conferences.htm

ACTUATOR 2006

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Roy Kornbluh, SRI International
roy.kornbluh@sri.com

The 10th conference on new actuators will take place in Bremen, Germany from June 14 to 16, 2006 and it includes a session on EAPs. The EAP sessions have generated quite a bit of excitement in previous years. As part of the conference there will be an exhibition on Smart Actuators and Drive Systems. Also, the conference will include the RoboCup 2006. The abstract date has been extended and it requested that if you wish to submit please do so as soon as you can. Information about the conference can be found on www.actuator.de

SAMPE 2006

From April 30 to May 4, SAMPE will hold its 2006 Conference in Long Beach, California, and for the first time it will include a session on EAP. This session will be Chaired by Yoseph Bar-Cohen, JPL, and Qibing Pei, UCLA and it will be an opportunity for interaction with materials and process scientist sand engineers who will attend this conference. During this session a demo of Dielectric EAP actuators that were made by Qibing Pei and his students from UCLA will be demonstrated. Information about this conference is available on http://www.sampe.org/events/2006longbeach.aspx

ROBIO 2006

The International Conference on Robotics and Biomimetics (ROBIO) is an annual IEEE conference. The ROBIO 2006 Conference will be held in Kunming, China from December 18 to 20, 2006. This conference brings together leading scholars and researchers worldwide to disseminate their most recent and advanced findings to bridge the frontier of knowledge between robotics and biomimetics – from meter scale down to nanometer scale. Major topics covered by ROBIO include

- Robotics - humanoids, bio-mimicking robots/ systems, flying robots, medical robots, rescue robots, manipulators, path planning, tele-operation, vision, sensing, tracking, control, fuzzy/neural net/genetic algorithms, etc
- Advanced Actuation Materials - artificial muscles, electroactive polymer actuators, electrostrictive polymer actuators, conjugated polymer actuators, ionic conducting polymer actuators, smart materials, etc
- Micro/Nano Technology - AFM/SPM based manipulation, micro/nano fluidics, nanotube/nanowire/DNA based sensors, MEMS/ Nano fabrication, sensors, and actuators, micro/nano robotics, assembly, and manipulation, etc.
- Cellular Biomimetics - molecular motors, DNA/protein manipulation and detection, molecular and cellular imaging, micro/nano scale energy conversion and storage, DNA/molecular circuits, molecular self-assembly, bio-informatics, etc.

All papers must be submitted electronically in PDF format by **July 1, 2006**. The maximum number of pages is limited to six in two-column IEEE format. An additional two pages will be allowed subject to extra page charges. Information can be obtained from Hong Zhang zhang@cs.ualberta.ca Web: http://www.cs.ualberta.ca/~zhang/robio2006/

ADVANCES IN EAP

Agricultural Research Service (ARS), Peoria IL

Electroactive Bioplastics

Jan Suszkiw, Vicki Finkenstadt, finkenvl@ncaur.usda.gov and Julius L. Willett

Recently, we showed that biobased plastics from agricultural feedstocks exhibit electrical conductivity at a level that is similar to other EAPs and have the potential for use as biosensors, controlled-release devices, artificial muscles and other applications (See Figure 10). Also, we are now considering its use in lithium batteries where it can help reducing the recharging time as well as make the batteries hold charge longer. Most PS are isolative in the solid-state (this product is not a gel electrolyte) but we grafted and doped the material to achieve the necessary conductance (currently around 0.001 S/cm) and we are continuing to improve this performance. Our normal test voltage in the resistivity measurements is 0.75 V.

FIGURE 10: Chemist Vicki Finkenstadt displays different samples of the new electroactive bioplastics [Photographed by Peggy Greb, ARS].

Generally, this group of materials is petroleum-based and our accomplishment is significant since we used plant-based renewable materials that are widely available and are inexpensive (about 20 cents a pound). By comparison, polyaniline emeraldine, one of the most widely used conductive polymers, costs $58 per gram. Use of bioplastics in certain electroactive applications could leapfrog some of the pitfalls associated with using petroleum feed-stocks, such as U.S. reliance on foreign suppliers. The patentability of these and other applications is now being reviewed. We anticipate we will have some working prototypes in the coming months. Further information is available on: http://www.ars.usda.gov/is/AR/archive/dec05/plastic1205.htm

University of Nevada-Reno

Magneto-Responsive Ionic Polymer-Metal Composite (MR-IPMC)

Kwang J. Kim (kwangkim@unr.edu)

Recently, our group came up with magneto-responsive ionic polymer-metal composites (MR-IPMC's). The MR-IPMC's were fabricated with precipitated (ppt) iron oxide particles (or other materials) within the ionic polymer matrix using a variety of iron salt reduction techniques. It was found that the precipitation of iron oxide within an ionic polymer can effectively induce not only magnetic responsiveness but also electric responsiveness. The vibrating sample magnetometry of a typical ppted iron oxide IPMC (Figure 11) shows that the magneto-responsive behavior of the fabricated MR-IPMC is evident.

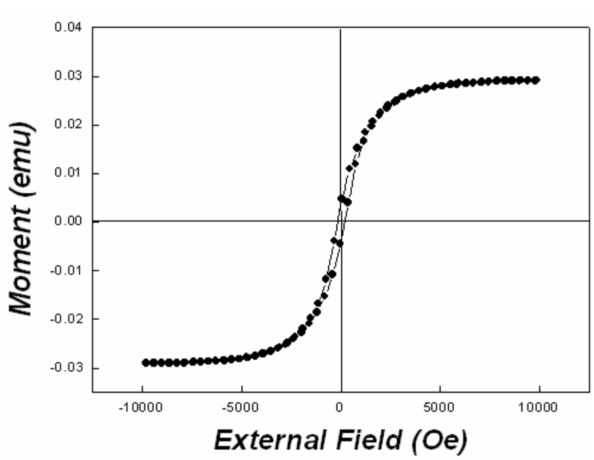

FIGURE 11: A magnetization curve for a MR-IPMC.

University of Pisa, Italy

A new contractile linear actuator made of dielectric elastomers

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Several types of applications would benefit from polymer-based contractile linear actuators. Within the class of dielectric elastomer actuators, two basic configurations are currently available for such a purpose: the multilayer stack (Figure 12a) and the helical structure (Figure 12b).

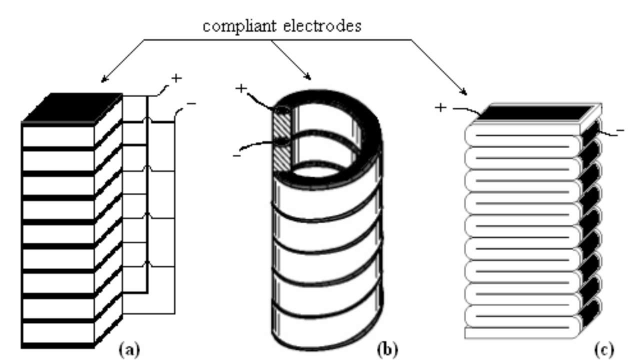

FIGURE 12: Stack (a), helical (b) and folded (c) dielectric elastomer actuators.

The first consists of several layers of elementary planar actuators stacked in mechanical series and electrical parallel [1, 2]. The second one relies on a couple of helical compliant electrodes alternated to a couple of helical dielectrics [3]. The fabrication of both these configurations presents today some specific difficulties, arising from the peculiarity of each structure. Accordingly, the availability of simpler solutions would boost the short-term use of contractile actuators in practical applications. For this purpose, we have developed a new structure [4], referred to as 'folded' dielectric elastomer actuator (Figure 12c). It consists of an electroded sheet of elastomer that is folded up and compacted. The resulting structure is equivalent to a multilayer stack with interdigited electrodes. However, with respect to a stack the new configuration is advantageously not discontinuous and can be manufactured in one single phase, avoiding layer-by-layer multistep procedures. Figure 13 shows in two photos a 15% contraction of a silicone-made prototype sample of a folded actuator driven by an electric field of about 16 V/µm. Further information will be presented at the next SPIE symposium "Smart Structures and Materials" (San Diego, 26 Feb.- 2 Mar. 2006).

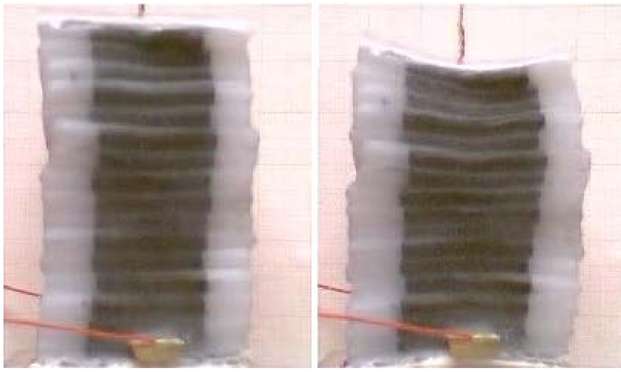

FIGURE 13: A 15% contraction of a prototype folded dielectric elastomer actuator.

References:

1. R. E. Pelrine, R. D. Kornbluh and J. P. Joseph, "Electrostriction of polymer dielectrics with compliant electrodes as a means of actuation", Sensor. Actuat. A-Phys, vol. 64, pp. 77-85, 1998.
2. M. Jungmann, M. Matysek, H. F. Schlaak, "Electrostatic solid-state actuators with elastic dielectric and multilayer fabrication-technology", Proc. of Actuator 2004, Bremen 14-16 June 2004, pp. 686-689, 2004.
3. F. Carpi, A. Migliore, G. Serra, D. De Rossi, "Helical dielectric elastomer actuators", Smart Materials and Structures, Vol. 14, pp. 1210-1216, 2005.
4. F. Carpi and D. De Rossi, "Attuatore, sensore e generatore a polimeri elettroattivi in configurazione ripiegata", Italian Patent, PI/2005/A/000095, 2005.

Virginia Tech and Discover Technologies

High Strain Dry Ionic Polymer Transducers

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Ionic polymer transducers also known as ionic polymer metal composites (IPMC) consist of an ion-exchange membrane plated with flexible conductive electrodes on their outer surface, and saturated with an appropriate diluent. Typically, the diluent used is water, which evaporates from the transducer membrane and limits the transduction in air or vacuum. Bennett and Leo [1] demonstrated that using 1-ethyl-3-Methyimidazolium trifluoro-methanesulfonate (EMI-Tf) ionic liquids as a non-volatile diluent eliminates this problem. Transducers made using these ionic liquids have been shown to be stable over 1 million cycles in air, as compared to about 1000 cycles for water-solvated materials. Furthermore, EMI-Tf has a superior electrochemical stability of 4V compares to 1.2V that of water, leading to an increase in strain.

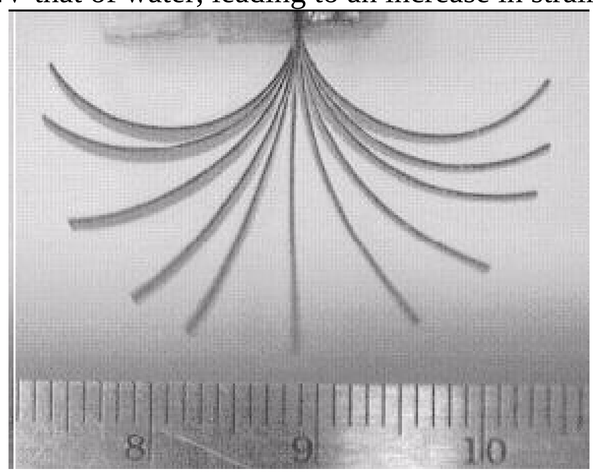


FIGURE 14: Deflected shapes of an IPT for a 4V square wave potential input.

Akle et al. [2, 3] developed a novel fabrication technique named the Direct Assembly Process (DAP), which enables superior control on the electrode morphology, diluents incorporated, and type of conductive powders used in the electrode. Figure 14, shows an ionic polymer transducer built using the DAP method with RuO_2 electrode and a Nafion 117 ionic liquid diluted membrane. Transducers fabricated using the DAP method, are optimized to produce large strains on the order of 10% at the external fibers of the actuator. Single walled carbon nanotubes are incorporated into the electrode to increase the speed of response to around 2%/s. Finally Akle and Leo [4] demonstrated out of plane actuation in ionic polymer transducers. The extensional actuation behavior along with the well known bending response is modeled with a linear and a quadratic function of the accumulated charge. This model is useful in understanding physical actuation mechanisms, which are still under debate.

References

1. Bennett, M.D. and Leo D.J. "Ionic Liquids as Solvents for Ionic Polymer Transducers". Sensors and Actuators A: Physical, 115:79–90, 2004.
2. Akle B.J., Bennett, M.D. and Leo D.J., "High-Strain Ionomeric-Ionic Liquid Electroactive Actuators" In press: Sensors and Actuators A: Physical.
3. Akle B.J., Bennett M.D.., Leo D.J., Wiles K.B. and McGrath J.E., "Direct assembly process: a novel fabrication technique for large strain ionic polymer transducers" Submitted to the Journal of Materials Research.
4. Akle B.J., Leo D.J., "Characterization and Modeling of Extensional and Bending Actuation in Ionomeric Polymer Transducers" Submitted to Sensors and Actuators A: Physical.

INDUSTRIAL NEWS/APPLICATIONS

Artificial Muscle, Inc. (AMI)

Charlie Duncheon, Acting CEO,
charlie.duncheon@artificialmuscle.com

In recent months, significant progress has been made at Artificial Muscle, Inc. (AMI) in the commercialization of its Electroactive Polymer Artificial Muscle (EPAM) technology. This progress includes:

- Additional patents have been filed and more are planned for filing in the near future.
- New dielectrics and electrode formulations are continuously being evaluated with promising results. AMI now has a dielectric formulation that operates over a broad range of temperatures from below freezing to hostile hot environments. Additionally, substantial improvements have been made in product reliability.
- An automated manufacturing process is under development and AMI is planning for volume production by mid 2006.
- Operating voltages have been decreased for the latest generation of EPAM, and a small, low-cost power supply is planned for 2006 shipments.
- Several new OEM contracts have been closed for EPAM development. AMI and its customers hope that these will lead to future volume production contracts.
- AMI is focusing resources on its patented diaphragm configuration, which addresses over 75% of current EPAM applications. Soon, AMI will announce multiple development products, including a new pump and valve product family, based on the diaphragm platform.
- The second installment of the A round financing was completed in August of 2005. AMI now has 32 employees.

AMI will update its website soon to reflect all these news [www.artificialmuscle.com]. AMI is looking forward to working with the EAP community in 2006 and making the commercialization of EAP technology reality.

Medipacs LLC, a Tucson AZ

Mark Banister *mbanister@medipacs.com*

Medipacs LLC based biotech company, has developed the World's first Digital Pump™ demonstrating the ability to pump fluids and gasses to any location on a geometric array plate. This Digital Pump™ (Figure 15) is a precursor to medical applications using EAP materials in the pump architecture and is currently being developed as a disposable infusion pump. The new infusion pump, the size of a cell phone, provides a low cost alternative to expensive disposable pumps currently on the market. Eventually the pumps will be available as a pre-dosed drug delivery or implantable device that can monitor patient fluids and deliver medicine.

The Medipacs EAP pump (Figure 16) provides a more accurate and inexpensive alternative to current disposable pumps on the market while allowing the delivery of medicines such as insulin very slowly over a long period of time using microchip controlled EAP gel actuators. In November Medipacs was awarded its first SBIR Phase I to develop a miniature pump for the US

Army medical Research Command using their EAP gel material and IPMC material that they will receive from Kwang Kim, UNR

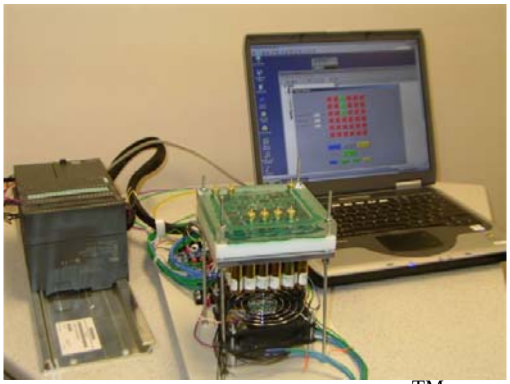


FIGURE 15: Medipacs Digital Pump™

FIGURE 16: EAP Gel prototype

About Medipacs: Medipacs opened its doors in June of 2004 at the Arizona Center for Innovation. Several patents are currently pending on this new pumping method for fluids and gasses. With the completion of its first prototype, the company is looking for suppliers and research collaborations to develop several types of EAP actuators that can be used in the pump system. Further information is available on www.medipacs.com

Parker Hannifin Corp., Pneutronics Division

Minimizing Industry Incubation

Drew Brenner, ABrenner@parker.com

To be successful in commercializing any technology, by industry standards, means achieving a specific percent return on investment (ROI) in a specific time frame. Before commercialization, an incubation time exists between the development of the technology (point of contact between technology holder and industry) and the resource commitment of the industry (commercialization of technology). Lengthy incubation times doom many technologies before they can find their place in the market.

So how can you decrease the incubation time and increase the probability your technology will be commercialized? The key is to make sure you have a thorough understanding of your technology and to properly educate industry decision-makers. You need to provide detailed, well-presented information to your contacts with documented support for ROI.

- What is the value statement to the specific industry?
- Why would a specific industry be interested in this enabling technology?
  - What does this technology offer that is superior to other technologies? Be specific and back up with ***summary*** laboratory data.
    - What are the electrical and physical requirements of the technology and the required electronics?
    - Actuation Displacement versus Applied Voltage
    - Actuation Force versus Applied Voltage
    - Stability, Time-based test reflecting physical/electrical stability at varying voltage levels and varying environmental conditions.
  - What are the pros/cons of this technology?
  - What Intellectual Property do you have with this technology?
- Who else is capable of offering similar enabling technologies?
  - Site specific information to ensure due diligence is conducted in a timely manner.
- When would this enabling technology be ready for manufacturing?
  - Time dependant answer based on sound research.

Answering these questions and clearly presenting these facts will assist with decreasing the time required for product commercialization. This will create a more positive, forward-looking ROI and a decrease in industry incubation.

AVAILABLE POSITIONS

Generally, available positions are listed on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/Positions.htm Other new opportunities include the following.

Ph.D. Studentship Position

EAP for Optical Applications

Funding is expected for a Ph.D. position, in the area of optical applications of electromechanically active polymers. One of the few commercial applications of electromechanically active polymer actuation is the gel-based light valve. A slab of gel is placed in the near vicinity of a set of inter-digital electrodes. When a potential difference is applied between the electrodes, the initially flat gel deforms into a diffractive grating. The diffraction mechanism relies on total internal reflection, i.e. the gel is not in touch with the electrodes. The diffraction grating is well-controlled, and is already used for AWG and VOA applications. Recently a projection display with VGA resolution was demonstrated, employing lasers of three different colors as the light source.

To understand actuation in these systems in deeper detail, especially taking into account the electromechanical properties of the gel, we would like to hire a Ph.D. student. She/He will investigate the dielectric, mechanical and optical properties of polymeric materials. She/He will help in the development of new light valves based on soft elastomers, and with new geometries. Also, She/He will participate in the ongoing research on dielectric elastomer and ferroelectret polymer actuators. A Masters degree in physics or chemistry, with an emphasis on material physics is required. Some exposure to polymer science would be advantageous.

The project will take place at University of Potsdam near Berlin. The project is financed by a company, therefore extended project stays away from Potsdam are expected. Interested young scientists are kindly requested to send their resumes and references to: Reimund Gerhard-Multhaupt, Department of Applied Condensed-Matter Physics, Am Neuen Palais 10, 14469, Potsdam, Germany. Enquiries may be directed to Guggi Kofod, gkofod(at)rz.uni-potsdam.de.

NEW BOOKS

Biomimetics - Biologically Inspired Technologies

Y. Bar-Cohen (Editor)

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

A new edited book about Biomimetics was published at the end of October 2005 covering the subjects of biomimetics and. Figure 17 shows the book cover-page and the graphics (prepared by David Hanson) illustrates the editor's idea of biomimetics where human learns from nature to produce mechanisms and devices.

Evolution has resolved many of nature's challenges leading to lasting solutions with maximal performance using minimal resources. Nature's inventions have always inspired human achievements and have led to effective algorithms, methods, materials, processes, structures, tools, mechanisms, and systems. This field, which is known as Biomimetics, offers enormous potential for inspiring new capabilities for exciting future technologies. There are numerous examples of biomimetic successes including making simple copies, as the use of fins for swimming. Others examples involved greater mimicking complexity including the mastery of flying that became possible only after the principles of aerodynamics were better understood.

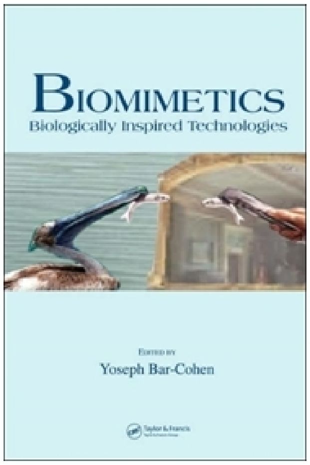


FIGURE 17: The cover page of the new book on biomimetics

Some commercial implementations of biomimetics, including robotic toys and movie subjects, are increasingly appearing and behaving like living creatures. More substantial benefits of biomimetics include the development of prosthetics that closely mimic real limbs and sensory-enhancing microchips that are interfaced with the brain to assist in hearing, seeing, and controlling instruments.

This book review technologies that were inspired by nature and outlook for potential development in biomimetics in the future. This book is intended as a reference comprehensive document, tutorial resource, and set challenges and vision for the future direction of this field. Leading experts (co)authored the 20 chapters of this book and the outline can be seen on http://ndeaa.jpl.nasa.gov/ndeaa-pub/Biomimetics/Biologically-Inspired-Technology.pdf

UPCOMING EVENTS

26 Feb. – 2 Mar. 2006	2006 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/Conferences/calls/06/ss/conferences/index.cfm?fuseaction=SSM03
Apr 30 to May 4, 2006	2006 SAMPE, "Creating opportunities for the new economy," Long Beach, CA. For information contact: Y. Bar-Cohen, yosi@jpl.nasa.gov, for instructions see http://www.sampe.org/news/submitpaper.aspx
June 14-16, 2006	ACTUATORS 2006. For information contact: Peter Sommer-Larsen, Risø National Laboratory, peter.sommer.larsen@risoe.dk;
First week of Dec.	Fall 2006 MRS Symposium C entitled "Smart Dielectric Polymers Properties, Characterization and Their Devices," will be held in Boston, MA vbharti@mmm.com
Dec. 18 - 20, 2006	ROBIO 2006 Conference will be held in Kunming, China, Dec. 18 to 20, 2006. For information contact Hong Zhang zhang@cs.ualberta.ca Web: http://www.cs.ualberta.ca/~zhang/robio2006/

EAP ARCHIVES

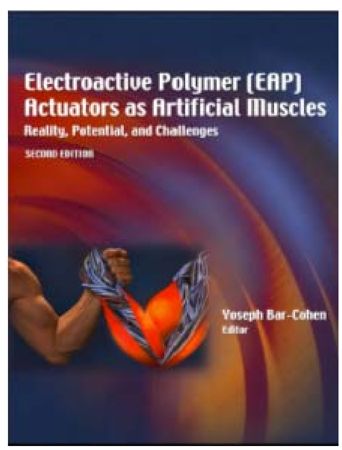
Information archives and links to various websites worldwide are available on the following (the web addresses below need to be used with no blanks):

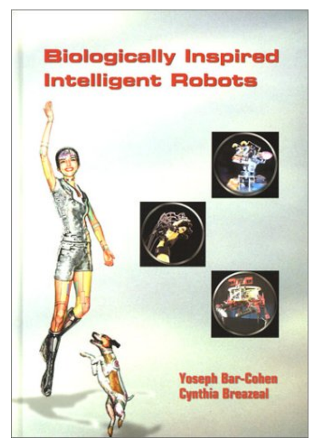
Webhub: http://eap.jpl.nasa.gov
Newsletter: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/WW-EAP-Newsletter.html

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

Books and Proceedings:

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





2nd Edition of the book on EAP

Y. Bar-Cohen (Editor)

In March 2004, the 2nd edition of the "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges" was published. This book includes description of the available materials, analytical models, processing techniques, and characterization methods. This book is intent to provide a reference about the subject, tutorial resource, list the challenges and define a vision for the future direction of this field. Observing the progress that was reported in this field is quite heart warming, where major milestones are continually being reported.

Biologically Inspired Intelligent Robots

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

The book that is entitled "Biologically-Inspired Intelligent Robots," covering the topic of biomimetic robots, was published by SPIE Press in May 2003. There is already extensive heritage of making robots and toys that look and operate similar to human, animals and insects. The emergence of artificial muscles is expected to make such a possibility a closer engineering reality. The topics that are involved with the development of such biomimetic robots are multidisciplinary and they are covered in this book. These topics include: materials, actuators, sensors, structures, control, functionality, intelligence and autonomy.

Albert Hubo

Happy New Year

WorldWide Electroactive Polymers (EAP) Newsletter

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