WorldWide ElectroActive Polymers

EAP

(Artificial Muscles) Newsletter

June 2005 | WW-EAP Newsletter | Vol. 7, No.1

http://eap.jpl.nasa.gov

1st Wrestling Match between Human and EAP Actuated Robotic Arms was Held on March 7, 2005 in San Diego, CA

FROM THE EDITOR

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

On March 7, 2005, a major milestone was accomplished in the field of EAP – we held the first Armwrestling Match of EAP Robotic Arm against Human (AMERAH). The competition was hosted by SPIE during the EAP-in-Action Session of the EAPAD Conf., at the Town & Country Resort, San Diego, CA.

Three organizations participated in this competition bringing their EAP actuated arms that were driven by different mechanisms. The participating organizations included: Environmental Robots Incorporated (ERI), Albuquerque, NM; EMPA, Swiss Federal Laboratories for Materials Testing and Research, Dubendorf, Switzerland; and students from Virginia Tech. Even though all three arms lost against the student, Panna Felsen, the ERI arm was able to hold for 26-second. This is a major accomplishment for the field and in order to get a prospective of the importance of this milestone one may want to remember that the first flight lasted 12-seconds. Drawing from this example of the first flight and its advances to the level of today, the editor is hoping to see a similar success in making EAP benefit every human being in one way or another. Further information about the competition is available on http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

FIGURE 1: Panna Felsen, 17-year old student from San Diego, CA, wrestling with the EAP driven arm of ERI, Albuquerque, NM.

LIST OF CONTENTS

ABOUT THE EXPERTS

Yoshihiro Nakabo

Recently, Yoshihiro Nakabo joined the National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan. He is still working as a visiting scientist at his former affiliation the Bio-Mimetic Control Research Center, RIKEN, and. At RIKEN, he worked on biomimetic soft robots using EAP actuators and high-speed robot-vision systems. Now, in his new affiliation at AIST he is working on safety and dependability of human interactive robots for which he is also using EAP actuators and vision sensors. The new e-mail address of Yoshihiro Nakabo is nakabo-yoshihiro@aist.go.jp

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

JPL Open House

In the middle of May each year, the Jet Propulsion Laboratory (JPL), Pasadena, CA, holds an open house allowing the public to view the space accomplishments and the innovation at JPL. Structured around the themes of technology, Earth, Mars, the solar system and the universe, visitors are given opportunity to see and learn how NASA missions come together. This year, the NDEAA Lab (established by and under the responsibility of the Editor of this Newsletter) participated with demos of its technology. Beside an ultrasonic/sonic driller/corer (USDC), ultrasonic motor and various novel mechanisms that were conceived and developed by the Editor and his Advanced Technologies Group, there were several EAP related exhibits that were presented. These exhibits include the robotic platforms for testing EAP: android head that was made by David Hanson and the robotic hand that was made by Graham Whiteley (can be seen on the WW-EAP Webhub http://eap.jpl.nasa.gov). Further, David Hanson brought his latest android head and showed the wide variety of facial expression that it is capable of making in a very realistic way. Also, the Virginia Tech robotic arm, which participated in the competition, was shown. Thousands of visitors participated in the Open House and many stopped by to see the exciting demos of the JPL's NDEAA Lab.

FIGURE 2: At the JPL open house on May 14, 2005, the public enjoyed the JPL's NDEAA Lab hands-on exhibits. In the middle of the photo David Hanson is posing as wrestling with the VT robotic arm and behind it is his latest android head.

THE FIRST ARMWRESTLING COMPETITION

In the first competition that was held on March 7, 2005, the participants used simple shape arms. Given that the technology is still far from being mature the rules of the competition were relaxed and the only major requirement was the use of EAP as the actuator. However, the ultimate goal is to win against the strongest human using as close resemblance of the human arm as possible. Success in accomplishing this goal will require significant advances in the infrastructure of the field of EAP 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 are 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.
- Bring public awareness and attract interest among potential sponsors and users as well as scientists and engineers.

The judges in this competition included Allen Fisher and Carolyn Fisher who represented the US ArmSports; Richard Landon - from Stan Winston Studio (SWS designed and created the robots and makeup for Spielberg's movie AI). Mr. Landon wrote chapter 6 in the Biologically Inspired Intelligent Robots book; John D. Madden - Univ. of British Columbia (Canada), who Co-chaired the 2005 EAPAD Conference; Joanne Pransky - World's First Robotic Psychiatrist www.robot.md; and Brian Thomas - Senior Event Manager, SPIE--The International Society for Optical Engineering. Three organizations brought their novel arms to the competition including ERI Limited, Albuquerque, NM; EMPA, Switzerland; and three senior students (Steven Deso, Stephen Ros, Noah P. Papas) from the Engineering Science and Mechanics Dept., Virginia Tech. The wrestling matches were held against the human opponent, Panna Felsen, 17-years old female student from San Diego, California. The student won against all the three arms, where the ERA arm held the longest against her lasting for 26-seconds, while the EMPA arm held for 4-seconds and the VT arm held for 3-seconds.

1. The ERI arm was driven by two groups of EAP actuators. One group consisted of dielectric elastomeric resilient EAP that maintained an equilibrium force and the second was composed of ionic polymer metal composites (IPMC) strips that flexed to increase or decrease the main resilient force.
2. The EMPA arm was driven by dielectric elastomer EAP using multi-layered scrolled actuators that were organized in 4 groups. Each of these groups was capable of lifting a mass of about 20-kg. Using electronic control, these actuators were operated similar to human muscles, where two of these groups acted as protagonists and the other two operated as antagonists.
3. The VT arm was driven by EAP batches that were made of PAN gel fibers that were enclosed in three separate electrochemical cells.

Competition Participants' Feedback

The following is the feedback from the three organizations that made an arm that participated in the competition. Also, included are comments from the human opponent, Panna Felsen, and other individuals who either participated as audience or heard about the competition and sent the Editor an e-mail about the competition.

Environmental Robots Incorporated (ERI)

Mohsen Shahinpoor shah@unm.edu

FIGURE 3: Mohsen Shahinpoor prepares his robotic arm while Panna Felsen and Allen Fisher (the representative from US ArmSports) waiting for the start of the wrestling match.

ERI is proud of its EWA-2 arm's accomplishment in holding for 26 seconds against the human opponent, Panna Felsen. The local Albuquerque magazine, New Mexico Business Weekly, wrote an article about ERI and its participation in the competition and chose it as the most entrepreneurial high tech company in New Mexico for 2005. Regarding the competition itself, in future competitions I would like to suggest that an arrangement will be made to allow the audience to have more direct viewing of the wrestling match.

Background about the ERI arm

In making the EWA-2 arm, ERI used dimensions that are within the level of a human arm. For the actuation of this arm ERO used PMMA and Derlin as well as 8 IPMC in a helical configuration and drove the actuators by 12 volts and 230 milliamps. For further information about the ERI arm please visit: www.environmental-robots.com

EMPA, Dubendorf, Switzerland

Lukas Kessler lukas.kessler@empa.ch, and Claudio Iseli

FIGURE 4: Panna Felsen wrestling with the EMPA made arm while Allen Fisher is coaching her.

We would like to question the idea of using an arm wrestling match to push the technology. We would like to recommend the consideration of other ways to perform a scientific comparison between the EAP technologies. Further, we believe that more teams will participate if the development cost can be made lower. This may be accomplished by reducing the required size of the arms or maybe select a competition game with fixed boundary conditions. Also, we would like to see the competition rules be adhered closely and those who do not meet the rules should be disqualified.

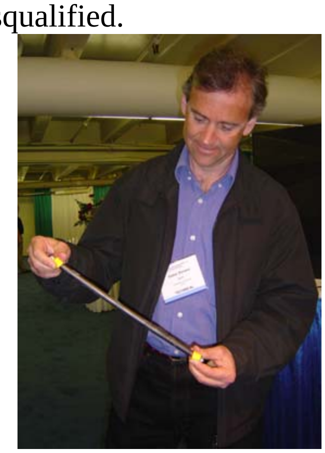


FIGURE 5: The head of the EMPA team from Switzerland, Gabor Kovacs, is holding an element of the dielectric EAP actuator. To drive their robotic arm 256 such elements were used in a protagonist–antagonist system

We would like to suggest that each team will be given 5-10 minutes to present background about their arms possibly using a PowerPoint presentation or even a video. We would like to see the organization of the competition completed several months before the conference.

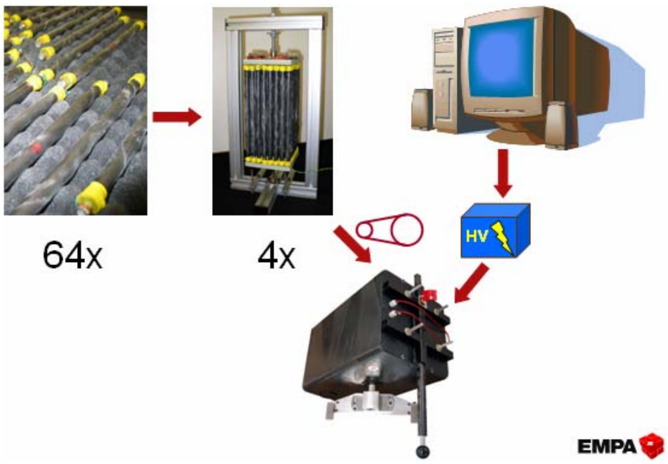


FIGURE 6: The components and system of the EMPA robotic arm

Background about the EMPA arm

Gabor Kovacs Gabor.Kovacs@empa.ch

The EMPA robotic arm was driven by dielectric elastomer EAP type using multi-layered scrolled actuators that were organized in 4 groups. Using electronic control, these actuators were operated similar to human muscles, where two of these groups acted as protagonists and the other two operate as antagonists. The arm had an outer shell made of fiberglass that was used as a shield for the electric section. The arm structure was made of composite sandwich consisting of fiberglass and carbon fibers. The specifications of the EAP actuators are given in the table 1. Further information about the EMPA robotic arm can be found on http://www.empa.ch/eap

TABLE 1: The specifications of the EAP actuators that were used to drive the EMPA robotic arm.

Parameter	Specification
Material	VHB4910 3M
Dimensions	Ø17x280mm
# layers	40
Nominal electrical field	100V/μm
Blocked force	11N
Elongation	35%
Manufacturing time	30min.
Weight	60g

Virginia Tech, Blacksburg, VA

FIGURE 7: Panna Felsen wrestling with the VT robotic arm while it is monitored by Noah papas.

At the EAP armwrestling competition in March, our robotic arm held against Panna Felsen for 3 seconds. The short period was the result of the fact that there is a time lag between the activation of the acid pump (coinciding with the start of arm wrestling) and the contraction of our muscles. A method of synchronizing the wrestling start time and activation our mechanism will need to be incorporated in future matches. Information about our Department of Engineering and Science at VT you can be found at http://www.esm.vt.edu/

Background about the VT arm

The Virginia Tech arm was driven by gel fiber artificial EAP actuators. These gel fibers were activated ionically by EAP that was manufactured by a multi-step process comprised of crosslinking and saponification of polyacrylonitrile (PAN) textile fibers. The processed fibers are pH-sensitive and contract or elongate based on a change in pH. In the initial design, a windshield washer pump sprayed 1 N hydrochloric acid on the artificial muscles.

NOTE: Using recently awarded funding a more efficient and responsive actuation system is being developed.

The biologically inspired arm that was used consists of hollow composite bones and joints that mimic natural human motion. The upper-arm bone was made of a protrusion at one end, emulating the natural attachment point of a human's subscapularis muscle, and also enabling the actuation of the arm. The forearm bone was designed to simulate the pronation of the wrist during the arm wrestling motion. The hollow bones were constructed in-house using a novel approach to the Vacuum Assisted Resin Transfer Molding (VARTM) process.

Another aspect of this arm was the incorporation of an actual artificial elbow prosthetic that was donated by the company called Biome and it mimics a human elbow. Also, the implanted wrist joint was designed to provide three degrees of freedom for the composite hand.

The human opponent, Panna Felsen

I would like to suggest placing requirements on the robotic arms to more closely follow the range of motion of a human arm. The robotic arms that are wrestling should have some amount of give on the forearm part (like the 1st arm from New Mexico and the 3rd arm from Virginia Tech) so that a human opponent can pull the arm closer to his/her body like in a real match. I had some trouble with the way the second arm was locked into place horizontally, as I could not move its "forearm" equivalent closer to my shoulder, and vertically because my elbow almost didn't touch the table when I held onto the ball at the end of this arm.

In your March 21, 2005 e-mail to your colleagues, you mentioned that you are considering having the robotic arms wrestle each other. Initially, I wondered why you didn't have the robots wrestle each other, but now that you've already had these robots lost to a person, if you have the next set of robots wrestle each other, the public will wonder how strong they are in comparison with the first set of robots and with me.

Before the match, Allen Fisher (the representative from US ArmSports) told me that fifteen pounds of force in the "wrong way" may hurt my arm. It was important that he showed me the proper technique for armwrestling. Essentially, he told me to lean in with my shoulder when I am winning, and to face him (which was diagonally to the right) and let the robot rotate my arm down when I am losing.

As far as my reaction to each of the arms, I thought that if my strength gave way for the first robotic arm, my arm would be quickly snapped back in the other direction due to the amount of resistance I felt. For quite some time during this match, I felt that I would not be able to beat the robotic arm, as all my strength was being used to keep the robotic arm from beating me. However, during the match Allen Fisher told me that I could beat it by reminding me to lean in with my shoulder; once I did that, beating the arm was rather "easy." For the second robotic arm, I immediately implemented the strategy of leaning in with the shoulder when I started to win, and this partially explains the ease with which I won. For the 2nd and 3rd robots, the match was so short that I hardly had time to think of anything except beating them.

INTERESTING FOLLOW-UP: For those who wonder what Panna Felsen is doing now that she graduated from high school - She got accepted to Caltech and she will start her undergraduate career in the coming Fall.

Other Feedbacks

Drew Brenner, *Technology Research Engineer, Parker Hannifin Corp., ABrenner@parker.com*

I really enjoyed this year's conference and the arm wrestling contest. What disappointed me most was the lack of understanding by the media as to what they were seeing. It seemed that most of the media just did not get or understand how important what it was that they saw. Going forward I have two suggestions:

1. Have some form of a media kit explaining in very simple terms what they are seeing.
2. Maintain a human component. This really forces the robot teams to account for real life

variability and makes the challenge a whole lot interesting. Maybe keep it as a Senior High School girl next year, then for 2007 a Senior High School Male, 2008 a College Female, 2009 a College Male, and the 2010 against a PRO arm wrestler. Or, hopefully, if technology advances quick enough this timeline may be shortened.

Bob Dennis, UMICH, bobden@umich.edu
I have two suggestions that you may want like to consider.

1. Make the future competitions available on-line as a live webcast, to maximize the involvement of people from all areas of research who might be interested.
2. Make future competitions, robot-vs-robot, instrumented with force platforms so you can stream live data on the forces during the competition. This really should not be too difficult if you require all competitors to mount their hardware to a standardized platform. You could also include real-time power consumption for each of the robotic arms. A live data stream would make the competition both memorable and very impressive from a technical standpoint. It would also have scientific value, at least in terms of functional assessment of performance.

Annapurna Karicherla, AKaricherla@sjm.com
I think, with the current robotic arms capability, having them wrestling each other is a great idea. This would most definitely decrease the liability burden in using human arm. It should be feasible to define the capability of humans in technical terms and make the arms performance measured against the human capability. I am certain that I will see a nice, robotic arm that looks and behaves just like mine by the next decade or so. Until then let's focus on the technology development.

Kwang Kim kwangkim@unr.edu
I think it is a good idea to focus on the technology advancement till we are ready for a match with a professional human wrestler. Also, it would be nice to use instrumentation to monitor technical data during the competition. Based on the data, a few different prize winners can be awarded.

Don Leo, VT. donleo@vt.edu
If you get more participants next year, one suggestion might be to have additional 'awards' that focus on specific aspects of the competition including for example 'Most lifelike', 'Most force', etc. These would not be cash awards but they would give added incentive to focus on specific aspects of the design. This idea is similar to what groups such as SAE do in their car competitions: there is an overall winner but there are also winners in specific categories.

M. Anthony Lewis txl@iguana-robotics.com
What about a robot capable of making a hop or a leap straight up in the air? The amount of energy the EAP can deliver into the machine will be proportional to the hop height. Eventually, a robot of the same weight as a human could be placed side by side with a person and a direct comparison can be made in performance

Ayoola K. Olorunsola, JPL, ayo@jpl.nasa.gov
I think adding consistency and fairness to the competition by requiring specific dimensions for the competing arms. For example require that an "elbow" be placed on the elbow pad, and from there specify a required arm length and angle such that the two arms will meet at the desired point, having an equal amount of leverage from the pivot.

Ji Su, NASA LaRC, j.su@larc.nasa.gov
My suggestion to the arm wrestling is to install a pressure sensor (EAP, piezo-polymer sensor) to monitor, in-situ, the pressure/force generated during wrestling. This way we will be able to get numbers that can be used to compare the performance and judge the advancement..

The Editor thoughts about near future armwrestling contests

The first armwrestling match between human and robotic arms driven by EAP has been a great success in terms of meeting the objectives that it was set for. We did not have a winning robotic arm because the challenge is a difficult one for the current capability of EAP. However, the competition led to accomplishing the major goal of making the public aware of this emerging technology and its enormous potential. A list of links to some of the media publications and websites that covered the event was posted on http://eis.jpl.nasa.gov/ndeaa/nasa-nde/nde-aa-l/newsclipping.htm). Another accomplishment that the challenged helped achieving is to attract the attention of many scientist and engineers to consider EAP as a topic of interest. Many are recognizing the fact that this is the time for pioneer-spirited individuals to join the field while it is emerging and to help contribute multidisciplinary expertise to shaping its direction while it is in its current stage.

Since the capability of the current EAP materials is still at a level that needs nurturing I would like to suggest that we measure the progress in the near future by either making a competition between robotic arms and/or test the capability of the individual arms. This way we can focus on the technology advancement without having to deal with the issues that are associated with physical contact between human and machine. There is no intent to make the challenge easier - once we have the EAP technology at the level of readiness that is sufficiently sophisticated and strong I will invite a professional human wrestler for a match.

There are several thoughts that were expressed by various individuals regarding the gauging of the capability. One of the suggestions is to have the arms lift a fixed mass (maybe 5 or 10 kg) and to do that at the shortest time. Other idea can be to see which arm will be able to lift the heaviest weight independent of the time that it takes. However, in matches with humans it is critical to have a high speed capability. To help setting a test fixture for the next competition and to gauge the arms performance in a quantitative way, Qibing Pei, who is now Professor at UCLA, has offered his assistance.

I do agree with the suggestions to have several award categories in order to encourage advancement in various aspects of the required technology.

RECENT CONFERENCES

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 Conference this year was marked with the most significant milestone hosting the historical event of the wrestling competition between human and EAP actuated arms.

It included 84 presentations and was well attended by leading world experts in the field including members of academia, industry, and government agencies from the USA and overseas. Significant progress was reported in each of the topics of the EAP infrastructure. The papers focused on issues that can forge the transition to practical use, including improved materials, better understanding of the principles responsible for the electromechanical behavior, analytical modeling, processing and characterization methods as well as considerations and demonstrations of various applications. The sessions about EAP materials were divided into the two principal groups that the Conference Chair defined: ionic and electric EAP. The electric EAP materials are driven by electric forces and involve mostly movement of electrons, whereas the ionic EAP materials consist of electrodes and electrolytes and involve mobility/diffusion of cations or anions. Papers in this conference covered the following topics:

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

The efforts described in the presented papers are showing significant improvements in understanding of the electromechanical principles and better methods of dealing with the challenges to the materials applications. Researchers are continuing to develop analytical tool and theoretical models to describe the electro-chemical and -mechanical processes, non-linear behavior as well as methodologies of design and control of the activated materials. EAP with improved response were described including electrostrictive, IPMC, dielectric, carbon nanotubes, conductive polymers, and other types.

As in past years, the EAP-in-Action Session was held on Monday, March 7, 2007 and in addition to the armwrestling competition, which was mentioned above, the attendees were given an opportunity to see seven demonstrations of EAP actuators and devices.

1. Gabor Kovacs and his EMPA team, Switzerland - components of their wrestling arm.
2. Jennifer Lalli, Andrea and Richard O. Claus, NanoSonic, Blacksburg, VA - Metal Rubber™ Flexible Conducting Interconnects and Sensors
3. Mohsen Shahinpoor and Massoud Ahghar, Environmental Robots Incorporated (ERI), Albuquerque, New Mexico jointly with Ohio Aerospace Institute, Cleveland, Ohio - A small model and video of a flapping wing system of a Solid State Aircraft (SSA) using IPMC
4. Matt Bennett, Discover Technologies LLC - Ionic polymer transducers
5. Chunye Xu, Lu Liu, Dai Ning, Calen Kaneko and Minoru Taya, Center for Intelligent Materials and Systems, University of Washington, Seattle - Largest Scale Electrochromic Polymer Swichable Window
6. Harsha Prahlad, SRI International - Expanding circle and an enhanced-thickness mode (soft vibrator) and a demo kit from the recent introduction of the new EAP products from Artificial Muscles, Inc.
7. Yoshihiro Nakabo and Kentaro Takagi, Bio-Mimetic Control (BMC) Research Center, RIKEN, Japan - Bio-Mimetic Robotic Applications of IPMC.

CALL FOR PAPERS & FUTURE CONFERENCES

SMART05 - II ECCOMAS

The SMART05: II ECCOMAS Thematic Conference on Smart Structures and Materials will be held in Lisbon, Portugal from July 18 to 21, 2005. The Editor of this Newsletter will be a Keynote Speaker at this conference. The subjects that will be covered in this conference include

- Electroactive Polymers
- Sensors and Structural Identification
- Active Materials and Actuators
- Structural Health Monitoring and Signal Processing
- MEMS and Structural Control
- Vibration and Shape Control
- Adaptive Crashworthiness
- Composite Modeling
- Software Tools and Optimal Design
- Identification of Materials Properties
- Nanotechnology
- Industrial Applications
- Demonstrators

Information about this conference is available on: http://www.dem.ist.utl.pt/~smart05. Further information can be obtained by contacting Carlos Mota Soares at carlosmotasoares@dem.ist.utl.pt

ICMEN 2005

The 2005 International Conference on MEMS, NANO, and Smart Systems (ICMEN) will be held from July 24 to 27, 2005, in Banff, Alberta, Canada. The objective of this conference is to provide a forum for the discussion of new developments, recent progress, and innovations in the design and implementation of MEMS, NANO, and Smart Systems-on-Chip. It addresses aspects of design methods of such systems. The emphasis is on current and future challenges in research and development in both academia and industry. The conference will cover the following topics:

- Electroactive Polymer Materials & Applications
- Nanoelectronics, Spintronic Devices and Systems

- Smart Sensor Technology and Measurement Systems
- Damping and Isolation
- Micro-fluidic Systems
- Active Materials: Behavior and Mechanics
- Nano-imaging, Scanning Probes, and Molecular Manipulation and Devices
- Industrial and Commercial Applications of Smart Structure Technologies
- Smart Electronics, Smart Structures, Integrated Systems, MEMS, and BioMEMS
- Nano-optics and Nano-photonic Devices
- Novel Fabrication Processes, Laser Micromachining and Nanomachining
- Nano-composites
- Bio-electronics, Bionanotechnology, and Molecular Nanotechnology

For information contact: Walied Moussa
walied.moussa@ualberta.ca
Website: http://www.icmens.org

MRS Fall 2005

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.

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 Ph. 651-736-8057, Fax: 651-737-5335, vbharti@mmm.com

SPIE 2006 EAPAD Conference

A call for papers was issued for the 2006 EAPAD Conf. where abstracts are due on Aug. 15, 2005 and the papers are due by January 29, 2006. This conference will be held again in San Diego, CA from 26 February – 2 March, 2006. As in past years, the objective is to identify improvements and development of new EAP materials, enhance the understanding of the electromechanical behavior, effective modeling of the electro-mechanics and chemistry, processing and characterization techniques, as well as applications of these materials. Further, this conference is seeking to promote the development of high performance EAP as smart materials and to increase the recognition of EAP as viable options for use in smart structures. In 2006, there are plans to hold another armwrestling competition, possibly focusing on wrestling between arms that are actuated by EAP. Papers are solicited on but not limited to 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

Abstracts are due on August 15, 2005, and manuscripts are due: on January 29, 2006. Further information about this conference and the call for papers are available on http://spie.org/Conferences/calls/06/ss/conferences/index.cfm?fuseaction=SSM03

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. Abstracts are due by September 1, 2005 and the final papers due on January 3, 2006. Information about this conference is available on http://www.sampe.org/events/2006longbeach.aspx

ACTUATOR 2006

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

The 10th conference on new actuators will take place in Bremen from June 14 to 16, 2006 and it includes a session on EAP. As part of the conference there will be an exhibition on Smart Actuators and Drive Systems. Also, the conference will include the RoboCup 2006. Important deadline is: 30 November 2005 and it is the due date for the abstracts. Information about the conference can be found on www.actuator.de

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 - MEMS/Nano fabrication, sensors, and actuators, micro/nano robotics, assembly, and manipulation, AFM/SPM based manipulation, micro/nano fluidics, nanotube/nanowire/DNA based sensors, 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.

Information can be obtained from Hong Zhang zhang@cs.ualberta.ca
Web: http://www.cs.ualberta.ca/~zhang/robio2006/

COOPERATION INITIATIVES

This section was formed to offer individuals who are seeking support of the EAP community ad a platform for expressing their need.

Canada - University of Alberta, Edmonton

Octopus arm

Yaakov Engel, *yaki@cs.ualberta.ca*,
Web: www.cs.ualberta.ca/~yaki

The Octopus arm is one of the most sophisticated appendages found in nature. It is an exceptionally flexible organ, with a remarkable repertoire of motion. In contrast to skeleton-based vertebrate and articulated robotic limbs, the Octopus arm lacks a rigid skeleton and has virtually infinitely many degrees of freedom. Due to its skeletonless nature, it is capable of stretching, contracting, folding over itself several times, rotating along its axis at any point, and following the contours of almost any object.

The basic mechanism underlying the flexibility of the Octopus arm (as well as of other organs, such as the elephant trunk and vertebrate tongues) is the muscular hydrostat [1]. Muscular hydrostats are organs capable of exerting force and producing motion with the sole use of muscles. The muscles serve in the dual roles of generating the forces and maintaining the structural rigidity of the appendage. This is possible due to a constant volume constraint, which arises from the fact that muscle tissue is incompressible. Proper use of this constraint allows muscle contractions in one direction to generate forces acting in perpendicular directions.

Needless to say, controlling such an arm poses an ormidable algorithmic challenge, which does not appear to be amenable to conventional control theoretic or robotics methodology. Recent advances in the field of Machine Learning, and specifically. Reinforcement Learning, have allowed controllers for a 2-dimensional simulated Octopus arm (Figure 8) to be learned from trial and error experience, without requiring human intervention [2]. We would like to achieve similar results with a real 3-dimensional robotic arm. To that effect, we are looking for collaborators interested in, and capable of constructing such an EAP-based arm.

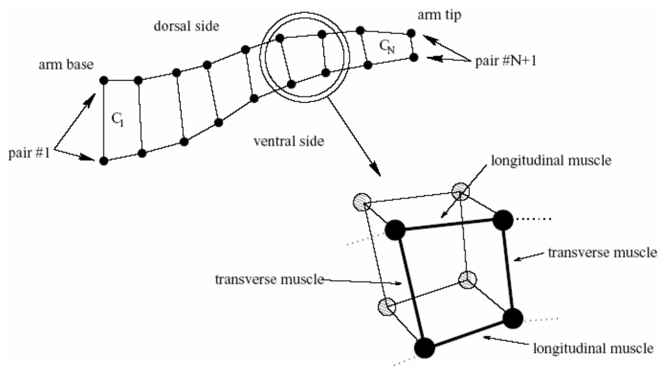


FIGURE 8: 2-dimensional simulated Octopus arm

References

[1] W.M. Kier, K.K. Smith, "Tongues, tentacles and trunks: The biomechanics of movement in muscular-hydrostats". Zoological Journal of the Linnean Society 83, 307-324, 1985.

[2] Y. Engel, P. Szabo, D. Volkinshtein, "Learning to control an Octopus arm with Gaussian process temporal difference methods", 2005. www.cs.ualberta.ca/~yaki/papers/octo_gprl.pdf

USA - Virginia Tech, Blacksburg, VA

Whole Skin Locomotion Inspired by Amoeboid Motility Mechanisms

Dennis W. Hong (dhong@vt.edu)

A novel locomotion mechanism for mobile robots is being researched at Virginia Tech. This mechanism was inspired by the motility mechanisms of single celled organisms that use cytoplasmic streaming to generate pseudopods for locomotion (Figure 9). The Whole Skin Locomotion (WSL), as we call it, works by way of an elongated toroid which turns itself inside out in a single continuous motion, effectively generating the overall motion of the cytoplasmic streaming ectoplasmic tube in amoebae.

With an elastic membrane or a mesh of links acting as its outer skin, the robot can easily squeeze between obstacles or under a collapsed ceiling and move forward using all of its contact surfaces for traction, or even squeeze itself through holes with diameters smaller than half of its nominal width (Figure 10), making this the ideal locomotion method for search and rescue robots that need to traverse over or under rubble, or for medical applications where a robot needs to move in and maneuver itself into tight spaces such as for robotic endoscopes.

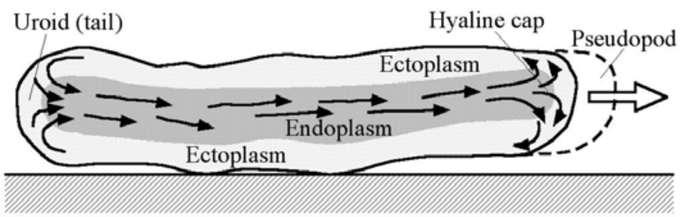


FIGURE 9: Motility mechanism of a monopodial amoeba.

The WSL mechanism is a new class of mechanism that converts contracting and expanding motion of a ring to a toroidal rotational motion (Figure 11). Thus, it does not require conventional actuators such as electric motors or linear actuators. One of the actuation methods being considered uses rings of electroactive polymer (EAP) strips around the toroid to drive the motion (Figure 12). EAPs maybe the ideal actuators for a small-scale implementation of WSL, since the strain they are able to produce is the type of displacement needed for WSL.

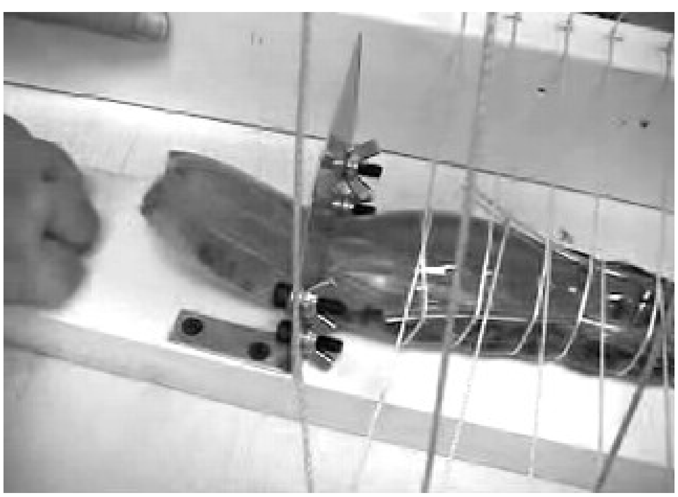


FIGURE 10: Moving through a hole with a diameter smaller than half of its nominal width.

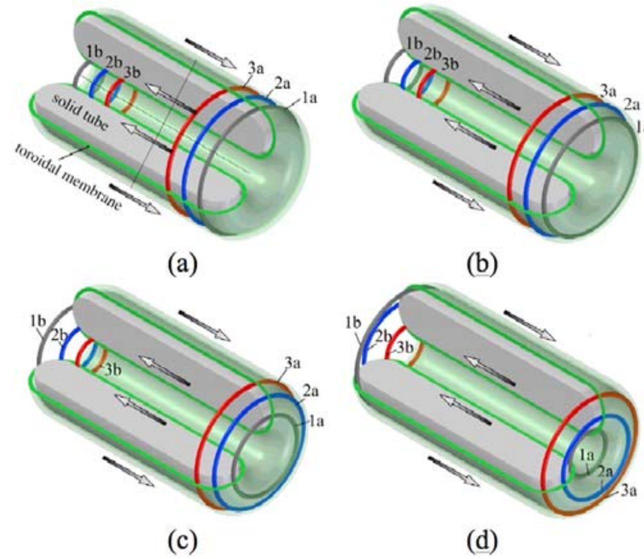


FIGURE 11: Motion generated by the rear contractile rings (1a, 2a, 3a) and frontal expansile rings (1b, 2b, 3b) for the concentric solid tube model.

A paper will be presented at the 29th ASME Mechanisms and Robotics Conference, Long Beach, California, September 24- September 28, 2005 on the WSL concept with preliminary experiments (Figure 13 and 14) and their results, demonstrating the feasibility of the WSL strategy.

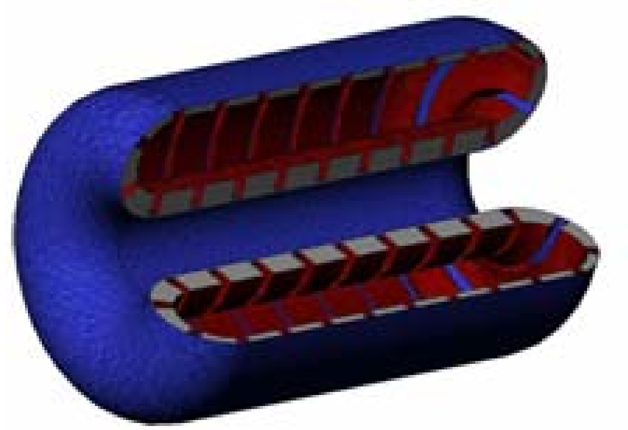


FIGURE 12: Small scale actuation strategies using EAP.

References

[1] Ingram, M. and Hong, D. W., "*Whole Skin Locomotion Inspired by Amoeboid Motility Mechanisms*", 29th ASME Mechanisms and Robotics Conference, Long Beach, California, September 24-September 28, 2005

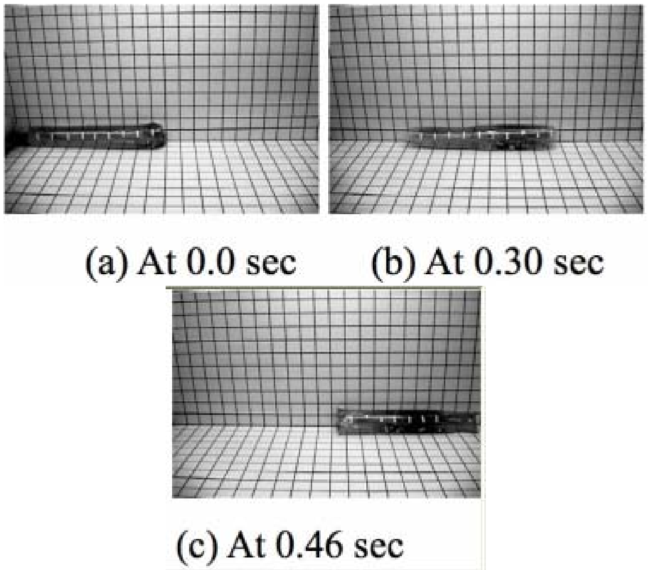


FIGURE 13: Sequence of pictures of the locomotion of the pre tensioned elastic skin model

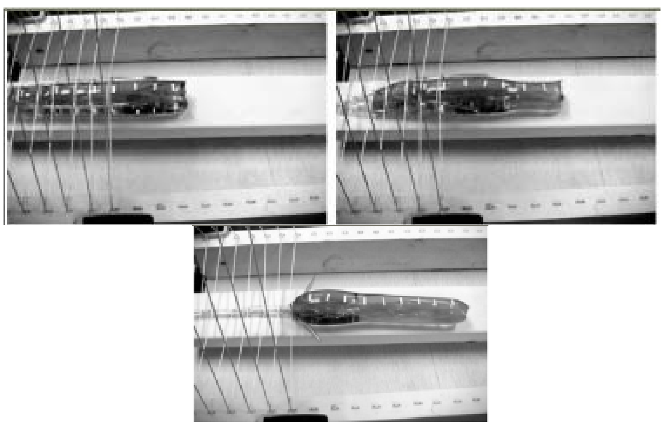


FIGURE 14: Sequence of pictures of the tension cord actuated model locomotion

ADVANCES IN EAP

GERMANY - Dresden University of Tech.

pH sensors based on the swelling behavior of polyelectrolytic hydrogels

M. Guenther, mguenthe@rcs.urz.tu-dresden.de
G. Gerlach, J. Sorber, G. Suchaneck, K.-F. Arndt

In order to realize a new type of pH sensor, a poly(vinyl alcohol)/poly (acrylic acid) (PVA/PAA) blend of hydrogel with a pH value dependant swelling behavior was used as chemo-mechanical transducer. A commercially available pressure sensor chip (Aktiv Sensor GmbH, Stahnsdorf, Germany) with a flexible thin silicon membrane was employed as mechano-electrical transducer for the transformation of membrane deflection into an appropriate electrical output signal. A thin film of PVA/PAA blend has been deposited onto the backside of the silicon membrane (Figure 15). The swelling or shrinking processes of the hydrogel were monitored by corresponding changes in the piezoresistance of an integrated Wheatstone bridge due to a stress state change inside a rectangular silicon membrane affecting proportionally the output voltage of the sensor [1]. The sensor chip was bonded to a socket with inlet and outlet flow channels. The aqueous solution to be measured was pumped through the inlet tubes into the silicon chip cavity.

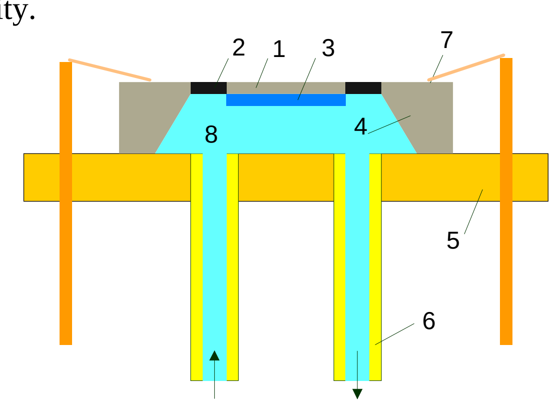


FIGURE 15: Operation principle of hydrogel-based sensors with PVA/PAA layer, deposited onto bending plate. Where: 1 bending plate; 2 mechano-electrical transducer (piezoresistive bridge); 3 swellable hydrogel; 4 Si-chip; 5 socket; 6 tube; 7 interconnect; 8 solution.

The change of the electrical potential at the gel-solution interface is a function of the pH value of the surrounding solution. Therefore, the gel deformation at different pH values of the solution can be considered as a mechano-electric effect. The influence of the kinetics of the induced charge (in the swollen polyelectrolyte gel) on the response time, the signal value and the sensitivity of the proposed pH sensors was investigated and the measurement conditions necessary for high signal reproducibility and long-term stability were determined. Time constants down to a few ten seconds and a sufficiently high sensitivity of 2.5 mV/pH at a signal resolution of 0.16 mV were obtained in the pH range between 3 and 4 for a sensor with a 6µm thick PVA/PAA layer (Figure 16). In this pH range, the rate of the signal drift caused by electromigration of hydrated ions was minimal, ΔU_{drift} = 0.7 µV/min. It was found that an initial conditioning in de-ionized water and a dynamic range limited to the gel volume phase transition at 2.5<pH<4 are conditions necessary for high signal reproducibility [2]. Measurements in solutions with pH<2.5 and at large pH changes should be avoided in order to maintain sufficient long-term stable sensor sensitivity [3].

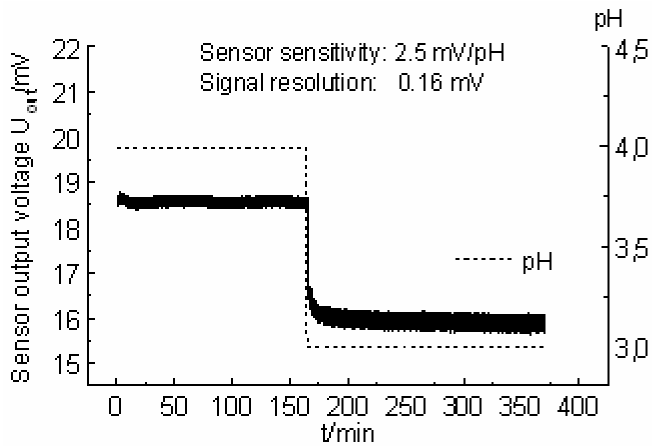


FIGURE 16: Sensor output voltage during deswelling process from pH4 to pH3.

Acknowledgments
The authors gratefully acknowledge support for this work from the Deutsche Forschungsgemeinschaft (Collaborative Research Center (SFB) 287, Project C11).

References

1. German Patents DE 101 29 985C2, DE 101 29 986C2, DE 101 29 987C2, June 12, 2001.
2. M. Guenther, G. Gerlach, J. Sorber, G. Suchaneck, K.-F. Arndt, A. Richter: pH sensors based on polyelectrolytic hydrogels, in: *Smart structures and materials: electroactive polymer actuators and devices*, Y. Bar-Cohen (ed.), vol. 5759, pp.540-548, Proc. SPIE, San Diego, CA, USA, March 7-10, 2005.
3. G. Gerlach, M. Guenther, J. Sorber, G. Suchaneck, K.-F. Arndt, and A. Richter, "Chemical and pH sensors based on the swelling behavior of hydrogels," Accepted for publication in Sensors and Actuators B, 2005.

INDIA – National Chemical Laboratory

Dual Phenomena in Response Time of Conducting Polymer Bi-layer Actuator

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

Conducting polymers represent a class of functional material whose unique properties are facilitating the development of intelligent material system due to ability to change their properties by an external stimulus. In many cases, the inherently conducting polymer (ICP) has to be placed on a flexible supporting substrate in the form of a bi-layer. The effect of the backing layer, its modulus, and thickness in conjunction with the ICP active layer thickness have been studied in our laboratory and this was reported in the previous issue of this WW-EAP Newsletter. On the other hand, the speed of response is also an important factor and it needs to be optimized. The question is - What are the factors that affect the strain rate and lead to faster deflections in such bilayers?

The main objective of our studies was to monitor the time response characteristics of PPy bilayer actuator by applying constant potential with one end of the actuator films kept free to measure the response in terms of bending angle. Figure 17 shows the plot of bending angle with time (i.e, actuation measurement time) of PET/Au/PPy (DBSA doped) actuator in 0.1 M aqueous $LiClO_4$ while the Figure 18 is for SO_4—doped PPy.

The data clearly indicates the presence of two slopes vs. 1.0 and 0.5 for the time (t) dependence of the bending angle (θ) following the relation $\theta = t^n$. Thus, it appears that there are two processes controlling the actuation in these bi-layers. When n ≥ 1 it may be associated with the electrostatic forces while the diffusion phenomenon is predominant when n = 0.5. The capacitative effects (double layer in electrolyte near the electrode surface) may play an important role for the former case while the ion insertion mechanism would be the cause for the latter. Our results have shown that, both electrostatic and diffusion phenomena are found not to be a function of solvent used, when water is replaced by acetonitrile and also dopants. The performance of conducting polymer actuators is a combined effect of electrostatic repulsion of like charges and ionic diffusion.

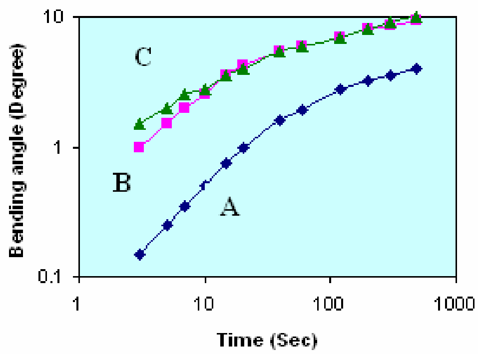


FIGURE 17: Plot of bending angle vs response time of PPy (DBSA doped) bi-layer actuator containing (A) 1.02 µm (B) 2.07 µm and (C) 2.37 µm PPy thickness.

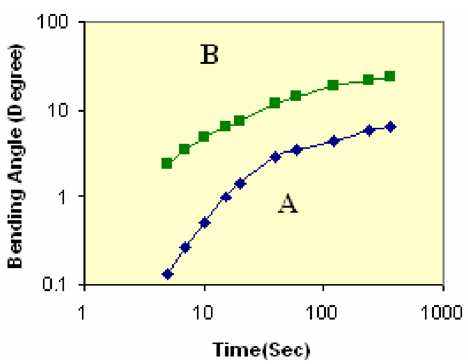


FIGURE 18: Plot of bending angle vs response time of PPy (H_2SO_4 doped) bi-layer actuator containing (A) 0.63 µm and (B) 1.17 µm PPy thickness.

From the practical applications, it is essential to optimize the parameters to obtain maximum response in short time. Our studies indicate that the backing layer modulus and its thickness also decide the time dependence characteristics.

The combination of the ICP with the backing layer with optimum geometry for maximum bending angle was also investigated for time dependence. In this case also the response time was found to be dependent on the modulus of the backing layer; PET giving the fastest response while the LDPE was much slower (see Figure 20).

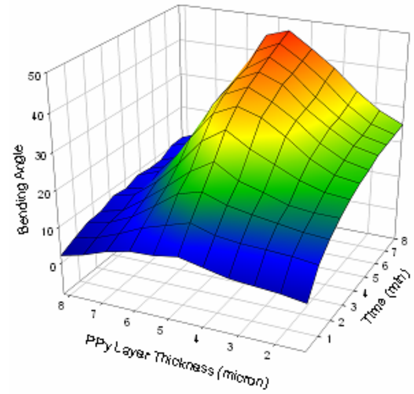
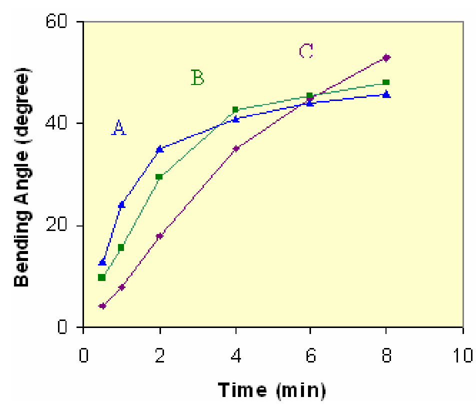


FIGURE 19: Effect of PPy layer on the time dependence of the actuator response in PPy / Polypropylene bi-layer actuator. Backing layer thickness 40 µm, applied potential 1.0 V, 0.1M $LiClO_4$ in CH_3CN



A : PET/PPy , B: PP/PPy , C: LLDPE-LDPE/PPy

FIGURE 20: Time dependence of the actuator response at 1.0 Volt for PPy / Insulating polymer bi-layer structures in 0.1M $LiClO_4$ electrolyte in acetonitrile. The thickness of active and backing layer was optimized as per the previous report, WW- EAP News Letter Vol.6, (2) December 2004 p.17.

Enhancing Piezo-sensitivity in Polyvinylidene Fluoride /Conducting Polymer Composites

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

The application of electroactive polymers such as polyvinylidene fluoride (PVDF) as piezo-sensor in robotics has limitations due to its insulating nature. In our attempts to make semi-conducting piezo-resistive sensors, PVDF has been combined with conducting polyaniline and its electrical resistivity studied with application of different mechanical loads. Such materials showed fairly high levels of piezo-sensitivity which depended on the composition, the dopant used during preparation, the particle size of the conducting phase etc. [1, 2]. Recently, it has been possible to enhance the piezo-sensitivity of these composites even further by electrical poling. The sensitivity factor was enhanced 100 folds by application of electrical potential for certain duration at appropriate temperature [3]. The effect of this poling treatment on the piezo-sensitivity of these composites is depicted in Figure 21. The touch sensitive device made from such films is shown in Figure 22 together with the response characteristics at low mechanical pressures.

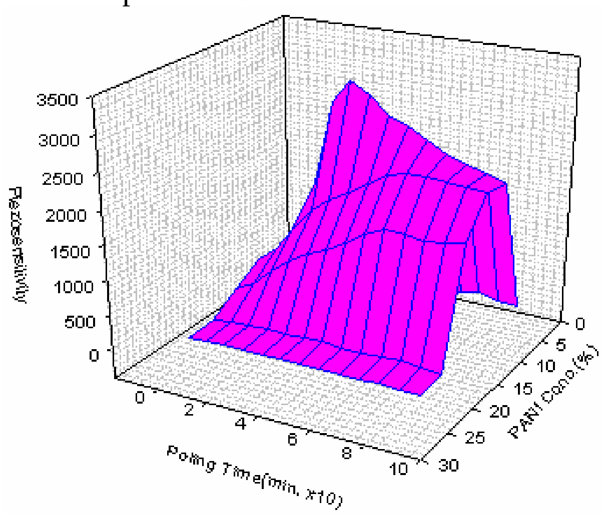


FIGURE 21: Effect of electrical poling on the piezo-sensitivity of PANI- PVDF composites. Applied electric poling voltage 80V, poling temperature 60 ^{o}C and film thickness of 50µm.

References

1. S.Radhakrishnan and S.B. Kar, Proc. SPIE, 4934, (2002) P.23
2. S.Radhakrishnan and S.B. Kar, Sensors & Actuators(A), 12 (2005), 474
3. S.Radhakrishnan and S. B. Kar, Indian Pat. (243/DEL/ 2004) USP Appl. No. 10/665348

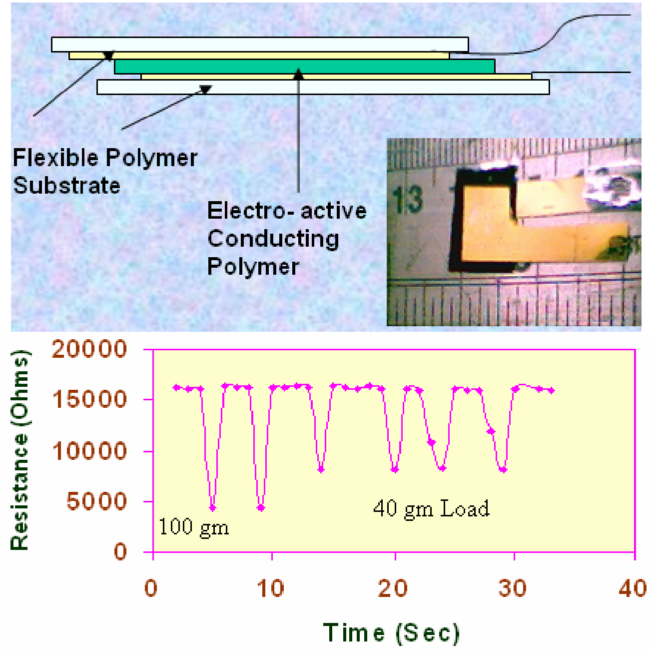


FIGURE 22: PVDF/ PANI Piezo-sensor with high sensitivity for use in tactile applications.

ITALY - Dipartimento di Ingegneria Elettrica

Elettronica e dei Sistemi
Università degli Studi di Catania
Luigi Fortuna: lfortuna@diees.unict.it
Salvatore Graziani: sgraziati@diees.unict.it
Claudia Bonomo: cbonomo@diees.unict.it
Pietro Giannone: pietro.giannone@diees.unict.it
Salvatore Strazzeri: salvo@eserviceweb.it

The Research Group of our Department focuses on the study of IPMC materials and has extensive expertise in the field of bio-inspired robots. This biomimetic activity includes not only dealing with robot structures but also their control and behavior. In order to emulate the movement of a biological tissue, there is a need to search for innovative materials light and soft, since most of the currently used materials are rigid and require high power.

Among all EAPs, Ionic Polymer Metal Composites or IPMCs seem to meet our required properties. IPMCs undergo large bending under relative low voltage of several volts. They work also in a reversible way: if mechanically deformed they generate a voltage across their thickness, hence they can be used as motion sensor. Their being light, soft and respond silently could not be fully exploited because of the lack of both: adequate technologies to fabricate the material and complete models able to describe their electromechanical behavior. Trying to give a solution to these limits, our group, that has expertise both in system science and measurements, started a research activity on the IPMCs. The activity has been divided into developing both: ***devices*** and ***systems***.

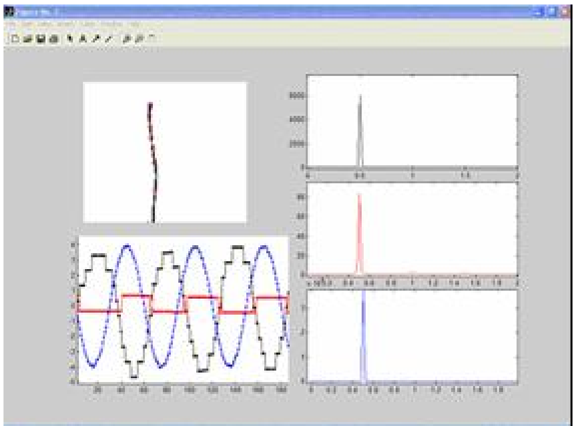


FIGURE 23: The front panel of the software tool developed to evaluate the IPMC deformation under AC voltage, starting from a video. This tool provides information about the deformation of a chosen point of a membrane, projected along X and Y axes, and the relative spectrum, allowing analyzing possible non linearity.

Our research led to several new results including a new electric model which was validated in describing the nonlinear behavior of IPMCs. A number of surveys have been performed in order to find the input/output relationship and to measure material properties, such as its life time or its bandwidth. Using the model helped in designing a worm-like robot that is based entirely on IPMCs and a video is available at:

http://www.scg.dees.unict.it/activities/biorobotics/movie.htm

Based on this research, a project involving six European partners, named ISAMCO (**I**PMCs as **S**ensor and **A**ctuator for **M**otion **CO**ntrol), has been funded by the European Union. The official site that describes this project is available on http://www.mediainnovation.it/progetti/isamco

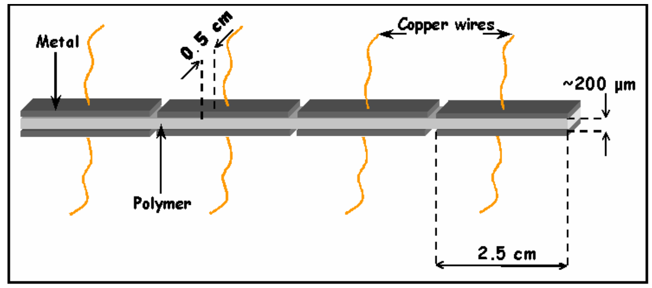


FIGURE 24: Scheme of a worm-like robot where both the skeleton and the actuation system are made of IPMCs. The control system was realized by a Cellular Nonlinear Network generating a pattern of ondulatory locomotion.

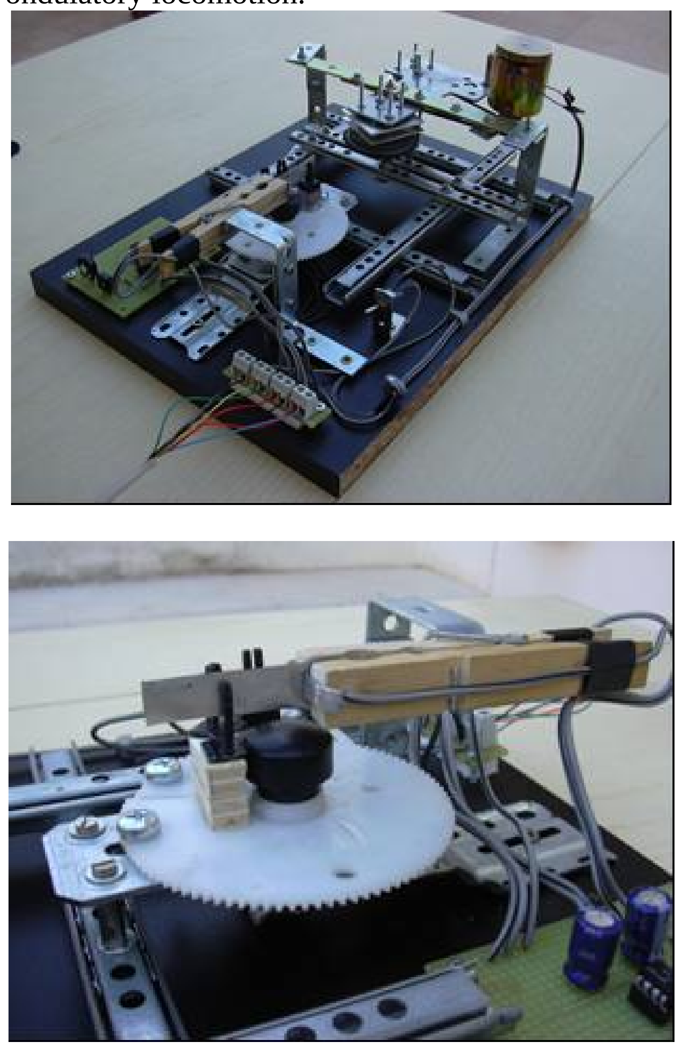


FIGURE 25: Photos of mechanical system developed to force harmonic oscillation with fixed amplitude varying the frequency using IPMC membrane as a sensor.

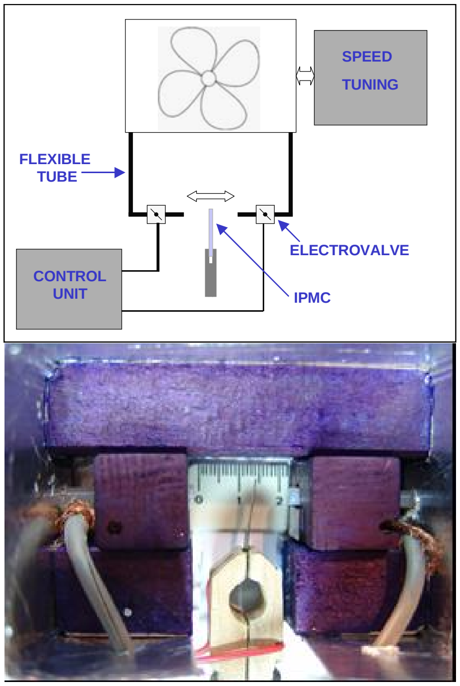


FIGURE 26: Schematics and photo of a system developed to force variable deformations, in amplitude, frequency and shape, using an IPMC membrane as a sensor. The system works in a wide range of frequencies and does not contact the IPMC during tests.

Most of the research activity is covered in the following publications.

References

1. P. Arena, C. Bonomo, L. Fortuna, M. Frasca, Electro-Active Polymers as CNN Actuators for Locomotion Control, Proc. of ISCAS 2002, Phoenix-USA
2. P. Arena, C. Bonomo, L. Fortuna, M. Frasca, CNN as Locomotion Pattern Generator for a Worm-like Robot, Proc. of Euroattractor 2002, Warsaw-Polonia
3. C. Bonomo, C. Del Negro, L. Fortuna, S. Graziani, Characterization of an IPMC strip's sensorial properties: preliminary results, Proc. of ISCAS 2003, Bangkok-Thailand
4. C. Bonomo, L. Fortuna, S. Graziani, D. Mazza, Ionic Polymer-Metal Composite Devices for Controlled Motion Systems, Proc. of Clawar 2003- Catania
5. C. Bonomo, Electrical behavior of IPMC membrane, Proc. of XI Intern. Workshop on computational phys. and material science-Trieste 2003
6. C. Bonomo, C. Del Negro, L. Fortuna and S. Graziani, Fabrication of IPMC and Characterization of its sensorial properties: preliminary results, Techn. Innov. and automation in the integrated appl. of electromagnetic and potential field methods in active volcanic areas-special issue Quaderni di Geofisica, 2003
7. C. Bonomo, L. Fortuna, S. Graziani, D. Mazza, A Circuit to Model an Ionic Polymer-Metal Composite as Actuator, Proc. of IEEE ISCAS 2004
8. C. Bonomo, L. Fortuna, P. Giannone, S. Graziani, A method to characterize the deformation of an IPMC sensing membrane, Proc. of Eurosensors 2004 – Roma
9. C. Bonomo, L. Fortuna, P. Giannone, S. Graziani, A sensor-actuator integrated system based on IPMCs, Proc. of IEEE Sensors 2004 – Vienna
10. C. Bonomo, L. Fortuna, P. Giannone, S. Graziani, A. Rizzo, Investigation on Non Linear Phenomena in IPMC Materials, Proc. of XII Intern. School-Conf. F&ANS, Minsk 2004
11. C. Bonomo, L. Fortuna, P. Giannone, S. Graziani, A low cost system to analyze the frequency response of an IPMC actuator, SPIE EAPAD 2005 San Diego, California

JAPAN - Tokyo Inst. of Tech., RIKEN and AIST

IPMC Sensor System

Masaki Yamakita[1,2], Akio Sera[1], Norihiro Kamamichi[1], Kinji Asaka[3] and Zhi-Wei Luo[2]
[1] Tokyo Institute of Technology
[2] Bio-mimetic Control Research Center, RIKEN
[3] Research Institute for Cell Engineering, AIST
yamakita@ctrl.titach.ac.jp,{sera,nkama}@ac.ctrl.titech.ac.jp

Our team have studied practical applications of the Ionic Polymer Metal Composites (IPMC) actuators, and applied the actuator to robotic systems such as biped walking robot and snake-like robot. In order to realize the control and soft actuation of IPMC actuators, a `soft` and `light` sensing device is needed. One of the most effective devices is IPMC itself.

We developed an IPMC sensor system using observer based on the linear system control theory. Generally, it is known that IPMC films generate electromotive voltage when bending or being deformed. Since the characteristics of output voltages are dynamic we identified it using input-output data as a linear time-invariant (LTI) system, and constructed a sensor system based on the observer.

Figure 27 and 28 show the experimental results of position control, and the PID control of the IPMC actuator was carry out using signal received from an IPMC sensor system. In these figures, it can be seen that the estimation of position and feedback control can be realized even though some estimation errors of are remained.

The stationary error of estimation appeared as a result of changes of dynamical characteristics, and it seems to be caused by changes of wet condition of IPMC films. Therefore, the stationary error can be removed by keeping the condition, e.g. coating the films perfectly or using it in the water. The frequency characteristic of the sensor system is shown in Figure 29. It can be seen that wide bandwidth of about 20 Hz is realized.

The application of IPMC in a sensor/actuator system poses many challenges if one seeks to apply them in a robotic systems, however, the characteristics of IPMC materials are quite promising. We think that IPMC sensors can contribute to practical application of IPMC actuator and other systems.

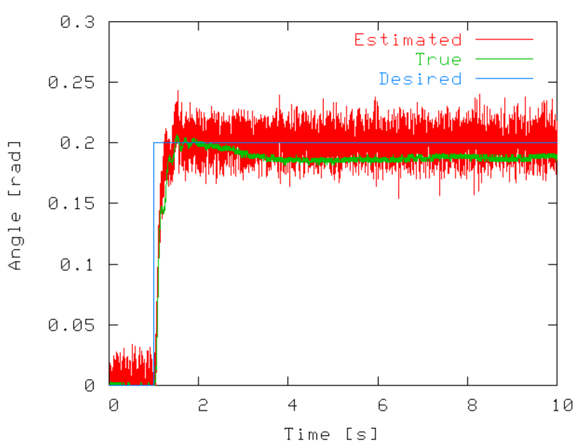


FIGURE 27: Experimental result (step signal).

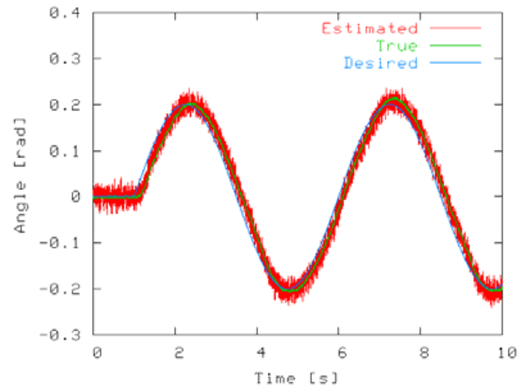


FIGURE 28: Experimental result (sine wave signal).

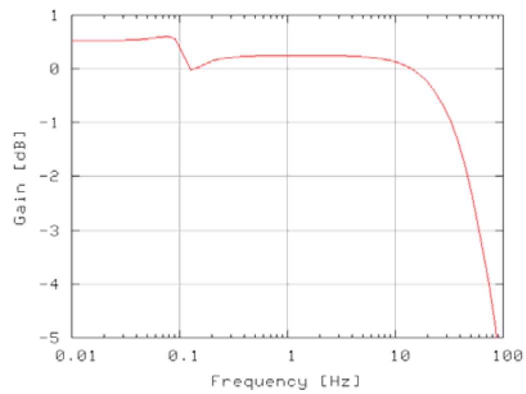


FIGURE 29: Frequency characteristics of sensor system.

JAPAN – AIST, RIKEN, & Nagoya University

Aquatic Locomotion Robot using IPMC

M. Yamamura (Nagoya Univ.), K. Takagi (Bio-Mimetic Control Research Center, RIKEN), Z. W. Luo (BMC, RIKEN), K. Asaka (AIST), Y. Hayakawa (Nagoya Univ.)

m_yamamura@nuem.nagoya-u.ac.jp, takagi@bmc.riken.jp, luo@bmc.riken.jp

IPMC (Ionic polymer metal-composite) can be used as a flexible actuators that bends in a wet condition by applying voltage (at about 3 V). This property makes them potentially great actuators for underwater robots. One of the swimming forms of aquatic animals is MPF (median and/or paired fin) propulsion. Rays and squids, which are typical animals are employing MPF propulsion, generate backward progressive wave on their ambilateral fins to get forward propulsion force.

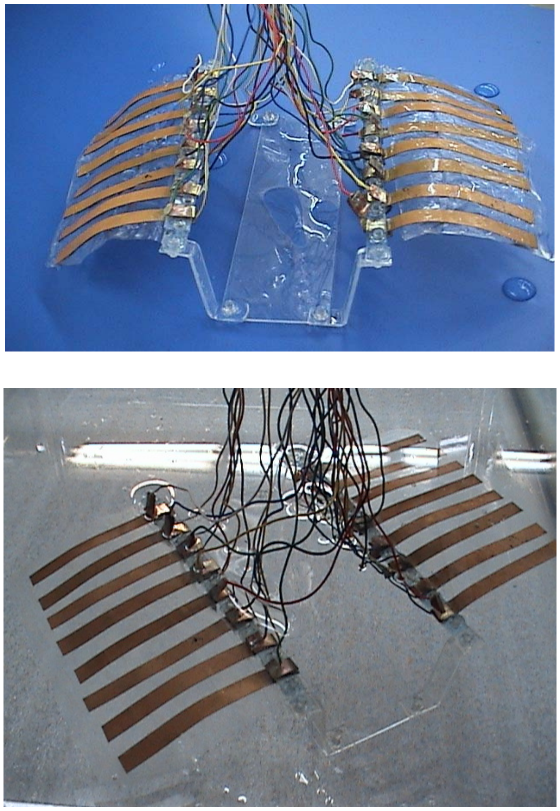


FIGURE 30: An aquatic locomotion robot using IPMC.

Using IPMC we developed an aquatic locomotion robot as shown in Figure 30. One of the fins consists of 8 strips of IPMCs covered with thin polyethylene film. The IPMCs were fabricated from Nafion^{R} through gold plating process. The size of the fin is 50mm*75mm, in which, the size of each IPMC strip is 5mm*50mm. Each IPMC actuator was made to be operated independently. We also developed micro amplifiers as shown in Figure 31. Each of these amplifiers has the size of 30mm*40mm and it is able to apply maximum current of 500mA which is enough to drive IPMC actuators used for the robot. To control the robot, we used a micro controller named C-Chip (30mm*40mm) developed at BMC RIKEN as shown in Figure 32. This controller consists of a microprocessor module and a D/A converter module. We are planning to mount these devices on our robot to realize autonomous locomotion.

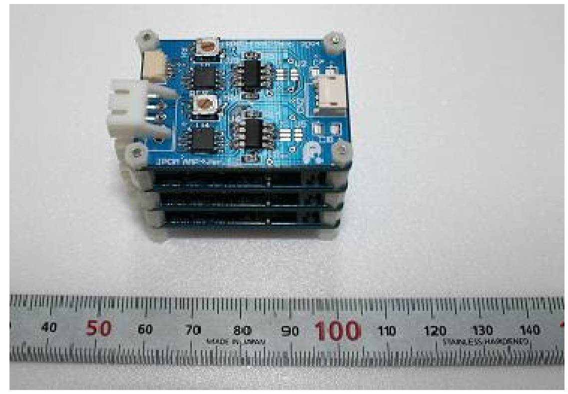


FIGURE 31: Small amplifier developed for driving IPMC.

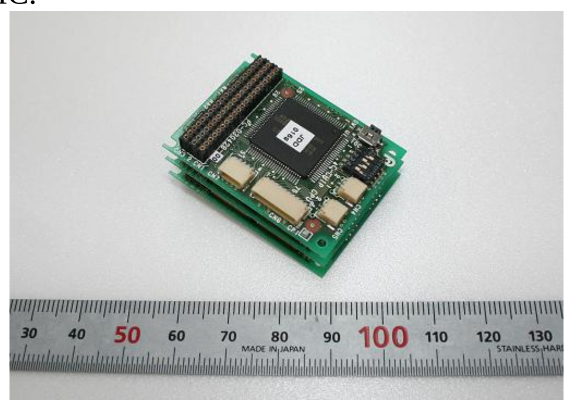


FIGURE 32: Micro controller "C-Chip".

To propel our robot, we used a sinusoidal voltage that activated each of the IPMC strips. The relative phase between each voltage was gradually shifted to generate progressive wave on the fin of the robot. The propulsion direction of the robot can be switched by reversing the sign of the phase shift.

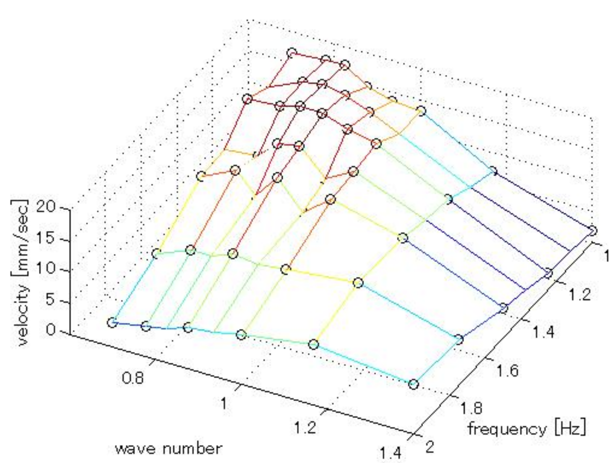


FIGURE 33: Relation of the robot's velocities for various control parameters.

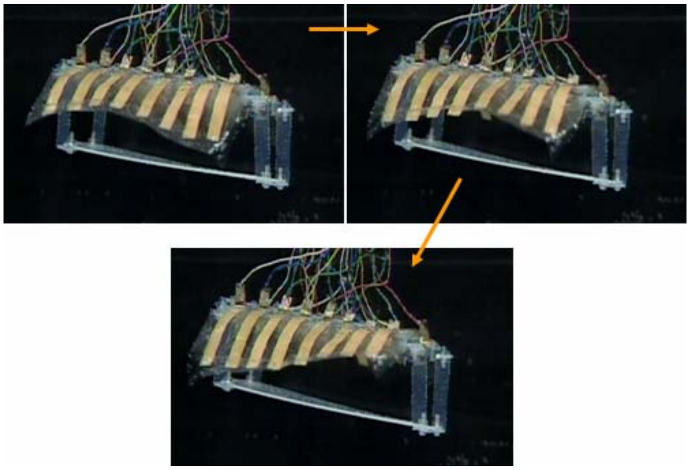


FIGURE 34: Sequences of the aquatic locomotion of the robot with fin motions.

The control parameters that are used in our system design include the frequency and the wave number. The wave number, which is related to the relative phase shift, is defined by numbers of the wave that is included in the body (fin) length. Since the propulsion velocity of the robot varies widely with respect to these control parameters, we measured the relation for one side of the fins. From the result that we obtained (see Figure 33), we found for our robot that the maximum velocity was about 17mm/sec at the frequency of 1.25Hz and with the wave number of 0.823. A series of photos of the robot's locomotion with fin motions is shown in Figure 30. In these photos, the robot is shown moving to the left direction. A movie of our robot is also available at http://www.bmc.riken.jp/~robot/video/IPMC_robo.mpg

JAPAN – RIKEN, AIST & Nagoya University

Snake-like Swimming Robot using Patterned IPMC

Yoshihiro Nakabo, BMC (Bio-Mimetic Control Research Center), RIKEN (The Institute of Physical and Chemical Research), Japan and AIST (National Institute of Advanced Industrial Science and Technology), Japan
Toshiharu Mukai, BMC, RIKEN, Japan
Kinji Asaka, AIST, Japan and BMC, RIKEN, Japan
Koji Ogawa, Nagoya Univ., Japan
Noboru Ohnishi, Nagoya Univ., Japan
nakabo-yoshihiro@aist.go.jp

We have realized a snake-like swimming robot using an IPMC artificial muscle. Although an IPMC usually can create a one-degree of freedom in its bending motion, in order to create a multi-DOF snake-like bending motion of an IPMC, we cut electrodes on the surface and made insulated patterns on it. By applying different voltages, we can control each segment individually. We have developed a variety of motions from this patterned IPMC actuator including a snake-like motion (Figure 35) [1].

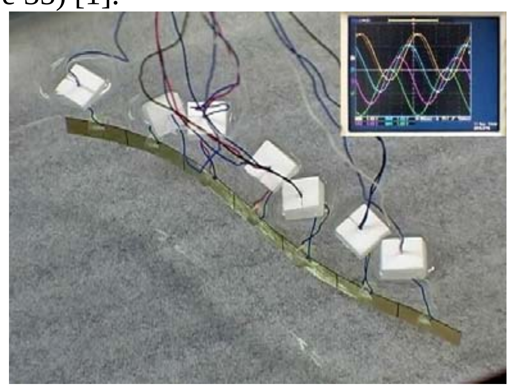


FIGURE 35: Snake-like swimming artificial muscle

The snake-like motion sweeps a smaller area than a simple bending motion. This makes it potentially suitable for application in robots that can swim in thin tubes, blood vessels, etc. (Figure 36).

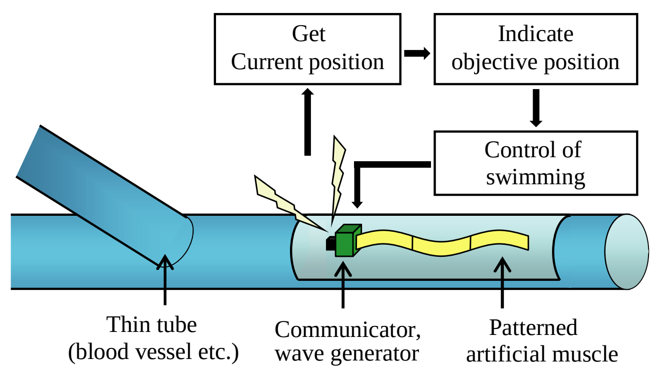


FIGURE 36: Concept of snake-like swimming robot

We measured the impelling force generated by the snake-like motion. By changing phases and frequencies of voltages which are input to each segment, we controlled the speed and the direction of the locomotion. We succeeded in making the muscle swim forward and backward at maximum speed of 4mm/s by finding the optimal phase and frequency (Figure 37). We also succeeded in making the muscle turn right and left by applying asymmetric waveform as an input wave [2]. The size of the IPMC is 12x140mm and divided into seven segments. The IPMC was made of Nafion 117 membrane with five times plating with gold.

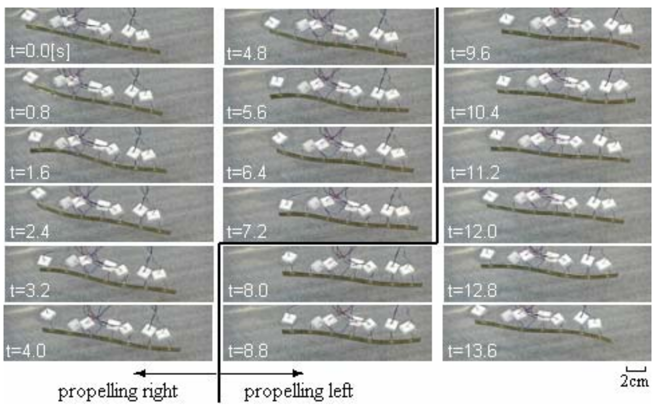


FIGURE 37: Forward and backward swimming of the robot.

Our future work should address to mount a battery and a controlling circuit on the IPMC and realize its independent swimming instead of connecting to a host PC by electric wires.

References

1. Y. Nakabo, T. Mukai, and K. Asaka: Kinematic Modeling and Visual Sensing of Multi-DOF Robot Manipulator with Patterned Artificial Muscle, *IEEE Int. Conf. Robotics and Automation* (ICRA 2005), Barcelona, pp.4326-4331
2. K. Ogawa, Y. Nakabo, T. Mukai, K. Asaka, and N. Ohnishi: Snake-like swimming artificial muscle, *Video Proc. of IEEE Int. Conf. Robotics and Automation* (ICRA 2005) Barcelona

SWEDEN - Micromuscle AB

MICROMUSCLE AB ANNOUNCES JOINT-DEVELOPMENT AGREEMENT - Unique Electro-Active Polymer Technology Enables Global Medical Device Manufacturer to Design New Applications

Gert Kindgren, Chief Executive Officer and President, Tel: +46 705 66 56 55, email:
gert.kindgren@micromuscle.com
www.micromuscle.com

On May 31, 2005, Micromuscle AB, Linköping, Sweden, has announced that it has secured a joint development project with a global manufacturer of medical devices that is based in the United States (The partner and application is currently not disclosed). Micromuscle will develop a new function for one of the partner's products. The new function is based on Micromuscle's technology and patents related to the use of electro-active polymers (EAP) and will enable products to enter new and interesting market segments.

The agreement follows an initial technology evaluation project that was successfully completed. "We are excited to announce this new partnership as it validates our position as the leader in this new and promising market," stated Gert Kindgren, CEO and President of Micromuscle. "The agreement is a proof of the commercial confidence in our technology and in Micromuscle as a company. The agreement is also the result of pursuing our business model and focusing sales effort on a selected market segment."

About Micromuscle

Micromuscle AB, Sweden, develops EAP related technology for use in medical and life science applications. Micromuscle was founded in 2000 as a spin off from leading research on conducting polymers at Linköping University. The main shareholders of Micromuscle are Industrifonden, CIMON Medical and Iteksa Venture. This company has patents and technology that cover design, manufacturing and applications of EAP materials for the field of medicine. Micromuscle focuses on vascular applications, including PTCA, where EAP materials have considerable potential and can be used to enable new functionality for medical devices. For this purpose, Micromuscle takes advantage of the capability to electrically control the behavior and properties of EAP materials.

Micromuscle is using the types of electroactive polymers that swell and contract in response to small voltage levels. This enables construction of small moving and force exerting components that are also called micromuscles.

USA - Hanson Robotics Inc.

David Hanson dayofid@hotmail.com web: www.hansonrobotics.com

During the JPL's Open House in May, David Hanson showed two of his humanlike robots demonstrating potential application for EAP actuators in artificial skin that makes facial expressions. EAP actuators could be very useful to make machines move more like living creatures, or devices as biologically-inspired robots. Hanson and his team at Hanson Robotics Inc, is specifically seeking to model the behavior and movements of people in robots that act and react virtually indistinguishable from their human counterparts. Such an objective represents a convergence point for multiple technologies, such as: artificial intelligence, cognitive systems, robust simulated facial expressions, bio-inspired bipedal locomotion, and artificial muscle technologies. If these technologies mature in an integrated fashion, it seems likely that the whole will be greater than the sum of the parts, just as it is in the real human organism. Already, to date, Hanson's social robots are capable of mimicking not just human emotions and facial expressions, but eye contact, face recognition, and naturalistic spoken conversation. It is hoped that these devices can serve to help to investigate what it means to be human, in many way: technically, scientifically, and artistically as well.

By engineering structural/mechanical chambers into elastic polymers, the power and force requirements of Hanson's facial expression robots fall within the output range of several existing EAP actuation technologies. Other benefits from this drop in force requirement include rendering the hardware lightweight and low power enough for mobile robots. The JPL open house inspires one to consider space applications of these robots; for instance, if the Robonaut (robotic astronaut) had a humanlike face, it could express certain types of information much more quickly. Facial expressions have been shown to disambiguate complex speech information more quickly than spoken word alone. A fearful facial expression can help to swiftly communicate an emergency situation for example.

FIGURE 38: Two android heads that make facial expression demonstrating potential applications for EAP actuators and artificial skin.

As the collaboration between robotics and EAP researchers progresses, it can be anticipated that potential breakthroughs in artificial muscles may allow robots to grow ever more humanlike in their behavior and performance. It is hoped that such early work at emulating the total human entity can help to humanize machines, perhaps eventually earning robots a place in the extended human family.

NEW BOOKS

Biomimetics: Mimicking & Inspired by Biology

Y. Bar-Cohen (Editor)
http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm

A new edited book is expected to be published in October 2005 covering the subjects of biomimetics and biologically inspired technologies. This book is in the final publication stages describes 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 39 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

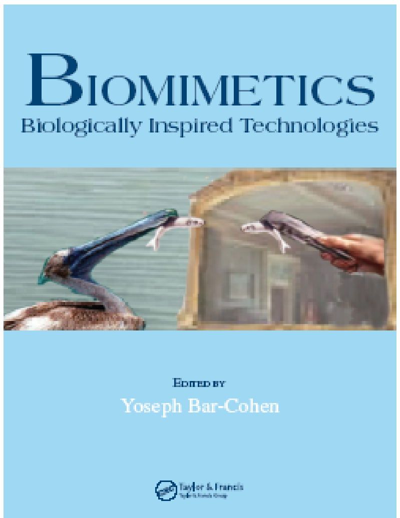


FIGURE 38: The draft of the cover page of the new book on biomimetics.

IPMC Artificial Muscles book in 2nd Edition

Mohsen Shahinpoor shah@unm.edu

The book by M. Shahinpoor, K. J. Kim and M. Mojarrad, "IMPC Artificial Muscles", ERI/AMRI Press, (ISBN No. 1-884077-07-2, 444 pages), was published in second edition. This book that was published by the principal author's company ERI Press first issued in 2004. The new edition includes a CD containing 36 videos of IPMC's in action as well as PowerPoint presentation about the state of the art of IPMC's and two complimentary samples of IPMC artificial muscles as well as a dynamic voltage signal generator to power the muscles for all EAP enthusiasts.

UPCOMING EVENTS

July 24-27, 2005	The 2005 International Conf. on MEMS, NANO, and Smart Systems (ICMEN) will be held in Banff, Alberta, Canada. For information contact: Walied Moussa walied.moussa@ualberta.ca Website: http://www.icmens.org
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,
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;
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

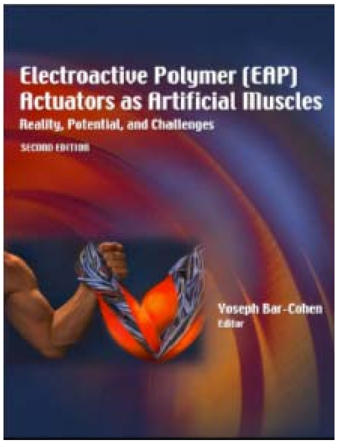
Biomimetics: http://ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/bm-hub.htm
Armwrestling Challenge: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

Books and Proceedings:

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

2nd Edition of the book on EAP

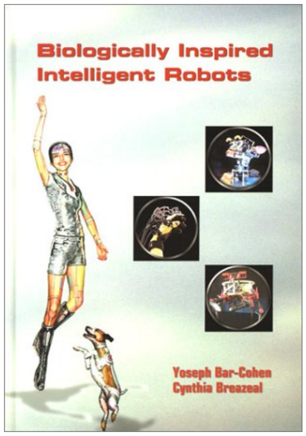
Y. Bar-Cohen (Editor)



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.

WorldWide Electroactive Polymers (EAP) Newsletter

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

All communications should be addressed to:

Dr. Y. Bar-Cohen, JPL, M.S. 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