WorldWide ElectroActive Polymers

EAP

(Artificial Muscles) Newsletter

July 2000 WW-EAP Newsletter Vol. 2, No. 1
http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-web.htm

FROM THE EDITOR

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The Editor's challenge to develop an EAP robotic hand that can win against a human in an arm wrestling match is continuing to be a distant possibility. However, as can be seen from this 3rd issue of the WW-EAP Newsletter, there has been a significant progress in the field of EAP towards making practical actuators. A growing number of organizations are now exploring potential applications for EAP. Some of the mechanisms and devices that are being considered are related to aerospace, automotive, medical, animation, toys, entertainment, exoskeletons, articulation mechanisms, robotics, noise control, haptic interfaces, and smart structures. To further assist in promoting collaboration among developers and potential users of the technology a series of WW-EAP websites were added to the current Webhub. These websites were initiated in response to direct inquiries received by the Editor. Some of these websites include: EAP in action Videos, EAP Recipes, EAP References, and Significant Events. Further, in response to the call that was made in the previous issue of this Newsletter, Osaka National Research Institute has contributed an IPMC sample for inclusion in the Materials International Space Station Experiment (MISSE) of the International Space Station (ISS). This experiment will provide an opportunity to determine the various effects of long-term exposure to the harsh conditions of space environment.

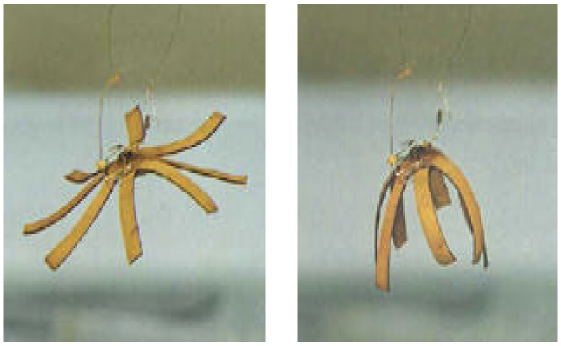
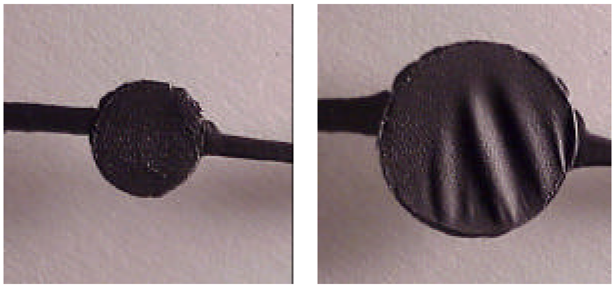


FIGURE 1: IPMC Multi-finger gripper demonstrated by ONRI at the SPIE's EAPAD 2000 Conf. that was held in Newport Beach, CA



Voltage Off **Voltage On**

FIGURE 2: Dielectric actuator demonstrated by SRI International at the SPIE EAPAD 2000 Conference.

GENERAL NEWS

The number of developers and potential users of technology related to EAP is continuing to grow. Forums and platforms were initiated to help this growth. Details about some of the recently added homepages, job opportunities, desired applications and upcoming conferences are briefly given in this Newsletter. Full details can be obtained directly from the WW-EAP Webhub that is hosted at the JPL's NDEAA Technologies Website: http://ndeaa.jpl.nasa.gov .

LIST OF CONTENTS

EAP References

The field of EAP is multidisciplinary and as a result some of the relevant research and engineering reports and papers are reported in technical publications, which are significantly unrelated in field of discipline. Many times, this causes difficulties locating reports and references on the subject of EAP. To assist those who are seeking information, a website was formed and it is accessible via: http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-references.htm

FIGURE 3: Roy Kornbluh from SRI International, USA (top), and Shingo Sewa and Kazuo Onishi from ONRI, Japan (bottom) demonstrating their latest development during the EAP In Action Session of EAPAD 2000 [Courtesy of ***Wen-Liang Liu,*** Taiwan]

WW-EAP Recipe

To address the current unavailability of commercial materials a website was formed describing the process of producing several such materials. This homepage is accessible via http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-recipe.htm

The fabrication procedure for four different EAP materials are described including:

1. IPMC – written by Keisuke Oguro from Osaka National Research Institute (ONRI).
2. Polypyrrole Actuator – written by José-María Sansiñena and Virginia Olazábal, JPL's NDEAA Technologies
3. Freeform Fabrication of Polyacrylamide and Polyacrylic acid cross-linked gels – written by Paul Calvert, University of Arizona
4. Dielectric Elastomers – Prepared by SRI International

WW-EAP In Action Videos

This site followed the SPIE's EAPAD Conference Session that carries the same name. This site includes videos showing IPMC and dielectric EAP actuators as well as electro Rheological fluid in action. Also, there is a video showing the session of EAP in Action that was held during the EAPAD 2000 Conference. This video was contributed by Satoshi Tadokoro, Kobe University, Japan.

Artificial Muscles - Significant Events

As an emerging field, the technology of EAP is seeing enormous progress and adequate visibility can be critical to the rapid transition of the technology to practical usage. Since May last year, three articles were published in Science on subjects related to EAP. These articles attracted enormous media and public interest and links to homepages that describe these articles are accessible via this new website. Further, other significant accomplishments of EAP researchers including ONRI's demonstration of an EAP catheter guide in a dog are included. The address of this website is http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-significant.html

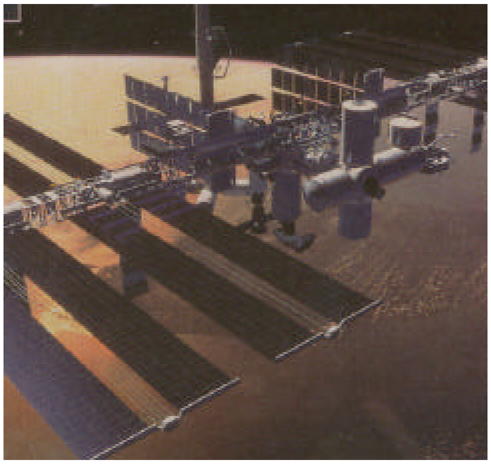


FIGURE 4: An IPMC was submitted by ONRI for inclusion in MISSE on the International Space Station.

International Space Station – MISSE

As the International Space Station (ISS) is being developed towards reality an unprecedented opportunity for long-term experiments in space became available. An opportunity to include an EAP material in the ISS's Materials International Space Station Experiment (MISSE) was reported in the previous issue of this Newsletter. In response, ONRI contributed an IPMC film and it is currently being prepared for placement in one of the four Passive Experiment Carriers (PECs) that were previously used to contain the MIR Environmental Effects Payload experiments. The MISSE PECs will be installed external to the ISS in late 2000 to early 2001, subject to approval by the NASA ISS program and it will be flown for periods of 1 to 3 years. The experiment time frame will correspond to solar maximum conditions, providing as severe a test environment in low earth orbit as possible.

EAPAD 2000 - Open Discussion

Reported by Wen-Liang Liu, *Materials Rese. Lab./ITRI Hsinchu, Taiwan*

As an emerging field, the development and application of EAP materials are still in the early stages. In an effort to identify potential needs, applications, and critical issues an Open Discussion Session was added to the list of sessions of the SPIE's EAPAD 2000 Conference. A panel of experts led the discussion and it consisted of the Conference Chair, CoChair, invited speakers and selected individuals (see Figure 5). Participants included individuals from Australia, Canada, Denmark, Germany, Italy, Japan, Korea, Spain, Sweden, Taiwan, and USA. The discussion was structured as an open debate starting with expression of thoughts from the panel members followed by solicitation of individuals' opinions. Efforts were made to air opinions of representatives from the different countries. The main objective was to brainstorm and no effort was made to reach a consensus. The comments that were made during the open discussion are summarized as follows:

1. Practical artificial muscles are still far from reality.
2. Currently, the scope of EAPAD applications is too wide.
3. There is limited understanding of the inter-relationship between material property, structure, composition and ionic constituents for modeling EAP micro-mechanism.
4. New synthesis methods for ionic EAP materials are needed.
5. It is essential to develop and enhance the capability to test and evaluate properties of EAP material.
6. It is critical to consider energy density (efficiency) of actuators during application.
7. Some ionic EAP materials (e.g., IPMC) possess both sensing and actuation functionality

FIGURE 5: The Experts Panel during the Open Discussion Session of the SPIE EAPAD 2000. From left to right: T. Otero, Q. Zhang, S. Nemat-Nasser, D. de Rossi, S. Wax and Y. Bar-Cohen. [Courtesy of Wen-Liang Liu, MRL/ITRI, Taiwan]

8. The conductive and electrostrictive EAP materials seem to be more ready for practical application than the gel and ionic polymer EAP materials.
9. Understanding the basic mechanisms and science behind EAP materials is an important foundation for applications.
10. Knowledge about material behavior and availability of new materials is essential for the engineering of effective applications.

EAP POSITIONS

Postdoctoral position in polymer actuator research in Denmark

Risø National Laboratory, the Technical University of Denmark and Danfoss A/S are conducting research and development towards developing linear actuators based on polymeric materials. The materials are polymers that contract or expand under an electric field. A whole new class of electrically controlled and flexible actuators will open a number of industrial applications such as dexterous robotic grippers, smart valves, advanced consumer products, and toys. See http://www.risoe.dk/fys-artmus.

The research focuses on electrically activated elastomers and we are seeking to characterize and model the electrical and electro-mechanical properties of such materials.

The position is for one year starting September 1, 2000. An applicant with experience in polymer research, electrostrictive properties or insulating properties of materials is preferred. The application deadline is August 15, 2000 and it can be sent to:

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Condensed Matter Physics and Chemistry
Department, phone +45 4677 4744, fax +45
4677 4791, peter.sommer.larsen@risoe.dk

Caltech Postdoctoral Scholars Position for EAP Electro-mechanical Studies at JPL

The California Institute of Technology (Caltech) Postdoctoral Scholars Program at the Jet Propulsion Laboratory (JPL) is inviting applicants to apply for a position at the JPL's NDEAA Technologies group in the area of electroactive polymers (EAP) actuators and devices. The research activity will include electromechanical studies towards the development of characterization methods as well as biologically inspired mechanisms for operation in space. Electroactive polymers are well recognized as emerging materials with enormous potential. A study is underway at JPL seeking to model the electromechanical behavior of these materials, which induce large displacements and exhibit non-linear characteristics. Experimental methods are being developed to better characterize the properties of these materials and mechanisms are investigated to take advantage of their response similarity to biological muscles earning them the name artificial muscles.

Applicants should have a recent Ph.D. in mechanical engineering, physics, electronic engineering or a related field. Appointment is contingent upon evidence of completion of the Ph.D. degree. Annual starting salary for a recent Ph.D. is approximately $42,000 and can vary according to the applicant's qualifications. Postdoctoral Scholars positions are awarded initially for a one-year period. Appointments may be renewed in one-year increments for a maximum of two additional years.

Please send curriculum vitae, bibliography, statement of research interest and a list of three references to Yoseph Bar-Cohen at the address listed below. The California Institute of Technology (Caltech) Postdoctoral Scholars Program and the Jet Propulsion Laboratory (JPL) are Equal Opportunity/Affirmative Action employers. Women, minorities, veterans and disabled persons are encouraged to apply.

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WORLDWIDE EAP INPUTS

DENMARK

The Danish Polymer Center

www.risoe.dk/fys-artmus

ARTMUS - Artificial Muscles

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The ARTMUS project involves collaboration between Danfoss A/S, Risø National Laboratory and the Technical University of Denmark. The main objective of the project is to develop a novel class of electrically controlled actuators based on polymer materials. The Danish Research Agency supports the project through the THOR program (Technology by Highly Oriented Research). The research focuses on two classes of EAP: Conducting polymer actuators, and dielectric elastomer actuators.

Conducting Polymer Actuators: Conjugated polymers can undergo considerable volume changes upon cycling between the oxidized and the reduced states. This is mainly due to the exchange of ions and solvent with the electrolyte, but conformation changes in the polymer may also be of importance. By proper design, such materials may be able to deliver a useful mechanical response to a low-voltage (~ 1 V) electrical stimulus. Our focus is on systems that are based on complexes between polypyrrole and sulfonated detergents. These systems have a relatively good stability in aqueous media, but are relatively soft compared to other conjugated polymers.

In order to simultaneously characterize the electrochemical and the mechanical response, we have designed a computerized set-up as shown in Figure 6. This set-up consists of a high precision micrometer translation stage, a microbalance with convenient dynamical range, a potentiostat and an electro-chemical cell, which is fixed to the moving parts of the translation stage. With this set-up, we can monitor changes in film length on the µm scale in response to the electrochemical stimulus, and changes in Young's modulus as a function of the doping level and aging can be followed.

The volume changes of these polymers depend in a non-trivial way on the morphology of the polymer. For macroscopic (> 1 cm), freestanding polymer foils we have achieved length changes in excess of 8% by proper choice of dopant and synthesis conditions. We believe that it is realistic to expect expansions in excess of 10% in the future. Thin films of polypyrrole – dodecyl benzene sulfonate (PPy-DBS), which show a linear expansion of ~3% in the film plane, may induce as much as ten times higher expansion in the perpendicular direction. By atomic force microscopy [*Smela and Gadegaard, 99*] this response has been shown to be both fast and reproducible.

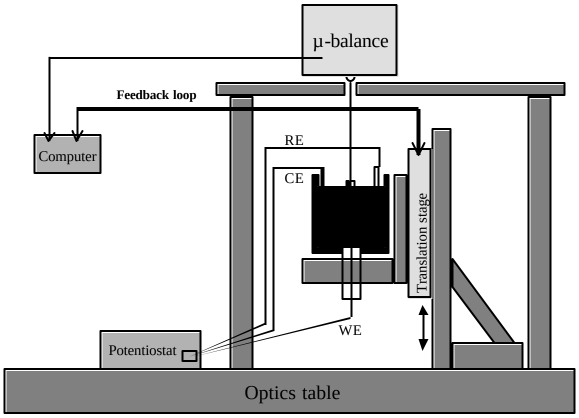

FIGURE 6: Schematic view of the test set-up.

FIGURE 7: Photographic view of the relaxed (top) and activated dielectric EAP actuator produced using a 3M (VHB-4910) tape.

Dielectric Elastomer Actuators: SRI has demonstrated actuators made of elastomer films sandwiched between compliant electrodes [Perline, et al, 00]. We have also constructed such actuators in the form of free hanging sheets of size 7 x 7 cm, which expands linearly by 25 % upon charging with 4kV. The active region expands 67% linearly and 105% in area. The actuators are easy to make using an acrylic adhesive tape from 3M (VHB-4910). The compliant electrode is a graphite powder containing grease. For practical actuators in robotic applications, we estimate that it is preferable to use 1kV maximum drive voltage. Currently, we are seeking several approaches to improving the elastomer dielectric properties.

***Reference**:*

Pelrine R, Kornbluh R, Pei QB, Joseph J., High-speed electrically actuated elastomers with strain greater than 100%. SCIENCE **287**, (2000) 836-839

Smela, E.; Gadegaard, N., Surprising volume change in PPy(DBS): An atomic force microscopy study. *Adv. Mater.* **11** (1999), 953-957.

ITALY

Pisa University, “E. Piaggio” Center

Realization of a human-like android equipped with EAP artificial muscles

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F. Battaglia , F. Di Francesco, and D. De Rossi

Electroactive polymer (EAP) artificial muscles may be used to mimic human muscles. To exploit this property we are developing a human-like android unit that can replicate human facial expressions. The android system is being developed with a capability to taste substances. Also, it would be able to mimic human expressions in response to the same food tasting analysis. The android is equipped with twenty-five artificial muscles and supported by a sophisticated array of sensors and data acquisition system. At the present, traditional electrical motors are producing the deformations/expressions. In parallel, efforts we are made to examine the use of electroactive polymers to serve as artificial muscles. Data is acquired by different acquisition cards, stored in a personal computer and analyzed through a dedicated neural net. A new driver that was designed and developed at our center in Pisa activates the android.

Our android is aided by neural networks (ANN) and uses sensors to detect rheological and organoleptic properties of food to determine the consistency and quality of the particular substances that are analyzed. A conductive polymer electronic nose consisting of tactile sensors is used as well as a strain gauge and high-resolution acoustic sensors to analyzed the chewed substances.

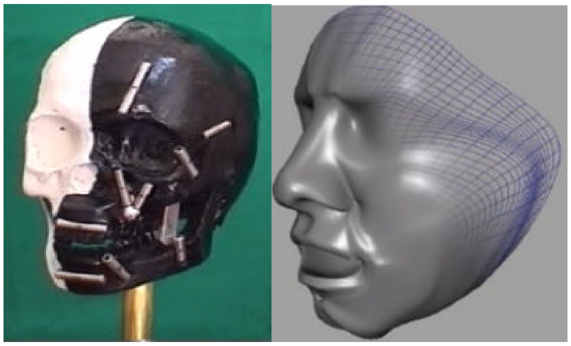

FIGURE 8: Left - Carbon fiber composite holding structure; **Right -** Virtual Face

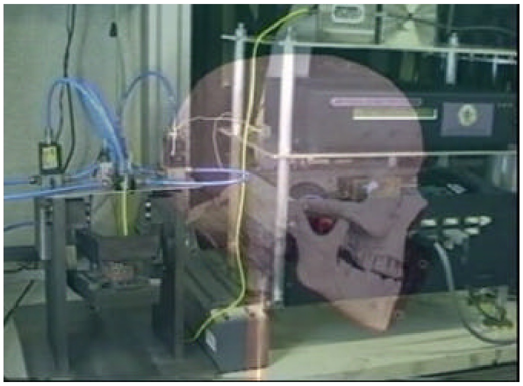

FIGURE 9: Data acquisition system

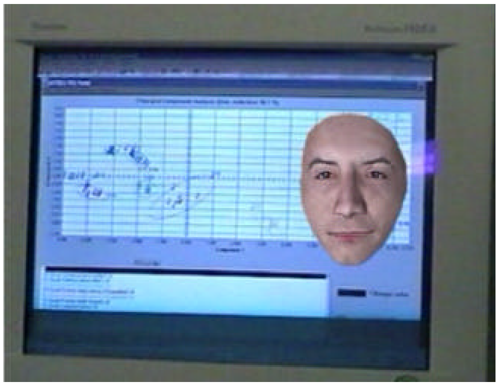

FIGURE 10: Data analysis

Human expressions are acquired by motion capture sequences. Human physiology and mechanical studies were needed to construct a carbon fiber composite support structure. This structure houses the sensors and actuators and it is covered with an artificial skin. The human skull was modified significantly leaving unchanged only the overall appearance. Analysis of muscles was conducted to obtain the suitable expressions that represent a chewing phase and it was emulated by dedicated actuators though analysis to mimic the expressions. The actuators are controlled using various force amplitudes and the mimicking accuracy and dynamics are investigated. Once we chose proper EAP materials for the android muscles, we will begin modeling them into the control system in terms of surface shape modifications that are needed to create the desired facial expressions.

So far we developed the android structure, designed the control systems and the core of the complete system. This control system drives simultaneously all the twenty-five actuators of the android allowing to conduct both facial expression and chewing motion. The system itself can acquire perceptions and expressions directly from a man model. It can store the new patterns, and manage them to effectively adapt actual expressions and provides information for the system design.

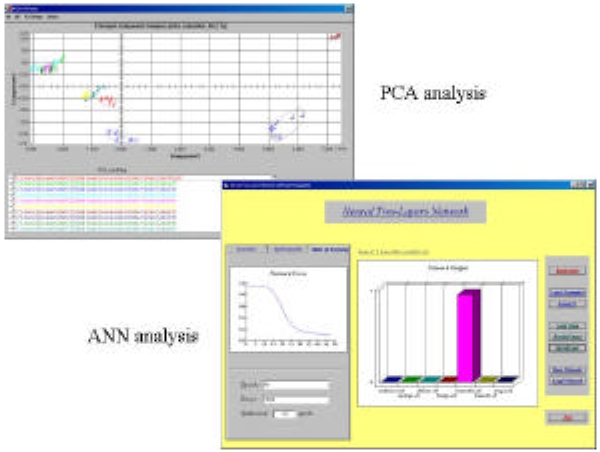

FIGURE 11: Principal Component Analysis (PCA) and ANN analysis of the Anadroid.

References

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JAPAN
Kobe University

Artificial Tactile Feel Display Using EAP actuator

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The purpose of our research is to produce tactile human feeling of the fine touch of the surface of a cloth. Conventional tactile displays can hardly express such a fine touch characteristics, because such mechanical devices that project the minute distributed stimuli on a human skin do not exist. To address this need, we developed a ciliary device using Nafion-Platinum composite type EAP actuator (known as IPMC or ICPF) [1].

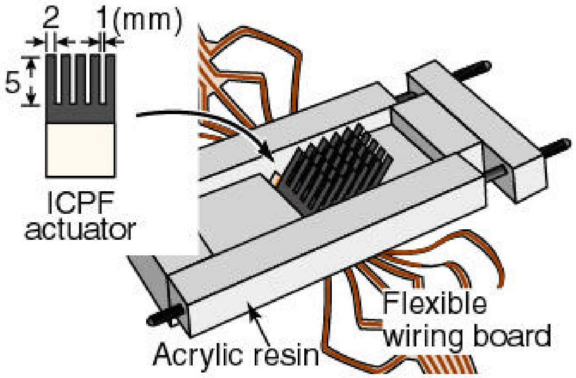

FIGURE 12: The structure of the ciliary device.

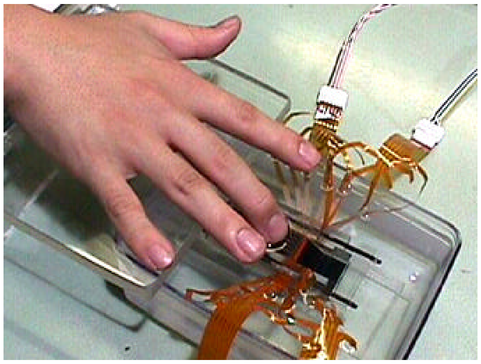

FIGURE 13: Experimenting finger touch.

To create complex tactile feeling, the there is a need for a fusion of elementary sensation generated by different kinds of sense receptors. We assume that combination of high/low frequency vibrations and pressure senses in the normal/shearing direction stimulates various sense receptors selectively, and generates the multiple elementary sensation. Additionally, high density of distributed stimuli is required to express delicate touch.

ICPF actuator [2] seems to offers the required properties to produce the above-required stimuli. The ICPF has sufficient softness, utilizing the passive material property, that complex control is not required. The low drive voltage is safe enough for the touch of fingers and ICPF films are easy to shape. Its simple operation mechanism allows to make a small and practical device. The developed device was designed with a number of cilia consisting of ICPF actuators, where a cilium is 2 mm wide by 5 mm long. High frequency drive generates vibratory stimuli tapping the skin surface. Whereas low-frequency drive makes a large motion to stroke the skin surface in the shearing direction projecting a sense of pressure.

We tried to display both pressure and vibration at the same time using a modulated low and high frequencies. The result clearly shows that over 80% of the subjects sensed some special tactile feeling. A comparison with real material samples shows that changing the lower frequency component produces several tactile feel emulating the materials. Especially, about half of the subjects responded to a towel and a denim with the same feeling. This result demonstrates that such a haptic display can present a subtle distinction of tactile feeling of cloth.

References

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2. K. Oguro, Y.Kawami and H. Takenake, Bending of an ion-conducting polymer film-electrode composite by an electric stimulus at low voltage, J. Micromachine Society, 5, 27/30, 1992.

KOREA

Inha University

Electro -Active Papers (EAPap) for Acoustic Actuators

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The possibility of Electro-Active Papers (EAPap) that can be used as acoustic actuators was examined. Paper is a sheet composed of a multitude of discrete particles, mainly of a fibrous nature, which form a network structure (see Figure 14). Since paper is produced in various mechanical processes with chemical additions, there is a possibility to prepare such a paper that can meet the requirements for acoustic actuators. A simple Electro-Acrive Papers (EAPap) was prepared by gluing two silver laminated papers in opposite direction so as to constitute the silver electrodes ouside the paper. When an electric voltage is applied to the electrodes the EAPap produces bending displacement. The performance of the EAPap is dependent on the excitation voltages, frequencies, type of adhessive, and the host paper. To investigate the operational principle of the EAPap, experiments were conducted with different adhesives and host papers, and results indicate an electrostriction effect associated with a combination of electrostatic forces of electrodes and the intermolecular interaction of the adhesive. Further investigations are underway to improve and stabilize the EAPap properties. Our EAPap actuators are lightweight and quite simple to fabricate offering significant advantages. Various applicable are currently being considered including: active sound absorbing materials, flexible speakers, and smart shape control devices.

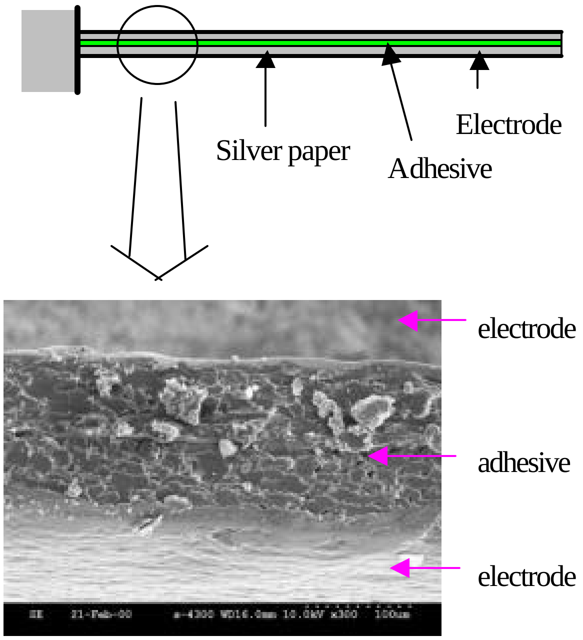

FIGURE 14: A view of the paper EAP

Reference

J. Kim, J.-Y. Kim and S.-J. Choe, "Electro-Active Papers: Its Possibility as Actuators," 7th International Symposium on Smart Structures and Materials, Vol. 3987, Newport Beach, CA, USA, March 2000.

SWEDEN

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Polypyrrole microrobot

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For almost a decade, the volume change of Polypyrrole (PPy) due to the oxidation and reduction of the conjugated polymer that is accompanied by a flow of ions to and from a liquid electrolyte has been used to make actuators [1-3]. At the Division of Applied Physics we have developed microactuators that are based on a bilayer of Au and PPy doped with dodecyl benzenesulfonate (DBS). These actuators were used to make miniature boxes that can be opened and closed [4].

Recently, we developed a novel fabrication method to create individually addressable and controllable microactuators that are based on a sacrificial layer [5]. Using this method, we made a microrobotic arm with individual controllable hinges. The robotarm can be compared to an arm with an "elbow" joint, a "wrist" and 2-4 "fingers. Each joint consisted of Au/PPy(DBS) bilayer microactuators. The elbow and wrist had two such microactuators parallel that could be individually controlled, to even achieve a minor rotation. For a more details we refer to [5].

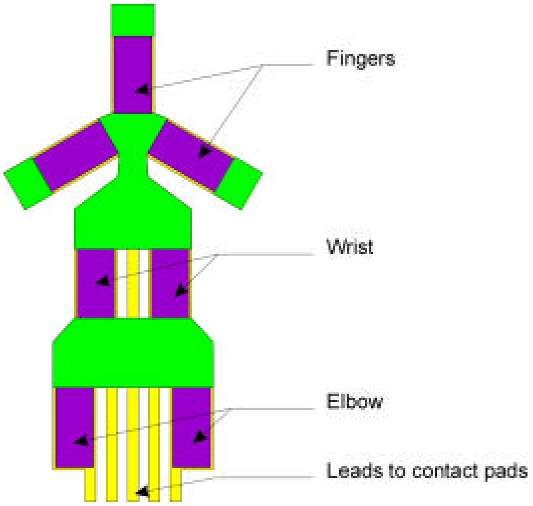

FIGURE 15: A schematic layout of the microrobotic arm.

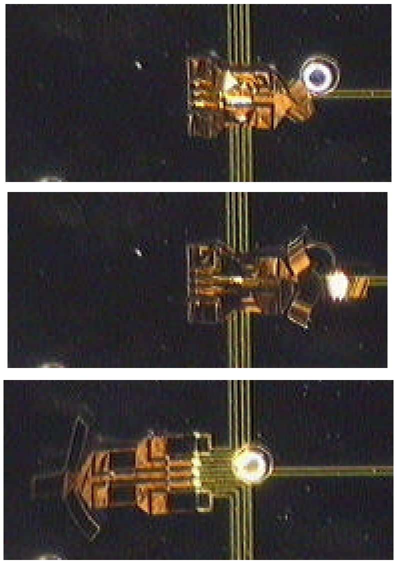

FIGURE 16: A sequence of photos showing the transfer of a 100 µm glass bead over a distance of ~250 µm.

Using a potentiostat, which was equipped with up to 6 working electrodes versus one counter and reference electrode, we could individually control each hinge (see Figure 15). We used the applied potential to control the amount of oxidation (reduction) of the PPy and thus the amount of bending. Using the robotarm we picked up, lifted, moved, and placed 100 µm glass beads over the surface crossing a distance of ~250 µm. We even made a "track system" of small polyurethane tracks (60 µm apart) and transferred the glass bead from track to track [6]. A photographic view of the motion sequence is shown in Figure 16.

This microrobot offers an excellent tool for cell manipulation. The robot could pick up cells, bacteria, or multi-cellular organisms from a sample and transferring it over a multisensor area to different measurement stations. Other applications might be novel surgical tools or robots to assemble other microdevices in a factory-on-a-desk

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2 T. F. Otero and J. M. Sansinena, Artificial muscles based on conducting polymers, Bioelectrochemistry and Bioenergetics, 38 (1995) 411-414

3 A. Della Santa, D. D. Rossi, and A. Mazzoldi, Performances and working capacity of a PPy conducting polymer linear actuator, Synth. Met., 90 (1997) 93-100

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6. Movies of the microactuators in action can be found at: http://www.ifm.liu.se/Applphys/ConjPolym/research/micromuscles/CPG_micromuscles.html

USA

Jet Propulsion Laboratory (JPL)

EAP Characterization

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Accurate determination of the properties of EAP materials is critical to potential designers of mechanisms and devices. Further, a performance matrix is needed to allow comparing their performance to other classes of actuators, including piezoelectric ceramic, shape memory alloys, hydraulic actuators, and conventional motors). For this purpose, JPL is seeking under a contract from DARPA to define a unified matrix, establish test capability and provide a centralized independent test lab.

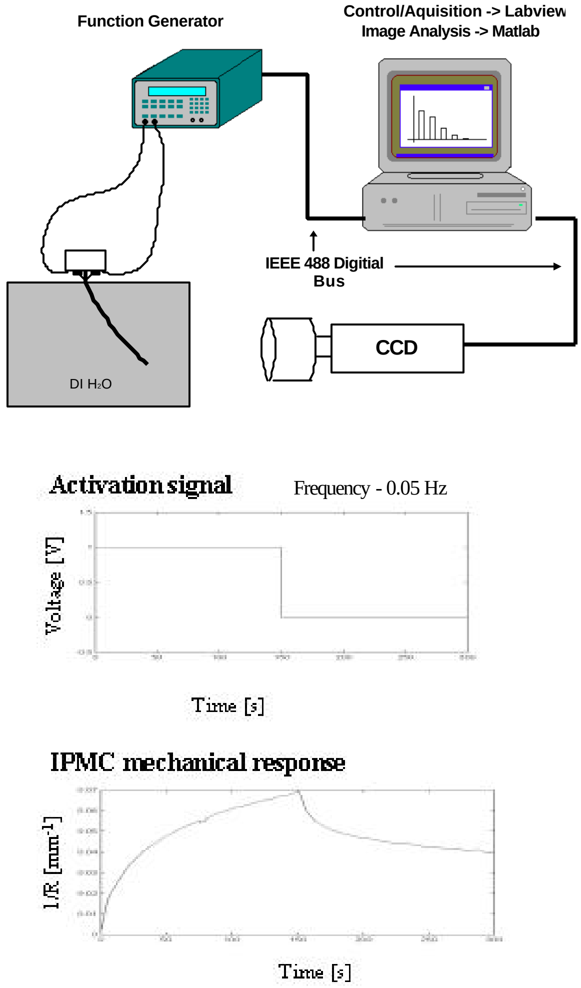

FIGURE 17: Mechanical Test Setup (top) and electromechanical response of IPMC. The bottom figure shows that IPMC continues to deform even under a DC field making the measurements a great challenge.

Key parameters and test methods are being developed and measurements are made with current emphasis on samples made of IPMC due to the complexities that are associated to this material system. Using video camera and Labview software the deformation of IPMC strips was recorded and digitized (Figure 17). Also, the electrical properties and response to electrical activation were measured. Nonlinear behavior was clearly observed in both the mechanical and electrical (Figure 18) properties. Currently, studies are underway to determine the electromechanical response under load and establish a reliable test methodology.

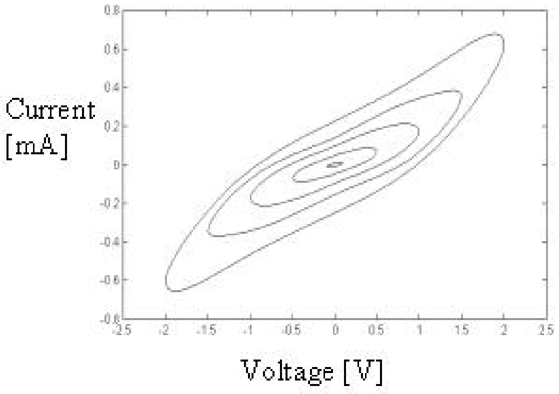

FIGURE 18: Nonlinear electrical response of IPMC

EAP fabrication at the JPL's NDEAA Lab.

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A growing number of NASA programs require mechanical actuators that can deliver high forces and displacements with reduced size and mass. Such reductions are expected to dramatically lower the size and cost of the launch vehicle that are needed for future missions. Alternatively, these same technology advances would allow including greater number of scientific experiments in a single spacecraft. EAP offers potential actuators to support this NASA need. These materials are capable of inducing large strains and allowing the application of forces onto objects. Of specific interest, the JPL's NDEAA Lab is seeking to develop effective ionic EAP. Even though different ionic EAP materials were demonstrated to operate in air [1-4], those actuators were involved with limitations in terms of force, displacement and/or durability. Efforts are currently underway to investigate various configurations based on the combination of increasing number of trilayers *[PPy || SPE || PPy]* and the operation configuration is shown in FIGURE 19.

In Figure 19, a PPy film is connected as the working electrode on the left of the triple layer, whereas on the right, the PPy film is connected as a counter electrode. During the oxidation of the working electrode a reduction of the counter electrode occurs simultaneously. The oxidation of the PPy film that acts as working electrode promotes the insertion of counter-ions from a solid electrolyte to the polymer structure and an expansion of the polymer occurs. Simultaneously, reduction of the conducting polymer at the counter electrode occurs promoting counter-ions to leave the polymer structure consequently causing contraction of the PPy. Complementary stress gradients are generated in the PPy || SPE interfaces and the triple layer bends in the right direction. Similarly, during the reduction of the working electrode an oxidation of the counter electrode occurs simultaneously. An opposite movement of counter-ions that were described previously takes place and the triple layer bends to the left.

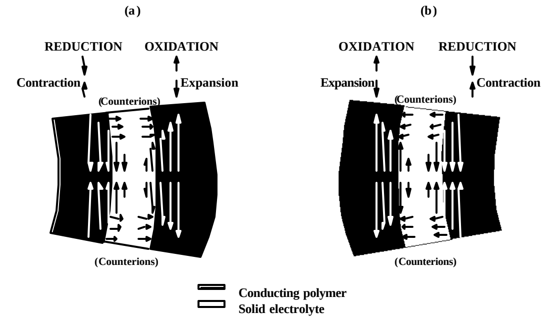

FIGURE 19: Bending movement of a [PPy || SPE || PPy] trilayer produced by complementary stress gradients generated in the PPy || SPE interfaces.

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SPAWAR SYSTEM, San Diego

Light Activated EAP Materials

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The goal of SPAWAR System Center's Visible-Light Activated Polymeric Actuator program has been (1) to optically drive and maintain a change in "charge state" of a polymer long enough for the polymer to contract or expand and (2) to minimize to requirements for optical power for robotic applications. Recently, a "jump molecule" has been found with an extremely long lifetime at room temperature, about 1.5 seconds. The decay curve for this molecule is shown in Figure 20.

A polymer gel in solution with this jump molecule was observed to contract about 20% when light was turned on and to expand reversibly to its original length when the light was turned off.

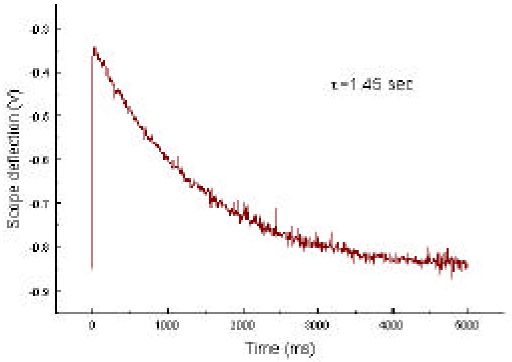

FIGURE 20: Jump Molecule Transient Absorption Decay using 455-nm radiation.

SRI International

New Class of Dielectric Elastomer Produces Extremely Large Strain and Energy Response

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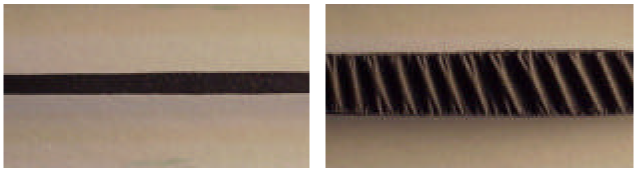
Researchers at SRI International have continued to further develop the electroactive polymer technology based on the electric-field activated response of elastomers with compliant electrodes. Recently the researchers identified a new class of polymers that exhibits an extremely high strain response. These acrylic elastomers, such as 3M Corporation's VHB series, have produced planar strains corresponding to a change in the active area of more than 300% for biaxially symmetric constraints (see photo on the cover page) and linear strains of up to 215% (see Figure below) for uniaxial constraints. The maximum specific elastic energy density (an indication of the amount of work the material can do) exceeds that of other known electric field activated materials, including single crystal piezoelectric ceramics. As reported in *Science* (February 4, 2000), one key to achieving such large strains and high energy density is the amount of initial elastic preload on the film. Optimal preload was also shown to increase the strain and energy density achievable with other elastomers, such as silicones. The discovery was made as part of a project to develop small actuators for micro machine applications sponsored by Japan's MMC/MITI/NEDO.

Basic measurements have confirmed that the electrostatic interaction of the free charges on the electrodes is responsible for most of the observed response. These measurements were made with the assistance of Guggi Kofod, a visiting scholar from Risoe National Laboratories in Denmark, and will be published in *Advanced Materials*.

SRI is actively using the new elastomer material in a variety of applications including artificial muscles for biomimetic robots. In April of this year, under contract to the Office of Naval Research, SRI demonstrated a six-legged walking robot powered by acrylic, artificial muscle actuators (see Figure below). This is believed to be the first fully self-contained EAP-powered terrestrial robot. Each muscle is driven by a small DC-DC converter. The joint motion is coordinated by a PIC microprocessor.

The acrylic material has also been shown to be promising as an acoustic actuator. SRI has built several low-profile loudspeakers based on acrylic films stretched over a frame. The largest actuator built to date measures 12 inches by 12 inches. These loudspeakers exhibit good frequency response and sensitivity in the mid to upper frequency ranges. SRI is currently exploring ways to improve the frequency response at lower frequencies.



Voltage Off Voltage On

FIGURE 21: Linear electrodes on a uniaxially-strained acrylic elastomer film expand in width in response to an applied voltage.

In addition to using the material for actuator applications, the high-strain capabilities of the material can be used to generate electricity from mechanical motion. Under contract to DARPA, SRI is developing "power shoes" that can harvest the energy of a heel strike to charge a battery or do other electrical work. Films of the acrylic material are incorporated into the heel of a shoe or boot. A bias voltage is applied across the films. The energy of the heel strike deforms the film. Using specially developed circuits, electrical energy is generated as the film returns to its initial state when the shoe is lifted. We have demonstrated a specific energy density of greater than 0.4 J/g with this material. Estimates of the maximum performance based on measured material parameters suggest that energy densities of more than 1.5 J/g are feasible. Such high energy densities suggest a number of power generation applications including replacement of heavier electromagnetic devices in engines, self-powered sensors and other applications.

Compared to silicone elastomers, the acrylic does have some drawbacks including greater viscoelastic losses and creep, and slower speed of response. Long-term durability of the material under high strain operation has not been established. Nonetheless, the extremely large electroactive response of the acrylic materials makes it promising for many applications.

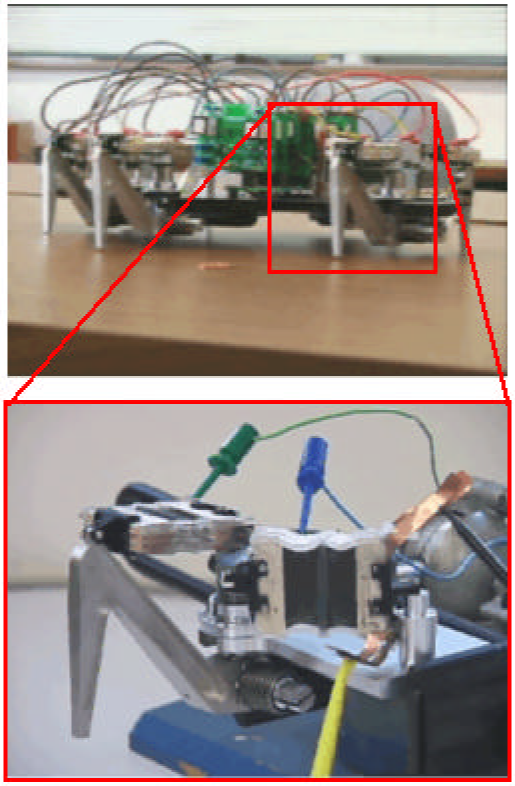


FIGURE 22: A self- contained EAP-powered walking robot (top) with six legs. Each leg is driven by two acrylic “artificial muscle” EAP actuators (bottom).

DESIRED EAP APPLICATIONS

The field of EAP has enormous potential to many areas and judging from the range of inquiries that the editor received so far it seems that almost any aspect of human life can be impacted. While some ideas may be science fiction it is important to scope the requirements to the level that current materials can address. As an emerging field, at that time, the Editor is not aware of any commercial product that is driven by EAP. Using EAP to replace existing actuators may be a difficult challenge and therefore it is highly desirable to see a niche application enabling new capabilities. In order to accelerate the progress towards practical applications this section was formed to provide those who are seeking to use such material a forum to express their need directly to the EAP materials developers. Interchange among those who are expressing the need and the developer is highly welcome and feedback as well as success story submitted to this Newsletter would be greatly appreciated.

AUSTRALIA -Aeronautical and Maritime Research Laboratory

Electro-active polymer as an actuator in flow control applications

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The Aeronautical and Maritime Research Laboratory works to support of the Australian Defense Force. Part of this role involves research into new technologies that have the potential to improve the aerodynamic performance of flight vehicles. In the last few years 'smart materials' such as Piezo-ceramic, Shape Memory Alloys and Electro-active polymer (EAP) have shown increasing promise as actuators in the control of the air flow over the surfaces of a flight vehicle.

One particular application where AMRL hopes to apply EAP is as an actuator in a zero mass flow (ZMF) jet. A schematic of a ZMF jet is shown in Figure 23.

A ZMF comprises a cavity, which has a small orifice flush to the surfaces of the air vehicle at one end and at the opposite end has a thin diaphragm. If this diaphragm is made from EAP polymer it can be driven by an alternating voltage to deform out of plane in a periodic manner. On the downstroke of the diaphragm, fluid is drawn into the cavity, while on the upstroke fluid is forced out. Over each complete cycle of operation, the net mass injected through the orifice is zero (hence the name ZMF jet), while the net momentum out of the orifice is non-zero. This injection of momentum (or energy) near the surface of the vehicle can modify the flow detail near the surface and in some cases can improve the aerodynamic characteristics of the vehicle. The same effect could be achieved by replacing the diaphragm with a piston or some other mechanical or pneumatic mechanism, but EAP has the advantage of simplicity and low weight, which are crucial requirements for flying vehicles.

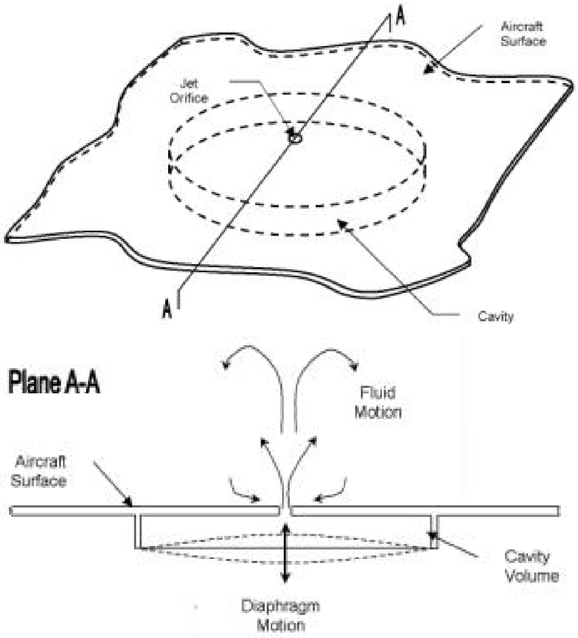

FIGURE 23. Schematic of a ZMF jet.

At AMRL we study aerodynamics predominantly in wind tunnels or using numerical simulation. However, when trying to understand basic flow behavior, experiments are often performed in a water tunnel. A water tunnel is similar to a wind tunnel with the exception that the fluid used is water and not air. We use water because it is very easy to make the flow visible by injecting food dye in the areas we are interested in studying. Since we do not fully understand the physics associated with ZMF jets, AMRL is keen to do some water tunnel experiments on these ZMF jet devices. EAP appears to be ideal for this application, since it has been shown to have excellent performance in water when compared to other 'smart materials'. AMRL is keen to acquire some samples of EAP and demonstrate a new application for the material.

FRANCE - HUTCHINSON - Centre de Recherche

http://www.hutchinson.fr

Interest in Piston Shape EAP Actuator

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We are seeking an EAP actuator that can be shaped as a piston actuator. This actuator needs to induce 10% strain and 3 MPa for with speed faster than seconds using low power. The displacement needs to be ±0.5 mm at 40 Hz decreasing with frequency, having a force of ±40 N and a blocking force of 200 N. The operation frequency band is 40 Hz to 200 Hz and cylindrical actuator dimensions are 60 mm height and 100 mm diameter.

ISRAEL - GeronTech

The Israeli Center for Assistive Technology & Aging http://www.jointnet.org.il/gerontech

Mechanical Suppression of Tremor

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GeronTech, a non-profit facilitator of innovative rehabilitative and assistive technologies, is planning the development of an orthotic system, based on soft actuators, for the mechanical suppression of tremor in the upper limbs of patients with Parkinson's, etc. The orthosis is designed to have low aspect and weight and fit conformally to the forearm. Currently in the feasibility study phase of the project, they are evaluating the suitability, for their application, of various candidate technologies for soft actuators and kinematic sensors. As part of their enabling technologies screening process, they are seeking third party capabilities in the development and fabrication of EAP materials having a force characteristic within the range 0.3 - 0.5 N.M/mm2, upper frequency response of 8-10 Hz. and a minimum lifetime of ~ 0.8 x 10E8 cycles. Further details available upon exchange of non-disclosure agreements.

SWEDEN - AEROTECH TELUB

Smart materials for anti -G suit

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With reference to our article concerning a "Device to apply pressure on a human body" that was published in the WW-EAP Newsletter, Dec. 1999, we hereby are seeking to get in touch with someone who can deliver or discuss future delivery of EAP actuators that can support our need. The actuators are needed for medical purposes and will be need in mass production scale. The specifications of our requirement are:

Gel/treads/bending beams/cylinders or anything that makes it possible to achieve a pressure of 0.025-0.06 MPa on a cylinder dia.100mm and length 100-150mm (to start with).
Reaction time 1-10 sec.
Low voltage max 28V
Activated at min 30-40 deg. C
Max working temp. 40-60 deg. C

UNITED KINGDOM (ENGLAND)

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EAP Amphibious Micro - Robots

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With the advent of new micro-machining technologies including micro-sensing, micro-actuation as well as microelectronics and micro-computation it is reasonable to assume that very small mobile robots will be built in the future (Holland & Melhuish 1996). The shrinking and integration of conventional technologies is, of itself, fascinating - however, (and perhaps with a little imagination) another route for the development of small-scale robots is also open to us in the form of the embryonic EAP technology.

One requirement of small robots will probably be to move through the environment. Natural systems have also tackled this problem and there is a useful biological literature on the movement in various environmental conditions of simple animals such as protozoa, bacteria, and maggots. Schöne (1984) reviews early and modern literature on taxes, kineses, and tropisms, and provides useful abstract models of the simplest biological sensor systems. Particular investigations of interest include Colombetti and Francesco (1983), Foster and Smith (1980), Ricci (1989), Koshland (1980), Bray (1992), and Feinleib (1980).

Consider the problem of getting a tiny amphibious robot to ascend a chemical gradient. This is a task easily solved by the *E.coli* bacterium without recourse to digital computers A study by

Marken and Powers (1989) showed that an extremely simple creature could use an extremely simple algorithm to climb a gradient reliably, and at more than half the speed of the optimal control-based algorithm; their quantitative work undercut the intuitive notion that the *E. coli* algorithm would be able to succeed only at some miserably poor rate. It is interesting to speculate how this might be achieved with EAP. Activities must be controlled and coordinated; sensing and action need to be appropriately correlated and choreographed. The body of the robot will, most likely, need to be multifunctional; particularly with the ability to sense and effect motion. One can imagine the robots body exhibit a series of undulations that propel and direct its motion. Possibly this might require novel bonding techniques to create laminar EAP structures.

Drawing inspiration from biological systems the IAS lab at the University of the West of England has been studying how the control and co-ordination of micro-robots could be achieved. We are keen to explore such ideas with new smart materials technologies such as EAP.

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http://www.mech-eng.leeds.ac.uk/res-group/biomedical/biomedical.html

Seeking Bio -Compatible EAP

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Recent research in tissue engineering has led to the conclusion that the material and functional properties of tissues are dependent on the physical as well as the chemical environment in which they are formed. For instance to grow artificial arteries the function of the cultured cells changes if the substrate upon which they are grown is strained during the growing process. There is therefore a possible need for 'moving' substrates in the tissue-engineering field. Of course there are numerous hurdles to overcome such as cell compatibility and substrate removal but the potential of EAP's to be formed into biological shapes and the low stress, high strain demands of this field may give them an advantage over other methods. We are currently engineering a number of tissues and are interested in performing some basic experiments on deforming substrates. Is a suitable EAP which could be applied to this field, bearing in mind the biocompatiblity constraints of cell cultures?

USA - OMNIFIC, NY

Seeking EAP Actuators

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Omnific International has not used EAP devices, but anticipates their applicability to the technology described in patents 5770913 and 6069420, which relate to actuators, motors and wheelless autonomous robots driven by oscillatory transducers. To date, feasibility models have been driven by a variety of transducer types including solenoids, voice-coil actuators, pneumatic bladders -bellows -and cylinders, NiTi wire segments, and bending piezoelectric devices (THUNDER). EAP devices oscillating somewhere in the subsonic to ultrasonic frequency spectrum can be useful for these devices as prime movers. Three types of basic designs have been used to create linear or circular motion. Orthogonal pairs of transducers driving by friction have been used. Another technique using pairs of orthogonal transducers use the concept of a Dynamic Surface Engagement Switch (DSES), which mimics the ability to dynamically vary the friction coefficient of mating surfaces. A third technique uses oriented fiber material driven by a single oscillatory transducer, which exhibits anisotropic mechanical engagement behavior. Robotic elements generally use three mutually orthogonal oscillatory transducers. Actuators/ robots with scale ranging from MEMS to horsepower scale industrial units are feasible.

VENEZUELA - Polytechnic University Institute

Seeking interface EAP to Nerves

Mónica Barros, barros@eldish.net and Annied Malaver

A thesis study is underway at the Electronic Engineering to establish an electronic interface between EAP materials and biological nerves. Biologically compatible materials are being sought to support this research. The research is conducted jointly with physical medicine and rehabilitation personnel from a local hospital.

BOOKS AND PUBLICATIONS

Springer-Verlag

http://www.springer.de

"Organic Electronic Materials" Grosso and Farchioni (Eds.)

Claus Ascheron, ascheron@springer.de or e.sauer@springer.de

A book about organic electronic materials is about to be published. This book contains material related to conductive polymers and electronic materials. It covers studies on the electronic properties of conducting polymers and organic molecular crystals, areas that have enjoyed increasing interest in recent years. This book is organized into two sections, one dedicated to conducting polymers, the other to organic molecular crystals. For each section a general introductory review provides background knowledge of the language and the main points useful for the comprehension of the remaining parts of the book. The reviews provide a more complete understanding of the underlying physics of the materials through the discussion of selected interconnected topics.

Fundamental theoretical methods and numerical procedures for the evaluation of the electronic energy levels are overviewed; this supports the phenomenological and empirical models often employed for the explanation of physical and chemical electronic properties of these materials.

UPCOMING EVENTS

March 5-7, 2001	SPIE joint Smart Materials and Structures and NDE, Newport Beach, CA., Pat Wight patw@spie.org Website: http://www.spie.org/web/meetings/calls/ss01/ss01_home.html
Dec. 3, 2001	MRS, Boston, MA, Website: http://www.mrs.org/

Grand Challenge for EAP
Arm wrestling with Human

WorldWide Electroactive Polymers (EAP) Newsletter

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