WorldWide ElectroActive Polymers

EAP (Artificial Muscles) Newsletter

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http://eap.jpl.nasa.gov

FROM THE EDITOR

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

This Newsletter issue reports the latest progress in the fields of Electroactive Polymers (EAP) and Biomimetics.

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GENERAL NEWS

This issue is the 42nd of the WW-EAP Newsletter. Over the last 21 years, this Newsletter has been published twice a year as an eDocument on the WW-EAP Webhub http://eap.jpl.nasa.gov This Webhub is a link of the JPL's NDEAA Lab Website http://ndeaa.jpl.nasa.gov of the Electroactive Technologies Group.

Standard for EAP

A paper about a standard for EAP materials is posted on the internet and can be read at http://dx.doi.org/10.1088/0964-1726/24/10/105025

ABOUT THE EXPERTS

Ji Su Received NASA 2019 Exceptional Technology Achievement Medal

Figure 1: Ji Su is a recipient of the NASA 2019 Exceptional Technology Achievement Medal.

The photo shows him at the Award Ceremony held at NASA Langley Research Center.

Ji Su, a senior research scientist, working at NASA Langley Research Center recently received NASA 2019 Exceptional Technology Achievement Medal for his work on development of electrostrictive graft elastomers (G-elastomers) and their applications in advanced aerospace technologies. As a new class of high performance electroactive polymers, G-elastomers do not only have demonstrated high electroactive performance such as high electric field induced strain and high electromechanical output power, but also proved an effective electromechanical mechanism. The mechanism allows the materials to increase the electric field-induced strain and the mechanical modulus simultaneously. Therefore, the electromechanical output power, which depends on both the electric-field induced strain and the mechanical modulus of the materials, can be significantly enhanced to meet the requirements in advanced aerospace technologies. Using the G-elastomers, Su and his group developed a hybrid electrometrical system that demonstrated a significantly improved actuation performance and proved a hybrid concept. The proven hybrid concept has been adopted in developing a series of actuators, transducers and energy harvesters. The hybrid electromechanical energy harvester shows that a 40% of electromechanical energy conversion can be achieved.

EAP FORMS AND SOCIETIES

The International EuroEAP Society

The 'EuroEAP – European Society for Electromechanically Active Polymer Transducers & Artificial Muscles' (www.euroeap.eu) is a non-profit International Association, whose main purpose is to contribute to and promote the scientific and technological advancement and the diffusion of Transducers and Artificial Muscles based on Electromechanically Active Polymers (EAP).

The Society operates at international level and it welcomes members from any country worldwide. If you are interested in learning more about the Society, please visit the website www.euroeap.eu and subscribe to become a Member of this unique Association in the EAP field and take advantage of the benefits of being a Member:

- Being part of the largest international scientific and industrial Association in the EAP field;
- Facilitated networking with experts and professionals in the EAP field, and easier access to the most recent developments;
- Reduction on the registration fees for the annual EuroEAP Conference;
- Discount on the purchase of the EuroEAP Conference proceedings;
- Possibility to apply to annual calls for short term scientific missions grants offered by the Society to foster or strengthen collaborations with any institution in any country of any continent;
- Possibility to participate to the annual Society Challenge;
- Possibility to disseminate your work via the broad EuroEAP emailing list;
- Possibility to participate to working groups on topics of scientific, technological and industrial relevance in the EAP field;
- Being a member of the General Assembly of the EuroEAP Society, with voting rights and eligibility to its Organs and Committees.

The next Annual Meeting of the Society will be held during the upcoming EuroEAP conference: www.euroeap.eu/conference.

UPCOMING CONFERENCES

2020 SPIE EAPAD Conference

The SPIE's 22nd EAPAD conference is going to be held from April 26 thru 30, 2020, in Anaheim, California. This conference, which is part of the Smart Structures and Materials Symposium, is going to be chaired by Yoseph Bar-Cohen, JPL, and Co-chaired by Iain A. Anderson, The Univ. of Auckland, New Zealand; and Herb Shea, École polytechnique fédérale de Lausanne, Switzerland. The Conference Program Committee consists of representatives from 32 countries. The Parallel Sessions are going to be held on Wed., as opposed to Thurs in the past years.

The papers will focus on issues that help transitioning EAP to practical use thru better understanding the principles responsible for the electro-mechanical behavior, analytical modeling, improved materials and their processing methods, characterization of the properties and performance as well as various applications.

There are going to be two Keynote Speakers and they are:

1. Yoseph Bar-Cohen, Jet Propulsion Lab (JPL)/California Institute of Technology (Caltech) will present the paper “Highlights from Chairing the EAPAD Conference for 22 Years”. As Yosi informed SPIE already, he is not going to continue chairing the EAPAD annual conference that he established and this is his farewell presentation.
2. Pinhas Ben-Tzvi, VT Robotics and Mechatronics Lab, Virginia Tech, Blacksburg, VA, will present “Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications”.

The invited papers are going to be as follows and, in compliance with the SPIE decision in 2019, starting in 2020, the invited papers will have only 20 minutes.

1. “Applying IPMC to Soft Robots” - Suzumori, Koichi, Tokyo Institute of Technology
2. “MXene-based Ionic Soft Actuator for Kinetic Art Soft Robots” - Oh, Il-Kwon, KAIST
3. “Liquid metals for functional polymers and soft devices” - Dickey, Michael D., North Carolina State Univ.
4. “Enhancing the permittivity of dielectric elastomers with liquid metal” - Majidi, Carmel, Carnegie Mellon Univ.
5. “Soft pumps for robots and wearables” - Cacucciolo, Vito, Ecole Polytechnique Fédérale de Lausanne
6. “Electromechanical Modeling of Plasticized PVC Gel Actuators and the Improvement in their Performances with the Additions of Ionic Liquids” - Asaka, Kinji, National Institute of Advanced Industrial Science and Technology
7. “Soft microelectromechanical systems and artificial muscles based on electronically conducting polymers” - Nguyen, Tran-Minh Giao, Univ. de Cergy-Pontoise
8. “Control of dielectric elastomer actuators based on self-sensing displacement feedback” - Stefan Seelecke, Uni Saarland
9. “Advances in electrostrictive graft elastomers and applications” - Ji Su, LaRC

The 22nd Annual EAP-in-Action Session and Demonstrations will be held on Monday 27 April 2020, 4:30 PM - 5:45 PM. It is chaired by Yoseph Bar-Cohen, JPL, and it is part of the EAPAD Conference. This Session highlights some of the latest capabilities and applications of Electroactive Polymers (EAP) materials where the attendees are shown demonstrations of these materials in action. In addition, the attendees interact directly with technology developers and given "hands-on" experience with this emerging technology. The first Human/EAP-Robot Armwrestling Contest was held during this session of the 2005 EAPAD conference.

The demonstrations at the EAP-in-Action will include:

Diaphragm actuator can lift 4kg with a 0.96g DE
Koji Ono, Aisin AW CO., Ltd
Mikio Waki, Wits Inc.
Seiki Chiba, Chiba Science Institution, Japan

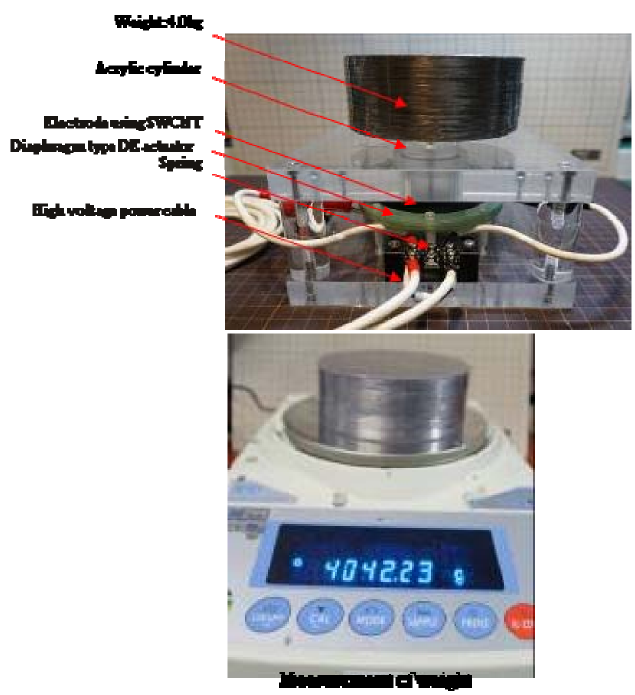


Figure 2: The dielectric elastomer actuator

Description: Using dielectric elastomer actuator that weighs only 0.96g and applying about 3kV, it will be demonstrated that the actuator can lift a weight of 4kg over 1-mm. It is driven at relatively high speed and the time required moving 1 mm could be 98 milliseconds. The DEA achieves high output using SWCNT electrodes suitable for acrylic dielectric elastomers. Currently, a new dielectric elastomer material and SWCNT are being developed. With such, the efforts are focused on making the actuator more compact and obtain higher output power. Within a year's time, the goal is to make a DEA that lifts 8kg.

Super flexible electrode for a DE made with CNT spray

Makoto Takeshita, Zeon Corp.
Mitsugu Uejima, Zeon Corp.
Mikio Waki, Wits Inc.
Seiki Chiba, Chiba Science Institution

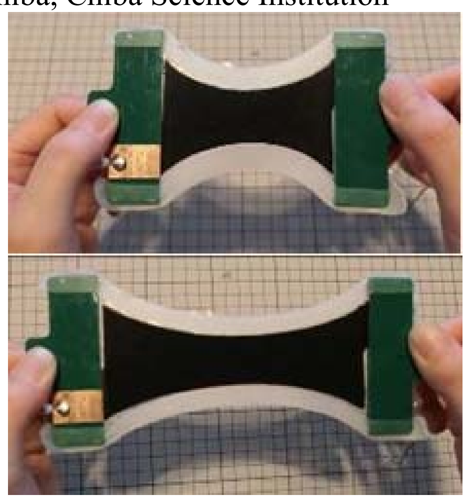


Figure 3: Stretching of rubber coated with CNT spray (before and after stretching)

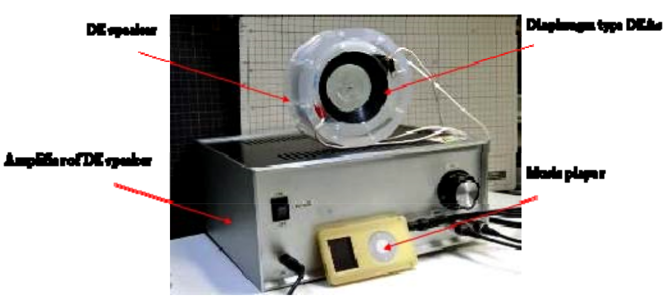


Figure 4: DE speaker made of rubber and CNT spray with conductivity imparted by CNT spray

Description: A CNT spray can impart conductivity of various materials through simple application alone, not requiring any special equipment or techniques. The sprayed CNTs are flexible and, after being dried, they remain conductive and connect even when bent or stretched. In addition, because of its excellent adhesiveness, it does not easily peel off or scatter after drying. It is very easy to use, able to be applied with a special CNT paint spray. Expensive dispersing equipment and special coating equipment are not required, doing away with troublesome dispersion work. With a CNT sprayer and dielectric elastomer, it is possible to make a DE easily, which can further promote DE research and trial production.

It is possible to change the content of CNTs according to the purpose. By simply applying CNT spray, the following can be easily achieved: DE electrodes, wiring of electronic circuits that require flexibility, mounting of electronic components on flexible PCBs, and rubber that requires flexibility. It is also possible to add conductivity to a sponge.

Synthetic Muscle™ in Robotics: Sensing and Shape-morphing

Lenore Rasmussen, Peter Vicars, and Calum Briggs, Ras Labs, Inc., www.raslabs.com

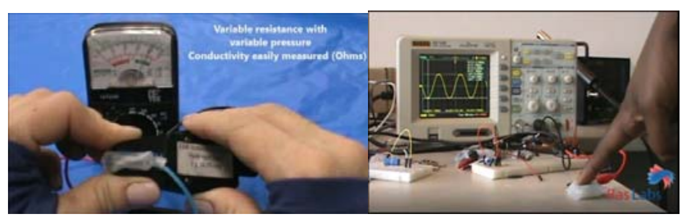


Figure 5: EAP pressure sensing using a simple multi-meter (left) and pressure sensing data analysis using an oscilloscope (right).

Figure 6: EMI® gripper using Synthetic Muscle™ shape-morphing system to handle a ripe blueberry with no damage.

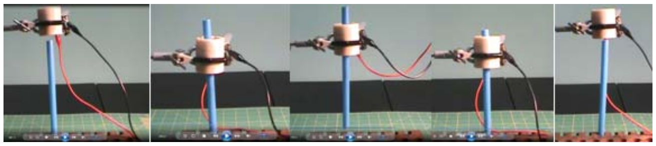


Figure 7: Pick and Place: Circular robotic gripper using Synthetic Muscle™ shape-morphing system to gentle handle a plastic straw with no damage.

Description: The Ras Labs' Synthetic Muscle™ is made of an EAP material that can be actuated controllably to contract and expand under low voltage (< 50 V). It can be used to sense pressure from gentle touch to high impact. The latest capabilities of this EAP material will be demonstrated.

Design advances in HASEL artificial muscles

Nicholas Kellaris[1,2], Shane K. Mitchell[1], Philipp Rothemund[1], Christoph Keplinger[1,2]

[1]Department of Mechanical Engineering, University of Colorado, Boulder, CO 80309, USA.

[2]Materials Science and Engineering Program, University of Colorado, Boulder, CO 80303, USA.

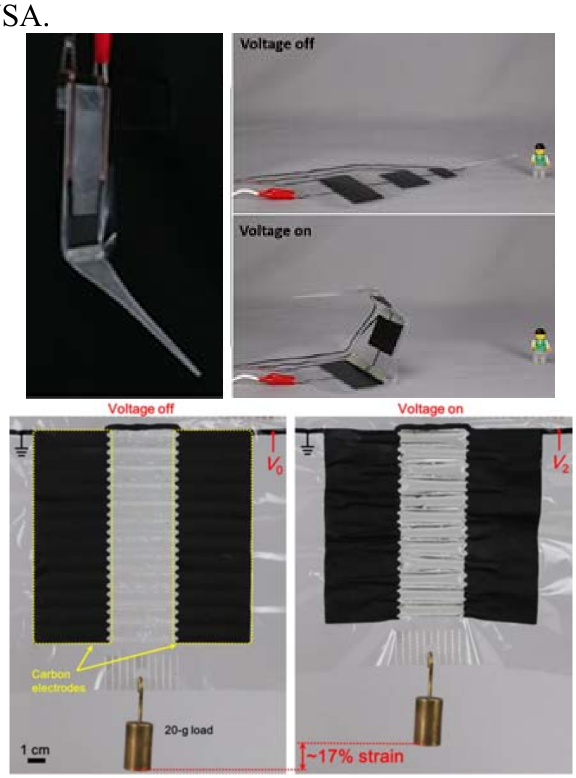


Figure 8: The latest HASEL actuator

Description: Some recent advances in HASEL artificial muscle designs will be presented. This includes a new HASEL geometry that enables increased strains versus traditional designs. In addition, we will demonstrate a new design of HASEL that uses bioinspiration to combine rigid and soft components and create an actuator capable of bending motion to enable fast, strong, soft-actuated joints that can be independently-controlled.

Virtual Reality Demo of underwater gesture recognition glove

Derek Orbaugh, Biomimetics Laboratory, Auckland Bioengineering Institute, University of Auckland

Figure 9: Virtual reality demo

Description: A glove capable of recognizing a range of hand gestures has been developed and it is translating these into commands for a virtual AUV. Dielectric elastomer strain-sensors were placed on each finger to measure the angular displacement in the proximal and distal directions. An IMU is placed in the dorsal side of the palm for complex gesture recognition. A haptic motor is used for feedback when a gesture is recognized. The virtual environment simulates an AUV floating in an underwater world for the user to interact with. The aim of this environment is to train divers before using our smart dive glove for underwater communication.

Coiled polymeric fiber based actuators for environment control and soft robotics.

Marcio Lima, Chief Application Scientist, Nano-Science & Technology Center, Lintec of America, Inc.

Figure 10: A few coiled polymeric fibers automatically open the roof of a simulated greenhouse in order to allow hot air to escape and control its internal temperature.

Figure 11: Three fibers operating as torsional actuators control the opening and close of blinds for light and air flow control.

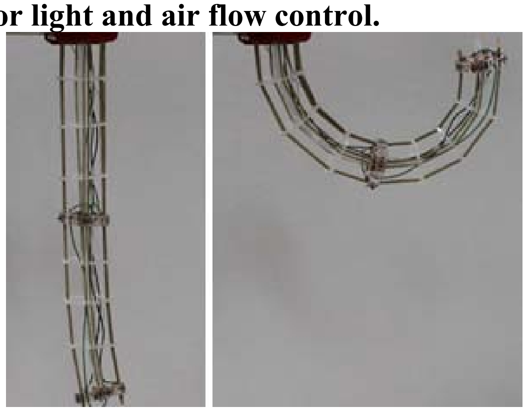


Figure 12: A "tentacle" 25 cm long and using 8 independent arrays of coiled, polymeric fibers. Movement took 2.5 seconds.

Description: It has been demonstrated [1, 2, and 3] that highly twisted polymeric fibers are also capable to generate impressive tensile actuation, providing large strokes and vastly exceeding the work and power capabilities of natural skeletal muscle. Contraction of over 50% and lifting capacity up to 270 pounds weight have achieved using single coiled fibers. These actuators are also can operate as torsional motors: a thin fiber can rotate heavy rotors at up to 100,000 rpm for 1,000,000 cycles. Actuation can be driven by electrical signals or by relatively small variation in environmental temperature, which can be converted into mechanical work. Bi-stable operation is also possible: energy is required only to change the shape of the actuator between two positions. **Figure 10** shows an example of automatic environmental temperature control using only coiled polymeric fibers, which are capable to open and close the roof a simulated greenhouse in order to regulate its internal temperature. No electricity is required. **Figure 11** shows torsional, electrically driven actuation to control light and air flow. Another filed of applications is on soft-robotics: since these actuators are very flexible, capable to produce large tensile strength and easily assembled into arrays they are suitable for construction of soft manipulators, as shown in **Figure 12**.

High Voltage Signal Generator (HVSG)

Markus Henke[1,2,3,] Zak Beh[1], Katie Wilson[1,3], Iain Anderson[1,3]

[1]PowerOn Ltd., 70 Symonds St, Auckland, New Zealand

[2]TU Dresden, Institute of Semiconductors and Microsystems, Dresden, Germany

[3]Biomimetics Lab, University of Auckland, Auckland, New Zealand

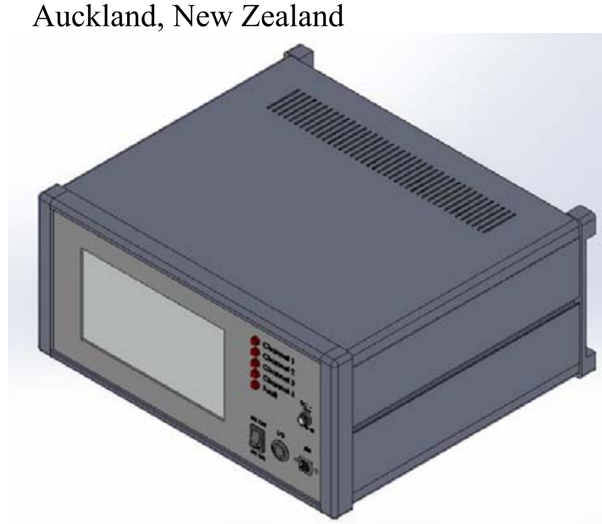


Figure 13: High Voltage Signal Generator (HVSG)

Description: The latest HV Generator will be demonstrated as driver dielectric elastomers (DEs) that is the result of our work since 2008. This HVSG power supply is also a controller for running demonstrators and experimental setups that require high voltage, with 4 independent channels. Dielectric elastomers, piezo electronics, electro stiction or robotics are some the applications for the HVSG. It is, multichannel unit that delivers several standard waveforms up to 1kHz and 4000V.

To simplify demonstrations and extend usefulness, the HVSG comes with rechargeable, high performance lithium-polymer batteries. An integrated controller, with touchscreen interface, further simplifies setup – and it included an interface bus to stream signals or for synchronization with other instruments.

Soft tactile detectors for soft grippers

Markus Henke[1,2,3], Dawei Zhang[1], Katie Wilson[1,3], Andreas Richter[2]
[1]PowerOn Ltd., Auckland, New Zealand
[2]TU Dresden, Institute of Semiconductors and Microsystems, Dresden, Germany
[3]Biomimetics Lab, University of Auckland, Auckland, New Zealand

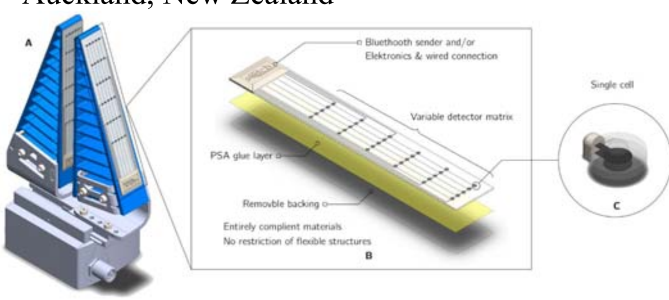


Figure 14: Soft tactile detectors for soft grippers

Description: We will present an implementation of entirely soft and stretchable geometric dielectric elastomer switches (gDES) for soft robotic components. The switches are arranged in 2D arrays to enable space-resolved tactile sense. Soft adaptive grippers have the ability to grip randomly formed objects by adapting their geometry. To do so, they undergo large three-dimensional deformations. Currently, there is a lack of electronics for touch detection in such grippers, because conventional electronics rely on rigid semi-conductor electronics, it hinders large deformations. Soft and stretchable gDES arrays give soft robotic grippers the ability to detect touch and do not prevent adaptive gipping.

We present a soft tactile sensor attached to an adaptive gripper unit and the design of a control-loop that can adjust the gripping force to the gripped object. A FESTO fin-ray gripper with all necessary peripheral components, such as pressure-controller and control-valves is used as proof of concept system. Fin-ray grippers are soft, adaptable grippers that can grip variously formed objects, but do not possess any sensing electronics for touch detection so far. Our soft tactile gDES sensor arrays give soft grippers the ability to "feel" touch.

Electroadhesive DEA-powered snake robot

Joseph Ashby[1], Samuel Rosset[1], Markus Henke[1,2,4,] Iain Anderson[1,3,4]
[1]Biomimetics Lab, University of Auckland, Auckland, New Zealand
[2]TU Dresden, Institute of Semiconductors and Microsystems, Dresden, Germany
[3]StretchSense Ltd., 114 Rockfield Road, Penrose, Auckland, New Zealand
[4]PowerOn Ltd., 70 Symonds St, Auckland, New Zealand

Figure 15: Electroadhesive DEA-powered snake robot

Description: We present here a bioinspired crawling robot based on the movement of Serpentes, using phased actuation to produce periodic deformation coupled with controllable adhesion through electroadhesive pads. This design allows the robot to traverse over smooth surfaces, a task its biological inspiration is unable to achieve as they rely on friction from their environment in order to generate forward motion. The electroadhesion would also allow the robot to operate in zero gravity environments, where traditional wheeled or walking robots cannot.

The design uses hinged rigid sections, which are linked by DE actuators, allowing them to bend. Changing the waveform of the periodic deformation, along with the phased actuation of the electroadhesive feet produces different motions accordingly.

On the record of the EAPAD conferences archive, the following is the list of the Co-chairs since the start in 1999 at Newport Beach, CA.

Year	Co-chair	Country
1999	Mohsen Shahinpoor, U. of New Mexico	USA
2000	Steve Wax, DARPA	USA
2001	Danilo De Rossi, Univ. degli Studi di Pisa	Italy
2002	Yoshihito Osada, Hokkaido University	Japan
2003	Geoff Spinks, University of Wollongong	Australia
2004	Peter Sommer-Larsen, Risoe National Lab.	Denmark
2005	John D. Madden, U. of British Columbia	Canada
2006	Jae-Do Nam, Sung Kyun Kwan University	S. Korea
2007	Gabor Kovacs, EMPA	Switzerland
2008	Emillio P. Calius, Industrial Res. Limited	New Zealand
2009	Thomas Wallmersperger, Univ. Stuttgart	Germany
2010	Jinsong Leng, Harbin Institute of Tech.	China
2011	Federico Carpi, Univ. of Pisa	Italy
2012	Keiichi Kaneto, Kyushu Inst. Of Tech.	Japan
2013	Siegfried Bauer, Johannes Kepler U.	Austria
2014	Barbar J. Akle, Lebanese American Univ.	Lebanon
2015	Gal deBotton, Ben-Gurion U. of the Negev	Israel
2016	Frédéric Vidal, U. de Cergy-Pontoise	France
2017	Jonathan Rossiter, University of Bristol	England
2018	Iain A. Anderson, The Univ. of Auckland	New Zealand
	Iain A. Anderson, The Univ. of Auckland	New Zealand
2019	Nancy L. Johnson, General Motors Co.	USA
2020	Iain A. Anderson, The Univ. of Auckland	New Zealand
	Herbert Shea	Switzerland

EuroEAP 2020 – 10th Intern. Conf. on EAP

Federico Carpi, University of Florence, Italy

EuroAP 2020 - the 10th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles held in Europe will take place at Val D'Orcia (Chianciano Terme), Tuscany, on 2-4 June 2020 (www.euroeap.eu/conference).

Figure 16: Val D'Orcia, Tuscany, Italy is the UNESCO World Heritage and it is the hosting site of the EuroEAP 2020 conference where the 10th anniversary of the conference series will be celebrated.

The EuroEAP conference is an international event with a special format, condensed in two days and a half. It is attended by experts from a diversity of countries worldwide and is designed to maximise interactions among participants, with invited lectures followed by participant presentations that comprise a short oral and an extended poster session.

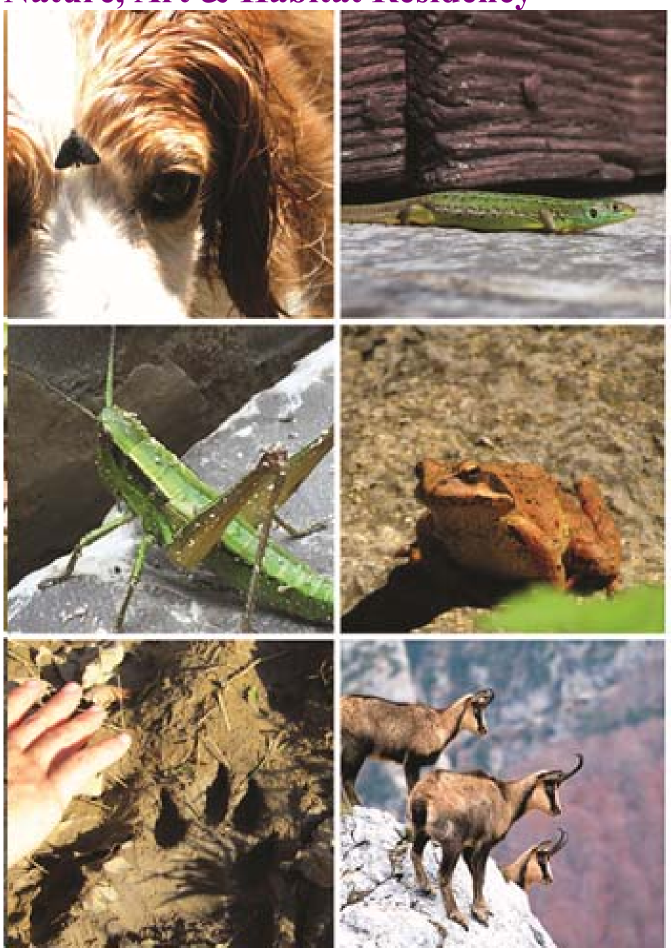
The invited oral presentations are given by world-leading scientists, young emerging researchers, as well as representatives of industry. The oral sessions, which allow all contributors to present their works, are intertwined by long poster sessions that facilitate discussions in a friendly atmosphere.

In addition, there is ample time for spontaneous meetings during breakfasts, coffee and lunch breaks, as well as during the organised social events, as all the participants stay in the same hotel. The cost for all the organised lunches and dinners are entirely included within the registration fees, which are also maintained competitively low by the non-for-profit organisation of this event.

Prototypes and products can be shown during the whole event by any attendee, at no cost.

This upcoming Conference will mark the 10th anniversary of this series, which will be celebrated combining a traditionally qualified scientific programme with a memorable social programme, at the UNESCO World Heritage natural and cultural environment (https://whc.unesco.org/en/list/1026).

Nature, Art & Habitat Residency



An open CALL to **Nature, Art & Habitat Residency (NAHR)** has been issued and it will be held at the ECO-Laboratory of Multidisciplinary Practice. This laboratory is located in the Taleggio Valley near Bergamo, Italy. This summer residency program is opened to professionals from various disciplines providing opportunities for research, discussions and advancing their work. NAHR's objective is to unfold and display a sensitive culture that responds to nature's needs and applications of nature's insights as a source of inspiration and measure of impacts on available resources. The ultimate goal of NAHR is to uncover intimate links between all living organisms in order to support development that is more resilient in successful coexistence of humans and nature.

At the 2020 TOPIC_Animals: Interdependence Between Species, NAHR will explore where and how species meet, and intersect, to co-create ecosystems in this post-human, post-anthropocentric era. The focus is specifically made on the place of animals in the contemporary ecological field.

Applicants are invited to stay at NAHR and develop a project based on their proposal that responds to the 2020 topic. During the months of June, July and August 2020, fellows will participate as residents at NAHR for a period between 2 and 6 weeks. For more details, please visit www.nahr.it

ADVANCES IN EAP

Aerospace Engineering-Propulsion/ MEMS

DEA Compressor to Create a Hybrid and Very Low Emission Distributed Propulsion

Babak Aryana, Independent Researcher/ Inventor
Babak.Aryana@Gmail.com

One of the most important specifications of a DEA compressor is its lower energy consumption compared to conventional compressors [1]. This exceptional characteristic makes engines using such a compressor be proper to create new configuration for distributed propulsion. **Figure 17** shows the specifications of a DEA compressor designed to operate in this engine, and **Figure 18** illustrates a table in which power produced by turbine section of a conceptual design of Pulse Detonation TurboDEA (PDTurboDEA) [2]. Obviously, turbine can produce much higher power than a compressor needs, when it uses very lean fuel that creates very low emission in different working condition **Figure 19**.

Stage Specification	Value
Λ	0.55
ψ	3.861⋱69
ϕ	0.692⋱308
ΔT_0 [K]	1237.⋱52
η_t	0.910⋱844
W_t [MW]	10.58⋱45
m_t [kg/s]	8.0696
B	5
η_m	0.99
γ_p	1.232

Figure 17: Turbine generates more than 10 megawatt power when compressor just needs less than 2 megawatt power to operate.

Item	Value
Number of actuators in a cell	36
Effective area of a tube [m^2]	0.000139457
Overall area of a tube [m^2]	0.000426669
Effective volume of a tube [m^3]	0.000278915
Total effective volume of tubes [m^3]	0.411678
Input air temperature [K]	288.976
Input air pressure [bar]	0.999637
Input air density [kg/m^3]	1.20531
Tubes number	1476
Middle duct radius [m]	0.25
Overall radius [m]	0.680749
Compressor Effective Area [m^2]	1.25953
Vessel pressure ratio	9.60342
Operating power [kW]	1990.67
Blocking Force of an Actuator [N]	8.67279
Total Blocking Force of Actuators [N]	1561.1
Pressure Applied by Actuators [Pa]	1.60295×10^7
Detonation Tube Initial Temperature [K]	884.442
Detonation Tube Initial Perssure [bar]	9.59993
Detonation Tubes Frequency [Hz]	48.7884
Real Air Mass Flow Rate [kg/s]	48.4176

Figure 18: DEA Compressor Specifications at Design Point

This high density power of turbine allows including few full electric propulsions supplied by turbine, which use DEA compressors. This configuration creates a distributed hybrid propulsion with considerably low emission that distributed high density thrust **Figure 20**.

Item	Value
Fuel	$C_{12}H_{23}$
Φ	0.3
f	0.02
f_b	0.0165686
EI_{NO_x} [$\frac{gm}{1000\ gm\ Fuel}$]	0.003639⋱98
Auto Ignition Time [ms . atm]	0.16964

Figure 19: PDTurboDEA uses very lean (equivalent ratio equal 0.3) fuel to produce least emission

Figure 20: in a modulized engine created based on DEA compressor, a compressor unit may be used to create a PDTurboDEA or a full electric thruster. Other components define how the thruster works when compressor can operate in different configurations.

References

[1] B. Aryana, "Implementing DEA to create a novel type of compressor," *Materials Science and Engineering C,* vol. 30, pp. 42-49, 2010.

[2] B. Aryana, "New version of DEA compressor for a novel hybrid gas turbine cycle: TurboDEA," *Energy,* vol. 111, pp. 676-690, 2016.

Brandenburg University of Tech. Cottbus, Germany

Conducting polymers in electrochemical chemotransistors: electrical affinity control and virtual sensor arrays

Yulia Efremenko and Vladimir M. Mirsky,
Nanobiotechnology, mirsky@b-tu.de

Most of sensor applications of conducting polymers are based on conductometric transducing. Different measurement configurations were suggested for this purpose [1]. The mostly sophisticated are 5- or 6-electrode configurations of electrochemical chemotransistor where 4 electrodes are used for the simultaneous 2- and 4-point conductivity measurements (s24 configuration [2]) while other electrodes control the redox state of the conducting polymer (**Figure 21**). These controlling electrodes may include only reference electrode or both reference and auxiliary electrodes. The s24-configuration provides continuous monitoring of sensor integrity. In some cases contact resistance can be used as an additional analytical signal while the delay between the kinetics of the contact- and bulk polymer resistance characterizes the rate of analyte diffusion and gives information on the analyte concentration [3]. Additional features are provided by electrical control of the redox state of chemosensitive material. If the sensor is working as redox sensor, external electrochemical control allows one to get a fast sensor recovery. For example, by this way the sensor recovery of polythiophen based NO_2 sensor was accelerated from many hours until a few seconds [4]. The fact that each redox state has independent affinity properties allows one to realize electrical control of affinity or to develop a concept of virtual sensor array consisting of only one chemosensitive element. Such a sensor was realized with chloride containing ionic liquid as a non-evaporable electrolyte connecting the formed on the gold film silver-chloride reference electrode and the deposited on the four gold strips layer of polyaniline serving as chemosensitive material [5]. Notably, this configuration allows one to perform electrochemical measurements (for example, cyclic voltammetry) in gases on in other non-conductive phases.

Experiments with trimethylamine vapor confirmed dependence of sensor affinity on the potential of controlling electrode. Biphasic kinetics of the sensor signal being measured at three different potentials corresponding to different redox states of the chemosensitive material allowed us to get nine almost orthogonal analytical parameters. Finally, this virtual sensor array was applied for analysis of fish freshness **(Figure 21**) [6].

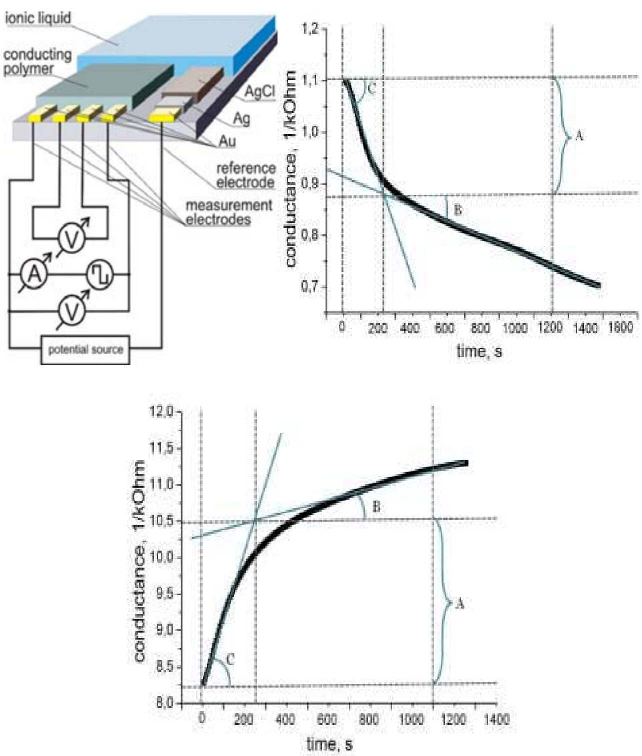


Figure 21: Design and wiring of the chemical sensor (electrochemical transistor) with electrical affinity control and examples of its response to the fish headspace at different redox states of chemosensitive material and storage time [6].

References:

1. U. Lange, V. M. Mirsky. Chemiresistors based on conducting polymers: A review on measurement techniques. *Anal. Chim. Acta*, 2011, 687 (2), 105–113.
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University of Bristol, UK

ElectroSkin: Soft skin-like robots you can put in your pocket

Jianglong Guo, Chaoqun Xiang, Andrew Conn, and Jonathan Rossiter, J.Guo@bristol.ac.uk

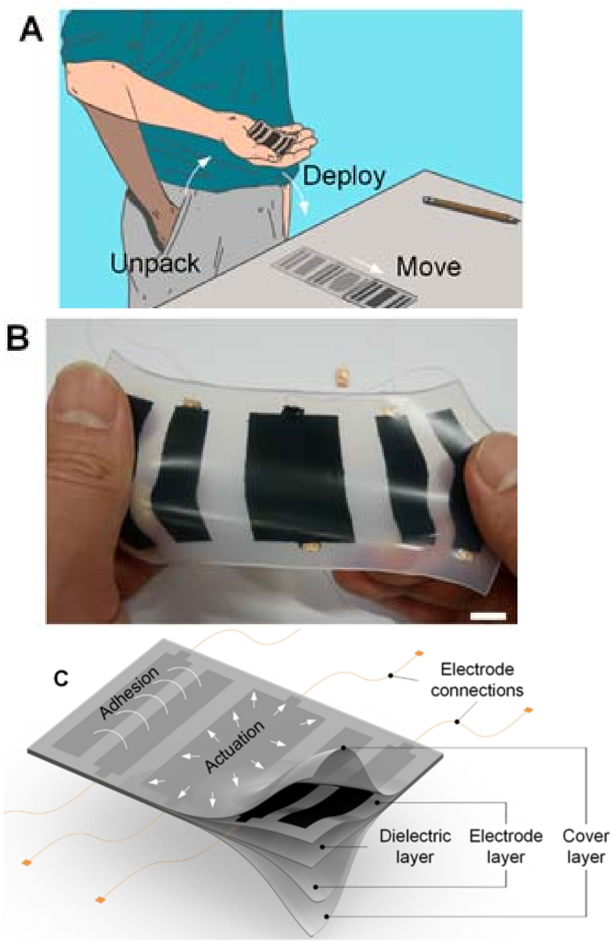
Traditional robots are rigid and incompliant, whereas soft robots are compliant and can stretch and twist to adapt to their environments. Until now, soft robots have separated their movement abilities from their capabilities to grip the surface they move on. Taking inspiration from biological skins and soft organisms like snails and slugs, researchers from the University of Bristol have successfully demonstrated a new robotic skin, ElectroSkin that crawls across a surface by alternately contracting embedded artificial muscles and gripping the surface using electrostatic adhesion. ElectroSkin is an active, stretchable, and portable artificial skin that combines dielectric elastomer actuators (DEAs) and soft electroadhesives (EAs) in a fully compliant multilayer composite skin-like structure. By taking advantage of the common characteristics of DEA and EA, regions of the composite artificial skin are defined as either active or passive. Active areas can be exploited as electromechanical actuators or as electrostatic gripper elements or both simultaneously. This embedded multimodality delivers a new technology of deformable active skins that can grip and move objects and self-locomote.

ElectroSkin robots can be scrunched up, put in one's pocket and then later pulled out and thrown on a surface where it moves. In the future, they could crawl up walls and across ceiling, explore difficult to reach environments including collapsed buildings, and be used in wearable second-skin devices. ElectroSkin is a new fundamental building block for a range of soft next generation robots, and is an important step toward soft robots that can be easily transported, deployed and even worn.

References

Jianglong Guo, Chaoqun Xiang, Andrew Conn, and Jonathan Rossiter, "All-soft skin-like structures for robotic locomotion and transportation", *Soft Robotics*, 15 November 2019

https://www.liebertpub.com/doi/10.1089/soro.2019.0059



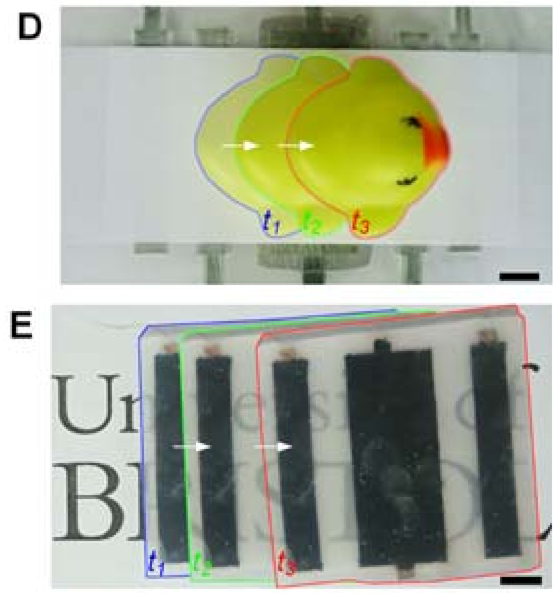


Figure 22: Active soft-smart structures with self-actuating, self-gripping and self-locomoting capabilities.

(A) Pocketable and deployable fully-soft crawling robot concept.

(B) A fully-soft ElectroSkin robot stretching in hand.

(C) Schematic diagram of the fundamental ElectroSkin design showing regions powered for electroadhesion and actuation.

(D) An ElectroSkin conveyor moving a yellow duck on a piece of office paper.

(E) A fully-soft ElectroSkin robot self-locomoting across a surface. Scale bars denote one centimeter.

University of California, Irvine (UCI)

Title: Cephalopod-Inspired Adaptive Infrared Materials and Systems

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Coleoid cephalopods (e.g., squid, octopuses, and cuttlefish) possess remarkable dynamic camouflage and signaling capabilities and thus constitute promising models for technologies that adaptively manipulate electromagnetic radiation. For instance, some squid can reversibly modulate their appearance and transparency due to their unique skin architecture, which encompasses bio-optical components called chromatophores and iridophores (**Figure 23 A and B**). Recently, our group has drawn inspiration from cephalopod skin for the engineering of adaptive infrared materials and systems that leverage deformable and electroactive polymers. In one example, we have developed a tunable thermoregulatory material that emulates the chromatophore-containing layers of squid skin.[1] For this material, mechanical actuation modifies the surface domain microstructure and thus dynamically changes the transmission/reflection of infrared radiation. Such functionality has enabled the application of this material in wearable systems that can regulate a user's body temperature (**Figure 23** C). Excitingly, our composite material can modulate its reflectance and transmittance by > 40 %, regulate a heat flux of ~ 36 W/m^2 with a power input of only ~ 3 W/m^2, and adjust the setpoint temperature over a window of ~ 8 °C. In another example, we have developed adaptive infrared-reflecting systems that emulate cephalopod chromatophores and iridophores.[2] For these systems, either mechanical or electrical actuation reconfigures the surface wrinkling and thus adaptively alters the diffusive/specular reflection (and absorption) of infrared radiation. Such functionality has afforded systems with arbitrary shapes that can effectively blend into different thermal environments (**Figure 23** D). Notably, our systems feature a simple actuation mechanism, tunable spectral range, weak angular dependence, fast response, amenability to patterning and multiplexing, autonomous operation, and stability to repeated cycling. Taken together, our work has underscored the possibilities afforded by the use of biomimetic principles for the design of artificial materials and systems that manage infrared radiation.

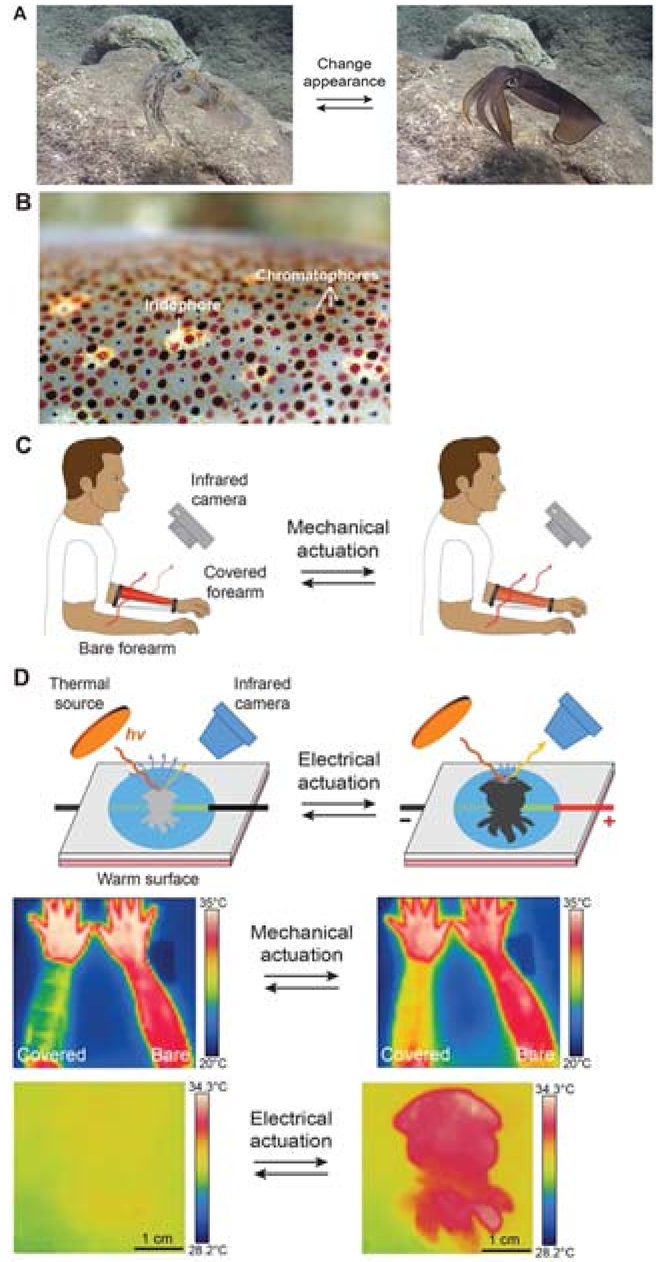

Figure 23: Cephalopod-inspired adaptive infrared materials and systems.
(A) Camera images of a squid changing its appearance in front of a rocky background.[2]
(B) An image of squid skin. The yellow, red, and brown circular regions are chromatophores, and the underlying bright iridescent regions are iridophores.[2]
(C) Schematics (top) and infrared camera images (bottom) of a human subject's forearm covered with a composite material-based sleeve before (left) and after (right) mechanical actuation.

Note that a bare right forearm is shown for comparison in each image.
(D) Schematics (top) and infrared camera images (bottom) of a squid-shaped, adaptive infrared-reflecting system before (left) and after (right) electrical actuation.

Note that the system was maintained under a constant thermal flux and positioned above a warm surface. [The images in (A) are reproduced from a video by H. Steenfeldt under the YouTube Creative Commons Attribution license, and the image in (B) was obtained by G. Hanlon and reproduced with permission of R. Hanlon.]

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University of Florence, Italy

Smart lenses that can electrically be reshaped to control astigmatism

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A joint team of researchers from the University of Florence, Queen Mary University of London and Imperial College, London, have developed new optical lenses that are entirely made of silicone and that can respond to an electrical stimulus, changing their shape, to vary their astigmatism [1].

In recent years, significant efforts have growingly been focused on the development of lenses with electrically tuneable focal length. They are intended to replace conventional glass-made lenses moved by motors for focussing, in systems that are limited by the complexity, size, weight and response time of this typical approach. Examples include video cameras in a broad diversity of products, including cell phones, medical diagnostic devices and flying drones, just to name a few.

Various strategies are being studied to address that need, using a diversity of physical principles and materials. However, studies have so far only considered the problem of controlling the focal length, but not the need for electrically tuning also other optical aberrations that can affect any lens, in the visible range.

In this work [1], the team has developed the first electrically tuneable silicone lens, whose shape can be modified by suitable voltages, to vary not only the focal length but also the astigmatism. The demonstrated fully elastomeric lens can be deformed with two degrees of freedom, using independent dielectric elastomer actuator segments (**Figure 24**).

The work opens up the possibility to electrical control even other optical aberrations, to implement versatile components for adaptive optics.

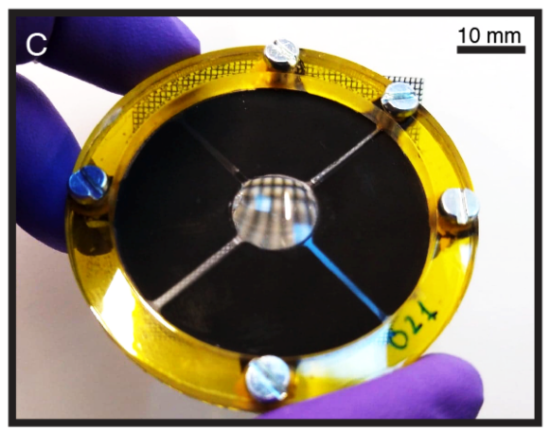

Figure 24: A prototype sample of the new lens with electrically tuneable focal length and astigmatism in the visible range (adapted from [1]).

Reference:

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University of Nevada, Las Vegas

Artificial Muscle Driven Soft Robotic Dorsal Fins

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The field of soft robotics is continually taking inspiration from biology, trying to utilize soft actuators to achieve the complex motions and structures found in the natural world. Some of the challenges researchers in the field face is fabricating the complex and intricate geometry of biological systems, as well as developing new soft actuators to use as artificial muscles. Great examples are found in the ample literature on biomimetic swimming robotics, which use soft actuators as fin structures for propulsion. While these systems are inspired by biology, they tend to lack the fidelity found in nature. Both the fabrication of the biomimetic structure and the use of artificial muscle to achieve the desired motion output are complex problems being investigated by researches from around the world.

This reported work introduces a new method for fabricating soft robotic systems, which retain the high fidelity found in nature. We leverage highly accurate CT scans and 3D printing technology to assemble a flexible hydrofoil based on the fin of the harbor porpoise whale. This fin is actuated using coiled polymer actuators (CPA), a rapidly emerging soft actuator, as an artificial muscle. The combination of this new design method and the coiled polymer actuators result in a highly accurate biomimetic fin capable of deforming in response to an external stimulus.

The methods developed give insight to a more general scientific framework under which virtually any biological or biologically engineered structure may be fabricated and used in other fields of research and development. This gives scientists and engineers a new avenue for designing and building novel biomimetic robotics that can uniquely perform and may even be used to manufacture highly accurate biological structures to be used in experimental studies and new and exciting research and development. For more information, visit:

1) https://www.advancedsciencenews.com/robotic-dorsal-fins-help-us-understand-aquatic-movement/
2) https://doi.org/10.1002/aisy.201900028
3) https://www.synopsys.com/simpleware/news-and-events/biomimicry.html

Figure 25: A soft robotic whale, being developed named "Lucille."

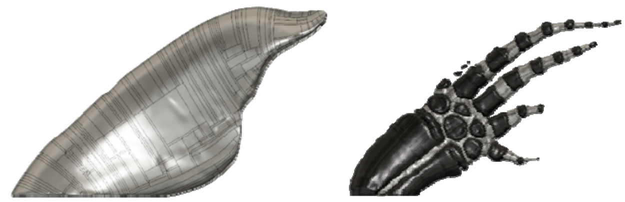


Figure 26: Soft tissue, bone and cartilage model imported into data process.

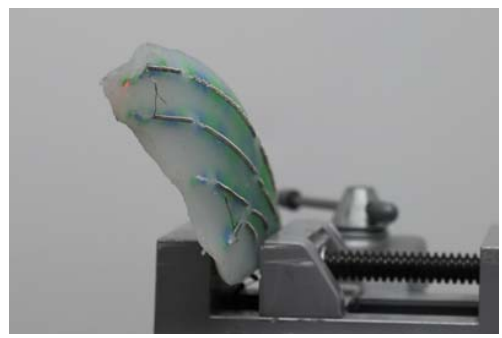


Figure 27: Fabricated artificial whale fin: a video can be found from supporting information at https://doi.org/10.1002/aisy.201900028

JOURNALS RELATED TO EAP & BIOMIMETICS

Bioinspiration & Biomimetics - Peer-reviewed journal publishing research that discovers and uses principles from natural systems to create physical models, engineering systems and technological designs. http://iopscience.iop.org/journal/1748-3190

Biomimetics - Peer-reviewed open access journal regarding biomimicry and bionics published quarterly online. https://www.mdpi.com/journal/biomimetics

International Journal of Smart and Nano Materials – Peer-reviewed open access journal publishing cutting-edge research into smart and nano materials and their applications, including energy harvesting, sensing, self-healing, and self-assembly. https://www.tandfonline.com/toc/tsnm20/current

Smart Materials and Structures – multi-disciplinary journal dedicated to technical advances in (and applications of) smart materials, systems and structures; including intelligent systems, sensing and actuation, adaptive structures, and active control. http://iopscience.iop.org/journal/0964-1726

Soft Robotics - Peer-reviewed journal covering research on the emerging technologies and developments of soft and deformable robots, including coverage of flexible electronics, materials science, computer science, and biomechanics. http://home.liebertpub.com/publications/soft-robotics/616

FUTURE CONFERENCES

Date	Conference/Symposium
April 26 - 30, 2020	The 2020 SPIE's EAPAD Conf. is going to be held again in Anaheim, CA. This Conf. will be the 21th annual one and is going to be chaired by Y. Bar-Cohen, JPL, and Co-chaired by I. A. Anderson, The Univ. of Auckland (New Zealand) and Herb Shea, Switzerland. The call for papers is posted at: http://www.spie.org/eap
May 24 - 29, 2020	The BIOTECHNO 2020, The 12th International Conference on Bioinformatics, Biocomputational Systems and Biotechnologies is going to be held at Venice, Italy. The call for papers is posted at: http://www.iaria.org/conferences2020/BIOTECHNO20.html and the submission website at: http://www.iaria.org/conferences2020/SubmitBIOTECHNO20.html
June 2-4, 2020	The EuroAP 2020, 10th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles will be held in Europe. It will take place in Val D'Orcia (Chianciano Terme), Tuscany. The call for papers is posted at: www.euroeap.eu/conference
June 20-23, 2020	The CIMTEC 2020, 9th Forum on New Materials will be held at Montecatini Terme, Italy.
June 25-26, 2020	The MDA 2020, 3rd International Conference on Materials Design and Applications 2020 will take place in Porto, Portugal. The call for papers is posted at: www.fe.up.pt/mda2020
October 12-14, 2020	The NICE-2020, an International Conference on Bioinspired & Biobased, Materials and Chemistry, will be held in the Negresco Palace located in the French Riviera You can find more information in the following website concerning this biennial conference is posted at: https://www.nice-conference.com

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

Recipes: 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

Armwrestling Challenge:

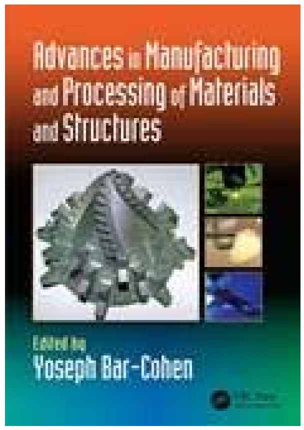
http://ndeaa.jpl.nasa.gov/nasa-nde/lommas/eap/EAP-armwrestling.htm

Books and Proceedings:

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

Advances in manufacturing and processing of materials and structures

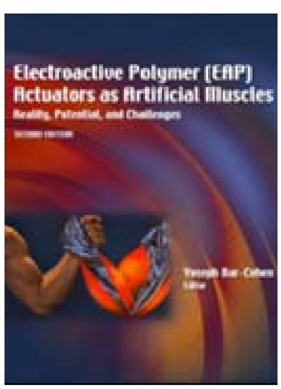
Y. Bar-Cohen (Editor)



The 10th book of this Newsletter Editor has been published by CRC Press on Oct. 2, 2018. This edited and coauthored book is entitled "*Advances in manufacturing and processing of materials and structures*" and it contains 544 pages [https://www.amazon.com/Advances-Manufacturing-Processing-Materials-Structures/dp/1138035955]. The book covers the latest advances in manufacturing and processing including additive and subtractive processes and it is intended to provide a compiled resource that reviews details of the advances. 3D printing is a key development that has been incorporated into this book covering its use to produce complex parts including composites with odd shape fibers as well as tissue and body organs.

2nd Edition of the book on EAP

Y. Bar-Cohen (Editor)



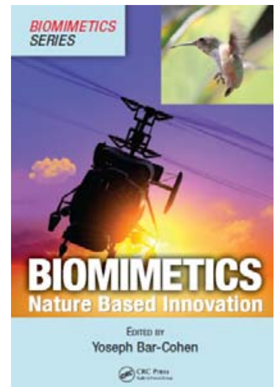
In March 2004, the 2nd edition of the "Electroactive Polymer (EAP) Actuators as Artificial Muscles - Reality, Potential and Challenges" was published.

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 heartwarming, where major milestones are continually being reported.

Biomimetics books series

Biomimetics – Nature Inspired Innovation

Yoseph Bar-Cohen (Editor)



This book contains 20 chapters covering various aspects of the field of biomimetics including Nature as a source for inspiration of innovation; Artificial Senses & Organs; Bio-mimicry at the Cell-Materials Interface; Multiscale modeling of plant cell wall architecture and tissue mechanics for biomimetic applications; Biomimetic composites; EAP actuators as artificial muscles; Refreshable Braille Displays Actuated by EAP; Biological Optics; Biomimicry of the Ultimate Optical Device: Biologically Inspired Design: a tool for interdisciplinary education Enhancing Innovation Through Biologically-Inspired Design; Self-reproducing machines and manufacturing processes; Biomimetic products; Biomimetics for medical implants; Application of biomimetics in the design of medical devices; Affective Robotics: Human Motion and Behavioral Inspiration for Safe Cooperation between Humans and Humanoid Assistive Robots; Humanlike robots - capabilities, potentials and challenges; Biomimetic swimmer inspired by the manta ray; Biomimetics and flying technology; The Biomimetic Process in Artistic Creation; and Biomimetics - Reality, Challenges, and Outlook. Further information is available at:
http://www.crcpress.com/product/isbn/9781439834763

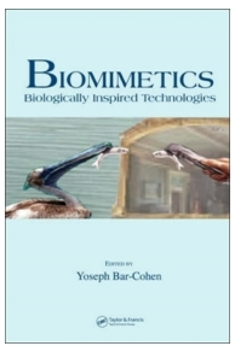
Architecture Follows Nature - Biomimetic Principles for Innovative Design

Authored by Ilaria Mazzoleni [***www.imstudio.us***](http://www.imstudio.us) *info@imstudio.us in collaboration with Shauna Price* http://www.crcpress.com/product/isbn/9781466506077

The book entitled "Architecture Follows Nature - Biomimetic Principles for Innovative Design" has been published by CRC Press as part of the book series on Biomimetics for which Y. Bar-Cohen is the editor. The homepage of this book series is: http://www.crcpress.com/browse/series/?series_id=2719

Biomimetics - Biologically Inspired Technologies

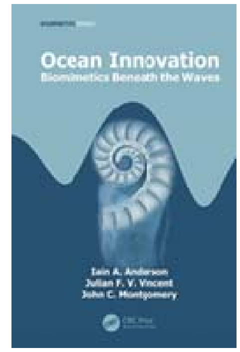
Y. Bar-Cohen (Editor)
http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi-books.htm



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

Ocean Innovation: Biomimetics Beneath the Waves

Authored by Iain A. Anderson *i.anderson@auckland.ac.nz, Julian Vincent, and John Montgomery*
https://www.crcpress.com/Ocean-Innovation-Biomimetics-Beneath-the-Waves/Anderson-Vincent-Montgomery/p/book/9781439837627



Generally, biomimetics is the idea of creating new technologies abstracted from what we find in biology. The book "Ocean Innovation: Biomimetics Beneath the Waves" seeks that technological inspiration from the rich biodiversity of marine organisms. Bringing both a biological and engineering perspective to the biomimetic potential of oceanic organisms, this richly illustrated book investigates questions such as:

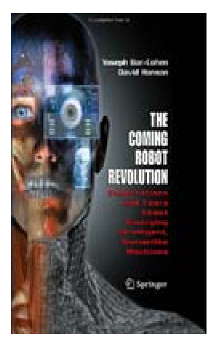
- How can we mimic the sensory systems of sea creatures like sharks, sea turtles, and lobsters to improve our ability to navigate underwater?
- What can we do to afford humans the opportunity to go unnoticed by marine life?
- How can we diffuse oxygen from water to enable deep diving without the risk of decompression sickness?

Each chapter explores an area where we, as divers and technologists, can benefit from understanding how animals survive in the sea, presenting case studies that demonstrate how natural solutions can be applied to mankind's engineering challenges.

Books about robotics

The Coming Robot Revolution - Expectations and Fears about Emerging Intelligent, Humanlike Machines

Yoseph, Bar-Cohen and David Hanson (with futuristic illustrations by Adi Marom), Springer, ISBN: 978-0-387-85348-2, (February 2009)

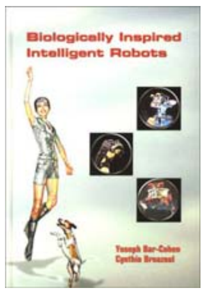


This book covers the emerging humanlike robots. Generally, in the last few years, there have been enormous advances in robot technology to which EAP can help greatly in making operate more lifelike. Increasingly, humanlike robots are developed for a wide variety of applications. These "smart" lifelike robots are designed to help with household chores, as office workers, to perform tasks in dangerous environments, and to assist in schools and hospitals. In other words, humanlike robots are coming and they may fundamentally change the way we live, even the way we view ourselves.

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.



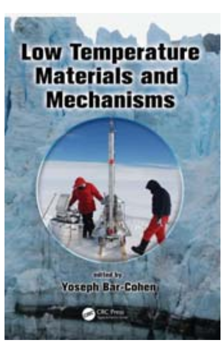
Other books

Low Temperature Materials and Mechanisms

Yoseph Bar-Cohen (Editor)

https://www.crcpress.com/Low-Temperature-Materials-and-Mechanisms/Bar-Cohen/p/book/9781498700382

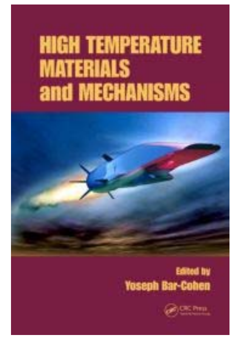
Published on July 1, 2016, this book addresses the growing interest in low temperature technologies. Since the subject of low temperature materials and mechanisms is multidisciplinary, the chapters reflect the broadest possible perspective of the field. Leading experts in the specific subject area address the various related science and engineering chemistry, material science, electrical engineering, mechanical engineering, metallurgy, and physics.



High Temperature Materials and Mechanisms

Yoseph Bar-Cohen (Editor)

http://www.crcpress.com/product/isbn/9781466566453



This book is addressing the growing interest in high-temperature technologies. This book covers technology related to energy, space, aerospace, electronics, metallurgy, and other areas. While some applications involve the use of materials at high temperatures, others require materials processed at high temperatures for use at room temperature.

Reflecting the multidisciplinary nature of the subject of high-temperature materials and mechanisms, the chapters bring as broad a perspective to the field as possible and are authored by leading experts in the specific subject. The book addresses the various related science and engineering disciplines, including chemistry, material science, electrical and mechanical engineering, metallurgy, and physics.

Happy New Year

WorldWide Electroactive Polymers (EAP) Newsletter

EDITOR: Yoseph Bar-Cohen, http://ndeaa.jpl.nasa.gov/nasa-nde/yosi/yosi.htm

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