References

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

EAP Activity in Italy

Interdepartmental Research Center "E. Piaggio"

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

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

FIGURE 7: Stimuli enabling mechanical responses of polyelectrolyte gels.

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

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

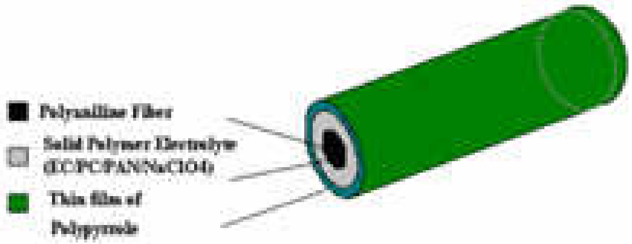

FIGURE 8: Scheme of a conducting polymer fiber actuator

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

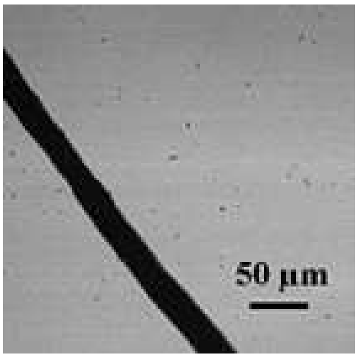

FIGURE 9: Photograph of a carbon nanotube fiber realized in our laboratory.

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

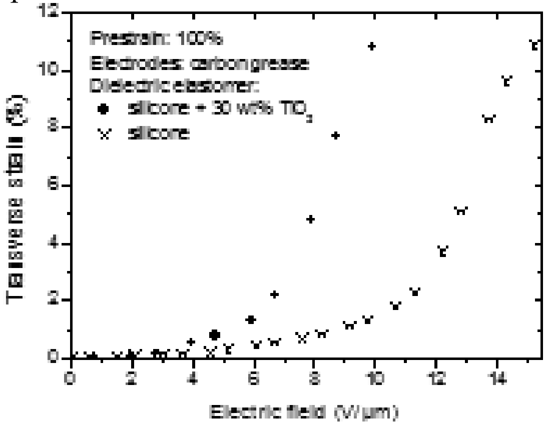

FIGURE 10: Strain-electric field curves of planar actuators made of a pure (crosses) and TiO_2-loaded (dots) silicone elastomer.

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

FIGURE 11: A new dielectric elastomer linear actuator.

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

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

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

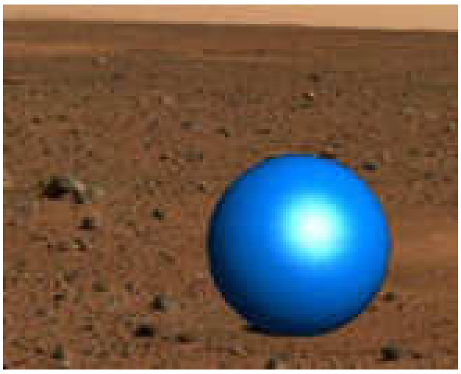

FIGURE 12: Drawing of a spherical elastic rover conceived for Mars exploration (adapted from [19]).

FIGURE 13: One model of FACE.

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

References

1. D. De Rossi, M. Suzuki, Y. Osada, P. Morasso, Journal of Intelligent Material Systems and Structures, vol. 3 (1992), pp. 75-95.
2. P. Chiarelli, A. Della Santa, D. De Rossi, A. Mazzoldi, Journal of Intelligent Material Systems and Structures, vol. 6, n°1, January (1995), pp. 32-37.
3. A. Della Santa, A. Mazzoldi, D. De Rossi, T. Gerlach , M. Kloepzig, ,Actuator 96 (Brema, Germania, Giugno 1996)
4. A. Mazzoldi, C. Degl'Innocenti, M. Michelucci, D. De Rossi, Materials Science & Technology C: Biomimetic Material, Sensors and Systems, v. 6 (1998), pp. 65-72
5. W. Rocchia, A. Mazzoldi, D. De Rossi, "Convenience of radial to longitudinal conversion in londucting polymer actuation", Advanced Materials, submitted.
6. A. Della Santa, A. Mazzoldi, C. Tonci, D. De Rossi, Materials Science & Technology C: Biomimetic Material, Sensors and Systems, v. 5 (1997), pp 101-109.
7. Della Santa, D. De Rossi, A. Mazzoldi, Smart Material and Structures, vol. 6 (1997), pp. 23-34.
8. R.H. Baughman, Changxing Cui, A.A. Zakhidov, Z. Iqbal, J.N. Barisci, G.M. Spinks, G.G. Wallace, A. Mazzoldi, D. De Rossi, A.G. Rinzler, O. Jaschinski, S. Roth, M. Kertesz, Science v. 284 (1999), pp. 1340-1344
9. G.M. Spinks, G.G. Wallace, L.S. Fifield, L.R. Dalton, A. Mazzoldi, D. De Rossi, I.I. Khayrullin, R.H. Baughman, Advanced Materials, vol 14, issue 23 (2002), 1728-1732.
10. E. Pelrine, R. D. Kornbluh and J. P. Joseph, Electrostriction of polymer dielectrics with compliant electrodes as a means of actuation, Sensors and Actuators A 64 (1998) 77-85.
11. R. Pelrine, R. Kornbluh, Q. Pei and J. Joseph, "High-speed electrically actuated elastomers with strain greater than 100%", Science, Vol. 287 (2000), pp. 836-839.
12. F. Carpi, D. De Rossi, "Improvement of electromechanical actuating performances of silicone dielectric elastomer by dispersion of titanium dioxide powder", IEEE Trans. Dielectrics and Elelectrical Insulation, submitted.
13. Q. Pei, R. Pelrine, S. Stanford, R. Kornbluh, M. Rosenthal, Electroelastomer rolls and their application for biomimetic walking robots, Synthetic Metals 135-136 (2003) 129-131.
14. F. Carpi, D. De Rossi, Dielectric elastomer cylindrical actuators: electromechanical modelling and experimental evaluation, Mater. Sci. Eng. C, vol. 24 (2004) pp. 555–562.
15. F. Carpi, D. De Rossi, "Attuatore elettromeccanico contrattile a polimero elettroattivo con elettrodi deformabili elicoidali", Italian Patent (2003), PI/2003/A/000043.

16. F. Carpi, D. De Rossi, "Electroactive polymer contractible actuator", PCT International Application (2004), PCT/IB2004/001868.
17. F. Carpi, D. De Rossi, "Theoretical description and fabrication of a new dielectric elastomer actuator showing linear contractions", Proc. of Actuator 2004, Bremen 14-16 June 2004, pp. 344-347.
18. F. Carpi, A. Migliore, G. Serra and D. De Rossi. Helical dielectric elastomer actuators. Smart Materials and Structures, submitted.
19. F. Carpi, Aldo Tralli, Danilo De Rossi and Paolo Gaudenzi, "Martian jumping rover equipped with electroactive polymer actuators: a preliminary study", IEEE Tran. On Aerospace and Electronic Systems, submitted.
20. Pioggia G., Ahluwalia A., Carpi F., Marchetti A., Ferro M., Rocchia W., De Rossi D., "FACE: Facial Automaton for Conveying Emotions", Applied Bionics and Biomechanics, 1(2), 2004.
21. Pioggia G., Ferro M., Kozlowski J., Marchetti A., Di Francesco F., Ahluwalia A., De Rossi D., "Automatic facial expression recognition by means of a neural approach", in Proceedings of the 2nd International Symposium on Measurement, Analysis and Modeling of Human Functions ISHF2004, Genova, Italy, 2004.

EAP Activity in Japan

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

Soft Actuators based on Conducting Polymers

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

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

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

"Self-organized" bending-beam actuator

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