Laboratory Introduction

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1. Introduction of AATC

The Advanced Automation Technology Center (AATC) of SRI International (SRI) focuses on the design, development, and transfer to its clients of advanced automation technologies. These technologies span a wide range of fields and include intelligent document understanding, 3-D machine vision, sensor placement, telerobotics, field robotics, and new transducer technologies such as artificial muscle. In the area of new transducer technologies, AATC works closely with other laboratories within SRI, sharing a wide range of facilities and equipment within SRI. These laboratories maintain state-of-the-art design, analysis, and fabrication facilities including special and general measurement and test equipment, an environmental chamber, a model shop, chemistry and spray fabrication facilities, and computer-aided design centers. AATC works closely with SRI's Physical Electronics Laboratory, which maintains clean rooms and other microfabrication facilities.

AATC has worked with a wide range of government and commercial clients in the US, Japan, and Europe. As a nonprofit institution, SRI transfers the technologies developed at AATC to the sponsoring commercial clients, or licenses them to manufacturing companies in the case of U.S. government-sponsored work.

AATC has worked on a wide range of robotic and transducer technologies. In the area of robotics, for example, AATC developed a laboratory prototype of a pipeline inspection robot. The pipeline robot used novel magnetic wheels that enabled it to travel on the walls and ceilings of 15-cm natural-gas pipes. Other research and development focuses on basic transducers; In addition to work on artificial muscle, AATC has developed novel levitated devices for applications such as sensors (flow meters, accelerometers, etc.), micromotors, and clean-room automation. AATC demonstrated what is believed to be the

world's first passive self-levitated (no bias forces) magnetic structure at room temperature. Another sensor area of interest to AATC is tonometry, a technique for measuring blood pressure unobtrusively and continuously. For a number of years AATC has developed tonometry technology, some of which is currently sold commercially.

2. Artificial Muscles

AATC has been investigating artificial muscles on the "Artificial Muscles in R&D of Micromachine Technology, industrial Sciences and Technology frontier Program" since 1992. The term artificial muscle, analogous to natural muscle, describes any actuator material that is substantially scale invariant in performance, where larger actuators can be considered as a collection of mechanically linked microactuators. For example, a single electromagnetic voice coil actuator is not an artificial muscle because it is not scale invariant (it has poor performance on small scales), and it is not a collection of mechanically linked microactuators. By contrast, a piezoelectric material has substantially scale-invariant performance, and a large, multilayer piezoelectric actuator consists of a collection of mechanically linked microactuators.

Our goal for the project is to identify and develop an artificial muscle with performance comparable to that of natural muscle. Such an artificial muscle would have overall performance greatly exceeding that of existing artificial actuators and could be used for small robots, inkjet printers, micro light scanners, micropumps, and a wide range of other microapplications. The artificial muscle would be particularly applicable to microdevices, for which existing actuator technologies are limited; but since it is scale invariant, it could also be used for a wide range of macro applications including robots, speakes, and motors.

The principle of operation of the electrostrictive polymers investigated by SRI is shown in Figure 1. Unlike other electrostrictive polymers (EPs), which work via molecular changes, SRI's EP materials work via bulk electrostatic forces (Maxwell stress). As shown in Figure 1, a relatively soft polymer is sandwiched between two compliant electrodes. When a voltage difference is applied between the compliant electrodes, the electrostatic forces squeeze and stretch the polymer, thus providing a mechanism for actuation.

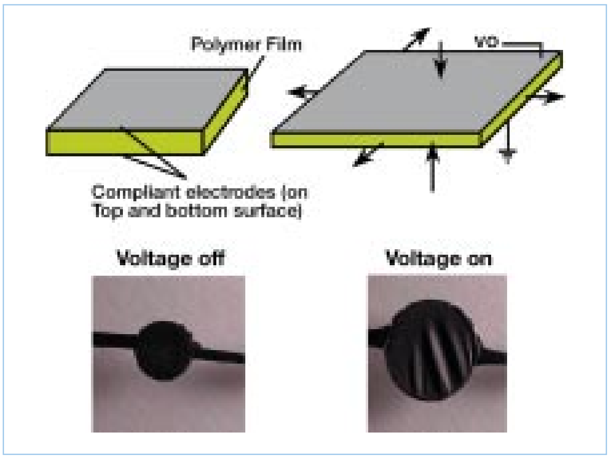

Fig. 1 Principle of Operation of Electrostrictive Polymers (Circular Black Areas in Bottom Photos are Active Electrode Areas).

Figure 2 shows a comparison between artificial muscle and other high-speed actuator technologies. Note that the performance of artificial muscle exceeds that of natural muscle.

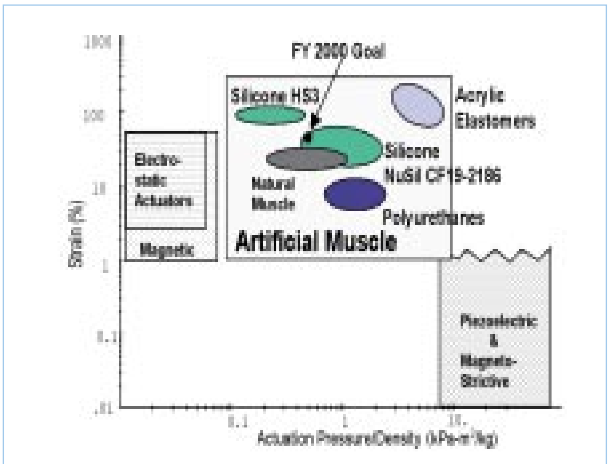

Fig. 2 Comparison Between High-Speed Actuator Technologies

Many polymer materials have been tested as artificial muscle. All insulating polymers show some response, Silicon and acrylic are dramatically better than others. Note that the strain of the acrylic elastomer can exceed 200%, and its energy density is higher than that of any known field-actuated material. The acrylic elastomer is a powerful material, but we note that silicone is faster, due to higher viscoelastic losses in acrylic. Silicones have a bandwidth greater than 1 kHz, while acrylic elastomers are currently limited to below 100 Hz. Research is now concentrating on ways to achieve the high strain and energy density performance of acrylics in operation at the speeds of silicones.

In addition to the polymer, SRI is investigating various electrode materials. Metals such as gold are typically too stiff and crack when actuated, but we have found that by suitable patterning they can elongate up to 80% while retaining their conductivity. For higher strains, particulate materials such as carbon black and carbon nanotubes in a binder generally work well.

We have developed a variety of ways to fabricate artificial muscle. Spin coating of polymers in solvents works well, and we have demonstrated muscle as thin as 1 µm. Thinner films reduce the operating voltage, which tends to be higher for electrostrictive polymer artificial muscle than it is for other electrostatically driven technologies.

We have designed and demonstrated a wide range of artificial muscle actuators. Examples include artificial muscle bimorphs and unimorphs capable of greater than 270 degrees of bending, artificial muscle diaphragms that can actuate from a flat to a hemispherical shape, and a range of simple linear actuators. Application-level devices, such as micro light scanners and minipumps, have also been demonstrated to show the wide applicability of the technology.

An interesting area for research and development has been the investigation of the unique actuation properties of artificial muscle and the design of actuators that can best exploit it. For example, uses a high prestrain in the polymer in one direction, together with a flexure design, to enhance actuation in the low prestrain direction.

3. Summary

Research on artificial muscles at SRI's AATC has reached an application phase. Strain, pressure, energy density, and response time performance parameters have increased by factors of 5-30 in the last 2 years. Technical progress continues in understanding the fundamental design of artificial muscles at the material, fabrication, and actuator levels. Thus, the near future of artificial muscle research at SRI's AATC will focus on both fundamental and application areas.