August 1999
AEROSPACE AMERICA

ENGINEERING

NOTEBOOK

NASA flexes its artificial muscles

When the MUSES-C mission spacecraft reaches the small near-Earth asteroid 4660 Nereus and begins its landing sequence sometime in 2003, it will drop a palm-size nanorover to the surface before touching down. This small NASA vehicle will view the surface with both a visual and an infrared camera. NASA scientists anticipate that, from time to time, dust will accumulate on the viewing window. To forestall viewing difficulties, they plan to install two tiny windshield wiper mechanisms Mounted on each side of the viewing window to wipe away the dust. Weighing less than 18 mg, each mechanism will have to rely on tiny artificial muscles about 13 mm long for movement. About 0.2 W of power applied to the muscles will cause them to contract or extend and move the wiper blades to clean off the window.

This tiny vehicle, called MUSES-CN (the N indicates it was built by NASA), will be the smallest rover ever to fly on a space mission. The diminutive robot has a mass of about I kg and carries instruments that observe in both the visual and near-infrared wavelengths. Its window wiper system will provide the first space test for artificial muscles. Success with these muscles could lead to space robots with animal-like flexibility and manipulation ability. The wiper blade, which is being built by Energy Science Laboratories (ESLI) in San Diego, Calif., is made of lightweight conductive material (aluminum and graphite) with a fiberglass microhair brush.

Finger-like function

The artificial muscles have been under development by Yoseph Bar Cohen of NASA-JPL for the past three years. They are based on a simple, lightweight strip of highly flexible plastic that bends and functions much like human fingers when electrical voltage is applied to it.

Bar Cohen and a small team of scientists and engineers in the U.S. and Japan are working to turn these strips into grippers and strings that can grab and lift loads, among many other potential uses. Known as artificial muscles or electroactive polymers (EAPs), these strips and strings could greatly simplify robotic spacecraft tasks.

Conceivably, these devices could replace damaged human muscles. "My hope is someday to see a handicapped person jogging to the grocery store using this technology, employing a joy stick to operate his leg," says Bar Cohen, leader of JPL's Nondestructive Evaluation and Advanced Actuator Technologies unit.

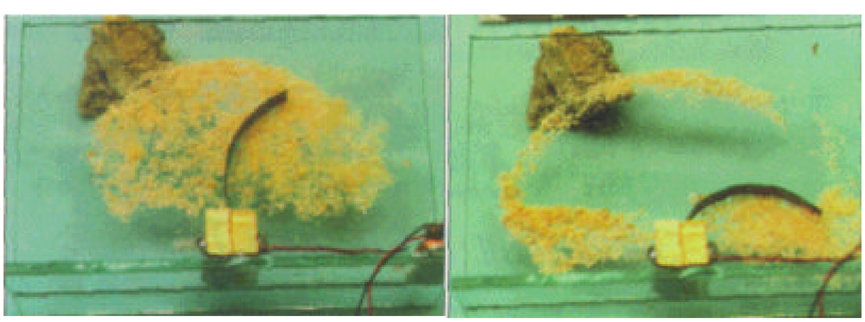
The MUSES-CN mission, led by the Japanese space agency, the Institute of Space and Astronomical Science, is designed to land the tiny rover on an asteroid following its 2002 launch and return a sample of the asteroid to Earth. "That's just the tip of the iceberg when it comes to space applications," adds Bar Cohen. "Electroactive polymers are changing the paradigm about tile complexity of robots. In the future, we see the potential for emulating the resilience and fracture tolerance of biological muscles, enabling us to build simple robots that dig and operate cooperatively like ants, soft-land like cats, or traverse long distances like a grasshopper."

Unlike human hands, which move by contracting and relaxing muscles, typical robotic arms use gears, hydraulics, and other expensive, heavy, power-hungry parts. In future planetary exploration missions, where robots will need to perform tasks such as collecting and manipulating samples of soil or ice, such mass and complexity become a problem.

To meet this challenge, Bar Cohen and his team have developed two types of artificial muscles that respond quickly to small amounts of electricity by lengthening or bending. The first is a flexible polymer ribbon made from chains of carbon, fluorine, and oxygen Molecules. When an electric charge flows through the ribbon, charged particles in the polymer get pushed or pulled on the ribbon's two sides, depending on the polarity. The net result: The ribbon bends. Using four such ribbons, Bar Cohen has fashioned a gripper that can pick up a rock.

The second consists of thin sheets wrapped into cigar-like cylinders that stretch when one side of a sheet receives a positive charge and the other a negative charge. These charges cause the wrapped sheet to contract toward the center of the

A dust wiper employs an ESLI-designed blade actuated by a bending EAP to remove dust from window.



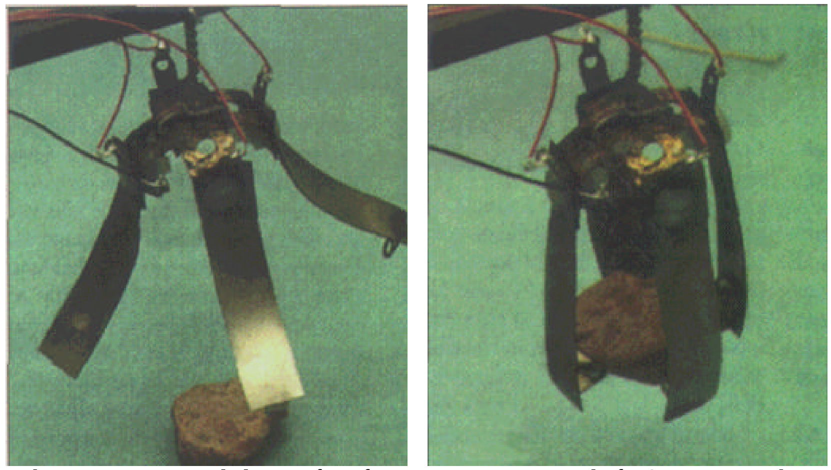
cylinder, and this constriction forces the cylinder to expand lengthwise. When the Power supply is turned off, the cylinder relaxes, enabling it to lift or drop loads.

For space applications, the researchers want to develop effective, lightweight, inexpensive actuators that use little power. In addition to the surface wiper, the group has developed a robotic arm (lifter and gripper) as well as a soil-removing rake.

The bending EAP actuator, which consists of perfluorinated ion exchange membrane metal composite (IPMC), has metallic electrodes deposited on the surface to a depth of 0-1 Pin from both sides. The IPMC actuator is based on a Processed Nafion film, mostly number 117 (a Dupont Product), which in its Processed form has a thickness Of 0.18 mm. These materials have been used as fuel cells and to produce hydrogen (hydrolysis) for many years. Their operation as actuators is the reverse process of the charge-storage mechanism.

Bar Cohen says that initially the researchers used platinum as the metallic electrodes mated with a liquid sodium cationic base. However, he notes that recently, in a cooperative Project with the Osaka National Research Institute, they got better results by using a gold coating and a liquid lithium cation-type bending EAP. He says the gold-coated actuator provides eight times better performance at a lower voltage. He also says that with the gold-coated actuator, electrolysis does not occur until 3 V are applied to the system.

He points out that electrolysis is a challenge that has to be overcome in using this material. With the platinum coated sodium actuators, the researchers find that electrolysis begins at 1 V. Since the EAP system needs 2-4 V to operate, they find that the heat at generated by electrolysis causes the protective coating to blister.



Robotic arm opens and closes a four-finger gripper composed of EAP actuators that can lift or drop objects.

Sealing in moisture

A protective coating for the artificial muscles is crucial. The muscles require moisture to operate. Without a skin-like coating, the material dries up after about 5 min and stops functioning. The material must be remoisturized before it can resume operations.

Bar Cohen Points out that even though he and his colleagues have developed a working prototype for the artificial muscles, his group continues to search for ways of optimizing the muscles and their coatings.

A recent coating introduced at NASA-Langley allowed the actuator to operate for about four months. The drive voltage ranged from I to 5 V at room temperature, The researchers kept the temperature as low as possible to avoid the side effect of electrolysis during activation. A test of the fatigue durability of the IPMC has shown that when immersed in water and exposed to 2 V and I Hz, the actuator would bend continuously without degradation for over I million cycles.

The fluorinated structure of the base Nafion film makes the application and adhesion of a coating to the IPMC difficult. To help solve this problem the researchers used a chemical etchant, Tetra-etch. They then exposed the etched surface to moist air, which enables adhesion. When they applied a low- modulus polysilicon coating (Dow Corning Dispersion Coating) to the surface of the etched IPMC electrode, they found improved adhesion compared to the untreated IPMC. This coating resists ozone, chemicals, moisture, ice, and ultraviolet radiation and handles temperatures up to 260 C while maintaining its performance and integrity.

Bar Cohen's group is also working with researchers at Virginia Tech on a technique to employ a self-assembled monolayer coating for the muscles, That type of coating consists of a single layer of molecules, which means it is very thin, yet can offer the same performance as a thicker layer.

The searchers have tested the operation of the muscles at -100 C and found that they worked well but required increased voltage to compensate for heat loss.

Spreading the word

Recently, research groups from around the world demonstrated their work on artificial muscles as part of a Society of Photo Optical Instrumentation Engineers' international Symposium on smart structures and materials. That meeting attracted far more people than anticipated, and the session had to be moved to a larger room.

Bar Cohen regards the difficulties of building artificial muscles as challenges rather than problems. He believes that communication with others in the field will advance the collective understanding of this technology. To help bring this about he maintains a web page at JPL with links to other researchers around the world [http:// ndeaa.jpl.nasa.gov].

He says he would like to set a challenge for researchers in this field: to build an artificial-muscled hand that could competitively arm-wrestle a human being. Achieving this, he believes, would be on a par with Deep Blue, the IBM computer that played chess so well.

***Edward* D. Flinn**
edflinn@pipoline.com