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Dr. Bar-Cohen is a physicist specializing in ultrasonic NDE and electroactive materials and mechanisms at NASA's Jet Propulsion Laboratory in Pasadena, CA. He established the Nondestructive Evaluation and Advance Actuators (NDEAA) Lab in 1991. Currently, he is developing electroactive polymer actuators - artificial muscles - for space-based and commercial medical applications.

NASA Tech Briefs: What types of technologies are developed at the NDEAA Lab, and how are they used by NASA and commercial industry?

Dr. Yoseph Bar-Cohen: The Non-Destructive Evaluation and Advanced Actuator (NDEAA) Lab is responsible for the development and implementation of innovative technologies. My team consists of Drs. Xiaoqi Bao, Zensheu Chang, Benjamin Dolgin, Stewart Sherrit, and Shyh-Shiuh Lih. We are also working with multidisciplinary leading experts in this country and overseas including Japan, Italy, and others. The focus is on phenomena that are associated with time-dependent mechanical displacements in the form of waves or vibrations induced by electroactive materials. We are seeking planetary applications and potential spinoffs to aerospace, medical, commercial, and others.

The NDEAA research and development thrust covers a broad range of topics and it was the result of our "getting out of the box" attitude and the JPL supportive environment. I established the NDEAA lab after joining JPL in May 1991, where initially the focus was the development of NDE methods that are based on two phenomena, leaky Lamb wave and polar backscattering, which I discovered. This initial effort was done jointly with Prof. Ajit Mal from UCLA. With time, we added to our "sandbox" research tasks that involve the development of mechanisms and devices that are driven by electroactive materials. With this growth we also broadened our cooperation efforts, which were enhanced by extensive involvement with technical societies, chairing and cochairing conferences, websites, newsletters, etc.

Currently, we are developing an ultrasonic drill, motor and pump, electroactive polymers (EAP) as artificial muscles, NDE and geophysical test methods, medical treatment and diagnostics methods, and the multifunction automated crawling system (MACS). We are covering the broad frequency range from several Hertz to several hundreds of megahertz with power levels from micro-watts to several hundred watts. In the low-frequency, high-power domain, we have the geophysical probing and the ultrasonic drill, the so-called Ultrasonic/Sonic Drill/Corer (USDC), which we developed with Cybersonics. Also, we are developing a piezopump and ultrasonic motor, as well as devices such as MACS that are using these actuators.

Our research in the area of EAP and the lead role that I played made NDEAA one of the world's leading labs in this field. Some of the unique devices that we developed include a dust wiper and a gripper that excited the imagination of many with regards to the potential of these materials. To promote the field of EAP, I posed a challenge to develop a robotic arm driven by these materials to arm wrestle with human and win.

In the high-frequency and high-power domain, we are exploring medical treatment methodologies jointly with the UCLA Medical Center, under the lead of Dr. Michael Kabo and Jeffrey Wang, M.D. Our NDE effort is under the high-frequency, low-power regime, where besides exploring science and applications for the two ultrasonic phenomena that I discovered, we are also involved with the development of an acoustic microscope on an endoscope. This device, which is operated at 200 MHz, is intended to view variations in the elastic properties of cells in the esophagus, which was a subject of an STTR task from NIH. The research was conducted jointly with QMI and Penn State University under the lead of Premindra Chandraratna, M.D., from UCI. The inventions that resulted from our innovation are covered by many New Technology Reports and patents, and were described in various issues of NASA Tech Briefs.

NTB: You've been involved in the development of piezoelectric motors and pumps, an ultrasonic drill, and geophysical probing techniques. Have any of these innovations been spun-off by NASA for commercial industrial use, or are they currently being used in space-related applications?

Dr. Bar-Cohen: We are continually seeking avenues to commercialize our technologies (e.g., USDC, ultrasonic motor, piezopump, MACS, and electroactive polymers), both through our own initiatives and in response to inquiries. The ultrasonic drill, which we are developing jointly with Cybersonics, is already being produced commercially by our partner. This drill is capable of drilling with low power and low pressure on the bit, drilling rocks as hard as basalt and granite. It does not require sharpening and it extracts the produced powder via an ultrasonic transport mechanism up the drilling bit. Its unique capabilities and robustness are making it highly attractive. This drill, the USDC, has been getting a lot of visibility as a result of NASA/JPL press releases and various publications. R&D Magazine awarded this drill as one of the 100 most innovative instruments for the year 2000. Currently, we are pursuing several space-related applications including a deep drill unit, the so-called Ultrasonic Gopher, which may reach several meters deep. We developed an ultrasonic rock abrasion tool (URAT) as a flight-like unit for a backup device to the Mars 2003 mission. We also have other exciting technologies with great potential, including our Piezopump that can be used as beeper-size peristaltic system to inject multiple types and doses of medications in real time as determined for specific patients.

NTB: How has NASA's work in magnetorheological (MR) materials played a role in your work in artificial muscles and simulated tissue?

Dr. Bar-Cohen: We are not working with magnetorheological (MR) fluids, but with electrorheological fluids (ERF). In principle, the response of MRF and ERF appears the same where the viscosity of the fluid increases as a function of the activation field level (magnetic or electric). The activation induces polarization in the particles that are suspended in oil and they form chains along the field lines. Since polymeric liquids are used as a suspension medium and since ERF are involved with the equivalent to change in stiffness, they are considered as part of the family of electroactive polymers so-called artificial muscles.

NTB: What is the MEMICA program?

Dr. Bar-Cohen: MEMICA is the initials for a haptic system of Remote MEchanical MIrroring using Controlled stiffness and Actuators (MEMICA) that we are developing jointly with Prof. Mavroidis from Rutgers University. MEMICA was conceived with the objective to provide teleoperators with an intuitive feel of objects that are being remotely manipulated. MEMICA is being developed to enable critical capabilities in support of human operation in space, potentially augmenting astronaut activity, providing countermeasures for zero-gravity, and establishing medical training simulators.

In its inactive mode, the actuator does not produce counter forces and thus, the user can disable the operation making it unperceived until needed. The key element of this system is the ECFS (Electrically Controlled Force and Stiffness) actuator that is based on a hybrid combination of Electro-Rheological Fluids (ERF) and electromagnetic actuation concepts. We are currently modeling, designing, constructing, and testing the actuator and we are seeking to produce a demonstration glove with ECFS actuators mounted on the various joints. The glove is being designed to induce both forces and controlled stiffness in order to provide the "feel" of remote or virtual mechanical conditions.

NTB: What are the real-world medical applications for telepresence and "virtual surgery"?

Dr. Bar-Cohen: MEMICA offers various potential applications both as a telepresence system using a surrogate robot (e.g., Robonaut type) or virtual reality. This technology is expected to have many spinoffs to terrestrial applications including medical, military, sport, training, entertainment, etc. For space, we are envisioning such applications as:

- Remote operation of Robots - Johnson Space Center's Robonaut is designed for telepresence control and it is intended to support remote tasks where it is operated as a surrogate robot. It is able to maneuver through areas too small for the current Space Station robots. The Robonaut is designed as an anthropomorphic robot, similar in size to a suited EVA (external vehicular activity) astronaut, and it is designed for mounting on a robotic arm that is capable of dexterous, human-like maneuvers to ensure safety and mission success. Robonaut was designed so that a human operator who is wearing a suit/gloves with sensors can control it. Unfortunately, due to unavailability of force and tactile feedback capability, the operator determines the required action by visual feedback; i.e. observing the Robonaut action at the remote site. This approach is very limiting, especially when handling fragile and small articles. A MEMICA system offers the necessary haptic interface, potentially allowing the operator to "feel" the mechanical conditions at the Robonaut site.

- EVA -Increasingly, astronauts are required to operate outside the Space Shuttle or the Space Station. This EVA is dangerous, stressful, tiresome, and often tedious, particularly when conducting delicate operations. Astronauts' suits are used to protect the operator from vacuum and temperatures of space, but they are not sufficiently compliant, causing great fatigue to the operators. MEMICA offers the capability to produce a powered suit that amplifies the physical activity of astronauts, making their activity less strenuous, thus reducing fatigue and operator errors.

- Zero Gravity Countermeasures - Extended human operation in space involves loss of muscles and bones. To minimize this space effect, an exoskeleton suit can be designed to allow astronauts to experience reaction forces at the level and orientation as would be expected on earth.

- Simulated medical procedures and guided medical operations - The ability to simulate an operation using virtual reality is critical to many technology areas. The capability to train medical staff or remotely guide the operation of the staff can benefit sites that are lacking local medical-care facilities or specialized medical staff. Patients, in such places as the South Pole, may have a teleoperated surgery performed by leading experts from remote facilities using on-site emergency equipment.

Besides helping distant and rural areas, as well as the military in battlefields, "telesurgery" can benefit future NASA missions. Manned missions are being pushed to new frontiers at growing distances from Earth and are expected to last years. A major obstacle may arise as a result of the unavailability of on-board experienced medical staff. MEMICA would offer mission personnel the ability to practice required urgent care procedures as they arise using virtual reality as well as remote guidance (taking time delay into account). With the aid of all-in-one-type surgical tools, astronaut(s) with medical backgrounds would be able to perform various urgent care procedures as they develop. The specific procedures will be updated by downloading from Earth the latest software onto the spacecraft's simulation system.

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