Smart as a Brick

Scientists strive to make inanimate objects smart

By IVAN AMATO

> *. . . here is also the virgin plant, which they terme the sensible tree, which after the least touch of one's hand I see fall down withered, and then againe revived after a little space.*
>
> — Father Andrew White (1579-1656), while on the West Indies island of St. Kitts (*Briefe Relation*, 1634)

With its broadcasts of sweet perfume and floral explosions of needle-like petals, *Mimosa pudica* has enchanted countless travelers. Yet in describing the plant, 17th-century Jesuit priest Andrew White referred not to its allure but to its "sensibility" — a word that now carries a curious double meaning.

The fly-sized leaves of *Mimosa pudica* flank stems called secondary petioles, which spring from a larger central petiole to form symmetrical, fan-shaped arrangements. Upon the slightest touch, the leaflets instantly move upward until they meet like dozens of praying hands. After about 15 minutes of "prayer," the plant regains its fullness.

Scientists suspect this remarkable behavior evolved to discourage insects from staying for dinner: No sooner does a hungry bug land on the plant than the leaflets fold up, either dropping the intruder Earthward or sending it fleeing in entomological terror.

Thus, the sensible tree lives up to both aspects of its name. In White's day, "sensibility" meant sensitivity; in modern usage, the term refers more to "good sense."

But would you say these plants are . . . well . . . *smart?*

Engineer and materials scientist Craig A. Rogers would. Indeed, using sensitive and responsive materials, he and others are now working to create inanimate objects with the same sensible combination of qualities, and they describe those objects as "smart." With an eye to the future, this emerging community of physicists, chemists, materials scientists, aerospace researchers and sundry others envision a day when inanimate materials and structures will become . . . well . . . intelligent — and perhaps even gain the capacity to . . . dare one suggest it? . . . evolve.

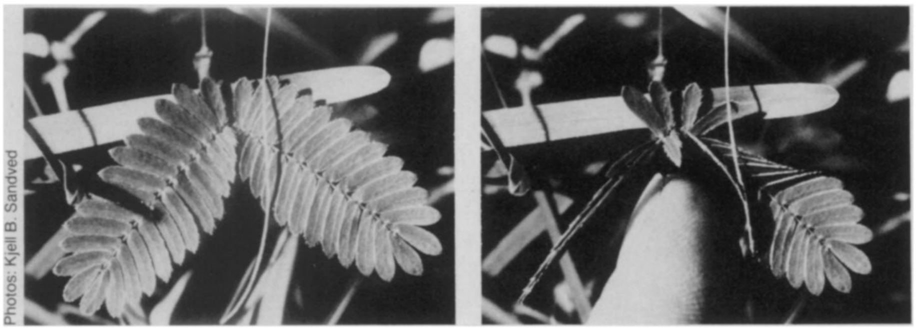
"The real idea of this whole concept is to mimic biological organisms," says Rogers, of Virginia Polytechnic Institute and State University (Virginia Tech) in Blacksburg. Barely a decade old, the concept he refers to goes by a variety of names, including smart materials, adaptive structures and intelligent systems. Perhaps the term that ultimately catches on will come from the title of the newly launched publication devoted to the field: Journal of Intelligent Material Systems and Structures.

By any name, this emerging, multidisciplinary endeavor involves using available materials and developing new ones to assemble structures that sense internal and environmental conditions and, when necessary, self-adjust to changes in those conditions.

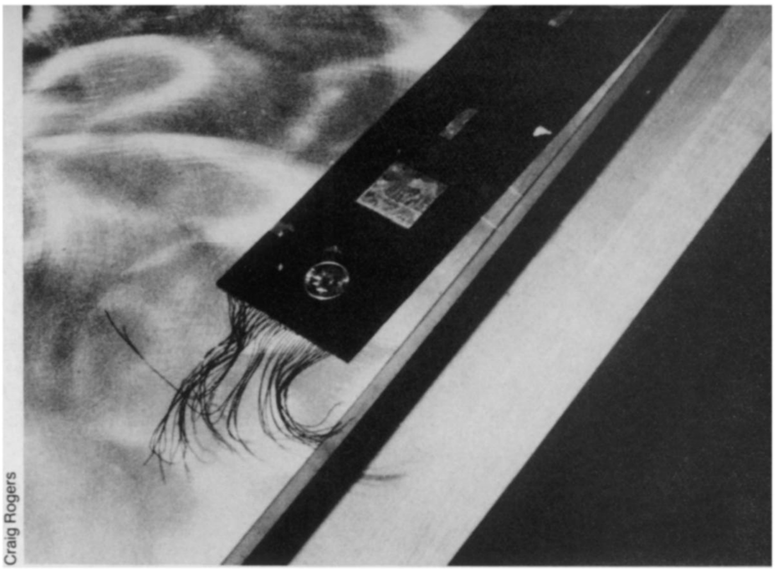
Smart structures now in the works — including space platforms, airplane skins and medical devices — combine three types of components. Traditional materials such as metals and ceramics, as well as more advanced polymers and composites, form the framework, or skeleton. Materials tailor-made to sense and monitor changes in temperature, pressure, acidity and other chemical and physical conditions take on a role resembling that of a nervous system. And components called actuators, which expand, contract, emit light, secrete chemicals or act in some other predictable manner, serve as the response systems.

In more advanced designs, researchers envision smart beams and other framework parts doing double duty as the sensing and actuating materials. To enhance the intelligence quotient, signals from sensors could feed into microprocessors, which would interpret them and relay instructions to the actuators. With neural network processors, some visionary researchers hope to develop materials that learn how to respond and adapt to conditions that change on time scales ranging from fractions of seconds to years. Some foresee structures that even evolve, reconfigure themselves or

Within a tenth of a second of being touched, outstretched leaflets of Mimosa pudica, *also called the sensitive plant, close together.*


Photos: Kjell B. Sandved

Researchers hope to smarten up structural beams by endowing them with an internal 'musculature' for actively controlling the beam's stiffness, vibrational and sound-dampening characteristics. In the prototype shown at right, filaments of a shape-memory nickel-titanium alloy can be seen coming out of the edge of a laminated strip of graphite-epoxy composite material.



Craig Rogers

grow in response to changing demands, much as bone increases its mass when routinely subjected to heavy loads.

"You could imagine making an aircraft or some sort of vehicle that reconfigures itself in response to the type of loading it might get," muses Theodore G. Duclos of the Lord Corp. in Cary, N.C., an international technology-development firm. Duclos says he expects nearer-term payoffs with so-called electrorheological (ER) fluids, which, in the presence of certain electric fields, rapidly metamorphose from free-flowing liquids to rigid pseudo-solids. A hollow beam filled with ER fluid and fitted with load-monitoring sensors could respond to changes in load by changing, say, its stiffness and vibrational frequencies. Smart shock absorbers, Duclos suggests, would have motion and force sensors for monitoring the ruggedness of the underlying terrain and a computer-controlled, ER-fluid interior for adjusting their damping strength to match the terrain.

Other scientists, primarily in the United States and Japan, are actively developing their own smart materials and intelligent structures, and are hoping to unleash some of them as early as this decade.

- Materials scientist Robert E. Newnham and his colleagues at Pennsylvania State University, University Park, are making the first generation of smart bricks. "We are developing a family of electroceramic components, which sense pressure or chemical changes in the environment and then make a motion, change color or exude a chemical," Newnham told SCIENCE NEWS. "They're like the human body in the sense that our eyes and our ears sense some change in our environment, and then we do something with our legs or our arms to respond to it."
- Researchers with NASA, McDonnell Douglas Corp. and other aerospace companies as well as several universities have been working toward smartening the composite skins of aircraft with embedded nerve-like networks of optical fibers that can keep track of temperature, stresses, strains and cracking, and can thus help determine the likelihood of potentially catastrophic material failure. According to Richard O. Claus of Virginia Tech, implanting the fibers during the manufacture of the composite materials should enable engineers to monitor the health of the skins from cradle to grave — as the materials cure, as they become airplane parts and throughout their service lifetime. In another smart-skins effort, researchers in Italy and the United States are developing texture-sensing "fingertips" that could enable robots to distinguish different surfaces.
- Rogers and his colleagues at Virginia Tech embed so-called shape-memory alloys — metals that return to a former shape when heated through a transition temperature — into composite materials. As the temperature changes and the imprisoned alloys try to resume their earlier shape, the surrounding composite resists the internal movements. In turn, this resistance changes mechanical properties of the composite, such as its stiffness and the frequencies at which it can vibrate.
- FlexMedics Corp. in Minneapolis already markets dental arches (used in braces) made of the most common shape-memory metal, a nickel-titanium alloy called Nitinol. These arches urge teeth into position with a gentler and more constant force than normal steel arches and with only one-third of the uncomfortable periodic adjustments usually required with normal steel arches, according to a company spokesman. Unlike steel, the Nitinol wire applies constant stress even as the teeth shift over time.
- Researchers at the Massachusetts Institute of Technology, NASA's Langley Research Center in Hampton, Va., the Jet Propulsion Laboratory in Pasadena, Calif., and elsewhere have set their sights on adaptive space structures that would serve as skeletons for large, precisely adjustable antennae or as platforms for sensitive instruments. By including, say, piezoelectric materials (which expand or contract in the presence of electric fields) or so-called magnetostrictive materials (which respond similarly but to magnetic fields), they hope to build autonomous space structures that can reconfigure themselves in response to factors such as age, wear or even the continuous thermal cycle of countless orbital treks in and out of sunlight.
- Scientists working in government, industry and university laboratories are developing strategies for actively controlling vibrations and noise in robotic systems, space platforms and machinery. Robots designed to carry out repetitive, high-precision motions, for example, are limited in productivity by the vibrations that result when an arm comes to a halt after moving rapidly. Vibration control — using smart ceramics that both sense the vibration and respond with their own vibration-damping motions — could reduce the amount of time a robotic system would have to wait between successive movements. The U.S. Navy has expressed interest in using similar approaches to making submarines even more sonar-stealthy. "As pressure [sound] waves come and hit the rigid body, you get a reflection," explains space structures engineer Benjamin Wada of the Jet Propulsion Lab. "If the pressure wave comes and hits a structure, which complies and moves, then there wouldn't be much of a reflection and it becomes a stealth structure."

"We think this [building smart structures] will be the stream of things in

Continued on p. 155

researchers to investigate the value of inducing lowered body temperatures in patients who have just suffered a heart attack or stroke. For years, surgeons performing operations that may temporarily limit oxygen supplies to the brain have reduced the risk of surgery-related brain damage by chilling patients in advance – generally by placing them in a cooled room and by infusing them with chilled intravenous fluids. And reports of children who have remained submerged in near-freezing water for prolonged periods without apparent brain damage indicate that low brain temperatures during oxygen deprivation can also protect brain neurons. Their new work, Buchan and Pulsinelli say, now clearly indicates that hypothermia of even a few degrees, soon after a loss of oxygen, can have an equally impressive neuroprotective effect.

Given those findings, Pulsinelli and others maintain that a degree of refrigeration might prove useful as an emergency therapy in victims of heart attacks or strokes. But for now, physicians note, hospitals are not prepared to induce hypothermia on an emergency basis.

"The question is, can you do it quickly enough?" says Buchan, now at the University Hospital in London, Ontario. He and others wonder whether any kind of drug can safely lower core temperatures with sufficient rapidity in human beings, whose body masses are substantially greater than those of any animals currently under such investigation.

Along with the challenge of dropping body temperatures quickly, researchers have yet to determine just how cold is cold enough. European researchers, who have reported successfully preventing brain damage in oxygen-deprived newborns by dunking them in chilled water for up to 15 minutes, have noted that longer exposures to temperatures below 29°C may prove detrimental. Similarly, while some early attempts to chill heart attack victims to 25°C effectively rescued brain neurons, Buchan says the treatment wreaked metabolic havoc elsewhere in the body. Among other things, the very low temperatures triggered coagulation problems and cardiac arrhythmias.

Recently, researchers have suggested cooling such patients to a more moderate 33°C. But ideally, Buchan says, physicians would like to cool the brain to these temperatures without having to chill the rest of the body – thus avoiding the various metabolic side-effects of hypothermia, including the adrenalin release that comes with intense shivering.

Buchan says one approach would be to inject cold saline directly into some of the cavities, or sinuses, in the brain. But so far, he says, no one has tested the approach in a clinical trial. □

Continued from p. 153

the future," says Iqbal Ahmad of the Army Research Office in Research Triangle Park, N.C. Adds Rogers: "I see the intelligent materials systems effort as the logical evolution of materials development in general." They and others note that a sense of community is beginning to emerge among the various scientists who have worked independently on such projects during the past 10 years.

The first major gathering of these like-minded investigators took place in the fall of September 1988 at Virginia Tech. Last March, a similar gathering occurred in Tsukuba, Japan. Researchers from the United States, Japan and Europe plan at least two more – in Hawaii and Japan – for this year. In addition, says Rogers, the organizers of as many as 20 other research conferences plan special sessions this year on smart materials and structures.

Thus a new research specialty is born. And as members of the community chalk up successes, financial support grows. In fiscal year 1989, for instance, the Army Research Office launched a three-year smart materials initiative with a budget of nearly $1 million per year. Other Defense Department research agencies have started similar programs with funding totaling more than $10 million. One researcher estimates that U.S. universities, aerospace and defense contractors, and government agencies such as NASA and the Defense Department will spend additional tens of millions of dollars this year alone on research into smart materials and structures. And when the researchers evolve a standard name for their specialty – a consensus that seems fairly imminent – funding agencies will finally have a label for the projects, which so far have been financed under the auspices of a variety of seemingly unrelated disciplines. Just having a label can mean a lot in terms of funding, Rogers says.

Although decidedly optimistic about his field's potential, Rogers cautions that terms such as "intelligent materials" tend to inspire unrealistic expectations. "We have a new and exciting concept," he says. But any talk of near-term applications to novelty items such as smart golf clubs with variable stiffness, could prematurely focus the curiosity-driven research and development necessary for the field to advance most effectively and for the benefit of the most people. "There are some snake-oil salesmen out there," he warns.

Rogers, Claus and others say U.S. researchers have an additional worry: the possibility of Japanese domination at the cutting edge of the new field. In the United States, investigations into intelligent materials and structures focus primarily on assembling smart systems using existing materials, such as shape-memory alloys and piezoelectric ceramics and polymers, as the actuators and sensors. But Japanese researchers are looking toward brand-new materials.

"We need a closet full of new sensor and actuator materials, and we don't seem to have the materials science people motivated enough [to invent them]," says Rogers. Japanese materials scientists are making significant advances, including building an artificial muscle fiber out of a novel polymer that contracts to about one-fourth its relaxed length, he says.

Claus of Virginia Tech voices the same concern: "Unless big changes happen in this country, I would expect that we'll see most of the technology developed offshore and shipped in."

No matter who capitalizes on smart materials and structures, the world is in for a change, predicts materials researcher Mukesh V. Gandhi of Michigan State University in East Lansing. As the technological innovations reach industries ranging from aerospace engineering to medicine to building construction, he says, "all aspects of our lives will be significantly touched." □