**Smart Dust**

**Airborne Smart Dust Sees & Hears & Reports**

**Ultimate Spy**
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Department of Electrical Engineering and Computer Sciences

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If Kristofer Pister has his way, we will never think about dust in quite the same way again. Pister is leading a team of researchers at the University of California at Berkeley that is developing tiny, electronic devices called "smart dust," designed to capture mountains of information about their surroundings while literally floating on air.

If the project is successful, clouds of smart dust could one day be used in an astonishing array of applications, from following enemy troop movements and hunting Scud missiles to detecting toxic chemicals in the environment and monitoring weather patterns around the globe.

The idea behind smart dust is to pack sophisticated sensors, tiny computers and wireless communicators onto minuscule "motes" of silicon light enough to remain suspended in air for hours at a time. As the motes drift on the wind, they can monitor the environment for light, sound, temperature, chemical composition and a wide range of other information, and beam that data back to a base station miles away.

Pister, an associate professor of electrical engineering and computer science at UC Berkeley, said he came up with the idea for smart dust eight years ago at a conference on future technology. "I realized that sensors, computers and communications were going to shrink down to ridiculously small sizes," he said. "So why not package them into a single, tiny device?"

Pister submitted a proposal to the federal Defense Advanced Research Projects Agency, a branch of the Defense Department, which agreed to provide about $1.2 million over three years to fund the project. Each mote of smart dust is composed of a number of microelectromechanical systems, or MEMS, wired together to form a simple computer.

MEMS are made using the same photolithographic techniques used to make computer chips. Once perfected, they are relatively easy and inexpensive to mass-produce. But unlike computer chips, which are solid, MEMS contain moving parts. Patterns are etched with light into a silicon wafer to create structures such as optical mirrors or tiny engines.

Each mote contains a solar cell to generate power, sensors that can be programmed to look for specific information, a tiny computer that can store the information and sort out which data is worth reporting, and a communicator that enables the mote to be "interrogated" by the base unit. Later versions may also contain a lilliputian lithium battery so the motes can operate at night.

While much of the technology used to develop smart dust already exists, the UC researchers are breaking new ground by integrating these systems into remarkably small, self-powered packages.

Pushing the Limits

"We are pushing the limits of miniaturization, integration and power management," said Brett Warneke, a graduate student in electrical engineering working on the project.

In one experiment to demonstrate the viability of the concept, researchers deployed a golf ball-sized device on Twin Peaks in San Francisco that measured weather conditions in the area - temperature, light, barometric pressure and humidity - and beamed that information back to a base station in Berkeley, more than 13 miles away.

So far, the smallest device the UC researchers have developed is 62 cubic millimeters - about the size of a pea - but Pister expects to shrink the devices to a nearly microscopic cubic millimeter by next summer. At that scale, they would be truly like dust: small enough to remain suspended in air, buoyed by the currents, sensing and communicating for hours.

One of the biggest hurdles the UC researchers face is building a mechanism that can survive on extremely low power but is still capable of sensing, sorting and sending vast amounts of information. For that reason, they have designed a computer operating system called Tiny OS that can function on a mere 512 bytes of RAM - about the amount of processing power found in a toaster.

The UC researchers are also experimenting with an ingenious optical communicator called a corner-cube reflector, which enables the motes to communicate while expending virtually no energy.

Pioneered at the University of California at Los Angeles, the reflector is essentially a tiny, hinged mirror that can flash millions of Morse code-like signals per second. When a smart mote is illuminated by a laser fired from the base station, the station can "read" the code reflected in the twitching mirror. The mirror itself is powered by electrostatic energy, the force that makes your socks cling together when they come out of the dryer.

Smart dust devices are now capable of communicating only with a single base station, but will eventually be able to share information with each other.

Such a system of "massively distributed intelligence" will vastly increase their ability to organize and communicate information.

"They will be able to do things collectively that they can't do individually, just like an ant colony," Warneke said. "An individual ant isn't very smart, but collectively, they are very smart."

Researchers are exploring a number of methods for deploying smart dust. One involves the use of tiny, unmanned aircraft that would spray motes over an area like a miniature crop duster and relay the resulting information back to a base station. MLB Co., a Palo Alto firm that develops experimental aircraft, has already built such a plane - an 8-inch radio-controlled aircraft equipped with a video camera that can stay aloft for 18 minutes at a speed of 60 mph.

MLB's "micro air vehicle" could be useful in a battlefield situation where low clouds impeded satellite surveillance. The tiny, unmanned plane could soar undetected above the battlefield, disperse a swarm of smart dust and begin relaying a stream of data about the movement of enemy troops and equipment.

The UC researchers are also exploring ways to prolong the time smart dust remains airborne by adding "wings" like those on maple seeds. A cubic-millimeter-sized mote dropped at 30,000 feet would normally take five hours to reach the ground. By attaching wings, the researchers hope to extend that period two- or three-fold.

Other researchers are attaching tiny legs to the motes to create so-called microbots or smart insects. Instead of wafting aimlessly through the air like dust, microbots could be programmed to perform specific tasks, such as crawling through a collapsed building to search for warm bodies.

"Smart dust is like the brain, and we're building the body," said Richard Yeh, a graduate student researcher specializing in micro-robotics who is working on the smart dust project.

Yeh and his colleagues have already developed the basic components of a smart insect - tiny, jointed members, which function as legs, and minuscule motors, the equivalent of muscles. All that remains is to connect the components to a mote of smart dust, a step Yeh expects to accomplish within weeks.

Although the smart dust research is supported by the Defense Department, its proponents see many nonmilitary applications for it, many for motes that would stay in one place.

Crunchless Cap'n Crunch

They could be used to detect fires and earthquakes, tailor the climate in office buildings to suit the preferences of individual workers, and monitor product quality from factory to consumer (a mote of smart dust could tell, for example, if a box of Cap'n Crunch had been exposed to high humidity, and lost its crunch, or if a crate filled with delicate electronic components had been dropped).

Like many other new technologies, smart dust clearly has the potential to be used for nefarious purposes. Foreign governments (or our own), terrorist organizations, criminals and industrial spies could use high-tech motes to spy.

"This is a technology of total surveillance," said Richard Sclove, founder of the Loka Institute, a nonprofit organization in Amherst, Mass., that studies the social implications of technology.

"I have no doubt that there will be plenty of benign and wonderful applications of this technology, but it's easier to imagine the lousy ones. The CIA and the National Security Administration would love to get their hands on this, and there's no way to control what they do with it."

While Pister acknowledges the possibility that smart dust could be misused, he says the potential benefits of the technology "far, far outweigh" any risks.

"You can find harmful effects in everything," added Yeh. "But the threat is small. If a rogue state wanted to use them to spy on us, they could do it, but not much more. They probably couldn't carry enough poison or gas to do much damage."

The specter of millions, or even billions, of electronic motes drifting around the globe has also raised concerns about the potential ill effects on the environment and health.

But Pister dismissed such concerns. "Even in my wildest imagination, I don't think we'll ever produce enough smart dust to bother anyone," he said. "Most of these materials are not environmentally harmful. Essentially they are made out of sand, and that's not toxic."

Potentially, the most dangerous element of a smart dust mote would be the lithium battery, Pister says, but its minuscule size would pose little risk.

"A small town throws away more batteries per year than we can distribute across the entire universe," he said. "It's really a question of trade-offs. If you can sprinkle a few ounces of battery over a rain forest and thereby get a better understanding of the ecology, that's a trade-off worth making."

And what if someone accidentally inhaled a mote of smart dust? "If by ill chance you did inhale one, it would be like inhaling a gnat. You'd cough it up post-haste. Unpleasant, but not very likely."

GATHERING DATA ON THE FLY

Researchers at the University of California are developing tiny, electronic devices called "smart dust" designed to capture information about their environment while literally floating on air. Each dust "mote" packs sensors, computers and wireless communicators onto a tiny silicon chip light enough to remain airborne for hours at a time. As the motes drift, they can monitor their surroundings and beam data back to a base station.

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EARLY PROTOTYPE

Smart dust ``macro-mote'' made with readily available components.

To test their concept, researchers planted golf ball-sized smart dust devices at Twin Peaks and on Coit Tower. Using a modified laser pointer, the device beamed weather information back to Berkeley.

Potential Uses

Military uses include tracking enemy troop movements from above and detecting chemical warfare agents in the air. -- Monitoring weather conditions around the globe and detecting fires and earthquakes are among the nonmilitary uses. -- Stationary motes could be used to monitor the quality of products from factory to consumer..