CENTER FOR EMBEDDED NETWORKED SENSING CENS

IMAGINE IF:

Endangered ecosystems could be equipped with chemical, physical, acoustic, and image sensors to continuously monitor global change.

Buildings could detect their own structural faults and respond to seismic events.

Buoys along the coast could alert surfers, swimmers, and anglers to dangerous bacterial levels in the water.

Engineers for CENS installing a robotic sensing system on the San Joaquin River in the California central valley.

Water quality and flow sensors positioned at the surface of the river.

These are the kinds of dreams that researchers at the Center for Embedded Networked Sensing are turning into reality through a collaboration between computer scientists, statisticians, seismologists, biologists, and engineers under the leadership of center director Deborah Estrin.

The approach uses sensors, computers, and wireless communication in systems that are distributed throughout the environment. These smart sensors and actuators allow researchers to monitor aspects of the world as a function of time and space to derive new knowledge that couldn't be obtained otherwise.

For example, CENS researchers have been able to demonstrate how different chemical and physical factors change when rivers come together. The work was done in the Central Valley of California at the confluence of the San Joaquin and Merced Rivers.

"In the Central Valley, there is a long-standing problem of high salt concentrations from agricultural runoff," explains Jeffrey Goldman, program development director at CENS. "The state right now makes measurements only very sparsely along the river at a single point, every so often. Based on those data, they developed models that suggest how they should release water for irrigation to try to minimize the impact of the salt.

"We're providing a much more detailed view of the mixing," says Goldman. "We'll be able to look at how salt is coming up from the groundwater and being deposited into the groundwater, and to feed those data into the models to help people manage the flow of water and irrigation in the Central Valley, which is a very important agricultural base for the whole nation."

CENS researchers have strung cables across the river and suspended a robotic shuttle from the cables. The shuttle can be controlled to move across the river and then up and down within the water in a grid pattern to make measurements on properties like nitrogen levels, dissolved oxygen, salt concentration, and flow.

"By deploying these technologies we've been able to see how mixing occurs, something that wasn't previously understood," notes Goldman.

CENS researchers have installed sensor platforms at the James Reserve in Riverside County, Calif., a research and teaching facility within the University of California Natural Reserve System. They use these platforms for terrestrial and aquatic monitoring, acoustical sensing of animals, and microscopic sensing of roots, fungi, and chemical constituents of soils.

> **"Explaining from the perspective of the biologist or seismologist in the field how the instrumentation needs to work—what's important and what's not—is critical to making things work."**

These networked instruments "constitute a complete ecology of observing systems suitable for reliable, long-term, automated measurements of organisms and ecological processes across 10 orders of magnitude in spatial and temporal scale—literally from microbes and molecules to whole watersheds," says reserve director Michael Hamilton. "Our unique test bed is internationally recognized as a foremost example of state-of-the-science terrestrial and aquatic ecological observing systems, and serves as a model for an emerging class of research infrastructure known as the ecological observatory."

Systems for aquatic monitoring are another thrust of the center. Lab-on-a-chip sensors for the identification of aquatic micro-organisms may help monitor, understand, and mitigate harmful blooms that cause fish kills, endanger human health, and result in economic effects. The ultimate goal is to put such sensors on a network of buoys offshore and observe these blooms as the events develop. Systems are currently being developed and tested at Lake Fulmor in the James Reserve.

Besides these and other practical applications, CENS researchers are exploring the fundamental research questions about the scientific and engineering design of embedded systems, and that work has helped this emerging field to evolve. "We've ended up in a different place than anticipated," Estrin admits. "Five to ten years ago we had an initial conception about what the problems were. But we've really learned from the experience what the real problems are and where the real challenges and opportunities are."

Their early strategy was focused on thousands of small devices, exploiting the power of many observations from fully autonomous systems. The issues were longevity and communication among the nodes of the system.

But the researchers have realized that even with many thousands of sensors, systems may still be undersampled. So the center is looking toward using multiple scales, mobility, adaptive sampling, and coupled human-observational systems as a new direction for research.

Throughout this process, communication has been key, says Goldman. "Engineers and computer scientists (each) have their own language. Left to their own devices, they would come up with something very neat, but not necessarily the most useful in the field," he laughs. "Explaining from the perspective of the biologist or seismologist in the field how the instrumentation needs to work—what's important and what's not—is critical to making things work."

FROM THE DIRECTOR
Deborah Estrin

"I grew up with the Internet research community, which taught me about the value and the transformative effect of a community going after a vision together. No one person can create it—no one person could create the Internet, for example. That's my technical culture. That's how you have impact."

— CENS DIRECTOR DEBORAH ESTRIN

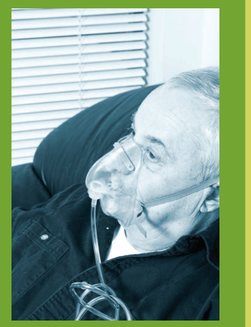
PUBLIC HEALTH APPLICATIONS OF EMBEDDED NETWORKED SENSING

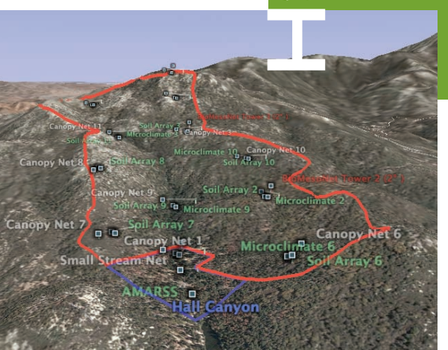
"We are starting to take advantage of the massively proliferated cell phone technology to apply mobilized and in-situ sensing observations to community health and public health issues," says CENS director Deborah Estrin.

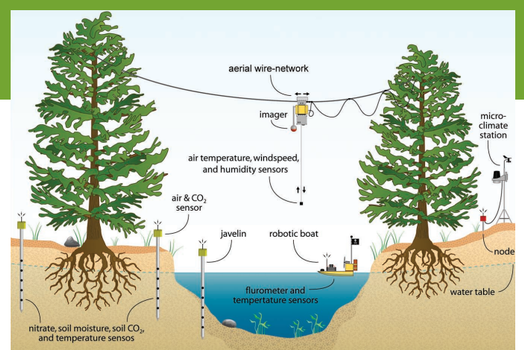
People may be exposed to different levels of environmental and health risks depending on their particular lifestyles, which involve familiar variables such as diet and exercise but also where they go, what they breathe, how they travel, and other factors.

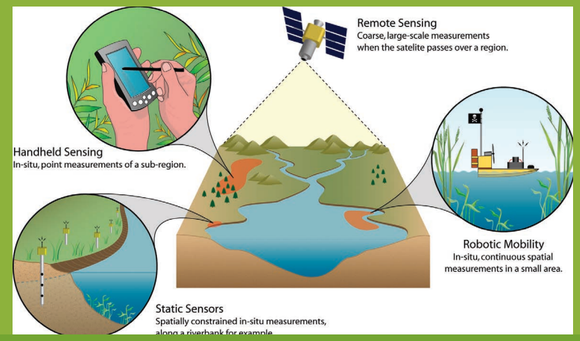
Principles of embedded network sensing may help researchers gain a better understanding of exposure levels encountered by individuals in their daily lives.

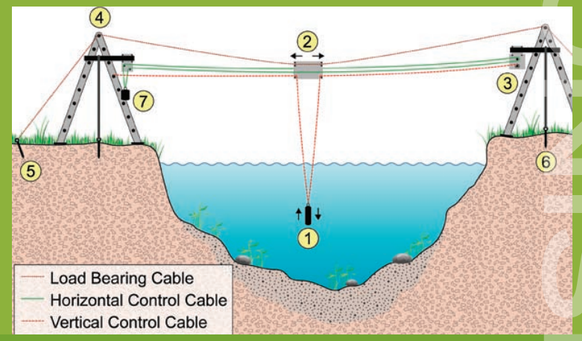
This work is in very early stages, says Estrin, but she anticipates asthma will be one of the issues they will work on. Data from weather information and smog and pollution sensing stations might be combined with detailed location information and activity level information on patients collected through a cell phone to gain a better understanding of the disease.











WOMEN @ CENS:
IDENTIFYING BEST PRACTICES FOR INCREASING GENDER EQUITY IN COMPUTER SCIENCE AND ENGINEERING

Although progress has been made over the last few decades, women still lag behind their male counterparts in representation in the fields of engineering, computer science, and physical sciences, especially at the graduate level. The Center has undertaken a project both to understand and to counteract women's persistent underrepresentation in these fields.

Called Women@CENS, the effort has been aimed at developing a demonstration model of an undergraduate research program that is designed to promote women's long-term commitment to science and engineering.

The intent is to go beyond simply offering an undergraduate research experience and documenting the outcomes of such an experience. Rather, the goal is to use the demonstration model as a basis to identify the best practices and strategies for successful undergraduate research programs across the country.

"Our idea was to increase the number of women and underrepresented minorities who consider moving on into graduate school," says center director Deborah Estrin. "We do that by attracting their attention and engaging them in undergraduate research. For a number of women it's important to see the applicability of their work, and so we've focused on how to build effective undergraduate research experiences, having them work in groups with certain amounts of structure to it, and helping them to get a feeling of what it is to do multidisciplinary research with a lot of mentorship by graduate students," she says. The experiences help them see "that it's not something that you go off and work by yourself in a corner, but that it's a highly collaborative and creative process."

With support from a three-year, $899,000-grant from NSF, the Women@CENS working group has developed an online survey looking at undergraduate research internship programs with a focus on the practices and processes that foster women's long-term commitment to engineering and computer science, explains education director Karen Kim.

An online survey was sent to NSF-funded undergraduate internship programs in engineering, computer science, and related fields. It was followed by interviews with a subset of survey respondents.

The researchers found that the majority of undergraduate internship programs enrolled at least 30 percent or more female participants, according to project manager Amy Fann. Survey respondents reported that increasing the number of women in engineering and computer science Ph.D. programs was an essential or very important program goal.

Less than 12 percent of programs reported that they conducted any type of training or professional development that addressed gender bias issues. In follow-up interviews with a subset of 20 program administrators who had completed the survey, the researchers found that a handful of programs do specifically incorporate professional development addressing gender-equity issues, but do so indirectly.

Examples of promising practices identified by the study include: ensuring that women faculty and graduate students are well represented on workshop panels; inviting women scientists as guest speakers and highlighting the work and contributions of women scientists; ensuring that female faculty mentors, graduate students, and support staff are available to provide small group or individual counseling/support as needed; and providing opportunities for women participants to network with campus and professional organizations.

Women @ CENS team. Front: Kimberly Misa. Back, left to right: Karen Kim, Wesley Uehara, Linda Sax. Not pictured: Deborah Estrin (PI), Christine Borgman, June Chang, Amy Fann,Farnaz Farzad