The Promise of Wireless Sensor Networks

Tiny battery-powered computing devices — embedded in the shoes of an Alzheimer's disease patient, in the soil near the San Andreas Fault or on site at a manufacturing plant — offer a new lens on the physical world and the means to interact with it in real time

Living alone in her quiet home, Harriet often feels lonely and depressed. Newly widowed at 82, she has little interest in physical activity and no zest for social contact. Eating is a chore. She doesn't feel like going out for a meal, and she doesn't feel like fixing food for herself. Consequently, Harriet's health is in serious jeopardy.

This combination of social isolation, inactivity and failing nutrition is alarmingly common among today's aging population, but information technology may offer the means to counteract a harmful outcome. Imagine that there's a tiny sensor embedded in one of Harriet's walking shoes and another on the peg where she hangs her outdoor jacket. Whenever these and other miniature sensing devices throughout Harriet's home notice her moving in the direction of her front door, the sensors use a wireless network to alert Sonya, across the street, and Roland, down the block, that Harriet is about to go for a morning walk. Sonya gets the suggestion on her TV, and Roland hears it by phone: "Call Harriet now if you want to go along for some exercise." Later the same day, Harriet learns much the same way that cabinet doors are opening in her neighbor Ruth's kitchen. Acting on a verbal cue that she hasn't eaten yet today, Harriet calls Ruth to suggest that they prepare and eat lunch together. The two end up sharing food, activity and conversation.

Such technology scenarios may seem far-fetched, even science fiction-like, but they are in fact close to becoming real. The key is wireless sensor networks, an intriguing new technology model in which behavioral and biological data is collected and analyzed for customized proactive computing applications. As the name implies, proactive computing aims to anticipate people's needs and take action to meet those needs on their behalf, relieving people of tedious data entry.

Intel has taken the initiative to invest in research and development of sensor networks, recognizing this technology as crucial to addressing the pending global age wave and public health crisis. Experts predict that the worldwide elderly population will grow dramatically as the post-World War II baby boom generation reaches retirement age. In the United States alone, the cost of caring for older adults is expected to escalate sharply in 2010, when 76 million baby boomers begin to reach age 65[1]. Cognitive and physical decline are also concerns. The Alzheimer's Association, for example, reports that more than 4 million Americans have the disease — a number that's projected to triple to 14 million by 2050 as the elderly population continues to increase.

Sensor networks hold promise for meeting these challenges because they have the potential to revolutionize healthcare, but Intel also sees the technology as having broad application in virtually all aspects of life and industry. Intel envisions a proactive

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[1] Center for Aging Services Technologies (CAST), 2002.

computing world in which a multitude of unseen, connected computing nodes automatically acquire and act on real-time data about a physical environment, helping to improve lives, promoting a better understanding of the world and enabling people to become more productive.

Inside Sensor Network Technology

Wireless sensor networks represent an entirely new way of looking at computing. In a sensor network, dozens, hundreds or even thousands of tiny, battery-powered computers, often called "motes," are scattered throughout a physical environment. Silently and wirelessly, each mote in this ad hoc network collects data, for instance, monitoring light, temperature, humidity, vibration or other environmental factors. The mote relays the collected data to its neighboring motes and then to a specified destination where it is processed. This sensory input, when gathered from all the motes and analyzed by more traditional computers, paints a comprehensive, high-resolution picture of the surroundings in real time.

What's in a mote? Essentially, the ability to sense, compute and communicate. Despite their complex functionality, motes have just three key hardware components: microprocessors, tiny microelectromechanical systems (MEMS) and low-power radios (also called transceivers). The microprocessors process the data, the MEMS sensors provide a broad array of sensory inputs, and the radios enable the motes to wirelessly transmit their sensor readings throughout the network.

New software enables the raw data collected by the sensors to be analyzed in various ways before it leaves the network, ensuring a proactive stream of information that can be acted upon in real time. Standard consumer AA or coin-style batteries keep motes "alive" for six months to a year, and researchers are exploring other sources of power to further shrink size and extend longevity.

Although the size, type and configuration of motes in a sensor network depend largely on the application, common design constraints include power conservation, compact form factor and limited memory and storage capacity. Moreover, motes must be reasonably economical to be suitable for practical applications. Fortunately, microprocessors, sensors and RF transceivers can be inexpensively produced in large quantities using conventional semiconductor manufacturing techniques. Several species of motes based on prototypes developed by Intel and the University of California at Berkeley have recently become commercially available at $50 to $100 (U.S.) each. Researchers at Intel expect that, with re-engineering, Moore's Law[2] and volume production, motes could drop in price to less than $5 each over the next several years.

[2] According to Moore's Law (posited by Intel founder Gordon Moore in 1965), the number of transistors on a chip roughly doubles every two years, resulting in more features, increased performance and decreased cost per transistor.

The combination of small size, low cost and wireless networking functionality makes sensor network technology exceptionally scalable. As price points become more attractive, scientists will be able to deploy many sensors simultaneously, with better proximity to the physical phenomena being monitored and more detailed tracking than has heretofore been possible, leading to ubiquitous computing.

Collaborating on Technology R&D

Research and development of wireless sensor network technology has been a collective effort linking Intel, university research centers, industry labs and government agencies. At Intel, researchers have been working actively on the technology since 2001. Their work has included extensive investigation into practical applications, underscored by ethnographic research and field studies, as well as developing prototype sensor networks for testing and demonstrating the technology. Meanwhile, other groups and labs at Intel work on core technology elements, including silicon advances and communications network research.

The mote technology itself was developed by Intel in collaboration with the UC Berkeley-based Center for Information Technology Research in the Interest of Society (CITRIS). UC Berkeley researchers also designed a sophisticated operating system called TinyOS specifically to manage mote hardware and software functionality. Freely available and open source, TinyOS has become the de facto industry-standard operating system for sensor network research and applications.

TinyOS is written in nesC, a programming language for deeply embedded systems. An extension of the popular C programming language, nesC supports the event-driven processing that is typical of motes, which remain “asleep” until sensors acquire data or receive messages.

Researchers around the world have developed numerous applications using nesC and TinyOS. However, if heterogeneous sensor networks are to be widely deployed, extracting meaningful data from those networks must be simple. TinyDB, a compatible database for sensor networks developed by researchers at Intel and UC Berkeley, was built to do just that. Designed with a graphical user interface and simple query structure, TinyDB transforms diverse kinds of sensor networks into user-friendly virtual databases rich with useful information about the real world.

Designing Sensor Networks for Healthcare

The best example of Intel’s efforts to explore the human side of sensor network technology is the company’s Proactive Health Research project. Since April 2002, a team based at Intel’s Hillsboro, Ore., campus has worked to develop technologies that benefit today’s aging population. The goal: catalyze research on proactive computing applications that promote health and wellness. Intel researchers expect their work will enhance quality of life for elders, including the ability to “age in place” — to stay home rather than move to institutions; improve healthcare through prevention and early detection of disease; lower soaring healthcare costs; and unburden family members and other caregivers.

Rooted in ethnographic research such as in-home observations and interviews, the team's work has focused largely on the needs of real people coping with mild to severe cognitive impairments. By studying extreme conditions such as Alzheimer's disease, researchers expect to discover core technology and applications that people will find useful in other health domains. For example, Intel researchers eventually hope to extend their research to other physical ailments such as cancer and cardiovascular disease. They see their work ultimately having implications not just for monitoring and management of such diseases, but potentially even for early detection and prevention, such as spotting behavioral or physical problems that could indicate the onset of Parkinson's disease.

Because of understandable concerns around privacy and security, Intel has made these aspects a core part of its research into sensor network technology. Researchers have learned, however, that many of the people they interview see the technology as a way to maintain privacy. This view is most prevalent among frail elders who face being institutionalized and losing the home they don't want to leave, or having to come up with the money to pay for a 24-hour care nurse so they can continue living at home. Seniors already living in a care facility where they are subject to 24-hour camera monitoring also respond positively to the technology as a way to regain the precious privacy they've lost. In many cases, such elders will gladly share nutritional and exercise data, and even confidential blood pressure information, with friends or designated caregivers if it will help them continue to live at home.

To help seniors age with more dignity and independence, Intel is developing in-home technology prototypes that assure private and secure data. Intel is also building sensor network interfaces that will allow elders to make decisions about the data they share, and who they share it with. Interfaces are made intentionally simple and transparent, so seniors won't need technical training to use them.

Intel is encouraged by the fact that simple sensor networks can be built today by adapting off-the-shelf technology, and home technologies for health and wellness are beginning to appear on the market. Intel is working with other companies, academic researchers and the government to help ensure that more proactive, interactive technologies will be commercially available to anyone who needs them by the end of decade, when boomers begin to retire in huge numbers.

Societal Impact of Sensing Technology

Because wireless sensor networks promise to usher in a new model of computing, the repercussions are certain to be felt beyond healthcare in society at large. Researchers at Intel and elsewhere are actively exploring and experimenting with innovative applications in a number of areas today, including environmental monitoring, agriculture, wildlife biology, public safety, structural engineering and manufacturing.

For example, in a pinot noir vineyard in Oregon's Willamette Valley, embedded sensors monitor temperature. Each mote takes one temperature reading per minute and stores the results, also recording the highest and lowest readings for each hour of the day. It's a small start, but someday researchers imagine a "smart vineyard" in which sensors monitor nutrients, keep the vines free from pests and mold, and track moisture — perhaps even sending alerts to irrigate as needed. The project also incorporates input from those who tend the vines, cultivate the soil and harvest the grapes, as well as the needs of vineyard managers, winemakers and wine sellers.

On Great Duck Island off the coast of Maine, scientists are using a prototype sensor network to monitor the nesting grounds of elusive seabirds called Leach's storm petrels. Coin--sized motes buried in burrows house sensors that continuously monitor light, temperature and barometric pressure. Readings are relayed to laptops, and then to an Intel lab in Berkeley, in near real-time, for interpretation. The result: Biologists get the information they need to observe the birds and protect habitat, with minimal human disturbance.

In San Francisco, 200 motes organized in an ad hoc sensor network track stresses on the Golden Gate Bridge. The motes measure how much the bridge sways from side to side, which can amount to several feet in strong winds. Using RF, sensor readings are wirelessly sent to more powerful computers for data analysis. Any anomalies might indicate a weakness in structural integrity, alerting engineers to repairs that can help keep the span safe in case of earthquake or other natural disaster.

Intel is also testing sensor network technology by installing motes that monitor cooling equipment in one of its manufacturing plants. In this project, sensors watch for abnormal vibrations that could indicate worn bearings or failing compressors in the machines. Alerts are wirelessly transmitted to a central control system, keeping small mechanical problems from becoming costly production issues.

Still other teams of researchers have field-tested sample sensor networks for monitoring the micro-environment in a redwood grove, for tracking the rescue operations of firefighters and for increasing crop yields through automated irrigation and maintenance.

These and other applications offer proof that sensing technology has enormous potential in terms of delivering new benefits to society. They also point to opportunities — in technology innovation, in increased productivity and in strategic advantage for any nation that intends to compete on a global scale.

Conclusion: Underwriting the Future

Ultimately, Intel envisions sensors built into roads, farms, hospitals, factories, office buildings, clothing, swimming pools, baby cribs, vehicles and even bandages — a ubiquitous computing infrastructure that consumers around the globe can tap into and take for granted.

But research is still in its infancy, and pursuing this goal will require long-term collaboration among industry leaders, academia and government. By underwriting sensor network R&D, these entities will fuel viable and scalable solutions to the cresting age wave and multiple other challenges faced by numerous industries and market segments.