From the Editor in Chief

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Of Smart Dust and Brilliant Rocks

M. Satyanarayanan

Sensing the state of the physical world and influencing it were implicit capabilities in Mark Weiser's vision of ubiquitous computing. These capabilities enable a seamless continuum between a user's personal computing environment and his physical environment. The better the approximation to a seamless continuum, the closer we get to Weiser's ideal of a "technology that disappears." Take, for example, a laptop display that dynamically adjusts its brightness based on ambient lighting conditions and knowledge of user preference. If done correctly, the user would never notice the dynamic adjustments. The display would simply be clear and easily readable at all times.

RICHER, SMARTER SENSING

Beyond such simple user-centric examples, we can imagine a much richer role for sensing. In effect, sensing creates something akin to a nervous system for the environment being sensed. The nervous system's sensitivity, speed, and accuracy will depend on the technology of the sensing infrastructure. Historically, the term *sensor* has meant "dumb sensor"—something like a strain gauge or thermocouple that generates a signal but involves no local computing. Inputs from many dumb sensors are typically fed to a computer that integrates the individual signals and triggers actions. Such designs have been used for process control in chemical, petroleum, and nuclear power industries for many decades. Unfortunately, dumb sensors suffer from many limitations. First, the distance the signals must traverse before they are processed limits their sensitivity. Even if you perform analog-to-digital conversion right at the sensor, communication latency limits sensing agility. Second, the centralized collection of sensor data before processing limits scalability.

A DISPOSABLE SOLUTION

In the mid-1990s, Kris Pister and his colleagues at the University of California at Berkeley made an important observation that revolutionized sensing. They noted that continuing improvements in VLSI technology would soon make it feasible to integrate a dumb sensor with a simple microprocessor, a limited amount of memory, a short-range wireless transceiver, and a small battery. You could organize a collection of such *smart sensors* as a self-configuring ad hoc wireless network. You could make the network's functionality highly flexible by dynamically downloading the code executed at each sensor. Instead of careful and precise placement of sensors and wiring, you could just scatter a handful of smart sensors over an area; these would self-configure and establish a wireless network through which sensed and partially processed information could be extracted. Produced in sufficient volume, this would make individual sensors so cheap that you could discard them after their batteries ran out.

If you added a handful of smart dust to every batch of concrete as it is mixed, the resulting buildings would essentially have a nervous system built into every structural element!

Pister used the term *smart dust* for such sensors, the name connoting both their small size and disposable nature. Bill Wulf, president of the National Academy of Engineering, hypothesized a fascinating application of smart dust for the construction industry. If you added a handful of smart dust to every batch of concrete as it is mixed, the resulting buildings would essentially have a nervous system built into every structural element! You could use such a nervous system to monitor structural decay over time due to factors such as corrosion of reinforcing metal. It could also detect overloads of design limits in time to avoid catastrophic damage.

The conceptual simplicity of smart dust hides many engineering challenges. You can find a good discussion of these challenges in a recent National Academy report entitled, "Embedded Everywhere: A Research Agenda for Networked Systems of Embedded Computers." Deborah Estrin, a guest editor of this issue, chaired the committee that wrote the report. Many academic and industrial research groups worldwide are now engaged in making smart dust a reality.

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BRILLIANT ROCKS

Smart dust is an *immersive sensing* technology: you must embed it in the space you wish to sense. Some situations might call for *nonimmersive sensing*. For example, legal or social impediments might restrict physically embedding sensors in a space. Cost considerations might also preclude immersive sensing in some cases. Covering a large area with smart dust could be prohibitively expensive, especially if you have to repeat the process frequently because of run-down batteries. Environmental concerns regarding safe disposal of smart dust could also play a role.

These situations might require a completely different approach. By analyzing electromagnetic or sound energy radiated or reflected from a space, you can infer many of the space's attributes from a distance. NASA and the geophysics community refer to this style of sensing as *remote sensing*. Aerial surveillance via satellite, manned aircraft, or unmanned drones falls into this category. Most of astronomy involves nonimmersive sensing using techniques such as spectroscopy. The Argus coastline sensing project, described in this issue's Applications department, is another example of a nonimmersive sensing application.

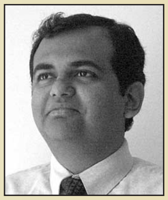
Historically a batch process, remote sensing first collects images and then processes them offline. The plummeting cost of computing now makes it economically feasible to build a sensing network in which image processing occurs concurrently with collection. The IrisNet project described in this issue exemplifies such an approach. Here, the sensor (a camera) is colocated with a computer of sufficient processing power to execute image-processing algorithms. A network of such sensor and computer combinations can provide coverage for a large geographic area. Playing on the smart dust terminology, I use the term *brilliant rock* to describe such sensor-computer ensembles. The name indicates the much greater computing power as well as physical size associated with each node in the sensing network.

FROM THE GUEST EDITORS

We are pleased to bring you this issue of *IEEE Pervasive Computing*, focused on sensing and actuation. We have a total of nine articles plus a guest-written Applications department. Because of space limitations, these nine articles span two magazine issues. Five articles appear in this October–December 2003 issue. One of these is the IrisNet article, "IrisNet: An Architecture for a Worldwide Sensor Web," mentioned in the main text. In "Event-Based Motion Control for Mobile-Sensor Networks," the authors investigate the role of mobility in sensor networks, with a particular emphasis on simple, scalable algorithms for motion control. In "A Learning-Theory Approach to Sensor Networks," the author proposes that we can treat various sensor network applications as instances of supervised learning. In "State-Centric Programming for Sensor-Actuator Network Systems," the authors introduce the state-centric abstraction that uses *states* as a natural vocabulary to describe spatiotemporal physical phenomena (for which sensor networks are typically designed). This is particularly useful to application programmers. And finally, in "Scalable Human-Robot Interactions in Active Sensor Networks," the authors investigate how a small number of people can scalably task and retask a network of many nodes.

Four additional papers (to appear in the January–March 2004 issue) complete this special issue. A service gateway for sensor networks is discussed in "Shaman: A Service Gateway for Networked Sensor Systems." In "Vineyard Computing: Sensor Networks in Agricultural Production," the authors showcase lessons learned from a real-world sensor network deployment in a vineyard. The efficient extraction of information from sensor networks via queries is the subject of "Query Processing in Sensor Networks," and in "Distributed Computation for Cooperative Control," the authors discuss a modeling tool and programming language for cooperative control systems with applications to sensor-actuator networks.

Deborah Estrin is a professor of computer science at the University of California, Los Angeles, and director of the Center for Embedded Networked Sensing, a newly awarded National Science Foundation and Technology Center. Her research interests include design of network and routing protocols for large global networks, sensor networks, and applications for environmental monitoring. She has a PhD in computer science from the Massachusetts Institute of Technology. She is a fellow of the ACM and American Association for the Advancement of Science. Contact her at destrin@cs.ucla.edu; http://lecs.cs.ucla.edu/estrin.



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Whereas smart dust is disposable, brilliant rocks are too big and expensive to simply throw away after use. Rather, I see a network of brilliant rocks as a reusable sensing infrastructure that many sensing services can dynamically customize through downloaded code.

Smart dust and brilliant rocks can complement each other. Consider a situation where you use a brilliant rock infrastructure to detect the onset of a natural phenomenon such as a riptide or an algae bloom along a coastline. You could then precisely direct a release of smart dust at the right time and location to study conditions such as water temperature or nutrient levels that can only be sensed immersively.

In general, by intelligently combining brilliant rocks and smart dust, we can create a nervous system for the physical world that has both always-on and on-demand components. The combination can give us the right balance of speed, accuracy, longevity, and cost-effectiveness for a particular application.

CALL FOR PAPERS

IEEE PERVASIVE COMPUTING
PERVASIVE COMPUTING FOR SUCCESSFUL AGING

Submission Deadline: 15 December 2003

Publication date: April 2004

IEEE Pervasive Computing magazine invites articles relating to the application of pervasive computing to the successful aging of the elderly population. We especially welcome papers reporting on original research and assessment of assistive environments, assistive devices, middleware, elder user models, and applications that support

- Aging independently
- Aging with or into disabilities
- Coping with dementia
- Coping with cognitive impairment (for example, Alzheimer's disease)
- Safe elder driving
- Remote monitoring and lifeline-like services of the future
- Medicine compliance
- Security and safety at home
- Coping with depression and loneliness
- Telehealthcare and telerehabilitation
- Entertainment and social aspects of elders

Submissions should be 4,000 to 6,000 words long. All submissions will be anonymously reviewed in accordance with normal practice for scientific publications. Electronic submissions via Manuscript Central (http://cs-ieee.manuscriptcentral.com) should be received by 15 December 2003. For submission and magazine guidelines, see our Author Guidelines (www.computer.org/pervasive/author.htm). In addition to full-length submissions, we also invite work-in-progress submissions of 250 words or less. These will not be peer reviewed, but will be edited by the staff into a feature for the issue. The deadline for these is 15 February 2004. This issue's guest editors are Sumi Helal, University of Florida; Gregory Abowd, Georgia Institute of Technology; and Andrew Sixsmith, University of Liverpool.