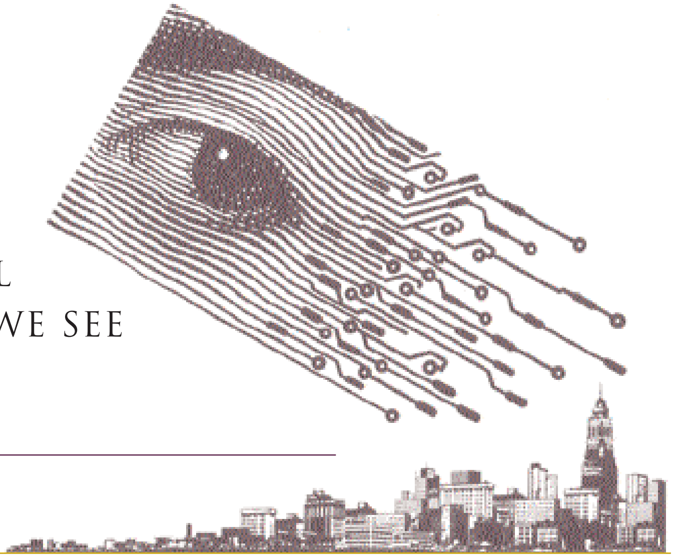
TECHNOLOGY WATCH



SPACES OF THE REAL:

HOW SENSORS WILL CHANGE THE WAY WE SEE THE WORLD

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"Surely, we are provided with senses as well fitted to penetrate the spaces of the real, the substantial, the eternal, as these outward are to penetrate the material universe."

Henry David Thoreau, *A Week on the Concord and Merrimack Rivers* (1849)

The Promise of Sensors

Since their birth, computers have been limited to their own internal worlds, calculating and thinking about numbers that arrive through a thin wire and exit through a light bulb. In the next few years, however, advances in sensor technologies will enable computers to see—and comprehend—the rest of the world. Sensors, devices that translate physical characteristics (such as direction, temperature, pressure, or light) into computer-readable signals, aren't new; the venerable thermostat is simply a temperature sensor, wired to turn on the heater or air conditioner when the temperature exceeds a set range.

A new generation of sensors is being developed at research centers like the University of California at Berkeley and PARC, and at companies including Intel and start-up Crossbow Technologies. These new sensors will be able to recognize a huge range of signals, from acceleration and location to the presence of toxic materials in the air. They will be tiny and cheap, small enough to be invisible, and cheap enough to be disposable. And most importantly, they will be

Figure 1 RFID Tags Fit Into the "D" on a Dime

wirelessly connected with each other and with the network. The combination of these factors means that for little more than the cost of packaging, users will be able to invisibly deploy or embed networks of sensors that can gather data in real time and immediately transmit that data anywhere.

These sensor networks are an opportunity not only to make computers smarter, but for organizations to refine and reform their basic processes for observing and reacting to change. Sensor networks deployed within an organization can improve the transparency, feedback, and responsiveness of internal processes. Externally, sensor networks provide opportunities to efficiently explore new or hostile territory, to measure environmental change, and to enhance the quality of products and services.

However, achieving these new capabilities will require not only proper design and application of sensor networks, but also changes in how organizations manage information. Like any new technological innovation, it will take time before we work out the truly disruptive applications, before we understand the potential business models, before we can with any confidence write a book like *Sensors for Dummies*. And yet even the early light from the dawn of the age of sensors has illuminated three opportunities or hints for the design and application of sensor networks: build applications that search the real world; respond to data, not schedules; and build information flows into the entire process.

Search the World

Already, early sensor networks are being deployed in conjunction with tags, through technology known as Radio-Frequency Identification (RFID). RFID tags, produced by companies like Alien Technology, are simply microscopic identifiers, a sort of "Hello, my name is . . . " label for products. When illuminated with a radio signal, they can uniquely identify the object to which they are attached. Using tags, your entire grocery purchase could be scanned instantly, and not only would the grocer know that you bought milk, but which carton of milk.

There's a cartoon in which a guy sitting at a computer turns to a co-worker and says, "I looked for Larry on Google, and Yahoo, and Excite. Finally I found him in the bathroom!" It's a joke because today, searching the Web is divorced from physical reality. The marriage of sensors and tags will potentially be able to locate any object, anywhere. This could transform activities like warehousing, storage, and retail, because there will no longer be any burden to putting an object in its "right place." The Dewey Decimal System, for example, is designed so that if you are looking for a book, you find a unique identifier for it in a card catalog; using that identifier, you can search the shelves for it. To put it another way, a Dewey address encodes a specific physical location. In a sensor-driven world, the book's actual physical location does not need to be correlated with a system of classification (admittedly there may be other good reasons to group similar books together). If you're

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looking for a specific book, you merely ask the local search engine where that book is, and it can tell you, not based on an assumption that a librarian has properly placed it on a shelf, but the actual, real, current, exact location.

This has enormous implications for supply chain management. Determining where shipments of raw materials, components, or products are, at any time, will allow for an improved capacity for responsiveness and adaptation to shocks or changes. It will also be much easier, less labor-intensive, and more reliable. Rather than requiring each package to be manually scanned by a FedEx employee with a hand scanner, a sensor could instead instantly uniquely identify each package in a shipment. Similarly, RFID tags hold out enormous promise for retail services such as guiding customers to products, instant checkout, and improved security.

While attractive, the total availability of data regarding the physical location of objects raises a number of challenges for enterprises. First, it requires a high degree of cooperation and coordination with suppliers, competitors, and transportation agencies to settle standards for data exchange, technical performance, and identification sequences. Consortia like the Auto-ID Center at MIT and the Global Commerce Initiative are dealing with these issues now. Second, the enormous amounts of data created must be analyzed, and in many cases even the most advanced statistical methods are still insufficient. Once analyzed, for the data to be useful, it must be integrated into existing enterprise resource management systems, an expensive and complicated task. Third, RFID tags that are embedded into products raise difficult and troubling privacy issues, and companies must be responsive to customer concerns. Finally, the data does little good itself unless it is used in real time to drive action, which itself will likely require changes in the way enterprises analyze data, make decisions, and communicate.

Respond to Data, Not Schedules

Traditional business processes, especially things like maintenance, are schedule-driven. An airline with a fleet of airplanes visits each one on a carefully regulated schedule, inspecting different components such as wings, engines, or brakes for potential damage or incipient failure. There's a tradeoff between risk and cost; it would be best to check the wings for cracks every day, or indeed before every takeoff, but the likelihood of new cracks developing between one flight and the next is small, and the cost of checking would be prohibitive. And so every enterprise performs its own cost-benefit analysis, scheduling tasks at some crossover point between acceptable risk and acceptable cost.

The presence of actual data, as opposed to assumptions (or fears), changes that for the better. Sensors embedded in load-bearing beams can inform workers if cracks develop. Sensors in gas tanks can look for leaks. Maintenance can respond to actual problems as they develop, rather than wasting time looking for problems that may not exist. Today, GE builds sensors

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into its aircraft engines; suspicious behavior such as temperature changes can be communicated not only to the cockpit, but also via satellite to remote analysis and monitoring stations. Airlines save money by being able to intervene much earlier in repairs, before serious damage has occurred but also by being able to avoid redundant and expensive checkups. As sensors become smaller, cheaper, and networked, this sort of functionality can be built into more common objects. Certainly, the idea of a 15,000-mile checkup for your car will soon be a thing of the past, replaced by real-time response to the problems that are really developing.

The wider implications for enterprises go beyond maintenance. Any business process is—or ought to be—in response to some measurable factor in the outside world. Being able to design those processes to be intimately and comprehensively tied to the actual measures not only improves performance dramatically, but also improves the allocation of resources. Schedules no longer need to be created; efforts are not wasted. Often, this means that humans can be entirely removed from the loop, in an equivalent to how a thermostat removes the need to be constantly checking the temperature and adjusting the furnace. Is it warm in here?

Build Information Flows Into the Entire Life Cycle

Fundamentally, the benefit of sensors is more data. And not merely more of it, but updated more often, arriving with lower latency, at higher fidelity. This can be a mixed blessing, of course, as resources and infrastructures strain to meet the increased demand of communicating, storing, and analyzing all of this new perception. What distinguishes this new fire hose of data from all those that preceded it (such as all of the data that resulted from the implementation of enterprise resource planning systems such as SAP) is that this data comes from a much wider range of the life cycle of a product or a process.

This plays out in two ways. First, data comes from much earlier and much later in the life of (for example) a product. Second, there are just as many new opportunities to use this information. Together, this allows events and trends far separated in time and space to influence each other. Sensors can collect more information on how customers are using products, long after the traditional focus groups have gone home, and reconfigure themselves based on the latest data. For example, wireless phones might continue to learn customer habits and cell tower coverage and adjust accordingly. In turn, that information should flow back to the product designers. Similarly, early raw material or component processing can be influenced by changes in demand far down the supply chain; if there's a sudden spike in demand for two-by-fours, timber companies ought to be cutting down different trees.

Sensors also change the nature of data from discrete points, taken at perhaps lengthy intervals, to a continuous flow. There's a danger in having too much information; according to control theory, too much feedback can be much worse than having too little, as

Tiny, cheap, wirelessly connected sensors empower the growing sensor networks that now provide companies access to increasing amounts and types of information. With this data companies will be poised to better detect and respond to both internal and external changes. While supply chains will likely benefit from such information visibility, organizations might also move from costly and time-intensive planning to real-time reacting to continuous and more expansive data feeds. However, organizations will have to embrace organizational change for the benefits of emerging sensor networks to be fully realized.

article abstract

anyone who's watched a novice driver overcorrect will believe. However, continuous flows also offer an important service to end customers by verifying and certifying the conditions over a product's lifetime. As products are assembled, shipped, stored, and displayed, they may encounter a wide variety of environments. Sensor networks, working with object tags and enterprise systems, can measure these environments and record each object's experience. When you buy that carton of milk, wouldn't you like to know if it had ever been over 40 degrees?

> "We need pray for no higher heaven than the pure senses can furnish . . . Our present senses are but the rudiments of what they are destined to become."
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> Henry David Thoreau, *A Week on the Concord and Merrimack Rivers* (1849)

Like the technological retoolings—especially of information technology—of the past, the effective use of sensors will require that organizations adapt their infrastructure. Even as storage capacity grows faster than the ability of processors to data mine it, so will sensor performance, and the amount of bytes-per-second of sensing that a dollar can buy, exponentially outstrip our ability to keep it all for later use. That's probably for the best, actually, not just for privacy reasons, but because it will impose a sort of necessary discipline on what data we keep and what data we can afford to throw away. In addition, the sensors will impose a huge burden on networking infrastructure and will require careful architecture to ensure that sensor-created traffic does not crowd out human-originated messages. Except, of course, when the sensors detect something urgent.

A set of challenges being created by sensor networks surrounds the issues of technology management. These networks of perhaps thousands or even tens of thousands of sensors could never be manually configured by a human. They must, on deployment, not only self-configure, but be addressable and searchable by humans. It's no good if a sensor is collecting and even reporting data if you have no idea where it is. Once deployed, sensor networks must be controllable and tunable.

However, the most pressing challenge is that of comprehension and synthesis. The opportunity is enormous: Sensor networks can, if they cooperate, detect and locate signals that no individual sensors could see. For example, the military is interested in this as a way to detect and identify "low-observable" or stealthy targets. By combining the views of thousands of sensors, each in a different location, you could build a three-dimensional map that combines and integrates the knowledge of each point. To work, this requires a coordinated combination of artificial intelligence, advanced statistics, and data mining, deployed throughout the network. However, software that can do this is still in its infancy.

The ultimate promise is the complete blurring, and eventual erasing, of the lines that separate our computers from the rest of the world. Cameras will look out at the world, microphones will listen, and in turn, computer-driven actuators will be able to move things around, turn on or off lights, and be able to make changes in the real world. We will not just be embedding computers; we will be embodying them, giving them a connection to and a basis in physical reality. Much of the talk of the '80s and '90s was of virtual reality, creating spaces within computers that we will visualize and visit. The real revolution will not be we humans descending into the computers' pretend world, but lifting them up into ours.