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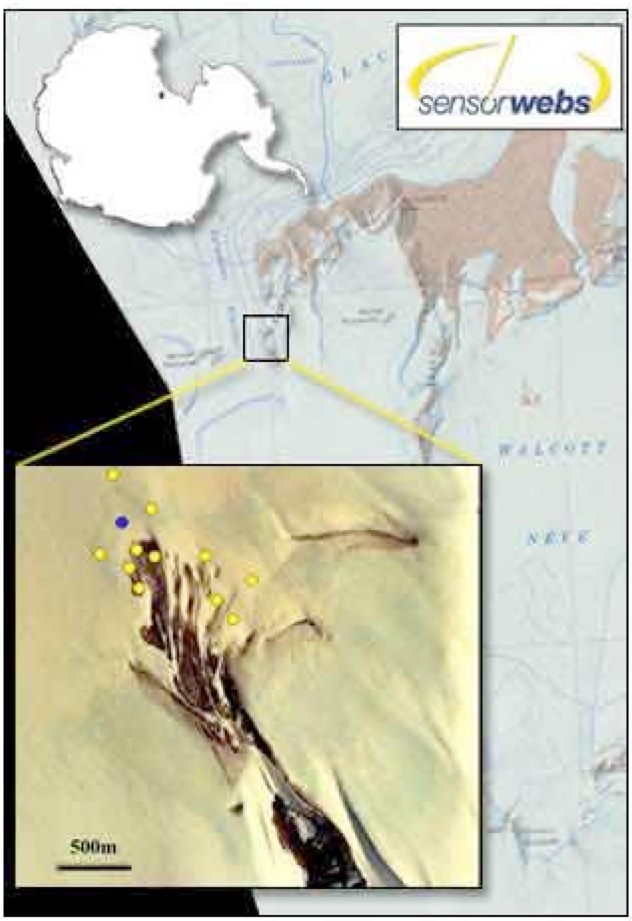
NASA Creates Thinking RF Sensors

Low-cost wireless sensor networks developed by NASA can detect environmental changes and take action in response to what they detect. Now RFID is set to make them even more effective.

By Jonathan Collins

Oct. 4, 2004—Instead of just interpreting the world in various ways, said Karl Marx, the point of a philosopher's work is to change the world. For the past seven years, NASA's Kevin A. Delin, has been thinking the same thing about sensor networks.

Delin initiated and manages the Sensor Webs Project at the NASA Jet Propulsion Laboratory in Pasadena, Calif., where a group of eight engineers is working on a new generation of wireless sensor networks. Unlike typical wireless sensor networks, which use sensors to detect environmental changes and report back to an external control system, the Sensor Web can share data throughout the network and use its embedded intelligence to act directly on any detected changes.



A map showing Sensor Web pod locations in Antarctica

So far the Sensor Web has been deployed in a monitoring role, where the core concept of the technology has proved to be reliable. Now the group is about to embark on trials that will extend the Sensor Web networks to not only monitor but also to react and control the environment around them. "You have to be very careful when deploying anything that automatically changes environmental conditions," says Delin, "but the technology is already there to do it."

NASA's interest in the Sensor Web stems from wanting to deploy such a network to monitor planets other than Earth. During a trial in Antarctica in the winter of 2002-2003, the Sensor Web was deployed over an area larger than 2 square kilometers. It measured soil and air temperatures, humidity and light at five-minute intervals in the MacAlpine Hills region of the Transantarctic Mountains. The harsh cold, dry Antarctic climate is similar to conditions found on Mars. "A Sensor Web on Mars could work to detect any potential life," says Delin. "In Antarctica, microorganisms can bloom very quickly then hibernate again, and a Sensor Web makes tracking that activity possible." But NASA also believes that Sensor Web technology could give a significant boost to U.S. government efforts to strengthen national security by reacting to activity in monitored areas.

The NASA/JPL Sensor Webs Project began in 1997, when Delin saw the possibility of using readily available technologies developed for telecommunications and IT markets to create a wireless network in which intelligence could be embedded. Since then, Delin's group has had the opportunity to develop the Sensor Web by testing the technology in a dozen different real-life environmental conditions, including at Huntington Botanical Gardens in San Marino, Calif., and at a water recharge basin near Tucson, Ariz.

The deployments have provided real benefits to the site hosts as well as to NASA. For example, at Huntington Botanical Gardens—where the Sensor Web measures the light level, air temperature and humidity and, in some cases, soil temperature and moisture—the garden staff discovered that two identical plants needed to be watered differently because of soil conditions around each plant.

At a water recharge basin just west of Tucson, Delin's group deployed 16 pods in a Sensor Web to measure the movement of water across the basin's surface, as well as to follow the penetration of the water into the ground. Sensors in each pod measure ambient air temperature, relative humidity and light level. In addition, the pods inside the recharge basin are equipped with a soil temperature sensor (at surface level) and two soil moisture sensors, one buried just below the surface and the second buried at a depth of half a meter (1.5 feet). These soil sensors are attached to the pods via long leads, which allow the pods to stay above water level so they can continue to communicate wirelessly.

NASA Sensor Web team members Dave Johnson and Kevin Delin prepare a pod for field deployment at a water recharge basin west of Tucson, Ariz.

Thanks to this deployment, NASA's partners in the project—the University of Arizona and Tucson Water (the city's water department)—now have a way to monitor activity in the water recharge basin 20 miles outside the city. And NASA had a way to test the Sensor Web's ability to detect an environmental change—such as the water moving in and out of the basin—that takes place at a predictable and measurable rate. The Sensor Web's results were also used as a ground-truth check against remote measurements taken from orbiting satellites. (To verify the accuracy of satellite observations, NASA takes ground-based measurements of terrestrial objects at the same time the satellite is measuring them and compares the data.)

For each of its Sensor Web deployments, Delin's team installed from 12 to 30 network pods, also known as nodes. Each pod consists of a microprocessor or microcontroller connected to whatever sensors may be required, depending on the application; wireless networking technology; and network operating software (developed by the Sensor Webs Project) that ensures that each pod in the web can communicate automatically with any other pod within its hundreds-of-meters transmission range. The pod is enclosed in a protective casing and powered by a rechargeable battery (like the ones used in cordless phones) that is often continually recharged through solar panels.

The Sensor Web is a distributed network, meaning that all the intelligence and data gathered by one pod is shared and used by the other pods. Different applications require different details, such as what data is collected and how frequently that data is recorded and shared with other pods. The software is loaded onto each pod before deployment, along with each pod's unique ID number, but the wireless capabilities of each pod means that the network can be updated and changed after the pods have been deployed. The goal is to provide a pervasive, continuous, embedded monitoring presence in a range of environments and over large spatial areas.

The pods communicate wirelessly using standard radio components taken from the cordless phone market. Operating at 900 MHz, each pod can broadcast for hundreds of meters to other pods within its range, thus distributing data throughout the network. How and when distribution occurs depends on the parameters of any given application; for example, a pod can be configured to collect and transmit data to every pod within range every five minutes. In addition, specific portal pods can provide end-user access points through an Internet connection, so that information on the Sensor Web can be monitored outside of the pods by pushing data through the Internet to a computer or engineer. A Sensor Web could also be controlled and changed through that same connection.

But the point of a Sensor Web is not merely to collect data and transmit it to a person who then acts on that information. Rather, the ultimate goal of a Sensor Web is to analyze the data collected by its sensors and then to respond accordingly. Intelligence embedded in the network operating system means it can be left to operate without the need to communicate with any end user or control system.

“The principle of the Sensor Web is not just to report back to the end user—a computer or an engineer outside of the Sensor Web,” says Delin. “Unlike in typical wireless sensor networks, in a Sensor Web, each pod shares with the rest of the network all the data with all the other pods. If the network senses that everything is looking fine, it just continues to monitor. However, if action needs to be taken, those commands can come from within the Sensor Web itself. The network operating system can control the web so that certain actions can bring a response controlled by the network, but the primary point of the portal is just to look inside the web.”

Sensor Web pod 15 at Huntington Botanical Gardens is covered in mud from nearby watering and has had an antenna chewed on by a small animal.

For example, at Huntington Botanical Gardens, dry conditions detected by a Sensor Web could cause the web to automatically turn on sprinklers. If pods also contained sensors that measure barometric pressure, the web could analyze light and barometric pressure levels to predict that rain was imminent and decide not to use the sprinklers after all.

According to NASA/JPL, its Sensor Web design could transform the monitoring and control of many environments in a way that could impact many areas, including agriculture and ecology, security and homeland defense, as well as space exploration.

For example, says Delin, a Sensor Web could be linked with the control system of a fire sprinkler network. If one sensor pod detects heat or smoke or both, it could automatically communicate with other pods in the network and determine whether the pod sensing the fire is reacting to a real event and act accordingly. By determining the temperature and smoke around other sensor pods, the Sensor Web could pinpoint exactly where any fire is and turn on sprinklers only in the area that needs them, as well as identify safe exit routes.

Now Delin believes RFID can bring additional functionality to Sensor Webs by adding readers to pods that can detect and identify tags that enter their broadcast range, or neighborhood. Say, for example, firefighters are equipped with active RFID tags able to communicate over suitable distances with sensors installed around a building. A Sensor Web can be deployed quickly because each pod is programmed to immediately detect which other pods are within their neighborhood and can begin transmitting and receiving data between pods wirelessly, according to the parameters set out in the network operating system. “Firefighters could ring the building with a Sensor Web that would monitor where they are inside the building,” says Delin.

Since every pod in the network shares all the data and intelligence through a distributed, decentralized architecture, the Sensor Web can work around the failure of one pod. The pods can even cover areas where it's difficult for signals to travel, such as buildings and other structures with lots of metal and liquid in them, as they are deployed in a mesh configuration where one pod typically broadcasts to four or more other pods. That means if one link between two pods is blocked by a metal structure, data can be routed around the obstacle by sharing the data with other pods.

Because pods can communicate automatically over significant distances, Delin maintains that the time it takes to set up a Sensor Web is normally constricted by the time it takes to get to each pod site and by the need to record the pod's geographical location so that it can be retrieved. Although the pods could be fitted with a GPS receiver to determine where they are and avoid having to map out their location, Delin maintains that the cost and power demands of a GPS receiver do not always make GPS a viable option.

Bamboo is used for mounting, because it's lightweight and resilient to the Antarctic environment.

Sensor Webs could have practical benefits for manufacturers. In an industrial environment in which a Sensor Web is linked to software that controls a manufacturing process, for example, the Sensor Web could track RFID-tagged components of a product being manufactured and use the intelligence embedded and shared in the web to ensure that automated processes are kept synchronized throughout a manufacturing process. "If there are too many subassemblies being developed," says Delin, "the Sensor Web can automatically slow down production to meet the capability of another part of the manufacturing process."

The difference between deploying a Sensor Web to do this versus using more traditional manufacturing control systems where the intelligence in the system resides on servers away from the shop floor is the cost and speed of deployment. "Wired control systems can cost up to $200 per foot of cabling deployed," says Delin. "With the wireless capabilities of the Sensor Web, that cost is avoided, and there is the additional flexibility for the network to automatically reconfigure around changes in the production layout."

RFID could also be added to the sensor network. A sensor pod fitted with an RFID tag could be attached to a mobile piece of equipment such as a forklift so that the piece of equipment could be among the objects monitored inexpensively by the Sensor Web.

From the start, Delin has required that the sensor networks be built from commercially available computing and sensor hardware, in order to benefit from the lower costs of such equipment and the development resources of the broad commercial market. "We use off-the-shelf hardware, but we develop the software and the packaging [the pod enclosure]," says Delin. "The advances in telecommunications and computing markets make microcontrollers—small processing chips that are developed and designed to handle limited or specific data—and other components cheaper and more powerful every 18 months. The large chip manufacturers have made it easy to ride Moore's law." The cost of a Sensor Web pod depends on the sensors that are required, but Delin says the cost can be as little as a "couple of tens of dollars each."

Now RFID is fitting into his plan. "As RFID technology becomes increasingly affordable, says Delin, "it can become a subcomponent of the Sensor Web."

Though Sensor Webs are still in their infancy, Delin believes the potential of such networks to help control environments and industrial processes are enormous. "Sensor Webs are now where PCs were in '81 or '82," says Delin. "They can perform relatively simple tasks today, but there is still a hell of a lot more development that we can do. Instead of asking where will they be deployed in five years time, it's more likely to be a case of, Where won't they be deployed?"