Sensing the world

In the near future, intelligent little sensors are all set to network themselves into a useful web around you

They could be as big as pocket radios, or as small as household dust—tomorrow's biggest pervasive networks are going to comprise tiny sensors, sampling everything on Earth and beyond. The idea is simple, yet startlingly effective—flood the world with a vast number of intelligent network sensors and use them to observe, study and analyse everything around them. That's what the incubators of tomorrow's technology, such as National Aeronautics & Space Administration (NASA), the Palo Alto Research Centre (PARC) and several universities have been working on—wireless sensor networks.

Sensors are all over our world—right from tiny ones that monitor your oven, to those that monitor a car's internal mechanisms. Sensors are also wired into smoke and fire detectors that cover industrial buildings and households. They have a simple job—to sense changes in physical conditions and act on pre-programmed instructions, or relay back information to a central authority. Thus, their behaviour is very predictable.

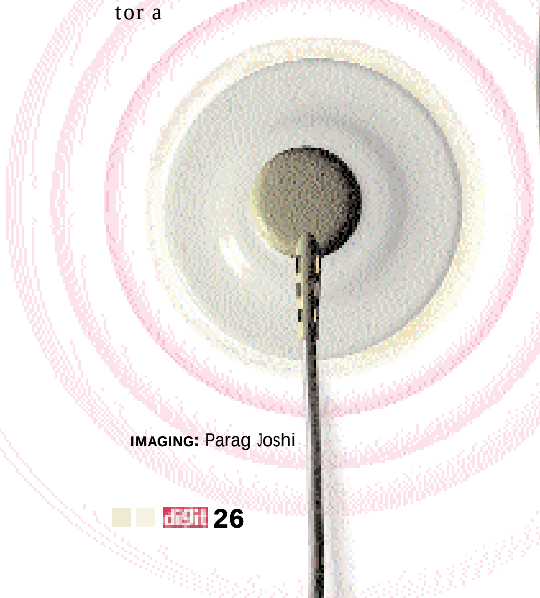
Going web-ing

That's where things are changing. At NASA's Jet Propulsion Labs (JPL)(***http://sensorwebs.jpl.nasa.gov/***), located within the California Institute of Technology, a team of dedicated scientists headed by Kevin A. Delin, is working towards teaming up simple sensors into a gigantic web of sorts. They have christened it the Sensor Webs project, and are looking at the emergence of intelligent, networked sensors, and focusing on acquiring and interpreting physical information over a large spatial area.

The Sensor Webs project is working with fixed, as well as mobile sensor platforms, which are made up of tiny multiple sensors that apart from sensing changes in the environment, can also communicate with each other. However, instead of using few expensive sensors that read and transmit high-resolution physical data such as readings taken over a wide area, the project looks at multiple, low-cost sensors working together with more sensors sampling, analysing and sharing local physical information. Thus, they form a wireless web of sensors that read, share and analyse external conditions, and go even further by reacting and adapting to the environment.

Each of the sensors has a processor, memory, radio transmission capabilities, a battery cell, as well as a solar cell—all of which sits within a plastic body. Each pod holds several such small sensors that first sample the physical characteristics they were designed for, share this information with neighbouring pods, and analyse and alter their behaviour accordingly. The information that is read and processed, hops all along the pod and other pods, till a common point is found from where the data can be shared with a central computing environment, called the base station. Redundancy is built into the web; if one sensor happens to go down, the neighbouring sensors realise this, and adjust their sampling rates in order to make up for the loss. In effect, the sensors are smart enough to understand the information, and then uplink that processed knowledge to the computers and teams monitoring them.

Now all this information has to be easily accessible to the team handling and



IMAGING: Parag Joshi

evaluating this data, irrespective of its location. Hence, JPL has designed these networks such that the data can be streamed on a real-time basis over the Internet, and be accessible from a browser. The sensor pods are built to withstand adverse elements such as rain, temperature fluctuations, etc. JPL is looking at building the sensors using standard off-the-shelf technologies and products such as transmission and sensing equipment. So it's not going to be all that expensive to get the Sensor Web up.

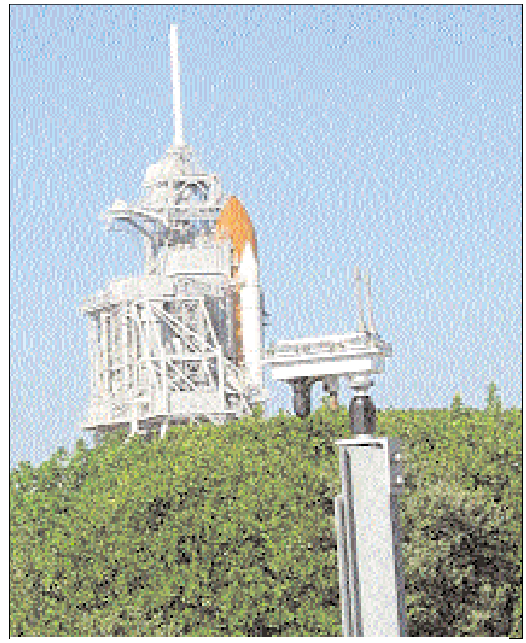
Web in action

Apart from the relatively low costs, what is also very promising is the fact that the webs are up and running at several places, with some success. JPL's teams have got working Sensor Webs in place at the Huntington Gardens, California since the year 2000. Called Sensor Web 3.1, this version shows improvements in the general system design over its predecessors. JPL has designed the v3.1 pods to be relatively more impervious to the vagaries of nature and the environment in which they have been deployed, as well as making them consume less power.

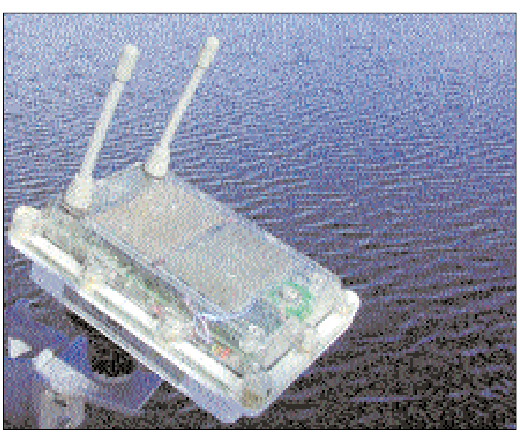
The Huntington Gardens deployment covers a large area, a substantial portion of which is a public place. The pods sample and graph real-time light levels, air temperature and humidity readings. Each pod is mounted very close to the ground, and can be additionally configured to take on readings of soil temperature and soil moisture. The system also allows for monitoring of the sensor pods themselves, and researchers can run check battery status, for example, on a real-time basis. The JPL team is using the garnered data to understand ecological balances in the area. You can dig into the Huntington project details at ***http://sensorwebs.jpl.nasa.gov/resources/huntington_sw31. shtml***.

Sensor Webs have also been deployed at NASA's Kennedy Space Centre, Florida, located right in the midst of a large wild life refuge. Aimed at monitoring the ecology of the area, the sensor pods are mounted in the lagoons located around the shuttle launch pads. All the pods conform to the strict Federal Communications Commission (FCC) rules for radio spectrum usage, and do not interfere with the communications channels used for the space program.

It's also being designed to be deployed in very hostile territory, such as the planet Mars. To test the network over similar conditions, the JPL team set up a Sensor Web in Antarctica. With 14 self-contained battery-powered pods equipped with solar panels, temperature and humidity sensors, and onboard radio communication gear, the team aimed to observe geo-physical phenomena unique to the area. Communication between the sensors was facilitated with two dedicated communication relay pods, and one mother pod that connected to a laptop, which was used to continuously download data from the Sensor Web. The study proved the Sensor Web to be a robust platform for monitoring the physical environment, even in the frozen wastes of Antarctica.



Sensor Web pods, monitoring the environmental conditions near the Space Shuttle at the Kennedy Space Center, Florida, have been rigorously tested to ensure that they confirm to all FCC regulations regarding electromagnetic interference (Sensor Webs Project, JPL, NASA)



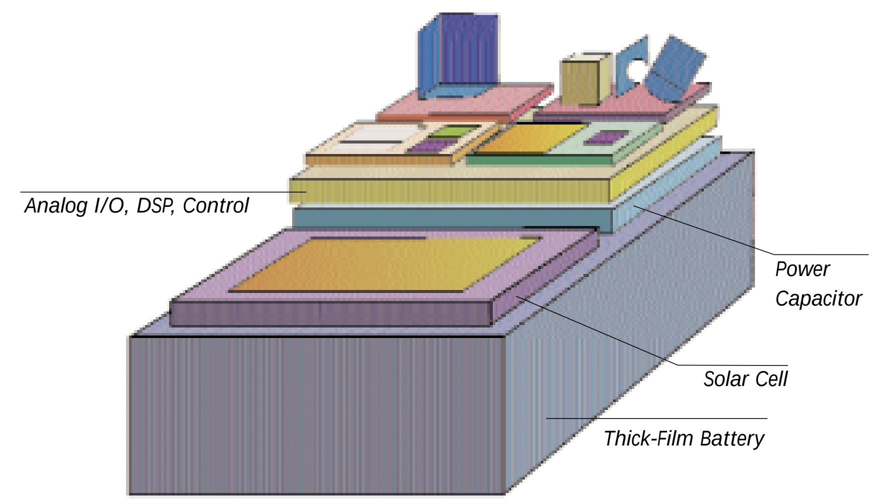
Yet another Sensor Web pod located at the Kennedy Space Center that shows no ill effects even after 5 months of coastal weathering (Sensor Webs Project, JPL, NASA)

Dust that thinks

At PARC, California, Dr. Feng Zhao and teams of scientists are working on several projects that are loosely described as Sensornets, or getting sensors to communicate and form ad-hoc networks of their own to exchange and process information. Research is now focusing on getting tiny cheap sensors—complete with battery power, networking controls and an onboard processing chip—that read, analyse and share information and yet, are so small that they could be mistaken for ordinary terrestrial dust. The applications are immense—right from animal conservation programs, to military applications, there exists tremendous opportunity to exploit networks of information gatherers...and PARC's teams are expecting this within the next 10-odd years.

Not very different in terms of appreciable size, is Smart Dust. Researchers at the University of California's Berkeley campus are working on creating a millimetre-scale platform for a massively distributed sensor network. It will probably turn out to look like a grain of sand—maybe smaller—but Smart Dust is going to come well-wired for computing. Complete with sensors, not-insignificant computational ability and bi-directional wireless communications, this will be cheap to produce and should address a wide range of applications.

Both the PARC and Berkeley's dust motes are going to have to live with very, very small volumes. Power supplies are going to be a crunch; even with solar panels, the idea is to squeeze work out of every joule of energy. Indeed, as in the case of the Berkeley mote, at any given point of time, there will just be a clock and a few assorted timers working. All actions are initiated by a time delay, or by the motes' own initiative. Researchers are, for example, looking at the mote being smart enough to contact the base station, in case something interesting, such as a relayed report or a sensor reading, turns up.



The Smart Dust project motes, being worked upon by the University of California, Berkeley, is going to be a self-contained, millimeter-scale sensing and communication platform for a massively distributed sensor network

Sands of time

Of course, the challenges are still there—current technologies restrict the size of the sensors. It would take some time to create dependable sensors that resemble household dust. Since sensors on the wireless networks (nodes), will need to operate autonomously, they need to have dependable power supplies. The Sensor Webs project for instance, does not look at microscopic devices, yet the implementation at Huntington Gardens was done with solar panels, and each sensor also had a battery.

Another crucial problem is that of actual networking. The sensors currently deployed on the Sensor Webs project, communicate using a mesh-type network, where each sensor links up to other neighbouring sensors on the local net via radio-based connections. With careful network management features built in, the wireless network is maintained as nodes get added or come off the network. Since it makes sense for each sensor to tune in, and talk, as and when required, the network will be dynamic in nature. To keep the network up and going, each sensor is being made smart enough to notice if a neighbouring sensor is going down, in which case, all the sensors around adjust their sampling rates in order to make up for the loss, whilst informing central command about it.

The data routing protocols will be customised for select applications, and will depend on the type of the sensor network. The communication protocols are still not standardised; indeed, there are several factors to be considered for the right protocol, such as battery power consumption, the amount of traffic, efficiency of transmission, as well as the numbers of nodes on the network. Since this is going to be a dynamic and relatively autonomous network, the protocols being considered range from the generalised Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) protocols, to the more exotic Ultra-Wideband (UWB), apart from the basic radio or cell-phone-style communications. Eventually though, each set of applications will use a dedicated protocol.

Information will be managed conveniently on a localised small-scale network. The Sensor Webs project, for instance, can have all the results sent over to a central server, from where, if needs be, each individual sensor can be monitored over the Internet. However, if the network comprises huge numbers of dust-sized sensors scattered just about all over the world, the sheer volume of information is going to be huge. Anticipating this, teams at PARC are working on a prototype search engine that will allow one to query this vast network. It could be the sensor world's Google, and be just as simple to operate. The query posed will be translated into a language that nodes can understand. Intelligent networks will then send back a reply based on the information just learnt. For example, you could query the Internet using this search feature, and find out if you have enough vegetables in your cold storage, or a soldier could query and find out if adequate ammunition is available in the local stockyard.

Dust at work

There's a large market of applications waiting for Smart Dust, and researchers are scrambling to tailor make solutions for it. Funded by DARPA, Smart Dust may be used as battlefield sensors in applications of military importance, as may the Collaborative Sensing project at PARC. In both cases, battlefield sensor style devices seem to be war's new toys.

Other possibilities include improved Human-Computing interfaces owing to tiny sensors mounted under your nails. Sensor-enabled interfaces for the disabled will give them a level of freedom in communications, and in personal interactions with other people.

Inventory control could be a case of a sensor-in-box talking to a sensor-in-shelf, thus enabling you to query and receive accurate inventory checklists instantly. The houses we live in could become intelligent, thanks to sensors that will monitor and accordingly adjust the temperatures inside the house to ensure the perfect day, weather, light…the possibilities are many.

Such sensors could monitor product quality and safety systems in factories, industrial areas and places containing hazardous materials. Sensors embedded in concrete, for example, could tell you when the structure has reached a fatal stress point. The University of California at Los Angeles (UCLA) now uses an intelligent sensor network to monitor seismic (earthquake-related) activity in the UCLA area. Built into buildings and programmed to detect structural damage, they could act as early warning devices. Also, plans are afoot to use it to scrutinise stockpiles and flow of weapons of mass destruction.

This is the beginning

Recent advances in micro-electronics, power supplies, wireless communication and other esoteric fields are working towards wiring up the world, and the possibilities of sensors ringing the world is a not-so-distant reality—from academia to industry, everybody is looking at this turning into a reality within the next decade. And ten years from now, cheap pervasive computing is just what we are going to get, from nano-scale sensor networks located right under our fingernails!

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