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Sensors have it covered

MEMS-packed smartphones double as nodes in a wireless sensor network that's fast blanketing the Earth

The ever-expanding ecosystem of smartphone apps owes a great deal to MEMS sensors. Indeed, smartphones, with their always-on Internet access and growing complement of sensor technologies, are quickly becoming the planet's premier wireless sensor network.

"The cell phone is inherently a sensor; even its microphone gives you information on what type of environment you are in, from background or perhaps traffic noise. By using sensor fusion, you can take information from all of these sensors, even the ambient-light sensor, and create apps that have never been thought of before," noted iSuppli Corp. analyst Jérémie Bouchard.

MEMS sensors in mobile handsets are allowing apps that not only dazzle users but could one day monitor the pulse of the planet. "We are interacting with the world in a more effective manner today because of the MEMS sensors in our mobile handsets; it's not just for the gee-whiz factor anymore," said Karen Lightman, managing director of the MEMS Industry Group (MIG). "All over the world, MEMS sensors are improving the quality of life for those using them."

"Today the Internet is just a brain that can find things and do calculations, but sensors will allow that brain to become aware of its surroundings," said Peter Hartwell, a senior researcher at HP Labs and developer of Hewlett-Packard's ultra-sensitive accelerometer. "We are adding a central nervous system to the Earth that will allow us to get the information we need to understand our impact."

Apple began the revolution by equipping the iPhone with an accelerometer to switch its display automatically from portrait to landscape orientation. The competition quickly followed suit. Now Apple has a storeful of novel apps that exploit the iPhone's accelerometer for gaming, health monitoring, sports training and countless other uses thought up by legions of developers.

The accelerometer's ability to respond to a user's motions has turned previously pedestrian operations (such as manual scrolling) into gamelike experiences (such as tilt to scroll), redoubling users' ardor for their mobile handsets. The race to add accelerometers to an earlier generation of smartphones has become this year's race to add MEMS gyroscopes, and next year's designs are likely to see the addition of barometric pressure, humidity and temperature sensors.

"Smartphones are getting smarter because of all the sensors being added to them; just having an Internet connection does not make your phone smart," said Seve Nasiri, founder of Invensense Inc. (Sunnyvale, Calif.), which brought the first three-axis gyroscope to market last year.

Invensense pitched its gyro to Apple; the OEM bought from a larger vendor, STMicroelectronics. But Invensense, which plans an initial public offering later this year, claims it has many design wins with Android handset makers and predicts that gyro-enabled Android handsets will hit the market by year's end.

"There are two camps now: the Apple camp and the Android camp," Nasiri said. "Apple has the luxury of being able to add new sensors to its iPhone, because of this army of developers they have creating apps that use them. Other smartphone vendors have been envious but were unable to match Apple's App Store.

"Android levels the playing field with an app store [Android Market] that rivals Apple's. Now Android handset makers don't have to identify the next killer application; they just have to add the sensors, and the app store will find the best ways to use them."

Said MIG's Lightman, "I believe there would be no app store phenomenon, if not for MEMS sensors."

The stakes are huge. As the price of some MEMS sensors dips below a dollar, every smartphone vendor is scrambling to match Apple's sensor complement. Hence the booming mobile device market for MEMS sensors, according to iSuppli's Bouchard, who predicts that next year MEMS chips in cell phones will pass the $1 billion mark-up from $821 million in 2010-and that the market will exceed $2 billion by 2015.

The first applications to make novel use of a smartphone's sensors were internal routines for power management that vendors themselves thought up after adding accelerometers to their devices. For instance, if software can deduce from vibrations that a cell phone is being carried in a vehicle, then the phone's Wi-Fi radio can be turned off to save power. Or if the phone is stationary, power can be saved by stopping the constant refreshing of data from the GPS receiver.

While those are smart functions, they do not take advantage of the information available from the multitudes of other smartphones in use. Apps that extend a sensor's range by using data from other phones are the next wave.

"There are two worldwide deployments of wireless sensor networks going on right now," said Benedetto Vigna, MEMS business unit director at STMicroelectronics (Geneva). "The first is in all mobile devices with MEMS sensors-cell phones as well as netbooks, laptops and other handhelds, like smart digital cameras. The second deployment is fixed-location, specialized sensor nodes that don't have all the functionality of a cell phone but are also connected wirelessly to the Internet."

Such fixed-location wireless sensor networks are spreading around the globe for dedicated applications ranging from environmental monitoring to bridge maintenance to emergency preparedness. Hewlett-Packard recently signed a deal to supply its supersensitive accelerometers to Shell Oil Co. for a wireless seismic imaging system that can locate new oil reserves. Meanwhile, smart utility metering systems worldwide are adding MEMS sensors to their wireless nodes.

Japan, for example, is upgrading its nationwide wireless gas meter network with accelerometers that are specialized for earthquake detection.

"Japan always had some kind of [quake] detector network, because earthquakes are so common there. But by retrofitting their wireless gas meters with accelerometers, they will have an improved network where every node is stationary and in a known location, unlike data from cell phones' accelerometers, which are always moving around in people's pockets," said Harvey Weinberg, senior applications engineer at Analog Devices Inc. (Norwood, Mass.)

Fixed-location wireless nets, however, can't keep pace with real-time population distribution, whereas smartphone sensor concentrations fluctuate with the distribution of users. Thus a smartphone-based wireless sensor network capable of monitoring air quality can become a higher-resolution network for toxic gas detection in a packed stadium.

In the United States, application developers are crowdsourcing seismic monitoring. The Quake Catcher Network, sponsored by Stanford University, asks members to volunteer the data from the accelerometers in their Internet-connected devices-mostly laptop and desktop computers-to expedite earthquake detection. The Quake Catcher has inspired a similar project, sponsored by the California Institute of Technology and called the Community Seismic Network, that aims to add data from the accelerometers in smartphones.

For now, these programs are content to document seismic activity; but since earthquakes radiate out from a point, eventually the projects will attempt to detect a temblor's

epicenter quickly enough to give nearby members up to 60 seconds' warning by calling their phones.

Other apps will use data from cell phones to provide less critical but equally utilitarian services. "There are all kinds of apps that could make use of the data streaming in from cell phones. Just knowing where people are is incredibly powerful," said Weinberg. "If a lot of people are waiting at a bus stop, maybe another bus could be added to that line, or in stores [the data from waiting customers' phones might signal that] more clerks are needed at the cash registers. Even the data from the microphone could be useful, for instance, to determine the direction from which a gunshot came."

Apps are available today that let medical doctors remotely diagnose patients, tapping cell phone sensors as diagnostic devices. With just one hour's notice, a service called 3GDoctor lets a patient consult with a doctor via a 3G videophone connection. An automated assistant collects a medical history and information on the symptoms, including, for example, an image of a wound or an audio sample of a cough. A doctor remotely evaluates the information, perhaps texting the patient to ask questions or to request further images or audio, then calls the person to discuss the diagnosis and make recommendations for treatment using the face-to-face capability of videophones that have both front- and rear-facing cameras.

"We have made the smartphone into a medical diagnostic sensor that is smarter than the normal office visit, where you get poked and prodded and they still don't know what's wrong with you," said David Doherty, head of business development at 3GDoctor. "Our belief is that every feature of a smartphone is a potential medical sensor that your doctor can use for diagnosis. You can use the camera and microphone to describe your problem, the display can show images to test your vision, a touchscreen can detect tremors in a finger. [In the future] there will be many more apps using other sensors that will help patients identify their problems for doctors."

For example, Doherty described a future wellness app that would observe people as they slept to determine the best time to wake them up, so that they would feel completely rested upon awakening. Instead of sounding an alarm at a preset hour, possibly interrupting a sleeper's dreams, the app would observe the subject's sleep patterns, analyzing breathing rhythms and tosses and turns, and awaken the individual at the right moment.

Other apps will concentrate on detecting medical emergencies, but without triggering the false alarms that can plague dedicated medical monitoring devices. "For instance, if the ambulance company gets a message from your phone that you've fallen, they can call you back [before sending out an ambulance] to see if maybe you've just dropped your phone," said Doherty.

In a few years, Doherty predicts, services like 3GDoctor will allow users to gather crowdsourced sensor data from other patients to self-diagnose an ailment.

For instance, after you recorded your cough with your cell phone's microphone, the recording could be matched against millions of other recorded coughs from people with known medical conditions.

"3GDoctor is an excellent example of how developers can create useful applications using all of a cell phone's sensors in a novel new ways," said iSuppli's Bouchard.

What's next?

By this time next year, in addition to accelerometers, magnetometers (compasses), global positioning systems, proximity sensors and gyroscopes (for precision motion sensing), many smartphones are expected to have barometric pressure sensors, for measuring altitude. The combined data from accelerometers, gyros, magnetometers and pressure sensors could enable dead reckoning even inside buildings, clearing the way for a slew of location-based services.

"Dead reckoning will improve people's lives by cutting down the time it takes to find things, to prevent people from getting lost, but even more serious applications are emerging for these sensors that could actually save lives," said Lightman. "We have only scratched the surface of the applications to which MEMS sensors can be put."

The next generation of MEMS devices will fuse data from multiple sensors. Inertial measurement units (IMUs) will combine an accelerometer, gyroscope, magnetometer and barometric pressure sensor on a single CMOS die. The three-axis gyroscope will allow precise headings to be maintained while the three-axis accelerometer measures linear motion and the three-axis magnetometer keeps the map for the user's location oriented correctly. The pressure sensor will enable the "tenth axis" by measuring altitude, thus allowing location-based apps to pinpoint a user's location by floor within a building.

"Within five years at Invensense, and probably at other MEMS vendors too, we will be marketing a complete 10-axis IMU on the same CMOS die," said Nasiri.

Other MEMS chip makers are also preparing integrated IMUs, but on a shorter timeline, by virtue of housing several MEMS chips in the same package. "ST will have an IMU in a single package within 2-1/2 years, but it will probably house multiple MEMS chips inside," said Vigna.

Vendors also plan one-size-fits-all combo sensors that could monitor the environment in a global mesh of Internet-connected handsets covering the Earth.

"We are working on a single-package environmental sensor that would measures temperature, humidity and pressure, and possibly also house a gas sensor," said Vigna.

Gas sensors are being designed to detect a wide spectrum of chemical and biological agents. Such sensors will range from infrared LED-based assays, cheap enough for inclusion in any phone, to ultraprecise laser-based spectroscopy chips that could enable high-end smartphones to determine all the substances floating around in "your" air-eventually even identifying airborne microbes from the guy coughing at the next table over.

All of these services will create a new layer over the Internet, composed of all the measurements that can be made at every node on the global wireless network, according Rich Duncombe, a distinguished technologist and strategist in HP's technology development group.

"Adding this extra layer of sensing on top of the Internet is the fourth [IT] wave, which we are just now entering and which will take about 20 years to complete," said Duncombe. "We have passed through the initial three information technology waves-mainframe computers, personal computers and networked computing-and are currently in the fourth wave, or the wave of 'IT everywhere.'"

Sampling of sensor vendors

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Manufacturer Epcos Accelerometer Gyroscope Pressure Microphone ✓ Oscillator

Manufacturer Freescale Accelerometer ✓ Gyroscope Pressure ✓ Microphone Oscillator

Manufacturer Gladiator Technologies Accelerometer ✓ Gyroscope ✓ Pressure Microphone Oscillator

Manufacturer Hewlett-Packard Accelerometer (sampling) Gyroscope Pressure Microphone Oscillator

Manufacturer Invensense Accelerometer ✓ Gyroscope ✓ Pressure Microphone Oscillator

Manufacturer Kionix Accelerometer ✓ Gyroscope Pressure Microphone Oscillator

Manufacturer Knowles Accelerometer Gyroscope Pressure Microphone ✓ Oscillator

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