John Edwards

Wireless Sensors Relay Medical Insight to Patients and Caregivers

In labs around the world, researchers are working on a new generation of wireless medical sensors and related networking technologies. Wearable sensors, whether functioning alone or connected into multinode body areas networks (BANs), are designed to help clinicians and other caregivers accurately monitor patients' temperature, heart rate, brain activity, muscle motion, and other critical data.

"The idea there is to have very light, basically disposable sensors that would be worn on the body to perform standard medical monitoring," says Bernie Liebler director of technology and regulatory affairs for the Advanced Medical Technology Association (AdvaMed), a medical device industry trade group based in Washington. "If you can do enough monitoring and collect enough information, then you would know what's happening with a patient, which would help a physician recommend a course of action," Liebler says. He notes that wireless sensor technology can also be used to give patients various types of audio and visual feedback, allowing them to relearn or readjust motion-oriented body actions affected by disease or accident. "The opportunities appear to be wide open at this point," he says. "New applications are appearing all of the time."

IMPROVING CARE AND CUTTING COSTS

Sensor technology developers as well as many medical industry business analysts feel that standalone sensors and BANs have the potential to both improve health care and lower costs by nipping lurking medical problems in the bud and speeding rehabilitation. But exactly how big an impact the technology will ultimately make on care and costs remains a matter of conjecture. "Any potentially highly beneficial technology will change the force of health care in some way," Liebler observes. "Whether it's large or small, you really can't tell in advance." Yet Liebler notes that evidence is rapidly mounting that sensor technology could revolutionize health care in much the same way that personal computers forever changed the way offices function. "There are some pretty large companies behind this [research] and they have a pretty firm belief about it," he says. "There are also many clinicians who also believe in it."

Like almost any promising technology, medical sensor research is being approached from a variety of directions. IMEC/Holst Centre, a wireless solutions research institute located in Eindhoven, The Netherlands, for instance, is addressing multiple conditions, including epilepsy, heart disease, and sleep apnea, with its sensor-driven prototype body monitoring system.


WASHINGTON UNIVERSITY

Dr. Chengyan Lu with a testbed network circuit card.

"If you develop sensors that measure all kinds of physiological signals—like heart rate, blood pressure, muscle tension and movement, and maybe even brain signals—you can combine this information and send it to a reader device, usually a mobile phone or laptop," says Harmke De Groot, ultralow-power wireless and digital signal processing (DSP) program director at IMEC/Holst Centre. "You can then analyze the data and do what we call personal health care."

BANs, such as the kind being developed at IMEC/Holst Centre, are designed to provide either continuous or time-frame-delineated insight into potentially life-threatening conditions. "You can, for example, detect if you're going to have an epilepsy attack, which can really help patients and caregivers," De Groot says. "It's also a very useful technology to detect and diagnose certain types of cardiac arrhythmic problems." She notes that many arrhythmic problems only appear immediately after the patient stands up or begins exercising. "If you have a [wireless] electrocardiogram (ECG) patch with a radio link sending all the data to your mobile phone and collecting it, you can be easily be monitored," De Groot says. "The doctor can look at the data and see if there's an issue, something that needs to be done." The technology can also be used on post-operative patients. "If they want to send you home but still want to check up on you," De Groot says. Other potential users include people living in nursing homes and other types of long-term care facilities.

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Wireless sensor monitoring is also poised to play an important role in patient rehabilitation. At the University of Bologna, Dr. Lorenzo Chiari, an assistant professor of biomedical engineering, is developing sensors for the European Union-sponsored project called CuPid, which stands for "closed-loop system for personalized and at-home rehabilitation of people with Parkinson's disease," a project that aims to provide personalized rehabilitation exercises for home-bound people with Parkinson's disease (PD).

People with PD suffer from motor and cognitive impairments that severely impacts their mobility and increases the likelihood of falls, "gait freezes," and other physical events that threaten functional independence, explains Chiari, who is also vice director of health sciences and technologies at the University of Bologna's Interdepartmental Center for Industrial Research (HST-ICIR). Until recently, PD treatment goals focused almost exclusively on symptom relief. Yet ongoing research by CuPiD partners and other PD experts now shows that motor learning activities can provide effective rehabilitation.

To address the needs of PD patients, CuPiD partners are developing a home-based personalized rehabilitation system including wearable sensors that enable audio biofeedback, virtual reality images, and other rehabilitative services. The training provided is unique to each patient and can be remotely monitored by physicians, nurses, and other caregivers. Besides providing enhanced and convenient therapy to PD sufferers, the technology is also expected to lower the cost and burden of traveling to a rehabilitation center.


IMEC/HOLST CENTRE

Harmke De Groot of IMEC/Holst Centre.

The CuPiD system uses wireless sensors to monitor the unique physical patterns experienced by PD patients. "They are used, for example, in the detection and prevention of the freezing of gait, which is a typical problem," Chiari says. "[Patients] freeze sometimes in a very unpredictable way and they're unable to move—to walk or to do what they intended to do—unless they receive an external stimulation."

Chiari says that wireless inertia sensors he works with generate data on both voluntary and involuntary body movements and can be used to help PD patients gain a measure of control over their symptoms. "The idea is to use wearable sensors to, first of all, better characterize this abnormality and then to help build some predictive algorithm," he says. The sensor data can also be used to power external stimuli, such as a biofeedback-initiated audio alert, which can help the patient prevent or halt a disabling event like a gait freeze.

For customized training and rehabilitation, Chiari is developing wearable sensors and related technologies that interact with virtual reality devices. The goal, he says is "to produce an immersive environment using a consumer video game system like a Nintendo Wii or PlayStation 2. "It will be a video game-like tool to help better train their functionality," he says.

Wireless sensor technology is crucial for meeting CuPid's objective of creating a system that doesn't physically hinder people who already face significant mobility challenges. "That definitely requires that the solution be wireless, as small as possible, and as limited as possible in terms of weight and size… allowing us to add this [system] as an object in [patients'] daily lives," Chiari says.


UNIVERSITY OF BOLOGNA

Sensor-delivered audio biofeedback can help a patient with PD maintain control over body movements.

MONITORING ON THE MOVE

Researchers are also hoping to use wireless sensor technology to create around-the-clock patient monitoring environments for hospitals and other medical facilities. Barnes-Jewish Hospital in St. Louis, Missouri recently tested a sensor network that allows vital signs to be tracked as patients move about the facility during convalescence or while waiting for tests or other procedures. The system, developed by researchers at nearby Washington University, monitored at-risk patients, measuring blood oxygenation and heart-rate readings at rates of once or twice a minute. The data was then transmitted to a base station where it was merged with other information in the patient's electronic medical record, such as lab test results.

Data collected by the system was continuously scrutinized by a machine-learning algorithm for any indications of clinical deterioration. Whenever a potential problem was detected in a patient's data stream, the system automatically placed a phone call to a nurse or other designated caregiver, alerting the individual to check on the patient.

The idea behind the test system was to create a virtual intensive care unit (ICU) "where the patients aren't wired to beeping machines and instead are free to move about as they please," says Dr. Chenyang Lu, a Washington University professor of computer science and engineering. "Patients in general hospital wards are usually monitored manually and infrequently today," Lu observes. In contrast, wireless medical sensors can supply continuous real-time monitoring of patients' vital signs, providing early warnings of possibly serious medical events.

The Barnes-Jewish Hospital test, which was conducted between 4 June 2009 and 31 January 2010, "demonstrated the feasibility of deploying a highly reliable, low-power wireless sensor network for continuous vital sign monitoring of hospitalized patients, Lu says. "In fact, our network achieved high reliability—a median 99.68%."

During the test, consenting patients wore a telemetry pouch around their necks. A finger-mounted pulse oximeter measured blood oxygenation and heart rates. The sensor nodes transmitted the oximeter data via 79 relay nodes scattered across the hospital to a base station, where the information was stored in a database.

Lu notes that while some IT and health-care experts have expressed doubts about the reliability of low-power wireless sensor networks in a hospital setting, the clinical trial showed that high-quality performance is achievable. "Our results also indicated that the vital sign data—heart rate and oxygen saturation (SpO2)—collected by our system has sufficient resolution for detecting clinical deterioration," Lu says. To help ensure seamless coverage and optimum reliability, the system's relay nodes were programmed into a self-organizing mesh network, which meant that if one node suddenly dropped out, the data packets could simply take another path to the base station.

Lu is now looking forward to proving the system's capabilities on a wider scale. "We want to build a robust clinical warning system and validate it through large-scale clinical trials," he says. "We hope to see such clinical warning systems gain widespread adoption to improve the outcomes and quality of hospital care." Lu also hopes to see wireless medical sensor networks move into homes, businesses, and other settings "so that we [can] also provide health monitoring and warning to the public, especially those with high risks due to various health conditions."

[POWER AND DEVICE SIZE ARE THE BIGGEST BARRIERS PREVENTING THE WIDESPREAD DEPLOYMENT OF SENSORS AND BANs.]

SIZE AND POWER CHALLENGES

Power and device size are the biggest barriers preventing the widespread deployment of sensors and BANs. "Battery life is important in terms of autonomy, so we need a long battery life," Chiari says. De Groot notes that achieving maximum autonomy and power efficiency requires creating small and highly efficient power sources. "The electronics have to be extremely low power," she says. "A normal coin cell battery is usually between 100–200 mA hours." Yet sensors, whether standalone or connected to a BAN, need a reliable power source that's much smaller than a typical coin battery. "You are probably going to have a printed film battery, maybe 6 cm^3 or so, and you are going down to 6 mA hours," De Groot predicts. "A major challenge in developing BANs is to bring overall power consumption down to a level where the system can be powered by energy harvesting (using a patient's ordinary physical motions to create power) or a microbattery that runs for months."

IMEC/HOLST CENTRE

A prototype headset, developed at the IMEC/Holst Centre, is capable of recording high-quality EEG signals and transmitting them wirelessly in real time to a receiver at distance up to 10 m away.

For now, IMEC/Holst Centre and Eindhoven-based semiconductor manufacturer NXP have developed an ultralow power biomedical signal processor, the CoolBio, that's designed to meet the energy requirements of planned BANs. De Groot notes that the CoolBio allows BAN sensor nodes to draw less power. Processing and data compression is performed locally on the BAN node, limiting power-wasting wireless data feeds while simultaneously adding motion artifact reduction and smart diagnosis functions.

De Groot observes that the new biomedical signal processor consumes only 13 pJ/cycle when running a complex ECG algorithm at 1 MHz and 0.4 V operating voltage. This C-programmable chip is voltage and performance scalable supporting a frequency range of 1 MHz up to 100 MHz with an operating voltage from 0.4 to 1.2 V. "We designed the CoolBio on the concept that if there's nothing to be done, then don't waste energy,'" De Groot says.

Lu also strongly believes that energy conservation is important to BAN success. "We learned the importance of minimizing human efforts in hospital environments where nurses are very busy," he says. "For example, we designed our wireless pulse oximeter to properly manage its power consumption so that its battery can last through the entire monitoring period of a patient—no more than 72 h in our trial—so that nurses do not need to replace the battery."

Regardless of the specific application, all wireless sensors rely on signal processing. "Robust signal processing is important to deal with the noise and impacts of patients' motion," Lu says. "It is important for sensors to be able to provide reliable measurements [despite] motions."

Chiari also feels that signal processing plays a crucial role in wireless medical sensor development. "From a variety of wearable sensor signals, like acceleration and angular velocity, we address events in real time, such as falls, transitions, and freezes," he notes. "It's vital to efficiently compress data to achieve efficient wireless low-power systems; filtering out, in a robust way, tremor from actual motion signals; real-time transcoding physical signals into sensory signals and providing sensory augmented experiences such as in biofeedback and neurofeedback solutions." Chiari notes that each one of the these processes involves a different DSP technique.

FUTURE TRENDS

While many observers are taking a "wait and see" approach on wireless medical sensors, Lu doesn't hesitate to state his enthusiasm for the technology. "It is one of the most important [technology] areas in this century," he says. "We are facing tremendous challenges with skyrocketing health-care costs, and the trend will get much worse with the aging society in the United States and many other countries in the world," he says. Lu feels that medical sensors are destined to play a major role in improving patient care and cutting costs. "This is one area where engineering and science can really make a revolutionary contribution to society," he says.

De Groot, like many other people involved in BAN research, feels that sensor use will eventually branch out from patient-care applications and into everyday life. She looks forward to a day when inexpensive BAN technology is integrated into clothing, sports accessories, and other personal items. But before this can happen, BAN technology will have to get smaller and less power hungry. "In the end, if you also want to use it on healthy people and on people going on in their daily lives, then miniaturization and integration is really, really important," she says. De Groot predicts that creating a BAN could eventually become as simple and convenient as slapping on a few Band-Aids. "Like an ECG patch that you just put on your skin and you put clothes over it—then you don't see it anymore."

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