News

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Pervasive Medical Devices:

Less Invasive, More Productive

David Geer

Wireless, robotic, and computer-backed medical devices are interfacing across the landscape, racing to accident scenes, performing surgery, and monitoring long-term care for young and old alike. With the potential for improved healthcare and long-term cost savings, pervasive devices offer healthcare some intriguing new alternatives.

ROBOTIC SURGERY

Orthopedic surgeons operate with a hammer, chisel, and saw. In knee replacement surgery, this means cutting where the replacement should go without cutting away too much bone or damaging surrounding sinews and ligaments. This difficult procedure, which depends on a surgeon's accuracy, raises considerable safety issues. That may be about to change.

At the Imperial College, London, Justin P. Cobb, chair of orthopaedic surgery, and his colleagues have developed Acrobot (Active Constraint Robot), a robotic surgical system that constrains partial knee replacement to safe, accurate parameters.

The surgical system consists of a standard PC, a real-time controller board, surgical planning software, and a robotic arm with drills and cutting tools. Imperial College medical-robotics engineers designed the Acrobot prototype, and Imperial College surgeons tested it.

Human guidance

To plan the operation, a surgeon uses the planning software to model the patient on screen using the patient's CT scan. The surgeon then conducts virtual surgery on the damaged knee, putting the replacement in exactly the right place. According to Cobb, this preplanning sets the software boundaries that will enforce the hardware boundaries around what the surgeon may and may not do in live surgery.

The purple hardware device suspended above the patient's knee is the Acrobot arm. The knee is open for surgery with rods holding it in position. The surgeon's hands [lower right] operate the force control handle during surgery.

During live surgery, the Acrobot arm is manipulated with a force control handle that senses the force and direction of the surgeon's movements. The computer uses this information to compare the surgeon's actions with allowed parameters and applies resistance using brakes to keep the operation within preplanned boundaries (that is, the space in which the surgeon can operate safely and accurately). A color-coded computer screen display also helps guide the surgeon by showing where the drill or cutting tool is within these constraints.

The surgical system knows the robot arm's location at all times based on information from encoders and software. When the surgeon moves the drill to within two millimeters of the safe, accurate boundaries, the robot applies its brakes and the surgeon feels a noticeable resistance. Between two millimeters and the edges of those boundaries, that resistance ramps up exponentially. "You actually have to push to get to the edges," says Cobb.

Healthcare benefits

In most cases, patients have recovered more quickly from robotic than

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in brief...

Bridging the Digital Divide

Benjamin Alfonsi

Across the globe, efforts are being made to narrow the digital divide—the wide split between those who have effective access to computing technology and those who don't. Many people rightly assume that, for the most part, these efforts are aimed at developing nations. But what about similarly situated people in rural or urban parts of developed nations, including the US? Is there sufficient overlap between the technological problems confronting developing countries and those confronting economically challenged areas in developed nations to spur a common solution?

THE SAME ... ONLY DIFFERENT

According to Matt Jones, associate professor of computer science at Swansea University in the UK, the issues affecting disadvantaged people in both developed and developing nations, with respect to computing and technology, are largely similar.

At Swansea's Future Interaction Technology Lab, Jones and his colleagues work on digital-divide issues, developing new mobile and ubiquitous computing interaction concepts. "In developing contexts, so many people are on the wrong side of the digital divide that the problem is more apparent," Jones says. "And [that is] perhaps more attractive for the market."

Ben Shneiderman, a computer scientist at the University of Maryland in College Park, agrees. "Poverty, illiteracy, poor health, and minimal technology experience are common aspects in disadvantaged parts of the US as well as developing nations, but the severity [in developing nations] is much greater and harder to remedy because of the lack of infrastructure."

According to Walter Bender, president of software and content of the One Laptop Per Child (OLPC) organization (http://laptop.org), cultural acclimation to technology is a much greater issue. "Alan Kay once said that technology is anything invented after you were born," offers Bender. "But in the case of [developing nations], it is as much a matter of when your culture would have been exposed to it."

Although the issues affecting all intended beneficiaries of digital-divide programs might be similar, the solutions to those issues might be very different. "Solutions that work in the developed countries cannot simply be transplanted to developing-country environments," says Vincent W. Bagiire, CEO of bridges.org. "Solutions must be based on an understanding of local needs and conditions."

The metamessage, says Jones, is to ensure that both the public and private sectors understand the importance of people-centered design. Involve the end users from the beginning of the process. Get the actual users to comment on newly designed prototypes. "If a project tries to impose a 'solution' without first understanding their needs and wider

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conventional surgery. Patient expenses were lower because they left the hospital sooner.

According to Cobb, surgeons can rely on the technology to operate precisely, with small incisions. Improving surgical accuracy improves patient outcomes—replacements work better and last longer—and could eliminate the need for additional operations.

Another outcome is that the technology makes knee replacement surgery less complicated, making it possible for less skilled surgeons to be very good at it—so it's ultimately less expensive. "When you 'deskill' something, you make it cheaper," says Cobb.

Results

This surgical system will likely face resistance from surgeons or patients who mistrust the technology. However, Cobb reports that their testing showed that Acrobot helped surgeons place artificial knees within two millimeters of planned placement 100 percent of the time. Control group surgeries were this accurate only 40 percent of the time.

WEARABLE MEDICAL DEVICES

While some medical devices such as Acrobot require the patient to come to the technology, many pervasive devices bring the technology to the patient.

CodeBlue

Exploring wireless sensor network technology for medical applications, the CodeBlue project (www.eecs.harvard.edu/~mdw/proj/codeblue) is a collaborative effort of Harvard University, the Boston Medical Center, the Spaulding Rehabilitation Center, the Boston University School of Management, the Johns Hopkins Applied Physics Laboratory, and 10Blade. CodeBlue seeks interest and collaboration from medical researchers, disaster response teams, and the business sector.

CodeBlue's research focuses on wireless sensor networks composed of *motes*—small devices generally consisting of a processor, memory, low-power radio, antenna, and power supply. The motes incorporate sensing, computing, and radio capabilities in small form factors with low power requirements. This facilitates mobility, allowing motes to gather data such as vital signs continually over long periods within the patient's natural environment. Doctors and nurses can use that data for real-time triage and large-population studies over time, according to Matt Welsh, assistant professor of computer science at Harvard University.

context, it is likely to fail," he says.

This might be another reason why economically challenged areas in developed nations are often excluded from such programs. "The approach is always to be in close touch with the users to understand their genuine needs, then try pilot projects, and scale up," says Shneiderman.

MOBILE MOTIVATION

Jones cites mobile technology as often being the first step or harbinger of a technological revolution. "In developing contexts, mobiles have been heralded as a 'leapfrog' technology, a way for certain countries to catch up with the developing world," Jones says. "The same is true for the disadvantaged sectors in developing countries themselves."

The reasons why conventional computing resources might not be having an impact in developing countries, he says, include limited reach of wired networks, prohibitively high cost, and societal factors such as lack of living space and privacy issues—the PC is often shared at home or controlled at work.

Mobiles, on the other hand, are referred to as "relationship appliances" or "personal technologies" precisely because they keep people connected to friends, family, news, and entertainment whenever and wherever they are. "Because such relationships are fundamental to all communities, the mobile's universal appeal is not hard to understand," says Jones.

Although mobile devices have limitations, particularly in terms of how they present information, Jones says societies will likely view access to technology as an essential right, and he expects to see more mobile computing initiatives to narrow the digital divide.

However, Bagiire points out that companies such as Voxiva (http://voxiva.com) originally developed telephone-based information systems for countries with illiterate populations and little or no Internet infrastructure, only to have to redesign them for use in the US and elsewhere.

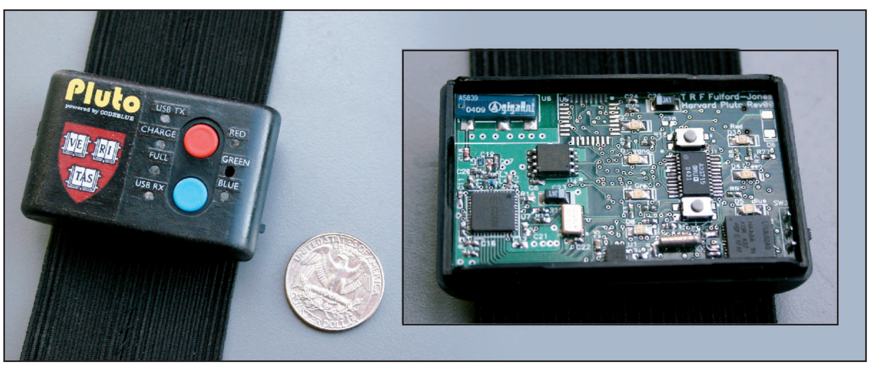
"If a software company develops a cheap, simple version of its popular software for use on older hardware—which it can sell to developing-country markets where refurbished computers are common—it does not want to see [that software] resold in developed-country markets where it might encroach on market share for heftier products," says Bagiire. In the developed countries, "they want to keep people 'buying up.'" He says the same situation exists with hardware.

According to Bender, there is no reason why certain technologies aimed at benefiting underdeveloped nations could not also benefit developed nations—except for having some features that he says might be superfluous, such as a hand crank for battery power. So are there any plans for OLPC to target needy children in the inner cities or rural areas of the US? "Certainly," says Bender. "But it's just not where we are starting on day one."

Pluto mote. One of the smallest motes is Pluto, a lightweight device that can be worn like a wristwatch. Patients can wear several Pluto motes to monitor such things as heart rate and respiration, explains Welsh. These sensors capture the data and upload it to a PDA, laptop, or PC residing in the patient's home.

The Pluto mote integrates the same components found in larger sensors (microprocessor, memory, battery, and so on) onto a single circuit board, saving size and space. Other space savers include a lightweight rechargeable battery and a surface mount antenna.

The Pluto mote employs an integrated three-axis accelerometer (used in motion studies). "We are working with a group at the Spalding Rehabilitation Hospital, studying patients with Chronic Obstructive Pulmonary Disease (COPD), Parkinson's disease, and stroke," says Welsh. In those applications, researchers look at patient limb movements during various activities. With Parkinson's disease, for example, one complication is tremors, in which the patient is afflicted with unexpected and uncontrollable limb movement. "Some of this is caused by the disease and some is a side effect of the medication that is intended to control it," says Welsh. Pluto motes can help researchers monitor limb movement in order to better predict tremor episodes and adjust medication dosages to head them off.



The Pluto mote, a lightweight sensing device that can be worn like a wristwatch.

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Vital Dust mote. The Vital Dust mote-based pulse oximeter uses GPS to track a patient's location en route to the hospital while continuously monitoring heart rate and blood oxygen saturation.

Sensors record vital signs in real time and pass them to a sensor gateway on the ambulance, which forwards the data to the hospital using either a cellular EVDO (*ev*olution *d*ata *o*ptimized) connection or an Iridium satellite connection. If the Vital Dust hardware can't connect to the gateway immediately, it can store the data in onboard memory until it can, so that nothing is lost, says Steven Moulton, associate professor of surgery and pediatrics at the Boston University School of Medicine.

In emergency response situations, such pervasive medical devices provide emergency room doctors with information about the number of incoming patients and their vital signs in advance. This helps them better prepare for the patient's arrival.

IBM

IBM is integrating existing Bluetooth-enabled sensors and smart phones with its WebSphere technology (www.ibm.com/websphere) to offer medical-device solutions in pilot tests under the Personal Care Connect Mobile Health Monitoring Solution. According to Kathy Schweda, a pervasive healthcare solutions executive at IBM, the technology and devices take data streams from Bluetooth communications, gather them on a cell phone near the patient, and send that data over an encrypted VPN tunnel to a server. There, the healthcare provider, insurance company, employer, or payer can use the information for such things as managing chronic conditions or monitoring the elderly.

IBM chose Bluetooth over other wireless technologies, such as Wi-Fi, because it consumed less power and was less expensive. Additionally, with its smaller transmission range, Bluetooth keeps data within a five- to six-meter radius. "It is less likely to be hacked," says Schweda.

Kidney failure pilot. At the Imperial College in London, IBM is combining its mobile health monitoring with Bluetooth-enabled scales and blood pressure cuffs from A&D Medical to monitor young adults and children with kidney failure. According to Schweda, these devices monitor patient blood pressure and weight to manage their fluid levels. The data, received by an Ericsson smart phone, is transmitted to a backend server, which makes the information available to medical professionals at hand. Nurses can monitor many more children at one time, checking the transmitted data for trends such as weight gain, rising blood pressure, and rising heart rate and alerting a physician when a patient needs attention.

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These monitoring tools can also help improve the patients' quality of life. "They can avoid coming in to see their primary care physician or coming in for dialysis earlier," says Schweda.

Diabetic monitoring. IBM's Personal Care Connect technology also has a pilot project to monitor diabetic patients. Using Johnson & Johnson's Lifescan glucose meter as the end device gives patients access to a very small, portable device for testing their blood sugar levels that can report the results to healthcare providers. The devices offer another long-term benefit, by providing closer blood sugar monitoring. This helps those monitored correct elevated levels more quickly and delay amputations, according to Schweda. This technology also lets doctors see graphs of the device readings, providing a better idea of how the data varies over time and what it looks like over long periods, says Maria Ebling, research manager of privacy-enabled context technologies at IBM.

Healthcare costs are positively impacted when timely, quality care leads to better outcomes and shorter hospital stays. According to Moulton, this will come through data mining. Mined data, taken via these sensors over time, has a predictive quality; when healthcare providers see similar data with patients in real time, they can act on it immediately, improving their precision.

Most of the technical challenges to the CodeBlue wireless-mote project involve developing sensor networks that can successfully route patient data from multiple sensors while avoiding network collisions. "Three sensors are no problem. Once you get up to six sensors, then the information collides and a lot of it doesn't get through," says Moulton.

Other challenges include adoption, which is impeded by the lack of technical training of many physicians. "As newer, younger people come into the system—people who are comfortable with handheld computers and the Internet, who are knowledgeable of the power of computing—things are going to change," says Moulton. Developers also need to create readable font sizes for the elderly and devices easily used by small children and older adults, says Schweda.

The biggest challenge is getting someone to pay for these technologies. The diabetic-monitoring kits can run upwards of US$1,500 for the blood pressure cuff, scale, glucose monitor, and phone. "The current reimbursement models for the payers don't accommodate these kinds of preventive measures in most cases," says Schweda.