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Ultrasound? Fetal Monitoring? Spectrometer?

There's an App for That!

By Leslie Mertz

Biomedical Smart Phone Apps Are Taking Healthcare by Storm

If you think your doctor is a mobile phone junkie now, you haven't seen anything yet. A profusion of new software applications, or apps, are either already here or coming soon to convert smart phones into biomedical devices that will play a larger role in healthcare. Engineers, computer programmers, medical professionals, and other researchers are jumping on the bandwagon to create apps and add-on devices, or peripherals, that turn a smart phone into a microscope, an ultrasound machine, or a heart-rate monitor, just to name a few.

Why Smart Phones?

One of the reasons for the boom in biomedical apps is that smart phones are incredible devices. They have powerful processors, considerable memory, an ample touch screen with amazing graphics, and built-in wireless connectivity for e-mail and Internet access. "They also have enough power to run third-party apps and peripherals, making them a valuable platform," said Satish Misra, M.D., senior editor at iMedicalApps.com, a Web site devoted to helping other health-care providers not only to find useful apps and devices but also to understand what is happening in mobile health technology. Misra is also

Digital Object Identifier 10.1109/MPUL.2011.2181019
Date of publication: 22 March 2012

2154-2287/12/$31.00©2012 IEEE

a second-year medical resident in internal medicine at Johns Hopkins University.

"The biggest benefit here is that you're taking an industry where there are billions and billions of dollars coming in from a huge consumer base and being invested into developing these devices. As a result, the industry is making these devices very sophisticated and packing in enormous amounts of computing power that's well beyond what the average consumer needs. It's almost like an arms race between every manufacturer, and the consequence of that is that these devices can do so much more than what they're marketed for," Misra noted.

Another reason for the boom is that a growing crowd of medical professionals already has smart phones and craves new and innovative apps. According to the 2011 Jackson and Coker Industry Report [1], more than 80% of physicians use some sort of smart phone, and a similar percentage use apps in their work everyday. Likewise, a survey of medical providers in Accreditation Council for Graduate Medical Education (ACGME) training programs revealed that more than 85% of respondents used a smart phone and half used apps in their clinical practice [2].

These health-care providers are the ones who are driving the app boom, said Misra, noting that the manufacturers aren't touting their smart phones as medical devices. "This is all very homegrown," he said. "One thing that we hear from institution after institution is that the physicians and nurses and other providers are the ones who brought this technology into the hospital, and then the information technology folks had to start catching up. I think when you have that almost grassroots implementation, the trend is bound to continue toward increasing the function."

A Bushel Full of Apps

Medical-related smart phone apps fall into three general categories. The first is reference and clinical-decision tools for health-care providers. Heralding back to the PalmPilot days, health-care professionals are already familiar with apps that serve as electronic libraries. "Every health-care provider who had a PalmPilot had Epocrates (a drug reference), and that's still probably the most commonly used smart phone app today," Misra said. Other currently popular apps are medical calculators and broad-based clinical references, such as the medical resource Medscape, that provide information about everything from diseases and symptoms to drugs and medical news.

The second category is apps directed at patients to educate them about their conditions and encourage them to take the necessary steps to stay healthy. "I think this will be an interesting area to watch," Misra noted. "We're starting to see a lot more sophisticated patient-education apps come out, and some really inventive things are on the horizon."

The third emerging segment is oriented toward mobile devices. According to Misra, "More and more, we're seeing smart phones become a nexus of modular peripherals, where the peripherals all plug into the smart phone and use the computing power of the smart phone itself or even use the smart phone as a power source to run the peripheral, we're talking about peripherals that go with the smart phone, so potentially plugging in an ultrasound, a flu screener, a blood-glucose meter, and an electrocardiogram (ECG/EKG) all into one device." Rather than having to rely on a collection of separate and large diagnostic machines, the new apps would allow a health-care provider to carry a few small peripherals and one phone. "We'd have both mobilization and the opportunity for centralizing all of these peripherals around a single device," he added.

Mobisante's system is a complete package that includes a cell phone and the ultrasonic transducer that plugs into the phone.

That usage will have particular value in under-resourced areas, he asserted. "For example, in Baltimore, which is where I am, we have two major academic centers and about half a dozen of other medium-sized hospitals; so there are many resources here in terms of healthcare," he said. "On the other hand, if you go to somewhere in sub-Saharan Africa where a health-care worker needs to get out to some remote area to do AIDS surveillance, that's the person who would really benefit from being able to plug a device into a smart phone, do the test, collect the data, and then upload and transmit the data by whatever system is available there for wireless communication. There's tremendous potential there."

Beyond these three categories of reference and clinical tools, patient-education apps and mobile devices, a national push is under way to encourage doctors' offices to switch to electronic health records (EHRs), which is another ripe area for new apps. EHR vendors are already releasing tablet versions of their software, and smart phone versions will be close behind. According to Misra, "The practice of medicine is going from laptop to mobile in terms of documentation, order entry, and things like that." Overall, he added, "The trend is certainly going to continue to increase the utilization of mobile devices for medical practice."

Devices: Portable Ultrasound

At conferences, in professional journals, and in the mainstream media, biomedical smart phone apps and peripheral devices are pushing their way into the spotlight. "For example, Mobisante is a company that has an ultrasound probe that plugs into a smart phone," Misra said. "It's a really cool idea."

The two chief drivers behind the new phone ultrasound system were portability and low cost, said David Zar, chief technical officer and cofounder of Seattle-based Mobisante and also a research associate and instructor in the Computer Science and Engineering Department at Washington University in St. Louis. The device, which is available commercially, is useful for cardiovascular and obstetrics care as well as other health-care screenings. "I've been doing ultrasound for about 20 years, focusing on low cost," Zar said. A few years ago, when cell phones became as powerful as laptops and desktop computers, "we realized that we could use a phone as an ultrasonic imaging device" (Figure 1).

The phone ultrasound system can fill some health-care gaps, he said. "The standard of care these days is imaging," he

FIGURE 1 Mobisante developed a complete phone-and-ultrasound package that offers low cost, ease of use, and portability. The company believes it will be especially beneficial in low-resource settings, such as rural areas and developing countries. (Photo courtesy of Mobisante.)

said. "I like to say, 'When you get a hangnail, they want an MRI.' We're all very used to it in the United States and Europe, but that's just not the case in other places." A phone peripheral like this could make a real difference in rural settings and developing countries where imaging machines are often lacking. Even in areas where computers and Internet access are luxuries beyond reach, cell phones are ubiquitous. "So it was a natural match that we were able to push the technology to develop this portable ultrasound system now and make it less expensive," Zar said. "Adding to that, there was no one else doing this. That always makes it attractive."

Mobisante's system is a complete package that includes a cell phone and the ultrasonic transducer that plugs into the phone. The system comes with the app-installed phone for several reasons, one being the need for a universal serial bus (USB) host port, which most mobile phones lack. Zar said, "We need a USB host port to plug in our probe, much like you would need to plug in your flash drive. While most phones have a USB port for charging, they don't have a host port to support reading a flash drive." Another reason was that Mobisante wanted a phone it could lock down to protect patient privacy. "We're storing and transmitting patient data, so we didn't want that on a personal phone," he added.

Besides cost and portability, the ultrasound device had to be easy to use, so that its operation wasn't restricted to highly trained technicians the way that traditional ultrasound machines are. "We wanted to decouple image acquisition and image interpretation. Image interpretation is where a lot of the training is needed," Zar noted. With Mobisante's device, nurse practitioners and community health workers in remote areas can quickly learn how to take good ultrasound images and do a cursory screening. If they see anything vaguely suspicious or questionable, they can transmit the image to a more highly trained radiologist who can follow up. "Our intent is not to replace cardiac or obstetrics ultrasound units. Our model in the United States and developed countries is to be an additional unit in point-of-care settings," he said. "Where we see the big gain here is to be able to do those kinds of things people always wanted to do with a big ultrasound machine but couldn't because it's too expensive, bulky, and complicated to use."

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In the future, Mobisante hopes to expand to other diagnostic tests. "We're looking at how to integrate additional sensors, so that we could add things such as blood pressure and weight," Zar said, noting that the company hopes to work with other groups that have developed apps. "Frankly, we're waiting for things to settle to see who has some of the best solutions, and then work with those to try to integrate a few things together. Ultimately, we've written the software to be open enough to plug in additional sensors so that we can make it a complete bedside analysis package."

Microscope and Spectrometer

Another notable use for smart phones came to the forefront in October, when researchers at the University of California (UC) Davis received media notice for turning a cell phone into a microscope. This group is also developing a mobile phone spectrometer.

"Microscopy and spectroscopy together are one of our main areas of research, and we normally use large research instruments, but for this project, we said, 'Let's make something smaller that could eventually and to some extent do the things that large instruments can do.' In the end, maybe this can be helpful and useful in point-of-care settings," said Sebastian Wachsmann-Hogiu, Ph.D., an associate professor in the Department of Pathology and Laboratory Medicine and facility director of the Center for Biophotonics Science and Technology at UC Davis.

He said that his group took a cue from a research team at UC Berkeley that developed a cell phone attachment, called *CellScope*, to record microscopic images. Adhering to the mantra that smaller is better, Wachsmann-Hogiu set out to create an attachment that was less bulky than the CellScope. "Our cell phone microscope starts with a regular cell phone like most people carry around these days," Wachsmann-Hogiu said. "The cell phone already has a camera that has a camera window. What we do is attach a very small microlens to the camera window, and when you bring an object close to the microlens, the phone can take microscopic images of your objects of interest." The researchers use after-market, glass microlenses, employing smaller-sized microlenses when they want larger magnification and vice versa.

"Microscopy is currently used a lot in the biomedical field. Particularly in pathology, microscopy helps diagnose many diseases," Wachsmann-Hogiu noted. For instance, pathologists may examine the size, distribution, and number of different blood or

other cells, or the morphology of tissue to aid in diagnoses. "With this in mind, we thought that making a microscope that is very small and portable would be useful, especially in third-world countries or even rural areas in the United States where diagnosis is needed quickly but access to large microscopes is not available," he added.

Unlike the microscope that utilizes commercially available microlenses, the spectrometer required Wachsmann-Hogiu's laboratory to develop the attachment, which is a small tube with a grating at one end and a slit at the other. When the camera takes a picture of a sample, such as a drop of blood, the grating disperses light from the sample into its component parts or spectra. "By measuring spectra, we can obtain information to some extent about the chemical composition of the sample," he said. He and his research group haven't worked out the breadth of applications for a portable spectrometer, but he said it might be useful for identifying certain molecules in the blood that could aid in disease diagnosis or treatment.

The next step in this work is smart phone apps. "We are looking into developing apps that would provide further analysis of the information that we record with the microscope or spectrometer," Wachsmann-Hogiu said. A smart phone is a perfect venue for this because of its high processing power. "It amazes me. The smart phones are doing things that computers used to do 10–15 years ago. A lot of development went into these phones to make them work that well, so we figured, why not use that?" he added.

Patient Monitoring for Providers

Another set of apps is allowing health-care providers to view multiple hospital patients' monitors on a smart phone. These apps will soon add the ability to continue monitoring patients once they leave the hospital and are at home again.

"About five years ago, we had about 70,000 monitored beds in the United States," said Alan Portela, chief executive officer of AirStrip Technologies, which developed the apps. These beds were primarily in hospitals' emergency rooms and critical care wings. Since then, hospitals have added monitors to step down areas that serve as intermediate units between critical care and normally staffed rooms, and the number of monitored beds has risen to about 300,000. "The trend is that every bed of the hospital will be monitored with some sort of medical device so that there will be about 800,000 beds within the next three to five years," he said. This will come at a time when healthcare will already have too few providers.

On top of that, Portela said that reimbursement models are adding more pressure. For medical facilities to be paid for outcomes, they now have to put more emphasis on keeping their patients healthy after they're discharged from the hospital. "Increasingly, doctors must consider huge amounts of data and information to make timely, informed, and accurate treatment decisions," Portela contended. "These data live in multiple, disparate systems, devices, and monitors." The answer, he said, is technology. "Instead of taking physicians to where the data are, we need to take the data to the physicians wherever they are. Physicians are becoming mobile professionals, so we need to get the data to them using the devices that they're starting to adopt, and those devices are tablets and smart phones."

San Antonio-based AirStrip Technologies is now working with a Qualcomm Inc. subsidiary to develop a home health-monitoring initiative that will address the new reimbursement model.

AirStrip Technologies developed three apps, all of which can tap into patient data collected by bedside monitoring equipment and transmit it in near real time to and between health professionals. The data is also zoomable; so providers can see even fine details in charts and graphs. AirStrip CARDIOLOGY focuses on ECG/EKG data (Figure 2); AirStrip OB provides fetal heartbeat, maternal contraction patterns, and other data; and AirStrip PATIENT MONITORING covers a wide range of physiologic patient data (Figure 3).

In addition, the San Antonio-based AirStrip Technologies is now working with a Qualcomm Inc. subsidiary to develop a home health-monitoring initiative that will address the new reimbursement model, Portela said. "In 2012, we'll be moving into the healthy home, and we're going to start with congestive heart failure by connecting physicians to the data from devices used to monitor the patients when they are at home. Examples are electronic scales for weight and body mass index, blood pressure cuff, ECG, and pulse oximeter (to measure oxygen levels in arterial blood)," he said. "Any combination of data from these devices provides more information than that provided to physicians

FIGURE 2 The smart phone app AirStrip CARDIOLOGY combines wireless mobile transmission of electrocardiograms with digital visual enhancement and touch screen capabilities, as well as automatic access to historical patient data. (Photo courtesy of AirStrip Technologies Inc.) AirStrip CARDIOLOGY is a trademark of AirStrip Technologies Inc.

FIGURE 3 AirStrip PATIENT MONITORING is an app that sends data securely, directly, and in near real time from hospital monitoring systems and bedside devices to a smart phone, allowing clinicians to check in on their patients remotely. (Photo courtesy of AirStrip Technologies Inc.) AirStrip PATIENT MONITORING is a trademark of AirStrip Technologies Inc.

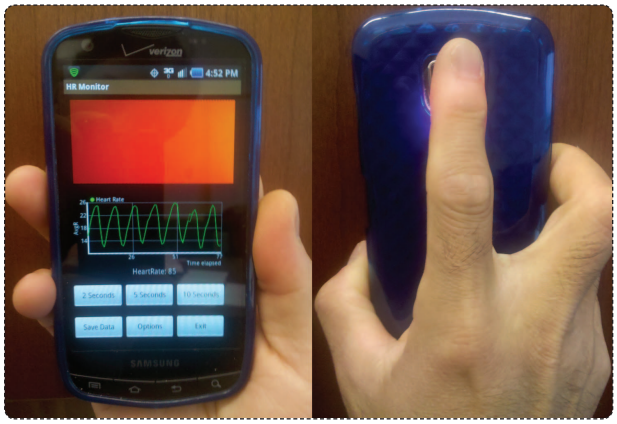

FIGURE 4 By simply holding a finger over a phone's camera and flash light, this smart phone app developed at the Worcester Polytechnic Institute can determine a number of vital signs, including heart and respiration rates. (Photo courtesy of Ki Chon.)

today. Today, you are discharged home, and there is little or no way to check on you."

Detection of Vital Signs

One group that is developing apps to monitor vital signs is the laboratory of Ki H. Chon, professor and head of the Department of Biomedical Engineering at Worcester Polytechnic Institute in Massachusetts (Figure 4). These apps, many of which he hopes to be commercially available in 2012, transform a smart phone into a portable diagnostic device. The first prototype, set for release in January 2012, uses the phone camera and flash to detect atrial fibrillation. Chon's research group now hopes to add other vital signs. "We already have algorithms to get the oxygen saturation (the amount of oxygen carried in the blood), respiration rate, and readings from the autonomic nervous system (the portion of the nervous system that controls involuntary actions such as digestion), which would have many applications such as diabetic autonomic neuropathy (a common but serious complication of diabetes), congestive heart failure, fatigue, and stress."

FIGURE 5 The PAM+ app is designed to encourage patients to become active health-care participants by allowing them to monitor pressure readings inside the heart and adjust their medications accordingly. (Photo courtesy of the USC Center for Body Computing and Keck School of Medicine.)

From there, the laboratory will look into developing an app for the identification of hypovolemia, or blood loss, which would permit the identification of potential health problems well before they become evident through blood pressure, heart rate, or other traditional diagnostic tests. Eventually, Chon hopes to also add continuous blood pressure monitoring capabilities.

Each of the apps works from the same simple finger placement on the phone. Chon explained, "You basically place your finger on top of the camera and the flash light, and hold it there. After some image processing, we extract one of the wavelengths—typically the green or red spectrum—and from that we can derive all of these different parameters."

He explained that the apps use the same basic principle as a pulse oximeter, a medical instrument used in hospitals to measure oxygen levels in the blood. "Like a pulse oximeter signal, you can see the signal from the pulse: the pulsatile signal," he said. In other words, with each heartbeat, it shows a time-varying signal due to the cardiac cycle. By measuring the time interval between peaks, one can determine the heart rate. In addition, a low-frequency modulation exists on top of this signal and that is reflective of respiration. Chon's group also noticed that the amplitude of the pulse oscillation decreases significantly during blood loss, so the app looks for that signature as well. The app for analyzing the autonomic nervous system can be used to differentiate between normal and diseased states.

For the atrial fibrillation prototype, the app uses the same pulsatile signal to detect the highly random heartbeat that is indicative of the condition. "Following the introduction of the prototype, we'll be doing a clinical study with the University of Massachusetts Medical School in Worcester and working with 45 subjects who have atrial fibrillation," Chon said. During this study, the researchers will test patients before and after they receive cardioversion, an electrical shock treatment used for abnormal heartbeat. The testing will ensure that the app's algorithm correctly recognizes atrial fibrillation and normal sinus rhythm. "Once that's been validated and published, then we'll be able to make it commercially available. We hope to have that done by the end of the summer," he added. Chon estimates that the commercial release of other vital-sign apps will follow in late summer or fall of 2012.

Altogether, Chon believes applications like these will have perhaps their greatest impact on patients, who can add apps to their phones so that they can monitor themselves. "In my personal opinion, it's the wave of the future," he said. "With all this push for preventative medicine and lower health-care costs, along with the proliferation of smart phones and all the things you can do with them, I think the smart phone is a good platform to empower people to be more vigilant about their own health."

Patient Education

Patient education is indeed a good use of smart phone technology, according to Leslie A. Saxon, MD, chief of the Division of

Cardiovascular Medicine at the University of Southern California (USC) and executive director of the USC Center for Body Computing. Researchers at the Center for Body Computing are developing an app that will help cardiovascular patients take more control of their health by monitoring pressures inside their own heart.

The center's app works in concert with a device called the *patient advisory module* (PAM) developed by St. Jude Medical. The module, which is currently undergoing a U.S. Food and Drug Administration (FDA) clinical trial, takes readings from (and rests on the skin above) a sensor that is implanted in the upper left chamber of the heart. The sensor measures atrial pressures that can become elevated in heart failure. "The PAM reads that pressure and then tells the patient what drugs to take based on twice-a-day reading," Saxon said.

"We thought, 'Well, that's really cool, but it could be more.' While it engages the patient because the patient takes the reading, it doesn't really partner with the patient in the sense that the patient is still told what to do," she said, likening it to "the same old paternalistic model" of doctors providing unquestioned instructions to patients. "So we said, 'Why don't we lay an app on top of that, one that's on the patient's smart phone, so that the patient can actually interact with the pressure in a way that engages, entertains, educates, and connects?' Those are all things that are enormously important when you're trying to drive compliance to medical care."

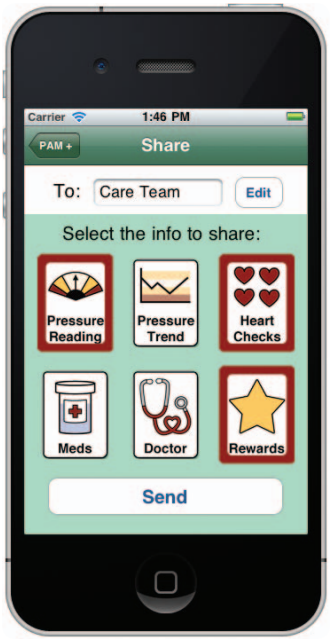

FIGURE 6 Through the PAM+ app, patients have options about what information they want to share. The rewards button refers to positive feedback and actual rewards, such as shopping credit points, that the patient has earned for following medical advice. (Photo courtesy of the USC Center for Body Computing and Keck School of Medicine.)

Through games, quizzes, and rewards, the PAM+ app makes learning fun, while giving the patients a virtual pat on the back for following their medical treatment plan. The "connect" aspect involves providing patient information to the health-care professionals who are managing the patient's health and sharing information with family members at the patient's request, Saxon said. "Anybody who has cardiac disease or any complex disease in this country has more than one specialist; connectivity is a highly valuable thing. How does my internist get information from my cardiologist? How does my heart failure doctor communicate to my nephrologist?" (See Figures 5 and 6.)

To develop the app, center researchers worked hand in hand with staff from USC's Viterbi School of Engineering and School of Cinematic Arts. The engineers built the app, and the cinematic arts professionals helped to design user interfaces, avatars, and augmented reality to take the storytelling up a notch and create something that would truly touch patients. Saxon remarked, "What's more emotional than your own health-care narrative, right?"

While the center developed the app specifically for the St. Jude device, she said it has a broader reach. "This app is a demonstration project that can be used for PAM or could apply to a number of different heart failure products," Saxon commented. The center is also developing patient-education apps that employ games to help patients understand other diseases. "For instance, we have games for patients with diabetes to play over their phones to help them understand and manage their blood sugar," she said.

"One of the things that we really wanted to do was to have a patient get rewarded. I think that's an important concept," she said. "The reward can be just bragging to your daughter in Vermont about how compliant you were or it can be getting Amazon points if you figured out what your dietary restrictions are and passed a quiz around that. These things can be really meaningful." After all, she said, "It's hard to be sick."

The Apps Parade

The range of apps on the market today or on their way to the market soon is astounding, and the number is growing. Almost every week, another latest and greatest app is announced, and Misra is busy sorting through them all at iMedicalApps.com "This Web site started out as a hobby for a couple of medical students and an orthopedic surgeon as little as a year and a half ago," he said. "It was partly born out of our own frustration in going through the thousands of apps in the app store and downloading a lot of duds, and in wanting to save other people that trouble."

He added, "That goal has stayed the same. We still see our role as helping health-care professionals not only to understand what apps and devices are out there that can make a difference to them and help them to do their jobs better but also to help understand what mobile health is and how that is going to help impact their practices. When you're talking about any emerging industry, there's usually a boom phase and this is definitely it."

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