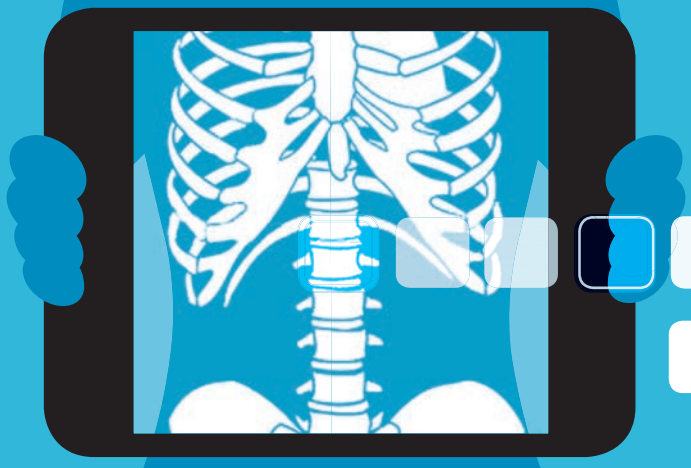
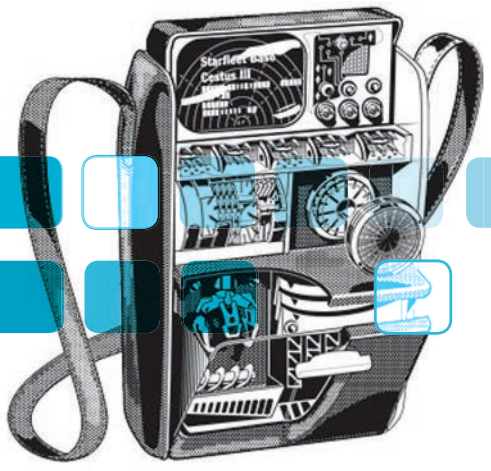
The X Prize Foundation wants engineers and doctors to build a functional tricorder—a science-fiction medical scanner. **The surprise is that many of the technologies they need to do it are already here.** BY ARIANA MARINI



patient, scan

necessity is the mother of invention.

That was true on a weekly television series back in the 1960s, when the writers of *Star Trek* needed to enable a character to quickly diagnose a medical problem. So they invented a device that could scan a patient in seconds.



The original Star Trek *tricorder has inspired generations of biomedical engineers to develop handheld diagnostic devices.*

The props department built a box with a strap, repurposed some high-end salt shakers, and the medical tricorder was born.

Star Trek was set centuries in the future, but researchers are busily at work building a fully functional tricorder today. They are spurred by $10 million being offered up by the X Prize Foundation and the Qualcomm Foundation, which have teamed up to launch a worldwide competition to develop a portable, wireless device that is able to accurately diagnose 21 specific health conditions.

In addition, all devices must be easy enough to use without extensive training, and must weigh five pounds or less.

thyself

A disposable nose clip developed by Xhale measures pulse, oxygen saturation, and other cardiorespiratory vital signs. The company also makes a monitor (right) that looks for chemical markers on the breath.

Turning science fiction into practical technology on a deadline—judges select a winner next fall—may sound like a tall order. But the promise of a multimillion-dollar prize has moved teams to accomplish some outlandish goals, from launching a privately built reusable spaceship to creating a production-capable ultra-high-fuel-economy car.

And people at the X Prize Foundation believe the capacity to perform some *Star Trek*-style medical diagnostics may take nothing more than some modified sensors and a clever smartphone app. To claim the prize, however, teams will have to combine multiple technologies and miniaturize them into a device that can fit in the palm of a hand.

"There really is no product out there today that can handle a multiplicity of health conditions," said Mark Winter, senior director of the Qualcomm Tricorder X Prize. While an increasing number of health apps are available for smartphones, "for the most part, the mobile health industry has focused to a large degree on fitness products," Winter said.

Winter believes the teams actively competing for the $10 million prize can do better. The competition attracted roughly 300 teams, which were narrowed down to 30 contenders in November 2013. X Prize will select the final 10 teams in August.

"I think that it's important to emphasize that our role at X Prize is to really try to create a threshold change, a movement, where the impossible or what's seemingly impossible becomes possible," Winter said. "We view this competition as sort of a version 1.0 demonstration to the world that, in fact, the technology, the talent, and the ability exist to actually create the device and to show that it can actually be effective and work."

According to the terms of the contest, the winning tricorder will be able to read such vital signs as blood pressure, heart rate, body temperature, respiratory rate, and oxygen saturation. The list of ailments that the device will diagnose runs from such common diseases as anemia, urinary tract infection, and strep throat to serious health conditions such as Type 2 diabetes, atrial fibrillation, stroke, and tuberculosis.

It is expected that such a variety of problems will be a challenge for one compact device to detect. For instance, teams must implement several types of sensors; some may require contact with body fluids while others could be completely noninvasive. The device may also need to include sensors to examine the environment around the patient, sniffing for biochemicals released into the air.

While no single device currently does all that, many technologies that could power a tricorder have already been developed, and more are on the way.

Take, for example, the Proteus Digital Health ingestible sensor, which signals when a patient has taken his or her medication. This may not sound like a *Star Trek*-worthy advance, but the company's chief medical officer, George Savage, argues that half of all patients fail to take medication or take it incorrectly. This is especially true if they take many pills, have memory issues, or do not like the side effects.

The ingestible sensor could alert caregivers about compliance issues, and the technology is elegant. The sensor itself consists of a 1-millimeter-square chip that contains a tiny, short-range radio transmitter and two battery terminals. When the chip is ingested, stomach acid acts as an electrolyte to create a circuit between the terminals and power the battery.

"Those three things, the anode, cathode, and the wet environment of your stomach, create a power source, which can then power up that novel integrated circuit and start to communicate a pulsed electrical signal which has been carried through your body's tissues," said David O'Reilly, chief product officer at Proteus. "What's important is there's no traditional pow-

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er source and there's no traditional antenna because it's using your body as a wire."

Each chip sends a unique signal that identifies the medication to a second device, a disposable patch worn by the patient. The patch receives the unique signals coming from each ingested sensor. The patch also has accelerometers and sensors to monitor heart rate, respiration, and physical activity.

"That second device then communicates the information on the medicine you swallowed, all of your therapy, and how your body is responding," O'Reilly said. The patch does this through a Bluetooth radio connection to a mobile phone or computer. Caregivers and patients can access the data on a secure application.

"I think about this as sort of the democratization of health care technology," O'Reilly said. "The more initiatives there are like Tricorder X Prize and what Proteus is doing and like what tons of the other people are starting to work on, the more we're going to really personalize therapy and allow consumers to take control of their own health care."

Xhale, a company based in Gainesville, Fla., also monitors compliance, but instead of relying on chips, it looks for chemical markers. It offers an alcohol-based food marker that drug companies incorporate into their medicines. Once the patient ingests the pill, the body absorbs the marker (or its metabolites) into the bloodstream. After taking the medication, patients blow into Xhale's SMART device, which identifies the markers on their breath. ("SMART" stands for "Self-Monitoring and Reporting Therapeutics.")

According to the company's CEO, Richard Allen, the method will tell if a patient has taken the right dose of the right medication at the right time. The SMART system can use several sensing technologies, including miniature gas chromatographs and surface acoustic wave sensors. The latter, the same type of MEMS used in first responder gas sensors, coat micrometer-size cantilevers with chemicals that bind only to a specific marker. As markers attach to the coating, they change the weight of the cantilever and alter its vibration. This signals that the medication has been taken.

Xhale has also developed a small, disposable sensor that attaches to the side of the nose. It measures pulse, oxygen saturation, respiratory rate, airway obstruction, and other cardiorespiratory information. The sensor could be teamed with ingestible markers to give physicians a clearer picture of how medication affects patients. In fact, the company claims the sensor is reliable and unobtrusive enough to replace many existing hospital monitoring systems.

A patch developed by Proteus captures data—such as heart rate, level of physical activity, and whether medication has been taken—from ingested and built-in sensors and sends the information via Bluetooth signals to a smart phone or tablet.

Delmedica's X-Halo compares breath temperature with core body temperature to predict when a patient is in danger of having an asthma attack.

Other companies are also using breath as a means to monitor health. Singapore-based Delmedica Investments offers the X-Halo thermometer, which monitors exhaled breath to predict asthma attacks. By comparing breath temperature with core body temperature, the device can predict when a patient is nearing an asthma attack. This would help patients, particularly children and their caregivers, know when to take medication or even get to a hospital before a severe attack occurred.

The X-Halo is simple enough for children to use. A user inhales through the nose and exhales into a mouthpiece, timing each action to a blinking LED. The mouthpiece directs the breath into a vacuum-isolated measurement block, where it warms a metal core until its temperature stabilizes. That usually takes a few minutes.

If the temperature is significantly higher than the body core, the device warns of an impending attack. The device stores up to 122,400 measurements, which doctors can scan for trends and to identify issues.

According to Jas Gill, the company's managing director, X-Halo can also help detect chronic obstructive pulmonary disease and respiratory tract infections, such as bird flu, SARS, MERS, pneumonia, influenza, and tuberculosis.

"The X-Halo can pick up the signal from these viral and bacterial infections before the patient has any physical symptoms, allowing him a small window of up to 48 hours in which to consult his or her physician," Gill said.

Meanwhile, a Cornell University associate professor of mechanical engineering, David Erickson, has led a team that developed a device that works with a smartphone application to detect cholesterol by analyzing color changes in a test strip. Users add blood, sweat, or saliva to the test strip. The liquid goes through a series of separation steps and chemical reactions. Users then insert the strip into the device, which looks a bit like a credit card reader. It illuminates the test strip evenly, takes a picture, calibrates the hue and saturation of the colors, and displays the results on the phone.

Right now, the device measures total cholesterol. Erickson is working on ways to break that data into low-density and high-density lipoproteins ("bad" and "good" cholesterol) and triglycerides. The lab developed a similar system to test for gum infections and measure electrolyte levels in sweat.

Apps can use smartphone cameras to look at other vital signs. Instant Heart Rate by Azumio, for example, analyzes fingertip color changes to count your pulse, the same technique used by medical pulse oximeters. AF Detect, an app developed by University College London and HealthSTATS, a Singapore-based company, uses similar technology to detect irregular heartbeats.

Pulsewave MAX from Biosign embeds sensors in an arm cuff and finger clip to measure five vital signs simultaneously and send that data to a cloud-based computer.

But specially built devices can do more. Scanadu, a California start-up that raised $1.6 million in capital on the crowd-funding website Indiegogo, has developed a small, white, circular device it calls the Scout that contains thermal, optical, and electrode sensors.

When users press the Scout to their foreheads, it begins to monitor such vital signs as heart rate, heartbeat regularity, blood pressure, blood oxygenation, breathing rate, and temperature—all within seconds. Scout sends the data via Bluetooth to a smartphone app, where users can track and analyze the information and, if they wish, share it with a physician.

According to Walter De Brouwer, the company's CEO and founder, "Scanadu Scout has the potential to completely disrupt the clinical pathway by bringing the place of care back into the home and into the hands of the consumers. It's a game changer for consumer medicine."

Scanadu is building on its existing technology in its entry for the Tricorder X Prize. Other companies are using the same strategy.

"The technologies imagined by the Tricorder X-Prize are either available now or on the cusp of availability," said Robert Kaul, CEO of Biosign, a Canadian company that builds medical devices. Biosign was developing a sensor platform when the competition was launched.

"We've been working on the Pulsewave MAX for over two years," Kaul said. "When the Tricorder

X-Prize was announced we saw immediately that our technology qualified for the contest."

Pulsewave MAX, an advance over the company's Pulsewave heartbeat and pulse measuring system, is bulky compared with other X Prize contenders; its sensors are embedded in an arm cuff and finger clip and were designed for immobile hospital patients. Still, it had a working system that transmitted five vital signs to a cloud computing system. Biosign's project team in the Qualcomm X Prize competition, Cloud DX, partnered with others to develop a system that could analyze blood, saliva, and urine.

Technology exists to do many of the tasks set out for a potential tricorder. Integrating them into single device is no easy challenge.

As Delmedica's Jas Gill put it: "We are charting an undefined path. No one has ever done this before, so there are no rules to follow."

According to Gill, "We have an expert team of engineers, biologists, scientists, designers, and doctors, but we are still experimenting, and learning as we go. In order to meet consumer, medical, and FDA standards, we have to make sure the device is accurate, seamless, and actionable. This is no simple feat."

The X Prize's Mark Winter said he thinks the main goal of the competition is to give consumers, care providers, and insurers new resources to improve health care quality and patient outcomes. In addition to driving down costs, putting tricorders in the hands of non-professionals could help individuals seek treatment before a malady becomes an emergency.

Winter said he hopes that engineers will recognize "the tremendous changes going on that they can participate in as engineers in bringing completely new types of health technologies to people that really were, in the past, solely in the domain of clinical laboratories." ME

Walter De Brouwer (above), CEO of Scanadu, demonstrates how his company's Scout device can be pressed against the forehead to measure blood pressure, heart rate, and temperature within seconds.

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