Star Trek Comes Back to Earth

Powered by a $10 million X Prize, researchers believe the TV show's tricorder diagnostic device may soon reach a hospital near you

by Alan S. Brown

ANYONE WHO watched *Star Trek* surely remembers the tricorder. The show's doctor, McCoy, would wave it over a patient (or pull out a sensor wirelessly connected to the tricorder) and come back with a complete diagnosis.

Today, *Star Trek's* tricorders look a little clunky. A typical smartphone is slimmer and has a larger display. It also has Bluetooth wireless and touch screens, two technologies that were apparently unknown in the show's 23rd century.

Yet those tricorders packed a lot of diagnostic power into a very small package. Although *Star Trek* debuted nearly 50 years ago, the tricorder's functionality still feels like science fiction.

This is about to change.

In January, the X Prize Foundation announced a $10 million competition to build a real tricorder in little more than three-and-one-half years. The winner of the Qualcomm Tricorder X Prize will bring the same powerful diagnostics, now found only in hospitals and medical laboratories, to everyone from suburban moms and camp counselors, to ER doctors and isolated caregivers in developing nations.

The announcement generated enthusiasm as well as skepticism. Roughly 200 teams and individuals have already signed up for the competition. On the other hand, we're talking about waving a black box at a patient and coming back with a diagnosis. Does anybody do that at your local hospital?

X Prizes often spark incredulity. They are designed to encourage giant leaps, and their goals naturally arouse doubts. Similar skepticism greeted the $10 million Ansari X Prize for a private spacecraft. Many claimed the costs and technical hurdles were too high. Others argued that they just needed to reimagine technologies NASA had already pioneered.

Burt Rutan and Scaled Composites won the prize by doing just that in 2004. His SpaceShipOne took off from underneath its mother ship, just as NASA's *X-15* did 45 years earlier. Rutan built his craft by taking advantage of modern materials, engines, and electronics.

The tricorder could trace a similar arc. This is because many experts believe we already have the technology needed to build one.

Generations of *Star Trek* fans have marveled at the show's futuristic technology. This toy tricorder hinted at the science fiction.

Sotera's wireless vital signs recorders are already in use. They are early signposts on the road to tricorder technology.

"I think the pieces exist. The real question is how they are assembled together," said Don Jones, a vice president of global strategy and market development at Qualcomm Life. The company develops wireless technologies for health, fitness, and the life sciences. Its parent company, wireless infrastructure giant Qualcomm, is bankrolling the Tricorder X Prize.

In 2005, Jones founded the Wireless-Life Sciences Alliance (WLSA) to promote the use of wireless technologies in healthcare. The association addresses everything from regulatory and privacy issues to reliability and medical device networking standards. WLSA may not have had tricorders in mind, but it has helped define the infrastructure a tricorder might use.

"The tricorder is a metaphor for what we're all about," Robert McCray, the organization's current president, said.

Convergence

There is an almost palpable belief among experts that the tricorder is close to a reality. Ask why, and they are likely to mention "convergence." This is shorthand for the way many factors—powerful computer processors, data analytics, sensors, artificial intelligence, cloud computing, and smartphones—are reinforcing one another to change what is possible.

Convergence, however, is not just about technology. It includes healthcare economics. Almost everyone involved in the Tricorder X Prize believes that the U.S. healthcare system is broken and that putting medical information in people's hands might fix it.

Take, for example, emergency room visits. In 2011, the insurance company Excellus, estimated that 44 percent of

Bottom photo courtesy of Sotera / Top photo Ray Thompson

emergency room visits in upstate New York were unnecessary. Those visits cost $160 million to $215 million per year. Another survey by PriceWaterhouseCooper estimated the nation spent $16 billion nationally on unnecessary ER visits.

Should patients see their doctors instead? Not necessarily. The Wellness Council of America estimated that 70 percent of doctors' visits are not needed.

Wireless diagnostics could help people determine when to visit an ER or doctor by accurately assessing conditions. It is not hard to imagine a system that analyzes coronary data and calls an ambulance before a stroke or heart attack even occurs.

Insurance companies could save billions of dollars by avoiding unneeded visits and intervening before emergencies arise. By ensuring patients take their medication properly, they could save many billions more by properly preventing or treating illnesses.

The economics are so compelling, Scanadu, a startup competing for the Tricorder X Prize, believes insurance companies will one day underwrite the cost of wireless medical technology to avoid unnecessary costs.

If economics are providing the push for personal diagnostics, then technology has created the pull. When Jones and McCray founded WLSA in 2005, most members envisioned linking wireless sensors with dedicated medical devices powerful enough to capture, analyze, and communicate sensor output.

That changed two years later when Steve Jobs unveiled Apple's iPhone. An explosion of apps followed. Many are now health-related, monitoring calorie intake, tracking daily jogs, taking pulses, and using AI to diagnose symptoms.

Apps are limited by phone memories and processors. Move the application to a server in the cloud and the possibilities are limitless.

Database In The Cloud

"Separate the box—the brains of the application—from the sensor, and you can make sensors small, light, and cheap enough to deploy broadly. Once you get that sensor data into the phone, it can send it to a database in the cloud, where it can be crunched and all the actionable items extracted," McCray explained.

The ability of the cloud to store and mine massive amounts of data will enable future diagnostic apps to do more than warn about heart arrhythmia, respiratory problems, infection, or fever.

What visionaries really want to do is to aggregate data from millions and even hundreds of millions of individuals. They will then mine it with learning machine software, which, like an autistic savant, randomly seeks correlations between different types of data to unearth patterns.

Predictive Medical Technologies, a San Francisco startup, has used this approach to generate powerful models that predict heart attacks or respiratory failure within 24 hours. Developed for hospitals, it mines patient lab reports, monitor output, nurse notes, blood tests, and other factors for warning signs. It is easy to imagine a similar cloud-based service.

It will take a body-wide network of sensors to pull this off. Surprisingly, the network infrastructure already exists. It is the Medical Implant Communication Service (MICS) band, which was originally developed for pacemakers and other implants.

"The bands were recently expanded to add on-body as well as in-body sensors. It's an internationally accepted standard, and a cornerstone on which we can build," Jones said.

Several small companies have already received Food and Drug Administration approval for wireless products connected to dedicated medical devices. These include Dexcom's glucose meter, Corventis' wearable electrocardiogram (ECG) device, and Sotera Wireless' vital signs monitor.

"These were concepts we talked about five years ago, prototypes three years ago, commercial products within the past two years, and now in clinical use," Jones said. The next step, he believes, will be to connect those sensors to apps using Bluetooth, which is cheap, energy efficient, and connects to virtually all smartphones.

Multiple Ideas

It was the growth of all those technologies that caught the X Prize Foundation's attention in 2010. "We were trying to think of how these different strands fit together. Someone mentioned the tricorder, and that concept seemed to bring together these multiple ideas," said Eileen Bartholomew, the organization's vice president of prize design.

Once she outlined the concept, she went looking for funding. Qualcomm was a natural. In addition to funding the prize, Qualcomm also underwrote the intellectual legwork needed to define the prize's sweet spot, where it could make a difference in technology development.

"For the tricorder, it was about advancing consumer-oriented tools that can predict and help manage medical conditions and also compile medical information," Bartholomew said.

In practice, this means the winning team must diagnose

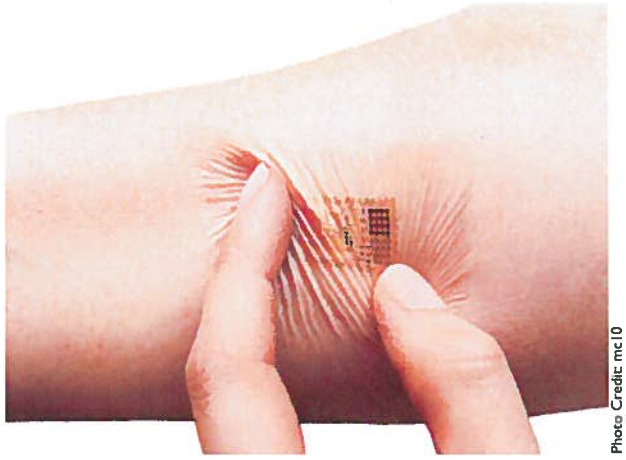


Photo Credit: mc10

The next generation? New and advanced technologies may not resemble their classic science fiction counterparts. For example, mc10's adhesive diagnostic systems flex and bend.

a set of 15 distinct conditions over three days. The diagnoses must be accurate, and the tricorder itself must be simple enough for a consumer to use without extensive training. Also, it must weigh no more than 5 pounds.

The foundation chose 15 conditions that push the limits of sensor technology and integration. These range from anemia, diabetes, thyroid irregularities, and sleep apnea to urinary tract infection, strep throat, and leukocytosis. They also include such life-threatening conditions as melanoma, atrial fibrillation, and chronic obstructive pulmonary disease (COPD).

The tricorder must also identify metabolic abnormalities, determine the absence of disease, and continuously monitor and log five vital signs, including heart electrocardiogram and oxygen content of the blood. Finally, it must diagnose at least three "elective" conditions that it choses for itself.

This is an impressive set of capabilities. To meet them, the winning tricorder must integrate a diverse set of sophisticated sensors and supporting technologies. Fortunately, researchers appear up for the challenge.

One example is the wireless flexible sensors developed by mc10 of Cambridge, MA (see pictures). Scarcely thicker than the plastic film used to transfer temporary tattoos to a child's arm, they attach directly to the body like a smart Band-Aid. They can sense changes in the body or accept data from other sensors and retransmit the information to a medical device or app.

At first glance, they look like flexible printed circuits. On closer inspection, they contain processing units, memory, sensor elements, a battery, and Bluetooth connectivity.

"Our adhesive sensors have all the components needed to build complete systems," said Kevin Dowling, mc10's vice president of research and development. Dowling likes to talk about freeing electronics from the tyranny of the wafer. "We're wrapping electronics in new form so we can put them on or in the body. They are designed to stretch and bend," he said.

Near right and opposite page: Flexible circuits adhere to the skin like band-aids, but behave like sophisticated medical instruments to monitor and communicate vital signs.

Photo Credit: mc10

This is not an easy thing to pull off. Granted, the thinner a material, the more flexible it becomes. This is true even for glass and brittle silicon. Yet to make its flexible sensors work, mc10 had to develop a new library of unusual structures—spring-shaped metals, buckling interconnects, silicon microribbons—to handle the body's full range of motion.

Dowling deposits the circuits on the top of conventional silicon wafers. He then grinds or etches away the bottom of the wafer until only a 20-micron-thin sliver is left, and transfers this to an adhesive-backed flexible plastic film.

While these chiplets are measured in fractions of a millimeter, Dowling can combine them to form flexible circuits that pick up electrical activity over large areas of the body.

"We can measure things we've never measured before, like electronic currents as they race across the surface of the heart. We can start to think about creating large arrays, and use strain-induced changes in the resistivity of the circuits to measure forces," Dowling said.

Dowling thinks his sticky sensors will prove popular with people who require medical monitoring, since they are unobtrusive and wireless. He is also teaming with Medtronic, a major medical device company, to create smart stents that can determine the effectiveness of heart surgery.

"We can add electronics to medical instruments any time someone needs in situ measurements, or use the electronics to help deliver medicine," Dowling said.

Chip-sized Laboratory

Others are working on similar, if larger, wearable sensors. Some may include a microelectromechanical system (MEMS) accelerometer to measure respiration, blood pressure, and heart rate. Others could use microneedles to draw tiny amounts of blood for analysis on a chip-sized chemical laboratory called (surprise) a lab-on-a-chip.

These sensors all involve contact. That may feel like cheating. After all, *Star Trek's* McCoy just had to wave his tricorder over a patient to get a diagnosis. The good news is that tricorder contestants have several powerful non-contact technologies they can work with.

One is simple visualization. Since primitive times, healers have relied on their eyes to diagnose certain problems. Smartphone cameras and AI software could do something similar, such as analyzing photos to identify skin cancer or strep throat. Add a wireless microscope and perhaps it could count white blood cells to check for anemia. More intriguing is hyperspectral imaging. Originally developed for NASA earth observatories, it captures hundreds of different spectra from a single image. Software could then analyze the data to determine the severity of wounds, burns, and infections; check the likelihood of ear and throat infections; and test for diabetic retinopathy, macular degeneration, and other eye diseases.

Thermography, which uses infrared sensors to measure heat distribution, has been used to take temperatures

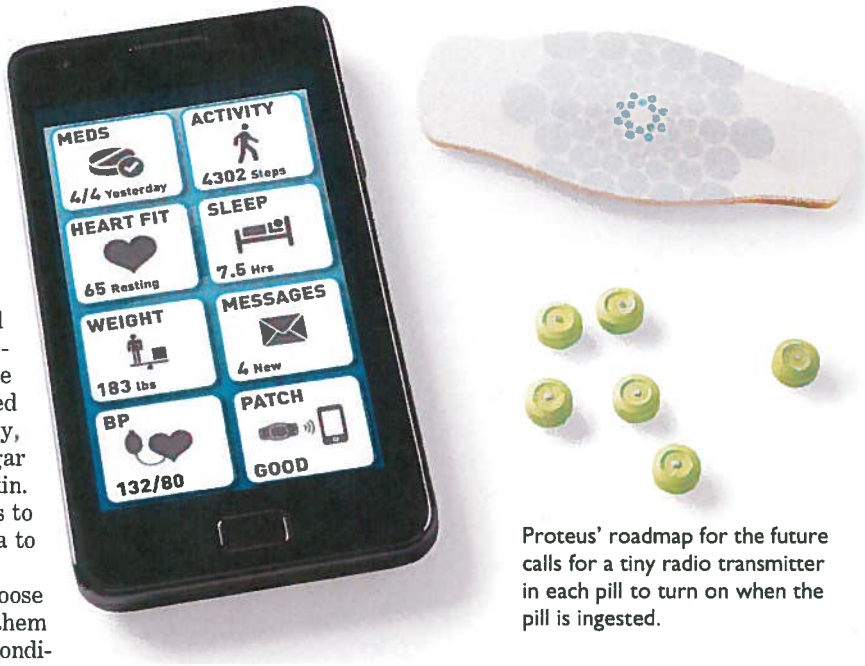
and detect excess heat generated by breast cancer for more than 50 years. Airports used it to screen passengers for atypical pneumonia during the SARS scare. It could check for influenza and bronchitis as well. By imaging blood vessels in the head, neck, and limbs, thermography could warn of stroke or deep vein thrombosis.

Lasers have attracted attention. Holy Cross University and the Naval Research Laboratory used a laser Doppler vibrometer to measure heart rate and blood pressure by clocking the speed of pulsing blood. At Princeton University, mid-infrared lasers measure blood sugar levels and diabetes by scanning the skin. Other Princeton researchers use lasers to detect exhaled nitric acid and ammonia to monitor asthma and kidney function.

There are many technologies to choose from. The challenge will be combining them in ways that monitor all the required conditions and vital signs in a device that weighs less than 5 pounds.

Then there are the optional conditions. A tricorder team could opt to merely add on three other diseases. Or it could try creating an entirely new type of medical service.

They could start by calling **Dr. George M. Savage,** *Massachusetts Eta '81*, chief medical officer of Proteus Digital Health of Redwood City, CA. His company makes edible circuits that can be taken with medication. Once in the stomach, the circuit signals that it has been swallowed. When used with an oral medicine and a smartphone app, it could track when patients take their medication, send reminders when they do not, and warn doctors if they go off their meds.



Proteus' roadmap for the future calls for a tiny radio transmitter in each pill to turn on when the pill is ingested.

Photo Credit: Proteus Digital Health

Photo Credit: mc10

Compliance may not seem like a problem worthy of *Star Trek* technology, but Dr. Savage disagrees. He argues that FDA approves all drugs only after they are tested under controlled conditions. This shows their absolute theoretical capabilities. Unfortunately, this is not how they are used in the real world.

"Half of all medicines are not taken correctly or not taken at all. This is especially true for people who are really sick and taking a lot of medicines," Dr. Savage explained.

This presents problems for doctors. "They see the patient is not looking good, but they are not sure if it's because of how the patient is taking the medication, the effectiveness of drug, or something else entirely."

Monitoring compliance could answer their questions objectively. Equally important, by clocking when a patient takes a pill and monitoring vital signs, it becomes possible to measure exactly how a medication affects an individual. This opens the door to truly personalized medicine.

"We want to create an objective, informative system to help patients and physicians make better recommendations based on a real understanding of what's going on," Dr. Savage added.

The thinking behind the sensor is a clever twist on wireless technology. It is made primarily from silicon and copper, two nontoxic materials, and encapsulated. The micron-scale chip is big enough to hold 5,000 transistors and a radio transmitter, yet small enough to fit inside a capsule or pill.

Potato Battery Projects

For power, Proteus' technology has more in common with science fair potato battery projects than high-tech electronics. Two dissimilar metals stick out of the chip. When they contact stomach acids, the redox reaction between them generates enough power to activate the chip. Using voltage modulation, each chip broadcasts its unique code to a wearable patch receiver that can retransmit the data to a medical device or smartphone.

This past August, the Food and Drug Administration approved the sensor's use in a capsule that can be taken with medicine. Proteus has applied for approval of the sensor in capsules that contain medication.

Proteus' ingestible sensor opens an entirely new way

of doing medicine. So do mc10's flexible sensors, as well as the non-contact sensors under development in labs around the world.

Despite all these new technologies, the winner of the Tricorder X Prize will have to overcome many hurdles. On the technical side, no one has ever combined so many different sensors into a single device, much less one that is affordable, easy to use, and lightweight.

Others worry that potential glitches in apps could cause the healthcare equivalent of a stock market computer trading meltdown. Privacy advocates worry about massive amounts of personal medical information floating around in the cloud, and whether it could be used by insurance companies to set rates or by employers to make hiring decisions.

Profoundly Democratic

Medical technologies have always been highly regulated. Yet the tricorder is profoundly democratic. It will ultimately give anyone with a smartphone more access to medical information than the best hospitals had two decades ago. Who knows where that will lead?

And that is the point, Bartholomew said. "We're starting with diagnosis, but one day it may help manage diseases. It may one day be as ubiquitous as your phone. No one imagined how smartphones and apps would evolve. The tricorder is going to live and breathe with you, and it will also evolve."

Like many people in the United States, she believes the national healthcare system is broken. Unlike nearly everyone else, the X Prize Foundation is not trying to fix the system by improving its components.

"We don't give a damn about the system as it is now. We're working from the outside in," she said.

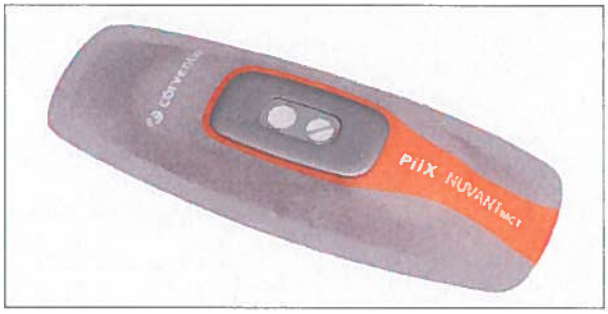


Photo courtesy of NUVANT

This PiiX wearable device, above, from NUVANT MCT/ Corventis can monitor vital signs while concealed beneath clothing, below.

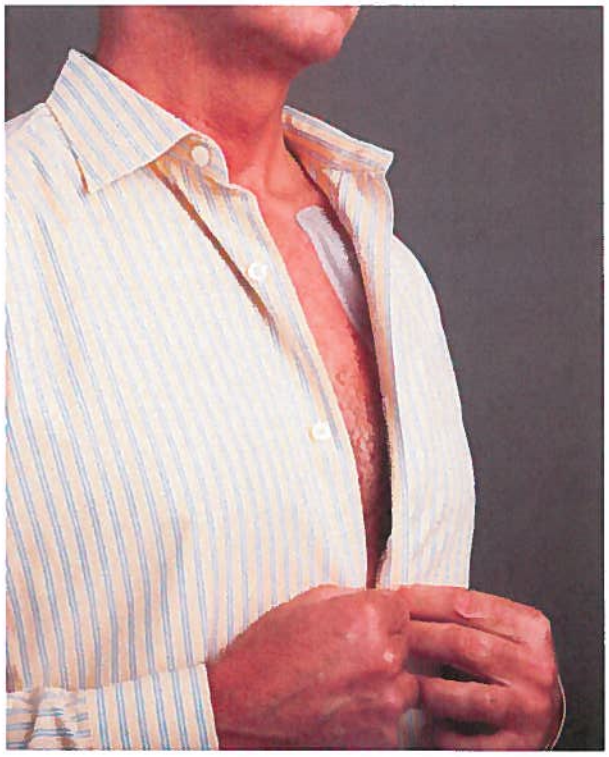


Photo courtesy of NUVANT

Graphic courtesy of Sotera

This graphic shows how today's wired "tricorder" technology could be put into use. Tomorrow's technology will scan vital signs without contact.

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