ROBOTICS TAKES OFF AT THE SCHOOL OF MEDICINE | BY JOE MIKSCH

OF MED AND MACHINE

Robots pique the human imagination.

More than 2,250 years ago, the Greek engineer Ctesibius envisioned many—and created more than a few—self-operating machines that, minus the "intelligence" provided by modern computing, did human work. About five centuries ago, Leonardo da Vinci sketched out a humanoid robot that could sit up and wave. In the 20th century, visions of robots and their possibilities gave Isaac Asimov a career.

On a practical level, in the real-world here and now, robots help us build cars, vacuum our carpets, and defuse bombs. They also, notably in the University of Pittsburgh School of Medicine, are taking a lead role in saving and improving lives.

For instance, Pitt investigators are in the early stages of two clinical trials testing a robotic arm controlled by people's brain impulses. Others at Pitt are perfecting a wheelchair with robotic arms, in the hope that wheelchair users will be able to do even more on their own. And in the operating rooms of UPMC hospitals, surgeons employ a four-armed robot to perform more precise surgery in smaller spaces. The robot's name: The da Vinci, after the man whose imagination led him to ponder robots more than half a millennium ago.

Robotics, cyberscience, and artificial intelligence are changing medicine and people's lives. For instance, Pitt and Carnegie Mellon's PerMMA wheelchair—reimagined on the left—uses robotic arms to allow people with quadriplegia to open doors and feed themselves.

ILLUSTRATIONS | JESSE LENZ

CYBER SNACKING

At the University of Pittsburgh Motorlab, you can see a monkey, its neural activity monitored and recorded by a tiny microelectrode array, feed itself marshmallows using a robotic arm rather than its hands.

When the monkey thinks of grabbing the food—presented to it at the end of a metal spindle—the microarray feeds the monkey's thought of using the robotic arm into a computer, which processes the information and feeds it to the arm. With almost no lag time, the monkey's thoughts cause the arm to reach out, grab the food, and bring it back to the monkey's mouth, at which point the primate stuffs the treat into its maw.

It's kind of nuts to watch. And yet it makes perfect sense: If you can find the neurons responsible for motor activity, you can figure out how these neurons communicate, and then, eventually, find a way to translate the signals to drive motion in a robotic arm. Pretty simple, conceptually. It's not at all simple, though, technologically speaking.

Pitt professor of neurobiology Andrew Schwartz is, in concert with Michael Boninger, Pitt professor and chair of the Department of Physical Medicine and Rehabilitation, edging this technology toward prime time at the University of Pittsburgh.

"We started thinking seriously about this in 1986," Schwartz, a PhD, says. "That was when we could demonstrate that we could decode these signals reliably from the brain. Once we had the data, we knew it could work."

A quarter century since he "knew it could work," Schwartz has surmounted many of the technological hurdles and is pressing ahead.

On a typically inclement early March day in Pittsburgh, technicians assisting Schwartz are less concerned with the weather than the installation and calibration of a remarkably expensive, brand-new robotic arm. The $400,000 device (the Defense Advanced Research Projects Agency—DARPA—has spent tens of millions of dollars on this research and technology so far) was built at the Johns Hopkins University Applied Physics Laboratory.

Looking like it might have fallen off RoboCop, the arm is mounted on a floor-to-ceiling pole in a small room, off a larger space packed with computers. A group of youngish men studying under Schwartz and a rep from the Applied Physics Laboratory surround it, fiddling with the device.

"This project was designed to be a prosthetic arm that goes on an amputee," Schwartz says as the work goes on. "It weighs nine pounds, so it weighs as much as a regular arm. It has the size of a regular arm and hand, and it can do things like lift 50 pounds." Also, Schwartz adds, the fingertips of the device have sensors that will offer users tactile feedback. Eventually. That's something that still needs to be sorted out.

(The technology Schwartz has developed has been featured on *60 Minutes* and in *The New York Times*, among other media outlets. This magazine ran a February 2005 feature, "Cyborg Medicine.")

While Schwartz is the lead brain behind the arm's technology, Michael Boninger, an MD and director of the UPMC Rehabilitation Institute, will lead the about-to-begin clinical trials.

Boninger is recruiting people with quadriplegia from spinal cord injuries for the trial. The group considered others with no use of their arms, such as people with amyotrophic lateral sclerosis, but thought the progressive nature of the disease would complicate the study.

The first trial, Boninger says, will further investigate the most effective way to record electrical signals from the brain. Each patient will have an array of 16 electrodes laid on the brain surface and then be instructed to move a cursor on a computer screen and, eventually, manipulate a prosthetic arm in a simple way while the array records neural activity. The trial will last about a month.

The second trial will last one year and will study how well participants can perform functional tasks with the arm, which will be mounted to a wheelchair. More sensitive arrays—each with 100 electrodes—will actually be implanted into the patient's brain rather than laid on the surface.

"We'll have much more time to train them and much more time to get participants to use the arm with multiple degrees of freedom," Boninger says. "I would hope that by the end of the year, they'll be able to do things so well with the arm that it will be of some practical assistance to them."

The trial is expected to begin late this year. It and the briefer trial are supported by $6.8 million in grants from DARPA and the National Institutes of Health.

No matter how well the trials work and how much is learned, Schwartz says, there's much to be done before his group can offer a commercially viable product.

"Well, it's one thing to demonstrate this in a lab, but will it be reliable enough to use every day? The machinery can break down a lot, then there's the issue of how long the [microarray] implants can stay in; the brain tries to reject them and encapsulate them," Schwartz says. "We'd like to have bilateral control [the ability for the brain to control two robotic arms simultaneously], but we don't know how that's going to work, and we're not sure how well you'd be able to move individual fingers …

"And one of the most critical factors is the patient's ability to learn. What I mean is that we're recording their neural activity, and they're trying to get their neurons to work this device. So they're trying to make their neurons fit our expectations."

THE THINKING WHEELCHAIR'S WHEELCHAIR

Equipped with robotic arms, which can lift a few pounds each and have dexterity enough to lift a magazine off a table, the Personal Mobility and Manipulation Appliance (PerMMA) is being prepped for clinical trials—and is being continually refined—at the Human Engineering Research Laboratories (HERL) at the VA Pittsburgh Healthcare System–Highland Drive. (The lab, affiliated with the University's School of Health and Rehabilitation Sciences, is moving to new space at Pittsburgh's Bakery Square development, also home to a Google campus, in July.)

Early one morning, Garrett Grindle, a graduate student researcher at HERL, and Juan Jose Vazquez, a research associate, were sitting with PerMMA in lead developer Rory Cooper's office, prepared to put it through its paces. Cooper is professor of orthopaedic surgery in the School of Medicine and FISA & Paralyzed Veterans of America Chair and Distinguished Professor of

A brain-controlled robotic arm may one day mean independence for those who can't use their own.

Rehabilitation Science and Technology in the School of Health and Rehabilitation Sciences. (He holds a number of other appointments, as well.)

PerMMA looks like a souped-up conventional electric wheelchair with side-mounted robotic arms terminating in pincers. It's about 3 feet wide, though it can get much smaller when the robotic arms are retracted behind the wheelchair base. It's the same height as just about any other wheelchair you'd see, except that it can lift its human partner a couple of feet in the air to grab something from, say, a kitchen cabinet or otherwise out-of-reach place.

"There are three modes of running it," Grindle says. "In some cases it's automatic. The 'big' task we have been able to do automatically is open a door." "Automatic mode" employs video cameras and Carnegie Mellon University–crafted software to tell PerMMA that it's at a door. The chair's user confirms that what PerMMA has detected is indeed a door and gives it the command to perform the task.

"We've also been able to write little programs to move the robots to a certain pose," Grindle adds. "The robot's pose is almost always the same for picking up a cup, so we move the joints automatically to a generic pose for picking up a cup. It is not that fancy from a software/algorithm point of view, but it is practical and works really well. Then we have direct user control: There are buttons people can manipulate, and we have a touch pad and voice control. The third option is a remote-control mode."

With that, Vazquez, who was sitting quietly at a desk, grabbed hold of two joysticks and made PerMMA's arms move and pincers contract and expand.

"See those two Web cams on the chair?" Grindle asks. "[Vazquez] can see what the person in the chair can see, but it's streaming over the Internet. What we think we might be able to do here is have a call center, like OnStar [the service that allows motorists to get help in an emergency just by pushing a button]. If a person is having a little trouble, they could call someone up—maybe a professional at a call center or a family member or other caregiver at home—and say they need help getting a bowl out of a cupboard." The person on the other end of the call could then take over control of PerMMA and help its user do what needs to be done.

Grindle hops into PerMMA to demonstrate. A magazine is on a round table in the middle of the office. Grindle powers PerMMA over to the table and reaches out, controlling one of the robotic arms with a joystick, and tries to grab the magazine. He's having trouble.

This is where Vazquez (or, in the future, perhaps a technician at a remote call center) comes in. Sitting at a desk a few feet away, he peers at a computer screen, which shows the table from Grindle's perspective. He grabs hold of one of the two joysticks on the desk (one for each of PerMMA's arms) and causes an arm to slowly move forward. With the arm extended, he opens its pincer-style hand, closes it on the edge of the magazine, and lifts it. Then he gently deposits it onto Grindle's lap.

Done—without the need for a visit from a caregiver.

PerMMA has some limitations. Its arms can only lift about 5 pounds, which is less than a gallon of milk weighs. Hence the Strong Arm project. Grindle says the team is very close to completing a working prototype of a robotic arm that has the ability to help PerMMA's user get in and out of the chair or lift a pot of boiling water off the stove.

"We're going with a 'lobster strategy,'" Grindle says. "We'll have one big arm on one side and a smaller, more dexterous arm on the other. The big arm will be slower (because of the care necessary when moving a person or something potentially dangerous like a pot of scalding liquid), but we've done some attitude surveys, and people say that even if it takes longer for the robot to do it, that's okay, as long as it can be done."

PerMMA and much of what HERL does are personal to Rory Cooper. When he was 20 years old, he was in the U.S. Army. While stationed in Germany, Cooper took advantage of some free time to go bicycling and was hit by a truck. His spinal cord was seriously damaged. Although he has use of his arms, he's been in a wheelchair ever since.

Cooper, a PhD, remains an athlete, having raced in and won the hand-cycle race in the 2009 Pittsburgh marathon. One of his goals as a researcher, engineer, and advocate is to make it easier for those with disablilites to lead full, active lives. PerMMA, he says, has the potential to allow people with severe physical impairments, such as those with quadriplegia, previously unheard of degrees of independence.

Cooper and his collaborators at the joint University of Pittsburgh–Carnegie Mellon University Quality of Life Technology Center, which is funded by the National Science Foundation, say that PerMMA is, "not just a wheelchair with 'added intelligence' and arms; it is a mobile robotic manipulator with a seat for a person."

In essence, PerMMA should become part of the person using it.

"If you're going to be using robots to assist people," Cooper says, "then you should take advantage of human intelligence. It's easy to create a robot that works in a fairly fixed structure or fixed location. But there's a lot of randomness in the world, and that's why I'm very excited to have a human in the loop."

In 2010, PerMMA was named one of *Popular Science*'s 10 most promising robots. Cooper thinks it deserves the honor. "This has the potential to really transform lives. Where we need to go is to improve the interaction between robots and humans, and that's what I'm working on."

THE ART OF SURGERY

In an operating room at UPMC Shadyside, Pitt surgeon Herbert Zeh sits at a console, peering into an incredibly high-resolution, three-dimensional viewfinder. His hands on two delicate-looking joysticks, he makes small, precise motions with his fingers.

His patient, a woman in her 60s with a large tumor growing on her pancreas, is several feet away from him. Above her is a four-armed robot. The arms are outfitted with a camera and surgical instruments inserted into the patient through tiny incisions.

Zeh cuts and cauterizes and ties off blood vessels from a distance. After about three hours, the tumor has been cut loose. It's 7 centimeters in diameter. The robot picks up the tumor, the patient's spleen, and a portion of the pancreas and inserts it all into a plastic bag, which it pulls it out of the patient. Zeh walks the bag to the pathology lab.

The pathology tech slices a section of the pancreas removed with the tumor to see whether there are any cancer cells in the margin of the organ. (Surgeons want to make sure that the margin is clean, reducing the chance that the cancer will regain a foothold in the part of the pancreas that remains in the patient.) Some cancer cells are visible in the slide the tech prepared, so Zeh heads back to the OR to remove a bit more of the pancreas.

In a way, what just happened is a good bit like laparoscopic surgery, a well-established minimally invasive surgical method. What's different here is, of course, the simple fact that a robot—the da Vinci Si, made by a California company called Intuitive Surgical—is doing the job.

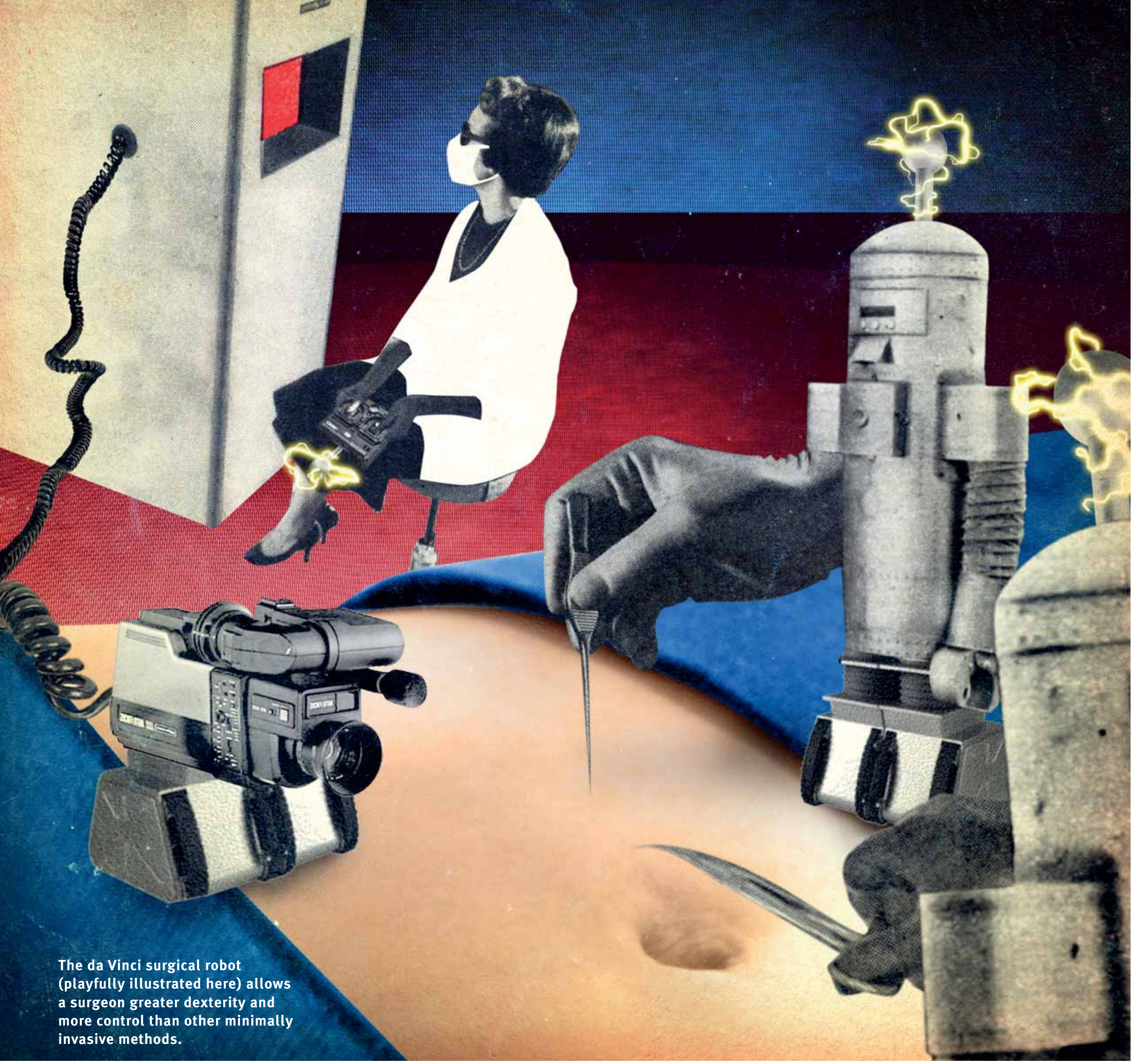
But what makes da Vinci better than just a shiny, new toy, Zeh says, is it allows the surgeon greater dexterity (the robotic instruments have a much wider range of motion than the essentially straight-forward ones used in laparoscopic surgery), greater precision (thanks to the three-dimensional, high-definition camera, calibration of the da Vinci's arms, and the fact that robots don't suffer from the slight hand tremors even the calmest surgeon exhibits), less scarring post-op, and much less blood loss.

"It's night and day" compared to open and even laparoscopic surgery, Zeh says, while waiting for the pathology results. "One of the things people have considered a drawback with it is that you don't have that tactile sense. But after many hours at the robot, it's like we can 'feel' through our visual feedback."

It's "like [how] some visually impaired people describe enhanced tactile sensation," adds James Moser, MD Pitt professor of surgery and codirector of the UPMC Pancreatic Cancer Center (and a frequent collaborator with Zeh on da Vinci–related research).

Pitt surgeons are far from the only ones using the da Vinci—there are 1,752 of them in operation worldwide, 1,285 in the United States, 55 in Pennsylvania (including five at UPMC hospitals). But Zeh and Moser are among the earliest adopters and innovators, having performed more robotic major pancreatic resections than any of their peers.

In 2010, Zeh and Moser published a paper in *Archives of Surgery* that was the first to



The da Vinci surgical robot (playfully illustrated here) allows a surgeon greater dexterity and more control than other minimally invasive methods.

establish that the da Vinci is safe and effective for major pancreatic resections. They believe further research will show that the robot improves patient outcomes.

Marshall Webster is executive vice president of UPMC and president of its Physician Services Division. He formerly served as Pitt's Mark M. Ravitch Professor of Surgery. He has long been an advocate of robot-assisted surgery. "This has been a profound advance," he says. "I've never done a robotic procedure—I've been out of surgery for eight years since I've been in this [administrative] role—but the results we've seen have allowed me to be very effective in selling the administration here on buying these $2 million machines."

UPMC, Webster says, sees about 160,000 operations per year, "and we're doing about 1,000 cases a year with robots. All of [the robots] are very busy, it's hard to get time on them now, and there are very few places in the country that have five da Vinci Si machines."

Pitt has 22 surgeons in nine specialties who use the da Vinci regularly. Each year, Webster says, that number will grow, as will the number of procedures performed.

"And, down the line, we're going to be able to do something like this," Webster says. "There'll be one console at Presby and another console in Bedford, Pa., where the patient is. Maybe the surgeon in Bedford needs assistance or a second opinion, and the surgeon at Presby can help wirelessly.

"Things are advancing so rapidly that it's not a matter of if, it's a matter of when."

And it's something that even da Vinci himself never envisioned. ■

To see the da Vinci doing origami and more, check out our Web Extra: pittmed.health.pitt.edu/Summer_2011/web-extra.htm.