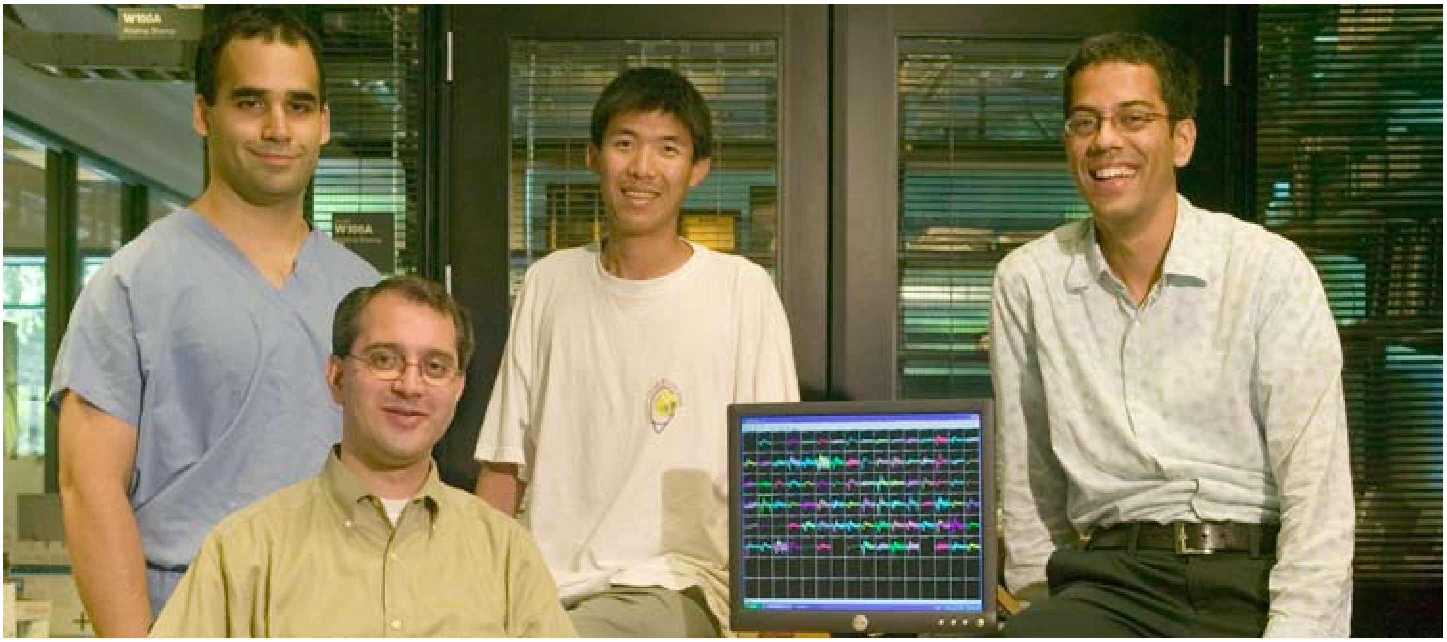
STANFORD TEAM ADVANCES PERFORMANCE OF "BRAIN-COMPUTER INTERFACE" FOR PARALYZED PATIENTS



Medical and EE doctoral student Afsheen Afshar, EE Assistant Professor Krishna Shenoy, EE doctoral students Byron Yu and Gopal Santhanam, and neurosurgeon Dr. Stephen Ryu (not pictured) are the authors of a breakthrough paper on brain-computer interfaces.

BY LOU BERGERON

Researchers at Stanford University's Schools of Engineering and of Medicine have developed a faster way to process signals from the brain for use in guiding prosthetic devices for the paralyzed. The new approach, outlined in a paper published in the July 13, 2006, issue of Nature, quadrupled the speed of previous systems, making the prostheses for the first time fast enough to be practical for patients.

"This work really gives a boost to the efforts to produce a workable brain-controlled prosthetic for people with paralysis," said Susan P. Howley, director of research for the Christopher Reeve Foundation, which provided funding for the research in the group of electrical engineering and neuroscience Assistant Professor Krishna Shenoy. Certainly bringing new hope to the paralyzed is the best outcome of the research, but the effort also demonstrates the power of interdisciplinary research. In this case, the advance could only come about at the intersection of information technology and medicine.

The prosthetic system that Shenoy and his team are working on is called a "brain-computer interface." The idea is to implant tiny electrodes in the brain to record the electrical activity of neural cells and to send those signals to a computer, which interprets them using an algorithm the researchers developed. The algorithm translates the signals into commands that can control a prosthesis, for example a computer or an artificial limb. Although it may sound straight out of science fiction, initial experiments in the 1960s showed that it could be done. Since then there have been two significant hurdles to developing a workable brain-computer interface. Essentially they have been challenges of signal and data processing.

The first has been simply making sense of the signals generated by neurons, the brain cells that create thoughts within the brain and transmit them down the spinal cord and out to the peripheral nerves by means of electrical impulses.

The second challenge, where Shenoy's team members applied their new approach, is interpreting those signals with enough speed and accuracy to make the interface practical to use for a patient.

THE NEED FOR SPEED

The standard approach to processing neural impulses has been to collect and translate them every step of the way as the subject thinks about moving the prosthesis from point A to point B. That's a valid approach, said Shenoy, if the user is doing things requiring continuous movement, such as drawing a line.

But all that collecting and processing slows down the prosthesis, and for many tasks, such as typing on a keyboard or turning off a light switch, it's not about the journey, it's the destination that counts.

Shenoy and his colleagues set out to shorten the process by focusing on the end point rather than processing every step along the way. They hoped to accurately forecast an intended target based on the signals the neurons sent out when the subject only thinks about moving an arm to that target.

The researchers worked with rhesus macaque monkeys in their experimental work. The monkeys were connected to the interface by a tiny silicon chip, less than one-tenth the area of a penny, holding 100 electrodes. The electrodes were implanted in the pre-motor cortex, which is on the surface of the front part of the brain and is one of the areas responsible for guiding a person's or a monkey's arm.

The monkeys were trained to face a computer screen, with one finger touching a central starting point and their eyes focused on another starting point nearby. When a target spot lit up elsewhere on the screen, the monkey knew that he was supposed to touch the target spot—but only when another on-screen signal told him to. Until the "go" signal was given, the monkey waited.

This waiting period was the critical phase in collecting the data for analysis. The brain waves the monkeys generated during this hiatus, when they were only thinking about moving their arms to the target spot, simulated the neural signals a paralyzed person would generate while thinking about moving a prosthetic arm or cursor to a particular spot, yet not physically doing so.

FINDING A 'SWEET SPOT'

The challenge was achieving the right balance. On the one hand, the scientists wanted the computer system to use as brief a neural signal as possible, recorded while the monkey was anticipating touching the target. On the other hand, they wanted to ensure that the system had enough information to predict the correct location of that target. In other words, the researchers wanted to find the "sweet spot," the point where the system would process the brain waves in the best balance of time and accuracy for a prosthesis.

As Shenoy and his colleagues saw hints of a sweet spot in their data, they deliberately ran tests at that speed. Ultimately they arrived at a result that was far superior to what others had previously achieved.

"You can quantify that sweet spot in terms of the rate at which the system is extracting data from the brain just the way you measure the data-transmission rates of computer modems," explained Gopal Santhanam, PhD, who did his graduate work in electrical engineering in Shenoy's laboratory and is one of two first authors of the Nature paper. In those terms, the data-extraction rate at the sweet spot works out to about 6.5 bits per second; that's about four times better than the peak performance of about 1.6 bits per second predicted by the best previous approaches, which used slower systems and then extrapolated to calculate a theoretical peak.

An accompanying paper in the same issue of Nature reported on the work by another research group, at Brown University, which has been working with human patients with spinal cord injuries to show that even years after an injury, they still have the needed neurons to control a prosthesis. Shenoy said that in combination, the work of the two groups makes the prospects "quite bright" for developing functional prostheses that patients could control with their thoughts.

"Our research is starting to show that, from a performance perspective, this type of prosthetic system is clinically viable," confirmed Stephen Ryu, MD, clinical assistant professor of neurosurgery and the other co-first author of the Nature paper, while adding a caveat. "But in order for it to be a practical system for a human, it also has to be safe and reliable." Currently, the electrodes last at most a few years. As with the development of pacemakers before them, the implants will have to be longer lasting before they'll become widespread.

Shenoy said the study proves it's possible to process neural signals fast enough to be useful to a paralyzed patient, adding that data-transmission rates can be used to approximate the number of words per minute the prosthesis would allow a user to type. Previous methods topped out at a few words per minute, but the end-point approach of his group peaked at 15 words per minute. That might not be speedy enough to land their brain-computer interface a job in the steno pool, but it's fast enough that a person could probably use it to communicate with the rest of the world without undue frustration. And though one might say that is the real end point of all their efforts, Shenoy thinks they can do better. "We really are viewing this as a starting point," he said.

Other authors of the paper are electrical engineering graduate students Byron Yu and Afsheen Afshar, who is also a medical student. The study was supported by National Defense Science and Engineering Graduate Fellowships, National Science Foundation Graduate Research Fellowships, Christopher Reeve Foundation grants, Bio-X Fellowship support, a Burroughs Wellcome Fund Career Award in the Biomedical Sciences, the Stanford Center for Integrated Systems, the NSF Center for Neuromorphic Systems Engineering at Caltech, the Office of Naval Research Adaptive Neural Systems, the Sloan Foundation and the Whitaker Foundation.