Team makes electronic skin that can sense touch

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Stanford scientists have developed a soft and stretchable electronic skin that can directly talk to the brain, imitating the sensory feedback of real skin using a strategy that, if improved, could offer hope to millions of people with prosthetic limbs.

"We were inspired by the natural system and wanted to mimic it," said Weichen Wang, whose team published its success in the journal *Science*. "Maybe we can someday help patients to not only restore motor function, but also restore their sensations."

Much faster, larger and more sophisticated circuitry is needed before so-called "e-skin" holds promise for people.

But, in a milestone, the device showed remarkable success in a lab rat. When researchers pressed the rat's e-skin and sent electronic pulses to its brain, the animal responded by twitching its leg.

Scientists have long dreamed of building prosthetic limbs that not only restore movement but also provide perception—sensing pressure, temperature and vibration, for instance—to help restore a more normal quality of life. Skin damage and amputation cause a massive disruption in the loop of perception and movement, so even simple tasks like feeling or grasping an object are challenging.

"If you pick up a glass of beer and you can't sense that it's not cold, then you won't get the right taste," said Ravinder Dahiya, professor of electrical and computer engineering at Northeastern University in Boston, who is also studying the use of flexible electronics to develop artificial skin.

Electronic skin also could be used to clad robots so they feel sensations in the same way that humans do. This is critical to the safety of industries where robots and humans have physical interactions, such as passing tools on a manufacturing floor.

But the sensation of touch is complicated. Human skin has millions of receptors that sense when they are poked or pressed, squeezed or scalded. They react by sending electrical pulses to the brain, through nerves. The brain responds by sending information back, telling muscles to move.

And biological skin is soft and can stretch, repeatedly, for many decades.

The Stanford team, led by chemical engineering professor Zhenan Bao, has been working on e-skin designs for several years. But an earlier effort used rigid electronics and 30 volts of power, which requires 10 batteries and isn't safe. And it wasn't able to endure continuous stretching without losing its electrical properties.

"The hurdle was not so much finding mechanisms to mimic the remarkable sensory abilities of human touch, but bringing them together using only skin-like materials," said Bao, in a statement.

The new e-skin is innovative because it uses networked layers of stretchable organic transistors that perceive and transmit electrical signals. When sandwiched, the layers are only about 25 to 50 microns thick—as thin as a sheet of paper, similar to skin.

Its networks act as sensors, engineered to sense pressure, temperature, strain, and chemicals. They turn this sensory information into an electrical pulse.

And the e-skin runs on only 5 volts of electricity.

To test the system, the Stanford team implanted it into a live rat. When the rat's e-skin was touched, a pulse was transmitted by a wire to the rat's brain—specifically, an area called the somatosensory cortex, which is responsible for processing physical sensations.

The rat's brain responded by sending an electrical signal down to its leg. This was done using a device that amplifies and transmits signals from the brain to muscles, mimicking connections in the nervous system called synapses.

The rat's leg twitched. Significantly, its movement corresponded to varying levels of pressure, said Wang, an engineering Ph.D. and first author on the new paper. For example, the team could increase the leg's movement by pushing the e-skin harder, which boosted the signal's frequency and the transistor's output.

If tested in humans, the device would not require implantation of a wire to send sensory information to the brain. Rather, the team envisions using wireless communication between e-skin and an electrical stimulator located next to a nerve.

Joe McTernan of the American Orthotic and Prosthetic Association said such research encourages technological advancements that could someday provide real-time biofeedback for people who have lost limbs.

"Although this skin technology is fairly new, there has been significant research and development in recent years that have focused on creating a positive tactile experience for the patient," he said.

The Stanford team's closed-loop system—from sensation to muscle movement—is "very exciting…very much a proof of concept," bioelectronics expert Alejandro Carnicer-Lombarte of University of Cambridge told the journal Nature.

In the field of artificial prosthetics, most researchers tend to work on individual components, he said. "Combining those things, in sequence, is not trivial."

Dahiya applauded the team's success in building flexible electronics and then making them work. "That's where they've done a nice job," he said.

But he said there's still a missing piece of the puzzle: creating memory. Unlike Stanford's e-skin, human skin learns how an object feels, then can anticipate it.

There's another challenge: The transmission of signals is currently too slow to be useful. The flow of information through the team's flexible carbon-based transistors is sluggish compared to more traditional silicon-based transistors, he said.

Such a delay "will not allow us to get a real feeling," Dahiya said. "And without real feeling, then you have a practical bottleneck."

At Stanford, the next step is to pack more and different sensors into the e-skin, to more closely replicate the many sensations felt by the human hand, said Wang.

"We're scaling up," he said. "It will be more advanced.

"The whole field is under development," he said. "It will take many more generations of developments to realize our target."

More information: Weichen Wang et al, Neuromorphic sensorimotor loop embodied by monolithically integrated, low-voltage, soft e-skin, *Science* (2023). DOI: 10.1126/science.ade0086

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