Sensitive Synthetic Skin in the Works for Prosthetic Arms

By combining carbon nanotubes with a specially designed polymer, researchers are making a material that looks, feels, and functions like human skin. The synthetic skin could lead to next-generation prosthetic arms with which users can feel a light touch, shake hands, cook, and type naturally.

Researchers at Oak Ridge National Laboratory (ORNL), in Tennessee; NASA; and the nonprofit National Institute of Aerospace (NIA), in Hampton, Va., plan to have a 6-square-centimeter patch of the synthetic skin ready by the end of next year. “With this technology, the artificial limb will come much closer to its human counterpart,” says ORNL researcher and Defense Advanced Research Projects Agency (DARPA) liaison Art Clemons.

The project is part of DARPA’s Revolutionizing Prosthetics program, which aims to build by 2010 a strong, lightweight mechanical arm that can touch and feel just like the real thing, send signals to amputees’ brains, and respond to direct brain control.

Double amputee Jesse Sullivan demonstrated a current prototype of the bionic arm at the DARPATechconference in August. Sullivan can stack plastic cups in a pyramid and pull a credit card out of his pocket—seemingly simple tasks that require very complicated feedback among nerve endings in the skin, neurons in the brain, and muscles. The mechanical-looking prototype arm currently has about 80 individual silicon-based sensors on the fingertips to give feedback on touch, temperature, and limb position.

The new artificial skin will incorporate many more sensors and will cover the metallic prosthesis, leading to a more natural-looking bionic arm. The skin—a rubbery polymer called polyimide that has been infused with tiny carbon nanotubes—is flexible, stretchable, lightweight, and tough. Initially designed for airplane pressure sensors, the polymer is durable, resistant to high temperatures, and piezoelectric. That is, it generates electricity in response to pressure or force, so you can measure pressure applied to its surface, says NIA’s Cheol Park, who is leading the pressure-sensor development. Carbon nanotubes enhance the piezoelectricity of the polyimide and make the polymer stronger, he says.

Temperature sensors will be embedded under the polyimide layer. The trick is to transfer heat as quickly as possible from the polymer surface to the sensors. Again, carbon nanotubes, which conduct heat along their length unusually well, will play a key role. Researchers at ORNL are trying to make nanotube-embedded polymers that conduct heat as well as human tissue does, says Ilia Ivanov, a nanomaterials researcher at ORNL. They will impregnate the polymer with an array of vertically aligned nanotubes, which will transfer heat from the skin surface to the temperature sensors underneath. Ivanov says the heat transfer should be fast. In 2006, researchers showed that a heat pulse travels 20 times as fast in a polymer containing the nanotube arrays than in the pure polymer.

Others have taken a different approach to making flexible electronic skin. In 2005, Japanese researchers outlined in the *Proceedings of the National Academy of Sciences* an electronic skin composed of pressure-sensitive rubber and organic semiconductors. A mesh of organic diodes acted as the thermal sensor, and a mesh of organic transistors read the data from the sensors. “Sensitive electronic skin is an indispensable component for humanoid robots,” says Takao Someya, one of the electronic skin’s inventors and an associate professor at the University of Tokyo’s Quantum Phase Electronics Center. The e-skin could also be used for prosthetics, but the sensors still need a factor of 10 improvement to be able to pick up tiny pressures that human skin can sense. (Someya’s group recently adapted similar technology to provide wireless power and communications to portable devices.)

The DARPA goal is to have an artificial skin that can measure a force as small as 0.1 newton, says NIA’s Park; the nanotube composite is not that sensitive yet. But Park and his colleague Joycelyn Harrison are close to reaching that goal. They are tailoring the material’s properties by changing the concentration of carbon nanotubes and the structure of the polymer matrix. They are also close to achieving the spatial resolution of human nerve cells, which can differentiate between two pinpricks 2 millimeters apart. The polymer composite so far has a resolution of 5 mm.

Another important question, says Park, is “once you get this kind of pressure signal, how can you deliver it to the brain [to make it] react.” Neuroscientists at the Rehabilitation Institute of Chicago appear to be on the path to an answer. They have found a way to redirect the arm nerves of amputees to their chest muscles, allowing them to use the chest to intuitively control a prosthetic arm and even to feel some pressure applied to the limb. They found that the patients could actually sense touch, heat, cold, and pain on the skin of the chest as if it were on the skin of the missing hand. In November, the researchers reported how the sensitive spots on the chest mapped to specific parts of the missing fingers and hands.

Even with such a map, researchers will need to design software algorithms and electronic circuits to process the various signals from the electronic skin and get them to the right nerve endings. But that challenge will come later. For now, the researchers face the task of perfecting the various sensors and materials and getting them to work together.

About the Author

Prachi Patel-Predd is a writer and radio reporter based in Pittsburgh. She last wrote for IEEE Spectrum Online about efforts to produce artificial joints that radio their status to doctors.