Technology and the Human Hand

The State of the Art in Artificial Hands, Hooks and Prehensors

Dr. William Craelius (Photo by Nick Romanenko, Rutgers Photo Services)

by Rick Bowers

As Jay Schiller taps out the notes of "Mary Had a Little Lamb" on the piano keyboard, a scientific stride is being made. Schiller, who lost his left hand in an accident in 1988, played the song using an experimental model of the first bionic hand that can be controlled through human thought. Though playing the song would generally be considered an insignificant accomplishment (it's just "Mary Had a Little Lamb" after all), hidden within the simple notes is the possibility for future improvements in upper-extremity prosthetics.

The invention of Rutgers University engineering professor William Craelius, who is assisted by a team of students and former students, the hand - known as the Dextra - is far below the level of that of the Six Million Dollar Man in the 1970s TV show, but it's a step in that direction.

Craelius hypothesized that the "circuitry" that sent messages to a phantom arm or hand could be harnessed to control an artificial hand. By hooking up an amputee to a computer and sensors and letting him think about moving his hand into certain shapes, Craelius and his team could "see" on the computer the signals that caused particular movements. Ultimately, he was able to "train" the computer to recognize which signals did what. He then made a sleeve lined with sensors to fit over the amputee's arm. The sensors would detect changes in the signals and move the Dextra hand accordingly.

Of course, all of this sounds great, but there are still a lot of problems that have to be addressed before such a thought-controlled hand that can take almost any shape can become a viable reality. "We are still far from approximating a human hand," Craelius says.

Craelius sees the lack of communication between human and machine as the main obstacle (*Science*, Feb. 8, 2002, Vol. 295). The human body receives and translates millions of brain impulses into movement, and duplicating this ability is impossible. Complex systems of control are being developed, however, and it has been shown that a monkey's brain signals were able to control an actual robotic arm in another state as the monkey watched it on a computer.

To make it possible for this to occur in the real world, however, would probably require implantations of electrodes and recording devices directly into the brain. Though this would take up too much space in the brain, the next possibility is to use an external device that can receive wireless messages from the brain. Craelius says that this is possible and that even brain implants might be possible within the next decade if transistors continue to become smaller. The problems then would likely be electromagnetic interference, battery limitations and sealing the devices well enough to protect them from corrosion.

The prize, however, is worth pursuing. With such a device, an amputee might be able to control all the fingers of an artificial hand, whereas state-of-the-art prosthetic technology only allows an amputee to move the hand as a unit rather than each individual finger. Such a capability would be a great leap forward in the functionality of prosthetic hands.

Other systems

Though bionics clearly has a long way to go, there are already numerous hand-like terminal devices on the market to help upper-extremity amputees.

These devices are typically either body-powered or electric-powered, and each system has its advantages and disadvantages. Body-powered devices that use cable and harness systems require the patient to use body movements (moving the shoulders or the arm, for example) to pull the cable and make the terminal device open or close much in the way a bicycle handbrake system works. Their advantages over electric-powered devices are that they are usually less expensive, lighter in weight, easier to repair and offer more visual and/or tension feedback to the body. Some amputees, however, dislike their mechanical appearance, and others find them difficult to use because of their reliance on physical ability.

Electric devices do not require a harness or cable and can therefore be built to look more like a real arm and hand if desired. In addition, body strength and body movement are not as important since the prostheses are battery-powered. In general, these systems also offer a strong grip force. On the downside, they are usually heavier, subject to battery weakness, much more expensive and more costly to repair. Newer battery chemistries, like lithium ion and nickel metal hydride, have, however, helped reduce their weight and increase their capacity and voltage.

Another major improvement of electric prostheses is the use of multiple methods of control to operate them. Electric prostheses are not all myoelectrically controlled, as some people think, explains William J. Hanson, president of Liberating Technologies, Inc. "Myoelectic means that you pick up a myo signal off the surface of the skin from the muscle that you intend to use to control the speed and direction of the prosthesis. But there are a lot of electric systems that are not myoelectric systems. They use pressure, a switch and a harness, a positional servo device or a strain gauge." Prosthetists today are often using more than one kind of control system for a single patient. For example, they might use myoelectrodes to control the hand and a positional servo transducer to control the elbow. "The advantage to that," Hanson says, "is that these are now independent controls, and the patient can control them simultaneously. In the past, you had to do one thing at a time. You flexed the elbow, stopped flexing the elbow, switched to the hand, opened the hand, closed the hand, and then extended the elbow. With the multiple input concept, you can do more than one thing at a time and, therefore, have smoother, simultaneous movements."

Currently, the body-powered and electric terminal devices available for arm amputees fall into four categories: hooks, prehensors, artificial hands and specialty terminal devices. The different types of terminal devices each have advantages and disadvantages and are better for some situations than others. Though no one product is able to fulfill all of the functions of a human hand perfectly, it is often possible for amputees who have more than one terminal device to easily and quickly switch from one type of device to another with the various quick-disconnect wrist units that are available and have become standard in the industry. One might, for example, use a functional hook or electric prehensor to perform some kind of work task, then disconnect it and switch to a natural-looking hand with artificial hair, freckles and skin color to go out to dinner a few hours later. As a result, amputees have many more options than they did in the past when they were often limited to choosing one device or another.

Hooks

"In the U.S., people prefer hooks to hands two to one," says Gerry Stark, CP, FAAOP, BSME. "In Europe, it's the opposite. The European market is willing to sacrifice function for cosmetics." Stark, a prosthetist and engineer at Hosmer Dorrance Corporation, a subsidiary of Fillauer, Inc., says Hosmer's main seller is hooks, which are usually body-powered, but sometimes electric.

The split-hook design, first patented by David W. Dorrance in 1912, allows the hook apparatus to hold and squeeze objects between the split hooks. Today, Hosmer offers a wide variety of split-hook designs, which have somewhat different functions.

Though many people prefer artificial hands for cosmetic purposes or electric hands for greater grip, split hooks also have many advantages, mainly their functionality, efficiency of use, finite grasping ability, durability, lower maintenance and repair costs and lighter weight. Using a hook, amputees can better see what they are trying to hold, while the size and thickness of artificial hands sometimes block their view. Because artificial hooks and hands can't feel, being able to see what one is doing (visual feedback) is especially important. This also makes hooks - which often have a nitrile coating to prevent slippage - generally better for picking up smaller objects. Also, because hooks are usually made of metal, amputees don't have to be as careful around heat, which can melt artificial hands.

Hosmer's most popular hooks - the number 5XA, 5X and 7 split hooks (Photos courtesy of Hosmer Dorrance Corporation)

Hosmer's most popular hooks are the number 5XA, the 5X and the 7.

Liberating Technologies also offers a body-powered split hook called the RSLSteeper Titanium Split Hook. The use of titanium for manufacturing this hook offers several advantages, says Liberating Technologies' Hanson. "The advantage to titanium is that it has strength approaching stainless steel but has the weight of aluminum. People will generally choose aluminum for the light weight because they don't want that extra weight on the distal end of their prosthesis, but they're not that happy with the strength of the aluminum hooks, so they go to stainless steel, but they're not happy with the weight. Titanium gives them the best features of both."

In addition to the company's line of body-powered split hooks, Hosmer also offers an electric split hook called the Synergetic Prehensor, which provides true proportional myoelectric control. It weighs about 13.23 ounces and has a pinch force of up to 25 pounds, which is much greater than that of most body-powered split hooks.

Motion Control, another subsidiary of Fillauer, Inc., recently came out with the Motion Control ETD, an electric split hook that has water-resistant housings, is rugged and weighs only 14 ounces.

Prehensors

Somewhere between a hook and

a hand are devices called prehensors, like the body-powered GRIP, produced by TRS Inc., and the Electric Greifer, produced by Otto Bock. These devices consist of a thumb-like component and a finger component and resemble lobster claws or pliers.

Prehensors are not as cosmetically pleasing as artificial hands, but like hooks, they are better able to offer visual feedback to the amputee. Most mechanical body-powered hooks are voluntary-opening. This means that users must open the hook by applying force through their cable system. The hook then closes on its own with the aid of rubber bands, which limit the grip strength of the device to the strength of the rubber bands. The GRIP, on the other hand, is a voluntary-closing device. This means that force must be applied to close it instead of to open it, making the grip strength dependent not on the strength of rubber bands but on the strength of the person using it. Voluntary-opening devices that are closed with the aid of rubber bands offer only visual feedback for control since the bands take over closing once an object is grasped and take the body out of the feedback loop. Because they close by the user's own strength, voluntary-closing devices provide a tension feedback to the body similar to that "felt" when using bicycle handbrakes. Since users can "feel" the tension, they can also control their grip incrementally, applying more or less force as needed.

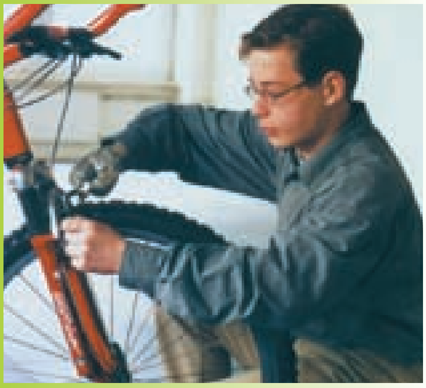
The GRIP 3 (left) and the GRIP 2S from TRS Inc. (Photo courtesy of TRS)

"I think that's an important factor," says Bob Radocy, the inventor of the GRIP. "We've produced a product that allows people to 'feel' what they're grasping. It allows them to control the objects that they're holding at a much higher level than in any other prosthetic system available. I can control my grip force from ounces up to hundreds of pounds with a voluntary-closing device."

The company also offers ADEPT Prehensors specifically for children, which are similar to the GRIP and emphasize function over human appearance.

The Otto Bock Electric Greifer prehensor has a number of additional advantages: It is voluntary-opening and voluntary-closing; it allows very wide opening; it includes built-in wrist flexion; it is battery-powered, and it is myoelectric, which allows it to take advantage of the body's own muscles for control. Its disadvantages are its heavy weight, its inability to be immersed in water, and its lack of "tension feedback" to the body that is available in voluntary-closing devices like the GRIP.

Another electric gripper is available from Liberating Technologies. The RSLSteeper MultiControl Plus Powered Gripper, which the company distributes, is lightweight (about 14 ounces), allows wide opening (more than three inches) and provides more than enough grip force (about 17 pounds) for most tasks, says Liberating Technologies' Hanson. In addition, its curved ends provide visual feedback much like that provided by split hooks.



The Electric Greifer
(Photo courtesy of Otto Bock)

The RSLSteeper MultiControl Plus Powered Gripper (Photo courtesy of Liberating Technologies, Inc.)

Hands

Though artificial hands are generally less functional than hooks and prehensors, some people still choose them because they look more like the human hand. To meet this demand, TRS developed the voluntary-closing Lite-Touch Biomechanical Hand, which is available for children and adults and looks more like a human hand than the company's GRIP and ADEPT high-function prehensors.

These hands were the first voluntary-closing hands that did not require a glove, Radocy says. Shaped to look like a human hand and molded in urethane, the hands use palmar prehension of the thumb, the index finger and the middle finger for grasping. They mainly appeal to those patients who like the voluntary-closing function, who like the ability to grip at the same level as their normal hand, who like the ability to "feel" what they are grasping, and who like the speed, the function and the efficiency of a voluntary-closing device, but who want all of these benefits in a package that's more anatomically correct. The Lite-Touch Biomechanical Hand is, in fact, a hybrid of a functional prehensor and a hand and offers some of the benefits of each.

Hosmer's latest products are the Soft Voluntary Opening Hand and the Soft Voluntary Closing Hand. Both of these hands have an inner hand shell and an outer cosmetic glove. "Our Soft Voluntary Opening Hand is similar to other products on the market, but it's slightly lighter and less expensive because it uses a nylon bulkhead," says Gerry Stark.

The Lite-Touch Biomechanical Hand
(Photo courtesy of TRS)

The company also offers the voluntary-opening CAPP (Children's Amputee Prosthetic Program) Hand for children, which they developed in cooperation with

TRS. "Until now, there's only been a voluntary-closing option for such hands," Stark says. "This one is nice because it doesn't use a glove that can restrict movement on the hand. We've taken the CAPP mechanism, which was originally a functional terminal device, and applied it for use with a semi-cosmetic hand."

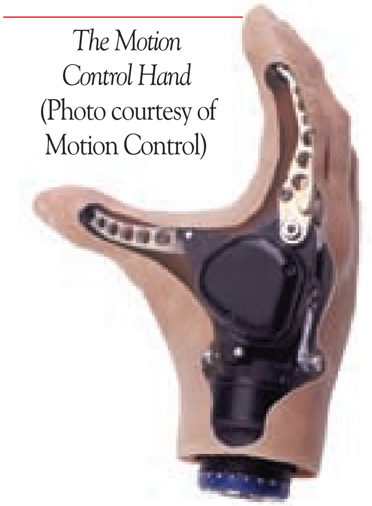
The myoelectric Motion Control Hand, manufactured by Motion Control, offers a wider grip, a quick-disconnect wrist, stronger fingers made from high-strength aluminum and composite plastics, a stronger motor that should last 10 times longer, a battery-save feature, and a patented safety release button that users can push to release the fingers if they happen to get stuck somewhere.

Otto Bock now offers the myoelectric Transcarpal Hand, which is especially good for amputees with long residual limbs or amputees with partial-hand or transcarpal-level amputations.

Some of the advantages of the Transcarpal Hand are its light weight, its short length and its ability to take advantage of the users' own wrist if they still have it. "This is a nice feature because someone who has that length of residual limb usually has some wrist motion left, and a correctly designed socket can take advantage of that," says Pat Prigge, CP, a clinical specialist with Otto Bock.

Otto Bock also manufactures the Sensor Hand, which isn't new, but is still state of the art because of the automatic grasp feature

The Motion Control Hand
(Photo courtesy of Motion Control)



of the hand. "It has sensors inside the hand that recognize pressure or how much grasp the hand is applying to an object being picked up," explains Prigge. "An anatomical hand would squeeze down on a glass a little harder as something is poured into it and it gets heavier. Likewise, the Sensor Hand automatically monitors grip force and grabs harder when objects get heavier so that they don't fall out of the user's grasp. As a result, users don't have to be as precise with their grip force." This solves one of the most

The Transcarpal Hand
(Photo courtesy of Otto Bock)

difficult problems for myoelectric users, Prigge explains. It helps ensure that they don't squeeze too little and drop something or too hard and crush something.

Another type of technology that the company has been using for about 10 years, but which many people are not aware of, is the company's grip force control system. "This system is programmed into the hand so that the grip force strength - how much grip force the hand applies to an object - is directly correlated to the signal strength that they put into the arm," Prigge explains. "The harder they contract, the higher the grip force is, so if they want to pick up something light, all they have to do is generate a small signal and the hand will close down to a light grip force and then stop. Otto Bock's proportional control of both grip force and speed is unique; however, other companies offer proportional speed control as well."

Fillauer, Inc., recently purchased the Swedish manufacturer Centri A.B., which manufactures a myoelectric hand called the Centri Ultralite. These hands are relatively inexpensive, lightweight (about three-fourths of a pound), short and fast, but do not have microprocessor control.

"The Centri Ultralite is particularly nice for women," says William Hanson of Liberating Technologies, which distributes the hand. "It's a slender, feminine-looking hand. Centri also makes larger sizes for men, and they are fine, but there are very few hands out there that are really feminine-looking."

Though the hand doesn't have built-in microprocessor control, the VariGrip circuit (microprocessor system) that Liberating Technologies makes can be put in the wrist and can control the hand. Microprocessor control is now the standard for electric terminal devices.

Liberating Technologies also offers a new microprocessor-based hand, the RSLSteeper MultiControl Plus Electric Hand, with the same circuit as the company's powered gripper. It has soft fingers to extend the life of the

RSLSteeper electric hands
(Photo courtesy of Liberating Technologies, Inc.)

glove and a breakaway thumb for emergencies. The company has also increased the grip strength with a larger and higher torque motor. At the same time, it's also lighter than some of the older hands and only weighs about three-fourths of a pound.

In addition, the company has a microprocessor-based children's hand, which is manufactured by Variety Ability Systems Inc. This hand includes VASI's Single Progamming Module (SPM) circuit, which allows the prosthetist to choose the best control strategy for the patient.

Specialty Terminal Devices

While hooks and prehensors like the GRIP and the Electric Greifer (Gripper) are functional terminal devices that perform many tasks, specialty terminal devices like the N-Abler allow single-function tools to be used on the end of a prosthesis. The N-Abler, which is manufactured by Texas Assistive Devices, LLC, is a terminal device that is a stable holder for a variety of interchangeable tools. Over 100 tools, such as specially modified wrenches, pliers, hammers, knives, forks, spoons, fishing rods and gardening tools, are now available for the device.

The N-Abler II (Photo courtesy of Texas Assistive Devices)

Gerald Blackwell, who lost both of his arms as a result of an electrical accident in 1995, uses two cable-operated hook prostheses, but when he performs certain tasks like working on cars and cooking, he uses his N-Abler devices and tool attachments, which can be interchanged with his hooks easily and quickly.

Gerald Blackwell uses the N-Abler II terminal device to work on cars, cook and perform many other tasks.

Recently, the company also came out with an important product to help double amputees like Blackwell. The Hands Free Tool/Implement Changer allows amputees who do not have a functional hand to easily insert or release tools from the mechanical locking ring on the N-Abler terminal device.

"The N-Abler has just turned my whole world around," says Blackwell. "I'm not quite sure if there's anything I'm not going to be able to do."

The Future

Because current artificial hands, hooks and prehensors generally make use of only a pinching or squeezing function, rather than the use of each individual finger, Craelius' work and the possibility of bionic control devices that can simultaneously control all the joints of all the fingers is extremely important. It could one day make the difference between terminal devices that are really pinchers (even though they might look like a hand) and terminal devices that really function like a hand and offer the multitude possibilities of hand movement. The Dextra is not there yet, but the long-term future is promising. ■

Manufacturers and Distributors of Terminal Devices for U/E Amputees

Hosmer Dorrance Corporation
800/827-0070
www.hosmer.com

Liberating Technologies, Inc.
508/893-6363
www.liberatingtech.com

Motion Control
888/MYO-ARMS (696-2767)
801/978-2622
www.UtahArm.com

Otto Bock
800/328-4058
www.ottobockus.com

Texas Assistive Devices, LLC
800/532-6840
www.n-abler.org

TRS Inc.
800/279-1865
www.oandp.com/trs