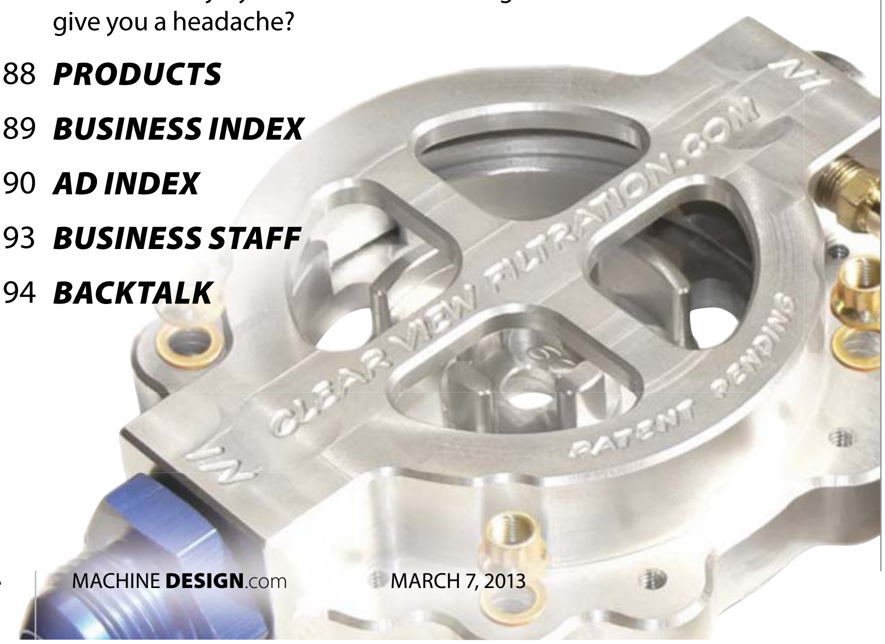
DEPARTMENTS

ON THE COVER
The most current version of DARPA's Modular Prosthetic Limb



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For at least eight years, **DARPA** has been funding R&D with the aim of building a better prosthetic arm, the Modular Prosthetic Limb (MPL). The primary objective is to advance the state of the art in prosthetics, making them more lifelike with more capabilities and more intuitive to control by amputees. Then, if all goes well, that R&D will be leveraged into both artificial arms and legs for wounded soldiers. The research results could also be used in other areas such as robotics.

It's an ambitious project with some far-reaching goals. For example, one goal is to have an arm/hand device that can be controlled by the amputee's thoughts. The project has made great strides, thanks to the concerted efforts of hundreds of scientists and engineers spread across 30 colleges and research labs, and millions of dollars in funding. Here's a look at what they've been doing.

Power

One of the many challenges in building the MPL was deciding on a power source. Initial estimates indicated it would need 50 W-hr for one day's activity, and the couldn't weigh more than 0.75 lb. Researchers explored several options. One, gas-powered generators, were too noisy and emitted noxious fumes. Another alternative, controlled chemical reactions — such as catalytically breaking down hydrogen per-

The Modular Prosthetic Limb, a project funded by DARPA, has been a major source of new technologies developed for prosthetics.

A project to perfect PROSTHETICS

A DARPA-funded effort pushes the state of the art in biomedical engineering.

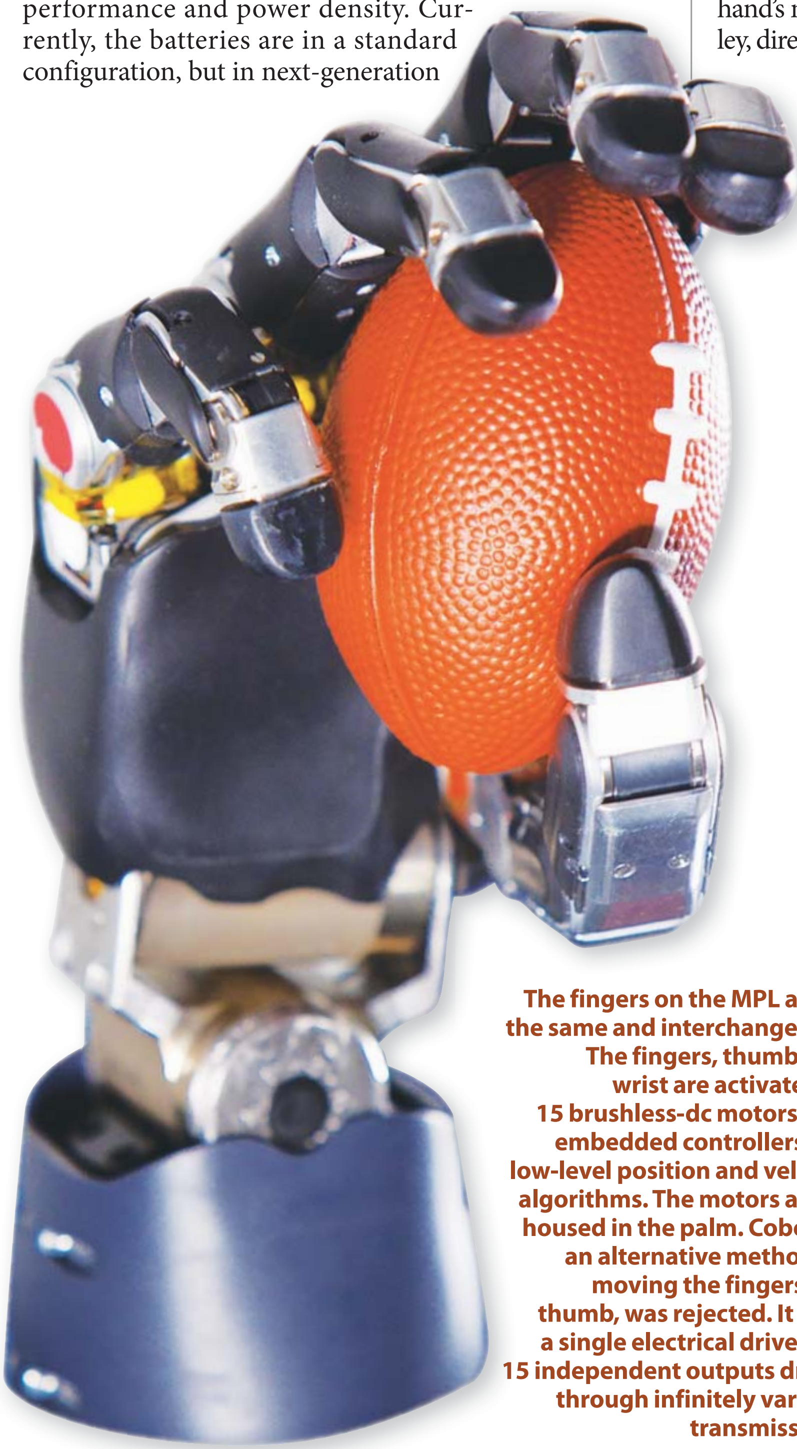
oxide to create gases that would spin small generators — was deemed too dangerous.

The team quickly settled on batteries largely based on the fact that the MPL's sensors and motors would all need electricity, and batteries provide it without extra equipment such as generators or combustion chambers.

"Today we are using lithium-polymer batteries," says Project Manager for MPL Development Matthew Johannes at **Johns Hopkins University**'s Applied Physics Lab (JHU APL). "We use them for their charge/discharge performance and power density. Currently, the batteries are in a standard configuration, but in next-generation designs, they could be custom shaped to make better use of the available space. As the design stands now, we have almost the entire forearm empty and available for batteries."

Lithium-polymer batteries are the power choice of several prosthetic companies, including **RSLSteeper** in the U. K. That firm's bebionic3 prosthetic hand uses 8.8-V lithium-polymer batteries with either 1,300 or 2,200 mAh, depending on how hard the patient will use the artificial arm. "The technology is well understood, commercially available, and provides a lightweight power source that can supply all the hand's motors when operated simultaneously," says Ted Varley, director of Development & Operations at Bebionic.

For the bebionic3, a single charge can power it all



The fingers on the MPL are all the same and interchangeable. The fingers, thumb, and wrist are activated by 15 brushless-dc motors with embedded controllers and low-level position and velocity algorithms. The motors are all housed in the palm. Cobotics, an alternative method for moving the fingers and thumb, was rejected. It used a single electrical drive with 15 independent outputs driven through infinitely variable transmissions.

The Wish List

DARPA managers laid out a long list of requirements for its Modular Prosthetic Arm (MPL). It included:

- Duplicate the five-fingered hand with an opposable thumb, and include a wrist, elbow, and shoulder.
- Give wearers feedback on objects the MPL touches or grasps, including temperature, texture, whether the object is hard of soft and how strong the grasp is, and proprioception, letting the wearer know the motion and position of arm.
- Have as many degrees of freedom as a human shoulder, arm, elbow, wrist, and hand: 26.
- Look, feel, and weigh the same as a human hand without being noisy.

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Resources:

Johns Hopkins University, Applied Physics Lab, *www.jhuapl.edu/prosthetics*

For another feature on prosthetic hands, scan this code or go to *http://machinedesign.com/article/giving-artificial-hands-a-sense-of-touch-0909* day for the average user. The MPL team is also looking for a battery that could supply a day's worth of power.

"Currently, the MPL needs two, maybe three battery swap outs per day," says Mike McLoughlin, deputy business area executive for Research and Exploratory development at JHU APL. The MPL needs more capable batteries because it has more electrical motors, processing power, and sensors.

Control

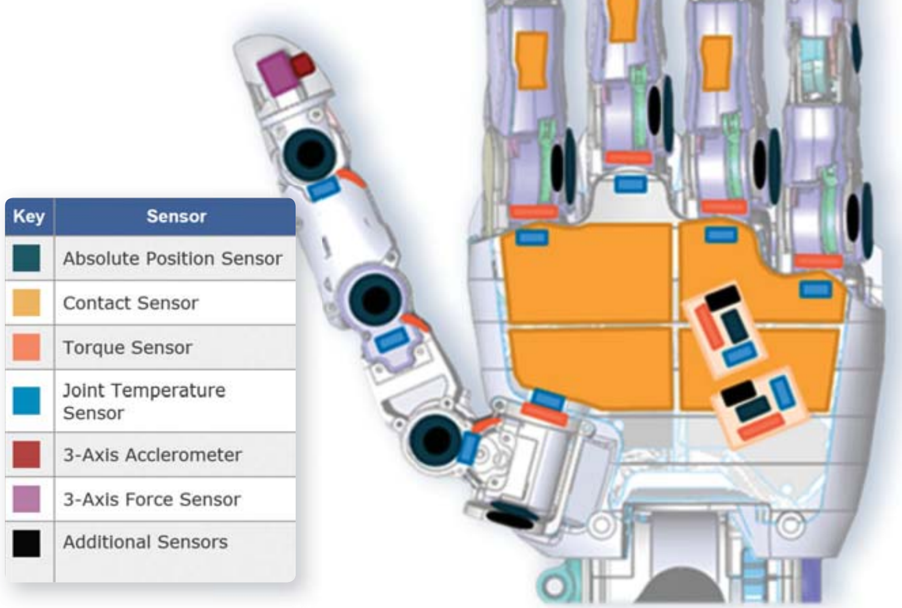
One of the most-difficult tasks will be to let users control prosthetics merely by thinking. In state-of-the-art prosthetics currently on the market, like the $25k to $35K bebionic3, movement of the elbow, wrist, and fingers is through myoelectric signals, those emitted by muscles when they flex. These relatively strong signals can be detected outside the skin, so it's a noninvasive approach (no surgery needed). When a wearer flexes certain rarely used muscles, the grip will contract or the wrist will turn. The downside of this approach is that it is difficult for the patient and can be taxing. There also aren't that many muscles that can be used, so controlling an arm with 10 degrees of freedom is almost impossible.

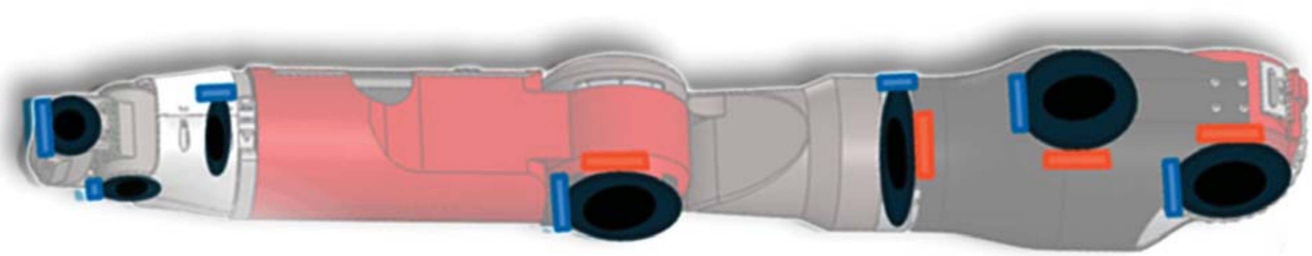
To get better control of the prosthetic, a pair of doctors on the team developed targeted innervation. In this approach, nerves are removed from one of the patient's rarely used muscles, usually in the pectoral region. The muscle is then repopulated with nerves from the amputated arm or hand. Electrodes placed over the reinnervated muscle now pick up electrical signals when that muscle is flexed. So when the patient wants to turn his wrist, he uses the same mental commands he once used to control his real wrist. This makes his reinnervated pectoral muscle flex, and that is picked up by an electrode to form the basis of a control signal.

This nerve switch works both ways. For example, when an ice cube is placed over his newly reinnervated pectoral, the patient feels a cold sensation in his absent hand. This can work with heat and texture, and the MPL team has toyed with the idea of adding an actuator to the patch holding the electrodes. It would push harder on the pectoral as the prosthetic hand's grip gets stronger.

This control technique also has several downsides. The first is that it requires surgery and about a

CHARACTERISTIC	
Degrees of freedom	26
Motors (degrees of control)	17
Weight of hand and wrist	2.9 lb
Weight of upper arm (with battery)	7.6 lb
Payload of hand (with wrist active)	15 lb
Payload of hand (with wrist static and upper arm active)	35 lb
Cylindrical grasp force	70 lbf
Two-jaw pinch force	15 lbf
Three-jaw chuck pinch force	25 lbf
Upper-arm joint speed	120°/sec
Wrist-joint speed	120°/sec
Hand open or close time	300 msec
Voltage	24 V
Communications	CAN





year of rehab before the patient starts using his new prosthetic. But this could be alleviated, says McLoughlin. "If reinnervation becomes popular for controlling prosthetics, the operation could become a matter of course given to patients when they first lose their limbs. It's like the fact that today, reconstructive surgery is done at the same time a tumor is removed from a mammary gland. It's the standard of care."

An additional problem is that there is little chance there will be one-to-one correspondence between salvaged reimplanted nerves and muscles of the arm and hand. An amputee might have only four viable nerve/muscle sites he can control independently, and biomedical engineers have to adapt the prosthetic to that limitation.

Another control method takes reinnervation one step farther by eliminating the need for nerves. Instead, electrodes are placed on the portions of the brain that control arm and hand movement. Fortunately, those areas are on the top of the brain and relatively easy to access in terms of brain surgery. In current experiments, wires run outside the patients head to a computer where brain emissions are decoded, algorithms applied, and control signals generated for the MPL. Patients (including the first, a monkey), have been able to move the prosthetic up and down, back and forth, and grip and let go, all without moving a muscle, just by thought.

The problems with this method involve the electrodes and getting the signals out of the body without needing a break in the skin. Such breaks, like portals used for dialysis, are common sites for infections. Researchers hope to solve this latter challenge by using wireless electrodes and sending power in and getting amplified signals out via induction. The signals need to be amplified because unlike the electric fields generated by flexing muscles, those created by active nerves cannot be reliably detected for decoding outside the body.

The second challenge might be more difficult to overcome: defending electrodes against attack by the body's corrosive environment and its antibodies and immune system. **MD**

MPL spin-offs

DARPA's MPL is an R&D project and not intended to ever be used by hundreds of amputees. That's why it's called a modular prosthetic. Biomedical engineers and rehab scientists can borrow and adapt technologies developed by DARPA for use in their own less-capable but also less-expensive prosthetics. And other industries, including defense, could likely find spin-off uses for the new technology being developed over the course of the program. In fact, they've already had several other industries show interest. For example:

- Sophisticated algorithms that turn relatively simple and crude signal trains into exacting and more-natural movements could be used on simpler prosthetics. Bebionic's prosthetic arm, for instance, uses simple control signals to activate one of eight different grips. That way, engineers need not give the patient so much control over his artificial fingers and thumbs, but the patient can still carry out most daily tasks.
- The hand, with small, high-torque motors that move the fingers, is being adapted for use as an end effector for explosive-handling robots. Earlier robots used to defuse IEDs and mines lacked the dexterity of the MPL. It is also possible that less-capable versions could be developed for factory-floor robots.
- Material research for the MPL discovered that ground-up carbon nanotubes mixed with other materials makes for a hydrophobic coating (one that repels water). Engineers are looking at ways to use this new hybrid material to line a prosthetic's socket (where what's left of the patient's limb is in close proximity to the prosthetic). The theory is that the lining would wick sweat and moisture away from the skin, improving comfort and reducing skin irritation.

To protect the MPL hardware against dust and moisture, researchers have developed a silicone "glove." The covering is also cosmetic and can be made to look realistic. But researchers had to be aware that if they made the glove too tight, it would put additional loads on the small motors used to move the fingers, thumb, and hand. The glove also had to allow tactile and temperature sensors access to what they were supposed to be "feeling."