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These Legs Are Made for Walking

Three years ago, with perhaps a bit too much fanfare, the U.S. Defense Advanced Research Projects Agency (DARPA) announced a new effort to develop a full-body, performance-enhancing exoskeleton—a powered, mechanical support system attached to a person's limbs. Reporters had a field day with the news, spinning out breathless and fantastic accounts of super-human soldiers capable of running for days, impervious to the elements, and fending off all manner of chemical and biological attack.

The reality of exoskeleton research was and is quite different. As the DARPA program begins to yield its first results, what is clear is that exoskeletons aren't going to magically transform men into killing machines. What they're really good at, it turns out, is enabling soldiers to carry heavy loads over great distances for hours at a time. They're also showing promise for others who do a lot of heavy lifting, including nurses, firefighters , and disaster recovery workers.

Of the three exoskeleton teams funded by DARPA, only one, based at the University of California at Berkeley's Human Engineering Laboratory, has made tangible progress. Last November, the lab's Berkeley Lower Extremity Exoskeleton (BLEEX) took its first test-walk outside the lab, the results of which were made public this week. On 1 March, IEEE Spectrum*'s senior associate editor Jean Kumagai spoke to lab director Hami Kazerooni, a professor of mechanical engineering at UC Berkeley, about the exoskeleton.*

Spectrum: It's been three years since DARPA launched its exoskeleton program. What's been happening since then?

Kazerooni: Our project has three phases. In Phase 1 we looked at the fundamentals, the elements needed to build an exoskeleton that walks. Phase 2 is designing a machine that is fieldable and robust; we're in the middle of the second phase now. Phase 3 will be working with companies for technology transfer and field evaluation.

LOAD-BEARING LEGS: The BLEEX lower extremity exoskeleton can carry 32 kilograms for hours.

It is important to define "exoskeleton" clearly for this program. Throughout history, the idea of making a person more powerful has been attractive to humans. You can see it in the movies and in books. The traditional definition of exoskeleton evolved from these fantastic concepts: it had two arms and two legs—you wear the machine, walk around and bust through doors, pick up heavy objects like a superman. General Electric had a research program in the 1950s to develop an exoskeleton of that sort.

We decided to rethink the idea of an exoskeleton. To a certain extent, robotic arms and legs are separate technologies with different applications. So we basically broke the exoskeleton in two: lower extremity and upper extremity for two distinct applications.

Who can benefit from each type?

Automotive assembly line workers and FedEx workers would use an upper extremity exoskeleton. We built the upper extremity exoskeletons, which hang from the ceiling, in places where the workers need to lift the heavy objects. These devices emulate forces on the worker's arms and trunk, which are much less than the forces needed to maneuver a load.

In its simplest behavior, when a person uses an upper extremity exoskeleton to move a load (such as a box in a warehouse), the device transfers to her or his arms a scaled-down value of the load's actual weight. For example, for every 18 kilograms that a load weighs, the worker supports only 2 kg while the device supports 16 kg. The worker still "feels" the load's weight, but it's less than what he or she would feel without the assist device.

A lower extremity exoskeleton, on the other hand, is a self-powered device for strength and endurance enhancement of humans. Our first prototype exoskeleton consists of two powered anthropomorphic legs, a power unit, and a backpack-like frame on which a variety of loads can be mounted. The device connects rigidly to the pilot—that is, the wearer—at the foot and more compliantly elsewhere. The exoskeleton allows the person to comfortably squat, bend, swing from side to side, twist, walk and run uphill and downhill, and step over and under obstructions while carrying equipment and supplies.

While wearing the exoskeleton, a person can carry significant loads over considerable distances without reducing his or her agility, thus greatly increasing his or her physical effectiveness. The exo has no hands, no upper extremities. Lower extremities exos are a lot harder to design, mostly because they have to walk and the power supply and computation are all self-contained in the device.

The Department of Defense, which funded this work, was attracted to this idea. Soldiers in the field don't really carry heavy loads in their arms, except their guns. They just have large backpacks. So a lower extremity exoskeleton is ideal for them.

Who else might use a lower extremity exoskeleton?

Our approach received a great deal of attention because it's feasible and pragmatic, not only for soldiers, but for firefighters, post-disaster rescue crews, and other emergency personnel who need to carry food, rescue equipment, first-aid supplies, and communications gear with minimal effort over any type of terrain for extended periods of time. This device was envisioned to provide a versatile transport platform for mission-critical equipment.

I think the fundamental technology we are developing will also be used to help people who lack full muscular support in their legs. This is even a greater challenge than what we have demonstrated thus far, but I'm confident that the fundamental building blocks of our work will lead to that in the near future.

So how does the BLEEX work?

Our research has four major components. Number 1 is power. The exo needs onboard power; otherwise you're confined to walking around in the lab. And the power supply needs to be small and portable, but still able to power the exoskeleton's actuators, computer, and all the sensors. There were no off-the-shelf power systems available, so we developed a hybrid hydraulic/electric power source. It runs on regular gasoline and it weighs about 14 kg. We're working to make a smaller, quieter, and more powerful power source.

The second component is the device design, which, as I described earlier, needs to be flexible enough to let the person walk, step over obstacles, go up and down stairs, swing their legs, squat, and bend forward and back. We spent a lot of time on a design that is minimally felt by the wearer while conferring maximum assistance and locomotion to the wearer.

Number 3 is the electronics. This is a body LAN [for local-area network] that hosts the computers and sensors. The exo has lots of sensors with mixed analog and digital signals, which all go to a central processor, but we can't send wires and cables everywhere. In an office, a LAN lets you simply connect your laptop to the network and communicate with other computers via a protocol. We created a network on the body; all the sensors and actuators are on the network and they talk via that one wire.

The fourth element is the control algorithm that runs the machine. The idea is to ensure that the exo will move in concert with the pilot with minimal interaction force between the two. The control scheme needs no direct measurements from the human or from the human-machine interface. If you walk forward, it walks forward; if you go backward, it goes backward; if you stop, it stops. And it does that without requiring direct input from the human; there are no joysticks, no keyboards, no push buttons. The person doesn't have to drive the machine—you simply walk, and the machine walks with you.

We then took these four technologies and we came up with a system—BLEEX—to show they are all feasible. We've had several visitors from DARPA and they've all had positive responses.

How much does the BLEEX weigh and what can it do at this point?

The existing exo has a 2-HP [1.5 kW] power source; it weighs about 45 kg, and it takes about 32 kg of load, so when you wear it, it feels like you're carrying 2 to 5 kg. We are also developing a quieter, more powerful engine—about 3.7 kW—that will enable the exoskeleton to carry loads up to 55 kg within the next six months. In addition, we are studying what it takes to enable pilots to run and jump with the exoskeleton legs.

The power supply lasts about 3 to 4 hours, depending on how much fuel you take with you. The exoskeleton runs on gasoline, which is cheap and readily available. I approached this project not with the idea of a mobile robot, like the Honda humanoid robot, but more like a mobile platform—a car or a truck on the street. So I wanted to make the machine refuelable in the field, just like any other mobile platforms like cars and trucks. Eventually, we would like to switch to JP8 fuel [a kerosene-based jet fuel], which is what the U.S. military might use.

What's left to do?

Phase 2, in which we make the device fieldable, is a great challenge. We must make this machine extremely robust, compact, light, and efficient. We're scheduled to start field tests in 2005.

Have you walked in the BLEEX yourself?

Yes, of course. It's a little rough sometimes, but you don't feel the load once it's powered and going. It walks with you.

See UC Berkeley's Human Engineering Laboratory Web site, http://me.berkeley.edu/hel/bleex.htm, for more information about the BLEEX, including videos of the exoskeleton in action.

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