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VA/NIH Prosthetics Roundtable
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Presentation highlights: Prosthetic and orthotic limbs

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BIOGRAPHICAL INFORMATION

Dr. Hugh Herr is an instructor at the MIT/Harvard Division of Health Sciences and Technology and the Department of Physical Medicine and Rehabilitation, Spaulding Hospital, Harvard Medical School. He is also the Director of the Biomechatronics Group within the Artificial Intelligence Laboratory at MIT. He obtained his PhD in Biophysics from Harvard University.

His primary research objective is to guide the designs of biomimetic robots and human amplification and rehabilitation technologies. Dr. Herr developed mathematical models that predict how the mechanics and energetics of running animals change with speed and animal size. He also employed crossbridge models of skeletal muscle to the design and optimization of a new class of human-powered mechanisms that enhance endurance for cyclic anaerobic activities. Recently, he helped to establish a new research program where native and cultured muscle tissues are engineered for machine actuation. Chemical, electromechanical, and genetic intervention strategies are used to enhance muscle robustness and contractile function, in vitro.

His work led to development of a new gait-adaptive knee prosthesis that combines magnetorheological and frictional effects to modulate knee resistive torque. Currently under clinical evaluation, the prosthesis is likely to be marketed within the year.

PRESENTATION

Current efforts are focused on developing lower-limb prosthetics that simulate, to the extent possible, the intricate and subtle biomechanics of human walking. “Troody,” an 18-inch two-legged robot modeled after the Troodon dinosaur, is as ambulatory machine that reflects the kind of autonomy envisioned for prosthetic limbs.

Specifically, this robot—created at Massachusetts Institute of Technology (MIT), under the di-rection of Professor Gill Pratt—not only carries its own brain (a microprocessor) and energy source (batteries mounted on its legs and tail) but also maintains its balance even amid terrain changes. Troody is autonomous from a control perspective, knowing how to balance in the standing and walking postures, as well as how to successfully walk over an object and maintain balance. Transferring the technology used in legged robots like Troody to prosthetics is one long-term goal.

As the Otto Bock C-Leg adapts to changing conditions, it relies on patient-specific, preprogrammed values. Once these dampening values are set manually by a prosthetist, the amputee then leaves the artificial environment of the limb-shop and experiences various disturbances, such as lifting up a suitcase or moving across irregular terrain. Regardless of the type of disturbance, the user is constrained to fixed values defined by the prosthetist. Moving beyond these limitations requires adaptive algorithms that incorporate biomechanical and clinical data in the modulation of joint resistance.

An artificial knee under development at MIT addresses this challenge and may represent a first step toward the goal of adaptive and autonomous prosthetic systems. This system uses an electromagnet along with a magneto-rheological (MR) fluid that can change, in milliseconds, from oil to near solid in response to a magnetic field. The fluid modulates damping between metal plates in the knee. Onboard sensors measure the force, bending moment, and position and feed the data to a built-in microprocessor that determines knee resistance at every moment.

When the artificial MIT knee was used by a female patient, a well-conditioned athlete and experienced skier, she was able to walk up and down steps with a natural motion for the first time. Previously, her prosthetic leg was held straight and dragged when stairs were climbed.

To allow a full realization of autonomous prostheses, several main interim objectives must be achieved, namely:

1. Continued development of computer models for human walking and running and their application to "smart" prostheses. Artificial leg systems must be continually programmed to become smarter, i.e., able to recognize pathological gait and make adjustments to joint impedance.
2. Linkage of the human brain and the prosthesis through neuroprosthetic technology. Neural prostheses are needed inside the body that can transmit signals to the external prosthesis, to have a direct measure of user intent. In this way, the brain can control the artificial knee of an amputee, telling the knee whether the user intends to turn left or right or that stairs lie ahead.
3. Incorporation of power into these systems to simulate, for example, the biological power of the knee and ankle. Actuators are needed at the joints that respond to signals from inside and outside the body. Even the current MIT knee and the Otto Bock C-Leg are not able to power human movement, as these systems can only modulate joint resistance or damping, a fact that limits the achievement of truly natural motion.

The future of orthotics and prosthetics can be envisioned as one involving the intelligent application of power. With highly adaptive and fully actuated orthotic and prosthetic joints, physically disabled people will be able to traverse greater distances with less fatigue. They will be able to walk with a higher level of dynamic cosmesis. For the first time, artificial joints will be able to move like biological joints, with similar trajectories. Accomplishing this will require close dialogue across disciplines. The collaboration that resulted in the MIT artificial knee was effective only with open and ongoing communication and detailed, accurate specifications about patient requirements. Lapses in these essential areas can result in devices that, while precisely engineered, are neither functional nor practical.

KEY POINTS

- The prosthesis of the future will be a powered system with distributed sensing and intelligence that tracks and responds to user intent. Technologies such as BIONs™ and MEMS likely will play an important role in these systems.
- More advanced computer models of human movement must be developed and programmed into orthotic and prosthetic limb systems.
- Communication among engineers, clinicians, and manufacturers is imperative.

REFERENCE INFORMATION

Citations

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