Prosthetic Devices that Augment and Restore Basic Functions

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Abstract

The field of rehabilitation robotics brings together engineers, neuroscientists, and clinicians to address areas of critical international need that relate to the human nervous system, its sensory-motor function, and interaction with its physical environment. The accelerating pace of basic and applied research in this field over the past decade has led to significant advances in medical practice in areas related to assistance, rehabilitation, and augmentation. Here are several examples of developments that convey their potential impact:

- *Assistance (compensate for impaired sensory-motor function).* Foot drop is a deficit of dorsiflexion characterized by an inability to lift the toes. It causes abnormal and hazardous gait, and affects nearly 7 million people in the United States suffering from complications of stroke, polio, multiple sclerosis, spinal cord injury, and cerebral palsy. Advances in power electronics, actuator design, and biomechanics have led to the development of active ankle-foot orthoses that vary the impedance of ankle flexion and extension in order to bear weight, align and protect the joint, and make it easier and safer for people suffering from foot drop to walk. Other examples of assistive technology with broad impact include exoskeletons, smart wheelchairs, and implantable devices that deliver functional electrical stimulation directly to the nervous system.

- *Rehabilitation (facilitate recovery of normal sensory-motor function).* With over 5 million survivors, stroke is the leading cause of long-term disability in the United States. Its debilitating consequences include loss of sensory-motor control and coordination. Advances in the design of haptic interfaces and in understanding both pathological and non-pathological human motor coordination have led to the development of patient-responsive robotic therapy for balance, walking, reaching, grasping and manipulating. Robotic therapy can be standardized and cost-effective, can facilitate quantitative diagnosis, and can lead to better outcomes than traditional therapy. Other examples of rehabilitative technology with broad impact include the use of deep-brain electrical stimulation to treat Parkinson's disease by modulating the basal ganglia, a key element of control loops associated with motor tasks in the central nervous system.

- *Augmentation (restore or enhance sensory-motor function).* In the United States there are about 250,000 people with spinal cord injury, often associated with partial or total

paralysis, and there are about 11,000 new cases every year. Advances in neuroscience, nano/bio-mechanics, micro/nano-scale manufacturing, and mechatronic design have led to implantable arrays that directly measure the activities of hundreds of neurons, which may provide high-fidelity signals to command motorized prosthetic limbs. Experiments with primates have demonstrated the potential of these brain-machine interfaces. Other examples of augmentative technology with similarly broad impact include motorized prostheses controlled by non-invasive neural sensors like electroencephalography that restore the ability to communicate, retinal implants that restore sight, and cochlear implants that restore hearing.

The vision that guides the work of my research group in this area is to develop and provide more equitable access to state-of-the-art prosthetic limbs that address the needs of amputees worldwide. One problem in particular on which we have focused over the past five years is restoring a sense of touch to users of prosthetic hands. The particular mechanism we use to restore touch is called *electrotactile stimulation*, which works by passing current through the skin with a pair of electrodes. Depending on the current waveform, this type of stimulation can feel like vibration, pressure, tingling, etc. One longstanding barrier to practical use of electrotactile stimulation for sensory substitution and haptic feedback is that variation in skin impedance (e.g., when electrodes peel or users sweat) leads to variation in sensation intensity, even to the extent of causing pain. Our work has eliminated this barrier by establishing an empirical relationship between stimulation parameters, skin impedance, and sensation intensity that allows us to modulate the stimulus in response to measurements of impedance in order to keep intensity constant.

Biography

Timothy Bretl is an Associate Professor of Aerospace Engineering at the University of Illinois at Urbana-Champaign. He received his B.S. in Engineering and B.A. in Mathematics from Swarthmore College in 1999, and his M.S. in 2000 and Ph.D. in 2005 both in Aeronautics and Astronautics from Stanford University. Subsequently, he was a Postdoctoral Fellow in the Department of Computer Science, also at Stanford University. He has been with the Department of Aerospace Engineering at Illinois since 2006, where he now serves as Associate Head for Undergraduate Programs. He holds an affiliate appointment in the Coordinated Science Laboratory, where he leads a research group that works on a diverse set of projects in robotics and neuroscience (http://bretl.csl.illinois.edu/). Dr. Bretl received the National Science Foundation Early Career Development Award in 2010. He has also received numerous awards for undergraduate teaching in the area of dynamics and control, including all three teaching awards given by the College of Engineering at Illinois (the Rose Award for Teaching Excellence, the Everitt Award for Teaching Excellence, and the Collins Award for Innovative Teaching).