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Intelligent Robotic Neuroprosthetics

Intelligent robotic neuroprosthetics are devices controlled directly from neural signals, and not through an intermediate device such as joystick. Signals are recorded from either the central or peripheral nervous system, decoded into a useful form, and then used to supply appropriate control input to a robotic device. Since these signals are inherently noisy and hard to interpret, the robot devices must incorporate some level of intelligence to make up for the shortcomings in the control signal. The specific devices can run the gamut from “traditional” limb prostheses, to fully-independent robotic avatars for hose with profound motor disablities.

Scope: Robotic neuroprosthetics are appropriate for individuals who are (a) incapable of motion, such as those suffering from total-body paralysis, (b) suffering from partial-body paralysis, such as often results from stroke, (c) incapable of fine motor control, such as those with cerebral palsy, or (d) those who need to control the device without conscious thought, such as lower-limb amputees. In all of these cases, cognitive function remains intact, but there is an impediment to generating body movements, be it neural (in the motor cortex) or physical (in the limb). The ultimate for of this research will be to identify and isolate the signals from the subject's nervous system, and to translate them into appropriate movements (both low-level motion, and high-level commands) for the robotic system.

Challenges: This area has a number of challenges for almost all of the sub-fields in robots. Manipulators must be light-weight and compliant, yet able to move quickly and handle loads similar to those dealt with by humans on a daily basis. Mobility devices, such a wheelchairs, must be aware of their environments and of the intentions of their human payloads to best overcome inherently noisy control signals. Prosthetic limbs and exoskeletons must be lightweight, and natural “feel”. All of these systems will require insights from the traditional robotics fields of mechanical engineering, control theory, and computer science as we move from low-degree-of-freedom, bench-mounted prototypes to real, through clinical studies, to real, working devices. From our point-of-view, however, the major challenges are compuational: How do we decode the neural signals (recorded using technologies such as electroencephalography, or the more invasive electrocorticography) reliably, quickly, and portably (on hardware that can realistically be incorporated into a mobile device)? How do we imbue these devices with enough intelligent to make them practically useful, and to overcome the inherent limitations in the control signal?

Impact: The impact of this research will be profound for a number of communities. As the population in the United States ages, the incidence of stroke and other age-correlated motor-disorders will increase dramatically. Workable robot prostheses will dramatically improve the quality of life for those not responsive to traditional therapies. For those with disorders such as cerebral palsy, robotic exoskeletons can be used to stabilize limb motions, making fine manipulation tasks (and a more independent lifestyle) possible.[1] Those returning from the battlefield with missing limbs will benefit from more naturally-controlled prostheses. Persons who cannot easily move can benefit from a mobile robot avatar that can allow them to experience other places, and to interact with people not immediately in their vicinity.

Of particular promise is the recent discovery at Washington University in St. Louis that signals from the

1 Cerebral palsy is often characterized by muscle tremors, making haptic-based approaches to control less applicable.

ipsilateral (same side) brain can be used to predict finger motions. Typical brain-computer interfaces use signals from the contralateral (opposite side) brain to predict an classify motion. While much progress has been made in this area, the ability to decode signals from the ipsilateral brain offers hope to those with hemispheric brain disorders, such as stroke, cerebral palsy, and certain traumatic brain injuries. Subjects with a dysfunctional left hemisphere will experience problems in moving the right-hand side of their body. However, with ipsilateral decoding, signals from the functional right hemisphere can be used to control right-hand side robotic prostheses, while the left-hand side of the body behaves normally. While work in this area is still preliminary, success would improve the quality of life for huge numbers of people.

Natural Human-Robot Interaction for an Aging Population

As the population ages, the judicious use of robotics will allow individuals to retain their independence and to live in their own homes for longer. Robotics technology can be used to bolster failing physical and mental abilities, allowing the routines of daily life to continue beyond longer than is currently possible. To achieve this, remote monitoring (using various robotic technologies) by medical professionals and family members will play a part but the effective adoption and use of robotic helpers by the elderly themselves will be the crucial make-or-break element.

Challenges: The main challenge will be one of proximal human-robot interaction. How can we allow the elderly, who are often not familiar with or trusting of technology, to effectively task a robot to assist them with the tasks of daily living? How do we allow this tasking to occur organically, using natural gestures and utterances, given the very real limitations of general-purpose gesture recognition systems operating in unaltered environments? How can we engender trust in these robotic systems? how can we make the tasking system robust, especially in the face of a user population with fading mental capacities?

Possible solutions: We must be cognizant of the current and near-future sensory capabilities of robotic systems. Where these fall short of our needs, we must scaffold them with additional hardware and software. An excellent recent example of this is the work of Charlie Kemp at Georgia Tech, which uses a laser pointer to designate objects for a robot to pick up. This work recognizes that general pointing-gesture recognition is currently unsolved, and that using a laser pointer neatly sidesteps the problem. Using this sensory scaffolding allows us to concentrate on the higher-level problems without becoming dependent on progress in low-level sensing technologies.[2] We propose an investigation into the shortcomings of current sensor technologies (from a robotic viewpoint), the currently available scaffolding technologies (RFID tags, localization systems, etc), and how to use the latter to address th former, rather than waiting on the perfect, fully-capable sensor system to arrive.

We also propose investigating how desktop interaction metaphors can be adapted to the real world, reducing the interaction bandwidth needed, and increasing the neglect tolerance (how long you can safely ignore the system without something going wrong) of the overall system. For example, when commanding the robot to move from one location to another, we can improve matters over a traditional joystick interface. The robot can move autonomously when there is a clear direction choice, without human input. When it comes to a decision, it can project two arrows on the ground (using a standard LCD projector), representing the two most likely directions. The human can select one of these by pointing at it with a laser pointer, gesturing with their hands, waving their Wii controller, or using another modality with which they are comfortable. The robot can project these iconic menu-option queries onto the world, and wait for input. Choices can be context-sensitive, and ranked by likelihood. These likelihoods can either be pre-programmed, or learned from experience. Although this limits the interactions that can take place, it makes the options and choices clear and unambiguous, especially for an elderly user population.

2 Of course, we do not mean to suggest that we should not look at hard sensor problems. We should not, however, wait until they are solved before tackling the higher-level application-driven problems in robotics.