DEVELOPING A BRAIN-MACHINE INTERFACE FOR DEXTEROUS CONTROL OF AN UPPER-LIMB NEUROPROSTHESIS

by

Vikram Aggarwal

A thesis submitted to Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy

Baltimore, Maryland
December, 2011

Abstract

A Brain-Machine Interface (BMI) uses electrophysiological measures of brain activity to communicate with external devices, bypassing normal neuromuscular pathways. Earlier research has demonstrated the robust coding capacity of neural activity for gross motor movements such as hand and arm trajectory, and opened up the possibility of a BMI for direct neural control of a prosthetic limb and the restoration of motor control for amputees, paralyzed individuals, and those with degenerative muscular diseases.

However, advanced upper-limb neuroprostheses for grasping and manipulation of objects will require BMIs for dexterous control of the multiple degrees of freedom involved in hand motion, including coordinated movements of the hand, wrist and fingers. Thus, with the advent of sophisticated multi-fingered prosthetic hands offering up to 21-DoF, the thrust of this thesis is to describe the design of BMIs for control of these advanced upper-limb neuroprostheses.

The first part of this thesis describes how a novel hierarchical classification scheme can be used to asynchronously decode individuated finger movements, wrist rotation, and complex grasp patterns with high accuracy. The second part of this thesis extends the decoding of discrete movements of the hand to continuous decoding of multiple endeffectors and complete arm, hand, and finger kinematics. Furthermore, since voluntary movements require decoding movement intent where cues indicating the onset and completion of movement are not known, a novel combined state and kinematic decoder is used to provide more accurate and smoother BMI control during periods of movement and no movement. The third part of this thesis uses Principle

Component Analysis to identify movement synergies and reduce the dimensionality of the kinematic output space, and thus significantly decreases the computational complexity of BMIs for dexterous control of the 21-DoF in the hand and fingers. Lastly, this thesis concludes by using the cortical control strategies developed in the first parts of this thesis to demonstrate, *for the first time*, a dexterous BMI for real-time control of a multiple-DoF prosthetic arm using non-human primates.

Thus, this thesis presents significant contributions towards understanding the neural mechanisms of how dexterous movements are encoded in the brain and the realization of a BMI for direct neural control of an upper-limb prosthesis by humans.