Cybernetic Interfaces for the Restoration of Human Movement through Functional Electrical Stimulation

Matthew Tresch^{1,2}, Kevin Lynch², Robert Kirsch³, Konrad Kording^{1,2}, Lee Miller^{1,2}, Sandro Mussa-Ivaldi^{1,2}, Eric Perreault^{1,2} ¹Rehabilitation Institute of Chicago; ²Northwestern University; ³Case Western Reserve University



Functional electrical stimulation (FES) is a promising technology for activating muscles in spinal cord injured (SCI) patients. The objective of our project was to develop an intuitive user interface and control system for FES that allows high-level tetraplegic patients to regain the use of their own arm. There have been three primary outcomes: contributions to the development of a technology that benefits those with high-level SCI, the development of biologically-inspired design principles for cyber-physical systems, and the deployment of an outreach program to introduce junior high students to the principles of cyber-physical systems.

There have been two main scientific thrusts: decoder development for determining how the subjects wish to move their arm, and controller development for getting the arm to the desired location (Fig. 1). We used human and animal models for each of these project components, to investigate practical issues relevant to our current human subject, and longer term questions dependent on the development of more robust cyber-physical interfaces for FES control. This poster summarizes some of our major accomplishments.

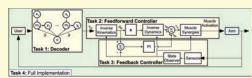
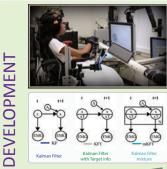
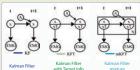


Fig. 1 - Project Summary Blocks indicate main project components





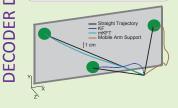


Fig. 2 - Real-time decoder development for SCI subjects. In years 1-4, we developed, evaluated, and deployed a decoder for reach intent for subjects with high-level SCI. The system has been evaluated as an interface to control a robot assistant.

Fig. 3 - Decoder structure The decoder was a probabilistic a mixture of Kalman filters incorporating eye gaze for stimating target locations, and electromyograms for continuous control. A variety of structures were evaluated in patients with varying abilities.

Fig. 4 - Decoder performance The mixture model performed best for all ability levels, though user preference changed with ability.

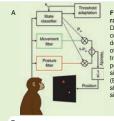
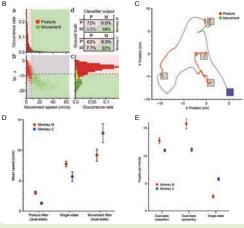


Fig. 5 - A hybrid BCI for reaching that incorporates neural estimation of movement state. Data from non-human primates. (A) Schematic of controller design. (B) Classifier performance for detecting movement state. (C) Continuous mixture of posture and movment decoders. Note rapid transition. (D) Performance difference of separate posture and movement decoders compared to a single decoder for the entire movement trajectory (E) Performance of hybrid decoder with estimated states to a hybrid decoder with known states and a single-state decoder



ᆷ

- 1. Mixture model performed more reliably than traditional decoders
- 2. Structure was extendable to various signal sources, including intracortical
- 3. Performance was robust in presence of gaze uncertainty.
- 4. Real-time performance for all continuous controllers was higher than off-line
- 5. Preference of SCI subjects varied with impairment level

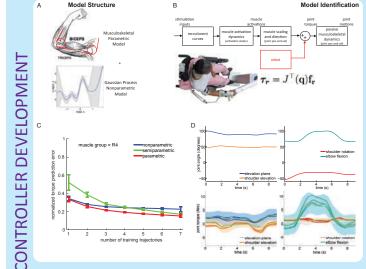


Fig. 7 - Identification and position control of a paralyzed arm. While model-based robot controllers can incorporate models built from first principles, the same is generally not true for physiological controllers. We therefore implemented a data-based approach. (A) Structure of semi-parametric model. (B) Process for system identification. (C) comparison of data required to train candidate model structures. (D) Model predictions of joint torque (bottom) during imposed movement trajectories (top). Model provides estimates of expected mean trajectory and variance about the mean

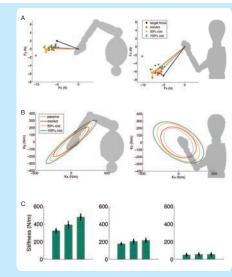


Fig. 8 - Controlling arm impedance

Impedance is a critical aspect of the FES controller, particularly during interactions with the environment. We developed a controller that allows impedance to be regulated independent from interaction forces, and evaluated this controller in our human subject. (A) Endpoint forces achieved with different levels of co-contraction (null-space control). (B) Corresponding measures of endpoint stiffness (C) Stiffness

Outreach

Our outreach program now runs independently at our partner school. Approximately 40 children participate in a full-year program integrated into the existing science curriculum.

The objective of the program is to enhance educational outcomes in science, math, technology, engineering, and communication. All aspects of the program are linked to the Common Core Standards for Math and Language Arts education. A summary of the curriculum is below.

Module 1: Cyber-Physical Systems in Rehabilitation

- Engineering design
- Sensors and measurement
- Actuators
- · Neurophysiology of human movement

Module 2: Introduction to Python programming

- Formal languages
- Python syntax
- Algorithmic thinking

Grade 8:

Module 1: Intermediate Computer Programming in Python · Development of practical skills

- Resources from code.org

Module 2: Interactive robot design

- Hummingbird robotics + Python
- Students design and implement CPS project