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

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Summary

Functional electrical stimulation (FES) is a promising technology for activating muscles in spinal cord injured (SCI) patients. The objective of our project has been 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. This work has had two primary outcomes: contributions to the development of a technology that benefits those with high-level SCI, and the development of biologically-inspired design principles for cyber-physical systems.

The project has had two main components: 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 have been using human and animal models for each of these project components, allowing us to investigate both the practical issues relevant to our current human subjects, and longer term questions dependent on the development of more robust cyber-physical interfaces for FES control. This poster summarizes progress during the course of the project with an emphasis on the past year.

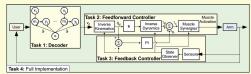
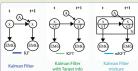


Fig. 1 - Project Summary Blocks indicate main project components

CONTROLLER

DEVELOPMENT



Straight Trajectory

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.



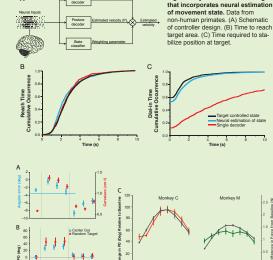
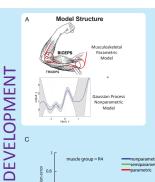
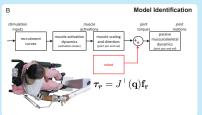


Fig. 5 - A hybrid BCI for reaching

Fig. 6 - Motor cortical recordings are not appropriate for controlling limb kinematics during interaction tasks. (A) Adaptation of hand paths when reaching through a velocity-dependent curl field. (B) Change in neural preferred directions during motor adaptation. (C) Relationship between neural changes and forces applied to the hand during reaching.

- 1. Mixture model performed more reliably than traditional decoders
- 2. Structure was extendable to various signal sources, including intracortical recordings
- 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





DECODER

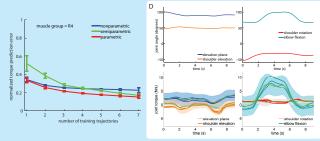
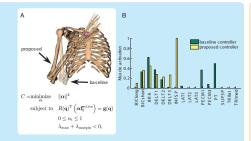


Fig. 7 - Identification and control of a paralyzed arm. While model-based robot controllers can incorporate models built from first principles, the same is generally not true for physiologic cal controllers. We therefore implemented a data-based approach. (A) Structure of semi-para metric model. (B) 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 vari-



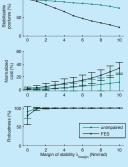


Fig. 8 - Controlling stability Stability is a critical aspect of the FES controller, particularly during interactions with the environment We developed a controller that allows stability to be regulated in addition to joint torques. (A) Cost function for controller. (B) Sample results for computed muscle activations, compared to a controller that does not consider stability. (C) Controller performance for simulated unimpaired arm and FFS arm

Outreach

This year, our outreach program has transitioned to running independently at our partner school. Approximately 40 children participate in a full-year program integrated into the existing science curriculum. This has been made possible through partnership with an NSF-funded Reach for the Stars program at Northwestern University.

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

Grade 7:

Module 1: Cyber-Physical Systems in Rehabilitation

- Engineering designSensors and measurement
- Actuators Computer
- Neurophysiology of human movement

Module 2: Introduction to Python program

- Formal languages
- Python syntax
- Algorithmic thinking

Module 1: Intermediate Computer Programming in Python

- Development of practical skills
- Resources from code.org

Module 2: Interactive robot design

- Hummingbird robotics + Python
- Student designed CPS project