Feedback control of upper extremity motion with FES

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Introduction

Usefulness of functional electrical stimulation (FES) systems to restore human motor functions is limited partly due to the lack of true feedback controllers. No feedback controller exists that can mimic the motions that a human can perform [1]. The complexity of the human musculoskeletal system is perhaps the major reason why previous attempts have failed. To control a system as complex as the human musculoskeletal system, a controller as complex as the human nervous system is required.

Method

The goal of this research is to develop a feedback controller that modulates the stimulation intensities of arm muscles, in order to produce arbitrary goal-directed motions. This goal is achieved using our recently developed motor control model that is based on muscle synergies [2]. Our model has the unique feature of resolving much of the complexities of the musculoskeletal system, by using a task-space representation of the arm (instead of the joint space representation). Therefore, near-optimal feedback controller of a complex musculoskeletal system is possible in real-time.

To test the developed motor controller model as an FES controller, RehaStim (Hasomed GmbH, Germany) is used to stimulate six muscles via transcutaneous electrodes (anterior/posterior deltoid, biceps brachii, triceps brachii, pectorialis major, and trapezius.

Initially, task-space models of the muscles are identified that map the stimulation intensity of each muscle to the amount of task-space (hand) force. These task-space muscle models are then used to construct a small number of synergies (co-activation of multiple muscles with known functions in the task-space). An arbitrary task (e.g. a certain motion direction) is decomposed into these synergies, resulting in the muscle intensities that produce the intended task.

Results

The preliminary results show that the synergy-based motor controller can control the motion of the arm in real-time, with acceptable error (about 1 cm tracking error) , and muscle activations that are close to optimal (about 11% increase in muscular effort compared with an optimal controller).

Discussion and conclusions

The important difference between our FES controller and previous attempts is the structure of the controller: task-space controller vs joint-space. Therefore, the controller complexity is greatly reduced, allowing for a more versatile controller. Furthermore, our synergy-based motor control model has higher bio-fidelity compared with other controllers, which may enhance the user experience and possible rehabilitation outcomes.

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