PROPORTIONAL DERIVATIVE CONTROL FOR PLANAR ARM MOVEMENT

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INTRODUCTION

Functional Electrical Stimulation (FES) is a technology that entails the stimulation of nerves and muscles with electrical current to restore movement in those with neurological movement disorders. The application of FES to upper extremities (UE) requires the control of gross motor tasks with a dynamic component. To date, the timing and amplitude of these artificial stimuli have been controlled by open loop pattern generators. It is thought that performance of FES systems can be improved by feedback control. This project involves the design of a controller for an UE model that implements the Proportional Derivative (PD) algorithm, and testing such a controller on a computational UE model that includes realistic dynamic properties of muscle.

METHODS

Controller performance was evaluated using a biomechanical model for arm movement in the horizontal plane. The model had two segments and was driven by six muscles, two of which were biarticular. Each muscle was modeled using a Hill-based approach. The contractile elements (CE) had realistic force-length and force-velocity properties, as well as activation dynamics. Muscle force was transmitted to the skeleton via a nonlinear series elastic element (SEE). Equations of motion were generated using SD/FAST (PTC, Needham, MA).

The Proportional Derivative (PD) controller generates a stimulation value u for each muscle whose magnitude is proportional to the errors in shoulder and elbow angles and their time-derivatives:

$$u = K_{p,1}(\theta_1 - \theta_{1,\text{target}}) + K_{d,1}\dot{\theta}_1 + K_{p,2}(\theta_2 - \theta_{2,\text{target}}) + K_{d,2}\dot{\theta},$$

where K_p and K_d are the proportional and derivative gains, respectively. Single joint muscles were only given feedback from one joint.

Forward dynamic simulations were performed for a single-target, planar reaching task. Initial joint angles were zero, and target joint angles were 45 and 90 degrees for shoulder and elbow, respectively. The feedback gains were set to identical values for all muscles and all joints, and varied to assess their effect on the performance of the reaching movement and on muscle forces.

RESULTS AND DISCUSSION

As expected, PD controller performance depended on feedback gains (Figure 1). When gains were selected to produce movements of sufficient speed and accuracy, undamped oscillation resulted. Model perfomance improved under two conditions: (i) when inertia of the limb segments was significantly increased, and (ii) when muscle response time was reduced, either by stiffening of the SEE or reduction of time constants in the activation dynamics model.

CONCLUSIONS

This computational model strongly suggests that oscillatory behavior may be an inevitable feature of proportional-derivative control for upper extremity FES. Further work will investigate the feasibility of an ‘intelligent’ controller based upon the Reinforcement Learning paradigm.

REFERENCES

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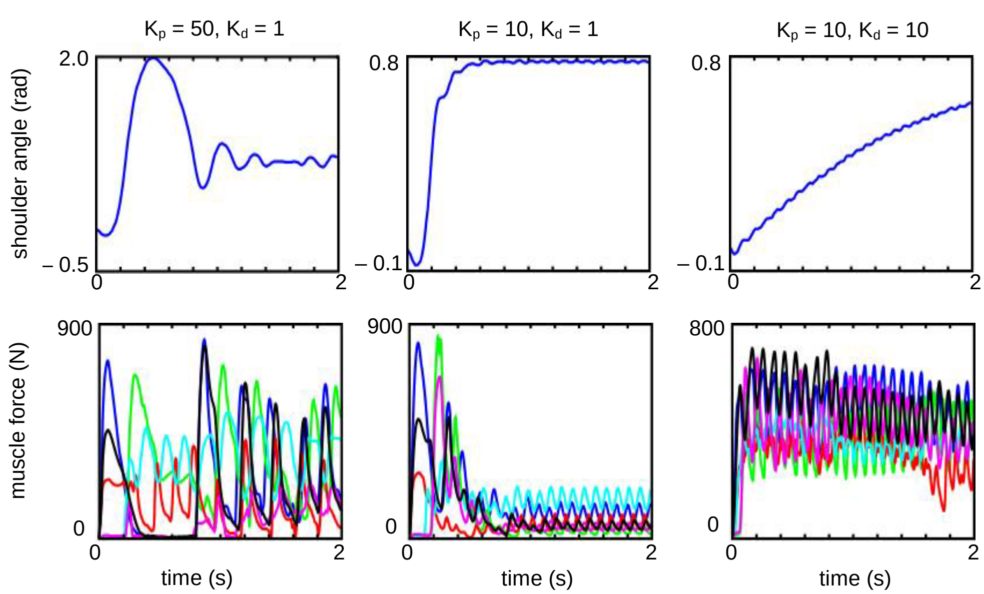

Figure 1: Simulation results: Time histories of joint angles and muscle forces for three feedback controllers