A PROPORTIONAL DERIVATIVE CONTROLLER FOR PLANAR HUMAN ARM MOVEMENT USING FUNCTIONAL ELECTRICAL STIMULATION

Kathleen Jagodnik[1,2], Robert Kirsch[1] and Antonie van den Bogert[2]

[1]Department of Biomedical Engineering, Case Western Reserve University, Cleveland, OH USA
(http://bme.case.edu/faculty_staff/kirsch/ ; rfk3@case.edu)
[2]Department of Biomedical Engineering, Lerner Research Institute, Cleveland, OH, USA
(http://www.lerner.ccf.org/bme/bogert/ ; bogerta@ccf.org)

INTRODUCTION

Functional Electrical Stimulation (FES) involves the electrical activation of peripheral nerves and muscles for the restoration of motor function. To date, FES technology has been applied to simple motions in both lower extremity (LE) and upper extremity (UE) systems. However, there remains a need for controllers capable of accomplishing more complex and goal-directed motions, such as reaching. The development of a control algorithm for UE FES systems that facilitates complex dynamic movements will expand the types of motion available to those with neurological impairments.

In this project, we applied a feedback controller to both a simulated UE FES system and to a human subject with a spinal cord injury (SCI). We selected Proportional Derivative (PD) control as our feedback controller due to its similarity to Equilibrium Point control, which has been shown to approximate human movement well (Feldman et al., 1998). The purposes of this study were (i) to design a PD controller stimulating six arm muscles to perform goal-directed reaching movements in the horizontal plane for a 2-segment arm model with realistic muscle properties, (ii) to evaluate its performance in a computational model of musculoskeletal dynamics, and (iii) to test this controller in a human subject.

METHODS AND PROCEDURES

Controller performance was evaluated using a biomechanical model for arm movement. The model had 2 segments (upper arm, forearm), 2 hinge joints (shoulder, elbow) and was driven by 6 muscles, which were modeled using a Hill-based approach.

A PD controller was applied to the arm model. This controller generates a response whose magnitude is proportional to the errors in joint angles and their time-derivatives. The controller has 24 gain parameters (6 muscles x 4 sensors). Optimal gains were found by minimizing a weighted sum of reaching error and muscle force, over a given set of 12 reaching movements.

The effect of controller architecture was tested by varying the number of free parameters (24, 16 and 2) in the PD controller.

Controller generality and robustness were tested by applying the optimized controllers to a set of 1,000 random reaching tasks; muscles were randomly weakened for the robustness test.

The 2-parameter PD controller was tested in a SCI human subject. Multiple trials of an elbow-extension task were performed with shoulder immobilized.

RESULTS & DISCUSSION

PD controller architecture was found to have a small effect on performance: it improved as the number of parameters specifying the controller increased.

The performance of the optimized 24-parameter controller on a typical simulated reaching movement is shown in Figure 1:

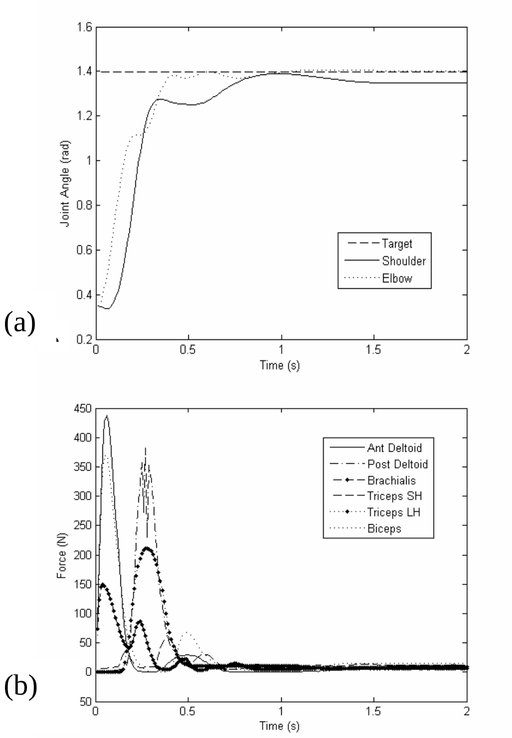

Figure 1. Optimized 24-parameter controller outputs for a (20° shoulder, 20° elbow) to (80°, 80°) reaching task. (a) Shoulder and elbow joint angles. (b) Muscle forces.

Performance on the generality test improved as the number of parameters specifying the controller increased (Table 1). All 3 controllers performed well, characterized by good accuracy and low muscular effort. In the robustness test, performance was less accurate for all 3 controllers than in the generality test, but was still acceptably good (Table 1).

Human subject trials showed generally good performance of the tuned PD controller. Performance variations from day to day, and within day, were observed and were attributed to spasticity.

SUMMARY

PD controller performance for our UE FES system was found to be good in simulation, with performance slightly improving as controller complexity increased. In our human system, PD controller performance could be good, provided that the human system was not subject to excessive anomalous behaviour.

REFERENCES

Feldman AG et al. *Motor Control*, 2(3): 189 – 205, 1998.

ACKNOWLEDGEMENTS

This work was supported by U.S. NIH predoctoral fellowship 5F31HD049326, grant 1R21HD049662, and contract N01HD53403. The authors thank Dimitra Blana and Edward Chadwick for their assistance.

PD Controller (# of parameters)	Test	Avg. Error (deg)	Avg. Effort (N)	# Failed Trials
24	Generality	5.29	22.18	0
	Robustness	7.28	15.69	107
16	Generality	5.32	23.26	0
	Robustness	7.41	16.00	117
2	Generality	5.50	25.10	0
	Robustness	7.51	17.31	122

Table 1. Generality and robustness test results. Number of Failed Trials is out of 1,000, defined as failure to terminate within 5 deg of both target joint angles.