FEEDBACK CONTROL FOR A HIGH LEVEL UPPER EXTREMITY NEUROPROSTHESIS

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INTRODUCTION

Individuals with C3/C4 spinal cord injury lose voluntary control of almost all muscles of the upper extremity. A neuroprosthetic system that applies electrical stimulation to paralyzed muscles can be used to restore function to these individuals. The controller for this system will generate the appropriate levels of muscle activation, based on the user commands. It also needs to compensate for errors caused by external disturbances and fatigue. This is necessary, because at that level of injury, voluntary correction for errors in the performance of the neuroprosthesis is not possible. In addition, due to the large number of shoulder and elbow muscles that must be controlled in high tetraplegia, purely experimental methods for developing the neuroprosthesis are inefficient and impractical. The goal of this project is to use a model-based approach to develop and test a feedback controller for this system.

METHODS

The musculoskeletal model of the shoulder and elbow used in this project is a finite element model built in SIMM (Software for Interactive Musculoskeletal Modeling, Musculographics, Inc.). It includes 28 muscles, six bones and five joints, with a total of 17 degrees of freedom. The morphological and muscle contraction parameters were obtained from cadaver studies performed by the Van der Helm group in Delft [1].

The open-loop controller that calculates the muscle activations required for a desired movement was designed as a static two-layer artificial neural network (ANN). It has a tangent-sigmoidal activation function for the hidden layer and a linear activation function for the output layer. In order to correct for position and orientation errors that are caused by fatigue or external disturbances, such as masses added to or removed from the hand, a feedback loop needs to be added to the previously designed controller. Its role is to model the relationship between error and the changes in muscle activation that will move the arm toward the desired position. Both the open-loop and the feedback parts of the controller are being developed using the musculoskeletal model, which was customized to simulate a person with C3-C4 level spinal cord injury.

RESULTS AND DISCUSSION

Figure 1 shows the predictions of the open-loop controller, which is an ANN with 20 neurons in the hidden layer, for the activation of two muscles, middle deltoid and upper trapezius, during a humeral abduction movement. The RMS error is 4.47% for the middle deltoid, and 6.05% for the upper trapezius. The performance of the ANN can be improved by optimizing its parameters.

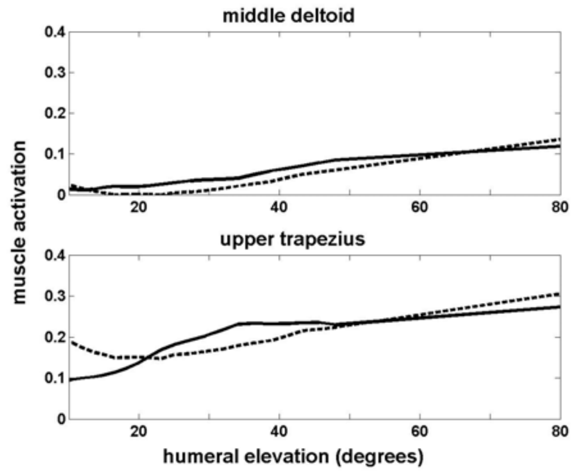

Figure 1: The solid lines are the activations calculated by the model, and the dotted lines are the ANN predictions.

When the feedback loop is added, the performance of the overall controller will be evaluated using the model in series with the system. A set of forward simulations will be performed with the output of the controller as input to the model, and the resulting endpoint position and orientation will be compared with the desired ones.

CONCLUSIONS

The preliminary results show that the ANN can accurately predict the muscle activations needed for a desired posture, and can therefore be used as the open-loop part of the neuroprosthesis controller. It is also demonstrated that the use of a musculoskeletal model can facilitate the development of the feedback controller, by simulating a C3-C4 SCI individual and realistic conditions of fatigue and external disturbances, both for designing and for testing the system.

REFERENCES

1. Klein Breteler M.D, Spoor C.W. and van der Helm F.C.T: *Measuring muscle and joint geometry parameters of a shoulder for modeling purposes*, J Biomech 32: 1191-1197, 1999.

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