EVALUATION OF A SYSTEM FOR REAL-TIME ANALYSIS OF MUSCLE FUNCTION: SHOULDER AND ELBOW MUSCLES

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INTRODUCTION

Non-invasive estimation is an established research tool in biomechanics with significant potential for clinical applications [1]. When implemented in real-time, the analysis can be done while the patient performs exercise, allowing immediate feedback to patient and therapist, as well as visualization and virtual-reality environments that respond to the data [2].

The Human Body Model (HBM, Motek Medical B.V., Amsterdam, Netherlands) is a full-body model for real-time biomechanical analysis. HBM performs a full-body mechanical analysis of movement, including skeleton kinematics using optical motion capture, inverse dynamic analysis, calculation of muscle lengths and moment arms, and muscle force estimation using static optimization. Static optimization uses the criterion of minimum squared muscle stress [4], with equality constraints to satisfy the measured joint moments and an iterative solution method based on recurrent neural networks [2]. HBM was recently extended by adding a large number of shoulder and elbow muscles. In this paper we evaluate the new model with respect to the following specific questions: (1) is computation speed still sufficient for the desired accuracy? and (2) does the model produce realistic estimates of muscle recruitment during simple arm exercises?

METHODS

Shoulder and elbow muscles (102 elements in each arm) were added using the models developed in [3], bringing the total number of muscle elements to 290 in upper and lower extremities. Inequality constraints were added to ensure that the shoulder muscles maintain stability in the glenohumeral joint as described in [4]. During real-time operation (Figure 1), iterations in the muscle force estimation algorithm are terminated after 5 ms. When the model has more muscles, fewer iterations will be performed, and this affects accuracy.

The relationship between computation speed and accuracy was evaluated off-line for a movement trial in which a subject performed various balance exercises for 30 seconds. Computation time per sample was varied and error in muscle force estimation was quantified by comparing to the most accurate solution which used 200 ms of computation time per input sample. Root mean square (RMS) error was computed over all time samples and all 290 muscles. This evaluation was performed on a 2 GHz Intel T2500 processor using a single core.

Validity of muscle force estimates was evaluated qualitatively for a static sequence of arm postures, in which the arm was abducted from 0 to 180 degrees. Recruitment of the deltoid muscle elements will be shown, divided into 11 elements in the scapular head and 4 elements in the clavicular head.

RESULTS AND DISCUSSION

At real-time computation speed, the static optimization algorithm converged to within 5 N of the solution, or 4% of the average peak muscle force during this movement trial (Figure 2). This suggests that the number of muscle elements can still be increased beyond the present 290, especially when processing can be distributed over multiple cores.

The simulated arm abduction exercise produced deltoid recruitment patterns similar to those reported in [4] (Figure 3). The recruitment patterns are notably asymmetric with respect to the 90 degree (horizontal) position, even though the net joint moment has a symmetric cosine profile. The asymmetry is caused by changes in moment arms and by the stability requirement for the glenohumeral joint.

We conclude that the model is able to perform static optimization in real time, and produces realistic estimates of shoulder muscle recruitment. Further validation of the model is an ongoing effort.

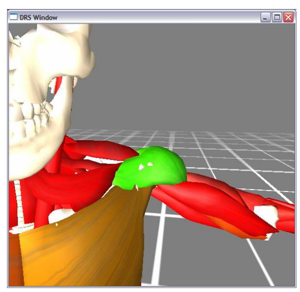

Figure 1: Real-time visualization of muscle force with color.

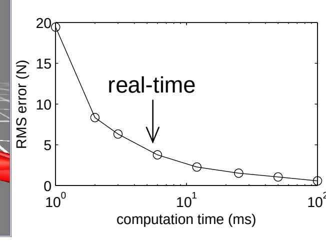

Figure 2: Error in muscle force as a function of computation time.

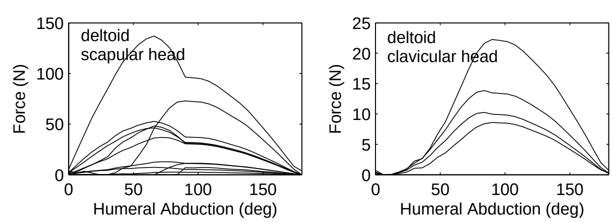

Figure 3: Recruitment of the fifteen deltoid muscle elements during simulated arm abduction exercise.

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