ESTIMATION OF JOINT TORQUE FROM THE SURFACE EMG

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ABSTRACT

Torque exerted about the elbow was estimated from flexor and extensor muscle surface EMG waveforms. An algebraic relation between joint torque and simultaneous flexor/ extensor EMG amplitudes was assumed, and a least squares method for identifying the parameters of this relation investigated. Initially, a simulation study investigated the performance of the least squares method and served as a tool to determine an appropriate experimental design. Then, multiple channels of flexor/ extensor EMG waveforms and joint torque were measured during non-fatiguing, slowly force-varying (quasi-isotonic), isometric contractions. Single/ multiple channel techniques for computing an EMG amplitude were used to identify an EMG to torque relation, and then estimate joint torque based on this relation.

INTRODUCTION

Accurate and reliable estimation of joint torque from observation of the surface EMG waveform would provide a safe, non-invasive tool for the control of cybernetic prostheses, as well as for the study of human movement and biomechanics. This problem was sub-divided into two stages, both of which were addressed in this research. First, the EMG amplitude was estimated from the EMG waveform. Single and multiple channel techniques were used. The multiple channel technique provided a higher quality EMG amplitude estimate. Second, joint torque was then estimated from the EMG amplitude. Since muscular co-contraction was always observed during moderate (or greater) muscular contraction, simultaneous flexor and extensor activity was considered.

EMG AMPLITUDE TO TORQUE RELATION

The torque measured about the joint ($\mathcal{T}_m$) was assumed to be algebraically related to the torques due to flexion ($\mathcal{T}_F$) and extension ($\mathcal{T}_E$) as: $\mathcal{T}_m = \mathcal{T}_F - \mathcal{T}_E$. In turn, the flexion and extension EMG amplitudes (s_F, s_E) were assumed to be related to $\mathcal{T}_F$ and $\mathcal{T}_E$ as the polynomials:

$$\begin{aligned} \mathcal{T}_F &= f_{F,1} \cdot s_F + f_{F,2} \cdot s_F^2 + f_{F,3} \cdot s_F^3 + \ldots \\ \mathcal{T}_E &= f_{E,1} \cdot s_E + f_{E,2} \cdot s_E^2 + f_{E,3} \cdot s_E^3 + \ldots \end{aligned}$$

where $f_{i,j}$ are fit parameters. With these assumptions, the error between the estimated and measured joint torque at each instant in time (t) was: $error_t = \mathcal{T}_{F_t} - \mathcal{T}_{E_t} - \mathcal{T}_{m_t}$. For a sequence of measurements at various levels of flexion-extension contraction, linear least squares techniques were used to minimize the mean square error (MSE) with respect to the fit parameters.

EMG TO TORQUE SIMULATIONS

Prior to acquiring experimental data, it was important to determine what tasks a subject should perform — i.e. it was important to determine what experimental data to actually acquire. To this end, EMG amplitudes were simulated (representing possible experimental tasks) and the conditioning of the least squares problem evaluated. The results suggested that two contractions, one dominant in extension and the other dominant in flexion, should be concatenated to form an experimental task. Co-contraction should be minimized, but need not be eliminated.

A second simulation study investigated three aspects of the identification technique — identification accuracy, identification repeatability and the influence of overfitting the model data. Flexion and extension EMG waveforms were simulated from known EMG amplitudes multiplied by Gaussian noise. Measured joint torques were simulated from the known EMG amplitudes and known polynomial (1^{st}-, 2^{nd}- and 3^{rd}-order) EMG amplitude to torque relationships. EMG amplitude estimates were formed from the simulated EMG waveforms using a moving average (244ms window) root mean square filter. This filter produced amplitude estimates with a signal to noise ratio of ≈ 31.6. MSE's in identifying the known EMG amplitude to torque relation were typically less than 2% of the combined flexion/ extension torque range. Overfitting the data by one or two orders only slightly degraded performance. Trial to trial repeatability of the identified EMG amplitude to torque relationship was influenced by the trial to trial repeatability of the EMG amplitude.

EMG TO TORQUE EXPERIMENTS

Subjects (two male, one female) were seated and strapped into a straight-back chair. The subject's right wrist was secured, via a wrist cuff, to an instrumented beam (which was rigidly attached to the chair). Torque about the elbow was measured as deflection of the beam. Up to five commercial electrode-amplifiers (Liberty Mutual MYO111) were placed on each of the flexor and extensor muscles of the elbow (up to ten electrode-amplifiers in all). A sequence of ten isometric, quasi-isotonic contractions was conducted.

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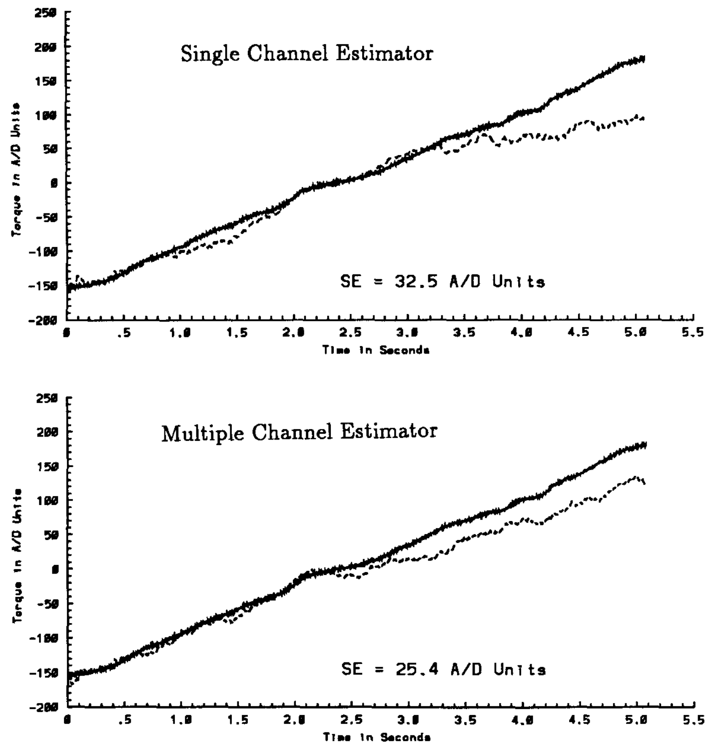

Figure 1: *Top plot is the estimated (dash line) joint torque using a single channel estimator and a third-order polynomial relation. The standard error (SE) is 32.5 A/D units. Bottom plot is the estimated (dash line) joint torque of the same trial using a four channel estimator and a third-order polynomial relation. The SE is 25.4 A/D units. Solid lines are the measured torque. Ordinate axes begin at ≈ 40% extension MVC and end at ≈ 40% flexion MVC. Polynomial relations were identified from the data of a separate trial.*

Each contraction followed an eight second elbow torque trajectory which linearly ramped in time from 50% maximum voluntary contraction (MVC) extension to 0% MVC extension/ flexion to 50% MVC flexion. A rest period of four minutes between trials was provided. Trial data were sampled by a 12-bit A/D converter (2048 Hz.). The initial and final one second of each recorded trial were excluded from joint torque estimation.

EMG amplitude estimates were made in two manners. First, a single flexion (extension) channel was passed through a moving average (244ms window) mean absolute value filter. Second, each sample from each flexion (extension) channel was normalized, rectified, and then summed with all other flexion (extension) samples from that time period. The summed data were then passed through a moving average filter. This multiple channel technique produced a higher fidelity EMG amplitude estimate.

Figure 1 shows a set of results for both single and multiple channel joint torque estimation. The multiple channel estimator had an estimation error ≈ 3% of the combined flexion/ extension torque range, and ≈ 75% that of the single channel estimator. Estimation was best when the polynomial algebraic relation was third order. Overfitting only slightly degraded estimation performance.

CONCLUSIONS

The simulation studies suggested that identification of an EMG amplitude to joint torque relation *in the presence of muscular co-contraction* could be accomplished without significant difficulty. The experimental studies demonstrated that higher fidelity EMG amplitude estimation led to improved joint torque estimation. The multiple channel estimator had an estimation error ≈ 3% of the combined flexion/ extension torque range.

BIBLIOGRAPHY

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ACKNOWLEDGEMENTS

This research was supported by NIH Grant No. AR40029 and U.S. Dept. of Education NIDRR Grant No. H133E80024.

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CH3068-4/91/0000-0878 $01.00 © 1991 IEEE