EMG AMPLITUDE ESTIMATION FROM TEMPORALLY WHITENED, SPATIALLY UNCORRELATED MULTIPLE CHANNEL EMG

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ABSTRACT

The amplitude of the surface EMG was estimated with multiple channels of EMG by first temporally whitening individual EMG channels and then optimally combining multiple channels. Surface EMG was recorded for non-fatiguing, constant-force, isometric contractions. A signal-to-noise ratio (SNR) was computed (deviations about the mean value of the estimate were considered as noise). A moving average root mean square (MARMS) estimator (245 ms window) provided an average $\pm$ standard deviation (A$\pm$SD) SNR of 10.7 ± 3.3 for the individual channels. Temporal whitening improved the A$\pm$SD SNR to 17.6 ± 6.0. Combining temporal whitening and spatial uncorrelation with four channels improved the A$\pm$SD SNR to 24.6 ± 10.4. On one subject eight optimally combined channels were achieved, providing an A$\pm$SD SNR of 35.0 ± 13.4.

INTRODUCTION

The surface EMG waveform is a complex spatial-temporal interference pattern of the electrical activity of the various underlying muscle tissues. Viewed as a random signal, the surface EMG has been shown to resemble a band-limited Gaussian random process. For isometric, isotonic contractions, the amplitude of the surface EMG has been observed to increase with the contraction level. Estimates of the surface EMG amplitude are utilized as the control input to proportional control myoelectric prostheses and have also been investigated as indicators of muscle force.

Typical surface EMG amplitude estimators have poor SNR performance. Previous investigators have, however, introduced two separate techniques for improving performance; 1) temporal whitening of a single EMG channel and 2) the use of multiple EMG channels [1,2,3]. The present investigation combined the two techniques. A stochastic multiple channel model of the surface EMG was constructed. Based upon the model, optimal estimators of the EMG amplitude were derived. These optimal estimators were then utilized in an experimental trial.

EMG MODEL

A single channel of surface EMG was modeled as being formed from a unit intensity, zero mean, wide-sense stationary, band-limited, correlation-ergodic, jointly Gaussian process multiplied by the EMG amplitude. Optimum maximum likelihood (ML) estimation of the EMG amplitude from a single EMG channel can be accomplished by temporally whitening the EMG signal and then performing a MARMS. To perform temporal whitening, a 4^{th}-order autoregressive (AR) model of the EMG power spectrum was assumed. The coefficients of the AR model were used to develop a whitening filter. L multiple channels of EMG were modeled as being formed from linear combinations of L independent single channels of EMG. Optimum ML estimation of the EMG amplitude from multiple EMG channels can be accomplished by individually temporally whitening each channel, then spatially uncorrelating the multiple whitened channels, followed by performing a MARMS. Hogan and Mann [1,2] discuss the technique for uncorrelating multiple channels.

METHODS

Subjects were seated and strapped into a straight-back chair. The subject's right arm was oriented so that the upper and lower arm were perpendicular to the floor, and the upper arm was directed laterally outward from the shoulder. The subject's right wrist was mounted, 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 eight commercial electrode-amplifiers (Liberty Mutual MYO111) were placed on the flexor or extensor muscles of the elbow.

A sequence of five sets of non-fatiguing, constant-force, isometric contractions was conducted. Each set consisted of four trials, one each at 10, 25, 50 and 75% of maximum voluntary contraction (MVC). Trials within a set were randomized. A rest period of two minutes between trials was provided. A total of 660 single channel/ 100 multiple channel recordings were acquired by an A/D converter. Subsequent processing was performed digitally.

RESULTS

A single trial for each subject at 50% MVC was utilized to form a temporal whitening filter for each EMG channel for that subject. This same trial was also used to form the spatial uncorrelation transformation. A SNR was computed for each amplitude estimate by considering deviations about the mean value of the amplitude estimate as noise. The raw EMG signal from all single channels was processed with a 245ms window MARMS estimator, providing an A$\pm$SD SNR of 10.7 ± 3.3. Temporal whitening improved the A$\pm$SD SNR to 17.6 ± 6.0. Four temporally whitened and spatially uncorrelated channels improved the A$\pm$SD SNR to 24.6 ± 10.4. On one subject, eight channels were acquired, from which optimal combination yielded an A$\pm$SD SNR of 35.0 ± 13.4. (For this subject, the A$\pm$SD SNR for the MARMS estimator was 11.8 ± 2.5.) A set of sample results is shown in Figure 1.

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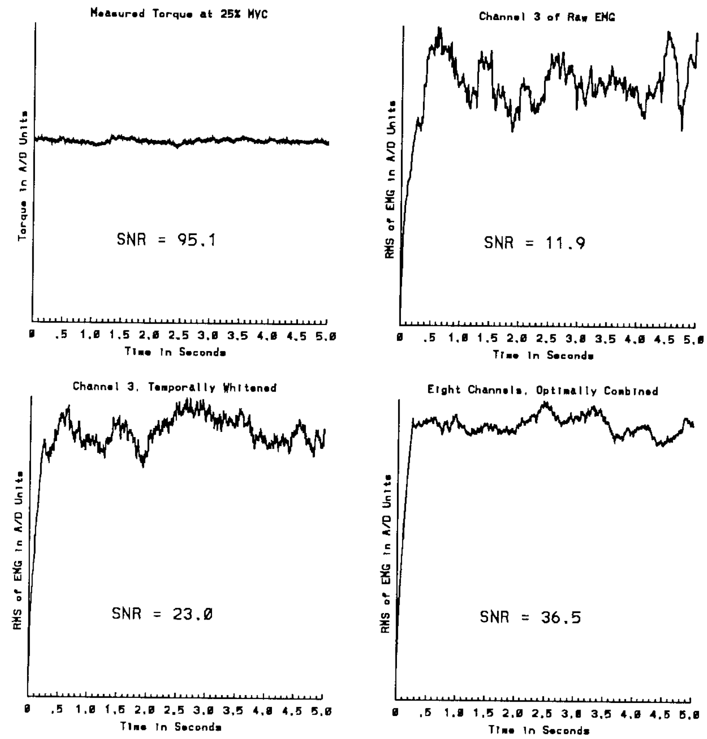

Figure 1: *Top left plot is the measured torque for non-fatiguing, constant-force, isometric contraction of elbow flexors at 25% MVC. Top right plot is the moving average root mean square (MARMS) estimate (245ms window) of the amplitude of EMG channel 3. Bottom left plot is the temporally whitened MARMS estimate of the amplitude of EMG channel 3. Bottom right is the temporally whitened, spatially uncorrelated (8 channels) MARMS estimate of the EMG amplitude. All data is from the same trial.*

DISCUSSION

The "standard" EMG amplitude estimator consists of an analog full-wave rectifier followed by a simple RC low pass filter. The MARMS estimator has been shown to provide an improvement over the standard estimator of approximately 25% [2]. Single channel whitening improved the standard estimator by approximately 35–100% [2,3]. The use of multiple channels improved the standard estimator by approximately 40–180% [2,3]. This investigation combined the two techniques of temporally whitening single channels and spatially uncorrelating multiple channels and found that an additive improvement results. Further, these results show that calibration of an optimal processor can successfully be achieved with a single five second contraction trial. With an eight channel estimator, the average SNR improved by approximately 197% over the single channel MARMS estimator (or an estimated 274% improvement over the standard estimator).

REFERENCES

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