Effect of Smoothing Window Length on RMS EMG Amplitude Estimates

Yves St-Amant[1], Denis Rancourt[1] and Edward A. Clancy[2]
[1]Mechanical Engineering Department, Laval University, Québec, P.Q., Canada, G1K 7P4
[2]Liberty Mutual Research Center for Safety and Health, 71 Frankland Road, Hopkinton, MA, USA, 01748

Abstract — This paper describes the results of a study on the influence of smoothing window length on the signal-to-noise ratio (SNR) of electromyogram (EMG) amplitude estimates. In a previous experiment, surface EMG waveforms were recorded for non-fatiguing, constant-force, isometric contraction of the biceps and triceps muscles. Based on these data, four different EMG processors were studied using smoothing window length durations spanning 24-500 ms. Results show that the SNR increases in a square root fashion with smoothing window length, as predicted by classical theory. These results are useful in choosing the length of the smoothing window in traditional surface EMG studies, and to adaptively tune the smoothing window length when the EMG amplitude is time-varying.

INTRODUCTION

The surface EMG waveform is a pattern of the electrical activity of a muscle. The amplitude of the surface EMG waveform has been used as a non-invasive tool for assessing the degree of muscular exertion. The quality of amplitude estimation can be quantified using a signal-to-noise (SNR) ratio value. For isometric, isotonic, non-fatiguing muscular contraction, the SNR of EMG amplitude estimates has been shown theorically to be related to the statistical bandwith B_s of the EMG signal, the number L of EMG channels recorded on a muscle, and the length T of the smoothing window applied to the data as $\mathrm{SNR} \approx \sqrt{2 \cdot B_s \cdot L \cdot T}$ [1]. The B_s and L factors have been experimentally examined previously, however, the influence of smoothing window length has not been analysed experimentally. The window length becomes quite important when the EMG amplitude is dynamically varied i.e. when muscular contraction varies with time. In this case, better results can be obtained if the window length is tuned during the contraction. When the EMG amplitude is rapidly varying, a short window length should be used and when the EMG amplitude is slowly varying, the window length should be made longer. This paper describes the variation of the SNR over a pratical range of window lengths to help select the appropriate window length for EMG amplitude estimation.

METHODS

This study is based on data acquired in a previous experiment [2,3]. Subjects were seated and strapped into a straight-back chair. The subject's right arm was oriented so that the upper limb was in a plane parallel to the floor with the elbow at a 90° flexion angle. The subject's right wrist was mounted, via a wrist cuff, to a cantilever beam. Torque about the elbow was measured by a complete stain gauge Wheatstone bridge. Up to eight commercial electrode-amplifiers were placed on the flexor and extensor muscles of the elbow.

A sequence of five sets of non-fatiguing, constant-force, isometric contractions was then conducted. Each set consisted of four randomized trials, one each at 10, 25, 50 and 75% of maximum voluntary contraction (MVC). A total of 660 single/100 multiple site recordings were sampled at 2048 Hz by an 12-bit A/D converter.

The relation between SNR and smoothing window length was studied with unoptimized/optimized single/multiple channel EMG processors. The sample mean of each EMG waveform was substracted from the data. These adjusted waveforms were then used to form the four processors as follow:

1) A single channel unwhitened amplitude processor was formed as the simple RMS processor. If the EMG waveform at sample t is denoted $m(t)$ and N is the smoothing window length, then the EMG amplitude estimate $\hat{s}_1(t)$ was formed as

$$\hat{s}_1(t) = \left[\frac{1}{N} \sum_{i=t-N+1}^{t} m^2(i) \right]^{1/2} ;$$

2) A single channel whitened (optimized) processor was formed by temporally whitening each data record, and performing RMS detection. A fourth-order moving average whitening filter was constructed for each electrode amplifier for each subject, and applied to all trials recorded by that electrode-amplifier. For each subject, a whitening filter was calibrated by averaging the autoregressive (AR) power spectrum coefficients computed from each 50% MVC trial.
3) A multiple channel (four channel) unwhitened amplitude processor was formed by equalizing the variance of each channel (based on the average variance of the five 50% MVC trials), then performing spatial-temporal RMS detection. If the multiple channel EMG (after variance equalizing) at sample t is denoted $m_k(t)$ and k ranges from 1 to L = 4, then this EMG amplitude estimate was formed as

$$\hat{s}_3(t) = \left[\frac{1}{N \cdot L} \sum_{k=1}^{L} \sum_{i=t-N+1}^{t} m_k{}^2(i) \right]^{1/2} ;$$

4) A multiple channel (four channel) whitened amplitude processor was formed by temporally whitening each channel, equalizing the variance of each channel, then performing spatial-temporal RMS detection.

The smoothing window length was varied from 24 ms to 500 ms for each processor. SNRs of each EMG amplitude were computed as the square root of the ratio of the squared

0-7803-3204-0/96$05.00©1996IEEE

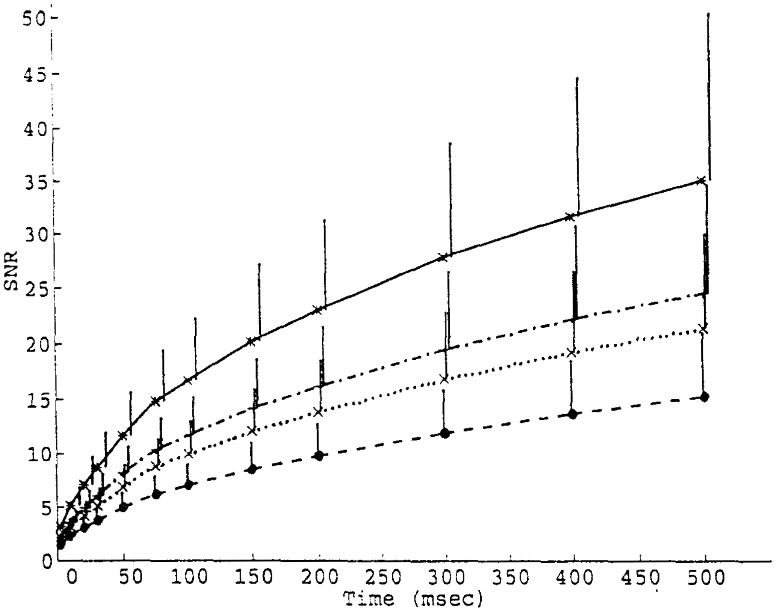

Fig. 1. SNR versus window length for four different RMS processors: multiple channel, whitened (—); multiple channel, unwhitened (...); single channel, whitened (-.-); single channel, unwhitened (---). The mean + standard deviation SNRs are shown where each entry averaged across 660 single channel recordings/100 multiple channel recordings.

amplitude estimate sample mean divided by the amplitude estimate sample variance. All computations were performed on an IBM-compatible PC using MATLAB (version 4.0).

RESULTS

Figure 1 shows the SNR performance for the four processors versus window length. Data of all contraction levels and all subjects were pooled together. In all cases, the SNR increases with window length, along with its variance. Optimized methods and spatial-temporal correlation consistently improve SNR performance over the entire range of window length that was studied. A least square fit of a square root was applied to the SNR of all processors. A scaling factor must be added to the SNR approximated formula to ensure proper fit.

In addition to the four RMS processors, similar processors using mean-absolute-value (MAV) detection were investigated. The MAV processors consistently performed slightly better than their RMS counterparts.

DISCUSSION

There is a clear tradeoff between the ability to follow a changing EMG and the SNR performance. This study shows that SNR performance can be significantly increased by choosing a longer smoothing window length — assuming EMG activity is constant. However, higher SNR variance should be expected. Better results can be obtained by choosing more sophisticated processors which adaptively tune window length. If adaptive EMG amplitude estimation is required, shorter window lengths should be selected. Note that between 30-100 ms window length, the SNR performance is approximately doubled, whatever processor is used. Since MAV processors are as good as the RMS ones, computations can be greatly reduced in real-time applications. The quality of fit of the square root function to the SNR makes this approximation very useful for adaptive EMG amplitude estimation. Further research will investigate the scaling factor and statistical analysis will be performed to analyze force level and subject influences.

ACKNOWLEGMENTS

Experimental data for this study were collected in the Eric P. and Evelyn E. Newman Laboratory for Biomechanics and Human Rehabilitation at the Massachusetts Institute of Technology. This work is partially supported by the National Institutes of Health under grant AR40029 and the U.S. Department of Education under NIDRR grant H133E80024.

REFERENCES

[1] N. Hogan and R.W. Mann, « Myoelectric signal processing: Optimal estimation applied to electromyography-Part II: Experimental demonstration of optimal myoprocessor performance, » IEEE Trans. Biomed. Eng., vol. 27, pp. 396-410,1980.

[2] E.A. Clancy and N. Hogan, « Single site electromyograph amplitude estimation », IEEE Trans. Biomed. Eng., vol 41, pp.159-167, 1994.

[3] E.A. Clancy and N. Hogan, « Multiple site electromyograph amplitude estimation », IEEE Trans. Biomed. Eng., vol 42, pp.203-211, 1995.