EMG Bandwidth Used in Signal Whitening

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***Abstract*—It has been demonstrated that whitening the surface electromyogram (EMG) improves EMG amplitude (EMGσ) estimation. But, due to the wide bandwidth ranges often used when whitening, custom high-cost electrodes (bandwidth of ~2000 Hz) have been used. This paper investigates the effect of limiting the bandwidth for the whitened EMG data. The change in the average error of EMG to torque estimation was observed for 54 subjects over different whitening bandwidths ranging from 20–2000 Hz. We found that the average error remained the same for bandwidth limits between 600 Hz to 2000 Hz, suggesting that wider EMG electrodes were not helpful with this data set.**

I. Introduction

Whitening of the surface electromyogram (EMG) has been shown to improve EMG amplitude estimation and to lower EMG-torque errors [1], [2]. The current adaptive whitening approach used in our laboratory [3] utilizes more signal bandwidth when EMGσ is large (SNR is high) but less signal bandwidth when EMGσ is low (more noise than signal only exists at the lower frequencies). This strategy has been shown advantageous when contraction levels extent to 50–75% of maximum voluntary contraction (MVC) [1], [3]. To take advantage of the broader bandwidth during higher contraction levels, our work has utilized custom-designed electrodes with a passband to nearly 2,000 Hz. As a result, we typically sample the incoming EMG signal at 4096 Hz and implement adaptive signal whitening over the entire Nyquist bandwidth (2048 Hz). However, most day-to-day contractions occur at average levels below 25% MVC. At these contraction levels, the adaptive whitening may be discarding much of the higher frequencies in the signal. Given the cost and effort required for custom electrodes, we wanted to rigorously investigate the role of bandwidth on EMGσ processing at more modest contraction levels. In this work, the maximum frequency out to which whitening was applied was limited using digital lowpass filtering. We examined bandwidth limiting for frequencies ranging from 20 Hz to the full whitening bandwidth of 2048 Hz. For each of these bandwidths, EMG to torque estimation was performed for 54 subjects and the average error in percent MVC flexion was computed.

II. METHODS

A. Experimental Data and Methods

Experimental data from 54 subjects (30 male, 24 female; aged 37.6±16.5 years) from three prior experimental studies were analyzed. This study was approved and supervised by the WPI IRB. All subjects had previously provided written informed consent. The three studies had nearly identical experimental apparatus and protocols (fully described in [3] and [4]). Subjects were seated and secured with their shoulder abducted 90^{o}, forearm oriented in a parasagittal plane, wrist fully supinated and elbow flexed 90^{o}. Their right wrist was tightly cuffed to a load cell (Biodex dynamometer; or Vishay Tedea-Huntleigh Model 1042, 75 kg capacity) at the styloid process. Skin above the muscles under investigation was scrubbed with an alcohol wipe. In one study, a small bead of electrode gel was massaged into the skin. Four bipolar electrode-amplifiers were placed transversely across each of the biceps and triceps muscles, midway between the elbow and the midpoint of the upper arm, centered on the muscle midline. Each electrode-amplifier had a pair of 4-mm (or 8mm) diameter, stainless steel, hemispherical contacts separated by 10 mm edge-to-edge, oriented along the muscle's long axis. The distance between adjacent electrode-amplifiers was ~1.75 cm. A single ground electrode was gelled and secured above the acromion process or on the upper arm. Custom electronics amplified each EMG signal (CMRR of approximately 90 dB at 60 Hz) followed by bandpass filtering (either a second-order, 10–2000 Hz bandpass filter; or 8th-order highpass at 15 Hz followed by a 4th-order lowpass at 1800 Hz). All signals were sampled at 4096 Hz with 16-bit resolution.

After a warm-up period, MVC torque was measured in both elbow extension and flexion. Two repetitions of five-second duration, constant-posture constant-force contractions at 50% MVC extension, 50% MVC flexion and rest were recorded. A real-time feedback signal consisting of either the load cell voltage or a four-channel whitened EMGσ processor (formed by subtracting the extensor EMGσ from the flexor EMGσ) was provided on a computer screen. Thirty-second duration, constant-posture force-varying contraction trials were then recorded. The subjects used the feedback signal to track a computer-generated target that moved on the screen as a band-limited (1 Hz) uniform random process, spanning 50% MVC extension to 50% MVC flexion. Three trials were collected. At least three minutes of rest was provided between contractions to prevent cumulative fatigue. Additional sensors were applied and tracking trials collected, but not used in this study.

B. Methods of Analysis

All analysis was performed offline in MATLAB. A four-channel whitened (but bandwidth restricted) EMGσ processor was used. Each processor used a 15 Hz highpass filter (causal, 5th-order, Butterworth) and first-order (i.e., absolute value) demodulation. The four-channel processor whitened each channel (causal algorithm of Clancy and colleagues [3], [5], [6]). Whitening filters were calibrated from one of the constant-force contraction sets, comprised of a 50% MVC extension, 50% MVC flexion and a rest recording. To restrict bandwidth, the whitened signal was lowpass filtered using a causal, 9th-order, Chebychev Type I whose cutoff frequency was selectable. Cutoff frequencies incremented by 10 Hz between 20 and 200 Hz, and then incremented by 100 Hz up to 2000 Hz. After bandwidth restriction, each signal was demodulated and then the four EMG channels were averaged.

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Finally, the EMGσ signal was formed by decimating this signal by a factor of 100 to a sampling rate of 40.96. To do so, the signal was decimated twice by a factor of ten (effective lowpass filter prior to downsampling of 16.4 Hz, causal, 9th-order, Chebychev Type I). The torque signal was similarly decimated, yielding a bandwidth approximately one tenth that of the input EMGσ signals [7]. Extension and flexion EMGσs were related to joint torque via the parametric model [2]:

$$T[m]=\sum_{d=1}^{D}\sum_{q=0}^{Q}e_{q,d}\sigma_E^d[m-q]+\sum_{d=1}^{D}\sum_{q=0}^{Q}f_{q,d}\sigma_F^d[m-q]$$

where *T[m]* is the decimated torque signal, σ_E is the extension EMGσ, σ_F is the flexion EMGσ, $e_{q,d}$ are extension fit coefficients and $f_{q,d}$ are flexion fit coefficients. Integer Q sets the number of signal lags. When integer D=1, the model is linear. When integer D=2, a nonlinear dynamic model is facilitated. Parameter Q was set to 30 for our linear model and 15 for our non-linear model. Fit parameters were found via least squares, regularized via the pseudo-inverse approach [2].

III. Results

Fig. 1 shows the average error (difference in the estimated vs. actual torque) from all 54 subjects for whitened multiple channel EMG, using the linear and non-linear models, as a function of maximum frequency used for whitening. The average error remains at almost constant value of 5.48% (non-linear) and 6.24% (linear) for maximum frequencies between ~600 Hz and 2000 Hz. Below maximum frequencies of ~600 Hz, the error increases. A steep error increase occurs for maximum whitening frequencies below 200 Hz.

IV. Discussion

EMG estimation was performed using different bandwidths of the whitened EMG in order to observe the change in error. It was observed that the error both for linear and non-linear models remained relatively constant over a wide range of maximum frequencies, i.e. 600 Hz up to 2000 Hz. This result questions the need for adaptive whitening over such a wide frequency range as 2048 Hz, at least for contractions at these levels. These data ranged in contraction from 50% MVC flexion to 50% MVC flexion, with an average contraction level below 25%. This result also supports eliminating the requirement to use custom high bandwidth electrodes when acquiring data with these contraction characteristics, as most off-the-shelf EMG hardware has a bandwidth up to ~500 Hz.

References

[1] E. A. Clancy and N. Hogan, "Single Site Electromyograph Amplitude Estimation," IEEE Trans. Biomed. Eng., vol. 41, pp. 159–167, 1994.

[2] E. A. Clancy, L. Liu, P. Liu and D.V.Z. Moyer, "Identification of constant-posture EMG-torque relationship about the elbow using nonlinear dynamic models," IEEE Trans. Biomed. Eng., vol. 59, pp. 205-212, 2012.

[3] E. A. Clancy and K. A. Farry, "Adaptive whitening of the electromyogram to improve amplitude estimation," IEEE Trans. Biomed. Eng., vol. 47, pp. 709–719, 2000.

[4] E. A. Clancy, "Electromyogram amplitude estimation with adaptive smoothing window length," IEEE Trans. Biomed. Eng., vol. 46, pp. 717–729, 1999.

[5] E. A. Clancy. (2010 Aug.). EMG Amplitude Estimation Toolbox:User's Guide. Alpha version 0.07, 2010 [Online]. Available: http://www.wpi.edu/~ted/emg_tool.htm.

[6] P. Prakash, C. A. Salini, J. A. Tranquilli, D. R. Brown and E. A. Clancy, "Adaptive whitening in electromyogram amplitude estimation for epoch-based applications," IEEE Trans. Biomed. Eng., vol. 52, pp. 331–334, 2005.

[7] L. Ljung, System Identification: Theory for the User.. Upper Saddle River, NJ: Prentice-Hall, 1999, pp. 491–519.

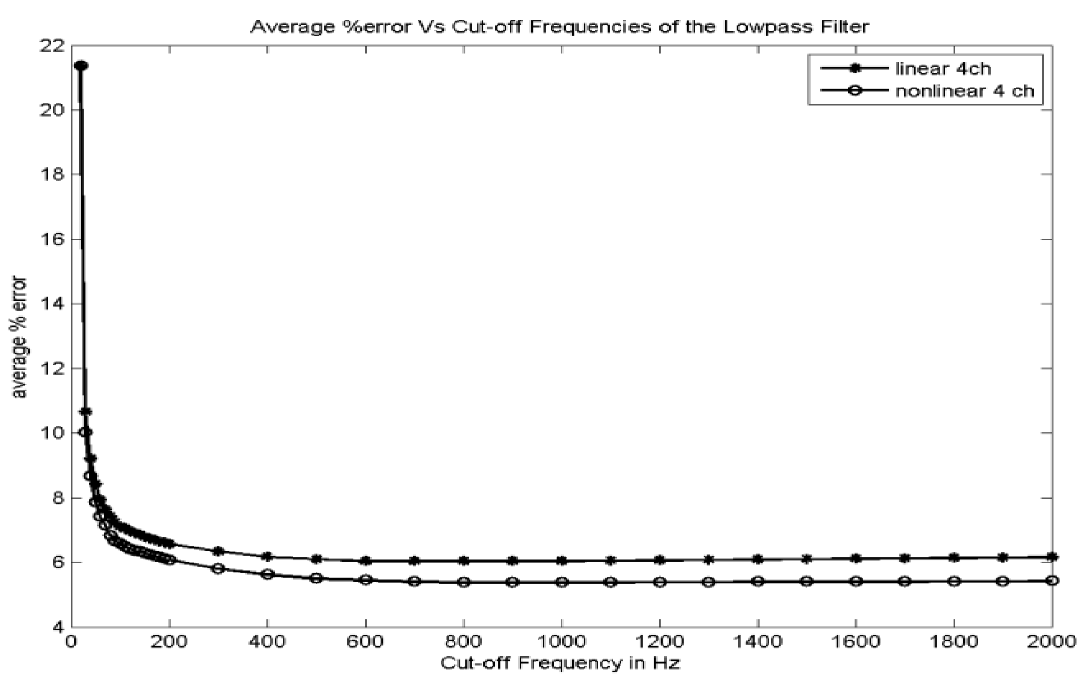

Fig. 1. Plot of average error (percent maximum voluntary flexion contraction) vs. maximum whitening frequency (a.k.a. cut-off frequency) for the linear and non-linear models.