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EMG AMPLITUDE ESTIMATION USING ADAPTIVE WHITENING

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Abstract — **Previous research showed that whitening the surface electromyogram (EMG) can improve EMG amplitude estimation. However, conventional linear-filter whitening fails at low EMG amplitude levels, perhaps due to additive background noise in the measured EMG signal. This paper describes an adaptive whitening technique, effective at low EMG levels, that cascades a non-adaptive whitening filter, an adaptive Wiener filter, and an adaptive gain correction. In experimental studies, subjects used real-time EMG amplitude estimates to track a uniform-density, band-limited random target. With a 0.25 Hz bandwidth target, either adaptive whitening or multi-channel processing reduced the tracking error to roughly half that of using force as the feedback signal. Increases in additive noise level, smoothing window length, and tracking bandwidth diminish the advantages of adaptive whitening.**

I. INTRODUCTION

Surface EMG amplitude is frequently a control input to myoelectric prostheses, a measure of muscular effort, and an input to EMG-to-force models. Whitening the raw EMG greatly improves the subsequent amplitude estimate (e.g., increasing signal-to-noise-ratio by as much as 63%[1]). However, conventional whitening filters perform poorly for contractions less than 10% MVC. Some *ad hoc* techniques for adaptively whitening EMG improved low contraction estimates [2,3]. This paper describes a more structured and effective technique for adaptive EMG whitening.

II. EMG MODEL AND ADAPTIVE WHITENING TECHNIQUE

Consider a single, discretely sampled channel of EMG m_i as a noise-free EMG r_i plus a background measurement noise v_i. Model the EMG as a band-limited, unit-variance random process n_i multiplied by the EMG amplitude s_i, and the noise as a wide-band Gaussian process. Thus, $m_i=s_i n_i+v_i$.

Based on this signal model, we whiten the EMG adaptively in three stages. The first stage is a conventional linear, non-adaptive whitening filter. The estimated spectrum of the noise-free EMG r_i shapes it as high-pass [1]. This stage whitens the noise-free EMG as desired, but unfortunately accentuates the noise. The second stage suppresses the noise with a Wiener filter. The Wiener filter's shape depends on the EMG amplitude, thus making it adaptive. The third stage applies an adaptive gain correction to give the whitened output the same variance as the unwhitened input. An unwhitened EMG amplitude estimate "bootstraps" the adaptive stages. The adaptive whitening filter is calibrated from two, 5-second, constant-angle, constant force contractions.

III. EXPERIMENTAL STUDY

In real-time tests on biceps and triceps EMG (four electrode sites each), subjects produced constant-angle contractions, modulating their EMG amplitude to track a uniformly random target on a screen. The target moved at either 0.25 or 1.0 Hz bandwidth, ranging from 50% flexion to 50% extension effort. Four EMG processors were compared with force feedback: 1) single-channel unwhitened, 2) single-channel whitened, 3) multi-channel unwhitened, and 4) multi-channel whitened. All used a 250 ms, mean-absolute-value smoother.

IV. DISCUSSION AND CONCLUSION

At 0.25 Hz, whitening and multi-channel processing reduced the single-channel unwhitened processor tracking error half way to the force feedback performance (see Table). At 1.00 Hz, all errors were statistically equivalent to the force feedback. The subjects' inability to track fast targets dominated 1.0 Hz errors. Slower tracking bandwidth, noncausal processing, and shorter smoothing windows give additional improvement from whitening.

TABLE: MEAN ± STD. DEV. TRACKING ERRORS (14 SUBJECTS) IN %MAX. EMG (%MVC FOR FORCE FEEDBACK).

EMG Processor	**Random Target**	
	0.25 Hz	**1.00 Hz**
Single-Channel, No Whitening	9.62±3.32	16.62±3.46
Single-Channel, Whitened	6.70±2.38	16.99±4.58
Multi-Channel, No Whitening	7.09±2.09	15.05±4.70
Multi-Channel, Whitened	6.35±2.18	15.07±3.93
Force Feedback	4.35±1.86	15.48±3.21

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