IMPROVING WRIST FORCE ESTIMATION WITH SURFACE EMG DURING ISOMETRIC CONTRACTIONS

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ABSTRACT

In this paper, methods for selecting channels to improve estimated force using fast orthogonal search (FOS) have been investigated, and a new method is proposed. The surface electromyogram (sEMG) signal acquired from linear surface electrode arrays, placed on the long head and short head of biceps brachii, and brachioradialis during isometric contractions are used to estimate force induced at wrist using the FOS algorithm. In this paper, the effects of the sEMG signal characteristics obtained from the arrays and channels' locations on the estimated force are investigated to find channels, resulting in force estimation improvement compared to using all available channels. Several methods for channel selection have been studied, showing that the sensitivity of the estimated force to the location of the channels is subject-dependent. The proposed method uses only the channels with highest mean of power spectrum density (PSD) and low cross correlations. The channels selected by this method have improved FOS force estimate compared to using all the available channels.

INTRODUCTION

An accurate and reliable estimation of muscle force is desired in many applications including design and control of powered prostheses, medical rehabilitation, and sports medicine [1-4]. The force produced by individual muscles cannot be measured directly, but the resultant torque at the corresponding joint can be. Surface EMG (sEMG), the spatial and temporal summation of dispersed action potentials travelling along the muscle fibers, has been widely used to obtain a relationship between muscle electrical activity (represented by the sEMG amplitude) and the generated muscle force.

Many studies have been done to estimate muscle force by mapping a relation between sEMG signals and output force [5-10]. The parametric approaches use Hill's muscle model [11], where muscle activation level is an input to the model, and the generated muscle force is calculated as the output [12]. Nonparametric modeling methods, e.g. using polynomial functions, artificial neural networks, Linear regression, and fast orthogonal search (FOS) are used without requiring any knowledge about muscle and joint dynamics, yet they have the capability of accounting for nonlinearities in the sEMG-force relationship [5-10].

In this study, surface electrode arrays with eight monopolar channels are used to map sEMG, obtained from the elbow flexor muscles during flexion, to the induced force at the wrist using the FOS algorithm. In addition, the best channels in terms of accuracy of the estimated force were found. Also the effect of channel locations and inter-electrode distance (IED) on the force estimate are studied.

METHODS

Four healthy subjects (2 females and 2 males; age 27±3 years) participated in the experiment. Subjects provided informed consent before participating in the experiment. The experiments were conducted using the QARM, a single degree-of-freedom (1-DOF) exoskeleton test bed, described in [12]. The QARM holds the shoulder and wrist in a fixed position to constrain the elbow flexion of the right arm to the horizontal plane while limiting the contribution of the shoulder and forearm muscles to force generation at the wrist. The elbow's axis of rotation is aligned with a pivoting aluminum bar, which can be locked in place for isometric contractions.

The sEMG signals were recorded using three monopolar linear 8 electrode arrays (5 mm spacing) from the elbow flexor muscles; the long head and short head of biceps brachii, and brachioradialis muscles. The fourth electrode of each array was located on the SENIAM sensor location recommendation for the biceps muscles. For the brachioradialis, the fourth electrode was placed at one-third the length of the forearm measured from the elbow. The EMG data were collected using the Bioelecttronica EMG-USB2 high density (HD) system, which sampled the EMG data at 2048 Hz. The experiment was conducted for three force levels, 20, 35 and 50% maximum voluntary contraction (MVC), at 90 degrees elbow joint angle during the isometric elbow flexion. MVC was measured at 90 degrees. The duration of each contraction was 5 seconds. For each subject, the data was collected in one session and three trials. Appropriate rest periods were provided in order to avoid muscle fatigue. Force at the wrist (elbow torque) was measured using an ATI 6-DOF Gamma force/torque sensor with a high stiffness of 9.1 × 106 N/m, sampled at 1000 Hz.

PROCESSING

Bipolar sEMG signals were obtained by subtracting neighboring monopolar signals with 5mm spacing. This resulted in seven bipolar channels. Each bipolar channel was band-pass filtered from 10 to 500 Hz using a 4th-order Butterworth filter. The linear envelope (LE) was obtained by rectifying and smoothing sEMG signals with a 300 point moving average filter to estimate the signal amplitude. Then, the rectified and smoothed sEMG signals were used as an input to the FOS algorithm to estimate wrist force. The FOS method is a time-domain technique for rapid nonlinear system identification that minimizes the mean square error of the estimate compared to the target data [13]. This approach has previously been used to estimate wrist force from sEMG of the upper arm muscles [5-7]. FOS determines each basis function and corresponding coefficient in a single iteration such that in each iteration the basis function with the greatest reduction in the estimation error is chosen, and this process continues until the stopping criteria are met. For instance, if no further candidates are found that improve the MSE or a pre-selected number of basis functions is reached, the process will be stopped [5]. The FOS method is fully described in [5].

RESULTS

In this study, a linear array electrode was used to record sEMG signals, during isometric contractions over three elbow flexor muscles. The recorded data were processed to estimate the force induced at wrist and assess how this estimate can be improved using a fewer number of channels. The wrist force was estimated from the sEMG signal acquired from the elbow flexor muscles using the FOS method. Force modeling was performed using the FOS method for two different channel configurations, seven bipolar channels (using all channels (AC)), and selected channels (SC) configurations. In the first configuration, the FOS was applied to all seven bipolar channels to estimate the generated force. In the SC configuration, three channels were used in the FOS method to predict the induced force at the wrist. For channel selection, the mean of PSD of all the channels were computed and sorted in a descending order. We selected 3 channels from the list as follows. First, we selected the channel with the highest PSD. Then, we keep adding other channels from the sorted list to the selected list if they do not have high correlation with the previously added channels. Force modeling is done for each subject separately. The first trial of the experiment was used for the FOS model training and the next two trials were used for testing the model. The evaluation criterion used in the validation process is the percent-relative-mean-square-error (pRMSE) which has commonly been used in the literature [5-7].

$$pRMSE = \frac{\sum_{n=1}^{N} \left(y(n) - \hat{y}(n)\right)^2}{\sum_{n=1}^{N} y(n)^2} \times 100\,,$$

where $y(n)$ and $\hat{y}(n)$ are the measured and estimated wrist forces, respectively. The pRMSE validation is the average of pRMSE of each trial used in the testing phase.

In order to study the effect of using a subset of the channels on the FOS algorithm accuracy, three channels were selected. As mentioned before, channels were selected based on having a higher mean of PSD compared to others as well as having lower correlation values with other channels. In Figure 1, the PSD of all seven channels for three muscles for one subject are shown. For this subject, the selected channels for each muscle are shown in Table 1. From Figure 1, it is clear that the selected channels have a higher mean of PSD relative to other channels. Also, their correlations were investigated before applying the FOS algorithm.

able 1: Selected channels for one subject.

BR	LHB	SHB
1, 4, 7	1, 4, 6	1, 4, 6

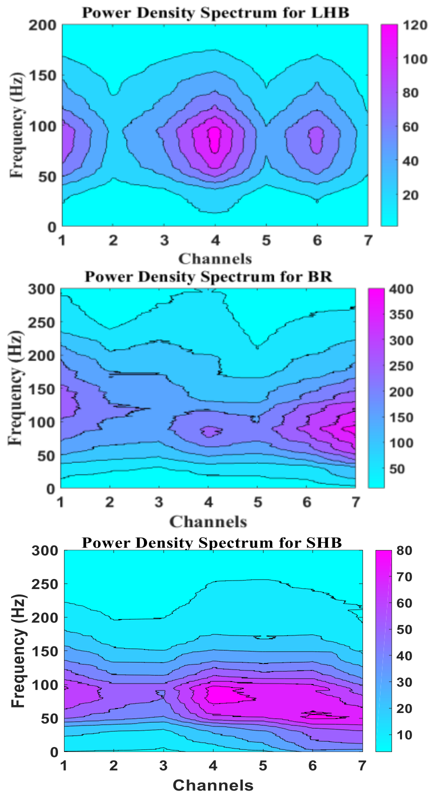

Figure 1: PSD across seven channels for one subject, for three muscles.

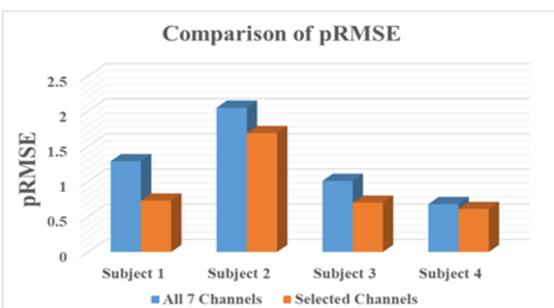

Figure 2: pRMSE comparison of AC and SC configuration.

After the channel selection step, the FOS method was used to estimate wrist force using the sEMG signals. Figure 2 shows the FOS's results using all seven bipolar channels and the selected channels for each subject. It is clear that the pRMSE values improve when the selected channels were used as an input to the FOS model compared to using all bipolar channels in all subjects. This indicates that a certain subset of channels contains higher PSDs and less cross-correlated information that are able to provide better force estimates. This can be beneficial in the HD-EMG recording where the number of channels is usually quite high, require more computational time and effort. Therefore, an appropriate selection method, which leads to better results with fewer channels, is beneficial. The pRMSE values for the two configurations are shown in Table 2.

Table 2: pRMSE across all subjects.

	AC Configuration		SC Configuration	
	Mean	SD	Mean	SD
Subject 1	1.29	0.87	**0.73**	0.41
Subject 2	2.05	1.1	**1.69**	0.035
Subject 3	1.01	0.19	**0.7**	0.048
Subject 4	0.68	0.28	**0.61**	0.14

These results suggest that for all subjects, the force estimate is improved when SC configuration is used along with the FOS algorithm. This means more accurate force estimation can be achieved by using three channels instead of all seven channels.

DISCUSSION

In this study, the recorded data was processed to assess how the wrist force estimate varied with location of channels as well as using selected channels based on the characteristics of the acquired sEMG signal. HD- EMG recording provides an opportunity to look at the effects of recording configuration on sEMG signal and consequently the force estimation. The signal characteristics are affected by the recording configuration [14]. Thus, it is investigated how the wrist force estimation based on sEMG is affected by the channels location and signal's properties acquired from those channels. In this regards, the effect of channels location on the pRMSE of the estimated wrist force is studied. The channels were divided into three categories; first half channels, second half channels, and the first, last and fourth channels (located on SENIAM recommendation place) of the array. Also, the effect of different IEDs on the force estimation was investigated. Three different IEDs were considered, 5 mm, 10 mm, and 15 mm spacing. The results suggest that there was no consistent effect of channels locations, on force estimate accuracy across all subjects.

Table 3 illustrates the results where for two subjects, there were improvements on pRMSE for the channels located on the second half of the array compared to using all bipolar ones, while for the others, there was no improvement compared to the AC configuration. Therefore, the effect of channels' location was subject-dependent, which might be due to the fact that different people's muscles may activate differently at various force levels while performing the same task [15]. Moreover, physical factors such as length or other characteristics of the subjects' muscles may influence the optimal IED for different subjects. Thus, it is hard to find specific muscle locations that can provide better representation of muscle activities and can generalize to different individuals. Because people have different muscles bulk, distribution of motor units, and strategies for muscles contributions when performing similar tasks. In addition, there was no consistent effect of IED on force estimation improvement across these subjects. The results are represented in Table 4.

Table 3: Effect of channel location on the pRMSE.

	First half of the array	Second half of the array	Channels 1, 4, 7
Subject 1	1.3	**0.87**	1.32
Subject 2	2.23	**1.47**	1.66
Subject 3	1.32	1.45	1.05
Subject 4	1.6	1.27	0.93

In this study, HD EMG recording provides an opportunity to determine the effects of recording configuration on sEMG signal, and wrist force estimate. Processing for more subjects is underway. Using fewer channels can be beneficial especially when machine learning algorithms are used for force estimation based on several HD-EMG channels.

Table 4: Effect of IEDs on the pRMSE.

	IED		
	5 mm	10 mm	15 mm
Subject 1	1.29	0.96	0.8
Subject 2	2.05	1.48	2.01
Subject 3	1.01	2.2	1.11
Subject 4	0.68	0.71	1.12

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