Recommended Surface EMG Electrode Position for Wrist Extension and Flexion

Hossein Ghapanchizadeh
Department of Electrical and Electronic Engineering, Faculty of Engineering, UPM Serdang, 43400, Selangor, Malaysia
h.ghapanchizadeh.eng@ieee.org

Siti A.Ahmad
Department of Electrical and Electronic Engineering, Faculty of Engineering, UPM Serdang, 43400, Selangor, Malaysia
sanom@upm.edu.my

Asnor Juraiza Ishak
Department of Electrical and Electronic Engineering, Faculty of Engineering UPM Serdang, 43400, Selangor, Malaysia
asnorji@upm.edu.my

***Abstract*— To obtain a high-quality surface electromyography (EMG) recording, the signal must be acquired as far as possible from the muscle innervation and tendon zone. This study presents a technique to indicate better electrode positions for surface EMG of the upper limb muscles during wrist extension and flexion. Ten volunteers participated in this research. Surface EMG signals were collected from flexor carpi radialis and extensor carpi radialis muscles. Three different electrode positions with 2 cm internal distance between the bipolar electrodes were investigated. The duration of muscle contraction was selected using the mean absolute value method for quantification, and the qualitative signal was observed through visual inspection. The power spectral density and signal-to-noise ratio were applied to compare and select the most feasible electrode position. The optimal signal from the flexor carpi radialis muscles was presented at 90%. The optimal position for the extensor carpi radialis muscles was shown at 90% of the electrode position over the forearm length. The presented method should be observed as an important step in every surface EMG application and research to ensure high quality of the signal.**

***Keywords*—electromyography; electrode position; power spectral density; signal to noise ratio.**

I. INTRODUCTION

Surface electromyography (SEMG) is a technique used to detect and monitor myoelectric signals during muscle contraction [2]. SEMG has been used for many purposes, such as detection of muscle activities [3] and diagnosis of nerve compression or injury [4, 5].

SEMG exhibits an amplitude between 0 and 2 mv (peak-to-peak) or 1.5 mv (rms) with a frequency band of 0–1000 Hz [6]. Various noises affecting SEMG include subcutaneous tissue layers [7], spread of innervation zone (IZ) [7], crosstalk from neighbor muscles [8], electrode size, and location of electrode position [9, 10]. The electrode position can significantly mislead the description of SEMG statistical and spectral factor electrode location and placement, thereby affecting SEMG evaluation [7].

The Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project, which was presented for 22 various muscles, was accorded on the workshop conclusions and the studies conducted by the SENIAM members. However, the SENIAM project does not include forearm muscles for wrist movements, which are used for daily life activities.

References [11, 12] had been published after the SENIAM project and concluded that the IZ and tendon zone (TZ) are unsuitable for electrode placement because the SEMG signals, which were collected from both IZ and TZ, were unstable and unsubstantial when estimated in terms of magnitude; reference [13] also showed that the IZ shifted during activities. Consequently, the recommended electrode site is located between the IZ and TZ to ensure good quality of the signal.

This study investigates the most feasible electrode site to collect high-quality SEMG signals during two daily wrist movements. Wrist extension and flexion have been investigated and a universal method to identify the optimized electrode positions over forearm present for wrist extension and flexion is concluded.

II. METHODOLOGY

A. Data Collection

Ten healthy young men (aged 23 ± 2 years) without neurological and orthopedic injuries participated in this research. The study was explained to all the subjects, and they signed an "Informed Consent" form before data collection. This research was approved by the Universiti Putra Malaysia Ethical Committee.

Before placement of the electrode, the skin was prepared by cleansing with an alcohol pad and shaved (if necessary) to clean the electrode site and increase the impedance between the electrode and skin. Three electrode positions were investigated over flexor carpi radialis (FCR) and extensor carpi radialis (ECR) muscles for wrist flexion and extension.

B. Electrode Position

For each subject, the first electrode site on each considered muscle was selected with 10–20 mm after lateral epicondyle for ECR and the medial epicondyle of the humerus for FCR, which are close to the origin of the muscle and far from the IZ and TZ [14]. The consequent position was selected after the first position, which is based on the image of human physiology (Figure 1) and the references [15, 16], which indicated selection over the belly area and close to the TZ with a center-to-center electrode distance of 20 mm. The reference electrode was placed over the elbow as the bony area.

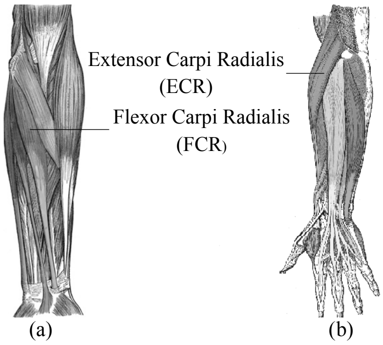

Figure 1. The superficial muscle of forearm [1].
a) Posterior. b) Anterior

Figure 2 presents the electrode position over the ECR. The first position (I) over ECR was selected close to the origin. The second position (II) over ECR was presented in previous studies [17, 18] with recommended distance of 3 cm from the lateral epicondyle to the medial distal epicondyle. The third position (III) was selected 20 mm after the second position and near the TZ.

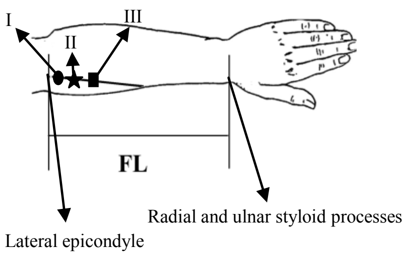

Figure 2. Electrode position of ECR. FL: Forearm length

First electrode site over FCR was selected with 10–20 mm after the medial epicondyle of the humerus. The second position (II) of FCR muscle, was selected between the position of references [15, 16] as position III, and the first position (I). The references [15, 16] recommended 5–7 cm from the distal to the line connecting the bicep tendon and medial epicondyle (Figure 3).

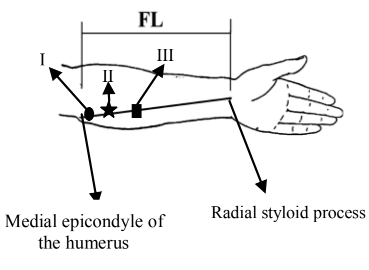

Figure 3. Electrode position of FCR. FL: Forearm length

The forearm length (FL) and the distance between the wrist and electrode sites (center of bipolar electrodes) were measured for each subject. The measurements showed the position of each bipolar electrode to conclude that the electrode site depends on subject FL.

C. SEMG Recording

The SEMG signals of the FCR and ECR muscles were sampled at 4 KHz in a single differential mode for each independent channel via the developed SEMG data acquisition system, which was presented in the reference [17] with adhesive and pre-gelled disposable Ag/AgCl Kendal Meditrace™ EKG circular electrode. The MediTrace™ circular electrode contained an 11 mm conductor with thick foam backing to provide stability and minimize the movement artifacts. Two adhesive electrodes with a center-to-center distance of 20 mm were placed for each position. After electrode placement, the connection wire was fixed using a transparent tape to avoid movement artifact noises.

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After placement of the electrodes, the subject was seated on a chair with an armrest. The SEMG signals were acquired during wrist flexion and extension. The subject was asked to repeat each movement six times with 500 ms for each iteration. LabView V2013 was used to monitor and record the raw SEMG signals, and MatLab V2013a was applied for further signal processing.

D. Signal Processing

The recorded SEMG signal was filtered using fourth-order Butterworth band-pass filter with cutoff frequency of 20–500 Hz. The signal was evaluated qualitatively by visual inspection to select the iteration for further processing. After separate the signal during muscle contraction, to standardization of signal values each signal normalized by equation (1). This method can be used for SEMG normalization to compare different features between electrode positions of same muscle during a task [18].

$$SEMG = x/\max|x| \tag{1}$$

Where x is filtered signal, max present maximum of signal which is the peak of signal and |x| shows absolute value of signal.

To determine the most feasible electrode position, Mean absolute value (MAV), power spectral density (PSD) and signal-to-noise ratio (SNR) were measured from the filtered signals. The criteria of the optimal electrode position included the highest density of signal validated through visual inspection and the values of MAV, PSD, and SNR. Figure 4 present an example of visual inspection during wrist flexion.

The MAV was calculated for each iteration after separated by visual inspection. The MAV is used to calculate the mean of the absolute values for each

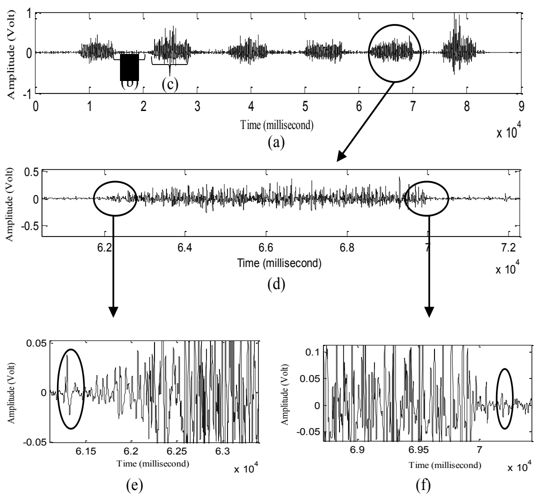

Figure 4. Visual inspection during wrist flection over FCR muscle. a) Six iteration of wrist flexion. b) Rest time. c) Muscle contraction. d) Selected iteration. e) Beginning of muscle contraction. f) End of contraction.

window, which represents each selected iteration. The MAV is calculated as follows:

$$MAV = \frac{1}{N}\sum_{1}^{N}|S(N)_{SEMG}| \qquad (2)$$

Where N is length of the signal (length of the window), and S (N) $_{SEMG}$ shows the SEMG signal within the window (points).

The PSD describes the data variance over the frequency components that show the amount of distributed power of the signal in the frequency band. In other words, PSD present value of spread the density of signal power with frequency. PSD indicates in data by finding frequency peaks according to specific periodicities. The PSD determines the average of the fast Fourier transformer (FFT) of signal magnitude squared during muscle contraction time. To calculate the PSD, the following equation was applied to the signal:

$$PSD_{SEMG} = \frac{1}{N^2}\,\left|\sum_{n=1}^{N} F_{\omega}\right|^2 \qquad (2)$$

Where N is the total time of the measured contraction or length of the signal, and $F\omega$ represents the Fourier transformation of the SEMG signal.

To determine the most feasible electrode position, the amount of noise must be validated. The optimal position should exhibit minimum noise during muscle contraction. Therefore, the SNR was applied to the SEMG signal.

The SNR measures the noise power over the useful signal. The power of SEMG signal was calculated as summation of the all power signal spectrum below 1000 Hz. The power of noise was estimated by any upper 20% of the frequency range to ensuring entire frequencies are above 500 Hz. The noise power was calculated as sum of the all frequency components [19, 20]. This research used the following SNR formula to calculate the noise at all electrode positions:

$$SNR_{dB} = 10\log\left({}^{P_{SEMG}}/_{P_{Noise}}\right) \qquad (3)$$

Where P_{SEMG} is power of the signal FFT, and P_{Noise} shows power of high frequency noise like motion noise.

III. RESULTS AND DISCUSSION

After signal processing, the optimal electrode position of each muscle and the distance between the wrist and electrode sites in each subject were determined.

The values of PSD, MAV and SNR_{dB} presented significant differences among the three electrode positions. The results demonstrated that the electrode positions affected the frequency features and noises of the SEMG signals.

The optimal electrode position of the ECR and FCR muscles in each participant related to FL during wrist extension and flexion was determined. The average of all ten subjects was calculated to express the most feasible electrode position (Table 1). The PSD, MAV and SNR_{dB} were applied to the SEMG signals to determine the optimal electrode position with high value in the frequency domain and low noise.

Table 1. Electrode site details from each subject

	FL	Position		
		I	II	III
Average± Standard deviation	27±1.5	25±1.1	23±1.1	21.5±1.1
Average of Percentage distance between wrist and middle of bipolar electrodes		89	87	78

The PSD and MAV presented the highest value at position I, which is near the muscle origin and far from the TZ same as SNR_{dB}. The PSD value during wrist flexion at the first position is more than the electrode position (I = 0.34 and III = 0.30) recommended by [15, 16]. Figure 5 shows that MAV value of position I has same trade as PSD value. MAV of position I is higher than other position during wrist flexion. The SNR_{dB} showed the highest value at the same position (Table 2). However, the SNR_{dB} value of the other positions are closer to the first position, which indicated accuracy of data acquisition.

Table 2. SNR_{dB} during wrist movement from different electrode position

Movement	Position		
	I	II	III
Extension	66	58	56
Flexion	74	70	66

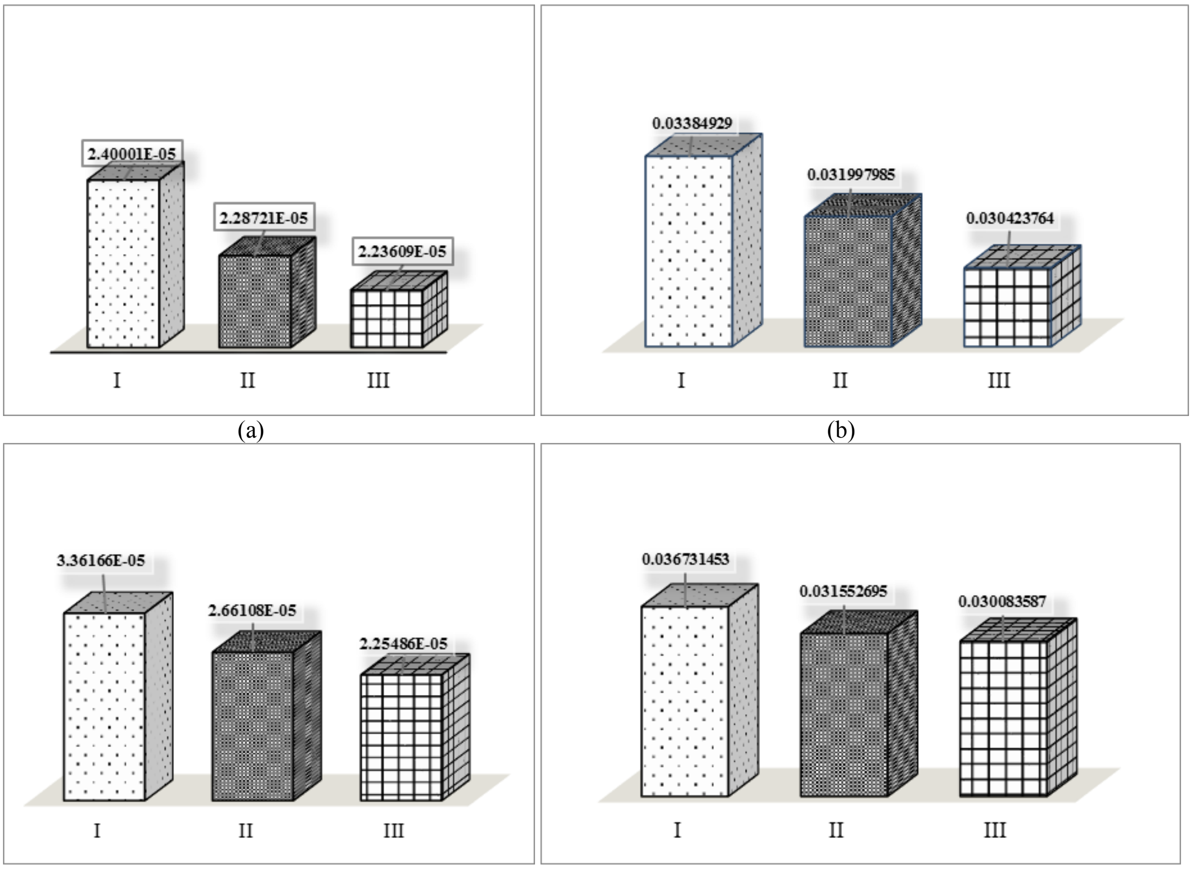

Figure 5. Value of PSD and MAV during wrist movements through three different bipolar electrode position. a) MAV values during wrist extension. b) PSD during wrist extension. c) MAV values during wrist flexion. d) PSD during wrist flexion.

The results showed that the PSD, MAV and SNR_{dB} values significantly increased at the first position over the ECR muscles. Figure 5 shows that the value of PSD and MAV are higher than the two other positions during wrist extension same as SNR_{dB}.

The optimal electrode position of ECR was found at 89% of the FL. The presented electrode position exhibited lower noise and higher MAV and PSD value than that of the position described by Mirecea et al. The most feasible electrode position of ECR is located near the muscle origin before the IZ and far from the TZ.

The optimal electrode position of the FCR was presented at 90% of the distance between the wrist and ulna of FL, which presented the highest values of MAV, PSD and SNR compared with all the other positions. The electrode position of FCR disagreed with the suggested position in the references [15, 16].

IV. CONCLUSION

This study aimsto identify the optimal electrode position to acquire SEMG over the upper limb during wrist movement by using a commercial adhesive electrode. The method was developed on the basis of the muscle origin, IZ, and TZ positions. Following the anatomical structure of muscle–fiber orientation, the FL and the internal electrode distance were both 20 mm. Mapping electrode site to achieve high-quality signals was also investigated. The results show significant differences between the electrode positions based on the qualitative and quantitative criteria.

This study recommends the most feasible position for wrist flexion at 90% of the FL over the FCR and 90% through ECR to achieve highly accurate SEMG signals for wrist extension.

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