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Effect of Surface Electromyography Electrode Position during Wrist Extension and Flexion Based on Time and Frequency Domain Analyses

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ABSTRACT

Surface electromyography (SEMG) is a technique used to detect and monitor muscle contraction during movements. SEMG signals carry important information about muscle behavior. SEMG has been used in many areas, such as in controlling SEMG-based robots and detecting muscle activities and exoskeletons. However, the complex nature of SEMG signals makes their application difficult. This study primarily investigates the effect of electrode placement or displacement on signal features using time and frequency domain analyses. Moreover, this study presents the effect of electrode position on mean absolute value, root mean square, and power spectra density during wrist extension and flexion. The SEMG signal is recorded from the extensor carpi radialis and flexor carpi radialis. Increasing the inter-electrode distance (IED) from 2 cm to 4 cm improves signal features during movement. Results also show that significant differences exist between various electrode positions in time and frequency domains and that different IEDs affect signal quality.

Keywords: surface electromyography, electrode position, mean absolute value, root mean square, power spectra density.

1. INTRODUCTION

Surface electromyography (SEMG) signals measure electrical activities in target muscles, and they can be acquired in two ways: through an invasive method using needle electrodes and through a noninvasive method using surface electrodes, which is called surface EMG (SEMG)[1-3]. SEMG is an important and useful tool for controlling certain types of robots, such as rehabilitation robots and prostheses[4, 5]. New approaches to SEMG data collection could improve the quality of detected signals, especially in the control of SEMG-based devices and in clinical practice. Electrode placement is the main stage for collecting SEMG signals with maximum useful information from target muscles. Hence, investigating the effect of electrode position on signal features may enhance outcomes based on SEMG signals. EMG signal analysis can vary depending on the recording method used. The consideration of SEMG characteristics, in particular, has been increasingly studied in recent years[6-9]. The amplitude of SEMG signal is random and the range is 0-10mV and the frequency band is 20-500Hz both are varying in each muscle [10]. Therefore, SEMG signal analysis depends on target muscles.

A raw recorded SEMG signal exhibits a complicated and quasi-random form. It contains important information and noisy information, the use of which can be difficult. SEMG signals can be presented in

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terms of time and frequency domains. The time domain is typically used as a real-time controller, measure of muscle force production, monitor number, and size and firing rate of motor units. By contrast, the frequency domain shows information on the number, size, and firing rate of active muscle fibers, as well as indicates muscle fatigue. During the collection of an SEMG signal from a muscle, the depth of the muscle, thickness of the subcutaneous tissues, innervation zone (IZ), tendon zone (TZ), and position of electrodes affect the description of time and frequency features[10]. Therefore, electrode placement plays a significant role in SEMG signal description.

Mean absolute value (MAV), root mean square (RMS), and power spectrum density (PSD) are the most common and well-known methods used by Moon et al.[11], Firoozabadi et al. [12], Ang et al. [13], Gibert et al. [14], and Jahani et al. [15].In the present study, we present the effects of electrode placement/ displacement on signal features, such as MAV, RMS, and PSD. The results reported in this paper are part of an ongoing research effort to develop guidelines for simplifying electrode placement. The objective of this research is to evaluate commonly applied SEMG feature signals and thereby assess the quality of electrode placement. The appropriateness of this study is also examined by comparing the effects of different electrode placements over time and frequency domains.

2. METHODOLOGY

The convenience sample comprised 20 individuals (males and females; age, 28 ± 5 years; fore arm length, 27 ± 2 cm). The exclusion criteria were neurological and orthopedic injuries. This experimental procedure was approved by the Universiti Putra Malaysia Ethics Committee.

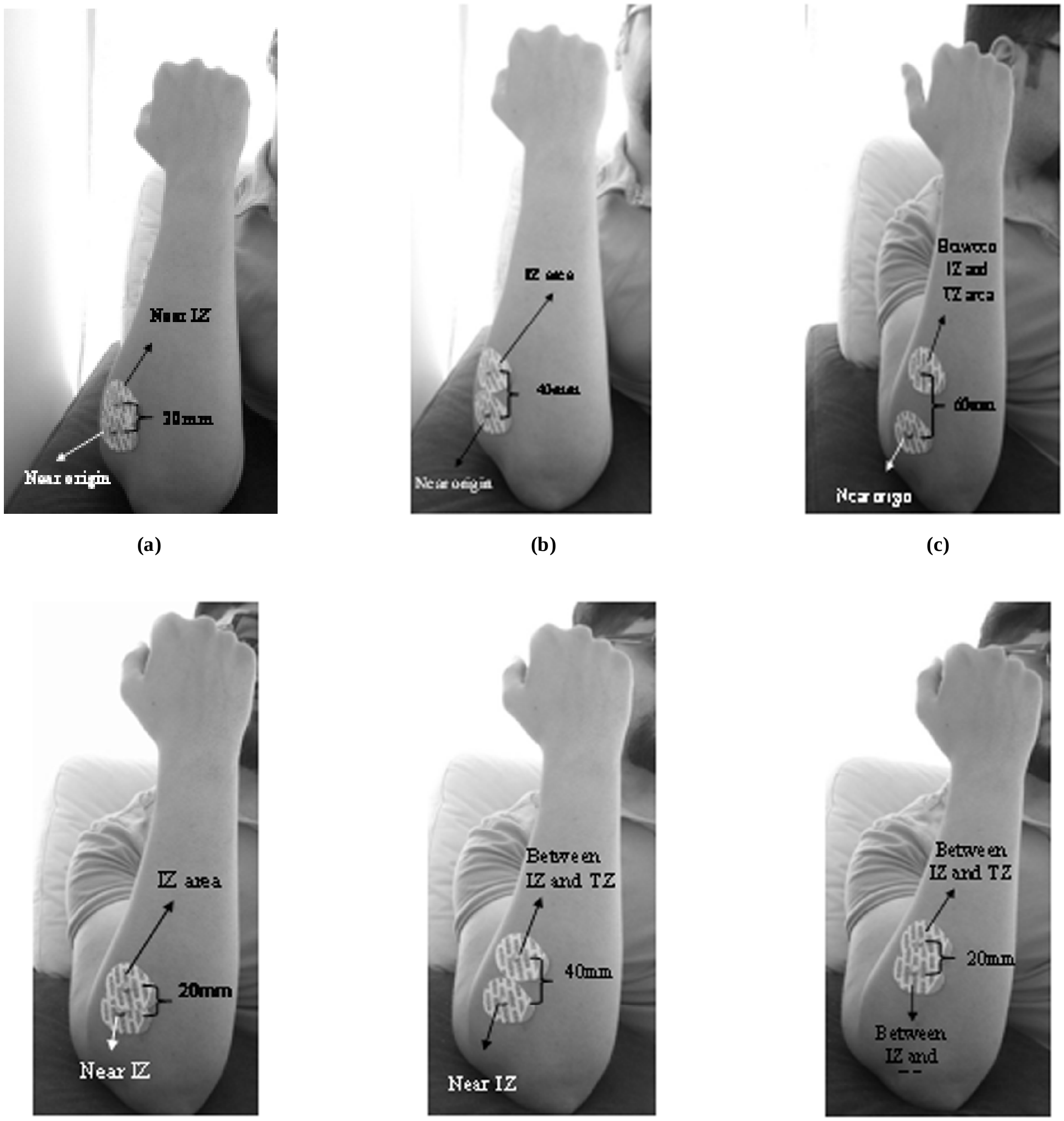
2.1. Data collection

The first step was to place the electrode over the target muscles. The landmark used in this study was based on the methods of Fagarasanu et al., Gray et al., and Barbero et al. [16-18]. After finding and marking the extensor carpi radialis (ECR) and flexor carpi radialis (FCR) muscles, three electrode positions and three different inter-electrode distances (IEDs) were investigated. Table 1 presents the details of the electrode positions and various IEDs.

Skin preparation was initiated first as an important step in SEMG signal acquisition. To obtain good signal quality and decrease the impedance between the skin and the electrodes, the skin was cleaned using an alcohol pad[19]. Shaving the skin (if hair was present) also helped decrease the noise and impedance between the electrodes and the skin [20]. Adhesive (Ag/AgCl) electrodes were used to record the SEMG signal in bipolar mode. After finding and marking the muscles, we placed two Ag/AgCl Kendall™ adhesive snap electrodes (Medi-Tracewith 10 mm contact) over each muscle. Figure 1 shows the electrode placements over the ECR muscle for each electrode position.

Table 1
Details of electrode placement over ECR and FCR muscle

Electrode place	*Position*
I	Near origin (IED = 2 cm)
II	Near origin (IED = 4 cm)
III	Near origin (IED = 6 cm)
IV	Near IZ (IED = 2 cm)
V	Near IZ (IED = 4 cm)
VI	Near TZ (IED = 2 cm)



(a) (b) (c)

(d) (e) (f)

Figure 1: Electrode position and IED over ECR muscle.
a) Position I. b) Position II. c) Position III. d) Position IV. e) Position V. f) Position VI.

Muscle contraction comes in two different types: isometric and isotonic contraction. Isometric contraction occurs when the muscle produces pressure without joint movement, such as when carrying or pushing objects. Although muscle fibers fireduring isometric contraction, no changes occur in muscle length or joint motion. Nevertheless, isotonic contraction leads to changesin muscle length and consequently causes joint movement. This type of contraction is the most important in daily hand movements. Two important daily wrist movements were examined in this study. The focus was directed tothe following two isotonic contractions:

- Wrist flexion: The palm is moved to the frontal aspect of the forearm (Figure 2 (a)).
- Wrist extension: Wrist extension occurs when the palm moves to the rearward position of the forearm (Figure 2 (b)).

(a) (b)

Figure 2: Hand movements. a) Wrist flexion. b) Wrist extension

The SEMG signal was recorded using a low-cost and portable multichannel surface EMG acquisition system, which was set with a 1,000 × amplification gain and a 15–500 Hz band pass filter. After connecting the electrodes to the system, each participant was instructed to sit on a chair with an armrest and perform wrist movements for one second.

Any signal acquired from any place can be damaged with noise. Hence, filtering raw signals is necessary before applying signal processing methods. The digital band pass filter was applied in this study. According to the literature, a Butterworth filter with a cut-off frequency of 20–500 Hz and an order of 4 is suitable for SEMG [21, 22].

2.2. Signal Analysis

2.2.1. Pre-processing

After filtering, the muscle contraction time was determined via visual inspection. According to the literature, visual inspection can be employed to ensure that the onset of SEMG is not obscured by artifact movement[23]. After signal separation during muscle contraction, each separated signal was normalized using Equation 1. This method can be used for SEMG normalization to compare different signal features between electrode positions[24].

$$SEMG = \frac{X}{\max|x|} \tag{1}$$

Where x is the filtered signal, *max*is the present maximum of the signal or the peak of the signal, and $|x|$ is the absolute value of the signal.

2.2.2. Signal Processing

RMS is one of the most important parameters used to describe signals during muscle contraction. RMS is obtained by calculating the root of the square sum of all samples and raising it to the power of two.

$$RMS = \sqrt{\frac{1}{N}\sum_1^N x^2} \tag{2}$$

Here, N is the total duration of muscle contraction, and x is the present SEMG signal amplitude.

The MAV equation is one of the most common techniques used in SEMG signal processing. The MAV is the average of the absolute values of an SEMG signal during muscle contraction.

$$MAV = \frac{1}{N}\sum_1^N |x| \tag{3}$$

Here, N is the total duration of muscle contraction, and x denotes the SEMG signal amplitude.

PSD calculates the summation of the FFT averages of signal magnitude squared during muscle contraction. To calculate PSD, the following equation was applied to the signal in this study:

$$PSD = \left| \sum_{n=1}^{N} \frac{1}{N} F_{\omega} \right|^2 \tag{4}$$

Where N is the total time of the measured contraction and $F\omega$ is the Fourier transform of the signal.

2.3. Statistical Analysis

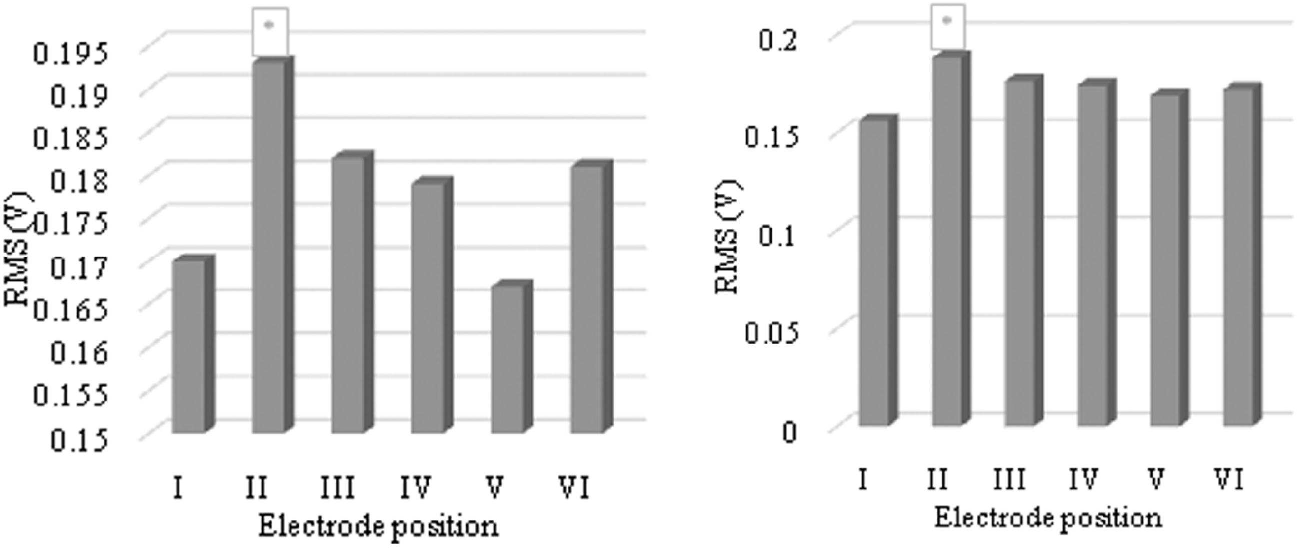
The results were statistically analyzed to show the significant differences between signal features through different electrode placements. ANOVA is a statistical operator that shows whether any significant differences occur between the averages of independent groups. In this study, each electrode position was considered one independent group. One-way ANOVA, followed by a least significant difference post-hoc test, was performed, and the values of $p \leq 0.05$ were considered statistically significant[25].

3. RESULTS AND DISCUSSION

Figure 3 illustrates that the RMS value can vary with different IEDs and electrode positions over target muscles during wrist movement. The post-hoc ANOVA shows that Position II is significantly different from Positions I and V. Position I features a 2 cm IED and is near the muscle origin, whereas Position V features a 4 cm IED and electrodes placed between the IZ and the TZ. Therefore, the RMS value shows sensitivity to electrode position and IED.

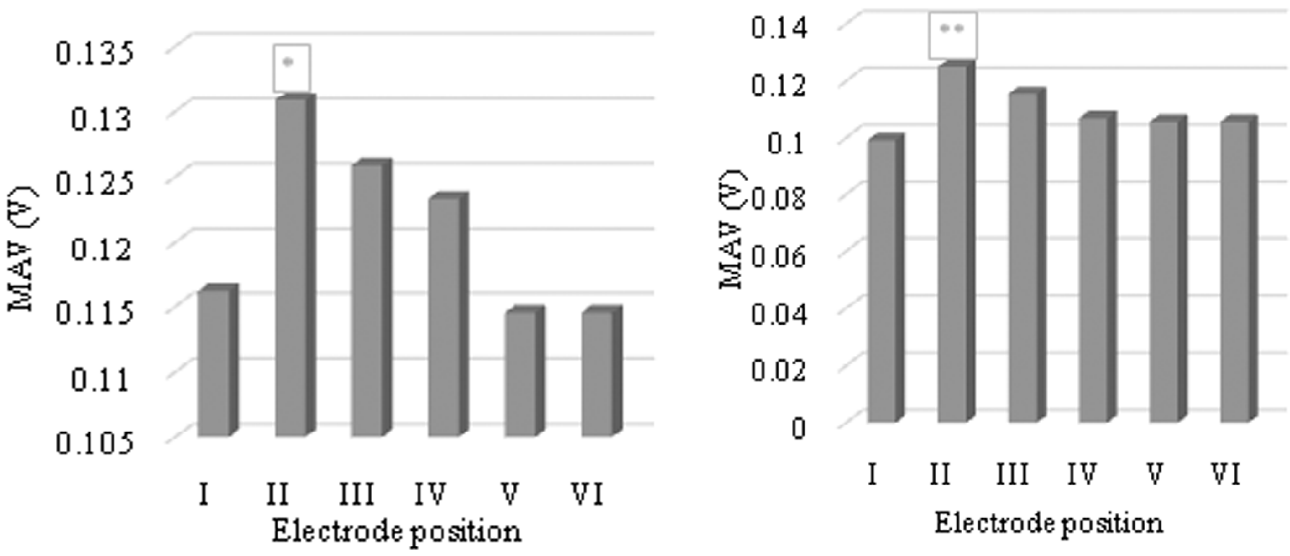
The results reveal significant MAV differences between Position II and Positions I, V, and VI ($p \leq 0.05$) during wrist extension, as well as different significance levels during wrist flexion (Figure 4). The MAV changeswith different electrode positions and IEDs during wrist movement. Figure 4 shows that the MAV significantly depends on electrode position and IED.

Figure 5 shows the maximum PSD with a significant difference level achieved in Position II, which features the same IED asPosition V. Moreover, the results indicate that PSD depends on electrode position and IED.



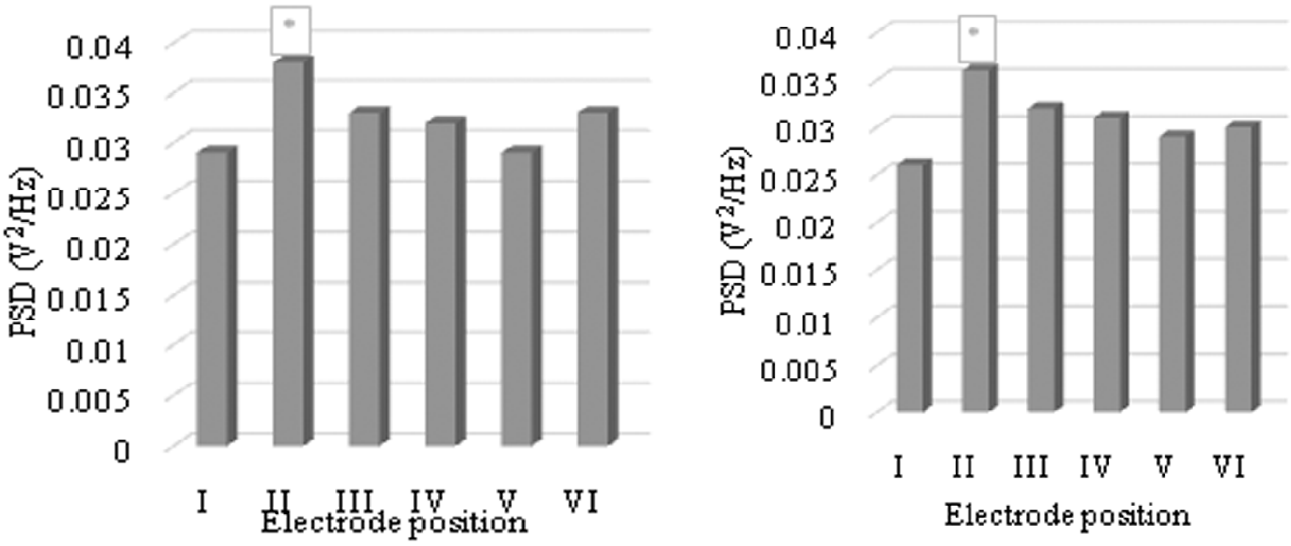
(a) (b)

Figure 3: RMS value during wrist movements.
a) RMS value during wrist extension from ECR muscle. b) RMS value during wrist flexion from FCR muscle
*** Post-hoc ANOVA shows the position II has significant difference with position I and V ($p \leq 0.05$).**



(a) (b)

Figure 4:MAV value during wrist movements.
a) MAV during wrist extension from ECR muscle. b) MAV value during wrist flexion from FCR muscle.
*** Post-hoc ANOVA shows the position II has significant difference with position I, V and VI ($p \leq 0.05$).**
**** Post-hoc ANOVA shows the position II has significant difference with position I, II, IV, V and VI ($p \leq 0.05$).**



(a) (b)

Figure 5:PSD value during wrist movements.
a) PSD value during wrist extension from ECR muscle. b) PSD value during wrist flexion from FCR muscle
*** Post-hoc ANOVA shows the position II has significant difference with position I and V ($p \leq 0.05$).**

Collecting data in different electrode positions can change signal features in both time (MAV and RMS) and frequency (PSD) domains. Our statistical analysis showsthat various electrode placementsresult in significant differencesin the MAV, RMS, and PSD. Furthermore, the MAV presentsa different significance level in comparison with that for all positions during wrist extension and flexion when electrodes are placed near the IZ and origin muscle. RMS depends on electrode position and PSD. The frequency feature (PSD) presentsdifferent values over different electrode positions. The MAVs also significantly differ inPositions I, V, and VI during wrist extension and inPositions I, II, IV, V, and VI ($p \leq 0.05$). Hence, the MAVs are more effective than RMS and PSD values.

4. CONCLUSION

This study shows the differences between signal features in time and frequency domains during wrist extension and flexion over different electrode positions. Time and frequency features are dependent on electrode position. These results should be applicable toSEMG-based controlled robotics and other SEMG pattern recognition systems.

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