Effects of Window Size and Contraction Types on the Stationarity of Biceps Brachii Muscle EMG Signals

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ABSTRACT

In order to analyze surface electromyography (EMG) signals, it is necessary to use techniques based on time (temporal) domain or frequency (spectral) domain. However, these techniques are based on the mathematical assumption of signal stationarity. On the other hand, EMG signal stationarity varies depending on analysis window size and contraction types. So in this paper, a suitable window size for an analysis of EMG during static and dynamic contractions was investigated using a stationarity test, the modified reverse arrangement test. More than 90% of the signals measured during static contraction can be considered as stationary signals for all window sizes. On average, a window size of 375 ms provides the most stationary information, 94.29% of EMG signals for static muscle contraction. For dynamic muscle contraction, the percentage of stationary signals decreased as the window size was increased. If the threshold of 80% stationarity was set to validate stationarity for each window size, a suitable window size should be 250 ms or lesser. For a real-time application that a size of analysis window plus processing time should be less than 300 ms, a window size of 250 ms is suggested for both contraction types.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *evaluation/methodology*; I.5.4 [**Patter Recognition**]: Applications – *signal processing.*

General Terms

Algorithms, Measurement, Performance, Experimentation, Human Factors, Verification.

Keywords

Electromyography signal, Feature extraction, Muscle computer interface, Myoelectric control systems, Reverse Arrangement test.

1. INTRODUCTION

Electromyography (EMG) signals are represent neuromuscular activity, which can be used to express movement intent for assistive device control and to detect abnormalities for ergonomic assessment or neuromuscular diagnosis [1, 2]. The analysis of EMG signals is usually performed based on either time (temporal) domain or frequency (spectral) domain [1]. However, these techniques are based on the mathematical assumption of signal stationarity [2]. In general, EMG during static (isometric) contraction is assumed as a stationary signal whereas EMG during dynamic contraction is a nonstationary signal [3]. A signal is stationary when the mean value, variance, and frequency content of the signal do not change over time.

Instead of test for signal stationarity, many previous works often presumed that EMG is stationary over the short-time interval [4]. On the other hand, in previous works on EMG stationarity test, conflicting results have been found which vary depending on experimental conditions, e.g. load, window size and contraction types [5]. So in this study, the effects of analysis window size and contraction types on the stationarity of EMG recorded from biceps brachii muscle were investigated at various load conditions using the modified reverse arrangement (MRA) test, a general non-parametric stationarity test [6]. The MRA test has widely used in assessing stationarity of EMG and other biomedical signals [3, 5, 7, 8].

2. MATERIALS AND METHODS

2.1 Data Acquisition and Experiments

EMG signals were collected from biceps brachii muscle using bipolar Ag/AgCl electrodes (H124SG, Kendal ARBO) and a common ground was placed on the wrist using an Ag/AgCl electrode (2237, 3M). All EMG signals were recorded by an EMG acquisition device (Mobi6-6b, TMS International BV) with a gain of 19.5x and a sampling rate of 1024 Hz. Movement artifacts (< 20 Hz) and high frequency noises (> 500 Hz) were removed using a band-pass equiripple FIR filter.

Six subjects participated in the experiments, 3 females (SJ1-SJ3, 21.0 years) and 3 males (SJ4-SJ6, 20.7 years). In present study, the subjects performed two experiments. In the first experiment (static contraction), the subjects were asked to perform five static levels of contraction by lifting the required mass (i.e., 1, 2, 3, 4, and 5 kg) at 90˚ of elbow flexion, as shown in Fig. 1(a). After the subject arm position was stable, as shown in Fig. 1(b), EMG data was recorded for 5 s (a trial). In the second experiment (dynamic contraction), the subjects were asked to perform an elbow flexion-extension task in duration of 5 s. Note that a full extension is shown in Fig. 1(c) at 0˚ and a full flexion is shown in Fig. 1(d) at 150˚. For both experiments, all subjects performed 5 trials per day for 4 separate days. In total, 100 (5 loads × 5 trials × 4 days) trial-sets were collected for each subject per contraction type.

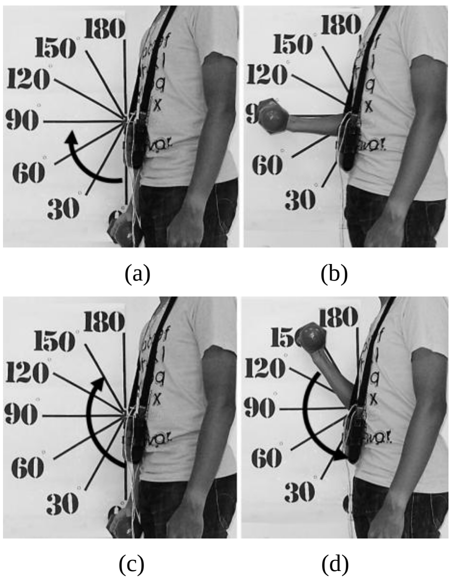

Figure 1. Apparatus used to apply 5 loads (a) lifting a load to a target angle (b) maintaining a load at 90˚ (c) performing elbow flexion from 0˚ to 150˚ (d) performing elbow extension from 150˚ to 0˚.

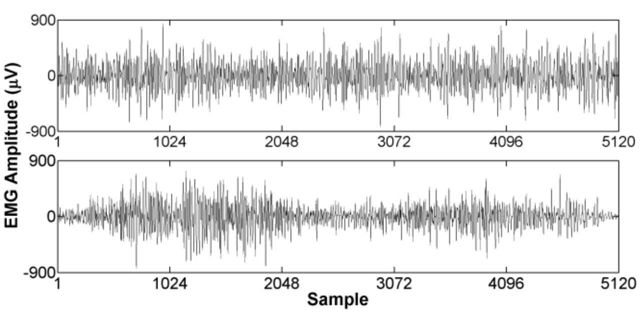

Figure 2. EMG signals acquired from biceps brachii muscle during (top) static contraction and (bottom) dynamic contraction in time domain from one trial (5 s in duration).

2.2 Stationarity test

There are many tests in the literature that can be used to test stationarity of the interested signal. Among the reported tests, the MRA test has shown the better performance than other tests, such as the run test [9, 10] and the reverse arrangement (RA) test [3, 5]. Although there has been much research on the stationarity of the EMG signals, no researches have been conducted to examine all factors (i.e., load, analysis window size, and contraction types) that influence the signal stationarity level (i.e., the conflicting results in literature).

Each EMG trial-set was firstly segmented by one of the six window sizes including 128, 256, 384, 512, 768, and 1024 samples (125, 250, 375, 500, 750, and 1000 ms) using an adjacent windowing technique [1]. Secondly, the MRA test was applied to test the stationarity of each EMG segment. The procedures of the MRA test [6] in which some parts are modified for this study is as follows:

1) The segment is divided into N equal, adjacent intervals by a sub-segment size of 32 samples.

2) For each sub-segment, the mean square value y_i (i = 1, 2, 3, …, N) is calculated.

3) The number of reverse arrangements (A) in the sequence $\{y_1, y_2, y_3, ..., y_N\}$ are counted when $y_i > y_j$ for $i < j$. In other words, A is the number of times that the value of the first data point y_1 in the segment is higher than each subsequent data point value, y_2, y_3, ..., y_N, and then this process is repeated for y_2, y_3, ..., y_{N-1}.

4) The test statistic z is calculated using the following equation:

$$z = \frac{A - \left[\dfrac{N(N-1)}{4}\right]}{\sqrt{\dfrac{2N^3 + 3N^2 - 5N}{72}}} \ . \tag{1}$$

5) The null hypothesis for this test is that the mean square value y_i is random that means the EMG signal is stationary. The null hypothesis is rejected at the significance level of 0.05 when the absolute value of the test statistic z is less than 1.96. So the EMG signal is classified as stationary or nonstationary for each trial-set.

6) For each window size and subject, the percent of the stationary signals is calculated using the following equation:

$$\text{\% of stationary signals} = \frac{N_z}{N_T} \times 100$$

where N_z is the number of segments which the absolute value of the z-score less than 1.96 and N_T is the total number of segments.

3. RESULTS AND DISCUSSION

EMG signals measured from the biceps brachii muscle are shown in Fig. 2 according to the static (top row) and dynamic (bottom row) contractions. The top row figure shows that although the subject was asked to maintain a constant load at a specific angle (i.e., an external load remains constant and there are no changes in muscle length [11]), the EMG amplitudes show some fluctuation. However, the fluctuation of static contraction EMG amplitudes is lower than dynamic contraction EMG amplitudes, as can be seen from the figure.

3.1 Static contraction vs window size

For the static muscle contraction, the stationarity level of the EMG signals is relatively low when the window size is small or large, as can be seen in Fig. 3. The peak of the EMG stationarity level is found at the 384- and/or 512-samples window depending on the subject. The relationship can seem like an inverse V-shape, which is consistent with the relationship found in Cho and Kim

[5]. On average, the 375-ms/384-samples window yields slightly higher stationarity level than other window sizes (94.29% of the signals). However, for all window sizes, more than 90% of the signals measured during static contraction can be considered as stationary signals. So it is possible to analyze the EMG signals using techniques in time domain and frequency domain for window sizes up to 1024 samples (1 s). Although the EMG amplitude and frequency information change over long time, the EMG signal can still be considered as a stationary signal if no significant change in muscle length or joint angle was found.

In the literature, the different sizes of stationary signal window have been found on the biceps brachii muscle, for example, 500 ms (500 samples at a sampling frequency of 1000 Hz) using the run test [2], 60-1000 ms (60-1000 samples at a sampling frequency of 1000 Hz) [12] and 512 ms (1024 samples at a sampling frequency of 2000 Hz) [4] using the graphic observation and the quantitative analysis of statistical properties' variation.

3.2 Dynamic contraction vs window size

The non-stationary of EMG signals measured during dynamic contraction can be affected by changes in muscle length, muscle force, and electrode location [13, 14]. For the dynamic muscle contraction, the percentage of stationary signals decreased as the window size was increased, as shown in Fig. 4. Because changes in muscle length and electrode position at the small window size is less than changes in muscle length and electrode position at the large window size.

If the threshold of 80% stationarity was set to validate stationarity for each window size, a suitable window size should be 250-ms/256-samples or lesser. It means that it is possible to analyze the EMG signals during dynamic contraction, which is more common in activities of daily living and has been widely used for myoelectric control systems such as prosthetic devices and muscle computer interfaces [1, 15, 16], using techniques in time domain and frequency domain for window sizes up to about 256 samples (250 ms).

In the literature, the window sizes used for stationary EMG signal recorded from the biceps brachii muscle are 250-1000 ms using the run and RA tests (250-1000 samples at a sampling frequency of 1000 Hz) [17], 167 ms (167 samples at a sampling frequency of 1000 Hz) using the run test [18]. Cho and Kim [5] mentioned that the possible reasons of the conflicting results found in the literature may be due to the difference muscle anatomy, testing method, and the window size selection.

3.3 Feature extraction vs window size

This finding may answer the results reported in Lorrain et al. [16] that the performance of simple time domain features in classifying the nine wrist-finger-and-forearm motions (static and dynamic contractions) is comparable to more complex classification methods of time-scale features, e.g. short-time Fourier transform, wavelet transform, and wavelet packet transform [19]. Because in the study the EMG data are segmented in windows of 128 samples (125 ms), which EMG can be considered as the stationary signals. To realize a real-time application, moreover, a size of analysis window plus processing time should be less than 300 ms [19]. Hence, a window size of 250 ms is suggested due to a compromise between feature bias (in short window sizes), and real-time constraints and signal stationarity (in long window sizes), and can be used for both contraction types as can be observed in Fig. 5. Note that at the same window size, the level of stationarity in the test of static contraction EMG signals is always lower higher than the level of stationarity in the test of dynamic contraction EMG signals.

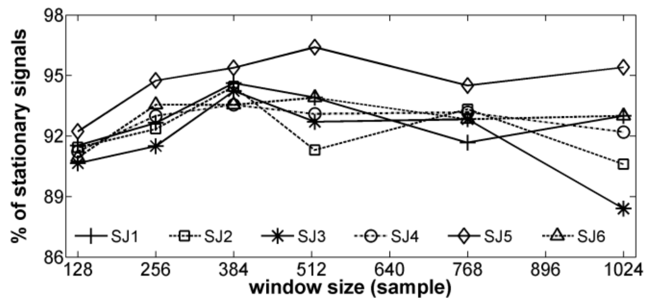

Figure 3. Percent of the stationary signals obtained from the MRA test when testing on static contraction EMG at various window size conditions for each subject.

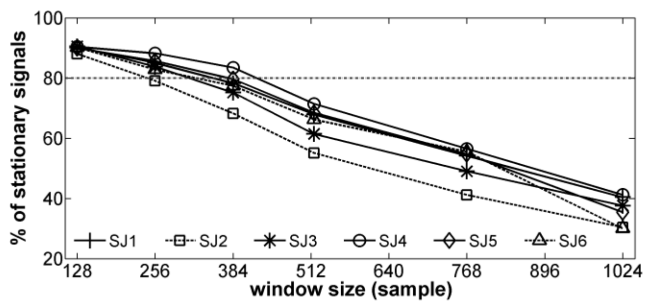

Figure 4. Percent of the stationary signals obtained from the MRA test when testing on dynamic contraction EMG at various window size conditions for each subject.

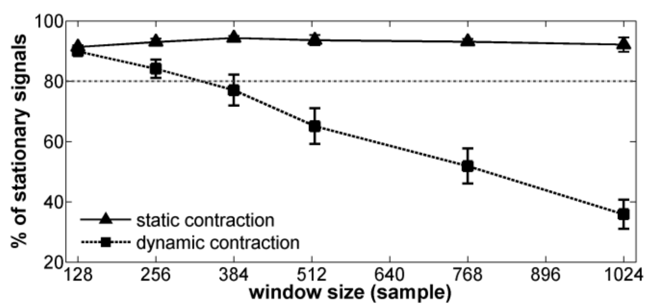

Figure 5. Average percent of the stationary signals obtained from the MRA test when testing on static and dynamic contractions EMG at various window size conditions.

4. CONCLUSIONS, LIMITATIONS, AND FUTURE WORKS

This paper presents the effects of window size and contraction types on the stationarity of surface EMG signals. To demonstrate the stationarity of EMG signal in the analysis of the EMG signals during static and dynamic contractions, the suitable window size are 375 ms and 125 ms, respectively. To compromise between feature bias and real-time constraints, on average a suitable window size for the analysis of both contraction types should be 250 ms. The results in this paper are evaluated based on only one muscle located on the upper arm during one-to-five kg load lifting conditions. The suitable window size may change when the EMG signals were recorded from other muscles and load conditions. Further, in case of the classifying motions that provide both contraction types together (e.g. dynamic contraction at the beginning and the ending of movement and static contraction at the middle of movement), the EMG signals may be stationary up to more than 250 ms.

Although in the literature the MRA test have shown a better performance than the other tests, i.e., the run and the RA tests, Chau et al. [8] suggested that the MRA test can detect non-stationarity due to time-varying mean or variance but cannot detect stationarity due to dynamic frequency content. So in future works, a new test which can detect all factors in both time and frequency information should be proposed.

5. ACKNOWLEDGMENTS

This work is funded in part by the Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0155/2554), by the FI MSTIC University Joseph Fourier Grenoble 1 (TIGRE project), and by NECTEC-PSU Center of Excellence for Rehabilitation Engineering, Faculty of Engineering, Prince of Songkla University.

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