Discrete Wavelet Transform Approach on the Electromyography Signal Processing during Rehabilitation Exercise

Nuradebah Burhan¹, Mohammad ‘Afif Kasno²*, Rozaimi Ghazali¹, Mohd Hafiz Jali¹, Md Radzai Said³
Faculty of Electrical Engineering¹, Faculty of Engineering Technology², Faculty of Mechanical Engineering³,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
nuradebah@gmail.com, mohammad.afif@utem.edu.my, rozaimi.ghazali@utem.edu.my

Abstract—Electromyography (EMG) signal analysis is one of the important approaches to evaluate muscle performance during rehabilitation exercise. However, the signal is highly non-linear in nature that required appropriate method to extract the accurate feature. This paper presents EMG signal feature extraction analysis using wavelet transform (WT) approach for resistance band rehabilitation. In this experimental work, three healthy subjects (age: 25±2.5 years and BMI: 23.5±2.0) were selected in this study. Each of the subject needs to perform dynamic contraction with lifting and lowering the resistance band for three different levels of the arm movement which are 30°, 90°, and 150°. Surface EMG electrodes were placed on the middle (belly) biceps brachii muscle to record the raw EMG signal. Recorded EMG signal was processed for feature extraction in signal processing in order to remove noise and extract the useful information in the signal. Regarding that, LabVIEW WA Detrend VI and Wavelet Denoise have been utilized in this study. Two common techniques of the EMG analysis, which are root mean square (RMS) and mean absolute value (MAV) were used to compare with the WT approach. The result shows that the EMG signal in WT approach has less variability in the EMG signal analysis as compared to the RMS and MAV that obtained through raw EMG signals.

Index Term—Electromyography, Wavelet Transform, Rehabilitation

I. INTRODUCTION

Rehabilitation is a healthcare therapy that widely uses for improving, maintaining and restoring physical strength, especially people after illness, injury or surgery. Rehabilitation consists of two parts which are post-surgery and gymnasmum. Post-surgery is a part to determine the ability and muscle strength of patients after surgery by using Principle of Manual Muscle Testing (MMT) and they need to perform several exercises with light resistance or weight [1]. After that, the patient will be transferred to the gymnasmum to perform rehabilitation exercise with the medium to heavy resistance or weight in order to gain their muscle strength.

According to that, electromyography (EMG) measurement is used to help analyze the signal transmitted from the desired muscle [2]. EMG is the specific measurement and analysis of muscle activity in biomedical techniques that concerned about the recording, analysis, and development of myoelectric. The myoelectric signals are referred to as the EMG signals where it is formed by small electrical currents, which is controlled by the central nervous system (CNS) that consists of α-motoneurons. Then, it stimulus transmission of nerve (axons) and reaches the motor endplates to all muscle fibers. The electrical signal that originates from the muscle fiber activation of a motor unit that is detected by using electrodes. There are two types of the electrodes can be used to detect the electrical activity in the muscle, which are surface EMG (non-invasive) and needles EMG (invasive) methods.

The surface EMG (sEMG) is one of the chosen method to record the muscle activity of the biceps brachii muscle. Mostly, researchers utilized sEMG electrodes is more convenience and suitability to apply since it can be applied without any medical certificate [3]. The detection process of the EMG signals is easily affected by various factors and types of noise such as muscle anatomy and the physiological process, and inherent noise that acquired from the hardware part that consists of amplification and digitization of the signal. Thus, it is very challenging to eliminate the noise from recorded EMG signal efficiently. Most of the common noise in EMG signal is produced from electrical noise which are inherent in the electronic equipment, ambient noise that is known as electromagnetic noise which acquired from the human body, motion artifact produced by the movement of the cable and interface of the power source, and crosstalk that produced from neighbouring muscle [4]–[7]. It shows that the sEMG method is easily influenced by environmental factors, especially during the collecting sEMG signal such as represented in Fig. 1 where the unfiltered signal is called a raw EMG signal.

![Image](Fig. 1. The illustrate of the raw EMG signal recording)
Based on Figure 1, the noise-free EMG baseline can be seen in the rest period which is when the biceps brachii muscle relaxed. De Luca et al. had mentioned the baseline noise is then formed by the combination of two noise sources which are extrinsic noise sources and intrinsic noise sources [8]. It can be detected whenever a sensor or electrode is attached to the skin. The averaged baseline noise is in a range 3 – 5 microvolts, the typically baseline noise started from 1 to 2 microvolts will be the target. Therefore, it needs to perform preprocessing and feature extraction in order to eliminate the baseline noise and unwanted parts in the sEMG signal [9].

The feature extraction method consists of three possible of techniques can be applied which are time domain (TD) features, frequency domain (FD) features, and time-frequency domain (TFD) features. Several authors described the application in biomedicine, radar, multimedia, and industry are a non-stationary signal that preferred to deal with TFD technique in the signal analysis since this method can provide signal information in both time and frequency domain [10]. In previous work, it is presented that the sEMG signal have both features in TD and FD techniques, the sEMG will be considered as a stationary which is in TD feature when the muscle contraction under constant force applied and in the meantime, the sEMG also contain various frequency components [11]. The TFD techniques can be classified into three methods which are short-time Fourier Transform (STFT), Wavelet Transform (WT), and Wavelet Packet Transform (WPT) [12, 13]. This study will be focused on the WT method in feature extraction for acquired the best features that represent raw EMG signal in time-scale. Biceps brachii muscle will be evaluated for rehabilitation exercise in order to analyze the acquired EMG signals.

II. METHODOLOGY

Three male healthy and right arm dominant subjects with normal body mass index (BMI) participated in this study. All the subjects had been informed earlier in order to avoid strenuous exercise two days prior to the measurements, and they must free from any muscular disease particularly on biceps muscles. The physical characteristic of the subjects in this study can be seen in Table I.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Male Subjects (n = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.5 ± 2.5</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70 ± 5.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170.4 ± 7.4</td>
</tr>
<tr>
<td>Body Mass Index (kg/height)</td>
<td>23.5 ± 2.0</td>
</tr>
</tbody>
</table>

In the present experiment, a wireless Z03 EMG preamplifier with the ground for surface recording, Motion Lab Systems, Inc. (Baton Rouge, LA, USA) was used to detect and record the biceps brachii muscle activity. The EMG preamplifier is a compact device with dimension 38mm x 19mm x 8mm that provides two contact sensors dimension of 12 mm disks with inter-electrode distance 18mm, and one reference contact (12 x 3 mm) bar separating the sensors. The type of contact material was used in the experiment is medical grade stainless steel. The EMG pre-amplifier have contained gain at 1kHz x 300±1%, CMMRR >100dB at 65Hz, input protection from radio frequency interference (RFI) filters and electrostatic discharge (ESD), and the power supply range of this device is between ±5Volts to ±15Volts. The raw EMG signal was recorded at a sampling frequency 1000Hz.

There are some protocol need to be followed before the experiment begin where the subjects is required to warm-up by performing three sets of dynamic contraction with lifting and lowering the weight. The subjects were allowed to take rest for minimum 2 minutes between each contraction to avoid the possibility of metabolic fatigue in the muscle. Recommended by Surface Electromyography for non-invasive Assessment of Muscles (SENIAM), it is necessary to perform skin preparation and electrode placement procedure. Each subject needs to clear the desired skin from any hair and exfoliating, then the skin will be cleaned with 70% Isopropyl Alcohol [14]. The preferred location of the electrode placement of the biceps brachii muscle is on the line between the medial acromion and the fossa cubit at 1/3 from the false cubit (the middle of the biceps brachii muscle) [15].

EMG data were collected from each subject within 3 days. Each subject needs to stand up straight and perform three levels of the arm movement where, when the arm was in angle position at 30°, 90°, and 150°. During the tests, the subjects need to hold the resistance band load for 10 seconds and there was a 2 minutes break between each biceps brachii muscle contraction to avoid any muscle fatigue during the tests. The load of the resistance band was used for each subject is 16kg. Fig. 2 shows the position of the arm level was conducted in these tests.

In the experimental setup, the wireless EMG preamplifier device was used for supplying the input signal to an NI USB-6009 data acquisition (DAQ) device from National Instruments. The signal acquired from the DAQ device will be as a signal source for LabVIEW 2016 model. Subsequently, the recorded EMG signal serves as input to the LabVIEW WA
Detrend VI and LabVIEW Wavelet Denoise Signal to remove the maximum extent of noise in order to restore the original signals.

### A. Discrete Wavelet Detrend Function

The LabVIEW WA Detrend VI was used to remove the baseline wandering by using wavelet transform approach which is an effective way to eliminate signals within specific subbands. In this work, WA Detrend VI in LabVIEW software was including threshold frequency and type of wavelet that will be applied. Threshold frequency is to determine the wavelet transform level and it had been set 0.3Hz as an upper-frequency limit to removes from the signal. The threshold frequency can be determined by the following equation.

$$\text{Threshold frequency} = \left[ \frac{\log_2 2t}{\log_2 N} \right]$$

where t is the sampling duration and N is the sampling points.

For detrending, a signal, discrete wavelet transform (DWT) was applied to the input for performing low-pass and high-pass filtered at each level to produce wavelet transform [1]. Figure 3 shows the DWT decomposition steps. There consist of two types of filters which are a low-pass filter ($G_0$ and $H_0$) and high-pass filter ($G_1$ and $H_1$).

![Fig. 3. The DWT decomposition steps](image)

The DWT reconstructed signal from the DWT approximation coefficient with the inverse DWT. The inverse DWT can be implemented with restoring the original signal with upsampling by a factor of 2 as illustrated in Figure 4. In our setup, the LabVIEW WA Detrend VI filtration of the signal is not only calculated by using DWT but, including the Daubechies2 (db2) wavelet algorithm.

![Fig. 4. The DWT reconstruction steps](image)

Regarding the Figure 3, an input signal that known as $s[i]$ will pass through ($G_0$ and $G_1$) and then downsampled by a factor of 2. The applying downsampled by a factor of 2 is to ensure that the low-pass filter output is same as the equals original input samples $s[i]$. Thus, there are no unnecessary information was added while the decomposition. The low-pass filters will remove the high-frequency signals and keep remain the slow trend while the high-pass filters will keep remain the high-frequency signals and remove the slow trend. The output of the low-pass filters provide an approximation of the signal and the high-pass filters provide the detail information about the signal. The symbol A and D in the figure 3 and figure 4 are represent the approximation and detail information of the signal, respectively. This process will be repeated until it achieved the desired number of levels.

### B. Discrete Wavelet Denoise Function

After detrending signal, the EMG signals acquired will pass through in wavelet-based denoising signal. In LabVIEW Wavelet Denoise Signal, there are many factors must be considered such as selection of mother wavelet, the number of the decomposition levels, threshold selection parameters, and rescaling function. Various families wavelet is provided in LabVIEW Wavelet Denoise Signal including Daubechies, Coiflet, Symlet, Biorthogonal, and Haar. The selection of the wavelet must be considered in order to acquire perfect reconstruction signal after decomposition signal. In wavelet basis function, the db4 Daubechies Wavelet and 10th decomposition level had been chosen in this work. Basically, the most common methods of thresholding signal had been used in the denoising signal are hard thresholding and soft thresholding. The two thresholding method can be defined as equation 2 and 3 below where T signifies the threshold and x denote wavelet coefficient.

**Hard thresholding:**
$$x_H = \begin{cases} x & \text{if } |x| > T \\ 0 & \text{if } |x| \leq T \end{cases}$$

**Soft thresholding:**
$$x_S = \begin{cases} \text{sgn}(x)|x| - T, & \text{if } |x| > T \\ 0 & \text{if } |x| \leq T \end{cases}$$

According to the both equations above, clarify that the hard thresholding coefficient above the threshold value are left unaffected and soft thresholding the magnitudes of the coefficients above the threshold decrease by an amount is same to the threshold value. Even though the hard thresholding shows that it is the simplest method, the soft thresholding was found better and outperformed the hard thresholding [17].

There are four principal rules to calculate threshold selection in wavelet as shown in Table 2 [18, 19]. The sqtwolog (Universal) that known as the fixed method is the first rule in thresholding method. The second threshold selection rule is Stein’s unbiased estimate of risk (SURE). This method uses the highest number of coefficients in the reconstruction process and it might lose too much of noise in the signal. The third rule is heursure (Hybrid) method which
The EMG analysis results from three male subjects with the same load performed for three different angles of the arm level in this study, which are 30°, 90°, and 150° and it can be shown in Table 3, Table 4 and Table 5. In the following tables presented the data recorded for raw EMG signal and data after denoising EMG signal.

Table II

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigsure</td>
<td>Adaptive threshold selection using the principle of Stein’s Unbiased Risk Estimate.</td>
</tr>
<tr>
<td>Sqtwolog</td>
<td>Fixed form threshold is equal to the square root of times the logarithm of the length of the signal $\sqrt{2 \log(\text{length}(X))}$.</td>
</tr>
<tr>
<td>Heusure</td>
<td>Selection using a mixture of the first and second rules.</td>
</tr>
<tr>
<td>Minimaxi</td>
<td>Threshold selection using the minimax thresholding principle.</td>
</tr>
</tbody>
</table>

Then, the last important part in denoising signal is to select a threshold rescaling function. In LabVIEW Wavelet Denoise Signal, three types of algorithms are available: one indicates that basic white noise, single level, which indicates the white noise, and multiple levels indicates noise model with non-white noise algorithm. The values of the detail from d1 to d10 are not within the rescaling threshold range will be removed from the signal. There is no rescaling range for the one (basic white noise) where it will be removed all the signals. The single level is rescaling using single estimation of level noise from the wavelet coefficients of the first level. The multiple levels rescaling at each level independently, which the threshold range is too low and it might delete the information signal. The comparison of three methods in rescaling threshold function can be represented in Fig. 3. The result of the comparison shows that the single level (white noise) was chosen as best method that can be used in threshold rescaling function because the threshold range used was standard for removing the signal.

The EMG signal analysis is based on the root mean square (RMS), mean absolute value (MAV), standard deviation (SD), variance (VAR), and the maximum value (MAX). According to that, MATLAB software was used as a medium to perform the statistical analysis. RMS can be acquired by calculating the mean value of the square of all the EMG signal values and divide it by the length of the vector N and then root all the values. The formula for RMS can be defined as below.

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^{N} x_i^2}$$  \hspace{1cm} (4)

Then, the mean absolute value is the summation of the all absolute value and then the values will be divided by the length of the vector N. It can be defined as the MAV formula below.

$$MAV = \frac{1}{x} \sum_{i=1}^{x} |x_i|$$  \hspace{1cm} (5)
As can be observed from the tables, features (MAX, SD, VAR, RMS, and MAV) was analyzed for raw signal and wavelet-based denoising signal. Results of the features, analysis show the denoising signal to have less VAR and SD. The low SD signifies that more data align with the mean and the low VAR shows less variability and more accuracy in the EMG signal analysis. Daubechies4 (db4) wavelet was chosen in the wavelet-based denoising signal because its more effective analysis in EMG signals compared with other Daubechies wavelet where it might be able loss useful information in EMG signal. The wavelet-based denoising signal not only depends on the chosen type of the wavelet, but also considered about the types of threshold as well. The Daubechies4 (db4) with soft heursure threshold method was used as the greatest eliminating noise from the EMG signal. It can be seen as the Figures below:

![Wavelet-based denoising signal for arm level angle 30 degree](image)

**Fig. 4.** Wavelet-based denoising signal for arm level angle 30 degree

![Wavelet-based denoising signal for arm level angle 90 degree](image)

**Fig. 5.** Wavelet-based denoising signal for arm level angle 90 degree

![Wavelet-based denoising signal for arm level angle 150 degree](image)

**Fig. 6.** Wavelet-based denoising signal for arm level angle 150 degree

IV. CONCLUSION

The selection of a wavelet-based function in detrending and denoising signal are one of the most precious aspects must be considered in the process. In this study, the best wavelet detrending parameters of EMG signal in order to remove baseline signal are Daubechies2 (db2) wavelet and threshold frequency is 0.3 Hz. Consequently, the best denoising parameters in filtration the noises affect the arm EMG signal are found when the Daubechies4 (db4) wavelet, the decomposition level at 10th, threshold selection rule and the algorithm is Heursure (Hybrid), and the rescaling threshold function is single level (white noise). The results presented are suitable useable because the data acquired were compared with the same EMG measurement technique. The results obtained for RMS and MAV after performing wavelet-based on detrend and denoising technique shows there are having slight differences compared with RMS and MAV at the raw EMG signal. In the previous research work were present and analyze the MAV feature of EMG signals in the feature extraction part. The results show that MAV feature have a better performance of the ratio between Euclidean Distance (ED) and Standard Deviation (SD) that known as RES index after using Daubechies wavelet techniques [21]. Thus, the finding of this study is presented that WT approach is more accurate and precise measurements in EMG signal. Most of the researchers attempts to study and analyze the muscle strength of the biceps brachii muscle based on the different gender and resistance load [22]–[27]. None of them have analyze the muscle strength of the biceps brachii muscle for three different arm level angle in the resistance band rehabilitation exercise. Thus, this study taking an approach to the evaluation of the biceps brachii muscle during the resistance band rehabilitation exercise in order to analyze the EMG signals based on the WT method as the EMG feature extraction technique.

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