The Utility of Wavelet Transform in Surface Electromyography Feature Extraction - A Comparative Study of Different Mother Wavelets

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Abstract—Electromyography (EMG) signal processing has been investigated remarkably regarding various applications such as in rehabilitation systems. Specifically, wavelet transform has served as a powerful technique to scrutinize EMG signals since wavelet transform is consistent with the nature of EMG as a non-stationary signal. In this paper, the efficiency of wavelet transform in surface EMG feature extraction is investigated from four levels of wavelet decomposition and a comparative study between different mother wavelets had been done. To recognize the best function and level of wavelet analysis, two evaluation criteria, scatter plot and RES index are recruited. Hereupon, four wavelet families, namely, Daubechies, Coiflets, Symlets and Biorthogonal are studied in wavelet decomposition stage. Consequently, the results show that only features from first and second level of wavelet decomposition yields good performance and some functions of various wavelet families can lead to an improvement in separability class of different hand movements.

Keywords—Electromyography signal, feature extraction, wavelet transform, means absolute value.

I. INTRODUCTION

ELECTROMYOGRAPHY (EMG), also referred to as the myoelectric (MSE), is a biomedical signal acquired from skeletal muscles.

Skeletal muscles are attached to the bone responsible for the movements of our body [1], and hence, recording and studying of EMG signal have fascinated many researchers to date. Since EMG reflects the anatomical and physiological characteristics of the muscle [2], it contains complicated properties. Therefore, interpreting EMG signal requires powerful techniques consistent with the non-stationary essence of EMG signal. To record EMG signal, two techniques are utilized, namely, Surface EMG (SEMG) and

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needle EMG. Although applying both mentioned techniques result in same records but SEMG is more popular. Compared to needle EMG, SEMG is a non-invasive technique and more convenient to use [3]. EMG has been called a multidisciplinary signal because there are many widespread applications for it in different fields such as electronics, medicine, anatomy, physiology, physical therapy, ergonomics and so forth [3]. Consequently, accurate analysis and scrutinizing of EMG signal has been greatly valued and have brought an improvement in the EMG control system in recent years [4], [5].

In this regard, Wavelet Transform (WT) has been used as a strong technique to extract the significant information of EMG signal and support the classification performance of EMG recognition system because the best classifiers do not perform well if they are not fed with proper features. Analyzing EMG signal by wavelet analysis comprised some advantages that other techniques lacked. The most important benefit of applying wavelet is the capability of providing time and frequency information of the signal simultaneously [6]. Although some other techniques such as Short Time Fourier Transform (STFT), Wigner-Ville distribution and Cho-William distribution had been used to study MSE but WT yielded a better accuracy and precision [7]. In addition, investigating EMG signal in time-frequency domain outperformed the EMG analysis in time domain [8] because in time domain, EMG is assumed a stationary signal and the non-stationary characteristics of EMG is ignored. In the other hand, applying frequency domain as the study space caused missing time information of the signal while using wavelet analysis provides a good resolution of time-frequency domain. Apart from all these subjects, WT has been known as a flexible approach for signal decomposition since various wavelet functions can be chosen as Mother Wavelet (MW) to analyze the signal. Moreover, wavelet analysis offers the facility of creating a desired MW for researchers according to their needs and wants. A multi-wavelet function was created by Khezri and Jahed [9] for SEMG processing to recognize different hand postures. The multitude MW of this study had been completed by evaluating the functionality of various wavelet families, such as Daubechies, Coiflets, Symlests and Biorthogonal. In spite the fact that there is not any defined rule

to choose MW, the similarity between signal and MW can play a significant role to find the proper wavelet function. In another hand, selecting MW based on the problem statement of research and the application is considerable too. In a recent study [10], different wavelet functions had been utilized to investigate SEMG for understanding muscle fatigue during walk. Accordingly, Daubechies45 was recognized as the best MW to determine the muscle fatigue. In another pattern classification for EMG feature extraction [11], different levels of various MW were used to find the useful resolution components. Finally, noise and unwanted parts of the EMG signal was reduced by selecting suitable MW and the signal was reconstructed based on effective EMG parts. In this research, seventh order of Daubechies family obtained the best performance.

In our study, the usefulness of WT in SEMG feature extraction through effective MW is investigated. Hence, Mean Absolute Value (MAV) of signal is designated as SEMG feature and two evaluation criteria, namely, scatter plot and RES index [12] are recruited to evaluate the results of SEMG feature extraction. It is worth mentioning many orders of different MW such as Daubechies, Coiflets, Symlets and Biorthogonal are used through multilevel wavelet decomposition and the performances of the members of these families are compared to each other. Ultimately, the improvement of class separabilty is illustrated in feature space of SEMG signal by scatter plots and RES values using suitable wavelet function.

II. SEMG SIGNAL ACQUISITION

The SEMG dataset applied in this research was collected by the University of Southampton in United Kingdom [13]. The dataset consists of four movements related to three hand postures, flexion/extension, co-contraction and isometric. In other words, the dataset includes wrist flexion/extension, finger flexion/extension, co-contraction and isometric. The whole data set was recorded through the participation of eighteen subjects, 10 men and 8 women between 20 and 30 years old. The SEMG signals were sampled at 1500 Hz applying a Noraxon 2400T in conjunction with Noraxon Myoresearch XP Master.

III. SEMG SIGNAL PREPROCESSING

There have been different techniques to preprocess EMG signal before feature extraction but windowing technique is usually applied as the current method [4] shown in Fig. 1-2. Data windowing technique includes two major methods: adjacent windowing and overlapped windowing. In this study, all the raw SEMG data were preprocessed using adjacent windowing.
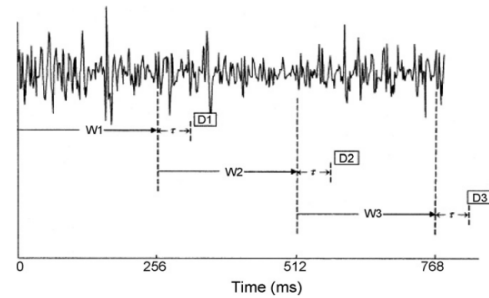

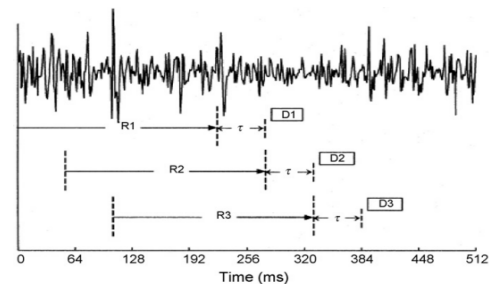
Fig. 1 Adjacent windowing technique [4]

Fig. 2 Overlapped windowing technique [4]

IV. WAVELET DECOMPOSITION AND FEATURE EXTRACTION

Wavelet transform is a proper tool for biomedical signal processing because wavelets can process signals that are non-stationary and time varying in nature. Wavelet, as the child of digital age consists of applied mathematical expression [14] yielding multi resolution analysis as an outstanding property. Accessing the hidden information in the heart of EMG signal is possible by the means of wavelet analysis because WT decompose signals into different scales. Hence, reaching different frequency components of the signal and the information of the time simultaneously is probable.

Furthermore, wavelet decomposition can be done in two forms: pyramid, known as WT and packet, known as Wavelet Packet Transform (WPT). In WT, the signal is divided into approximation and detail in first level. Afterwards, only approximation is decomposed into another approximation and detail and this trend is continued in the next levels while using WPT requires decomposing the signal into approximation and detail in first level and then breaking every approximation and detail into another two parts takes place in every level. For that reason, WT is realized by a low pass filter bank but WPT is implemented by a basic two-channel filter bank [15].
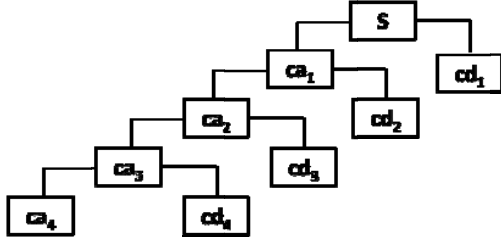
Fig. 3 Wavelet transform decomposition tree in four levels

In this study, WT has been used to extract features considering the simplicity and less calculation. WPT generates huge amount of data which requires more time and energy consumption for analysis. The SEMG signal is decomposed after preprocessing stage to provide approximation and detail coefficients subset in four levels because four levels decomposition represented better performance than other levels in some literatures such as [16], [17]. To find the optimal wavelet function, 36 wavelet functions in various families, Daubechies (db1-10), Coiflets (coif1-5), Symlets (sym2-8) and Biorthogonal (bior1.3-6.8) have been used. After obtaining the wavelet coefficients (cD1-cD4, cA4), the procedure of extracting features begins with the MAV calculation of coefficients for the whole subjects of data set. Subsequently, the features are scrutinized based on a statistical measurement method which is defined by the ratio of a Euclidean distance to a standard deviation, RES index shown in (1), (2) and (3) and scatter plot [11]. Scatter plot played the role of a quality estimator in this study and could support the performance of RES index. The whole procedure of SEMG feature extraction of this paper is demonstrated in the form of a block diagram in Fig. 4. As it is demonstrated in this diagram, the best features produced by best mother wavelets are selected after the feature evaluation stage through applying two mentioned evaluation criteria.

$$\text{RES index} = \frac{\overline{ED}}{\overline{\sigma}} \qquad (1)$$

$$\overline{ED} = \frac{2}{K(K-1)} \sum_{p=1}^{k-1} \sum_{q=p+1}^{K} \sqrt{(\bar{x}_1^p - \bar{x}_1^q)^2 + (\bar{x}_2^p - \bar{x}_2^q)^2} \qquad (2)$$

$$\bar{\sigma} = \frac{1}{IK} \sum_{i=1}^{I} \sum_{k=1}^{K} S_i^k \qquad (3)$$

In (2), $\overline{ED}$ is the distance between coordinates of a pair of clusters p and q in n-dimensional Euclidean space. In our case study, p and q are movements number (wrist flexion/extension=1, finger flexion/extension=2, co-contraction=3, isometric=4) and K is the number of total movements that equals to four. Also, the formula of the dispersion of clusters p and q known as $\bar{\sigma}$ is shown in (3).
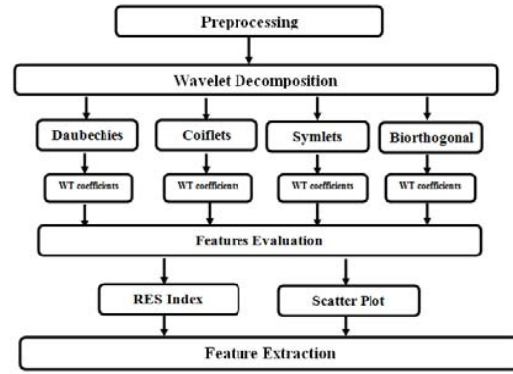

Fig.4 The procedures of SEMG feature extraction from wavelet coefficients using different MW

V. RESULT AND DISCUSSION

In the very first step of SEMG processing, MAV features are calculated for the raw signal without using any preprocessing method. Afterward, the scatter of features is plotted for the raw signal. Comparing to the similar research using MAV features for EMG feature extraction [11], our raw signals seem much contaminated with noise as shown in Fig. 5(a). Therefore, preprocessing stage is really needed to reduce the noise of signal. Fortunately, adjacent windowing responds the need of noise reduction noticeably in our study and makes data well prepared for feature extraction.

In the next stage, the entire data set of EMG signals is decomposed by WT applying 36 wavelet functions of four wavelet families in four levels as mentioned in details in last section. The values of RES index and scatter plots have been obtained in all cases. The information about this procedure in the fourth order of Daubechies (db4) is illustrated in Fig.5(b-f) during four level decomposition. The most significant common result for these entire mother wavelets was that the WT decomposition coefficient subsets of level one and two represent the best quality of separation in the various hand movements. As it is obvious, the separability of four hand posture classes are very good in cd1 and cd2 Fig.5 (b-c). Nevertheless, the distance between movement classes is such short in level three and four, (cd3, cd4 and ca4) Fig. 5(d-f) that much overlapping is appeared between movements. To sum up, the separation quality of hand movement classes decreases in feature space parallel to wavelet decomposition level increasing in this study. The reduction of RES index values in higher levels confirms the behavior of scatter plots too. As a result, it is concluded that only EMG decomposition coefficients (cd1 and cd2) are reliable enough to reconstruct the EMG signal from their features.
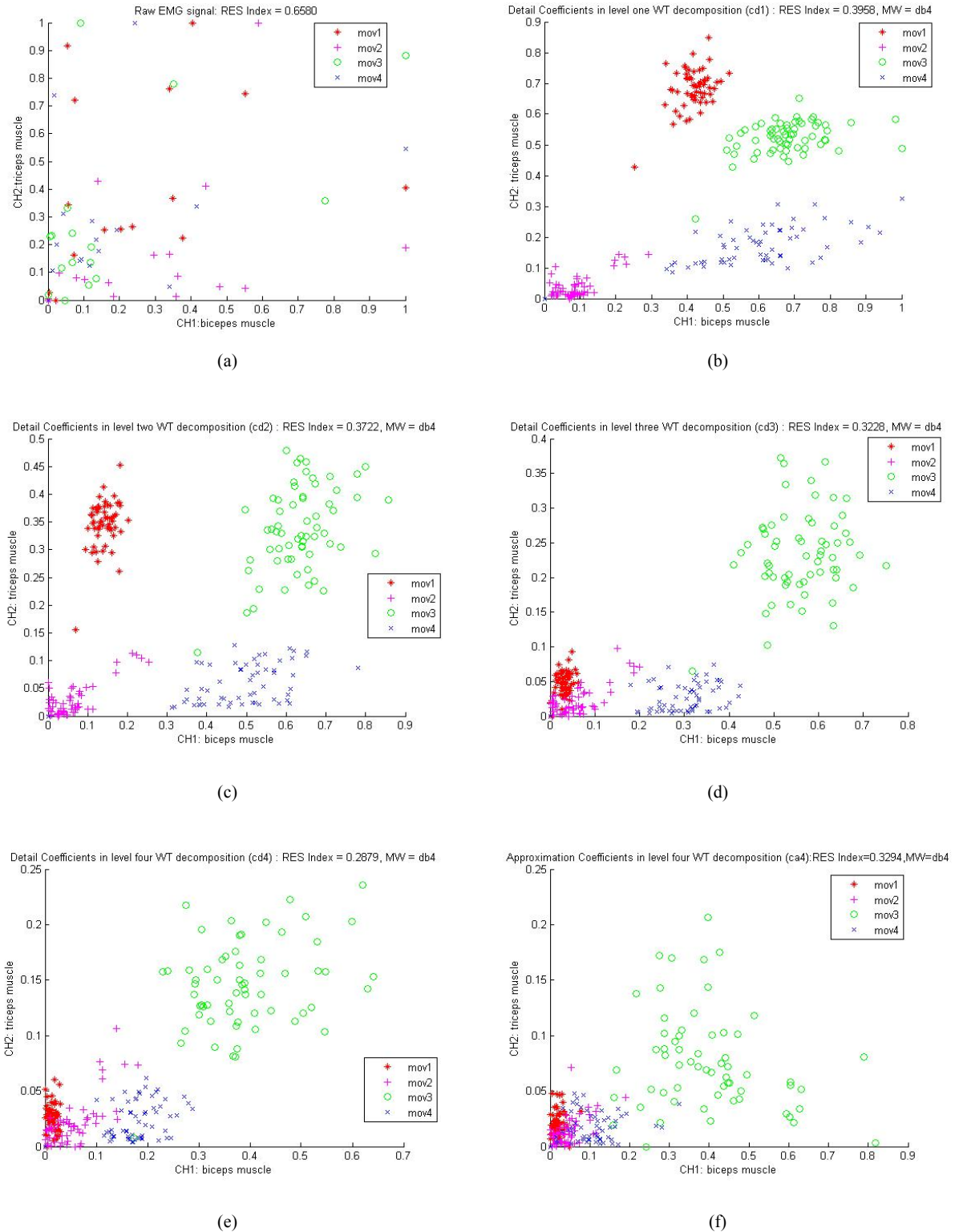
Fig. 5 The scatter plots of MAV features obtained from (a) Raw signal, (b) level 1 wavelet coefficients (cd1), (c) level 2 wavelet coefficients (cd2), (d) level 3 wavelet coefficients (cd3), (e) level 4 detail wavelet coefficients (cd4) and level 4 approximation wavelet coefficients (ca4) with two muscle channels, biceps and triceps and four hand movements
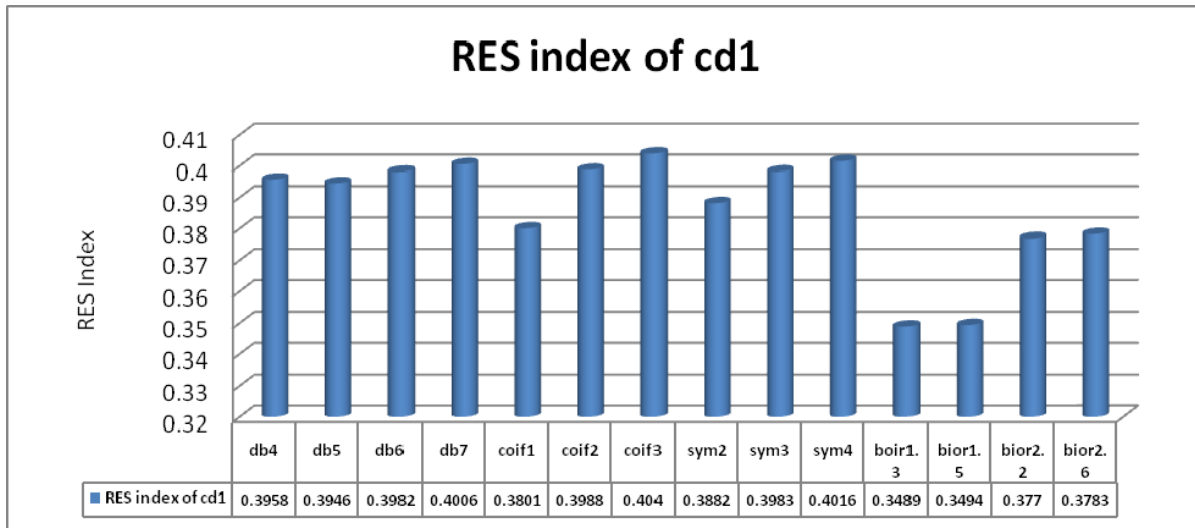
Fig.6 RES index bar chart of level one decomposition of coefficients subset (cd1) for MAV features based on different mother wavelets
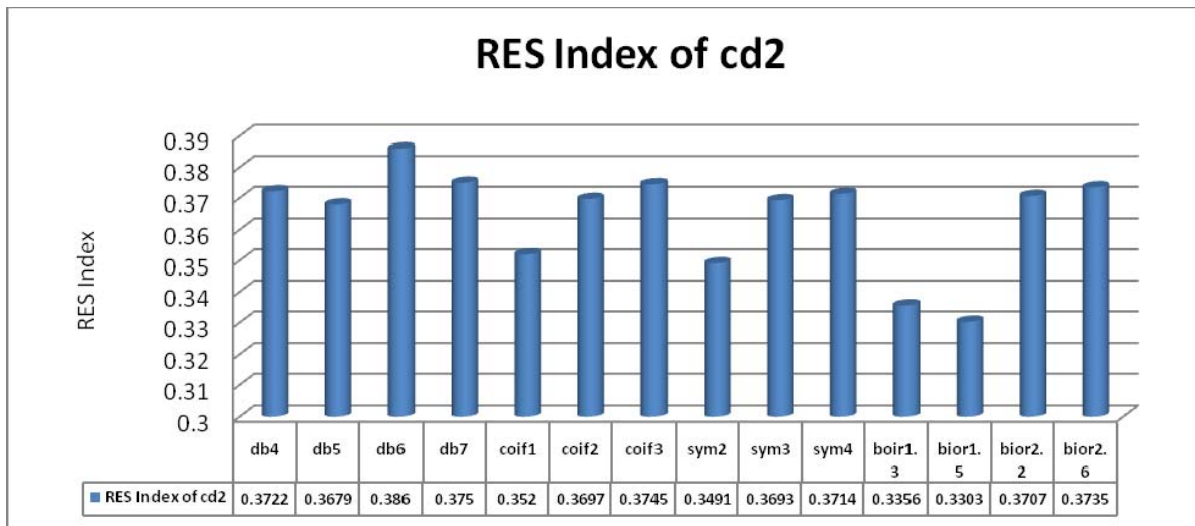

Fig. 7 RES index bar chart of level two decomposition of coefficients subset (cd2) for MAV features based on different mother wavelets

In this way, it is expected to observe a rise in the accuracy of classification after using the reconstructed signal based on cd1 and cd2.

Another conclusion which has been drawn is related to the performance of different wavelet functions. The fourth and seventh orders of Daubechies (db4, db7), the third order of Coiflets (coif3) and the fourth order of Symlets (sym4) outperforms the other functions. The bar charts of RES index of MAV features based on first and second level of WT decomposition coefficients are illustrated in Fig. 6-7 pointing out the values of RES indices. In addition, RES index of MAV features implies a quantitative confirmation for scatter plot in

our research but using just one of these criteria cannot analyze EMG signal in a deterministic approach. In some way, both of these evaluation criteria, scatter plot and RES index, play a complementary role for each other. Ultimately, only some orders of every wavelet family can reach good RES value and present reasonable scatter plot. Hence, the performances of 14 of 36 functions are selected for more accurate comparative study in the form of bar chart (Fig6-7). As these bar plots show, the ratio of Euclidean distance to standard deviation in level one is higher than this amount in level two. Meanwhile, the scatter plots of first and second level decomposition indicate acceptable separation between four movements.

Accordingly, reconstruction of EMG signal based on both levels 1 and 2 and also using some other related techniques to evaluate the reconstructed signals are considered as future work.

VI. CONCLUSION

Achieving the rich information of EMG signal through feature extraction based on wavelet decomposition and improving the separation quality of various hand movement classes in feature space are the objects of this study. Hereupon, thirty six mother wavelets have been utilized to decompose SEMG signal in this research and the features extracted by these mother wavelets have been compared to each other. The investigation of SEMG features by means of two evaluation criteria, RES index and scatter plot, manifests this consequence that only features from the first and second level of WT decomposition yield acceptable behavior in separabilty points of view. Moreover, the most suitable functions as MW for SEMG signal recorded from biceps brachi and triceps brachi muscles are recognized as db4, db7, coif3 and sym4 in this study.

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