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Quantification of EMG Signal By Wavelet Analysis

Md. Moshiur Rahman[1*], Abdul Kudus[1] and Eric Abel[2]
[1]Department of Physics, Jahangirnagar University, Bangladesh.
[2]Department of Biomedical Engineering, University of Dundee, UK.

Abstract

Intramuscular Biomedical signals has been processed by using discrete dyadic wavelet transform, to identify the distinct events like positive sharp waves, fibrillation potential and motor unit action potentials(MUAPs). Wavelet, filter bank and multi-resolution scales are used and compare the wavelet transform with the more classical short-time Fourier transform approach to EMG signal analysis. The cubic B-spline wavelets and its first derivatives were used to convolute the signal. Wavelet maxima (WM) vectors are considered as detection parameter to identify the events. The maxima are always found to be the highest in the first scale, so it is considered to detect. PSWs and MUAPs are detected from EMG signal on the basis of their characteristics, through the MATLAB-GUI and the corresponding FP and PSW are being modified into different scales of dyadic wavelet transform which could be analyzed quantitatively or qualitatively or both. Normal and abnormal MUAPs are distinguished by their amplitude and subsequently identify type of neuromuscular disorder.

Keywords: EMG, MU, MUAPS, PSW, FP, Wavelet etc.

Introduction

Biomedical signals are observations of physiological activities of organisms, ranging from gene and protein sequences, to tissue and organs images. Different types of biomedical signals, used in our daily life are Electrocardiogram (ECG), Electroencephalogram (EEG), Electromyogram (EMG), Electrooculogram (EOG) etc. Observing these signals and comparing them to their known norms, any disease or disorder is often detected. A considerable amount of information regarding the bioelectrical state of a muscle is hidden in the time-varying spatial distribution of potentials in the muscle. Unfortunately, it is not clinically feasible to obtain high-resolution three-dimensional samples of the spatial potential distribution, since this would require the insertion of hundreds of electrodes into the muscles. The amplitude of the integrated signal e.g. Motor Unit Action Potential (MUAP) depends of the density of the muscle fibers

*Author for correspondence e-mail: sushi.math14819@juniv.edu

connected to the motor neuron (McPherson L M, 2016). Defected muscle can induce some membrane instability and subsequently result fibrillation potentials (FPs) that signify the contraction of discrete muscle fibers. Although the contractions are too small to analyze clinically but needle EMG is sensitive for detection and a series of events should be taken to investigate abnormality in signal. The original signal is complicated one, can't provide empirical information because of its non-stationary and nonlinear properties, inclusion of diverse noises and artifacts or integrating signals from different physiological route. Hence signal processing is required to reduce the noise and revive the desired physiological information for diagnosis of any kind of abnormality.

To process the signal is challenging, advanced signal-processing methods like Fourier Transform, Adapting Filtering, Independent Component Analysis (ICA), Multi-channel Analyzer (MCA), and Wavelet transform are applied on it to achieve the accurate and actual signal. The Fourier transform provides a good frequency resolution of the stationary signal but for non-stationary it tells nothing about timing which is key concern of biomedical signal processing (Gulshan, 2015; Phinyomark, 2011). Wavelet Transform (WT) is a suitable technique to decompose the signal into its components based on the basis function namely called "wavelet" (Gulshan, 2015). Several studied reported that the Wavelet Transform (WT) is a worthy mathematical tool having higher resolution and better performance over Short Time Fourier Transform (STFT) for visualization of EMG signal (Canal, 2008; S Karlsson, 2000; P Bonato, 1996; G De Michele, 2003; G. Wang, 2006). In wavelet transform, the waveform is divided into segments of scale instead of dividing into sections of time (Semmlow, 2004). The Continuous Wavelet Transform (CWT) is infinitely redundant, offers an oversampling of the signal but large number of coefficients are required to treat the signal uniquely and recovery of the original waveform become inflated (Gulshan, 2015). In order to overcome this complications the discrete wavelet transform (DWT) has been introduced where the signals are translated into a new scale, usually powers of 2, and a scaling function is used for smoothing the original signal before further processing (Gulshan, 2015). The MUAP is the integration of spatial and temporal action potential of signal muscle for all fibers in a MU. The wavelet transform (WT) is an efficient mathematical tool for analyzing a non-stationary and fast transient signals like MUAP (Saleh Ahmed, 2009; Raez, 2006). These types of signals e.g. needle EMG signals are being analyzed in Matlab followed by two steps, signal processing and mechanical modeling (Staudenmann Didier, 2007). This is performed in several stags like high pass (HP) filtering, adaptive whitening, and rectifying processing, low pass (LP) filtering, eliminating noise and normalizing for suitable shape. In both HP and LP bi-directional first order Butterworth filter is used. If the chosen wavelet match the shape of the MUAP, the WT affords the best possible energy localization in the time-scale (Guglielminotti P, 1992) . Dealing with multi component signal like MUAP, WT is a substitute of time frequency demonstrations having advantage of being linear, providing a multi-resolution illustration and not being affected by cross terms. (Olmo, 1997). To quantify the PSW and FP, EMG signals are analyzed through discrete wavelet transform with dyadic filter bank process.

Methodology

The wavelet transform is similar to the Fourier transform with a completely different merit function. Fourier transform decomposes the signal into sine function and cosine function i.e. the function localized in Fourier space, whereas the wavelet transform is represented as an arbitrary function that is superimposed with wavelets and superimposed function can be decomposed into different scales, where each level is then further decomposed with a resolution adapted to the level.

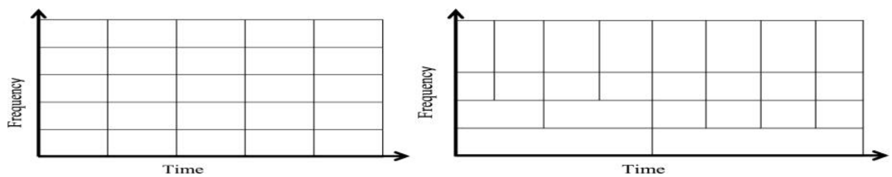

Figure (a): Fourier transforms Figure (b): Wavelet transform

Figure 1: Comparison of Time-Frequency resolution between FT and WT.

Actually wavelet transform decomposes the signal into a set of basis functions which are accomplished by comprising a LP filter that share the scaling property. The signals are smoothed through the LP filter and details are enhanced with the HP pass filter at each scale. The product of the wavelet and basis function produces a third function that signifies the modified version of the original function. In contrast to the Fourier transform, the wavelet transform allow to carry the localization in both the time domain through the translation of the wavelet prototype and in the frequency domain via translation of the wavelet. Figure-1 shows the comparison of Time-Frequency resolution between FT and WT.

Data collection (Raw signals)

EMG data, from the patients, attending the Neurophysiology Clinic at Aberdeen Royal Infirmary, UK was saved in an anonymous test file and sent for analysis. The intramuscular EMG data that are being analyzed are digitized at a sampling frequency of 24 KHz. The insertional activity yields the important information about the muscle's condition and the innervation nervous system.

Mathematical Tools

Matlab® 2013a has been used to analyze and work on the data collected from clinical EMG. Matlab is used because it is a fourth-generation programming language and has a prototype numerical computing ability. It also permits variety of matrix operations, graphical representation of functions and data, application of algorithms, design of new interfaces for new users and interfacing with other programming languages like FORTRAN, C/C++ or Java. A DWT was computed with a fast filter bank algorithm by designing a wavelet appropriately. To detect different event in EMG, a wavelet that could identify the singularities and changes in gradient is required. That means the wavelet should be smooth to afford good time-frequency localization. The cubic B-spline wavelet and its first derivatives (Figure-2) are used to decompose the signals into its frequency with good time localization using different scales of signal (Unser M, 1994**).** Multi-resolution analysis with DWT was used for better localization and frequency resolution.

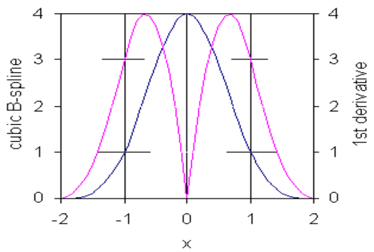

Figure 2: Cubic B-spline function and 1st derivative B-spline wavelet.

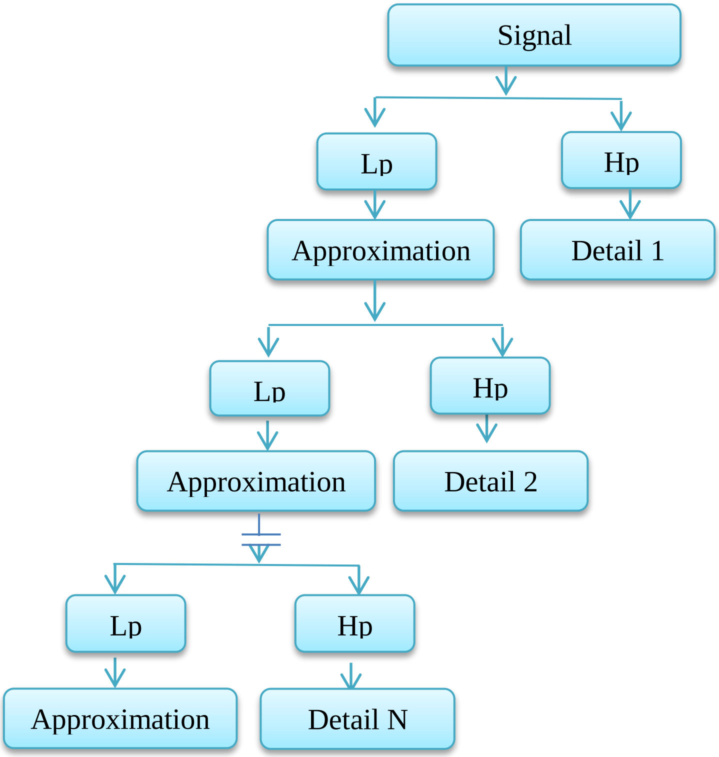

Figure 3: Block-diagram of the multi-resolution wavelet analysis.

The original signal is passed through two routes such as high pass (HP) filter and low pass (LP) filter. The output of the HP filter yields the detail information of the signal for WT at that scale and the output of the LP filter is fed to the next scale, where again the details are extracted by the HP filter as shown figure -3. This process is being continued until necessary information is found with the signal.

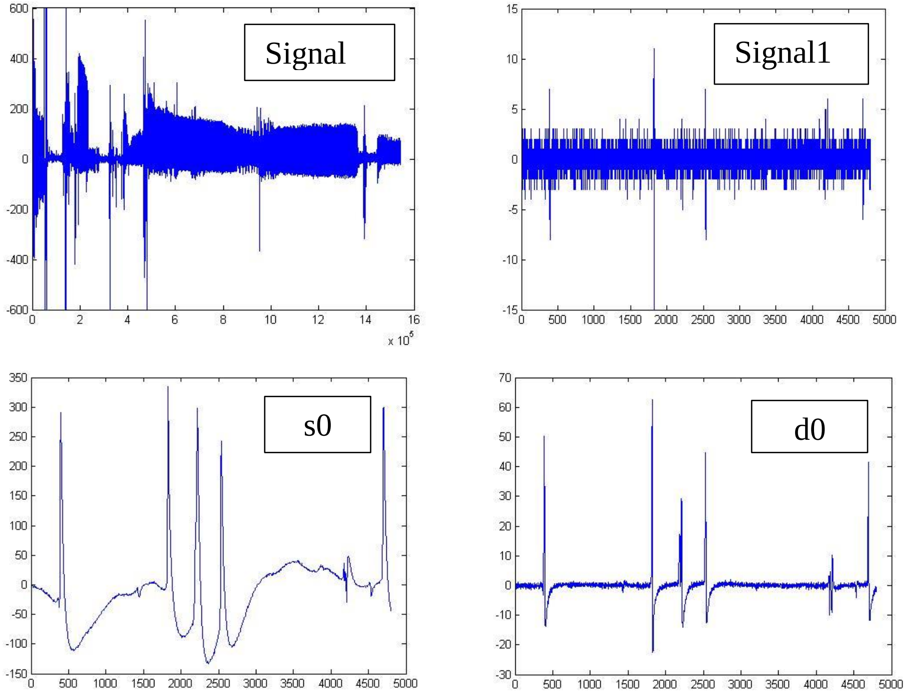

Figure 4: A part of EMG signal and its corresponding wavelet transform into scale 2^0(s0, d0).

Algorithm form EMG processing

In the first stage, the signal is convolved with scaling function to provide an approximate signal (s_0) that can be represented as a series of B-spline spaces. The program is written on basis of the turn based technique developed (Abel E, 2006). The machine readable redundant dyadic wavelet transform with B-spline is defined as ‘‘rdwtbspline2017’’ and is declared as ‘‘function [s d s0 d0]’’. The variable‘s’ and ‘d’ represent the convolved signal with the refinement function and wavelet function respectively.

Results and Discussions

The electrical changes, generated by activity of the MU can be acquired, called motor MUAP. MUAPs detection is the most important event and findings in EMG that signify the condition of the neuromuscular system. In order to distinguish the MUAP from other events like PSWs or FPs, the number of phases within the MUAP should be considered. The straight forward way to estimate the MUAPs is multi-polarity that it would have more positive or negative phase than FPs therefore WM. The MUAP shape fluctuates due to many factors like ages, type of the muscles and needle position but it is repeated in a usual manner which is called stability and variability. MUAPs detection in EMG is important to signify the condition of the neuromuscular system. Normal and abnormal MUAPs are distinguished by their amplitude since the abnormal MUAPs have a very large WM. MUAP can be analyzed quantitatively or qualitatively or both. The number of turns and phases in a MUAP and their position gives the time duration which subsequently identify the healthy and unhealthy MUAP. The qualitative approach in particular, associated to skilled physicians and can't provide measurable information for assessment purposes of determining a disease severity, or its progress (Richfield E K, 1981). Quantitative EMG extract quantitative information or features connected to the activity of MUs of the muscle and is usually performed by inference pattern that extracts information directly from composite EMG signal (Brown William F, 2002). The time interval of a MUAP is a superior pointer to replicate the density of the fibers adjacent to the needle (Akaboshi K, 2000) and is used to differentiate between neurogenic disorders and primary muscle diseases since long-durations MU usually arise in chronic neurogenic disorders.

To analyze the EMG signal, it is necessary to investigate and categorize the action potential, fibrillation potential (FPs) and positive sharp waves (PSW) respectively. From this point of view individual FPs and PSWs from different EMG signal has been depicted on the basis of their characteristics as mentioned in the experimentation, through the MATLAB-GUI and the corresponding FP and PSW are being modified into different scales of dyadic wavelet transform. Figure-5 shows a part of the processed EMG signal in 6 dyadic scales and Figure-6 shows the PSWs and FPs in a segment of EMG signal. Horizontal axis represents the number of events (or time duration) and vertical axis represents the amplitude. In figure-7, the MU and AMU are identified according the generated action potentials. The initial intension was to segregate between normal MU and abnormal MU, and differentiate the MUAP from other events like (PSWs or FPs), by considering the number of phases within the MUAP. It is very difficult to differentiate MU and AMU since there is lot of noise and the signal don't have well-defined positivity or negativity. After modified the signal through WT, the noise has been reduced and the MU and AMU can be distinguished on basis of negative and positive amplitude and their magnitude. In general, an EMG signal contains a lot of waves of different shapes like PSWs, FPs etc. The modified signal that represents either FP or PSW both has negative spike and positive spike. The negative spike indicates the raising gradient of the original signal (FP or PSW) whereas positive spike signify the reversing gradient of the signal. In a conventional graphical EMG signal the dip shape indicate the positive portion and hump shape or above zero value indicate the negative portion. In the original EMG signal it is obtained that FP have initial short and sharp positive deflection.

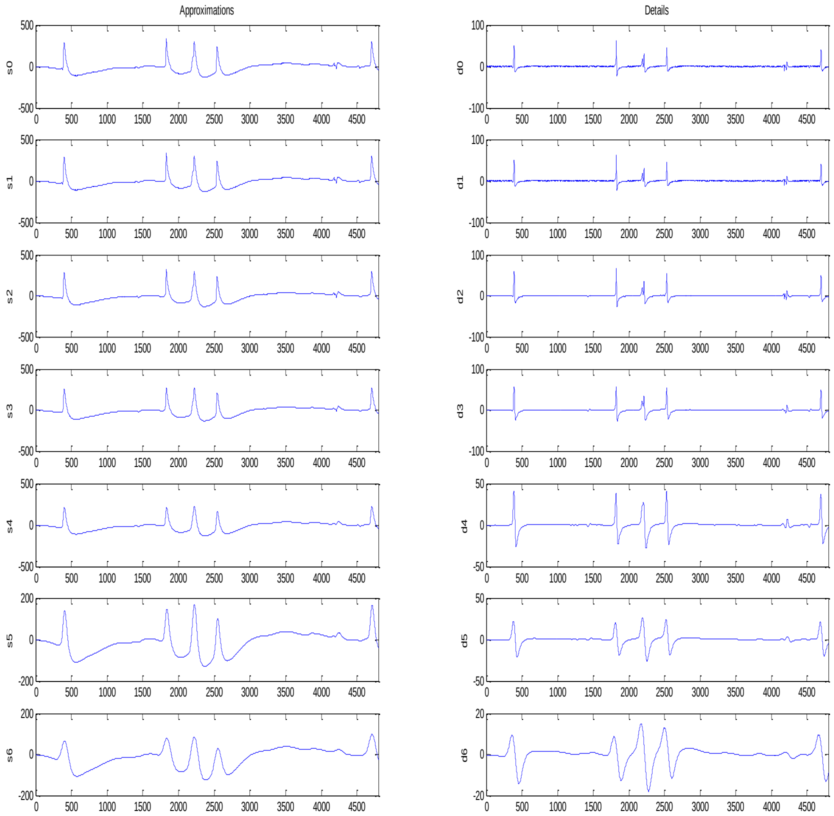

Figure 5: The comparison between the approximate and processed EMG signal in 6 dyadic scales

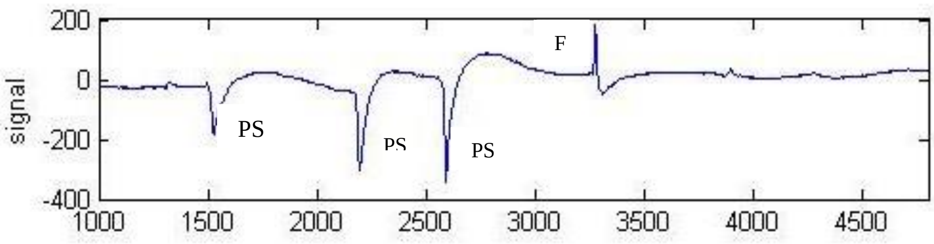

Figure 6: PSWs and FPs in a segment of EMG signal.

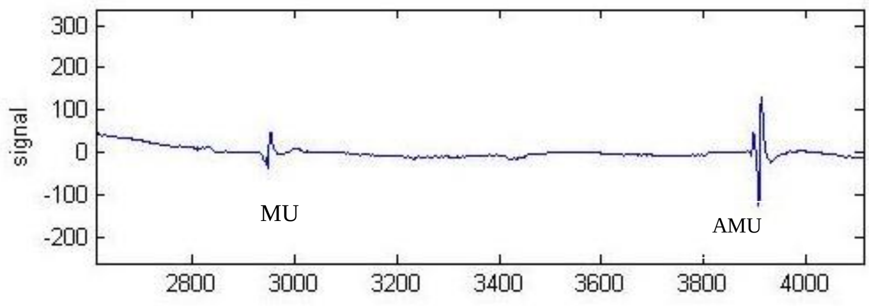

Figure-7: MUAPs in a segment of EMG signal.

Conclusion

The digitized EMG has been processed by dyadic discrete wavelet transform with B-spline wavelet. The wave maxima and phases are considered as the parameter to identify the events but nearest events could provide multi-polarity which may be cause of false detection. The parameter area of wave form identify the myopathy abnormalities by computing index thickness which indicates the ratio of area-to-amplitude and the stability parameters quantify the degree of variability in MUAP shape at sequential discharges. Although the refinement function works as a good filter and decompose the signal well but the duration of any events has great importance to identify and classify them. Therefore, the most prominent future work is to modify the computer aided algorithm by adding the well-defined time period for investigation and detection of events like FPs, PSWs and MUAPs or its normality and abnormality.

References

[1] L M McPherson, F Negro, C K Thompson, L Sanchez, C J Heckman, J Dewald and D Farina D (2016) "Properties of the motor unit action potential shape in proximal and distal muscles of the upper limb in healthy and post-stroke individuals," *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society,* p. 335–339.

[2] Gulshan, Ruchika Thukral and Manmohan Singh (2015), " Analysis of EMG Signals Based on Wavelet Transform-A Review," *International Journal of Web Engineering and Technology,* vol. 2, pp. 3132-3135.

[3] Angkoon Phinyomark, Chusak Limsakul and P Phukpattaranont(2011), " Application of Wavelet Analysis in EMG Feature Extraction for Pattern Classification," *Measurement Science Review,* vol. 11, pp. 45-52.

[4] M. R. Canal (2008) "Comparison of Wavelet and Short Time Fourier Transform Methods in the Analysis of EMG Signals," *Journal of Medical Systems,* pp. 1-4.

[5] P Bonato, G Gagliati and M Knaflitz (2000), "Time-frequency analysis of myoelectric signals during dynamic voluntary contractions: a comparative study," *IEEE Transactions on Biomedical Engineering,* vol. 47 , p. 228–238.

[6] G De Michele, S Sello, M C Carboncini, B Rossi, and S K Strambi (1996) "Analysis of myoelectric signal recorded during dynamic contractions – a time–frequency approach to assessing muscle fatigue," *IEEE Engineering in Medicine and Biology Magazine,* vol. 15, p. 102–111.

[7] G Wang, Z Yan, X Hu, H Xie and Z. Wang (2003), "Cross-correlation time-frequency analysis for multiple EMG signals in Parkinson's disease: a wavelet approach," *Medical Engineering and Physics,* vol. 25 , pp. 361-369.

[8] J. L. Semmlow (2004) Biosignal and Bimedical Image Processing MATLAB-BASED APPLICATIONS, Rebert Wood Johnson Medical School, New Brunswick, New Jersey, USA.

[9] Saleh Ahmed, Shamim Ahmad, Omar Faruqe and MD Rashedul Islam (2009), "EMG Signal Decomposition Using Wavelet Transformation with Respect to Different Wavelet and a Comparative Study," in *ACM International Conference Proceeding*

[10] Reaz M B I, Hussain M S and Mohd-Yasin F (2006), "Techniques of EMG signal analysis: Detection, processing, classification and applications," *Biological procedures online,* vol. 8, no. 1, pp. 11-35.

[11] Staudenmann Didier, Jim R. Potvin, Dick F. Stegeman, Jaap H. van Dieen (2007); “Effects of EMG processing on biomechanical models of muscle joint systems: sensitivity of trunk muscle moments, spinal forces and stability.," *Journal of Biomechanics,* vol. 40, no. 4, pp. 900-909.

[12] P Guglielminotti and R Merletti (1992); "Effect of electrode location on surface myoelectric signal variables: a simulation study" .

[13] F Laterza and G Olmo (1997), "Analysis of EMG signals by means of the matched wavelet transform," *Electronics Letters,* vol. 33, no. 5 , pp. 357-359.

[14] Unser M, A Aldroubi and S J Schiff (1994), "Fast Implementation of the Continuous Wavelet Transform with Integer Scales," *IEEE Transactions of Signal Processing,* vol. 42, no. 12, pp. 3519-3523.

[15] Abel E, Meng H, Forester A and Holder D (2006) "Singularity characteristics of needle EMG IP signals," *IEEE Transaction on Biomedical Engineering,* vol. 53, no. 2, pp. 219-225.

[16] Richfield E K, B A Cohen and J W Albers (1981), "Review of quantitative and automated needle electromyographic analyses," *IEEE Trans. Biomed. Eng.,* vol. 28, no. 7, pp. 506-514.

[17] Brown William F, Charles F Bolton and Michael J Aminoff (2002), Neuromuscular Function and Disease: Basic, Clinical, and Electrodiagnostic Aspects, vol. 1, Saunders, pp. 311-348.

[18] Akaboshi K, Masakado Y and Chino N (2000); Quantitative EMG and motor unit firing behavior using a concentric needle with quadrifilar electrode," *Muscle & Nerve,* vol. 23, no. 3, pp. 361-367.