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Biomedical Signal Analysis through Wavelets: A Review

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***Abstract*— Wavelet-based signal processing has become commonplace in the signal processing community over the past few years. One of the most important applications of wavelets is removal of noise from biomedical signals and is called de-noising which is accomplished by thresholding wavelet coefficients in order to separate signal from noise. A biomedical signal is a non-stationary signal whose frequency changes overtime and for the analysis of these signals Wavelet transform is used. This paper describes the method of wavelet transform for the processing and analysis of biomedical signals.**

Keywords— Wavelets, DWT, De-noising, wavelet coefficients, biosignals.

I. INTRODUCTION

A signal is a physical quantity which differs with respect to time, space & contains information from source to destination. Signal may me continuous or discrete. The signals which is described by a continuous function (for example a recording of a speech signal or music signal, which measures the current in the cable to the loudspeaker as a function of time) is called continuous signals. The signals which is described by a sequence of numbers or pairs of numbers is called discrete signals. The biomedical signals can be classified with regard to their source, application or in terms of the signal characteristics. Biological signals can be considered to be continuous or discrete. Continuous signals include temperature, pressure and chemical concentration, while discrete signals include electrical impulses generated by individual nerve cells. These signals can be classified into broad classes dependent on the rate and nature of the variations that take place Biomedical signals originate from a number of sources including the following:

Bioelectric Signals: This is a generic term for all of the electrical signals generated by nerve and muscle cells. The source is the membrane potential which, under certain circumstances, may generate an action potential.

Bioimpedance Signals: The electrical impedance of tissue contains important information concerning its makeup, blood volume, endocrine activity etc. These signals are normally obtained by injecting low-current (<20mA) sinusoidal electrical signals into the body at frequencies between 50kHz and 1MHz, and monitoring the relationship between the current and the voltage.

Bioacoustic signals: Many biological phenomena generate acoustic outputs, and these are indicative of the function being performed. A good example of this is the "lub-dub" sound produced by the pumping heart.

Biomagnetic Signals: All of the organs in which electrical activity occurs, generate magnetic fields as a result of this activity. These organs include the brain, heart and lungs as well as the skeletal muscles.

Biomechanical Signals: These signals include motion and displacement as well as pressure, tension and flow within the organism. Unlike electrical and magnetic signals, these signals generally do not propagate (with the exception of pressure), and so are mostly measured at source.
Biochemical Signals: These result from chemical activity within the organism which can alter its chemical composition in both subtle and gross ways.

Bio-optical Signals: These are signals related to the optical reflectance or transmission of the tissue. For example, blood oxygen levels may be determined from the relationship between the reflectance of IR and visible wavelengths.

Table 1: Characteristics of some bioelectric signals

Classification	Acquisition	Frequency Range (Hz)	Dynamic Range	Description
Action potential	Micro electrode	100 – 2000	10μV – 100mV	Cell membrane potential
Electroneurogram (ENG)	Needle electrode	100 – 1000	5μV – 10mV	Potential of a nerve bundle
Electroretinogram (ERG)	Micro electrode	0.2 – 200	0.5μV – 1mV	Evoked flash potential
Electroencephalogram (EEG)				
Surface	Surface electrode	0.5 – 100	2 – 100μV	Multichannel scalp potential
Delta range		0.5 - 4		Children, deep sleep
Theta range		4 – 8		Temporal & central – alert state
Alpha range		8 – 13		Awake, relaxed, closed eyes
Beta range		13 – 22		
Sleep spindles		6 – 15	50 – 100μV	Bursts of 0.2 – 0.6s
K-complexes		12 – 14	100 – 200μV	Bursts during deep sleep
Evoked potentials (EP)	Surface electrode		0.1 – 20μV	Brain response to stimulus
Visual (VEP)		1 – 300	1 – 20μV	Occipital lobe 200ms duration
Somatosensory (SEP)		2 – 3000		Sensory cortex
Auditory (AEP)		100 – 3000	0.5 – 10μV	Vertex
Electrocorticogram	Needle electrode	100 – 5000		Exposed brain surface potentials
Electromyogram (EMG)				
Single fibre	Needle electrode	500 – 10000	1 – 10μV	Action potential – single fibre
Motor unit action pot.	Needle electrode	5 – 10000	100μV – 2mV	
Surface EMG (SEMG)	Surface electrode			
Skeletal muscle		2 – 500	50μV – 5mV	
Smooth muscle		0.01 – 1		
Electrocardiogram (ECG)	Surface electrode	0.05 - 100	1 – 10mV	

II Biomedical Signal Processing

Signal processing indicate any manual or mechanical operation which modifies, analyzes or else manipulates the information contained in a signal [1]. The broad field of signal processing is multidimensional signal processing. In the application of signal processing, wavelets provide a mathematical tool for the hierarchical decomposition of function [2]. Noise is the major problem in signal processing. Noise removal can be done by removal of small coefficients [3]. Noise consists of high frequency components is referred to as linear de-noising. The corresponding scales of the Wavelet Transform are set to zero. Noise is assumed by non-linear de-noising or wavelet shrinkage that to consist of low energy [3].

Signal de-noising refers to the process of removing the noise from a signal. It is the main problem in signal processing. To estimate a clean version of a given noisy signal is the main goal of natural signal de-noising [4]. The noise may corrupt the signal in many cases in a significant manner, and it must be removed from the data in order to proceed with further data analysis. While de-noising the signal it increases perceptual quality, increase compression, effectiveness, facilitate transmission bandwidth reduction and improve the accuracy of the subsequent feature extraction and patter recognition process [5].Using simple filtering operations, it is very difficult to remove the noises [6]. By using traditional methods, it is difficult to recover the noises present in the signals.

Electrocardiograph (ECG) is used to measure the rate and regularity of heartbeats. The nature of ECG signals is oscillatory and periodic. A complete ECG beat has a distinct and characteristic shape. In ECG signal, the sources of noise may be either cardiac or extracardiac. By various noises contaminate the ECG signal [10]. Electroencephalography (EEG) is used to diagnose the abnormal activity of the functionality of the brain. It involves the information about the function of the brain [11]. Electromyography (EMG) is used to record the electrical activites produced by skeletal muscles. While recording the EMG signals it usually includes some noises. Instead of achieve a good performance in control of the prosthesis, the major problem here is the noisy EMG signals [12]. The biomedical signals may easily affected by noise and detecting those noise from the signals with a powerful and advance methodologies is becoming a very important requirement.

III. Wavelet Transform

In general, a wavelet is a wave like oscillation with amplitude that starts at zero, increases and then decreases to zero. One of the main functions of wavelet transforms is used to reduce the unwanted noise and blurring in the signals [8]. Wavelet transform is the best technique used for de-noising the signals [7]. The Wavelet transform achieves a correlation analysis, consequently the output is expected to be maximal when the input signal most resembles the mother wavelet. The wavelet de-noising methods offers high quality and flexibility for the noise problem of signals and image. The wavelet transform is classified into Discrete Wavelet Transform and Continuous Wavelet Transform. Discrete Wavelet Transform (DWT) based de-noising is performed, to meet the mathematical criteria to obtain the discrete sequences as discrete wavelet function. If the analyzing function is waveform adapted then DWT based de-noising can be performed better [9]. Dividing the continuous time function into wavelets is referred to us Continuous Wavelet Transform (CWT).

Signal decomposition is referred as the way of decomposing a given signal into a sum of simpler signals. To have a scale invariant interpretation of the image enables multi-resolution decomposition [4]. Decomposing a signal into scales with different time and frequency resolution is done by Multi-Resolution Analysis (MRA) algorithm [13]. The small number of resulting coefficients is relatively good decomposition. To decompose a signal wavelet transform uses some set of basic functions [9]. By means of classification of spectral peaks, transient spectral peaks were detected and investigate into distinction between sinusoidal and noise components. The classification is based on descriptors derived from properties related to time-frequency distributions [15].

There are many types of wavelets they are, daubechies wavelet which is described by a maximal number of vanishing moments for some given support. In Haar wavelet which is an order of rescaled square shaped function which together to form a wavelet family. Symlet wavelets are an improved version of Daubechies wavelets with increased symmetry. Coif lets wavelets have scaling functions with vanishing moments. In Mathieu equation, the Mathieu equation is a second order differential equation with periodic coefficients. In Legendre wavelet, the Legendre function have common applications in which spherical coordinate system are suitable.

Signal reconstruction generally means that the determinations of an original continuous signal from an order of equally spaced samples. Reconstructing the original sequence from the thresholded wavelet detail coefficients leads to a de-noised (smoothed) version of the original sequence. Inverse Discrete Wavelet Transform (IDWT) is used to reconstruct the original signal. Calculate high resolution log-spectral features of the input noise signal to reconstruct the signal [17]. Therefore wavelet transform is a reliable and better technique than Fourier transform technique. The biomedical signals require high storage and high bandwidth for storing and transmitting. Compression of the signals refers to reducing the redundancy in it. The signal compression techniques are limited to the amount of time required for compression and reconstruction, the noise embedded in the raw signal, and the need for accurate reconstruction of the waves [19].
An indispensable tool for a variety of applications such as classification, compression and estimation is wavelet transform. Signal information in wavelet development is conveyed by a comparatively small number of large coefficients. This property of the wavelet transform makes the use of wavelets mainly ideal in signal estimation. It has been revealed that wavelets can eliminate noise more effectively than previously used methods.

Wavelet transforms can decompose a signal into numerous scales that represent dissimilar frequency bands, and at each scale, the position of signal's instantaneous structures can be determined approximately. The purpose is to satisfy certain mathematical necessities and is used in representing data or other functions of wavelet. The Wavelet Transform provides a time-frequency illustration of the signal. A signal is examined and expressed as a linear combination of the sum of the product of the wavelet coefficients and mother wavelet is wavelet transform [10]. The original signal is transformed using predefined wavelets in wavelet transform. The wavelets are orthogonal, biorthogonal and multiwavelets. By calculating signal to noise ratio of the signal, the accuracy of the wavelet transform is determined after reconstruction of a signal. Some of the applications are identifying pure frequencies, de-noising signals, detecting discontinuities and breakdown points, detecting self-similarity, Compressing images.

Discrete Wavelet Transform is the same to filtering it by a bank of filters of non-overlapping bandwidths which vary by an octave. It is based on sub-band coding is found to yield a fast calculation of Wavelet Transform. It is easy to implement and diminishes the calculation time and resources required. When

A set of dilations and translations of a preferred mother wavelet is used for signal analysis. It is important to know the behavior of these filters with these wavelet coefficients. According to the mother wavelet design the coefficients of these filter banks are determined.
Continuous wavelet transform (CWT) converts a continuous signal into extremely redundant signal of dual continuous variables translation and scale. The resulting changed signal is easy to interpret and valuable for time-frequency analysis. The mother wavelet is scaled or dilated by a factor of 'a' and translated or shifted by a factor of b to give (under Morlet's original formulation) [S. kadambe et.al (1999)]:

$$\psi_{a,b}(t) = \left(\frac{1}{\sqrt{|a|}}\right) \times \psi\left(\frac{t-b}{a}\right) \quad \text{….(1)}$$

Where a and b are two arbitrary real numbers. 'a' and 'b' represent the dilations and translations parameters respectively in the time axis. The parameter 'a' contracts (t) in the time axis when a < 1 and expands or stretches when a > 1. Hence 'a' is called the dilation (scaling) parameter. For a < 0, the function results in time reversal with dilation. Mathematically, when't' is replaced in equation by (t – b) it causes a translation or shift in the time axis resulting in the wavelet function. It is very helpful in analyzing the signal that contains sharp spikes and discontinuities. The mother wavelet can be represented by (ψ (t)) and the baby wavelet (B(t))are obtain by scaling the mother wavelet to form family of wavelet. They are written as

$$\psi(t) = e^{j\omega t} e^{-t^2/2} \quad \text{....(2)}$$

$$B(t) = \frac{1}{\sqrt{a}} \psi\{(t-\tau)/\ a\} \quad \text{....(3)}$$

A set of dilations and translations of a preferred mother wavelet is used for signal analysis. It is important to know the behavior of these filters with these wavelet coefficients. According to the mother wavelet design the coefficients of these filter banks are determined.

Wavelet filters

Discrete Wavelet Transform is performed by repeated filtering of the input signal using two filters. The filters are, a low pass filter (LPF) and a high pass filter (HPF) to decompose the signal into different scales. The output coefficient gained by low pass filter is the approximation coefficient.

The output coefficient of high pass filter is detailed coefficient. The approximation coefficient is consequently divided into new approximation and detailed coefficients. By choosing the mother wavelet, the coefficients of such filter bank are calculated. This decomposition process is repeated until the required frequency response is achieved from the given input signal [16,18].

Wavelet families

2.1 Daubachies: Commonly, Daubechies family wavelets are signed dbN (N is the order).This wavelet belongs to orthogonal wavelet.

2.2 Coiflets :A discrete wavelets designed by Ingrid Daubechies to have a scaling function with vanishing moments. The scaling function and the wavelet function must be normalized by a common factor. By retrogressive the order of the scaling task coefficients and then reversing the symbol of every second one is the wavelet coefficients.

2.3 Symlet: The symlet family wavelets are signed symN (N is the order). The symlets are nearly symmetrical, orthogonal and biorthogonal wavelets suggested by Daubechies as modifications to the db family. The properties of the two wavelet families are similar [20].

2.4 Biorthogonal : Biorthogonal filters state a superset of orthogonal wavelet filters and have found their use in virtually all areas where wavelets are used. The biorthogonal family wavelets are signed as bior. Biorthogonal wavelet transform has frequently been used in numerous image processing applications, because it makes possible multi resolution analysis and does not produce redundant information.

The wavelet analysis of bio- signal is performed using MATLAB software. MATLAB is a high performance; interactive system which allows to solve many technical computing problems. The MATLAB software package is provided with wavelet tool box. It is a collection of functions built on the MATLAB technical computing environment. It provides tools for the analysis and synthesis of signals and images using wavelets and wavelet packets within the MATLAB domain. Using wavelets abnormalities in the signals can be detected. Here the normal ECG and abnormal ECG waveforms are shown and the results are shown in the wavelet toolbox to find out the abnormalities.

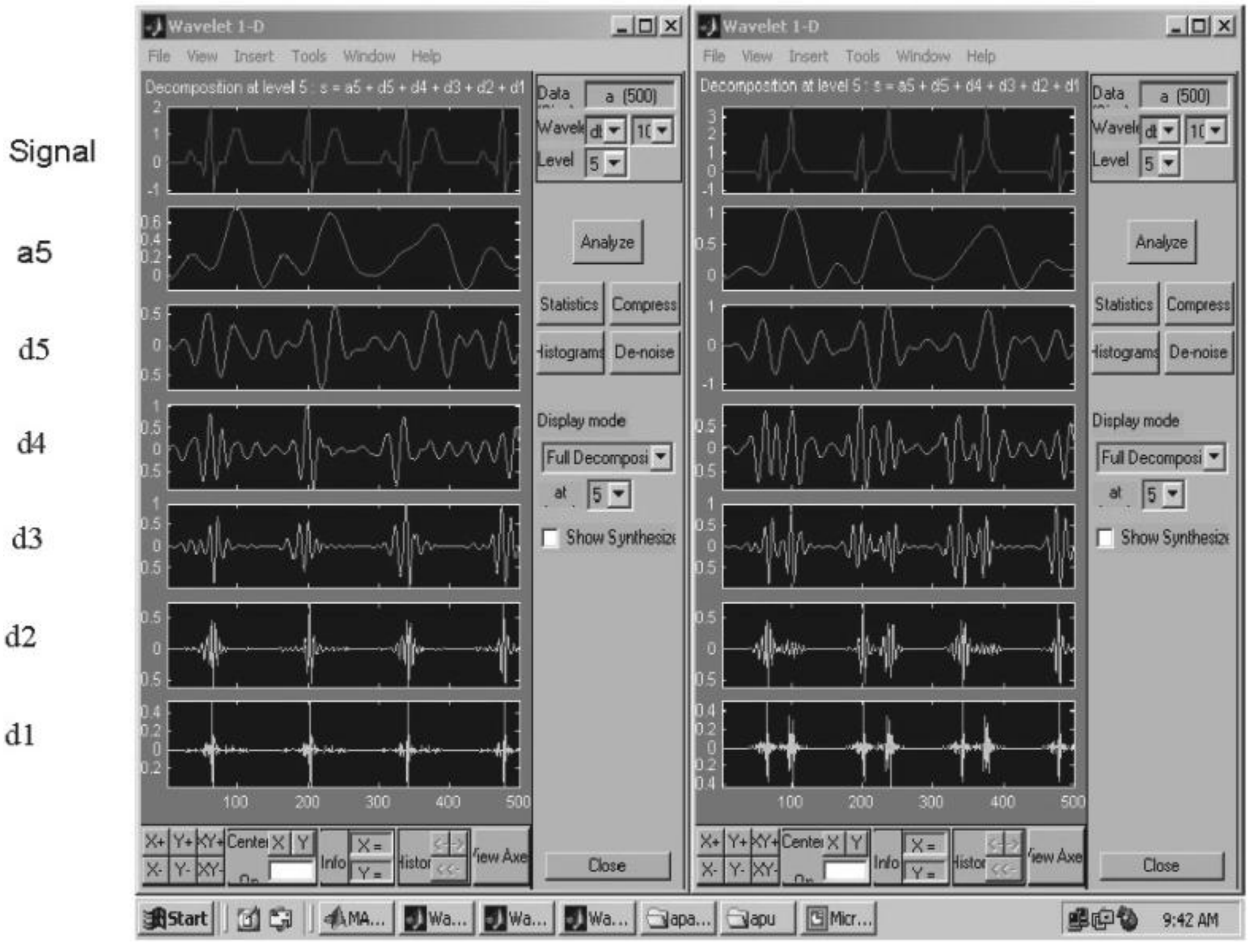

Fig. 1. Comparison of abnormality "hyperkalemia" with normal ECG wave

TABLE II: Various abnormalities and their characteristic feature

S. No.	Name of abnormality	Characteristic features
1	Dextrocardia	Inverted P-wave
2	Tachycardia	R-R interval < 0.6 s
3	Bradycardia	R-R interval > 1 s
4	Hyperkalemia	Tall T-wave and absence of P-wave
5	Myocardial ischaemia	Inverted T-wave
6	Hypercalcaemia	QRS interval < 0.1 s
7	Sinoatrial block	Complete drop out of a cardiac cycle
8	Sudden cardiac death	Irregular ECG

Some Application of Wavelets

Wavelets are a powerful statistical tool which can be used for a wide range of applications, namely
- Signal processing
- Data compression
- Smoothing and image denoising
- Fingerprint verification
- Biology for cell membrane recognition, to distinguish the normal from the pathological membranes
- DNA analysis, protein analysis
- Blood-pressure, heart-rate and ECG analyses

• Finance (which is more surprising), for detecting the properties of quick variation of values
• In Internet traffic description, for designing the services size
• Industrial supervision of gear-wheel
• Speech recognition
• Computer graphics and multifractal analysis
• Many areas of physics have seen this paradigm shift, including molecular dynamics, astrophysics, optics, turbulence and quantum mechanics.

Wavelets have been used successfully in other areas of geophysical study. Orthonormal wavelets, for instance, have been applied to the study of atmospheric layer turbulence. In one study by J.F. Howell and L. Mahrt, turbulence measurements were taken over a nine-hour period and analyzed using wavelet decomposition. In another study by Brunet and Collineau, turbulence data recorded over a corn crop was analyzed using the wavelet transform. Wavelets have also been used to analyze seafloor bathymetry or the topography of the ocean floor. In one study by Sarah Little, the use of wavelet analysis revealed patterns, trends, and structures that may be overlooked in raw data. Also, the use of methods like local oracles allowed for separation of data in regions of interest. Several other geophysical applications such as analysis of marine seismic data and characterization of hydraulic conductivity distributions have also been used. The usefulness of wavelets in data analysis is clear, particularly in the field of geophysics, where large and cumbersome data sets abound. Studies such as the atmospheric layer turbulence and corn crop turbulence have further shown the proficiency of wavelets in the analysis of time-dependent data sets

IV. CONCLUSIONS

Wavelet transform has been a very novel method for the analysis and processing of non-stationary signals such as bio-signals in which both time and frequency information is required. Since the application of wavelet transformation in electro cardiology is relatively new field of research, many methodological aspects (Choice of the mother wavelet, values of the scale parameters) of the wavelet technique will require further investigations in order to improve the clinical usefulness of this novel signal processing technique. Simultaneously diagnostic and prognostic significance of wavelet techniques in various fields of electro cardiology needs to be established in large clinical studies.

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