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Algorithm for QRS Complex Detection using Discrete Wavelet Transformed

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Abstract: This paper is based on algorithm for detection of arrhythmia and QRS Complex with the application of DWT on ECG (Electrocardiogram). The ECG signal is generated from the bioelectrical activity of the heart that is mixed with various kinds of noises. The QRS Complex is detected after removing of the noises from the ECG signal with help of the DWT. The presented work is contrivance in MATLAB software for analysis of MIT/BIH arrhythmia database and produces the rate of the sensitivity of 99.33% with DWT. The Baseline wanders in the ECG signal removed with the help of DWT. The execution of this algorithm for QRS detection is estimated against the standard MIT/BIH arrhythmia. The average value for QRS complex detection is found 99.33%. This also refers to that, DWT working principle and technique for analysis in the detection of ECG signal is preferable.

Keywords: ECG – Electrocardiogram, DWT – Discrete Wavelet Transformed, QRS complex analysis and detection.

1. INTRODUCTION

The human body produces various kind of bioelectrical signals among which the ECG is signal generated by the human heart. This signal is recorded and analyzed to diagnose any cardiac abnormalities present. These Bioelectrical signals are recorded by an ECG machine, so it is most commonly known as ECG signals. The ECG signal is a continuous wave of deflection in the heart bioelectrical activities [1]. The signal is measured by placing various electrodes or leads to the human body and carefully monitoring the change in the voltage between the leads. These leads are named as lead I, II & III and are unipolar leads, that is placed on the right and left arms and on left leg (i.e. RA, LA and LL). Other leads such as V1 to V6 are bipolar leads place across the chest of the person. The ECG signal generated as shown in Figure 1, has some important features and characteristics, that is P-Wave, QRS complex and T-Wave. The QRS complex is the most prominent part in the ECG signal. Each signal in waveform determines some features so the analysis can be done on its amplitude and time intervals [2]. The shape and time interval of the waveform provide vital information about the heart present condition. Due to this feature of ECG signals, it acts as a base for determination of the heart rate for classification of the cardiac cycle and serves as the fundamental for the automated analysis algorithm of ECG signal [3].
In a 30-minute ECG signal recording there are more over 1000 beats of heart that are needed to be analyzed, hence visual analysis of the signal might lead to missing of vital information in the signal. Therefore, an efficient automated system is needed to correctly and efficiently detect all the information present in the signal. However, there are several methods and techniques that can be used to analysis with the QRS complex detection and analysis for ECG signals. One of such is the famous Pan-Tomkins Algorithm [4] in 1985, to detect the QRS complex in the ECG signal. The Pan-Tomkins algorithm uses techniques of analyzing the amplitude, position, slope, width information and magnitudes and a special LOW PASS and HIGH PASS FILTERS.

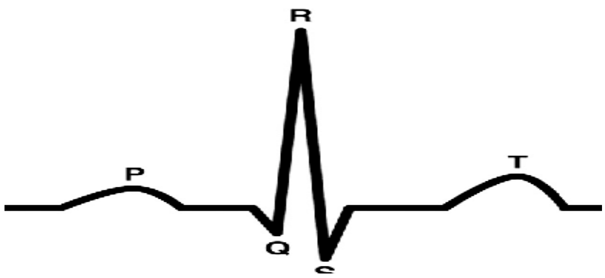

Figure 1 ideal ECG waveform

This paper offers an alternative method for QRS complex detection i.e. using DWT method that helps in identification of valid and optimal waves in ECG signal based on selective wavelet coefficient method to rebuild the QRS complex. The method is based on the wavelet detail coefficient after filtering the noise component in the ECG signal. In this paper, the number of signal from MIT-BIH arrhythmia database is tested with the algorithm proposed.

2. METHOD

a. Wavelet Transform

The wavelet transform is mathematical tool for analyzing the signals with changing frequency in relation to time. It is a small wave with restricted duration having an average value of zero. [6]. The specific characteristic of a wavelet transform is shifting and scaling, which is helpful in analyzing various kind of variation in a given signals [7]. It allows the analysis of data in both time and frequency domain simultaneously. A graphical representation of ECG signal in time-frequency domain can be done by wavelet transform at different resolution and scale [8]. The selection of wavelet does not have any specific way to choose rather it depends upon the type of signal that is to be analyzed and its application. There is a various form of a wavelet transformed such as Biorthogonal, Coiflets, Daubechies, Haar, Mexican Hat, Meyer, Morlet, symlets.
The wavelet transform equation (1) for a given signal x(t). [5]

$$W_i\, x(k) = \frac{1}{\sqrt{i}} \int_{-\infty}^{\infty} x(t)\, \Psi\left(\frac{t-k}{i}\right) dt \qquad (1)$$

Here,
i → dilation parameter,
k → translation parameter
Wavelet transform are classified in two category are: 1) Discrete Wavelet Transformed (DWT) and 2) Continuous Wavelet Transformed (CWT).

b. Discrete Wavelet Transform

The Discrete Wavelet transformed became one of the advanced digital signal processing techniques over the last few years. That has provided a great prove of good time resolution at high frequency and good frequency resolution at low time resolution. The wavelet technique works on simple basic steps of forward DWT and inverse DWT of a signal i.e. decomposition and reconstruction of the signal respectively. The decomposition and reconstruction of the signal are done basically by downsampling and upsampling with the use of High-pass filter and low Pass filter respectively operated by the factor of 2 as shown in figure 2(a). The block with symbol g(n) defines the lowpass filter and ↓2 block shows the downsampling and the block with h(n) defines the high pass filter and ↑2 block indicates the upsampling. The given input signal x(t) is continuously decomposed into a total of four sub-group signal with three detail signals resolution of d1(n), d2(n) and d3(n) also a detail coefficient of C1(n) shown in figure 2(a). The three-level inverse DWT has a low-pass and high pass filter with similar parameter as the above forward DTF. The four sub-signals formed is continuously reconstructed to have an output signal x(t), as shown in figure 2(b).

The output obtained from the inverse DWT and the input of the forward DWT are similar [9 10]. Discrete Wavelet Transformed can be represented by equation (2). [11]

$$W(m, n) = \sum_m \sum_n x(n) e^{-\frac{1}{2}}\, \Psi\left(2^{-j} n - k\right) \qquad (2)$$

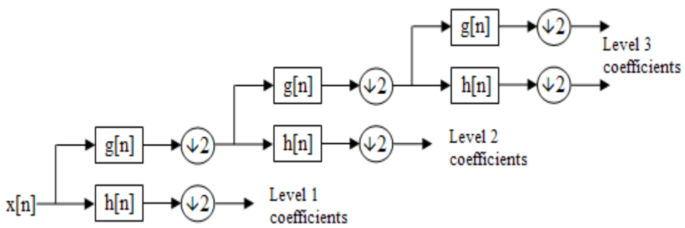

Figure 2. DWT Decomposition

3. METHODOLOGY

In this paper, R peaks and QRS complex of the ECG signal are identified and arrhythmia is detected on the basis of heart rate is done with the implementation of several stages of DWT as shown in the flowchart below in figure 3.

a. Pre-processing

The raw ECG signal is encapsulated with several kinds of noises that affect the ECG Signals accuracy, so it is necessary to remove such noises so that accurate and optimal detection of the signal can be done. One such noise associated with ECG signal is the baseline wandering noise that is associated with the signal due to artefact or respiration or movement of the subjected person. The Baseline wander has a frequency range of about 0 Hz to 0.5 Hz.

The methodology that is used to reduce or eliminate the baseline wander is done by the decomposition of the signal up to 8 levels. Which generate an 8_Detail coefficient i.e. D1 to D8 and a set of approximation coefficient. The ECG recorded data is taken from the MIT-BIH arrhythmia database available on Physionet.org [12]. The sampling frequency (fs) of the selected data is 360 Hz therefore according to Nyquist rule if the selected signal has a maximum frequency (f_{max}), the sampling frequency (fs) ≥ (f_{max})/2. This implies that the maximum frequency should be in the order of 130 Hz, i.e. f_{max} = 130 Hz, so the frequency range of the real signal is found to be between 0 Hz to 130 Hz. The table 1 below shows the detail coefficient and range of the given signal.

Table 1 Frequency range of Detail coefficient of DWT

Detail Coefficient	**Rang Frequencies**
D_1	65 – 150 Hz
D_2	32.5 – 65 Hz
D_3	16.25 – 32.5 Hz
D_4	8.125 – 16.25 Hz
D_5	4.062 – 8.125 Hz
D_6	2.031 -4.062 Hz
D_7	1.015 – 2.031 Hz
D_8	0.507 – 1.015 Hz

Table 2 Cross Correlation

Signal Detail coefficient	Cross Correlation %
D_1	12.03
D_2	3.2
D_3	7.6
D_4	26.8
D_5	48.2
D_6	45.7
D_7	38.8
D_8	23.3

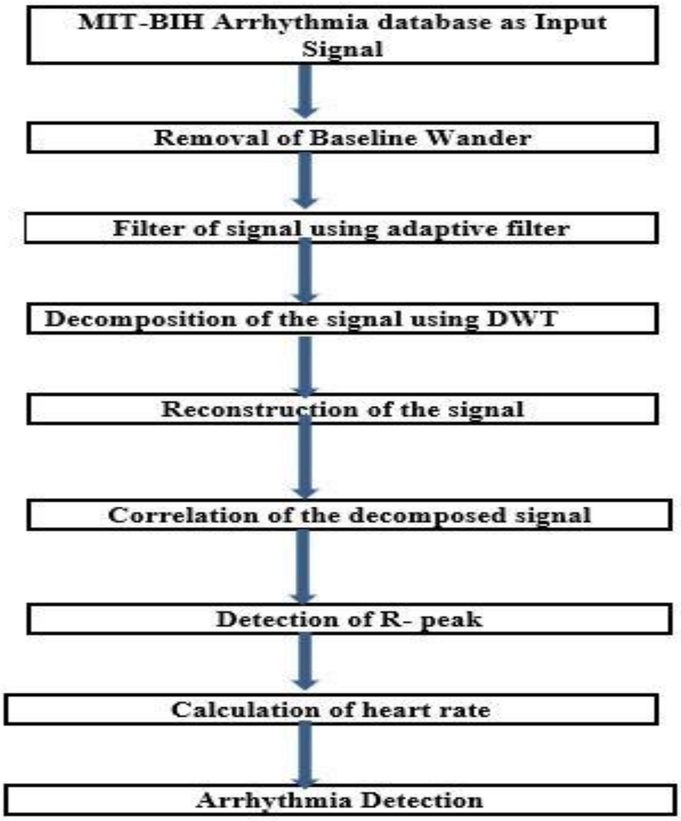

Figure 3 Flowchart of DWT Stages

b. QRS Complex Detection

Most of the important information related to the heart signal is associated with the QRS complex that lies between 3 Hz to 40 Hz [9].

The coefficient of wavelet scale levels from 1 to 8 is shown in series of figure 4. The decomposed signal that is the detail coefficient and approximation coefficient is extracted from the signal using DWT.

To choose the optimal coefficient the correlation coefficient is compared between all the individual decomposition signals with the original extracted ECG signal using percentage cross-correlation equation (3) as given below

$$CR = \frac{\sum_{j}^{n} x(j)y(j)}{\sum_{j=1}^{n} x(j) * \sum_{j}^{n} y(j)} * 100 \qquad (3)$$

Here

X → is the input signal i.e. original ECG signal

Y → is the reconstructed ECG signal with d4 coefficient

The coefficient with the highest cross-correlation is selected from the table 2. The highest cross correlation percentage is found with D_5 coefficient. The table2 shows the percentage of the detail coefficient

4. RESULT AND CALCULATION

The ECG signal used for the algorithm is available on Physionet.org section of MIT-BIH arrhythmia database and all selected signal is having a sampling frequency of 360 Hz to analyse and check the performance of the presented algorithm. Table 3 below shows the list of selected signals and the sensitivity achieved by the presented algorithm.

The sensitivity (Se) of the result is calculated statically that also help in checking the algorithm. The sensitivity is calculated using simple formula as shown in equation (4).

$$S_e = \frac{T_P}{T_P + F_N} \quad (4)$$

Here
T_P → True Positive
F_N → False Negative

Table 3 Calculated Results

ECG signals	T_B	T_P	F_N	S_e
106	1507	1497	10	99.3%
118	2166	2152	14	99.4%
119	1987	1982	5	99.7%
203	2531	2351	0	100%
123	1515	1492	23	98.5%
All	9706	9474	52	99.3%

The following step below is summary of the proposed algorithm for detection of QRS complex and R peak of ECG signal through direct wavelet transform and arrhythmia detection

- As the raw ECG signal is comprised of noise, so the signal is denoised using a Discrete Wavelet Transform (Daubechies wavelet db4).
- Correlation of the extracted detail coefficient and choosing the best detected wavelet detail coefficient among the all detail coefficient.
- The R-peak detection is done first by locating the point of every sample and selecting the prominent peak of the signal i.e. the sample greater than the defined threshold of 19% of max_peak of detail coefficient D_5.
- Now the whole sample length of signal is analysed as: if the length of the signal length is greater than given length of the signal minus one and signal length greater than signal length plus one and signal is greater than 19% of max_peak(D_5) and the beat is count is incremented by one for every detected peak.
- To calculate the beat count per minute the count is divided by the signal time span in a minute. The rate of detection of the presented algorithm is better than some of the result such as [13] (average of 95.74%) and [14] (96.65%) and [15] 98.1%. The presented algorithm can be improved and expand to extract other important features of ECG signal such as P & T -wave, ST-segment.

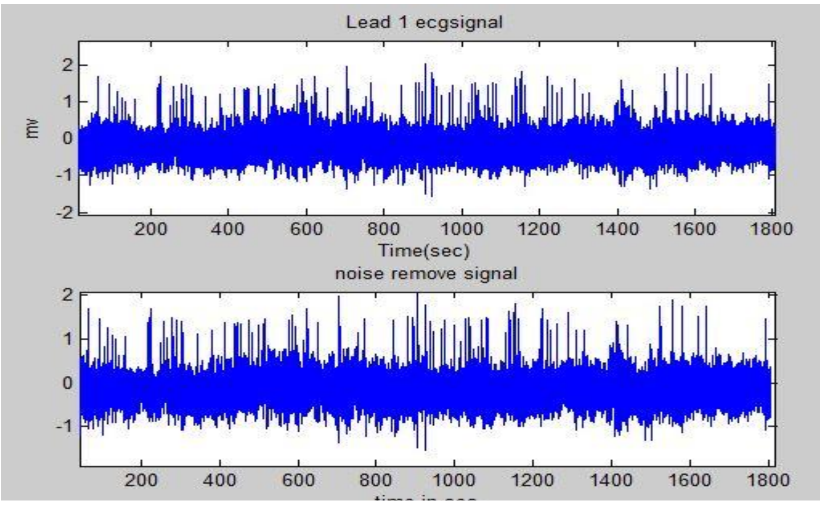

Figure 4. ECG signal with noise and ECG filtered signal

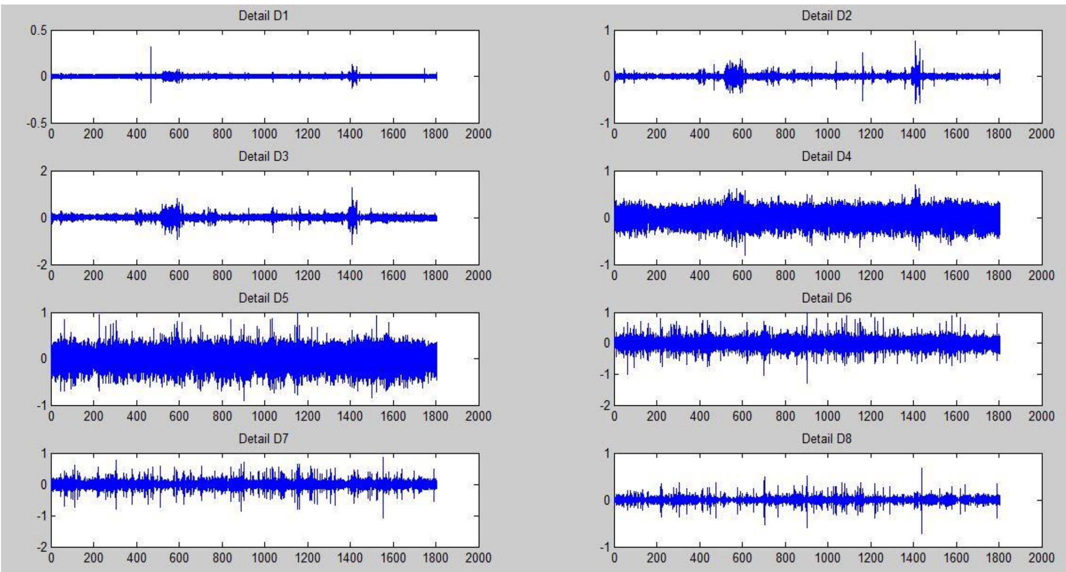

Figure 5. Detail coefficient signals

5. CONCLUSION AND FUTURE WORK

In this paper, the analysis of ECG signal for detection of QRS complex is done by DWT. The comparison between all the extracted detail coefficients of signal is done by cross-correlation with original signal. The proposed algorithm is a simple and required less computation time with better detection sensitivity that produces a result of overall average sensitivity of 99.33%. If beats per minute (BPM) are less or greater than the predetermined medical value then arrhythmia is detected like Bradycardia, tachycardia. In future, the proposed algorithm can be extended to identify various other kinds of heart related abnormalities by using statistical methods and features extraction technologies.

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