Global Journal of researches in engineering
Electrical and electronics engineering
Volume 12 Issue 1 Version 1.0 January 2012
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Real Time Implementation of Analysis of Ecg Characteristic Points Using Discrete Wavelets

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GJRE-F Classification: FOR Code: 090609

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I. Introduction

The ECG is a graphic record of the direction and magnitude of the electrical activity that is generated by depolarization and repolarization of the atria and ventricles.[1] One cardiac cycle in an ECG signal consists of the P-QRS-T waves. To find a heart disease, physicians inspect ECG for the existence of abnormal patterns like irregular beat, inter- atrial block, ST level change, morphologic change, and so on. However, bio-signals being non-stationary signals, the reflection may occur at random in the time-scale (that is, the disease symptoms may not show up all the time, but would manifest at certain irregular intervals during the day). From the practical point of view, for the effective diagnostics, the study of ECG parameters have to be carried out over several hours. The volume of the data being enormous, the study is tedious and time consuming and the possibility of the analyst missing the vital information is high. Hence, computer based analysis and classification of diseases can be very helpful in diagnosis.

A large number of techniques exist in the literature for the automatic detection and classification of ECG beats, P wave features and myocardial ischemia through the identification of ST deviations and P -wave variations in the ECG. These include the use of Time Domain Approaches, Artificial Neural Networks, Principal Component Analysis, Fuzzy and Neuro-Fuzzy Systems etc.

While the use of wavelets for analysis and classification of biomedical signals, including some components of the ECG, are well documented [6, 7]. Wavelets offer an important information-rich parameterization method for data reduction of the ECG time-series [8]. Recently, of the number of techniques proposed to detect these features, our procedure using discrete wavelets proved to be one among the best.

II. Electrocardiogram

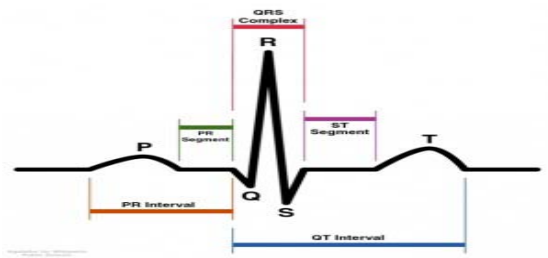

Fig 1 : ECG waveform

An electrocardiogram (ECG) is a graphical record produced by an electrocardiograph, which records the electrical activity of the heart over time. The signal is constructed by measuring electrical potentials between various points of the body using a galvanometer. Understanding the various waves and normal vectors of depolarization and repolarization is very important to obtain useful diagnostic information. ECG signals have a wide array of applications throughout the medical field in determining whether the heart is functioning properly or suffering from any abnormalities. Fig.1 shows an example of a normal ECG trace, which consists of a P wave, a QRS complex and a T wave. The P wave is the electrical signature of the current that causes atrial contraction; the QRS complex corresponds to the current that causes contraction of the left and right ventricles. The T-wave results from the current generated during rapid repolarization of the heart.

a) P-wave features

This is a recording of atrial depolarisation. Most

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of the time this starts in the sinoatrial (SA) node and the predominant direction of the impulse across the atria is inferiorly and from right to left. This generates a positive deflection in the leads that look at the heart from below. A typical P wave is is 0.06 to 0.10 sec (60 to 100 ms) in duration and is 0.2 mv to 0.3 mv in amplitude. As five of the six chest leads are mostly on the left side of the body and in approximately the same vertical plane there will generally not be much difference in the P-wave in these leads with small positive deflections seen in each. Lead V1 looks across the atria and sees the atrial depolarisation pass across its view. Thus the P-wave typically has a biphasic waveform in this particular lead. Occasionally, if there is damage to the SA node, the initiation of the electrical activity can arise from other parts of the atria. If this is lower down in the atria the impulse has to move in the opposite direction to normal. In these circumstances P-wave deflections are in the opposite direction. The P-wave can be thought to have two components. The first half of the P-wave is made mainly by the right atrium. The second half comes from the left atrium. The best two leads to examine the P-wave are leads II and V1 as they look at the atria in opposite directions. These two leads are typically used as rhythm strips as they emphasis the P-wave. (Lead II looks along the axis of the atria, and V1 looks across the atria.) Disease processes that cause strain on the right atrium cause a typical enlargement of the first half of the P-wave. This gives a taller, peaked P-wave. Lung disease could lead to right atrial strain and thus this tall P-wave is known as P pulmonale. Enlargement of the left atrium causes exaggeration of second part of the P-wave and this leads to the typical bifid "m" shape in lead II, and larger negative deflection in second part of the P-wave in lead V1. This is called P mitrale.

b) QRS Complex

The QRS complex is a structure on the ECG that corresponds to the depolarization of the ventricles. Because the ventricles contain more muscle mass than the atria, the QRS complex is larger than the P wave. In addition, because the His/Purkinje system coordinates the depolarization of the ventricles, the QRS complex tends to look "spiked" rather than rounded due to the increase in conduction velocity. A normal QRS complex is 0.06 to 0.10 sec (60 to 100 ms) in duration. Not every QRS complex contains a Q wave, an R wave, and an S wave. By convention, any combination of these waves can be referred to as QRS complex.

i. *Tachycardia*

Tachycardia typically refers to a heart rate that exceeds the normal range for a resting heart rate. Ventricular tachycardia is a potentially life-threatening cardiac arrhythmia that originates in the ventricles. It is usually a regular, wide complex tachycardia with a rate between 120 and 250 beats per minute. a. Some tachycardias are relatively harmless and need no treatment, but others can be life- threatening [22]. Ventricular tachycardia is a common, and often lethal, complication of a myocardial infarction (heart attack).

ii. *Bradycardia*

A slow rhythm, (less than 60 beats/min), is labeled Bradycardia. This may be caused by a slowed signal from the sinus node (termed sinus Bradycardia), a pause in the normal activity of the sinus node (termed sinus arrest), or by blocking of the electrical impulse on its way from the atria to the ventricles (termed AV block or heart block). Bradycardia may also be present in the normally functioning heart of athletes or other well conditioned persons. Sinus bradycardia is an unusually slow heartbeat where the normal pacemaker is still in control. This commonly occurs in athletes or during a state of deep relaxation. However, the slowing of the heart rate can also be abnormal. [23]

iii. *Bundle branch block*

A bundle branch block refers to a defect of the heart's electrical conduction system. Prompted by the clinical impression that patients with right bundle branch block have a better prognosis than do those with cardiographic evidence of a left bundle lesion. [24]. When a bundle branch or fascicle becomes injured (due to underlying heart disease, myocardial infarction, or cardiac surgery), it may cease to conduct electrical impulses appropriately. This results in altered pathways for ventricular depolarization. Since the electrical impulse can no longer use the preferred pathway across the bundle branch, it may move instead through muscle fibers in a way that both slows the electrical movement and changes the directional propagation of the impulses. As a result, there is a loss of ventricular synchrony, ventricular depolarization is prolonged, and there may be a corresponding drop in cardiac output.

iv. *Ventricular fibrillation*

Ventricular fibrillation occurs in the ventricles (lower chambers) of the heart; it is always a medical emergency. If left untreated, ventricular fibrillation can lead to death within minutes. When a heart goes into V-fib, effective pumping of the blood stops. V-fib is considered a form of cardiac arrest, and an individual suffering from it will not survive unless cardiopulmonary resuscitation (CPR) and defibrillation are provided immediately. Ventricular Fibrillation (VF) and Ventricular Tachycardia (VT) are life-threatening cardiac arrhythmias generally observed in adults with coronary artery disease[21].

c) ST-SEGMENT

The ST segment represents the time between the ventricular depolarisation and the repolarisation. The ST segment begins at the end of the QRS complex (called J point) and ends at the beginning of the T wave. Normally, the ST segment measures 0.12 second or less. The precise end of depolarisation (S) is difficult to determine as some of the ventricular cells are beginning to repolarise. Abnormalities of the ST segment may

consist of either abnormal straightening, depression, or elevation. ST segment changes can be caused by serious impairments such as hypertension or coronary artery disease.

i. *Myocardial Ischemia*

Heart disease is the one of the leading causes of death all over the world with Myocardial Ischemia and Infarction (collectively called Coronary Heart Disease or CHD) being the most common among these cardiac disorders. Myocardial Ischemia and Infarction stem from the insufficient supply of blood to the heart muscle (myocardium) due to blockages in the coronary artery, which is responsible for providing blood to the heart. The development of plaque within the coronary artery that blocks more than 7000 of the lumen of the vessel can cause symptoms of Myocardial Ischemia, such as decreased exercise tolerance and exertional angina to appear. At times this may be the first instance where the subject begins to experience effects of the suboptimal operation of the heart due to decreased blood supply. As large areas of the heart muscle become ischemic, its relaxation and contraction patterns are affected which causes variations in the ST-level and T-wave in the Electrocardiogram (ECG) due to the development of an injury current [10] between the ischemic and non-ischemic regions of the heart. If the blood supply to the heart muscle is restored, Myocardial Ischemia can be reversed thus making the early and correct diagnosis of Myocardial Ischemia an imperative task. Myocardial Infarction, however, is not reversible and represents the death of heart muscle due to prolonged lack of blood supply to the heart.

III. Wavelet Transform

Wavelets are a powerful tool for the representation and analysis of such physiologic waveforms because a wavelet has finite duration (compact support) as contrasted with Fourier methods based on sinusoids of infinite duration. It is possible to analyse any signal by using an alternative approach called the multi resolution analysis (MRA). MRA, as implied by its name, analyses the signal at different frequencies with different resolutions. Every spectral component is not resolved equally as was the case in the STFT. MRA is designed to give good time resolution and poor frequency resolution at high frequencies and good frequency resolution and poor time resolution at low frequencies. The Wavelet analysis does this by using a windowing technique with variable-sized regions. Discrete wavelet transform (DWT) is obtained simply by passing a discrete signal through a filter bank.

Wavelet theory can be understood and developed only by using such digital filters[4]. This is the meeting point between wavelets and sub band coding and the origin of two different nomenclatures for the same concepts. In fact, wavelet transform and sub band coding are so closely connected that both terms are often used interchangeably. Filter banks are structures that allow a signal to be decomposed into sub signals through digital filters, typically at lower sampling figure 2 shows a two-band filter bank.

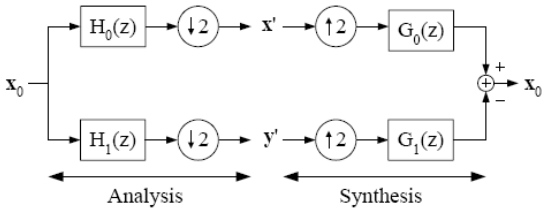

Fig 2 : One-level two band perfect reconstruction filter bank.

The DWT analyses the signal at different resolution (hence, multiresolution) through the decomposition of the signal into several successive frequency bands. The DWT utilizes two set of functions ø(t) and Ψ(t), each associated with the low pass and the high pass filters respectively [11].These functions have a property that they can be obtained as the weighted sum of the scaled (Dilated) and shifted version of the scaling function itself:

$$\phi(t) = \sum_n h[n]\phi(2t - n) \quad (1)$$

$$\psi(t) = \sum_n g[n]\phi(2t - n) \quad (2)$$

Here, h[n] and g[n] are the half band low pass filter and high pass filter respectively.

IV. Methodology

The block diagram shown below are the steps to detect and extract the P, QRS, ST segment .The individual steps are described separately in the following topics.

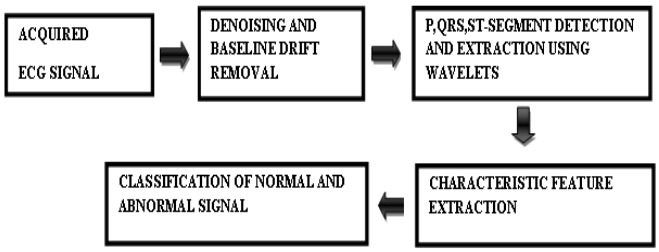

Fig 3 : Block Diagram of ECG characteristic points extraction

a) Denoising And Baseline Drift Removal

The ECG signal is acquired using Biokit physiograph and abnormal data are collected from www.physionet.org. Pre-processing of ECG signals helps us to remove unwanted components in ECG comprises of Power line interference, Electrode pop or

contact noise, Patient–electrode motion artifacts, Electromyographic (EMG) noise, Baseline wandering.

Among these noises, the power line interference and the baseline wandering are most significant and can strongly affect ECG signal analysis. The power line interference is a narrow-band noise centered at 60 Hz (or 50 Hz) with a bandwidth of less than 1 Hz. Usually the ECG signal acquisition hardware can remove the power line interference. However the baseline wandering and other wideband noises are not easy to be suppressed by hardware equipments. Instead, the software scheme is more powerful and feasible for offline ECG signal processing. Digital filtering methods as well as wavelet based methods are used to remove baseline wandering and the other wideband noise.

Pre-processing is done by three different methodologies. To facilitate P wave extraction the baseline drift is removed using a 4th order low-pass Butterworth filter with a 3 dB cut-off at 0.05 Hz. To aid QRS complex extraction, the baseline wandering and the above noises are removed by taking two approximation level coefficients such as A4 and A10 of Daubechies wavelet. Because of increasing the levels of decomposition the baseline wander gets corrected automatically. Moving Average Algorithm is used to remove the baseline drift and discrete wavelets are used to remove the noises for ST segment detection.

b) P Wave Extraction

P-wave extraction or isolation can be performed by various methods like Emperical Mode Decomposition (EMD), Fast Fourier Transform, Dyadic Transform, Application of time window or a moving average filter etc. Here P wave extraction, was performed by using Daubechies wavelets.

c) QRS Complex Extraction

i. *R peak detection*

Peaks of the R waves in signals from the MLII lead have the largest amplitudes among other leads. In order to detect the peaks, specific details of the signal were selected. Details 2^3 – 2^5 were kept and all the details were removed. This procedure removes low frequencies and high frequencies. The attained signal samples were then squared. High amplitude transitions of the signal were then more noticeable, even if R peaks are deformed. Then a practically lower limit is applied on the signal to remove unrelated noisy peaks. Since no subsequent beats will occur in less than 0.25 second, pseudo-beats are also removed. Detection of R peaks is very important because they define the cardiac beats. Heart rate is the important parameter that is detected for analyzing the abnormality in the heart. Heart rate is calculated based on R-R interval.

ii. *QRS complex extraction*

For QRS complex extraction the denoised ECG signal is decomposed into 6 levels by using DWT and the approximation (A4 and A6) coefficients are reconstructed separately. By subtracting A6 from the A4, QRS complex is extracted.

d) St-Segment Detection By Fft Approach

An FFT computes the DFT and produces exactly the same result as evaluating the DFT definition directly; the only difference is that an FFT is much faster. The DFT is defined by the formula. [12][13]

$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N} kn} \qquad k = 0, \ldots, N-1 \qquad (1)$$

And the FFT is given by-

$$X(k) = \sum_{j=1}^{N} x(j)\omega_N^{(j-1)(k-1)} \qquad (2)$$

Inverse discrete Fourier transform (IDFT) is given by

$$x_n = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{\frac{2\pi i}{N} kn} \qquad n = 0, \ldots, N-1. \qquad (3)$$

Where as the IFFT can be formulated as-

$$x(j) = (1/N) \sum_{k=1}^{N} X(k)\omega_N^{-(j-1)(k-1)} \qquad (4)$$

Fast Fourier transform (FFT) is speed-up technique for calculating discrete Fourier transform where DFT, which in turn is discrete version of continuous Fourier transform, which indeed is origin for all its versions. So, historically continuous form of the transform was discovered, then discrete form was created for sampled signals and then algorithm for fast calculation of discrete version was invented.

ALGORITHM

1) As one can see the ECG is uneven. Thus our first step is to straighten it. The idea is to apply direct fast Fourier transform (FFT), remove low frequencies
2) Restore ECG with the help of inverse FFT (IFFT).
3) Our third step is to find local maxima. To do that we use windowed filter that “sees” only maximum in his window and ignores all other values. On this step we use window of default size.
4) Now we should remove small values and preserve significant ones. Here we are using a threshold filter.
5) In this case the result is good but in general case we cannot be sure we have all the peaks. So the next step is to adjust filter window size and repeat filtering. (All peaks of the signal detected)
6) Find all the peaks (R-peaks) values.
7) Create two temporary matrixes according to length of the input sequences.

8) Move the two matrixes (naming i.e. current and next) from the peak value towards down and compare the current and next matrixes value. It should decreases from top to bottom.
9) When these two values became equal or started increasing; at that point we will get the S or J point.
10) The same process can be repeated for T onset point detection or considering the sampling rate of the signal we can get T onset by adding sample value from S/J point (here we can get T-onset by adding 150 samples).

This technique is called as falling edge method and a small demerit of this method is that here we have to consider S and j point as same. As our main motto is to find out Ischemia, so this method can be useful because in most of the cases; as the S and J point is same in Ischemic condition. This method can also be implemented for other ECG signals like (ST Segment starting from J point) and we can analyses the problems with accuracy. [14]

i. *Wavelet Compression*

Instead of submitting the ST segments directly to the classification phase, they were pre-processed to reduce the number of classifier parameters. Pre-processing was performed by using biorthogonal wavelets, bior1.1 and bior2.2, with decomposition levels from 1 to 3.

In many filtering applications we need filters with symmetrical coefficients to achieve linear phase. None of the orthogonal wavelet systems except Haar are having symmetrical coefficients. But Haar is too adequate for many practical applications. Biorthogonal wavelet systems can be designed to have this property. This is our motivation for designing such wavelet system. But the price is that non-zero coefficients in analysis filters and synthesis filters are not same. In orthogonal wavelet system, Ø(t) is orthogonal to Ψ(t) and its translates. In biorthogonal system our requirement is that Ø(t) be orthogonal to Ψ'(t) and its translates.

e) Characteristic Feature Extraction And Classification

To classify the abnormalities of the P wave, QRS complex, ST segment some features are extracted. Some of the features like amplitude, frequency, energy, Heart rate are extracted. These are given to the neural network classifier for the classification. The abnormalities like atrial block, Tachycardia and Bradycardia, Bundle block, ventricular fibrillation, ischemia can be detected.

V. Results

The algorithm for P wave extraction, R peak detection, QRS complex extraction, ST segment detection of ECG signal is implemented using MATLAB and LabVIEW. The wavelet analysis helps to find all the intervals in the ECG signal, which helps in detecting various cardiac abnormalities.

a) Matlab Simulation Results

i. *Baseline Drift Removal And Noise Cancellation*

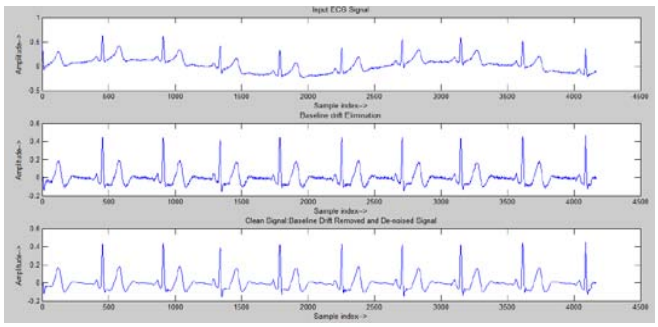

Fig 4 : Performing Baseline Drift removal and Noise cancellation.

ii. *P Wave Extraction*

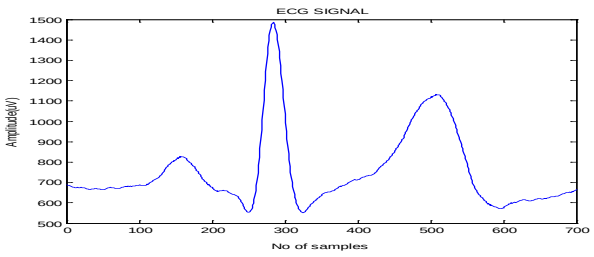

Fig 5 : A single ECG signal

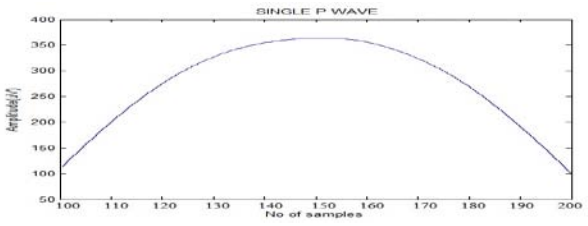

Fig 6 : Isolated P wave

iii. *Qrs Complex Extraction*

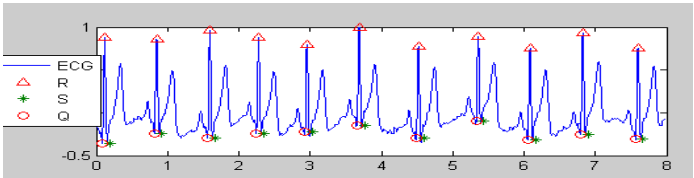

Fig 7 : QRS detected signal

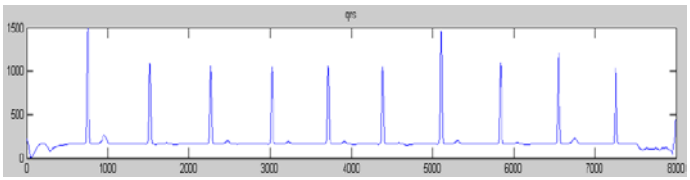

Fig 8 : Extracted QRS complex

iv. *St-Segment Detection*

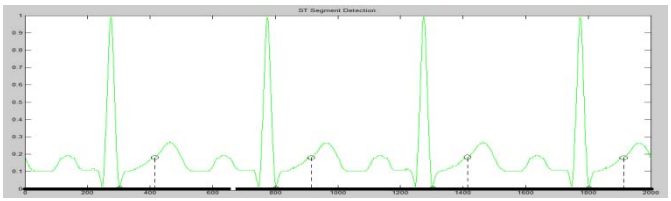

Fig 9 : ST Segment Detection of Standard or Normal ECG Signal

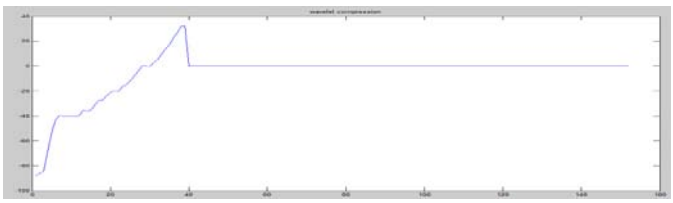

Fig10 : Level-2 Wavelet Decomposed ST-Segment of Normal ECG signal.

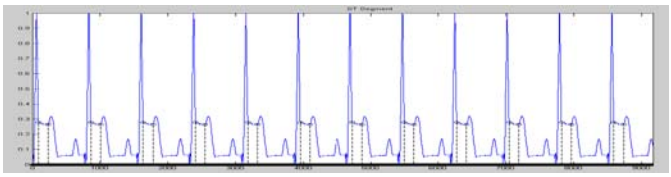

Fig 11 : ST- Elevated Segment Detection (J-point & T-onset point)

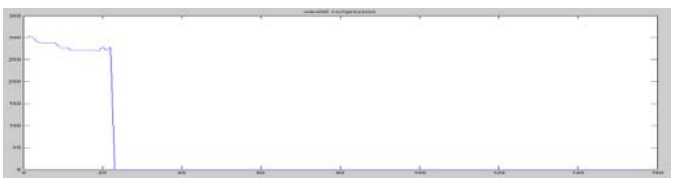

Fig 12 : Level-3 Wavelet Decomposed ST-Elevated Segment.

b) Labview Simulation Results

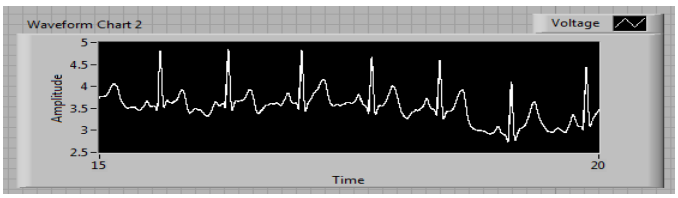

Fig 13 : ECG signal acquired from Biokit using DAQ

Fig 14 : ECG signal after baseline correction and noise removal

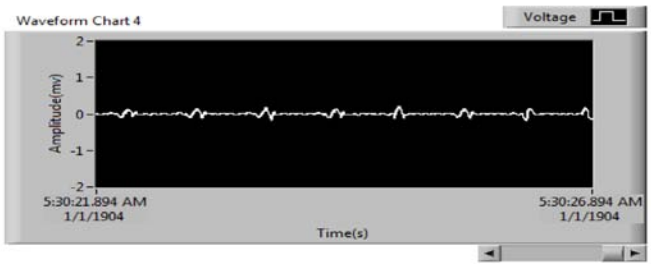

Fig 15 : ECG signal with P waves

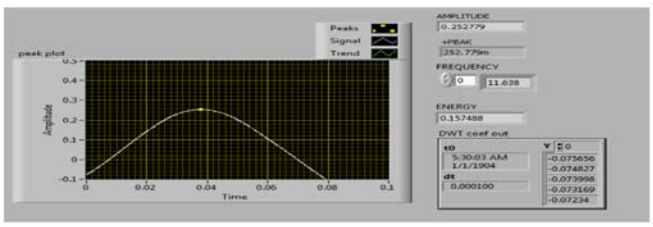

Fig 16 : Isolated P wave and its characteristics

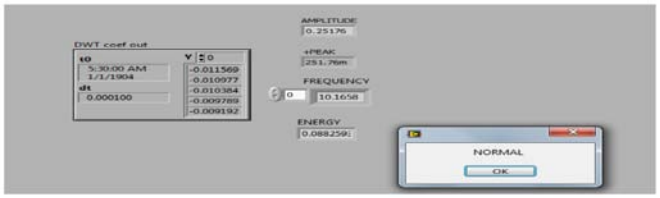

Fig17 : Classification of the signal as normal using neural netwoks

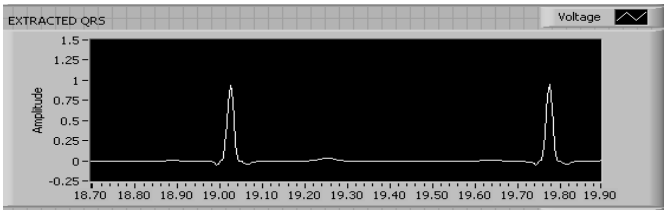

Fig 18 : Extracted QRS complex

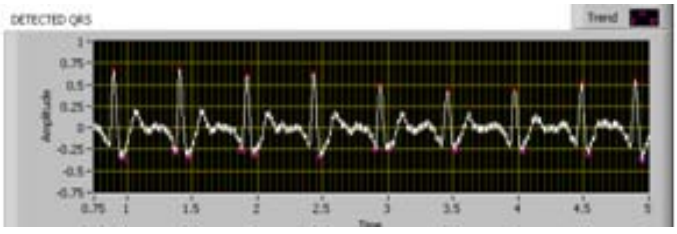

Fig 19 : QRS complex detection in Tachycardia signal

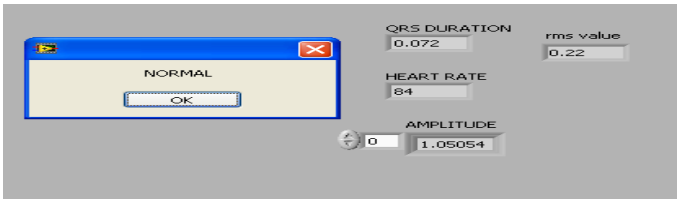

Fig 20 : BPN classification- Normal signal

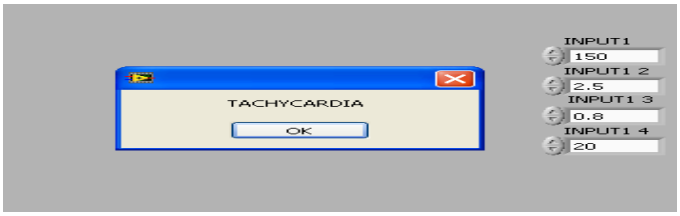

Fig 21 : BPN classification -Tachycardia signal

VI. Conclusion and Future Enhancement

In this paper, we have proposed an algorithm based on discrete wavelet transform for the extraction of P wave, QRS complex, ST segment. T wave extraction and analysis is currently under our research.The above wavelet technique provides less computational time and better accuracy for classification, analysis and characterization of normal and abnormal patterns of ECG. The automatic feature extraction and classification was implemented using MATLAB and Lab VIEW. So this feature extraction method can be used as a primary measurement tool for automatic and on line disease classification. But some of the ECG waveform may show very erratic nature due to electrode contact noise or some complicated cardiac abnormalities. The algorithm is not tested with them because of lack of availability of that special kind of database.

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