Robust Detection of R-Wave Using Wavelet Technique

Awadhesh Pachauri, and Manabendra Bhuyan

Abstract—Electrocardiogram (ECG) is considered to be the backbone of cardiology. ECG is composed of P, QRS & T waves and information related to cardiac diseases can be extracted from the intervals and amplitudes of these waves. The first step in extracting ECG features starts from the accurate detection of R peaks in the QRS complex. We have developed a robust R wave detector using wavelets. The wavelets used for detection are Daubechies and Symmetric. The method does not require any preprocessing therefore, only needs the ECG correct recordings while implementing the detection. The database has been collected from MIT-BIH arrhythmia database and the signals from Lead-II have been analyzed. MatLab 7.0 has been used to develop the algorithm. The ECG signal under test has been decomposed to the required level using the selected wavelet and the selection of detail coefficient d4 has been done based on energy, frequency and cross-correlation analysis of decomposition structure of ECG signal. The robustness of the method is apparent from the obtained results.

Keywords—ECG, P-QRS-T waves, Wavelet Transform, Hard Thresholding, R-wave Detection.

I. INTRODUCTION

THE graphical tracing of depolarization and repolarization activities generated by the heart gives rise an Electrocardiogram (ECG) that can be measured by placing an array of 12 different electrodes referred as ECG leads on the body surface of a patient. Long term ECG recordings are performed by monitoring ECG signals from one or two leads in order to monitor any abnormal cardiac rhythm that cannot be observed during normal ECG test. This typical tracing consists of a series of repetitive waves namely P-QRS-T and sometimes U waves that arises from isoelectric line, this indicates electrical activity. Each of these waves has an important relation with the heart, with P-wave representing depolarization of atria, QRS complex representing ventricular depolarization and T-wave is associated with ventricular repolarisation.

Cardiologists look for life threatening disturbances in the intervals, amplitudes and areas of these waves recorded from the surface electrocardiogram. QRS complex is the most prominent feature in electrocardiogram because of its specific shape; therefore it is taken as a reference in ECG feature

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extraction. R wave detectors are very useful tools in analyzing ECG features thus form the basis of ECG feature extraction.

Modern era of medical science is supported by computer aided feature extraction and disease diagnostics in which various signal processing techniques have been utilized in extracting features from the biomedical signals and analyzes these features. The objective of computer aided digital signal processing of ECG signal is to reduce the time taken by the cardiologists in interpreting the results.

Various ECG feature extraction techniques have been developed so far which have their own merits and demerits. Some methods consist of series of band pass filters having frequency range of QRS complexes but these methods have limited accuracy in analyzing ECG features in presence of high frequency noise as well as the ECG signal affected by severe base line drift. Some techniques involve Artificial Neural Networks but their implementation is difficult because of their long learning phase. For practical purposes, the detector must withstand against any kind of noise and physiological changes in the graphical tracing of cardiac excitation and delivering the results promptly with accuracy.

The method developed by Li et al [1] involves preprocessing of initial QRS beats to select modulus maxima greater than threshold and post processing to remove the unrelated noisy peaks appearing as R-waves. The method uses four thresholds for the detection of modulus maxima at four different scales. Mahmoodabadi et al [2] suggest the selection of details d3-d5 for R-Wave detection, whereas S.C.Saxena et al [3] employs detail signal d4 for detection of QRS peak. The method described in this paper is robust and simple to implement with no requirement of preprocessing and the selection of detail signal d4 has been justified by energy, frequency and correlation analysis. Further, attempt is made to calculate total number of R waves using hard thresholding.

II. MATERIAL

A. Wavelet Transform

In wavelet transform, a linear operation transforms the signal to decompose it at different scales. In case of discrete wavelet transform (DWT), filters of different cut-off frequencies are used for analyzing the signal at different scales. For this purpose, the signal is passed through a series of highpass and lowpass filters in order to analyze low as well as high frequencies in the signal.

Filtering operations change the resolution of the signal [4] whereas sub sampling (down sampling/up sampling) results in the change of the scale. That is why in case of DWT the signal is analyzed at different frequency bands with different

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resolution by decomposition into coarse and detail information. In DWT, there are two sets of functions namely scaling and wavelet functions corresponding to lowpass filter and highpass filters. The decomposition of the signal by the wavelets results the components with respect to frequency content in the original signal. The hierarchy of wavelet decomposition is shown in Fig. 1.
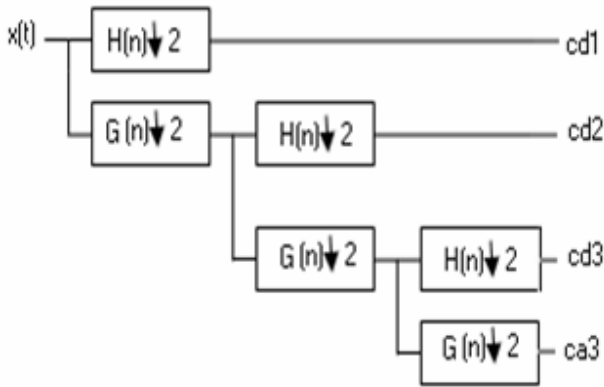

Fig. 1 Wavelet Decomposition Stages

We can write a general transformation equation [3] as follows:

$$x(a,b) = \int_{-\infty}^{\infty} x(t)\psi_{a,b}(t)dt \qquad (1)$$

Where x(t) is the given signal to be processed. For wavelet transform, the function ψ(t) is given by:

$$\psi_{a,b}(t) = \left(\frac{1}{\sqrt{a}}\right) \times \psi\left(\frac{t-b}{a}\right) \qquad (2)$$

Where $\psi_{a,b}(t)$ is a window of finite length, 'b' is a real number known as window translation parameter and 'a' is a positive real number called as dilation or contraction parameter.

Thus continuous wavelet transform (CWT) of the signal x(t) can be written as:

$$X_w(a,b) = \left(\frac{1}{\sqrt{a}}\right)\int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-b}{a}\right)dt \qquad (3)$$

Where * denotes the complex conjugation [4]. In other words, it can be viewed as a measure of similarity between the signal and wavelet.

The admissible conditions for ψ (t) as mother wavelet are as follows [5]:

• It must have finite energy.

$$E = \int_{-\infty}^{\infty} |\psi(t)|^2 \, dt < \infty \qquad (4)$$

• If $\hat{\psi}(f)$ is the Fourier Transform of ψ(t) i.e.

$$\widehat{\psi}(f) = \int_{-\infty}^{\infty} \psi(t)e^{-i(2\pi f)}dt \qquad (5)$$

Then the following condition must hold

$$C_g = \int_0^{\infty} \frac{|\widehat{\psi}(f)|^2}{f}df < \infty$$

• Fourier Transform must be real and vanish for negative frequencies. It is convenient to analyze the signal if the wavelet is dilated and contracted because the time-frequency plane can be conveniently covered for the dilation and contraction [6].

Wavelet transform is popular because it satisfies energy conservation law and original signal can be reconstructed [7].

B. Wavelet Selection

The selection of relevant wavelet is an important task before starting the detection procedure. But there is no universal method suggested to select a particular wavelet. The choice of wavelet depends upon the type of signal to be analyzed. The wavelet having similar look to the signal being analyzed is usually chosen [2]. The are several wavelet families like Harr, Daubechies, Biorthogonal, Coiflets, Symlets, Morlet, Mexican Hat, Meyer etc. and several other Real and Complex wavelets. However, Daubechies (db6) and Symlets (sym11) family of wavelets have been found to give details more accurately than others. Moreover, these wavelets show similarity with QRS complexes and energy spectrum is concentrated around low frequencies [2]. Therefore, we have chosen the above two mentioned wavelets for extracting ECG features in our application.

C. Database

For the analysis of detector performance, it is necessary that a standard database must be chosen so that the obtained results can be interpreted with respect to that manually annotated database. ECG signals required for analysis are collected from Physionet MIT-BIH arrhythmia database [8] where annotated ECG signals are described by- a text header file (.hea), a binary file (.dat) and a binary annotation file (.atr). Header file consists of detailed information such as number of samples, sampling frequency, format of ECG signal, type of ECG leads and number of ECG leads, patients history and the detailed clinical information. In binary data signal file, the signal is stored in 212 format which means each sample requires number of leads times 12 bits to be stored and the binary annotation file consists of beat annotations [8].

III. METHOD OF DETECTION

ECG signals (.dat files) downloaded from Physionet are first converted in to MatLab readable format (.mat files). The signals from both leads now become readable separately. Then the signals from lead-II are only taken for our analysis. Detection process is performed on forty two records from lead-II and completed in the following steps-.

A. Decomposition of Signal

The signal under test is decomposed up to a desired level depending upon dominant frequency components in the signal. The choice of desired level of decomposition is dependent on whether the required frequency components for analysis are available in the wavelet coefficient at that level. The maximum number of decomposition levels depends upon the

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TABLE I
DESCRIPTIONS OF RECORD 100.DAT

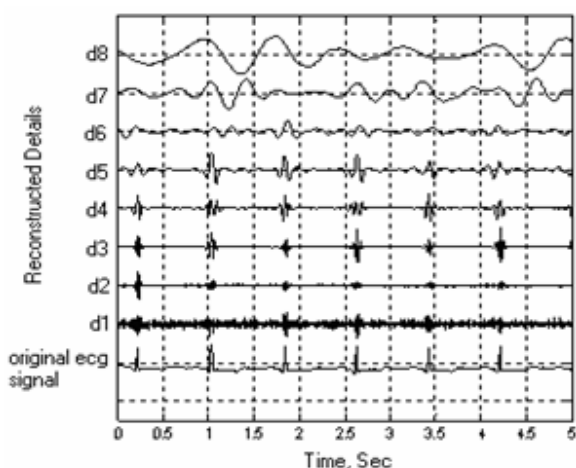| Beats	Before 5:00	After 5:00	Total
Normal	367	1872	2239
APC	4	29	33
PVC	-	1	1
Total	371	1902	2273

Fig. 2 Decomposition of ECG signal using 'db6' wavelet for 100.dat

total number of samples present in the signal. The relationship can be expressed as-

$$2^N = n$$

Where N = total number of levels of decomposition,

n = total number of samples in the signal to be expressed as power of 2 for full decomposition of the signal.

As an example the signal descriptions of 100.dat are shown in Table I.

The wavelet decomposition structure of 100.dat using db6 wavelet is shown in Fig. 2. The waveform shows signals decomposed up to 8 levels only. Although the original signal is of 30 minutes duration, for better illustration, details are scaled and signal is shown for five seconds duration only. The original signal is shown at the bottom of the plot above which details of eight wavelet scales are shown.

B. Selection of Detail Coefficient (d4)

The detail coefficient d4 has been chosen to detect R wave based on the following analysis-

• *Energy Analysis* Most of the energy of a normal ECG signal is concentrated within the interval of about 80 ms spanned by QRS complex and having a frequency range of 2-45 Hz. Normally isoelectric segments- PQ, ST and TP contain no energy and the signal amplitude is zero over these corresponding intervals. The energy content for the decomposed levels of 100.dat is calculated and the plot is shown in Fig. 3.

During energy analysis of ECG signal, the signal has been decomposed up to the maximum level depending upon the

length of the signal to be expressed as maximum power of 2 and zero padding to the signal under test is avoided in order to express length of the signal as the integer power of 2. This is needed because after zero padding, the energy is observed as highest at higher level of decomposition where information related with QRS complexes is irrelevant.

The energy plot shows that the energy is highest at level-4. Therefore, we consider that d4 carries the dominant details of QRS complexes. The sum of energy of all detail coefficients and the remaining one approximation is equal to the energy of
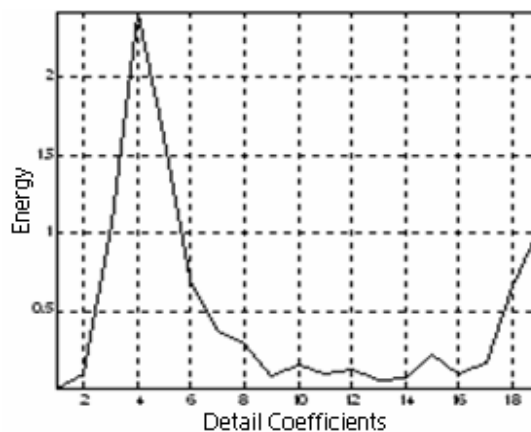

Fig. 3 Energy plot of wavelet decomposition structure of 100.dat

a single ECG record under test. Therefore, this energy level diagram of decomposition structure proves the energy conservation principle of wavelet transform. It means that original signal can be faithfully reproduced from the decomposed components and the information in the original signal is preserved during decomposition.

• *Frequency Analysis* Another justification of selecting d4 signal is its available frequency components correlated with that of the QRS complex. Therefore the Fourier Transform of the d4 signal is performed which is shown in Fig.4. The bandwidth of the d4 signal is found to be 2.5 – 39.5 Hz which is almost same as that of a QRS complex. Therefore we have chosen d4 signal of 100.dat for our further analysis.
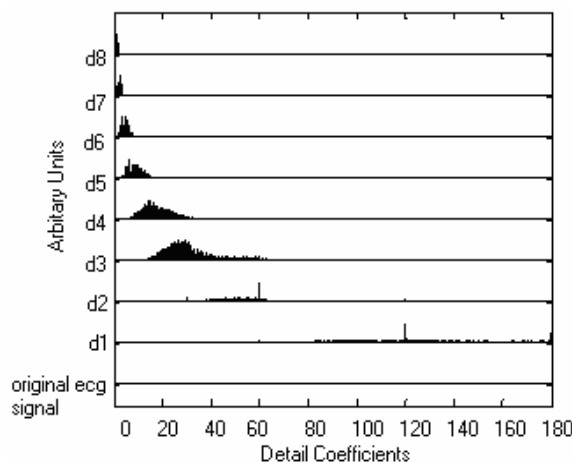

Fig. 4 Frequency distribution of details and ECG signal

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- *Correlation Analysis* In addition to the above two analysis, the cross-correlation analysis between all the decomposed signals individually with the original ECG signal was performed. This provides us the time domain relationship between the original and the decomposed signals. The values are shown in Table II.

TABLE II
CROSS-CORRELATION COEFFICIENTS

Details	Cross correlation coefficients
d1	0 .0247
d2	0.1127
d3	0.3858
d4	0.5847
d5	0.4777
d6	0.3161
d7	0.2299
d8	0.2003

From Table II, It is clear that value of cross correlation coefficient is highest for d4. Therefore, it is evident that d4 is highly correlated with the original signal in time domain.

C. Thresholding

The selected detail coefficient d4 is used to perform the detection of R-wave. For this purpose a practical lower limit is applied to remove unrelated peaks appearing due to noise. There are several thresholding methods known. Here we apply hard thresholding in which the samples below a predetermined threshold are set to zero. The threshold is selected as 15% of maximum value of d4 and applied as follows-

$$thresh = 0.15 \times \max(d4)$$
$$if (d4(i)) = thresh$$
$$(d4(i)) = 0$$

D. R-Wave Positions

The number of remaining coefficients of d4 after thresholding is taken as a possible number of R-waves and their positions are taken as possible R-peaks. R-wave has the highest peak in QRS complex. Following the assumption that no two QRS complexes be found during less than 200 ms, a refractory period of 200 ms is applied after detection of first peak which gives rise to actual number of R-waves [7].

IV. RESULTS AND VALIDATION

The algorithm has been tested on MIT-BIH Arrhythmia Database in which each recording is of 30 minutes duration. Forty two records were tested for R peaks. The overall accuracy obtained out of total (98453) beats, 95543 peaks and 3298 error peaks were detected using db6 while using sym11, 83068 peaks out of 98453 and 15385 error peaks were detected. Thus achieved overall accuracy of detection using db6 and sym11 are 96.65% and 84.37% respectively. The positions of the R peaks has been detected and marked on the original signal. The waveforms with the positioned R peaks for signals 100,101,103,105,106 are shown in Fig. 5(a)-(e). The positions are marked as '*'.
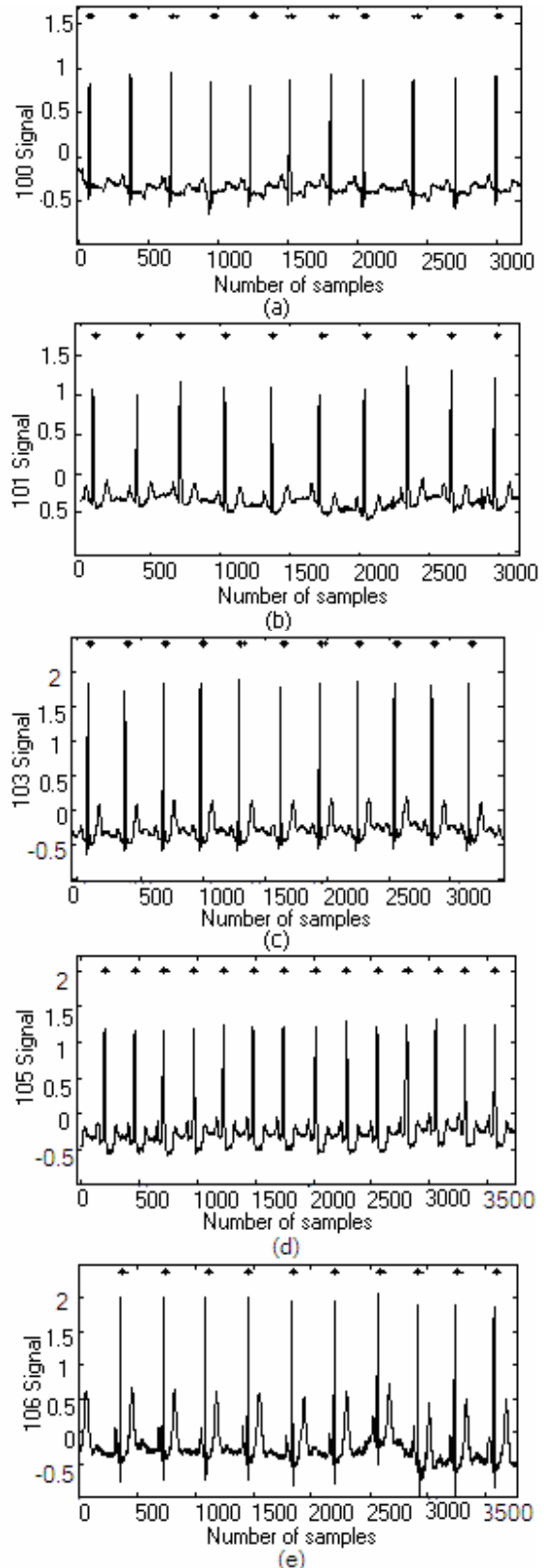

Fig. 5 Positioned R-peaks in original ECG signal: (a) 100 (b) 101 (c) 103 (d) 105 (e) 106

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V. Conclusion and Discussion

An algorithm for R-wave detection using wavelet technique has been developed. In this detection process, the importance of using a particular type of linear transform i.e. wavelet transform has been highlighted in which the noise is filtered at each level of decomposition eliminating the requirement of any preprocessing. This ensures the robustness of the method which has been further confirmed using different records of the database embedded with noise. Moreover, the dominancy of details of R wave in d4 level was further confirmed by Fourier transform. The time domain relationship between the d4 and the original signal was also confirmed by cross-correlation analysis. The technique can be employed in the extraction of other ECG features and classification of various heart related diseases. The results with db6 have been found to be more stable by varying threshold than sym11 which picks up false peaks. The effect of zero padding has also been eliminated during energy analysis making the algorithm simpler and less time consuming.

References

[1] Cuiwei Li, Chongxun Zheng, and Changfeng Tai, " Detection of ECG Characteristic points using Wavelet Transforms",IEEE Trans. Biomed. Eng, Vol. 42, No. 1, 1995

[2] S. Z. Mahmoodabadi, A .Ahmadian , M. D.Abolhasani, M. Eslami, J. H. Bidgoli, "ECG Feature Extraction Based on Multiresolution Wavelet Transform," Proceedings of the 2005 IEEE, Engineering in Medicine and Biology 27th Annual Conference Shanghai, China, September 1-4, 2005.

[3] S.C. Saxena, V. Kumar and S.T. Hande, "QRS Detection using New Wavelets", Journal of Medical Engineering & Technology, Volume 26, November1, pages 7-15, (2002)

[4] Robi Polikar,"The Wavelet Tutorial Part IV, Multiresolution Analysis: The Discrete Wavelet Transform", www.cs.ucf.edu/courses/cap5015/WTpart4.pdf, (2008).

[5] Paul S addition, "Wavelet Transforms and the ECG: A Review," Institute of Physics Publishing, Physiol. Meas.26 (2005) R155-R199.

[6] C.S. Gargour and V. Ramachandran, "A Scheme for Teaching wavelets at the introductory Level", Frontiers in Education Conference, 1997. 27th Annual Conference. 'Teaching and Learning in an Era of Change'. Proceedings. Pittsburgh, PA, USA, 5-8 Nov 1997, http://fie.engrng.pitt. edu/fie97/papers/1030.pdf

[7] J.S.Sahambi, S.N. Tandon, R.K.P. Bhatt, "Using Wavelet Transforms for ECG Characterization, An Online Digital Signal Processing System", IEEE Engineering In Medicine & Biology, Jan/Feb, 1997

[8] http://www.physionet.org/mitdb

[9] Wills J.Tompkins, Biomedical Digital Signal Processing, Prentice Hall of India, New Delhi. 1993, ISBN: 0-13-67216-5

[10] Romero Legarreta, PS Addition, N Grubb, GR Clegg, CE Robertson, KAA Fox, JN Watson, "R-Wave Detection Using Continuous Wavelet Modulus Maxima", Computers in Cardiology 2003, 30, 565-568 ,0276-6547/03, IEEE 2003.