ECG Signal Analysis using Wavelet Transform and Automatic Detection of Anomalies Present in Patients ECG using MATLAB

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Abstract – This paper proposes the study and analysis of Electrocardiogram (ECG) wave. The proposed method consists of three stages. The first stage consists of ECG signal generation through which any value of heartbeat, intervals between the peaks and amplitude can be set so that any desired ECG waveform can be obtained .In the second stage for the analysis purpose different types of ECG signals are downloaded from MIT/BIH arrhythmia database. This downloaded signals are denoise using the daubechies wavelet (db2) which is a family of orthogonal wavelets are applied on the different signal and the performance is evaluated in terms of SNR (signal to noise ratio), PRD (percent root difference).In third stage automatic detection of anomalies present in the ECG signal of patient is done with the reference to P, Q, R and S peaks. All of this entire process is done by using the MATLAB program.

Keywords: ECG, wavelet transform, SNR, PRD, Additive white Gaussian noise (AWGN).

I. INTRODUCTION

The ECG is the electrical manifestation of the contractile activity of the heart. The ECG is the most commonly known recognized and used in biomedical signal. The variations in the normal electrical patterns indicate cardiac disorders. Cardiac cells are electrically polarized in the normal state. The inner and outer sides of cardiac cells are negatively charged. The fundamental electrical activity of heart is called depolarization in which these cardiac cells can lose their normal negativity. This depolarization is propagated from one cell to another call due to which a depolarization wave is produced that can be transmitted across the entire heart. This depolarization wave produces a flow of electric current and it can be detected by keeping the electrodes on the surface of the body. Once the process of depolarization is complete, the cardiac cells are able to restore their normal polarity called as repolarization. All of this electrical activity of heart is recorded by number of electrodes placed on the surface of body

The previous method of ECG signal analysis was based on time domain method. But to study all the features of ECG signal, frequency representation of a signal is also required. So for the frequency representation of a signal, FFT (Fast Fourier Transform) technique is applied. But this technique is not sufficient to provide the information regarding the exact location of frequency components in time. Due to this reason FFT technique is immediately switch to STFT (short term Fourier transform).The short term Fourier transform was also not sufficient because its time frequency precision is not optimal. To overcome this drawback wavelet transformation is used. Wavelet transform now become a common tool for analyzing the ECG signal due to its characteristics of time –frequency localization. Wavelet transform is able to overcome the limitations of conventional methods like FFT and STFT.

II. SYSTEM MODEL

ECG SIGNAL GENERATION:

The ECG signal is generated with the help of Fourier series It is use to represent a wave like function .It decomposes any periodic signal into a sum of set of oscillating functions known as sine’s and cosines .For the generation of ECG signal, MATLAB is used as a simulating tool.

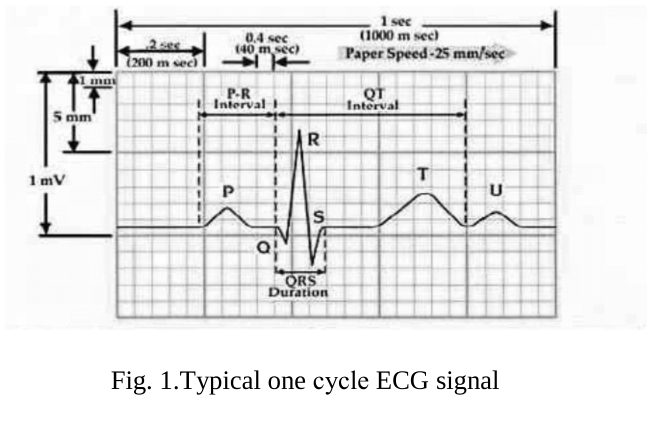


Fig. 1.Typical one cycle ECG signal

A typical scalar electrocardiograhic lead is shown in Fig(1),where the signifiacnt features of the waveform are the P,Q,R,S and T waves [4]

ECG signal Analysis:

The initial step in ECG signal analysis is either to generate the ECG signal or to download the signal from the database availabe online.Here we have use MIT-BIH

Arrhythmia database.Various ECG signal records are used for experiments and algorithm is tested from different record 101,102,103,104 and 105.The database is sampled at 360Hz and the resolution of each sample is 11 bits/sample over 10mV range.The analysis is carried out using MATLAB program which contains “wavelet toolbox”.In this paper we are analyzing the ECG signal by denoising it.

Signal Denoising:

The downloaded five different database used for simlutaion purpose are considered as original signal or free from noise.Therefore White Gaussian noise is added to original ECG signal.It can be added to any noise that might be intrinsic to the information signal.It has uniform power across the frequency band for the information system and it has a normal distribution.The performance of the denoising signal is calculated by using percent root mean square difference (PRD) and signal to noise ratio(SNR).

Automatic detection of anomalies present in patients ECG signal:

Patients ECG signal readings are compare with the reference ECG signal readings. If the patients ECG signal lies in the scale of reference ECG signal then the output of simulating tool will be ‘Normal’,otherwise the output will show the name of anomaly.For example, if ‘R-R interval’ greater than or equal to 0.6 second,than output will show ‘Normal’ and if ‘R-R interval’ is less than 0.6 second than output will show ‘Tachycardia’ which is the name of abnormality present for the deviation in the pateints ECG signal.

III. PREVIOUS WORK

ECG signal analysis using wavelet transform is previously done by C.Saritha ,V.sukanya, Y.Narasimha Murthy in which an attempt was made to generate the ECG waveform by developing a suitable MATLAB simulator and in the second step, using wavelet transform, the ECG signal was de noised by removing the corresponding wavelet coefficients at higher scales [1].Analysis of ECG signal de noising using wavelet transform is previously done by Roshini T, Shoukath Cherukat, Seena V in which analysis of ECG signal de noising is done using wavelet transform. Different ECG signals from MIT-BIH arrhythmia database are used with added AWG noise. The biorthogonal wavelet transform is applied on the different signal and the performance is evaluated in terms of PRD (percent root difference), SNR (signal to noise ratio)[2.]ECG simulation using MATLAB is done by R.Karthik in which the aim of the simulator is to produce the typical ECG waveforms of different leads and as many arrhythmia as possible. The ECG simulator is a MATLAB based simulator and is able to produce normal lead II waveform [3]

IV. PROPOSED METHODOLOGY

When we notice the ECG signal, we observe that a single period of an ECG signal is a mixture of triangular and sinusoidal waveforms. This means that QRS, Q and S portions of ECG signal can be represented by triangular waveforms. P, T and U portions can be represented by sinusoidal waveforms. Once we generate each of these portions, at last they are added together to obtain ECG signal. Hence for this purpose Fourier series can be used for representing ECG signal because Fourier series is a way to represent a function as the sum of simple sine waves. It decomposes any periodic signal into the sum of a set of simple oscillating function like series and cosine.

By using Fourier series:

$$f(x) = (a_o/2) + \sum_{n=1}^{\infty} a_n \cos(n\pi x/1) + \sum_{n=1}^{\infty} b_n \sin(n\pi x/1),$$

$$a_o = (1/1) \int_T f(x)\,dx \qquad , T= 21 \qquad (1)$$

$$a_n = (1/1) \int_T f(x) \cos(n\pi x)/1)\,dx \qquad , n=1,2,3 \qquad (2)$$

$$b_n = (1/1) \int_T f(x) \sin(n\pi x)/1)\,dx \qquad , n=1,2,3 \qquad (3)$$

Experimental / simulation. Now let’s take QRS waveform at the centre and all siftings takes place with respect to this part of the signal.

To generate periodic QRS portion of ECG signal: The calculations are as following-

From equation (1), we have

$f(x) = (-bax/1) +a \qquad o < x< (1/b)$

$f(x) = (bax/1) +a \qquad (-1/b) < x < 0$

$$a_0 = (1/1) \int_T f(x)\,dx$$

$a_0 = (a/b) * (2 - b)$

$$a_n = (1/1) \int_T f(x) \cos(n\pi x/1)\, dx$$

$$a_n = (2ba/(n^2\pi^2)) * (1 - \cos(n\pi/b))$$

$$b_n = (1/1) \int_T f(x) \sin(n\pi x)/1)\, dx = 0$$

(Because the waveform is an even function)

$$f(x) = (a_0/2) \sum_{n=1}^{\infty} a_n \cos(n\pi\, x/1)$$

The output waveform from the above calculation is as following:

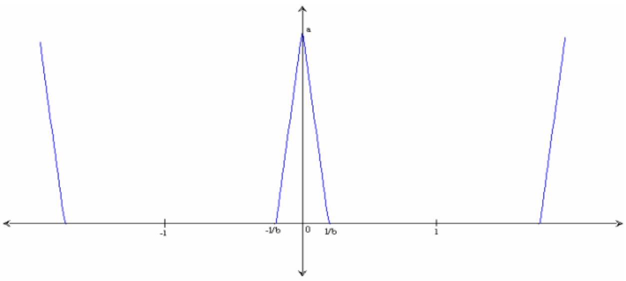


Fig 2. Generating QRS waveform

To generate periodic P wave portion of ECG signal: The calculations are as following-

$f(x) = \cos((\pi bx)/(2l))\ (-l/b) < x < (l/b)$

$$a_0 = (1/1) \int_T \cos((\pi bx)/(2l))\, dx$$

$a_0 = (a/(2b))(2-b)$

$$a_n = (1/1) \int_T \cos((\pi bx)/(2l)) \cos(n\pi x/l)\, dx$$

$a_n = (((2ba)/(i^2\pi^2)) (1-\cos((n\pi)/b))) \cos((n\pi x)/l)$

$$bn = (1/1) \int_T \cos((\pi bx)/(2l)) \sin(n\pi x/l)\, dx$$

bn = 0 (because the waveform is a even function)

$$f(x) = (a_0/2) + \sum_{n=1}^{\infty} \cos(n\pi x/l)$$

The output waveforms from the above calculation are as following:

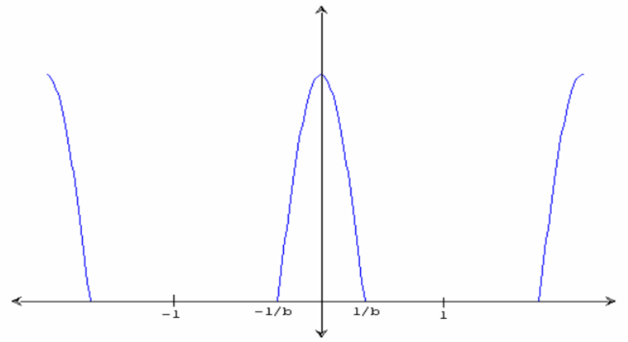


Fig. 3. Generating P waveform

Experimental research model for ECG signal de noising: In this paper the initial step for signal de noising is to obtain the signal from MIT-BIH Arrhythmia database. Various ECG signal records are used for experiments such as 101,102,103,104 and 105.The sampling frequency of each data base is 360 Hz and the resolution of each sample is 11 bits/sample over 10mV range. These signals are considered as free of noise signals. Thus these noise free signals are added with white Gaussian noise. After adding the AWG noise, the signal to noise ratio (SNR) and the percent root mean square difference(PRD) between the original signal (noise free signal) and the reconstructed signal(noise added signal) is calculated

Percent root mean square difference (PRD): The recorded ECG signal is often contaminated by noise and the artifacts that can be within the frequency band of interest and manifest with the similar characteristics as the ECG signal itself. In order to obtain useful information from the noisy ECG signal we need to process the raw signal. Distortion is a way by which we can quantify the difference between the original and the reconstructed signal. The most prominently used distortion measure is the percent root mean square difference (PRD) and it is one the measures that show how much reconstructed signal is similar to the original signal

$$PRD = \sqrt{\frac{\sum_{n=1}^{N} [U[n] - \hat{U}[n]]^2}{\sum_{n=1}^{N} [U[n]]^2}} \times 100$$

Where U[n] is the original signal

And Û[n] is the reconstructed signal

Signal to Noise Ratio: Signal to noise ratio (SNR) is a measure of power ratio between a signal and noise. It is expressed in terms of the logarithmic decibel scale

$$\text{SNR} = 10 \text{ Log } 10 \left(\frac{Esignal}{Enoise} \right)^2$$

$$\text{SNR} = 20\text{Log } 10 \left(\frac{Esignal}{Enoise} \right)^2$$

Where Esignal is the root mean square amplitude of the signal

And Enoise is the root mean square amplitude of the noise

Automatic detection of anomalies present in patients ECG signal: Mostly ECG readings are analyzed by qualitative analysis and quantitative analysis

1)Qualitative analysis: In clinics, mostly ECG readings are analyzed qualitatively ,which means that on the basis of deviation in the patients ECG signal with reference to the original signal is analyzed and then the anomaly in the patients ECG is detected.

2) **Quantitative analysis:** In this type of analysis, ECG signal is observed on the basis of deviation in the values of P,Q,R,S,T and U wave of the patients ECG signal . For example : If R-R interval is greater than 1 second than the anomaly will be detected as 'Bradycardia' at the output of MATLAB command window

In this paper we are doing the quantitative analysis by observing the ECG signal with reference to the characteristics features of the P, Q, R, S, T and U wave. While simulating the MATLAB code the specifications are default which can vary according to the patients ECG reading. For example, the default heartbeat rate is 72bpm.It can be change to 62bpm as per the patients ECG reading. If the patients ECG reading for the R-R interval is greater than 1 second than the output of MATLAB tool will show 'Tachycardia' otherwise the output will show 'Normal'.

V. SIMULATION/EXPERIMENTAL RESULTS

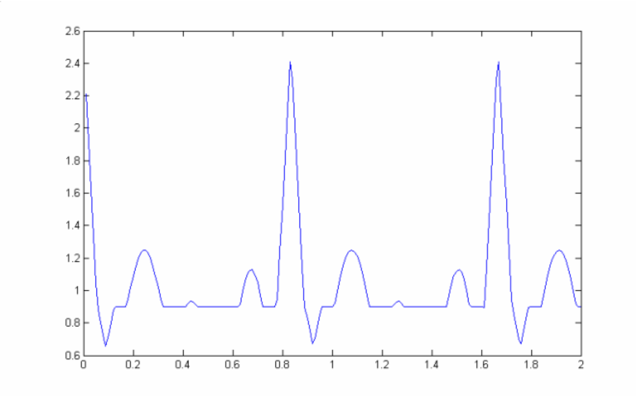


Fig.[4]

Experimental result from ECG signal generation: The ECG signal can be generated by using the Fourier series. Initially QRS waveform is generated and then P waveform is generated. After obtaining both the waveforms they are added together in order to extract the desired waveform. So the generated output ECG signal by MATLAB is show below in Fig [4]

TABLE1. DEFAULT AMPLITUDES FOR DIFFERENT ECG WAVE

S. No.	Name of wave	Amplitude
1.	P wave	0.25 mV
2.	R wave	1.60 mV
3.	Q wave	25% R wave
4.	T wave	0.1 to 0.5 mV

TABLE2. INTERVALS FOR DIFFERENT ECG WAVE

S. No.	Name of interval	Duration
1.	P-R interval	0.12 to 0.20 s
2.	Q-T interval	0.35 to 0.44 s
3.	S-T interval	0.05 to 0.15s
4.	P-wave interval	0.11 s
5.	QRS interval	0.09 s

Experimental result from ECG signal analysis: To analyze the ECG signal, five different types of database sets are downloaded from MIT/BIH database. These signals are considered as original signal or free from noise. Fig [5], Fig [6] and Fig [7] shows the waveform of original signal (which is considered as free of noise), denoise waveform and the waveform for both original signal and de noised signal in MATLAB wavemenu.Here we have used daubechies (db2) wavelet

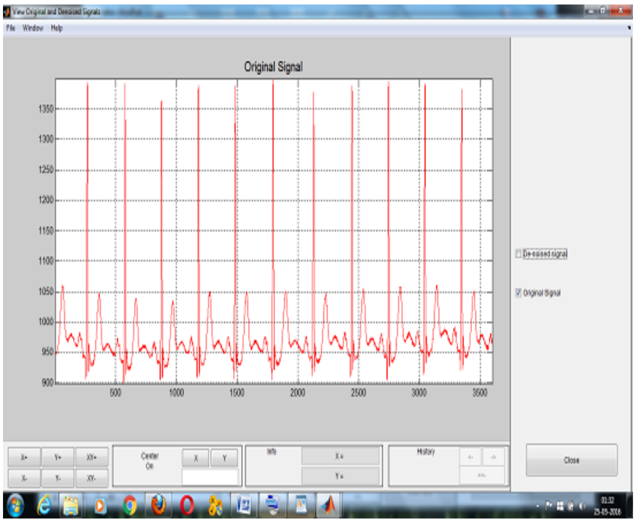
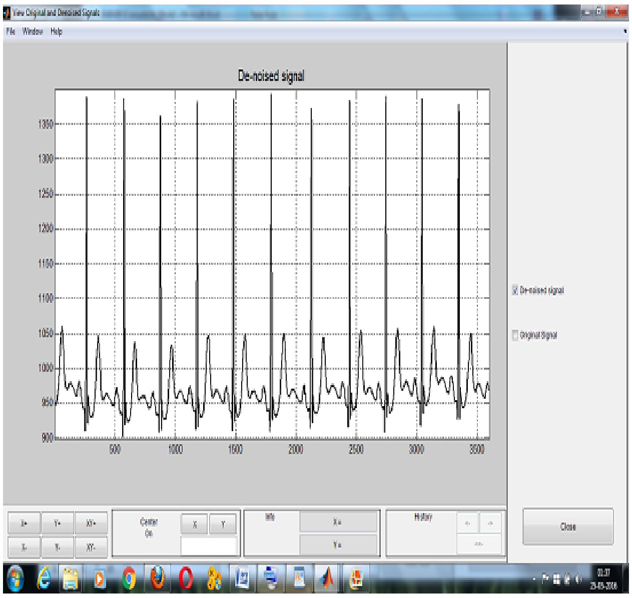


Fig.[5]



Fig[6]

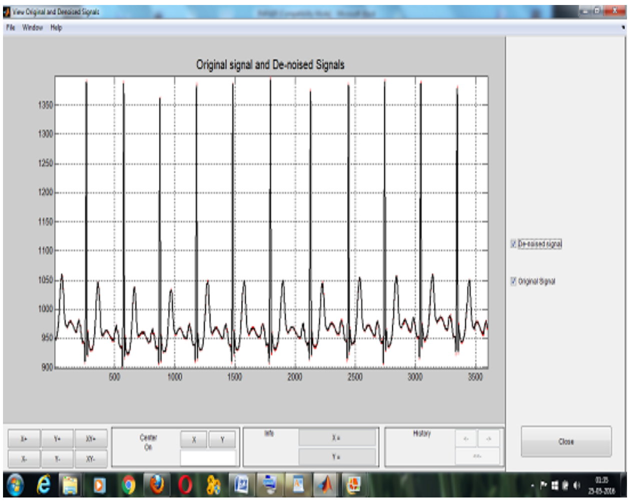


Fig [7]

White noise is added to the signal in order to measure the performance of the de noising. It is evaluated by the measures like signal to noise ratio (SNR) and percent root mean square difference (PRD).Fig [8] shows the waveform for the signal generated after adding the White Gaussian noise to the original signal.

Experimental result from automatic detection of abnormality present in patient's ECG:

Abnormality in the patient's ECG can be detected automatically by doing the appropriate coding in MATLAB software. The reference values of P, Q, R, S, T and U wave are set as the default values which can be change according to the amplitude and duration of patients ECG reading. Following abnormality shown in Table 3 can be automatically detected by using MATLAB tool.

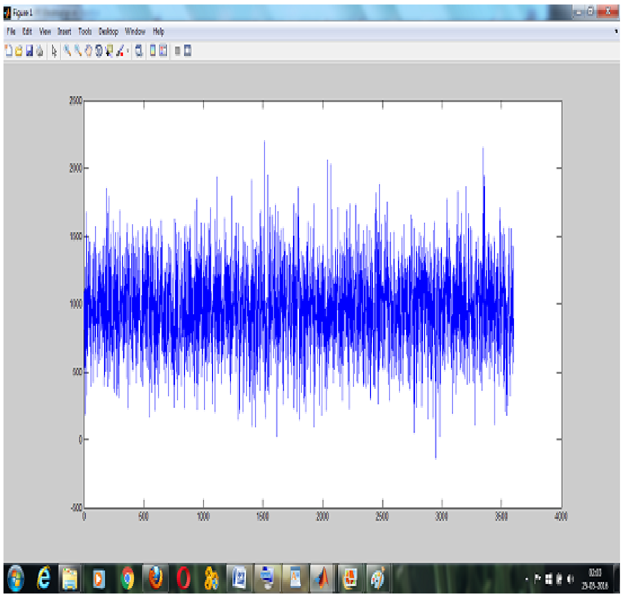


Fig [8] AWGN signal

TABLE 3. INTERVALS FOR DIFFERENT ECG WAVE

S. No.	Name of abnormality	Characteristics 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<0.1s
7	Sinoatrial block	Complete drop out of cardiac cycle
8	Sudden cardiac death	Irregular ECG

VI. CONCLUSION

The ECG signal can be generated by using the Fourier series. The simulating tool used for the signal generation is MATLAB software in which signal generation and analysis can be done easily. Removal of noise from the ECG signal is necessary because it may cause serious and major problem in the visual inspection of the signal. Wavelet transform for de-nosing of the ECG signal. It is very important to analyze the ECG signal of patient on the basis of accurate deviation in the values of P ,Q ,R ,S ,T and U wave with respect to the amplitude and duration of the reference values. By doing appropriate coding in the MATLAB software tool automatic detection of abnormalities can be detected with respect to the patients ECG signal.

VII. FUTURE SCOPE

The future work will focus on the comparative study for the generation of ECG signal by using different types of transform series. We will also compare the results with different filters which are used to generate the ECG waveform. This means that we will synthesize the signal and do analysis by comparing it with different methodologies. In this paper after obtaining percent root mean square difference (PRD) and signal to noise ratio (SNR) at the analysis section, we will focus on achieving the compression ratio. Data compression algorithm will be use to reduce data storage by removing the redundancy wherever possible to increase the compression ratio. The future work for the automatic detection of abnormality present in patients ECG, we will do comparison of the output of patients ECG readings with the peripheral symptoms associated with patient in order to obtain the accuracy of our work.

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