On an Algorithm for Detection of QRS Complexes in Noisy Electrocardiogram Signal

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***Abstract*—Electrocardiogram (ECG) signal provides the valuable information for detection of abnormal heart disease. Detection of QRS complexes is the first step towards recognition of heart disease from the ECG signal. ECG would be much more useful as a diagnostic tool if unwanted noise embedded in the signal is removed. The aims of the work are to (i) ECG signal enhancement using empirical mode decomposition (EMD) based method. (ii) Detection of QRS complexes using continuous wavelet transform method from the enhanced signal. The experiments are carried out on MIT-BIH database. The results show that our proposed method is very effective and an efficient method for fast computation of R peak detection.**

***Keywords*:** ECG signal, MIT-BIH Arrhythmias database, Empirical mode decomposition, Wavelet transform, QRS detection.

I. INTRODUCTION

ECG is a nearly periodic signal that reflects the activity of the heart. A lot of information on the normal and pathology of heart can be obtained from ECG. However, the ECG signals being non-stationary in nature, it is very difficult to visually analyze them. Thus the computer based method is required for ECG signal analysis.
Transmission of ECG often results in the corruption of signal due to introduction of noise [1]. Various factors are responsible for introduction of noise including poor channel conditions, Baseline wander (caused by respiration), 50 or 60 Hz power line interference etc. Analyzing such a noisy signal is bound to give erroneous results. Thus the signal is first made free of noise, a process called denoising or rather we may call it enhancement. A number of methods have been incorporated for enhancement of ECG signal. These are filter banks, neural network, adaptive filtering etc. Empirical Mode Decomposition is a recent development which provides a powerful tool for decomposing a signal into a finite number of IMFs (intrinsic mode functions). ECG analysis basically involves QRS complex detection and subsequent feature extraction. The block diagram of the proposed method is shown in Fig. 1. However, the basic principle of all the methods involves the transformation of ECG signals using different transformation techniques including Fourier transform, Hilbert transform, wavelet transform etc. Physiological signals like ECG are considered to be quasi-periodic in nature. Various approaches have been implemented for R-peak detection. They are of finite duration and non stationary in nature. Hence, a technique likes Fourier series (based on sinusoids of infinite duration) is inefficient for ECG signal analysis. On the other hand wavelet, which is a very recent addition in this field of research, provides a powerful tool for extracting information from such signals.

The paper is organized as follows: Section II describes the theoretical background which includes empirical mode decomposition and continuous wavelet transform. Section III shows the methodology of the proposed technique, experimental results and analysis are described in Section IV and Section V represents the conclusions for this paper.

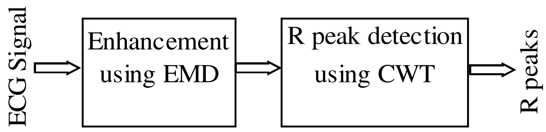

Fig.1 Block diagram of the proposed method

II. BACKGROUND

A. *Empirical Mode Decomposition Method (EMD):*

A new non-linear technique, called empirical mode decomposition method, has recently been developed by N.E.Huang *et al* for adaptively representing non-stationary signals as sums of zero mean AM-FM components [2]. EMD is an adaptive, high efficient decomposition with which any complicated signal can be decomposed into a finite number of intrinsic mode functions (IMFs). The IMFs represent the oscillatory modes embedded in the signal, hence the name intrinsic mode function. The starting point of EMD is to consider oscillations in signals at a very local level. It is applicable to non-linear and non-stationary signal such as ECG signal. An intrinsic mode function is a function that satisfies two following conditions [2].

(i) The number of extreme and the number of zero crossings must differ by at most 1.
(ii) At any point the mean value of the envelope defined by maxima and the envelope defined by minima must be zero.

A systematic way to extract the IMFS is called the sifting process and its algorithm is given below

i) Identify all the extremes of *x* (t).

ii) Interpolate between minima, ending up with a signal *min*(*t*) and similarly between extreme to give *max*(t).

iii) Compute the average:

$$e(t)=(min\,(t)+max\,(t))/2$$

iv) Extract the detail: *d*(t) = *x*(t)-*e*(t) (Steps 1-4 are repeated till d(t) satisfies both the criteria of IMF)

v) Iterate on the residual e(t)

In practice, after a certain number of iterations, the resulting signals do not carry significant physical information. To prevent this, we go for some boundary conditions. We can stop the sifting process by limiting the normalized standard deviation (nstd) [3].

where

$$nstd = \sum_{t=1}^{T} \frac{(\chi_i(t)-\chi_i(t+1))^2}{(\chi_i(t+1))^2}$$

The nstd is set between 0.2 and 0.3 for proper results [3].

The sifting process was applied on an ECG signal to obtain the various IMFs. This has been represented in Fig. 2. The EMD method is a powerful tool for analyzing ECG signal. It is very reliable as the base functions depend on the signal itself. It is very adaptive and avoids diffusion and leakage of signal.

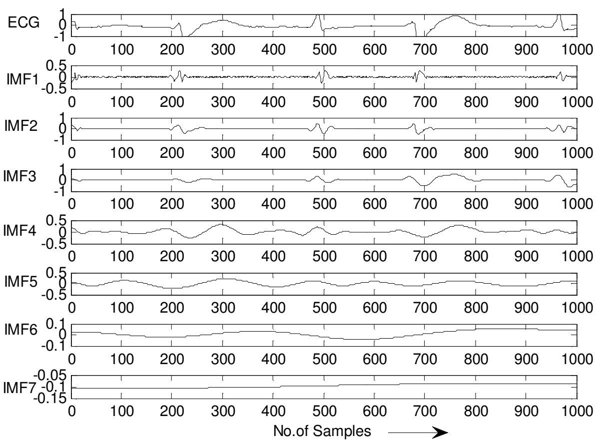

Fig.2.The Original ECG and seven IMFs of the signal

B. Continuous Wavelet Transform:

Wavelets are also another powerful method for the representation and analysis of ECG signal. They have been implemented for the analysis of physiological waveforms like ECG, Phonocardiogram etc. [4]-[7]. This is because wavelet has finite duration as compared to Fourier methods based on sinusoids of infinite duration.

Wavelet transforms are applied to decompose the signal into a set of coefficients that describe the signal frequency content at given times.

The continuous wavelet transform of the signal, *x*(t), is defined as [5].

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

Here Ψ(t) is the analyzing wavelet function

a is the dilation parameter and

b is the location parameter of the wavelet

Fig.2. shows that the Original ECG and seven IMFs of the signal. Actually the wavelets are generated from a single basic wavelet Ψ(t), the so called mother wavelet, by scaling and translation.

$$\psi_{s,\tau}(t) = \frac{1}{\sqrt{s}} \psi(\frac{t-\tau}{s})dt \qquad (2)$$

Here τ is the scaling factor and √ (1/s) is for normalization across the different scales. Due to the scaling and translation, Wavelet Transform is localized in both time and frequency. Several Mother Wavelets like Mexican-hat and Morlet have been used in ECG signal analysis. The mother wavelet has a lot of significance for the efficiency of the process. In this paper we have used a Haar Wavelet as the mother wavelet because the oscillatory nature of other mother wavelets results in several ridges for each ECG component, while only one pair of ridges is generated via the Haar wavelet due to its configuration. The Haar mother wavelet function Ψ(t) as shown in Fig. 2 can be described as:

$$\Psi(t) = 1 \quad 0 \le t < 1/2$$
$$= -1 \quad 1/2 \le t < 1$$
$$= 0 \quad \text{otherwise}$$

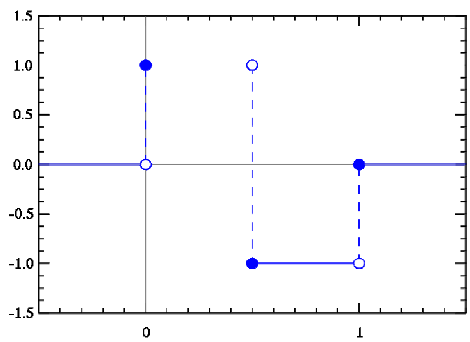

Fig. 3 Haar mother wavelet

We have chosen CWT over DWT because unlike DWT there is no dyadic frequency jump in continuous wavelet transforms [5]. Also high resolution in time-frequency domain is achieved

III. METHODOLOGY

A. Enhancement Technique using EMD:

The basic principle of enhancement of ECG signal using EMD is expressing the noisy ECG as sum of a series of IMFs. It has been shown that the 1st IMF contains nothing but high frequency noise [4]. So we can easily eliminate this component. The next two IMFs contain both noise as well as information. It has been shown that if we remove the 2nd IMF there is heavy distortion of the R- peaks [8]. In order to remove noise while preserving the information we go for filtering.

The whole procedure can be described by the following algorithm.

i. The ECG signal is first decomposed into IMFs. The sum of these IMFs should represent the signal well. The IMFs are obtained using the sifting process described in the earlier section.

ii. The first four IMFs are removed by using low pass Butterworth filter as the noise comprises the higher frequency components. We use a Butterworth filter because of its inherent characteristics of having a flat frequency response.

iii. The 1st IMF is now eliminated. We reconstruct the enhanced signal by eliminating the 1st IMF and adding up the rest IMFs.

B. R-peak Detection using Continuous Wavelet Transform

The basic principle is involved by using a threshold detector [5]. The various steps are described below:

i. The enhanced signal is transformed using continuous wavelet transform.

ii. Positive maximum peaks are larger than a threshold are selected. The main threshold is chosen as a fraction of root mean square of the signal. We have chosen this to be around two times the root mean square of the signal after carrying out a series of experiments.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

We have used MIT-BIH database to validate the efficiency of our proposed method. Simulation is carried out in MATLAB environment. We have added white Gaussian noise to the clean ECG signals to obtain a collection of noisy ECG signals with SNR varying from 5 dB to 15 dB. The enhancement algorithm is then used and the SNRs of the enhanced signals are calculated to find the efficiency of the proposed method. Table I shows the SNR improvement after enhancement.

Table II indicates the detection error rates and sensitivity between proposed (EMD and CWT) method and DOM method. Here *FP* denotes false positive i.e. false peak detection and *FN* denotes false negative i.e. failure to detect. The total detection error rate (D.E) is calculated as (*FP* +*FN*)/(Total no of R peaks *100). The average detection error rate is found to be 0.01%. Efficiency is measured in terms of sensitivity given by

$$Se = \frac{TP}{TP + FN} x100$$

Here *TP* stands for true positive which is the total no of peaks correctly detected by the detector. Sensitivity is calculated to be 99.84 % which shows that the method has a good efficiency.

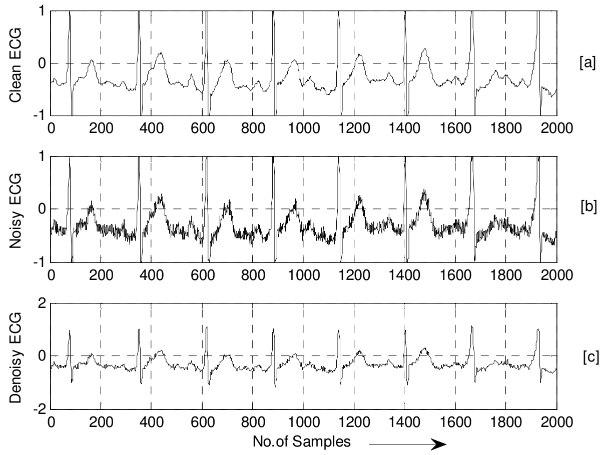

Fig. 4. (a) Clean ECG signal (b) Noisy ECG signal after the addition of White Gaussian Noise (c) Denoising signal after enhancement.

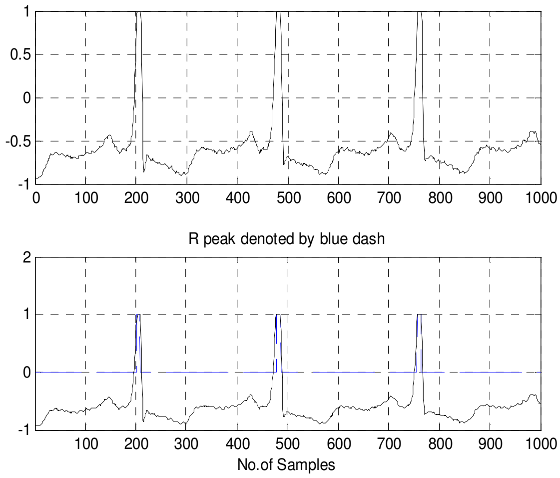

Fig.5 R peak detection using Continuous Wavelet Transform

TABLE I

EXPERIMENTAL RESULTS OF ENHANCEMENT METHOD USING EMD

Noisy signal SNR(dB)	MIT BIH Record	Enhanced Output SNR(dB)
5	200_1	8.3
	201_1	8.6
	202_1	8.7
	210_1	8.7
	230_1	8.5
10	200_1	13.5
	201_1	13.7
	202_1	13.3
	210_1	13.6
	230_1	13.3
15	200_1	18.5
	201_1	17.1
	202_1	17.8
	210_1	18.3
	230_1	17.5

TABLE II

COMPARISON BETWEEN PROPOSED AND DIFFERENCE OPERATION METHOD

MIT BIH DATA	TP	EMD & CWT METHOD (PROPOSED)				DOM METHOD			
		FP	FN	D.E (%)	Se (%)	FP	FN	D.E (%)	Se (%)
200	2601	0	01	0.04	99.9	00	00	0.00	100
201	1963	2	12	0.71	99.3	03	00	0.15	100
202	2136	8	00	0.37	100	08	00	0.37	100
203	2982	2	30	1.07	98.9	06	01	0.23	99.9
205	2656	0	01	0.05	99.9	10	00	0.38	100
208	2956	0	05	0.16	99.8	08	00	0.27	100
209	3004	0	00	0.00	100	00	02	0.06	99.9
210	2647	0	04	0.15	99.8	10	00	0.38	100
212	2748	0	04	0.16	99.8	01	01	0.07	99.9
213	3251	0	02	0.06	99.9	07	02	0.27	99.9
215	3363	6	00	0.18	100	00	10	0.29	99.7
217	2208	0	00	0.00	100	00	00	0.00	100
219	2154	0	00	0.00	100	01	00	0.05	100
220	2048	0	00	0.00	100	02	00	0.09	100
221	2427	0	04	0.16	99.8	04	06	0.41	99.7
222	2484	0	20	0.81	99.2	06	00	0.24	100
223	2605	0	00	0.00	100	01	00	0.04	100
Total	2448.7	1.05	4.88	0.01	99.84	3.9	1.29	0.21	99.94

IV. CONCLUSION

Our sole objective of this paper is to develop a method for efficient analysis of ECG signal. In this piece of work, we have proposed a novel method of enhancement of ECG signal using empirical mode decomposition (EMD). Deviating from other approaches of using EMD, we have proposed the use of low-pass Butterworth filters for efficient noise removal and implemented continuous wavelet transform for R-peak detection. We have found that the efficiency in case of CWT is better as compared to other methods. The average detection error rate for CWT is 0.01% .The sensitivity of CWT is 99.84%.

Thus our method of signal enhancement and R-peak detection using empirical mode decomposition method and continuous wavelet transform is a novel, efficient method having less computation time, hence best suited for analysis of ECG signal for clinical purposes.

REFERENCES

[1] Guodong Tang and Aina Qin, "ECG Denoising based on Empirical Mode Decomposition," 9th International Conference for Young Computer Scientists, pp. 903-906, 2008.

[2] N. E. Huang, Z. Shen, S. R. Long, M. C. Wu, H. H. Shih, Q. Zheng, N.-C. Yen, C. C. Tung, and H. H. Liu, "The empirical mode decomposition and the Hilbert spectrum for nonlinear and nonstationary time series analysis," *Proc. Roy. Soc. Lond*, vol. A 454, pp. 903–995, 1998.

[3] Hualao Ling, Qiu-Hua Lin, and J.D.X.Chen, "Application of the Empirical Mode decomposition to the analysis of Esophageal Reflux Disease," *IEEE Transactions on Biomedical Engineering*, Vol.52, No.10, 2005.

[4] Sreeraman Rajan, R. Doraiswami, M. Stevenson, and R.Waltrous," Wavelet based bank of correlators approach for phonocardiogram signal classification", *IEEE proceedings*, pp. 77-80, 1998.

[5] A.Ghaffari, H.Golabayani, and M.Ghasemi, "A new mathematical based QRS detector using continuous wavelet transform", *Computers and Electrical Engineering*, vol.34, pp. 81-91, 2008.

[6] Conor McCooey, Dinesh Kant Kumar, and Irena Cosic, "Decomposition of Evoked Potentials using Peak Detection and the Discrete Wavelet Transform", *IEEE proceeding* , pp 2071-2074, 2005.

[7] Szi-Wen Chena, Hsiao-Chen Chena, and Hsiao-Lung Chanb, "A real-time QRS detection method based on moving-averaging incorporating with wavelet denoising", *Computer methods and programs in biomedicine,* vol. 82, pp. 187–195, 2006.

[8] Yan Lu, Jingyu Yan, and Yeung Yam, "Model Based ECG denoising using empirical mode decomposition," *IEEE International Conference on Bioinformatics and Biomedicine*, pp. 191-196, 2009.

[9] Yun-Chi Yeh and Wen-June Wang, "QRS complex detection for ECG signal, The Difference Operation Method", *Computer Methods and Programs in Biomedicine, vol.* 9, pp. 245-254, 2008.

[10] D.Benitez, "The use of Hilbert Transform in ECG Signal Analysis", *Comput. Biol .Med*, vol. 31, pp. 399- 406, 2001.

[11] A.Barros, A.Mansour and N.Ohnishi,"Removing Artifacts from ECG signals using independent component analysis", Neuro-computing, vol. 22, pp-173-186, 1998.

[12] G.D. Clifford and L. Tarassenko, "One-pass training of optimal architecture auto-associative neural network for detecting ectopic beats," *Electron Letter,* vol. 37, no. 18, pp. 1126-1127, Aug. 2001.

[13] P.M. Agante and J.P.M de Sa, "ECG noise filtering using wavelets using soft thresholding methods", *In Proc. Comput. Cardiology* , pp. 535-542, 1999.

[14] Jing- tian Tang,Xiao –li Yang, "The Algorithm of R peak detection in ECG based on empirical Mode Decomposition", *IEEE, 4th International Conference on Natural Computation.*

[15] Yun-Chi Yeh, Wen-Jun Wang, and Che Wun Chiou, "Cardiac arrhythmia diagnosis method using linear discriminant analysis on ECG signals", *Measurement* vol. *42*, pp. 778-789, 2009.