Wavelet and Energy Based Approach for PVC Detection

Awadhesh Pachauri and Manabendra Bhuyan
Department of Electronics and Communication Engineering Tezpur (Central University) Nappam, Tezpur Assam
awadhesh.pachauri@gmail.com, manab@tezu.ernet.in

Abstract— **This paper describes a wavelet and energy based technique for the detection of ventricular premature arrhythmic beats in Electrocardiogram (ECG) that are of great importance in evaluating and predicting life threatening ventricular arrhythmias. Premature Ventricular Contraction (PVC) can be seen in ECG as abnormal wave shape of the QRS complex. A new scheme is proposed for the detection of premature ventricular beats, which is a vital function in rhythm monitoring of cardiac patients. The method for classifying the abnormal complexes from the normal ones is based on the concepts of RR-interval of detected R peaks and energy analysis of ECG signal. ECG R-peaks have been detected by wavelet method in which ECG signal has been decomposed to the required level by selected wavelet and the selected detail coefficient d4 by energy, frequency and correlation analysis undergoes thresholding and decision logic to detect R-peaks. An RR-interval window is placed between the two successive R-peaks when the RR-interval exceeds beyond a predefined threshold. Furthermore, window based energy analysis of ECG signal is performed by eliminating the low frequency samples and a higher energy window beyond a predefined threshold is analyzed. An intersection of these two windows gives rise actual number and positions of PVCs in the ECG signal.**

Keywords- ECG, PVC, Wavelet Transform, Signal Energy, R-wave Detection, and Window based technique

I. INTRODUCTION

The electrocardiogram (ECG) comprises of valuable clinical information and is the most efficient method for the diagnosis of cardiac abnormalities. Normal conduction of the heart originates at the sino-atrial node giving rise the normal heart beats. Premature beats may originate from ventricular region or atrial region. These premature beats are not life threatening but these beats become of utmost importance when they occur too frequently. The premature beats that occur in the ventricular region are called as premature ventricular contractions (PVC) or ventricular premature beats (VPB). The early and accurate detection of these beats is essential to diagnose the life threatening arrhythmias[1].

PVC is evident in ECG waveform as an abnormal wave shape of QRS complex. Spontaneous occurrence of PVCs in the ECG waveform is the hallmark of drug toxicity and cardiac abnormal conduction. PVCs are diagnosed by prematurity, wide QRS complexes in ECG waveform [2].

Many PVC detection and classification algorithms have been developed so far. The PVC detection algorithms include Discrete Cosine Transform (DCT) and autoregressive modeling [3], symbolic dynamics [4], correlation coefficient in ECG signal [5], while the PVC classification algorithms are developed mainly using Artificial Neural Networks [6] considering timing information between the detected peaks as a feature set for classification. The energy based algorithm has not been reported so far.

The results from previous works suggest that the combination of waveform shape and timing interval features is critical for robust detection. Finally, a proficient PVC detection algorithm has been developed which combines the RR interval features of ECG by R-wave detection using wavelet and energy analysis of ECG signal. The combination of both these analysis contributes to the development of an expert PVC detection algorithm.

II. MATERIALS

A. *Wavelet Transform*

The wavelet transform is defined as the projection of a signal on the set of basis functions, referred to as wavelets that are derived from a basis function (i.e. mother wavelet) by dilation and contraction operations. This transform is based on the convolution of the signal with a dilated filter [7]. Wavelet analysis divides the signal into different frequency components and depends upon choosing a mother wavelet. The signal under study is represented as a linear combination of dilation and translation parameters of this selected mother wavelet. If the scale is continuous then the transform is called continuous wavelet transform. If the scale is discrete, the transform can be either orthogonal or non-orthogonal [8].

A general transformation equation [9] can be written as follows

$$x(a,b) = \int_{-\infty}^{\infty} x(t)\psi_{a,b}(t)dt \tag{2.1}$$

Where x(t) is the given signal to be processed. In case of continuous wavelet transform, the function $\psi(t)$ can be expressed as

$$\psi_{a,b}(t) = \left(\frac{1}{\sqrt{a}}\right) \times \psi\left(\frac{t-b}{a}\right) \tag{2.2}$$

Where $\psi_{a,b}(t)$ addresses a window of finite length, and ‘a’, ‘b’ are real numbers known as dilation or contraction

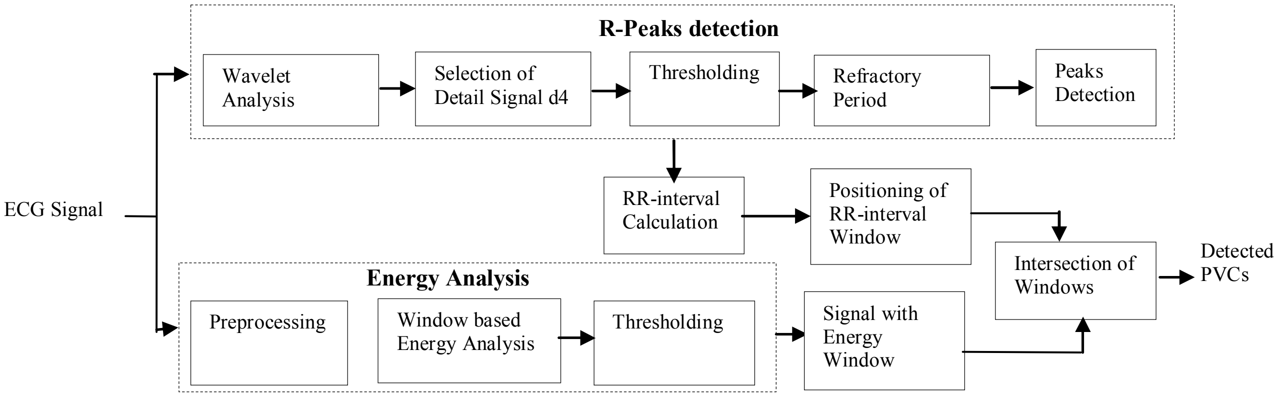

Figure 1. Block diagram of PVC detection algorithm

parameters and window translation parameter respectively. In case of continuous wavelet transform, the dilation and contraction parameters change continuously [10].

In case of discrete wavelet transform, the wavelet function can be represented as follows [11]-

$$\psi_{m,n}(x) = \frac{1}{\sqrt{a_0^m}}\psi\left(\frac{x}{a_0^m} - nb_0\right) \tag{2.3}$$

In case of Continuous Wavelet Transform, the transformation equation can be expressed as-

$$X_w(a,b) = \left(\frac{1}{\sqrt{a}}\right)\int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-b}{a}\right)dt \tag{2.4}$$

Where * denotes the complex conjugation [9].

In the multi-resolution analysis of the signal, each stage comprises of two digital filters (highpass and lowpass filters respectively) and two downsamplers by 2. These highpass and lowpass filters are related to each other by the following relation-

$$g[L-1-n] = (-1)^n \times h[n] \tag{2.5}$$

Where g[n] and h[n] denote the highpass and lowpass filters respectively, and L is the filter length expressed in number of points[12]. Both filters are odd index alternated inversed versions of each other. Lowpass to highpass conversion is made by the $(-1)^n$ term.

The wavelet transform upholds the energy conservation principle and the original signal can be faithfully reproduced.

B. *Signal Energy*

A signal can be defined as a function of varying amplitude through time so signal strength can be estimated by the area under the curve that may have a negative part. This negative part also contributes to same extent as the positive part of the signal having same size. Therefore, signal energy can be calculated either by squaring the signal or taking its absolute value, then finding the area under that curve [12].

The total energy for any continuous time signal x(t) over the time interval $t1 \le t \le t2$ is defined as

$$E = \int_{t1}^{t2} |x(t)|^2 \, dt \tag{3.1}$$

Where $|x|$ denotes the magnitude of the number x.

Similarly, the total energy in a discrete time signal x[n] over the time interval $n1 \le n \le n2$ is defined as

$$E = \sum_{n=n1}^{n2} |x[n]|^2 \tag{3.2}$$

III. METHOD OF DETECTION

The detection process consists of two steps. ECG peaks are detected by wavelet analysis of ECG signal under test and simultaneously window based energy analysis of ECG signal is performed. For the analysis of detector performance, standard MIT-BIH database is chosen and signals from lead-II of records 100, 105 and 114 and 116 are taken for analysis [13]. The algorithm for PVC detection is outlined in figure 1. The detection process is performed on record 105, lead II as an example and completed in the following steps-

A. *R-Wave Detection*

The accurate detection of R-wave positions in ECG is an important task as they form the basis for the detection of premature and wider QRS complexes. In this case, the R peaks are detected by the wavelet analysis of ECG signal. Daubechies (db6) wavelet has been found to be suitable for R peak detection because of its similarity with QRS complex and its energy spectrum is concentrated around low frequencies [14].

The ECG signal under test is decomposed to 8 levels using db6 wavelet and further, energy, cross-correlation and frequency analysis of all the obtained decomposed detail signals are performed to select the relevant detail coefficient for ECG peak detection. In these analyses, the detail coefficient (d4) obtained after decomposition has been found to possess maximum energy and highest value of

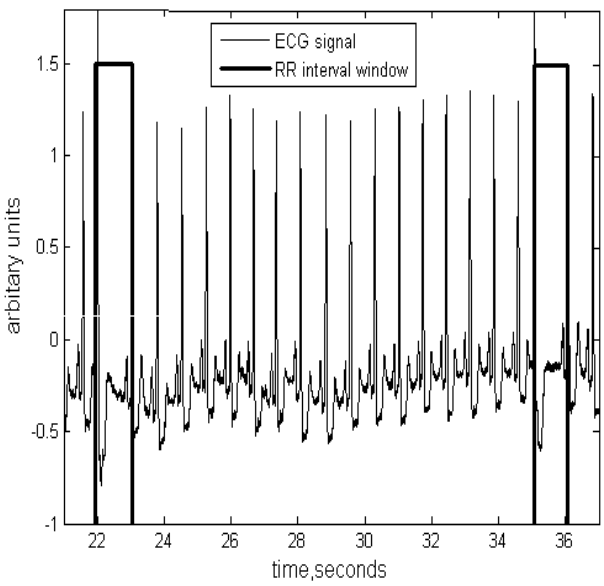

Figure 2. ECG signal with RR-interval window after thresholding

cross-correlation coefficient. Also the Fourier analysis of d4 shows the frequency range similar to that of ECG signal. The selected d4 signal undergoes thresholding to eliminate most of unwanted ECG peaks and further a refractory period of 200 ms is applied to detect the actual peaks [15].

The interval between successive peaks is calculated and 75 % of maximum value of RR-interval is set as threshold. Finally, a window is placed between two successive peaks when the RR-interval exceeds the preset threshold as shown in figure 2.

The onset of these windows gives rise number of PVCs in the signal. A total of 12 PVCs are detected in record 105 by this method. But if the same concept is followed in case of record 114, two false PVCs are detected. Therefore, RR-interval concept has to be correlated with some other concept to take the decision of actual number of PVCs.

B. Signal Energy analysis by moving window

Almost all the signals downloaded from ECG database are affected by low frequency artifacts; therefore, preprocessing of the record under test is an essential factor before starting the detection process. The signal under test is filtered by fourth order Butterworth highpass filter having cut-off frequency of 2 Hz to remove any baseline drift that can cause incorrect calculation of signal energy.

The preprocessed ECG signal undergoes energy analysis by moving window technique. For this purpose, a window of 600 ms is selected and the energy of this window is calculated. Further, the window is shifted by 600 ms and the energy of the succeeding window is calculated. If the signal length is not divisible by window size, zero padding can be done to calculate the energy of last window. The total number of samples in the window gives only one value per window. These calculated window energy values are expanded to the length of the signal by repeating each

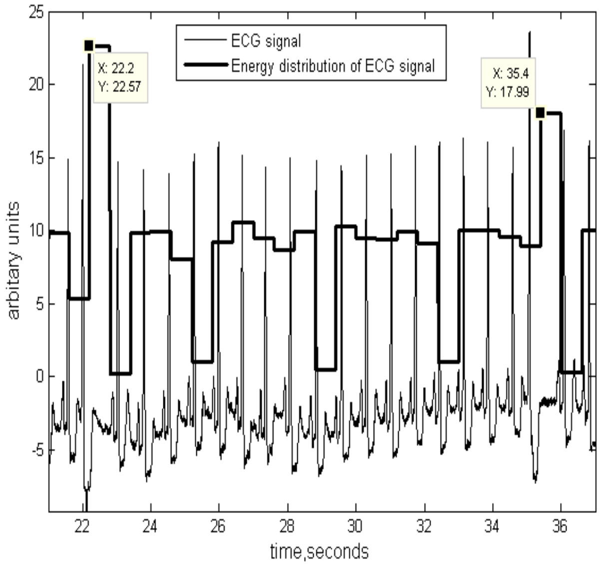

Figure 3. ECG signal and its energy distribution

window energy value to the length of the window. A part of ECG signal under test and its energy distribution is shown in figure 3. It is clear from figure 3. that energy is highest at two locations (X-axis) 22.2 and 35.4 seconds respectively. The parts of the signal having lower energy values are removed by thresholding by applying a threshold greater than 60 % of the maximum value of the energy. This results in the positioning of energy window between the two sections of the signal which may correspond to actual PVCs. The onsets of these windows give the probable number of PVCs. In this case, 14 PVCs are detected for record 105 whereas record 105 comprises of 12 PVCs.

IV. PVC DETECTION

As already stated in section III.A that RR-interval concept for PVC detection may hold good for one signal but may not work in case of record 114, lead II. Similarly, window based energy analysis is not successful for record 105 under test. Therefore, intersection of both RR-interval and energy window is considered suitable for the detection of actual number and position of PVCs. Hence in the next step, RR-interval window obtained in III.A is superimposed over energy window (obtained from III.B) and an intersection window is found which gives the actual number and positions of PVCs in the signal as shown in figure 4. The onsets of all the intersection windows are registered as the number and positions of PVCs in the signal. In the figure 5, the number of PVCs in the record 105 are calculated and their positions are marked as ☆.

V. RESULT AND VALIDATION

The algorithm has been validated on MIT-BIH database. Four records 100, 105, 114, 116 are tested for premature beats. These records all together comprises of 37 PVCs the obtained accuracy for record 100 & 105 is 100 % whereas overall accuracy for all the four records is 86.48 %.

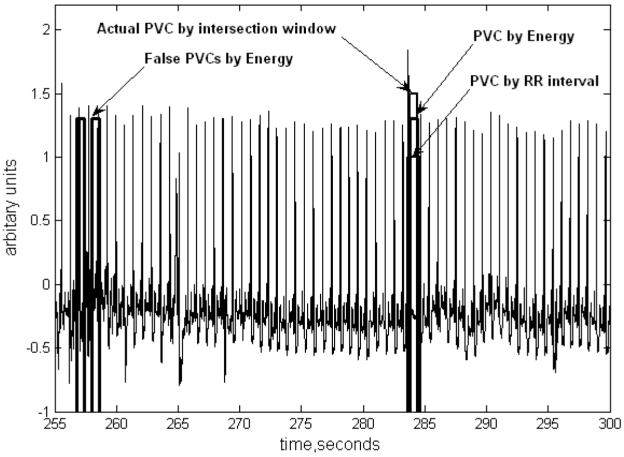

Figure 4. Detected PVCs by both methods and two false PVCs by energy

VI. CONCLUSION AND DISCUSSION

A wavelet and energy based algorithm for detection of premature beats in ECG is developed. The algorithm incorporates the RR interval concept as well as window based energy analysis for exact detection of PVCs in the ECG signal under test. So far RR interval along with correlation coefficient and neural network has been used by the researchers to detect and classify premature beats. This algorithm opens a new pathway where the energy is observed higher in the areas where PVC exists in the ECG signal. The algorithm works well when the PVCs in the signal are apparent as wider QRS complexes with prematurity and paves the path to detect wider PVCs as done by using symbolic dynamics. It is felt that, similarly energy can also be used as a feature. Energy feature for various data records can be used as input to the artificial neural network (ANN) to train it and a classification of a record can be obtained.

The algorithm is implemented on last five minute segment of record 100 and first five minute segments of other records. Last five minute segment of record 100 is considered as it has only one PVC at 25:13 duration of the signal. Record 105 is taken for PVC diagnosis as it comprises of maximum number of PVCs. The energy analysis is simple to implement just after eliminating low frequency samples. Zero padding is required if the signal length is not divisible by selected window size.

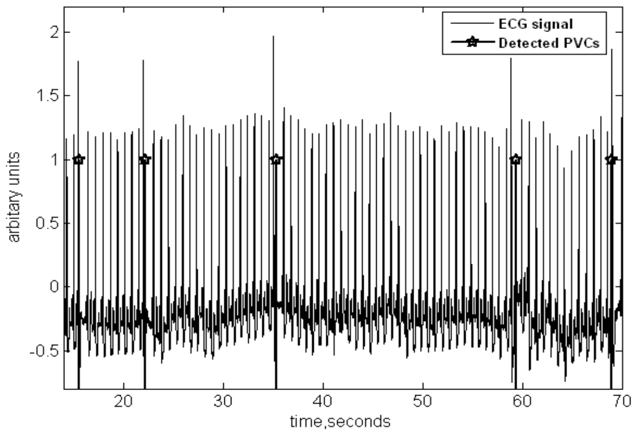

Figure 5. ECG signal along with detected PVCs

VII. REFERENCES

[1] Ramaswamy Palaniappan, Cuta Navin Guptu, Chan Kap Luk, Shankur M. Krishna, "Multi-parameter DETECTION OF ECTOPIC HEART", International Workshop on Biomedical Circuits & Systems, IEEE 2004, -7803-8665-5/04~$20Q,0200 04 IEEE pp S2.4-1-44

[2] Mudit Jain, Snigdha Chaturvedi, Varun Mithal, "Detection of Abnormalities and Diseases in ECG Data", BTP Term 1 Report, Dept of Computer Science and Engineering, IIT Kanpur INDIA, November 8, 2008

[3] Joseph S.Paul, M.R.S.Reddy, V. Jagadeesh Kumar, "Automatic detection of PVC's using Autoregressive Models", Proceedings - 19th International Conference - IEEE/EMBS Oct. 30 - Nov. 2, 1997, pp 68-71, Chicago, IL. USA

[4] Lichu Zhao, Matt Wiggins, George Vachtsevanos "Premature Ventricular Contraction Beat Detection based on Symbolic Dynamics Analysis", Proceedings of the IASTED International Conference CIRCUITS, SIGNALS AND SYSTEMS May 19-21, 2003, pp 48-50, Cancun, Mexico 48.

[5] Chuang-Chien-Chiu , Tong-Hong_Lin and Ben-Y1 Liau, " Using Correlation Coefficient in ECG waveform for Arrhythmia Detection", Biomedical Engineering applications, basis and communications, 2005

[6] Omer T. Inan, Laurent Giovangrandi, and Gregory T. A. Kovacs," Robust Neural-Network based classification of Premature Ventricular Contractions using wavelet transform and timing interval features", IEEE transactions on Biomedical Engineering , Vol. 53, No. 12, December 2006

[7] Stephane Mallat, "Zero-Crossings of a Wavelet Transform", IEEE Transactions on Information Theory, vol. 37, no. 4, July 1991, pp 1019-33, 0018-9448/91/0700-1019$01.00 01991, IEEE

[8] Mahesh Venkatraman and Venu Govindaraju, "Zero Crossings of a Non-orthogonal Wavelet Transform for Object Location"0-8186-7310-9/95 $4.00 *0* 1995 IEEE, pp 57-60

[9] 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

[10] Dean Cvetkovic, Elif Derya Übeyli, Irena Cosic, "Wavelet Transform Feature Extraction from human PPG, ECG and EEG signal responses to ELF PEMF exposures : A Pilot Study ", Digital Signal Processing, 18 (2008), 861-874, www.elsevier.com/locate/dsp

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

[12] Sanjay Sharma, "Signals and Systems" , S. K. Kataria & Sons, New Delhi, Jan 2008

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

[14] S.Z. mahmoodabadi, A. Ahamadian. M.D. Abolhasani, M. Eslami, J. H. Bidgoli, "ECG Feature Extraction Based on Multiresolution Wavelet Transform," Proceedings of the2005 IEEE, Engineering in Medicine and Biology 27th Annual Conference Shanghai, China, September 1-4, 2005

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