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Identification of Premature Ventricular Contraction in ECG Signals – A Review

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Abstract: The electrocardiogram (ECG) signal is the graphical representation of electrical activity of the heart. Diagnosis of most of the cardiac problems requires ECG feature extraction. Premature Ventricular Contraction (PVC) is a type of arrhythmia which occurs due to insufficient oxygen supply. Several PVCs in a row exhibit ventricular tachycardia (VT), an arrhythmia which is potentially fatal. This paper presents an exhaustive review of several methods used in identifying PVC arrhythmia in ECG signals. Several Promising algorithms based on autoregressive (AR) models, artificial neural networks (ANN), support vector machines (SVM), discrete cosine transform (DCT), Hilbert transform (HT), teager energy operator (TEO), DCT-TEO and other important methods are considered. Simulations are carried out using Matlab software. Various records of MIT BIH arrhythmia database are used for testing. Efficacy of various methods measured with statistical parameters like accuracy, sensitivity, positive productivity and specificity, are found to be 99.8%, 99.8%, 100%, 99.9%

Keywords: ECG, Arrhythmia, PVC, TEO, DCT

I. INTRODUCTION

A. Ecg

Electrocardiogram (ECG) is a noninvasive method used for detecting cardiovascular diseases. Waves on ECG are P wave, QRS complex and T-wave. P wave is low amplitude, low frequency feature attained from atrial depolarization. QRS complex consists Q-wave preceding R wave, due to the depolarization of inter ventricular septum, R-wave is again due to ventricular depolarization in the ECG waveform, and S wave is due to late depolarization of some ventricular areas. QRS complex is the prominent feature required for identification of cardiac arrhythmia.

B. QRS detection

Evolution of computer technology led to the development of many software algorithms for QRS complex detection.

These software algorithms have reduced the hardware complexity required earlier for the QRS detection. Today, the QRS detection required for cardiac diagnosis is entirely computer based. Strong energy is required by sino atrial (SA) node for ventricular depolarization to occur, which results in normal ECG beat termed as normal sinus rhythm data, whereas when SA node fails to trigger the pulses, its functioning is taken up by the other parts of myocardium such as ventricles or atria called as ectopic beat. PVC beat occurs when the trigger pulse required for depolarization is initiated by the ventricles. PVC beat constitutes a wide, bizarre QRS complex with no preceding P-wave. ECG waveform being a low frequency signal (0.05-100 Hz) gets easily contaminated with the PLI noise, baseline wander and other artifacts while recording which makes accurate peak detection a difficult task. Computer-assisted cardiac arrhythmia detection can play a significant role in managing cardiac disorders. Many algorithms were presented for peak detection and arrhythmia classification. Gary Friesen[1] et al have implemented nine different algorithms for QRS peak detection based on first, second order derivatives and digital filters and observed that none of them were able to detect all peaks without false positives. J.Pan and W.J.Tompkins[2] have developed a real time QRS detection algorithm using adaptive thresholding for reliable peak detection and achieved a sensitivity of 99.3%. This algorithm proved effective in accurate peak detection under noisy conditions but at the cost of computational complexity. Ivo Iliev[3] *et al* devoted his work for development of a QRS detector with less memory requirement to identify the actual QRS peak position from the deviated one. Paul S.Addison[4] has discussed continuous wavelet transform and discrete wavelet transform usage for the analysis and extraction of QRS complex from nonstationary signals like ECG. He suggested it as a powerful tool for diagnosing cardiac pathology. O.Dwyer[5] et al proved that arrhythmia classification is possible based on QRS width.

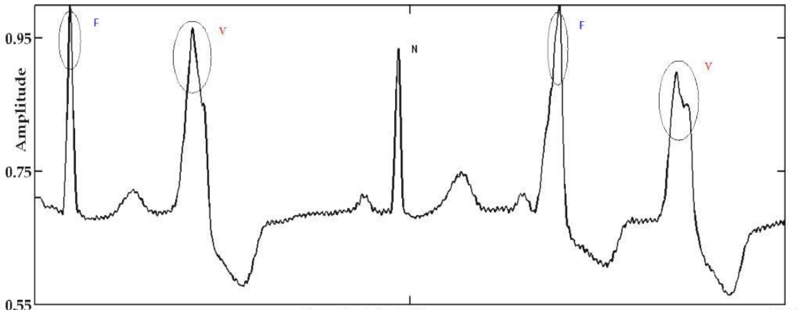
C. Premature Ventricular Contraction (pvc)

A PVC or premature ventricular complex, is an event where the heartbeat is initiated in the ventricles by Purkinje fibers rather than by SA node. SA node is the normal heartbeat initiator. PVCs in ECG can be observed as QRS complex with abnormal wave shape. Various characteristics of PVC are

D. Features of PVC

1) Wider QRS complex: (≥ 120 ms) with abnormal morphology
2) Premature: occurs earlier to the one expected for the next sinus impuls
3) ST segment and T wave change
4) Usually followed by a full compensatory pause
5) Retrograde capture of the atria may or may not occur

The electrical activity of the heart detected by the ECG enables PVCs to be easily distinguished from normal heart beat. Although PVCs can be a sign of reduced oxygenation to the heart muscles, PVCs may even appear sometimes in healthy hearts. PVCs occur when the ventricles contract prior to the arrival of electrical impulses from SA node. It is less dangerous if a single PVC beat appears in the ECG. Risk of sudden cardiac death prevails if PVC beats with different configurations of QRS complex occur continuously in the ECG such as F (fusion of PVC with normal beat), V(PVC beat) and N(normal beat) of the ECG record-208 of ML-II taken from MIT-BIH database is shown in the figure1.



Heart disease occurs frequently in patients with right ventricular PVCs and present in all patients with left ventricular and biventricular PVCs. Occurrence of PVCs in the ECG signal alters the morphological features, which has made peak detection complicated. Many algorithms were presented in the literature for PVC identification. Murthy[6] et al proved that, PVC data can be identified from normal data based on minimum phase correspondent (MPC). J.S.Paul[7] et al, combined the concepts of DCT and cepstral filtering for identification of PVCs under noisy conditions upto 10dB. Bert.Uwe[8] et al have developed different algorithms using derivatives, digital filters, wavelets and Hilbert transform methods for QRS peak detection and discussed the comparative results. D.Benitez[9] et.al has used the Hilbert transform to find the QRS peak based on the envelope of ECG beat. A nonlinear TEO is used in comparison with the Hilbert transform for PVC identification based on peak detection. The statistical parameters used as performance measures of the algorithms are accuracy, sensitivity, positive predictivity and specificity as defined below

$$Se = \frac{TP}{TP + FN} \qquad (1)$$

Positive predictivity:

$$+P = \frac{TP}{TP + FP} \qquad (2)$$

Specificity : Sp=

$$\frac{\text{number of true negatives}}{\text{number of true negatives} + \text{number of false positives}} \qquad (3)$$

Accuracy is expected to measure how well the algorithm predicts both sensitivity and specificity. TP is true positives, FN is false negatives, and FP is false positives. The sensitivity is the ability of the algorithm in detecting the percentage of true beats and positive predictivity +P is the ability of the algorithm in detecting percentage of beat detections which were in reality true beats.

II. VARIOUS ALGORITHMS USED FOR PVC IDENTIFICATION

A. New Concepts for PVC detection[6]

A new algorithm was proposed for PVC detection, a vital function for rhythm monitoring in cardiac patients. A transformation of the first difference of digitized ECG is used for the detection of QRS complexes. Concepts of minimum phase and signal length are used for classification of abnormal complexes from normal ones. The parameters obtained from a linear discriminant function using a training feature vector set are used for classifying the complexes.

B. Automatic Detection of PVCs using Autoregressive Models[7]

An attempt has been made to automate the detection of PVCs using autoregressive models. Since application of modeling techniques on time domain signals involve very large orders, Discrete Cosine Transform (DCT) of windowed ECG signals was used for analysis. Two distinct sets of DCT coefficients are resolved which represent DCT of system function (action potential) and excitatory function respectively. System function corresponds to action potential. An autoregressive model developed for the system function characterizes the features required for identifying the PVC. Application of this algorithm to MIT-BIH database has identified the PVCs efficiently, even from noisy records of up to 10dB. Paced beats, LBBBs and RBBBs, are not identified due to their wider QRS complexes.

C. Identification of PVCs in surface Electrograms using the envelope of DCT[8]

Concepts of DCT cepstrum an algorithm was developed for PVC identification. DCT coefficients define the envelope of ECG. Since DCT coefficients have decaying nature, decay rate of the envelope is used for analysis of time domain features of ECG. DCT coefficients for a PVC beat exhibit a faster decay rate than that of normal beat and this characteristic enables PVC identification. Decay rate was quantified with Energy Packing efficiency (EPE) defined as the number of coefficients in which 90% of total energy is packed. EPE calculated is 3-10 coefficients and 30-40 coefficients respectively for PVCs and a normal beat. This algorithm worked well for noisy records upto an SNR of 10dB except for Paced beats and LBBs.

D. Automatic Detection of Premature Complexes in ECG Using Wavelet Features and Fuzzy Hybrid Neural Network[12]

An algorithm using discrete wavelet coefficients and fuzzy hybrid neural networks was developed. Cardiac beats have been detected based on the differential of compressed wavelet coefficients using Linear Approximation Data Transfer (LADT) method and adaptive thresholds. Sum and variance of the squared wavelet coefficients and the R-R ratio of successive beats are applied to a self organizing sub network cascaded to a multi layer perceptron as final classifier. The c-means and Gustafson-Kessel algorithms have been applied for the self-organizing layer. Potential of the method was examined using MIT_BIH arrhythmia database. Results reveal high detection rate of 99.43% and high sensitivity of 99.65% on 59864 detected beats and 100% sensitivity and specificity on premature beat recognition.

E. Detection of PVCS with Support Vector Machine[13]

Support vector machines (SVMs) are supervised learning models for classification or pattern recognition. This algorithm described SVM for PVC identification in surface ECGs. Features required for the classification are attained by analyzing the heart rate, morphology and wavelet energy of ECG beats from a single lead. MIT-BIH arrhythmia database records are subjected to different SVMs following the 'Association for the Advancement of Medical Instrumentation' (AAMI) recommendations.

F. On The Detection of Premature Ventricular Contraction14

A new approach for automatic detection of PVCs was presented, based on morphological derivatives and information theory techniques. Using these approaches a set of patient invariant features is introduced. Sensibility and specificity results (96.35% and 99.15%) show the potential of the algorithm when applied to the MIT-BIH Arrhythmia database.

G.Robust Detection of Premature Ventricular Contractions using a Wave-Based Bayesian Framework

Detection and classification of PVCs is of considerable importance for holter and critical care patient monitoring. It is essential for the timely diagnosis of serious heart conditions. Accurate detection of PVCs is required in case of life-threatening arrhythmias. A model-based dynamic algorithm for tracking the ECG characteristic waveforms using an extended Kalman filter was developed in this paper. This algorithm can work on single or multiple leads. A 'polargram' is a polar representation of the signal, which is constructed using the Bayesian estimation of state variables. A novel measure of signal fidelity by monitoring the covariance matrix of signals by filtering procedure was proposed. Tracking the signal fidelity and the polar envelope simultaneously leads to the detection of PVCs. various records of MIT-BIH arrhythmia database, are used for distinguishing normal and PVC beats. Statistical parameters measured with the proposed method are, an average detection accuracy of 99.10%, aggregate sensitivity of 98.77%, and aggregate positive predictivity of 97.47%. Furthermore, the method is capable of 100% accuracy for records that contain only PVCs and normal beats.

H.Wavelet and energy based approach for PVC detection[16]

The algorithm discussed in this paper is a wavelet and energy based technique for PVC detection, required for evaluating and predicting life threatening ventricular arrhythmias. Abnormal complexes can be distinguished from the normal ones on calculating the RR-interval and energy of ECG signal. Wavelet decomposition method decomposes ECG signal to the required level using suitable mother wavelet and the proper detail coefficient. R-peaks are detected by subjecting the wavelet coefficients to thresholding and decision logic. when the RR-interval exceeds a predefined threshold an RR-interval window is placed between two successive R-peaks,. A window based energy analysis of ECG signal is performed where low frequency samples are eliminated and a higher energy window is analyzed. This analysis gives rise to actual number and position of PVCs in the ECG signal.

I. PVC Detection by Energy Analysis[17]

PVC detection algorithm based on the energy analysis of ECG signal is discussed. Energy analysis of preprocessed ECG signal is done by defining a window of 600 ms duration and applying the higher threshold. This results in positioning an energy window on the time scale in the areas rich in wider beats. The onset or offset of these energy windows gives an idea of the number of PVCs available in ECG signal. Performance of the algorithm can be improved further by analyzing the energy of same ECG signal with another window of 100 ms. Intervals between the successive peaks above a predefined lower threshold results in windows between two successive ECG peaks with higher interval. At one instance, the algorithm takes higher energy values as possible PVCs and at another instance, it considers the PVCs where peak to peak interval is higher. The intersection of higher energy windows and higher peak to peak interval windows is taken as the actual PVC beats in the signal. This algorithm achieves 100 % accuracy.

J. Detection of Premature Ventricular Contraction Beats Using ANN[18]

Accurate detection of PVCs is required for diagnosis of life-threatening arrhythmias. A data based approach was developed in which the wave morphology in terms of Form Factor (FF) and R peak amplitude are calculated. Artificial Neural Network (ANN) is used for classification of PVC beats from normal ones. The obtained sensitivity (Se), specificity (Sp) and accuracy are 94.11% and 97.5% and 96.45 respectively.

K.Research on premature ventricular contraction real-time detection based support vector machine[19]

Algorithm discussed a support vector machine (SVM) for real-time detection of PVC from normal beats and others. This includes a signal feature extraction module and a statistical pattern recognition module. In feature extraction, time, frequency and morphological features are extracted, here six features are selected and made up a feature vector for input the pattern identifier. After this, an SVM is used to recognize PVC from normal beats. This classifier is suitable for the requirements of precision and real-time at the same time. Subjecting MIT-BIH arrhythmia database records to the algorithm, the correct rating is more than 97%. By comparing with other methods, this algorithm achieves favorable results both in real-time and accuracy requirement.

L. High-Precision Real-Time Premature Ventricular Contraction (PVC) Detection System Based on Wavelet Transform[20]

Robert Chen et al., have discussed a high-precision real-time detection system for PVC detection. R-peaks are detected based on wavelet transform (WT), and then new algorithm was used to detect PVCs. The proposed PVC detection algorithm combines the sum of troughs and minimums of R-peaks to detect PVCs. A crucial function of morbid warning is implemented to alert the user when PVC is detected. The proposed algorithm was applied on MIT-BIH Arrhythmia Database. The system was also implemented on FPGA to illustrate its high precision and real-time performance.

M. ECG Signal Processing: Detection of Arrhythmia PVC[21]

The objective of this paper was to develop an algorithm for detection and classification of different cardiac arrhythmias from the recorded ECGs, the algorithm can efficiently handle noise like power line interference and baseline shift caused by unstable amplifiers during the ECG measurement. The characteristic shape of QRS and its frequency of occurrence are commonly used to classify arrhythmias with the records of the subjects from MIT-BIH database.

N. Classification of Premature Ventricular Contraction in ECG[22]

Identification of PVCs from normal beats is crucial to predict the possibility of heart failure. This algorithm focussed on the classification of PVCs heartbeats using time series approaches. Experiments were carried out using well-known machine learning methods, including neural networks, k-nearest neighbour, decision trees, and support vector machines. Statistical parameters used as performance measures are accuracy, sensitivity, specificity. Out of various classification methods, k-NN algorithm achieved the best classification rate. The results revealed that the proposed model exhibited higher accuracy, sensitivity, and specificity rates of 99.63%, 99.29% and 99.89%, respectively.

O. QRS Detection and PVC Beat Recognition Using a Generalised Teager Energy Operator[23]

A novel algorithm using Generalized Teager energy operator (GTEO) is presented in this paper for automatic QRS peak detection and PVC beat identification. This algorithm is carried out in two stages. First stage is QRS detection followed by a second stage of PVC beat recognition with an optimum order of GTEO required for each stage. GTEO of second order can be used for QRS detection, and a seventh order can be used for PVC beat recognition. The proposed algorithm was tested on MIT-BIH Arrhythmia and AHA databases. The records chosen contained both PVC and normal beats. Sensitivity and specificity parameters are used as performance measures of the proposed algorithm. Advantages of GTEO are its simplicity, robustness and speed. Results revealed that the algorithm works well for QRS detection and PVC recognition with sensitivities of 99.5% for QRS detection and 97.4% for PVC recognition, and specificities of 99.8% for QRS detection and 99.1% for PVC beat recognition.

P. Parametrical modelling of a premature ventricular contraction ECG beat: Comparison with the normal case[24]

The aim of this work is to develop parametrical Gaussian kernel based models of PVC beat and normal ECG beat. Basically, the model constitutes N Gaussians whose parameters are estimated by optimization of a specific criterion. Validation of the model is achieved using MIT/BIH databases. Results show that modeling of normal beat used 18 parameters whereas only 15 parameters are needed for modeling of a PVC beat.

Q. Cardiac Arrhythmia Detection by ECG Feature Extraction[25]

An algorithm was developed for the detection of cardiac arrhythmias like premature ventricular contracture (PVC), right bundle branch block (RBBB) and left bundle branch block (LBBB) based on extraction of various ECG features and their intervals (i.e. RR, QRS, etc). The proposed algorithm was tested on MIT-BIH Arrhythmia database. Efficiency of the algorithm depends on the proper extraction of the features and their intervals of ECG signal. This simple algorithm gave satisfactory results of measured specificity and sensitivity of 92% and 91% respectively. This proved the algorithm to be a better choice in clinical field of cardiac arrhythmia detection. The efficiency of the algorithm can be improved by using higher order statistics and support vector machine.

R. Premature Ventricular Contraction Arrhythmia Detection Using Wavelet Coefficients[26]

PVC arrhythmia detection is very much important in clinical diagnosis. An algorithm based on the use of wavelet detail coefficients was discussed for detection of PVC beats from normal beats. The algorithm was tested on various records of the MITBIH Arrhythmia Database. This method uses single fixed thresholding of detail coefficients, to separate normal beats from the PVC beats. The required threshold was obtained combining two DWT detail coefficients. Results revealed that good classification of normal and PVC beats can be achieved using DWT detail coefficients.

S. Wavelet Power Spectrum Analysis for PVC Discrimination[27]

This paper presented a technique for PVC screening. Wavelet power spectrum analysis was applied to extract some characteristic features form ECG beats. Required data for the implementation of the algorithm is taken from the records of MIT-BIH arrhythmia database. The discriminant analysis with Mahalanobis distance was used as classifier to discriminate between sinus group and PVC group. The classification with combined features achieved the best performance with sensitivity of 81.99±1.07% and specificity of 90.38±0.64%. This study proposed a technique for screening PVC from ECG trace. Features like MF, VR, SK, and KT are studied separately in data distribution analysis. This classification with combined features gave the best performance with sensitivity of 81.99±1.07% and specificity of 90.38±0.64%. Recently, wavelet transform is widely used in medical signal analysis. From previous works by authors, the wavelet transform were employed in several studies associated with ECG analysis such as prediction of defibrillation outcome, ventricular fibrillation detection, prediction of ventricular arrhythmias, and prediction of sleep apnea. In this study, the wavelet transform also gave promising results in PVC screening. The preliminary results in this paper show wavelet power spectrum based- PVC discrimination in comparison with Fourier transform.

T. Detection of PVC in ECG signals using fractional linear prediction[28]

A modeling technique for the detection of QRS complex based on the fractional linear prediction (FLP) was proposed in this paper. In FLP modeling, QRS complex is represented by a vector of three coefficients. Evaluation of the model is achieved in two steps. In the first step, the FLP coefficients are used to model QRS complex waves effectively and compared with the Linear Prediction coefficients in terms of signal-to-error values. In the second step, to validate the effectiveness and robustness of FLP modeling over LP modeling, several classifiers are fed with the three estimated coefficients to discriminate PVC beats from normal beats. This study has successfully demonstrated that LP modeling can be replaced with FLP modeling for QRS complex modeling. An accuracy of 92.6%, sensititvity of 77% and specificity of 93.7% are obtained with FLP modeling.

U.Identification of PVCs based on peak detection with Teager Energy Operator[29]

A nonlinear modeling algorithm using the characteristics of TEO for PVC Identification based on R peak detection was proposed. Using Teager energy operator envelopes were extracted for the ECG beats form the records taken from MIT-BIH database constituting the, normal beats, fusion beats and PVC beats. Thresholding the extracted envelopes resulted in an impulse spike for normal and fusion beats, which illustrated that the energy required for ventricular depolarization was originated from SA node. For a PVC beat, no peak was detected after thresholding as the extracted envelope is having low amplitude and ripples which indicate that the energy required for ventricular depolarization was generated by ectopic foci due to the failure of SA node. This algorithm is very simple using just only three samples compared to Hilbert transform based. Figure2 depicts the detection of R-peaks of corresponding PVC beats and normal beats with the proposed algorithm. Results reveal that error detection rate using TEO model is less than that of Hilbert transform method. TEO model proved to be computationally efficient in distinguishing the PVC beats from normal beats even in the presence of noise. Extension of this algorithm can be used for ECG enhancement and other arrhythmia identification.

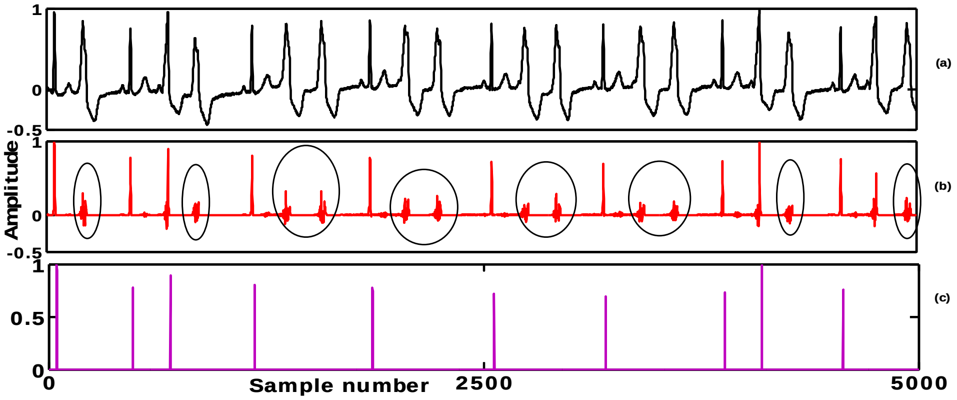


Figure 2. MIT-BIH data record #119 (a) PVC beats encircled; (b)R-Peaks encircled (c) thresholded R-peaks for normal beats

V. Identification of Premature Ventricular Cycles of Electrocardiogram Using Discrete Cosine Transform-Teager Energy Operator Model[30]

Motivation behind the use of nonlinear Teager energy operator for the analysis of nonlinear ECG data is its attractive feature of tracking the instantaneous changes in the energy of nonlinear signals. An attempt was made in this paper to extract the energy of the ECG signal using only three samples based on which PVCs are identified from normal beats. Discrete cosine transform is used for transformation of ECG beat to frequency domain. Interesting feature of DCT is, packing the energy in few low frequency components nearer to the origin. Envelope of the DCT coefficients corresponding to ECG beat is obtained using Teager energy operator and compared with existing method of cepstral filtering. ECG beat can be identified as PVC beat if the decay rate is faster otherwise normal. Envelope of PVC beat decays within 10 to 15 coefficients with cepstrum model and 5 to 11 coefficients with TEO model whereas envelope of normal beat decays within 34 to 48 coefficients with cepstrum model and 29 to 39 coefficients with TEO model. With low decay rate TEO model proved to be efficient in PVC identification. TEO was found suitable for identifying PVC beats under noisy environment with a signal to noise ratio of up to −5 dB, compared to cepstrum model which can identify the PVCs corrupted only with Gaussian noise. Statistical parameters like sensitivity, predictivity, and detection error rate are calculated as performance measures. Also DCT-TEO method could identify paced beats, LBBB, and RBBB.

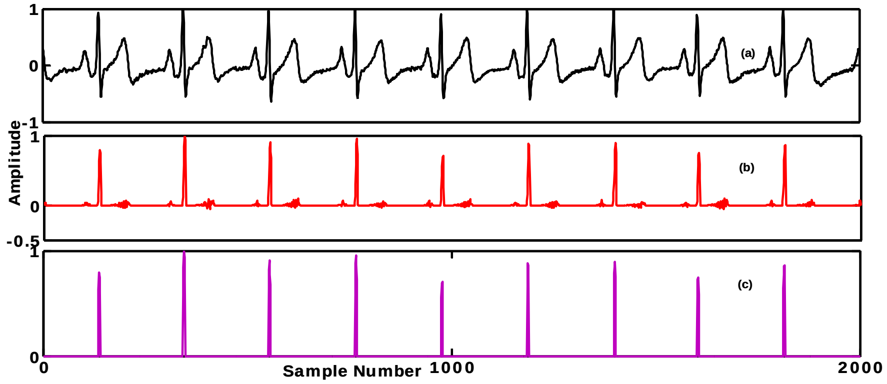


Figure 3. (a) Online recorded ECG with normal beats; (b) R peaks with the proposed method and (c) thresholded R-peaks

The energy extracted reflects the envelope of action potential which in turn represents the QRS complex(R-peak) of the ECG beat. Ability of TEO to process the real time data is tested with a data acquired in the laboratory. Peaks detected indicate that the recorded ECG is normal as shown in figure 3. Envelopes extracted correspond to R-Peaks. Detected R-peaks for PVC beats are encircled in trace (b) of figure 4 compared to that of normal beat for record #119. EPE is calculation of number of DCT coefficients which pack 90% of the energy. EPE or ε_i=0.9 is the factor for distinguishing PVC beats from normal ones. EPE calculated with the proposed DCT-TEO method for PVC and normal beats is shown in figure 5.

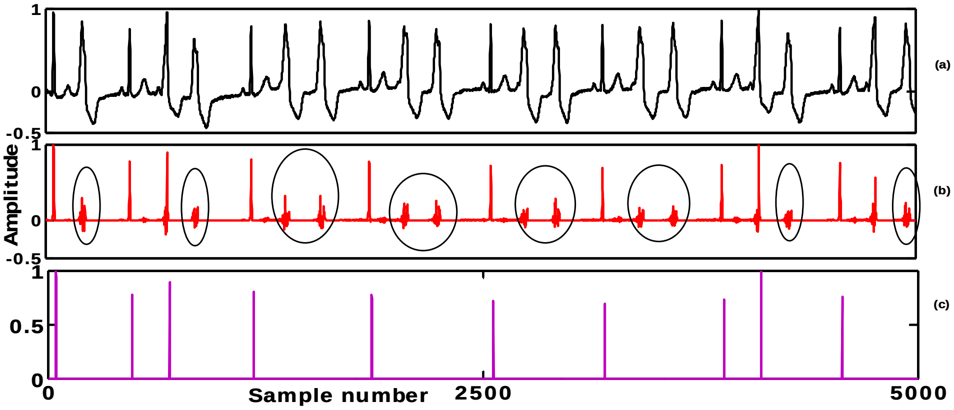


Figure 4. MIT-BIH data record #119; PVC beats encircled in trace (a); R-Peaks encircled in trace (b); thresholded R-peaks for normal beats in trace (c).

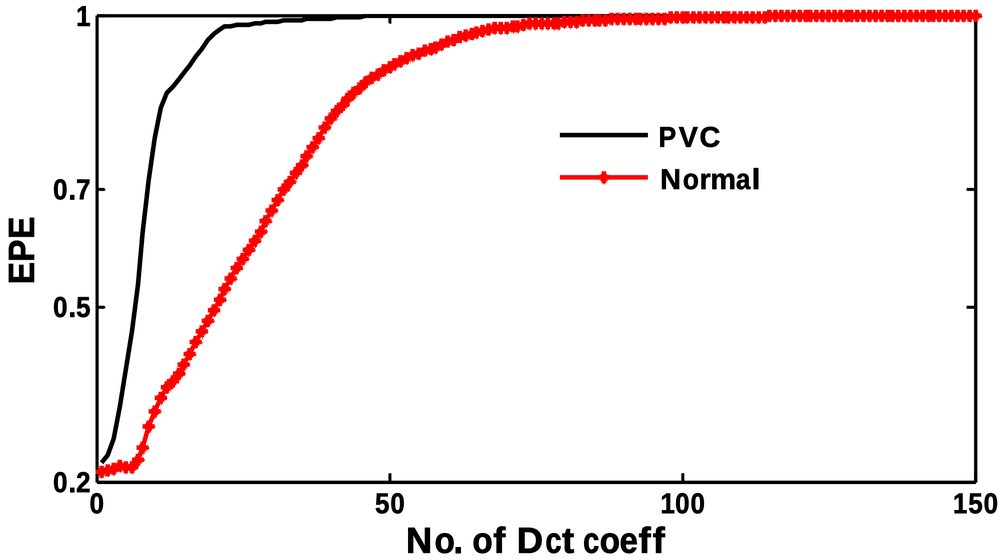


Figure 5. EPE for PVC and normal beats with DCT –TEO

III. RESULTS AND CONCLUSION

This paper discussed several promising methods for identifying PVCs in ECG signals. Various records of MIT-BIH physionet archive were used for testing. Performance comparison of various methods was obtained with the calculation of statistical parameters like accuracy, sensitivity, positive predictivity and specificity as presented in Table-1. A conclusion can be drawn that TEO and DCT-TEO models are observed to be reliable and efficient methods for PVC identification.

Table 1. Comparison Table for PVC detection using different methods

Sno	Method	Acc (%)	Se (%)	+P (%)	Sp (%)
1	New Concepts for PVC detection[6]	-	-	-	-
2	Automatic Detection of PVCs using Autoregressive Models[7]	-	-	-	-
3	Identification of PVCs in surface Electrograms using the envelope of DCT[8]	-	-	-	-
4	Robust Detection of Premature Ventricular Contractions Using a Wave-Based Bayesian Framework[15]	99.10	98.77	97.47	-
5	Research on premature ventricular contraction real-time detection based support vector machine[19]	-	-	-	-
6	Detection of PVCs with support vector machine [13]	-	-	-	-
7	On the detection of PVC[14]	-	96.35	99.1	-

				5	
8	Wavelet and energy based approach for PVC detection[16]	-	-	-	-
9	PVC Detection by Energy Analysis [17]	100	92.68	96.3	-
10	Detection of Premature Ventricular Contraction Beats Using ANN[18]	96.45	94.11	-	97.5
11	ECG Signal Processing: Detection of Arrhythmia PVC[21]	-	-	-	-
12	High-Precision Real-Time Premature Ventricular Contraction Detection System Based on Wavelet Transform[20]	94.73	-	-	-
13	Automatic Detection of Premature Complexes in ECG Using Wavelet Features and Fuzzy Hybrid Neural Network[12]	-	100	99.43	100
14	Classification of Premature Ventricular Contraction in ECG [22]	99.63	99.29	-	99.89
15	QRS Detection and PVC Beat Recognition Using a Generalised Teager Energy Operator[23]	-	97.4	-	99.1
16	Parametrical modelling of a premature ventricular contraction ECG beat: Comparison with the normal case[24]	-	-	-	-
17	Cardiac Arrhythmia Detection By ECG Feature Extraction[25]	-	91	-	92
18	Premature Ventricular Contraction Arrhythmia Detection Using Wavelet Coefficients[26]	98.48	97.21	-	98.67
19	Wavelet Power Spectrum Analysis for PVC Discrimination[27]	-	81.99	-	90.38
20	Detection of PVC in ECG signals using fractional linear prediction[28]	92.6	77	-	93.7
21	Identification of PVCs based on peak detection with Teager Energy Operator[29]	99.8	99.8	99	99
22	Identification of Premature Ventricular Cycles of Electrocardiogram Using Discrete Cosine Transform-Teager Energy Operator Model[30]	99.9	99.9	99.9	99.9

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