Classification Methodology of CVD with Localized Feature Analysis using Phase Space Reconstruction Targeting Personalized Remote Health Monitoring

Naresh Vemishetty [1], Amit Acharyya [1], Saptarshi Das [2], Shivteja Ayyagari[3], Soumya Jana[1], Koushik Maharatna [4], Paolo Emilio Puddu [5]

[1]Indian Institute of Technology, Hyderabad, India
[2] University of Cambridge, UK
[3] Gitam University, Visakhapatnam
[4] University of Southampton, Southampton, UK
[5] Sapienza, University of Rome, Rome, Italy

Abstract

This paper introduces the classification methodology of Cardiovascular Disease (CVD) with localized feature analysis using Phase Space Reconstruction (PSR) technique targeting personalized health care. The proposed classification methodology uses a few localized features (QRS interval and PR interval) of individual Electrocardiogram (ECG) beats from the Feature Extraction (FE) block and detects the desynchronization in the given intervals after applying the PSR technique. Considering the QRS interval, if any notch is present in the QRS complex, then the corresponding contour will appear and the variation in the box count indicating a notch in the QRS complex. Likewise, the contour and the disparity of box count due to the variation in the PR interval localized wave have been noticed using the proposed PSR technique.

ECG database from the Physionet (MIT-BIH and PTBDB) has been used to verify the proposed analysis on localized features using proposed PSR and has enabled us to classify the various abnormalities like fragmented QRS complexes, myocardial infarction, ventricular arrhythmia and atrial fibrillation. The design have been successfully tested for diagnosing various disorders with 98% accuracy on all the specified abnormal databases.

1. Introduction

According to the survey conducted by World Health Organization (WHO), Cardiovascular Diseases (CVD) are the primary drivers for the high mortality rate all over the world among all the non-communicable diseases [1]. There is an utmost necessity to classify even the minute abnormalities of the heart beat in the current scenario. To address the consequences of CVD in healthcare infrastructure, affordable and reliable devices for remote health care monitoring devices need to be developed.

Accounting this, we have proposed a localized analysis on the extracted features of the individual PQRST complexes by Phase Space Reconstruction (PSR) technique. In the field of nonlinear dynamics, PSR technique is widely used for classifying even the small desynchronisation phenomena in time-series data [2]. In the PSR technique, the original signal and the delayed version of it is plotted to get the dynamic system's trajectory. This gives a closed contour for a periodic signal of regular oscillations of the system. Recently PSR technique has shown prospect of detection of Ventricular Arrhythmias (VA) [3] when analyzed statistics on large dataset of many samples. However, since it works on several stored PQRST complexes globally there is a high chance of miss classification of important and interesting diagnostic features of the individual ECG beats consisting of fragmented QRS complexes or missing of P wave or any desynchronisation in the individual ECG beats.

Hence, in this paper we propose PSR based localized methodology will use the extracted characteristics intervals (QRS interval and PR interval) from the FE block as shown in Fig.1 (a) and detect the desynchronization in the given intervals after applying the PSR technique. The State-of-the Art techniques may enable to extract the P and T waves correctly in following diseases (sinus arrhythmia, atrioventricular conduction variation and many more) [4], [10] where more likely P and T waves still be detected even though these are absent in the real life signals for the following diseases (Ventricular Arrhythmias, Atrial fibrillation and flutter) resulting in wrong diagnosis and therapy followed. Whereas the proposed methodology will detect the abnormal variation in the intervals and produce the corresponding contour and shows the disparity in the box count. The box count value of the abnormal wave intervals is different from the box count value of the normal ECG wave intervals. For the best results from PSR technique we have filtered the ECG signal by keeping the cut-off frequency of 1 Hz and 30 Hz using a fourth-order

high-pass digital filter followed by low-pass filter respectively [5].

For the analysis of healthy and abnormal ECG signals we have taken the test cases from the MITDB and PTBDB of the physionet [6]. The paper is organized as follows. Section 2 describes the proposed methodology and its detailed explanation. Section 3 shows the analytical results and concludes the discussion.

2. Proposed methodology

Fig.1 represents the block diagram of the proposed methodology for the classification of CVD. As shown in Fig.1, ECG samples are initially stored in the memory, for the analysis of stored healthy ECG and unhealthy ECG signals, the boundaries are extracted using our proposed Boundary Detection (BD) methodology [7] and the output of BD is applied to FE block [4] to get the following features QRS complex and PR interval of each and every individual beat. The proposed localized feature analysis methodology takes the features from FE block and plot the PSR of all the intervals and calculate the box count.

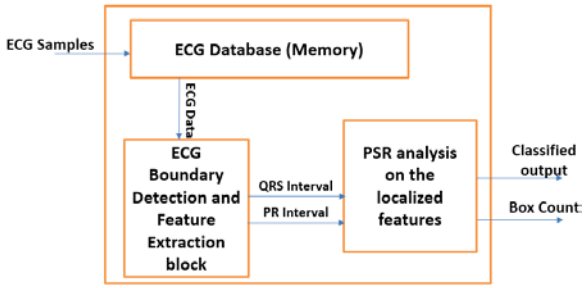

Figure 1. Block level diagram of proposed methodology

2.1. Boundary detection and feature extraction of ECG using DWT

Using our recently proposed BD and FE blocks [7], [9] we extract QRS complex and PR interval of ECG signal from the third and fifth decomposition levels of Haar DWT (Discrete Wavelet Transform) respectively. This module is combination of Modulus-Maxima Analysis (MMA) and Time Domain Morphology (TDM) and provides the intervals along with their indices for all the ECG frames as the outcome by taking the coefficients obtained from DWT block.

2.2. Proposed classification methodology on localized features

The proposed classification methodology takes the QRS complex and PR interval of ECG signal as the input to find the PSR plot and the box count, to maintain all the ECG samples amplitude between 0 to 1 we have normalized the samples using the below equation to ensure that all the values are within the range (0,1).

$$\tilde{x}(t) = (x(t) - x_{min})/(x_{max} - x_{min}) \quad (1)$$

In the above equation x_{max} and x_{min} are the maximum and minimum values of the interval for which we apply the PSR. For the desirable results we have delayed the ECG intervals for 10 ms [8], since the sampling frequency of ECG is 1 kHz we gave the delay of 10 samples. In the PSR technique, a dynamic system trajectory is constructed by plotting the featured signal and the delayed version of it along the coordinate system, the plotted waveform gives a contour based on the featured signal which is given as input. The result of PSR will give a 2D image (PSR plot), describing the trajectories in the image and they are analyzed using the box counting technique [2]. The 2D image has been resized into high resolution gray scale of pixel size N x N, where 'N' is an integer and the value chosen is 'N=1024'. If the trajectory in the image is passed through any of the pixel, then we consider it as a black box (n_b) and rest of the pixels are considered as white boxes (n_w) in the image. Table I shows the pseudo code of the proposed methodology.

PR interval Analysis: For the healthy ECG beat, we can

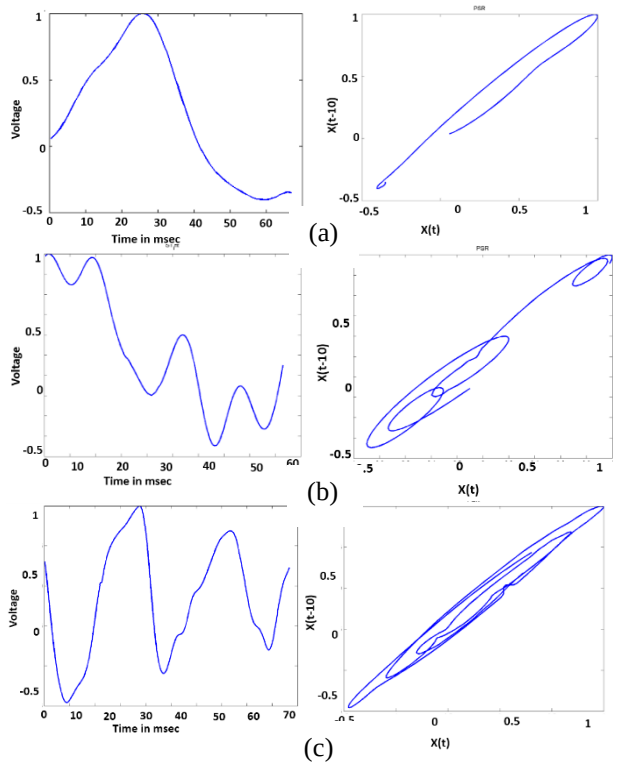

Figure .2 (a) Illustration of P wave of healthy ECG and its corresponding PSR plot, (b) P wave of Atrial Fibrillation and its PSR plot, (c) P wave and its PSR with more chaotic effect.

see a positive and negative deflected P wave based on the ECG leads we are monitoring whereas absence of P waves are observed in abnormal ECG wave like Atrial Fibrillation (AF), the baseline appears as noisy and sometimes it appears as flat for AF. Fig. 2(a) shows the image of the healthy P wave and its PSR plot, Fig.2 (b) represents the absence of P wave and its corresponding PSR plot. We can see a closed contour for the normal P wave in the Fig. 2(a) whereas in Fig. 2 (b) and Fig 2(c) we can observe large chaotic motions in all the trajectories indicating an abnormality in the P wave and in the box count. The main reason of chaotic behavior in the PSR plot is due to more number of irregularities in the P wave of AF ECG signal. The number of black boxes visited by the P wave of healthy ECG and the P wave of abnormal ECG signals will differ based on the irregularities in the wave as shown in Fig. 4 (a).

Table. I Pseudo code to find the PSR plot and the Box count of localized features

1) Apply filtering on the ECG signal to remove the noise and baseline wandering
2) Get the localized signal (PR interval and QRS complex) from the Feature Extraction block
3) Store the samples in the text file (interval.txt)
4) Delay the localized signal by 10 milli seconds or 10 samples
5) Store the delayed signal in another text file (delay_interval.txt)
6) Normalize both files (interval.txt and delay_interval.txt)
7) Plot both the normalized signals in Matlab, the outcome is the PSR plot
8) Store the plot as an image
9) Resize the image to desired number of pixel, here the plot is resized to 1024 x 1024
10) Calculate the box count occupied by the trajectories in the resized image
11) Classify the localized ECG signal as normal or abnormal based on the Box count.

QRS complex Analysis

PSR technique behaves in a particular manner whenever there is an irregularity in the QRS complex. Fig. 3(a) shows the QRS complex of a healthy ECG signal and the corresponding PSR plot, Fig. 3(b) and (c) show the QRS complexes with irregularities and their PSR images. The proposed methodology will be able to identify the notches and fragmented QRS complexes like RsR′, Rsr′, RSr′, notched S and many other variations in the QRS complex. The irregularity in the QRS complex leads to the variation in the PSR plot as compared to the QRS complex of normal ECG signal. As shown in Fig. 3(a) the PSR plot

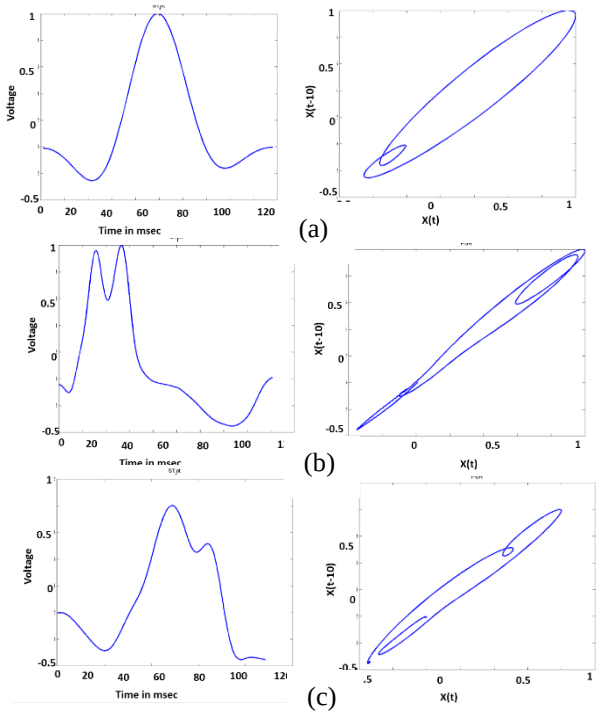

Figure. 3 (a) Illustration of healthy ECG signal QRS complex and its corresponding PSR plot, (b) Illustration of RsR′ and its corresponding PSR plot, (c)Illustration of Notched R and its plot

of the QRS complex is a closed contour whereas Fig. 3(b) represents the RsR′ variation, the corresponding PSR shows chaotic variation which occupies more number of black boxes in the PSR image compared to the QRS complex of healthy ECG signal. Similarly, Fig .3(c) is the notched 'R', the variation in the S wave clearly shown in the corresponding PSR plot. The box count of the fragmented QRS and the normal ECG signal differ from the variation of irregularity in the QRS complex. The difference in box count is shown in the Fig. 4(b)

3. Results and discussion

The proposed methodology is implemented in Matlab and has been tested on the 80 ECG test cases taken from Physionet PTBDB and MITDB [6]. Fig. 4 shows the statistical analysis of the results, the horizontal line indicates the number of images tested for the analysis. The vertical line indicates the box count occupied for each image. The methodology has been successfully tested for diagnosing various ECG abnormalities like fragmented QRS complex, atrial fibrillation, myocardial infarction and ventricular arrhythmia with 98 % of accuracy on all the subjects. The statistical analysis of PR interval is shown in Fig. 4(a), for the healthy ECG signal the upper limit box count value of PR interval is 8000, whereas the box count of the ECG signals with abnormal P waves

occupying the box count greater than the value of 10,000, the increment of box count is due of irregularities in the P wave of AF. Fig. 4(b) shows the statistical behavior of QRS complex, the box count for the abnormal signals

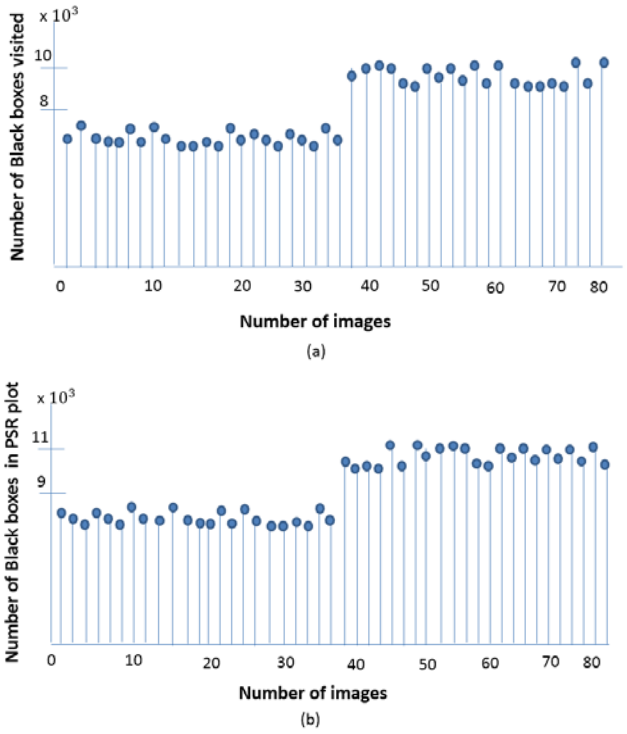

Figure. 4 (a) Statistical analysis of PR interval, (b) statistical analysis of QRS complex.

like fragmented QRS complexes is exceeding 11,000 whereas the upper limit for normal QRS complex box count is less than 9000. The variation in the box count is due to the irregularity of the QRS complex for abnormal signals.

4. Conclusion

In this paper, we have proposed a novel classification methodology to detect the cardiovascular diseases using localized features (PR interval and QRS complex) of ECG signal and the PSR technique. The proposed methodology uses QRS complex and PR interval from the feature extraction module and detects the irregularities in the localized intervals using the PSR technique. Presence of notches in the QRS complex leads to chaotic behavior in the PSR plot which increase the number of box count as compared to the normal ECG wave. Similarly, variation in the contour and the box count in the PR interval is observed using PSR technique. The methodology has shown 98 % of accuracy upon validating on various abnormalities like fragmented QRS complexes, myocardial infarction**,** ventricular arrhythmia and atrial fibrillation taken from MITDB and PTBDB database.

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Address for correspondence.
Name. Amit Acharyya
Department of Electrical Engineering, Indian Institute of Technology, Hyderabad, INDIA. Pin Coe: 502285
E-mail address. amit_acharyya@iith.ac.in
http://www.iith.ac.in/~amit_acharyya/