Arrhythmia Classification by Heart Rate Variability Analysis using Symlets based on Time-Frequency Features

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ABSTRACT
The activities of autonomic nervous system can be accessed using information on heart rate modulation mechanism. HRV analysis is a well-known non-invasive tool that gives information on heart rate modulation mechanism. This paper presents a work on HRV analysis to distinguish normal sinus rhythm from atrial fibrillation, supra-ventricular arrhythmia and premature ventricular contraction. Basically a technique for detection of the heart disease Arrhythmia grounding on HRV signal data analysis is presented in this paper. The R-Peak detection is done using wavelet Symlet7 at second level decomposition. The time-frequency parameters such as SD Ratio, LF/HF Ratio and pNN50 are used for HRV analysis. The ratio LF/HF of HRV spectra represents a measure of sympatho-vagal balance. As this parameter shows better results for only short term recordings hence other parameters such as SD Ratio and pNN50 are considered for HRV analysis for both long-term and short-term recordings.

General Terms
Signal Processing, Wavelets

Keywords
Heart rate variability, Symlet, SD Ratio, LF/HF, pNN50, Poincaré Plot, PSD Plot, Heart rate, Heart beat, HRV, wavelet

1. INTRODUCTION
Electrocardiography or ECG for short is a technique of recording bioelectric current generated by the heart muscles. The graphical representation of this recording is called electrocardiogram. A typical ECG waveform comprises of an initial P-wave followed by QRS complex and then a trailing T-wave. The heart rate is the repetition of QRS complex in one minute. So it varies from normal patient to diseased person. Heart rate becomes slow or fast according to situations. Different types of thoughts, emotions, and changes in environmental conditions cause immediate change in heart rates. The instantaneous heart rate is called 'Heart Rate Variability' (HRV) and it varies between two consecutive heart beats [1]. ECG signals come with many types of noises viz., baseline drift, power line interference, electrode contact noise, internal amplifier noise, muscle noise and motion artifacts etc. A pre-processing of ECG signals is as such necessary to avoid erroneous analysis [2]. QRS detection is one of the most important works for HRV analysis. In this work ECG signals are decomposed up to fourth level using Symlet7 and the second level decomposition is considered for less computation and better R-peak detection [3]. For the HRV analysis the time-domain parameters SD Ratio and pNN50 and the frequency domain parameter LF/HF Ratio have been used.

NN50 is the number of interval differences of successive NN intervals greater than 50ms. The proportion pNN50 is derived by dividing NN50 by the total number of NN intervals. All these measurements of short-term variations estimate high frequency variations in heart rate and are thus highly correlated [1].

The parameter SD Ratio is the ratio of SD1 to SD2 where SD1 is the length of semi-minor axis and SD2 is length of semi-major axis of the Poincaré plot. Poincaré HRV plot is a graph in which each inter-beat (RR) interval is plotted against next RR interval. The quantitative analysis of the Poincaré plot is based on the notion that each RR interval is influenced by previous vagal and sympathetic modulations over the heart rate and therefore the pairs of successive RR intervals form an attractor in the Poincaré plot [4].

Power spectral analysis is a popular tool for analyzing the activity of the autonomic nervous system (ANS). The ANS is divided into three main sub-systems: the parasympathetic nervous system (PNS), the sympathetic nervous system (SNS), and the enteric nervous system (ENS). Power spectral analysis of the RR series is characterized by two main components: a high frequency component and a low frequency component. The high frequency components, having the bandwidth 0.2-0.4 Hz are mainly modulated by the PNS of the ANS and the low frequency components of bandwidth 0.04-0.15 Hz are modulated by the SNS of ANS. The ratio of low frequency power (LF) to high frequency power (HF) is considered as a measure of sympatho-vagal balance [1], [5].

The aim of this work is to distinguish the ECG records of normal patients from those of abnormal patients suffering from atrial fibrillation, supra-ventricular arrhythmia and premature ventricular contraction by doing analysis of ECG signals using parameters like LF/HF ratio, SD ratio, pNN50, Power spectral density plot, Poincaré plot.

2. METHODOLOGY
The ECG data that have been used for the experiments have been obtained from the MIT-BIH database [6]. Each ECG signal data that have been considered is of a duration of 30 minutes. The sampling frequency of normal sinus rhythm and supra-ventricular arrhythmia is 128 Hz. For atrial fibrillation it is 250 Hz and for premature ventricular contraction it is 360 Hz.

In general ECG signals contains noise interference, so to avoid erroneous conclusions, we do pre-processing using low-pass filters, high-pass filters and differentiators. The pre-processed ECG signal is then decomposed up to fourth level using Symlet7. In this work the second level decomposition is considered for better R-Peak detection as number of computations is less as compared to first level [3]. RR intervals are calculated both w.r.t. time and number of samples, which serve as inputs for time-frequency parameter analysis.

2.1 Symlet Wavelet

In general wavelets comprise a family of basis functions that describe signals in a localized time and frequency format. Ingrid Daubechies made discrete wavelet analysis practicable by inventing compactly supported orthonormal wavelets. The names of the Daubechies family wavelets are written 'dbN,' where 'N' is the order, and 'db' the "surname" of the wavelet. The symlets are nearly symmetrical, orthogonal and bi-orthogonal wavelets proposed by Daubechies as modifications to the 'db' family. The symlet family wavelets are written as 'SymN.' In 'SymN,' 'N' is the order. The properties of the Daubechies family wavelets and the symlet family wavelets are similar. In the following figure a few symlet family wavelets are shown:

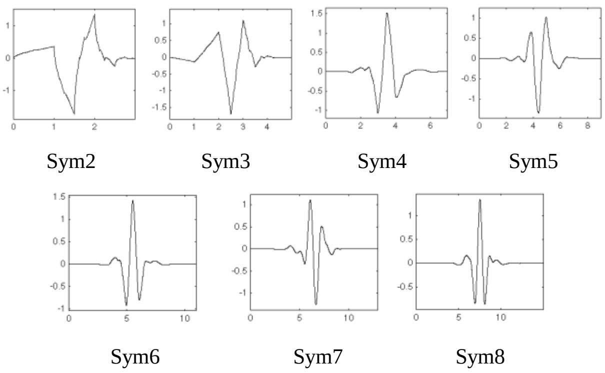


Fig 1: Example of symlets

2.2 Decomposition

In a multiple-level wavelet decomposition process, a signal is broken down into many lower resolution components. At each level, a filtering and sub-sampling is done which results in halving of the time resolution and doubling of the frequency resolution. The sequence x(n) is passed through several levels made up of low pass analysis filters h(n) and high pass analysis filters g(n). At each level of decomposition detailed information is produced by the high-pass filter and coarse approximations are produced by the low-pass filter [3].

2.3 True R-Peak Detection

Wavelet decomposition is done up to fourth level and the approximate coefficient of second level is taken for R-Peak detection. It is so done, because it results in less computation without any loss of information. By simply using a search algorithm, using a threshold, all the peaks are found out with their respective locations. Since some ectopic beats are there, so some peaks are not R-peaks, so by using a threshold of 0.85 x mean of all detected peaks, the true R-peaks are detected.

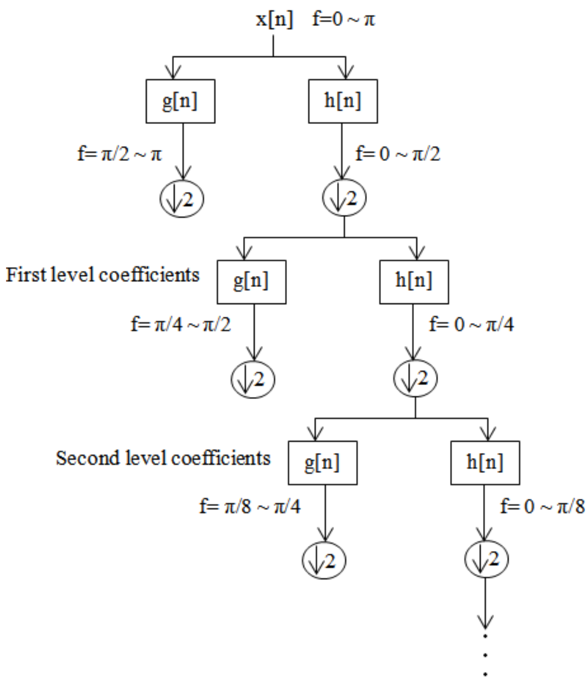


Fig 2: Decomposition using Symlet7

2.4 HRV Analysis using time-frequency parameters

2.4.1 SD Ratio

Poincaré HRV plot is a graph in which each RR interval is plotted against next RR interval (a type of delay map). A so-called Poincaré Plot is created from all RR intervals. The Poincaré plot is a diagram in which each RR interval of HRV time series is plotted as a function of the previous RR interval [4]. In the present work pairs of RR intervals lagged by one, two, and four beats have been used. The quantitative analysis of the Poincaré plot is based on the notion that each RR interval is influenced by previous vagal and sympathetic modulations over the heart rate and therefore the pairs of successive RR intervals form an attractor in the Poincaré plot. Two consecutive RR intervals represent one point in the plot. The first RR interval (RR_n) represents the x-coordinate, the second interval (RR_{n+1}) the y-coordinate [8]. The Poincaré plot looks elliptical for normal sinus rhythm and scattered for abnormal sinus rhythm. SD ratio is the ratio of measurement of semi-minor axis to measurement of semi-major axis. For normal sinus rhythm the SD ratio is less than one and less as compared to SD ratio for the others.

2.4.2 pNN50

It is the variability of difference in RR intervals. NN50 is the total number of interval difference of successive RR intervals greater than 50ms. pNN50 can be derived by taking the ratio of NN50 to the total number of RR intervals. NN50 is less in normal sinus rhythm so pNN50 is less for normal sinus rhythm [1], [9].

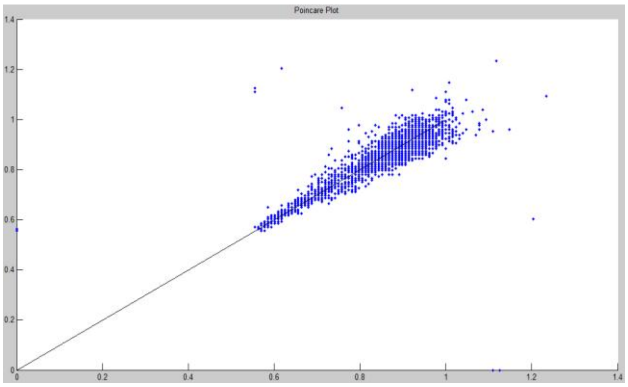
2.4.3 LF/HF Ratio

The high frequency spectral component (HF) obtained from RR series spectra is a representative of vagal modulation activity and the low frequency component (LF) is of sympathetic or of mixed sympathetic and vagal modulation activities. The ratio LF/HF represents a measure of balance of sympatho-vagal activity. In the work Fast Fourier Transform has been used to find Power spectral density of signal. The Total Frequency Spectral Power shows the size of the entire area within all frequencies. The LF/HF, an expression of autonomic balance, is the optimum cooperation between the sympathetic and parasympathetic nervous systems. Large values of the ratio can indicate that the sympathetic nervous system's influence has increased [5]. The power density function also shows the distinction between normal sinus rhythm and abnormal sinus rhythm.

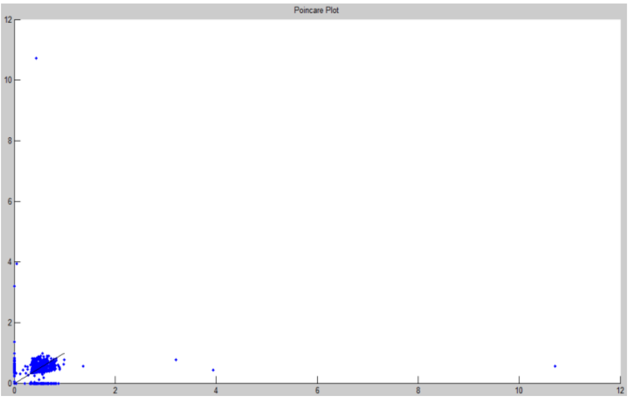
3. RESULTS

For the experiments the ECG signal data of the MIT-BIH database from physionet.org [6] have been used. Normal sinus rhythm data, atrial fibrillation data, supra-ventricular arrhythmia data and premature ventricular contraction data having duration of 30 minutes each, have been considered. For obtaining the results we used the well-known MATLAB software. The results in terms of plots and a table are shown next.

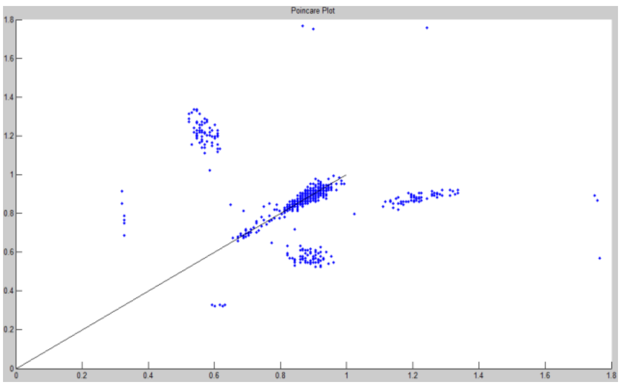
3.1 Plots



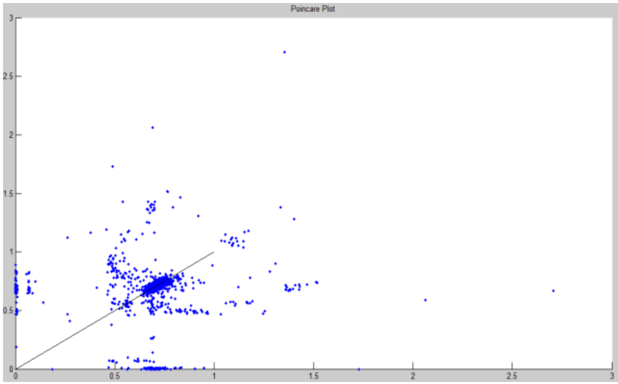
NSR - 16773



Atrial - 4043

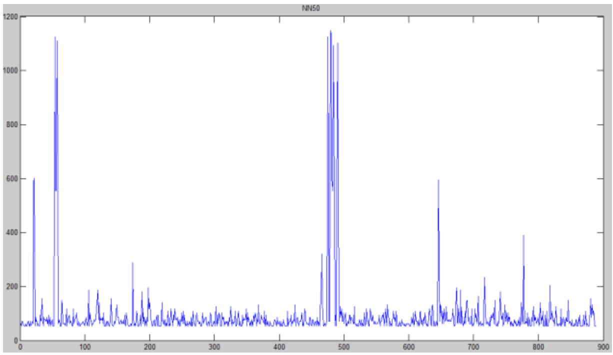


Supra - 803



PVC - 233

Fig 3: Poincaré plots



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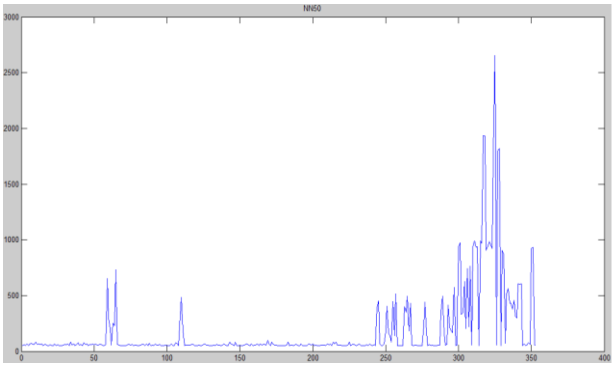

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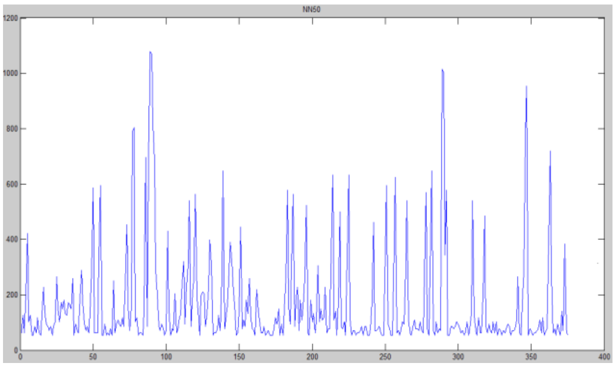

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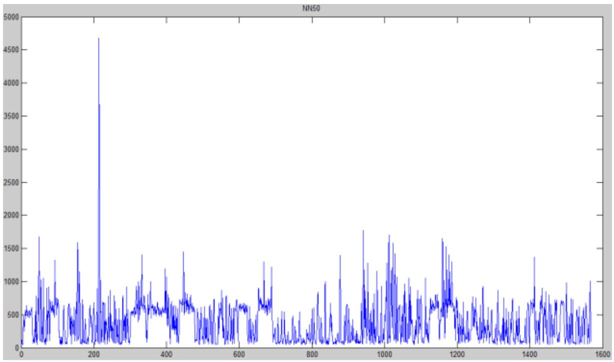

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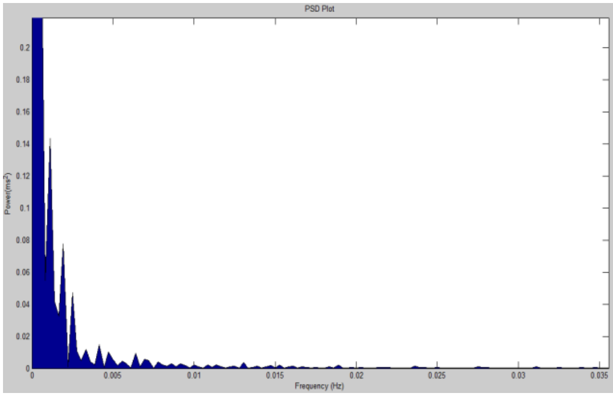
Fig 4: NN50 plots



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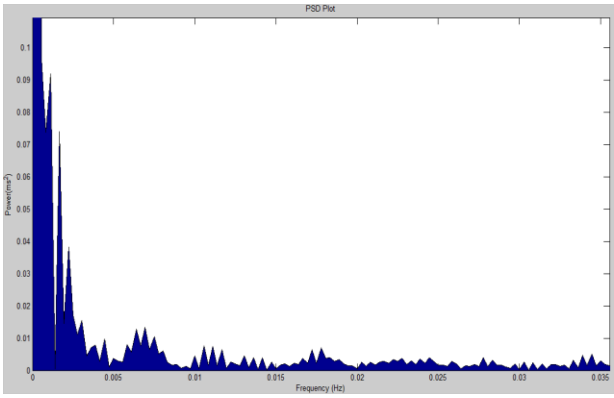
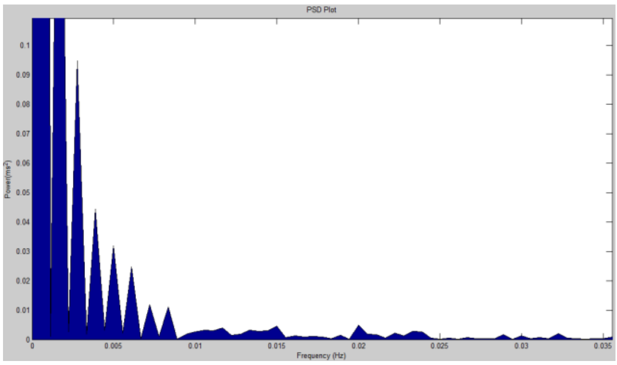


Atrial - 4043



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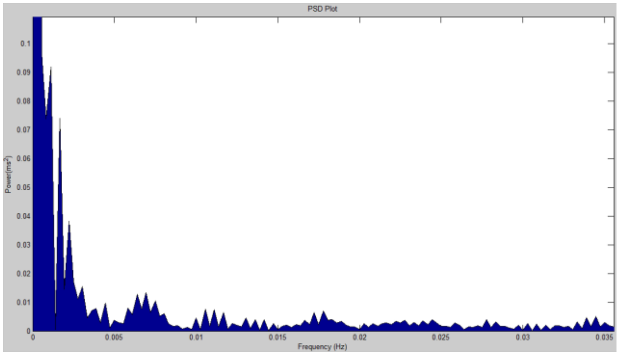

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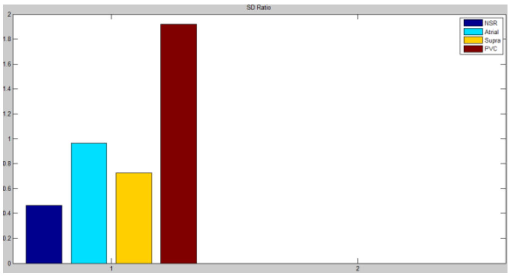
Fig 5: Power spectral density plots

3.2 Table

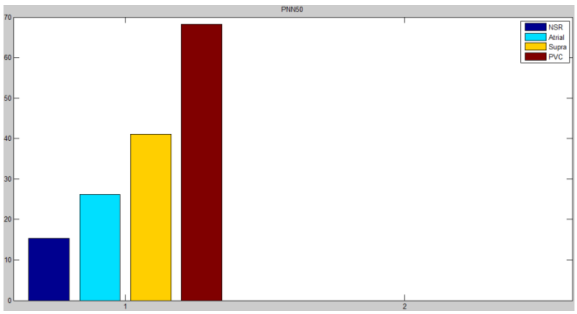
Table 1. Time-frequency parameters

Signal	Parameters		
	SD Ratio	***pNN50***	***LF/HF Ratio***
Normal Sinus Rhythm (NSR)	0.4645±0.1860	15.3215±2.2709	1.4326±0.2799
Atrial Fibrillation (AF)	0.9636±0.0791	26.1775±3.7560	0.8571±0.0999
Supra-ventricular Arrhythmia (SVF)	0.7266±0.1937	41.1100±8.3383	0.9804±0.0736
Premature Ventricular Contraction (PVC)	1.9192±0.3330	68.2475±5.9765	0.6856±0.0919

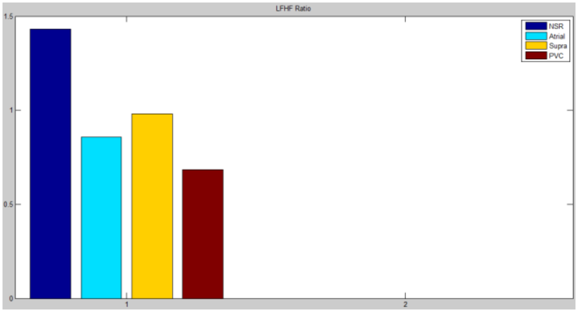
3.3 Bar Plots of Time-Frequency Parameters



SD Ratio



PNN50



LF/HF Ratio

4. CONCLUSION

In this paper, a work to detect the heart disease Arrhythmia through classification of abnormal ECG data from normal ECG data has been presented. The ECG records obtained from the MIT-BIH database are pre-processed in steps by filtering using low-pass filters, high-pass filters and differentiators and are evaluated using Symlet7 wavelet and the normal R-peaks are detected for doing further analysis for HRV. The accuracy of R-peak detection has been found to be 95%. From the table and bar plots we see that the LF/HF ratio of normal sinus rhythm is 1.4326 which is high as compared to abnormal and this shows the influence of the sympathetic nervous system. pNN50 of PVC is 68.2475, which is more as compared to all, because the total number of interval difference of successive RR intervals greater than 50ms is more, as compared to all. This is because of ectopic beats, but in normal sinus rhythm the total count is less, because maximum RR intervals are above 500ms. SD ratio is higher for PVC as compared to all, as more variations are there in RR intervals and it shows that the Poincaré plot is more scattered and least scattered for normal sinus rhythm, that is, Poincaré plot is concentrated and elliptical. Thus using Poincaré plot we can differentiate ectopic beats and normal beats. This differentiation can be done even by visualizing Poincaré plots. Thus we could distinguish the ECG records for normal sinus rhythm from those for abnormal conditions of atrial fibrillation, supra-ventricular arrhythmia and premature ventricular contraction.

5. REFERENCES

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