Heart Rate Variability Analysis of Normal Sinus Rhythm, Atrial Fibrillation and Supraventricular Arrhythmia Using ApEn, HRV Index and LFHF Ratio

Vaishali Ingale, Dr Sanjay Nalbalwar, Narottam Das

Abstract:- Heart rate variability (HRV) is the result of variation in time between two successive heart beats. HRV is the tool for investigation of healthy and diseased condition. It also reflects an influence of autonomic nervous system on function of heart. In this study, our aim is to distinguish normal sinus rhythm from atrial fibrillation and Supraventricular arrhythmia. Here the ECG signal is pre-processed and R-peak detection is done using Coiflet2 wavelet. HRV analysis is done by three statistical parameters such as ApEn, HRV triangular index and LF/HF ratio. The ratio between low and high frequency components (LF/HF ratio) of HRV spectra represents a measure of sympatho-vagal balance. But this parameter shows better results for short term recordings hence another parameters ApEn and HRV triangular index are considered to analyze HRV analysis for both long term and short term recordings.

Index Terms:- ApEn, Coiflet, Decomposition, Histogram, HRV triangular index, LF/HF Ratio

1 Introduction:-

Different types of thoughts, emotions, and changes in environmental conditions affect the internal & external stimulations which cause immediate change in heart rate. Heart rate becomes slow or fast according to situation. The instantaneous heart rate is called 'Heart Rate Variability' (HRV). This HRV is a physiological condition where the time interval between two consecutive heart beat varies.

ECG signal mainly contains noise of different types, namely power line interference, baseline drift, electrode contact noise, muscle noise, the internal amplifier noise and motion artifacts. In order to avoid erroneous conclusion because of noise interference, preprocessing of ECG signal is necessary [1]. Detecting QRS complexes in the ECG is one of the most important task that needs to be performed. This stage is crucial in basic ECG monitoring systems and is also important for all other ECG processing applications. In this work the ECG signal is decomposed into using Coiflet2 wavelet function up to third level and first level is taken for better R-peak detection. Time domain statistical parameters like HRV triangular index, ApEn and frequency domain statistical parameter like LF/HF ratio are used for HRV analysis.

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Autonomic Nervous System (ANS) is a part of nervous system that controls all organs & systems of the body and maintains the body under stable conditions. It consists of two sub systems; these are Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS). SNS increases heart rate but PNS decreases it [2].

Power Spectral analysis is one of the well-established tools for the analysis of ANS. A typical spectrum of RR series is characterized by two main components such as high frequency component and low frequency component. This high frequency component is mainly modulated by the PNS of ANS having band of 0.2-0.45 Hz and low frequency component is the result of SNS of ANS having band 0.03-0.15 Hz. Consequently the ratio of LF to HF power is often considered as a measure of sympatho-vagal balance [3]. This method seems to be useful for short term recording under control condition in healthy population and this ratio was not preferable for determination of sympatho-vagal balance in patients with advanced stages of cardiac disease [2].

Hence we have used another statistical nonlinear parameter Approximate Entropy (ApEn) and linear parameter HRV triangular index for time domain analysis. Lack of regularity in physiological time series is often quantified by computing ApEn. It is related to the probability that segments of 'm' data samples which are similar (that is closer each other than a given distance 'r') remain similar when the segment length increases to 'm+1'. Lower is the probability greater is ApEn [4].

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The HRV triangular index measurement is the integral of the density distribution divided by the maximum of the density distribution. Lower is the HRV triangular index more is the repetition RR intervals shows diseased condition [10].

Aim of this work is to distinguish normal patient from arrhythmia patient like atrial fibrillation and supraventricular fibrillation using the statistical parameters LF/HF ratio, ApEn, HRV Triangular index and plots like PSD plot, Histogram plot and RR plot.

2 Methodology:-

In this work we have taken the ECG signals from MIT-BIH data base. The ECG signals often contain different types of noise, so in order to avoid erroneous conclusion of analysis, these signals are pre-processed using low pass filter, high pass filter and differentiator [1]. The sampling frequency is 128 Hz for Normal Sinus Rhythm & Supraventricular Fibrillation Arrhythmia and 250 Hz for Atrial Fibrillation [5]. Signal duration for analysis is taken as 30 min. The noise free ECG signal is then decomposed using coiflet2 wavelet function. Here the first level of decomposition is considered for R-peak detection and R-R intervals are calculated in time which is taken as input for different statistical parameter analysis. For better HRV analysis we have considered some statistical parameters based on both time domain and frequency domain such as Approximate Entropy, HRV triangular index and LF/HF ratio. By analysing these statistical parameters we have classified normal sinus rhythm, atrial fibrillation and supraventricular arrhythmia.

2.1 Coiflet Wavelet:-

In general wavelets are described by the family of basis functions that describe signals in time and frequency format. In this method, Coiflet wavelet is selected as the wavelet basis function. The Coiflet function was constructed with vanishing moments not only for wavelet function Ψ(x) but also for scaling function Φ(x). The scaling function of the Coiflet exhibits interpolating characteristics, which implies that the wavelet allows a very good approximation of polynomial function at different resolution[6].

The following equations are to be satisfied in the Coiflet wavelet function.

$$\int x_a \Psi(x)\, dx = 0; \quad (1)$$
for a=0,1,2,3,4…….L-1;

$$\int \Phi(x)\, dx = 1; \quad (2)$$

$$\int x_a \Phi(x)\, dx = 0; \quad (3)$$
for a=0,1,2,3,4…….L-1;

Where x is signal, L is the order of Coiflet function, Φ(x) is a scaling function associated to Ψ(x)[6].

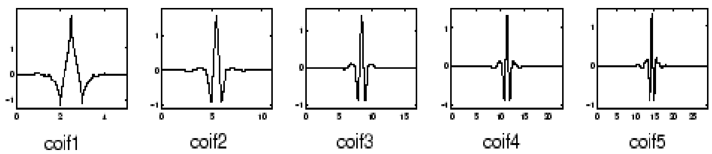

Fig-1 Types of Coiflet Transform

These functions are shown to be smoother and symmetric. This observation indicates that at different resolution, the approximation of polynomial functions can be better achieved. The symmetry property of the Coiflet is desirable in the signal analysis work due to the linear phase of the transfer function[7].

2.2 Decomposition:-

In multiple-level wavelet decomposition process, signal is broken down into many lower resolution components. At every level, the filtering and sub-sampling will result in half the time resolution and double the frequency resolution. The sequence f(n) is passed through several levels made up of low pass g(n) and high pass h(n) analysis filters. At each level detail information d(n) is produced by the high pass filter and coarse approximations a(n) is produced by the low pass filter[7].

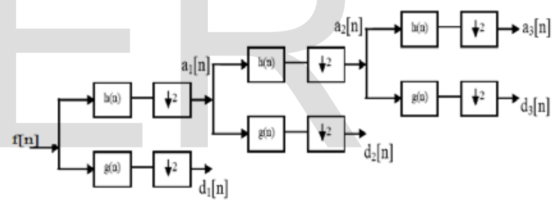

Fig-2 Decomposition

2.3 R-Peak detection:-

R-Peak detection is done by two level searching algorithm. A low threshold is chosen to find the location of all peaks. This first level detects few false peaks which are removed in second level by choosing another threshold.

2.4 HRV analysis using Statistical Parameters:-

2.4.1 ApEn Analysis:-

The importance of ApEn lies in the fact that it is a measure of the disorder in the HR signal. It has higher value in the case of normal heart rate. Hence, the ApEn will have smaller value for cardiac abnormal cases, indicating smaller variability (high regularity) for beat to beat intervals[8]. In calculation of ApEn, two parameters m & r must be fixed during computation. Here the length of segments are taken as 100 and threshold r is set between 10% to 25% of standard deviation of data, which is recommended in many articles and now r = 0.2 is used in almost all HRV studies[4]
.

ApEn is calculated as

$$\mathrm{ApEn}(r, m) = \ln\left(\frac{C_i^{m}(r)}{C_i^{m+1}(r)}\right) \quad (4)$$

A high degree of regularity means that sequences which are similar for m intervals are likely to be similar also for the next m + 1 intervals, while this is unlikely to occur for normal rhythm. Thus low values of ApEn reflect high regularity, which means arrhythmia[9].

2.4.2 HRV Triangular Index Analysis(HRV TI):-

This is one of statistical parameter which can classify normal sinus rhythm from abnormal signals like atrial fibrillation and supraventricular fibrillation[10]. The HRV Triangular index is calculated as follows

$$HRV\ Index = \frac{Total\ number\ of\ all\ RR\ intervals}{Count\ of\ Max\ RR\ intervals} \quad (5)$$

Since the normal sinus rhythm is irregular, count of Max RR intervals is less as compared to atrial fibrillation and supraventricular arrhythmia. Hence HRV-TI of normal sinus rhythm is higher. As atrial fibrillation is more regular as compared to supraventricular arrhythmia, HRV-TI of supraventricular arrhythmia is higher than atrial fibrillation.

2.4.3 LF/HF ratio Analysis:-

High frequency spectral component defines vagal modulation activity and low frequency spectral component defines sympathetic modulation, but the ratio represents a measure of balance of sympatho-vagal activity. Here FFT is 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 is an expression of autonomic balance that is the optimum cooperation between the sympathetic and parasympathetic nervous systems. An enlargement of the quotient can indicate an increased influence of the sympathetic nervous system[2].

3 Results:-

Normal sinus rhythm, atrial fibrillation and supraventricular arrhythmia signals each having duration 30 minutes are taken from MIT-BIH data base from Physionet.com[5].

Plots:-

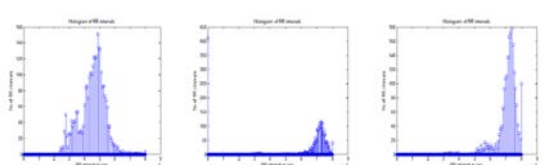

Fig-3 Histogram

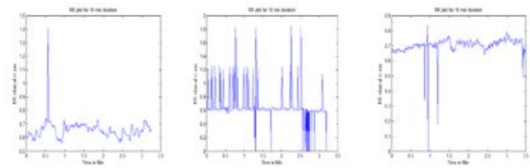

Fig-4 RR-plots

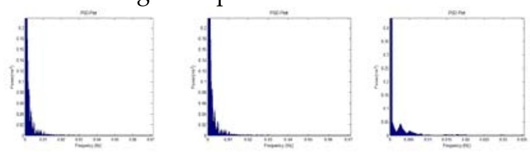

Fig-5 Power spectral density plots

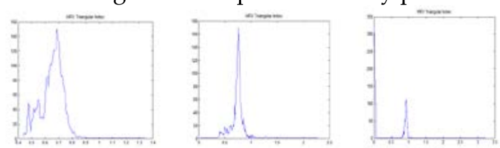

Fig-6 HRV Triangular Index

Table-1 for Statistical Parameter:-

Types of Arrhythmia	ApEn	HRV Triangular Index	LF/HF Ratio
Normal Sinus Rhythm	0.0504±0.0318	22.5826±3.8732	3.3726±0.6170
Atrial Fibrillation	-0.0422±0.0399	6.4915±3.5772	0.9138±0.0550
Supraventricular Arrhythmia	-0.0099±0.0149	12.3599±1.3776	1.3618±0.4014

4 Conclusion:-

Here the original ECG signal is preprocessed through the steps like filtering using low pass and high pass filter and differentiator. In the pre-processed ECG signal, normal R-peaks are detected for further HRV analysis. Efficiency of R-peak detection is 97%. From the table we see that the ApEn of normal sinus rhythm is positive and higher than abnormal, this is because normal sinus rhythm is more irregular (no repetition). Similarly HRV triangular index of normal sinus rhythm is 22.58 which is higher as compared to abnormal, since the count of maximum RR intervals is less. LF/HF ratio of normal sinus rhythm is 3.726 which is high as compared to abnormal, which shows the influence of sympathetic nervous system. This way we could distinguish the normal sinus rhythm from abnormal signal like atrial fibrillation and supraventricular arrhythmia.

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