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HRV Analysis of ECG Signal using Wavelet Transform

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Abstract - *Heart rate variability (HRV) is a physiological phenomenon of variations in time between consecutive heart beats. It is typically derived from the variation in the beat to beat interval of ECG signal. In the last few years, the interest in HRV appears to be growing in almost every field of clinical application. In this paper, heart rate variability (HRV) is analyzed and various features are extracted from ECG signal. Discrete wavelet transform is used for noise removal and R peak detection of ECG signals. The ECG Signal is taken from MIT-BIH database. The results are based on some features including time domain, frequency domain and nonlinear parameters of HRV which are extracted and calculated.*

Key Words: **ECG, Wavelet Transform, HRV, RR interval, PSD**

1. INTRODUCTION

ECG is a graphical recording of bioelectric current or voltage signal generated as a result of physiological changes in the heart muscles. It is generally measured by placing a series of electrodes at specific location on patient's skin. Due to changes in various environmental and physiological condition our heart does not beat at a regular rhythm. ECG plays a significant role in identification of heart rate changes and various heart diseases. Along with ECG another new aspect of studying, determining and understanding an individual health is the measurement of HRV. In heart rate variability, we are interested in capturing the variation that occurs between successive heart beats [1] [2].

Hypertension, respiratory, metabolic, exercise, age, gender, etc. can be effective factors which are responsible for changes in the heart rate variability. This fluctuation of HRV is associated with some specific pathologies such as diabetes, arrhythmia [3].In the last few years HRV will become an important and cost effective method to assess information about patient's cardiac condition.

In this work, we extract parameters for time domain analysis such as mean and standard deviation of RR interval, RMSSD. Then we are doing Frequency analysis where the power spectral density is calculated using Welch method.SD ratio and Spectral entropy is calculated and nonlinear HRV analysis. The Poincare plot in HRV is widely used to detect and monitoring many important and critical diseases. Here all these parameters useful for comparison of the normal and arrhythmia affected samples

2. METHODOLOGY

Analysis for HRV begins with the ECG signal. The raw ECG data of MIT-BIH arrhythmia database has been downloaded from the physionet.org and uploaded in MATALB .Each recording of this database were digitized at 360Hz sampling frequency. All 8 ECG samples are of standard Lead II and of 30 minute duration.

2.1 Pre-processing

Noise removal is very necessary part in ECG or HRV signal analysis. ECG signal are recorded with many noise such as muscle noise, grid noise, base line drift, power line interference, motion artifacts. These noises must be removed in order to get useful information from the signal [4]. Power line interface (PLI) at 50Hz or 60Hz removed from the ECG signal by using IIR notch filter. Wavelet transform is used for removing base line wander and other high frequency noises from the ECG signal. In WT analysis high frequencies evolution is done using short time interval and a long time interval used for lower frequencies. Hence, using this property, high frequency component of short duration filtered out successfully by Wavelet Transform [1].

2.2 R peak detection

Signal processing of ECG signals mainly done in two stages, firstly removing the various noises present in the ECG signal and then R-peak detection. The wavelet transform is used for R peak detection in place of Fourier transform as it provides information in both time and frequency domain simultaneously. Wavelet analysis is able to decompose signals into many lower resolution components, which allows accurate feature extraction from non-stationary signals like ECG signal. A wavelet family is obtained by applying a scale factor and translational factor to the basic mother wavelet [1] [5] [6].The Daubichies are nearly orthonormal, symmetrical wavelets. The name of the Daubichies family wavelets are written as 'dbN', where 'N' is the order, and 'db'is the surname [5]. In this work ,we considered "db4" Wavelet as this wavelet shown similarity with the ECG waveform and gives details and more accurate results than others.

In wavelet decomposition process, a signal is broken down into various lower resolution components. At every level of decomposition, filtering and sub-sampling will result

in halving of time resolution and doubling of the frequency resolution. The signal denoted by sequence h (n) is passed through multiple levels made up of high pass filter g (n) and low pass filter f (n) analysis filters. Fig (3) shows a schematic diagram of the multiple-level wavelet decomposition process. At each level of decomposition, low pass filter produces detailed information and coarse approximation is produced by the low pass filter [7].By using a searching algorithm and threshold of 0.45×max of all peaks , the R-peaks with their respective location are detected.[5]

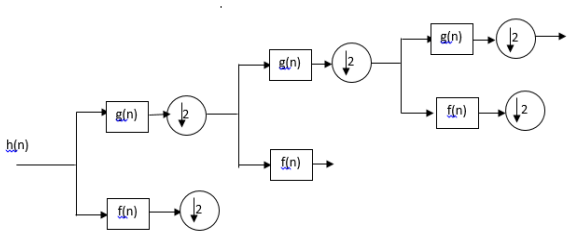

Fig -1: wavelet decomposition

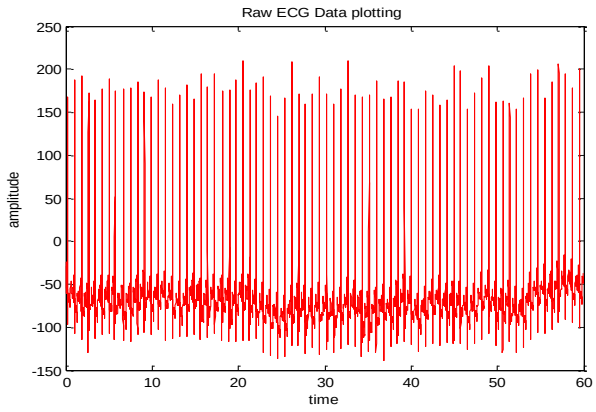

Fig -3: ECG signal

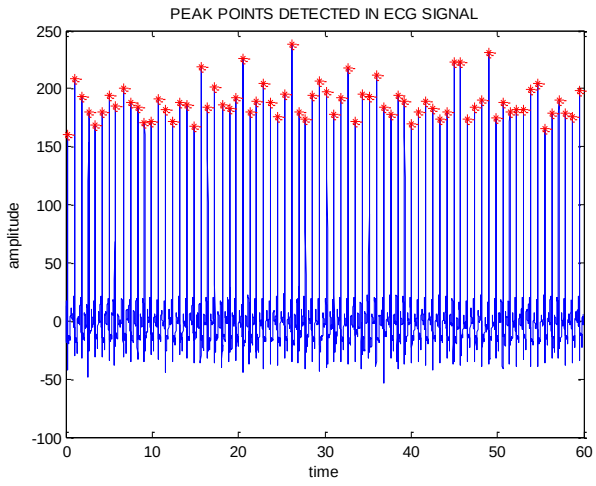

Fig -4: R-peaks detected in ECG signal

3. FEATURE EXTRACTION

HRV has been analyzed by extracting some feature from RR interval of ECG signal. Based on these features, there are two type of analysis one is linear which can be divided into time domain and frequency domain and other is non-linear analysis.

3 .1 Time domain analysis

Method exist for HRV analysis in time and frequency domain combined is called linear analysis. time domain analysis associated with the overall variability of the R-R interval over the time of recording .they are (RR mean) mean value of all R-R interval, standard deviation of all R-R interval (SDNN), square root of the mean squared difference of successive R-Interval, (pNN50) percentage of difference between adjacent RR interval differing more than 50msec. figure (5). RR interval histogram of ECG signal. The RR interval histogram is used for mathematical analysis of time domain parameter [8].

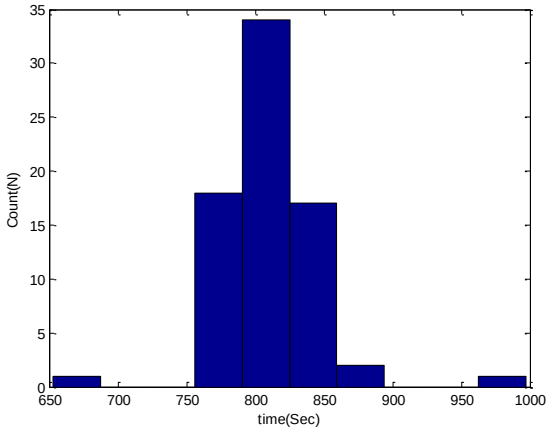

Fig -5: RR histogram

3.2 Frequency domain analysis

Frequency domain techniques uses power spectral density analysis which can be used to separate the complex HRV signal into its different spectral components. In spectral density analysis power is distributed as a function of frequency. Frequency domain HRV analysis mainly comprised of very low frequency components (3.3-40 mHz), low frequency components (40-150 mHz) and high frequency components (150-400 mHz) .PSD can be estimate using two methods, based on Fast-Fourier Transform (FFT) and autoregressive (AR) method modeling in spectral analysis of HRV [3].fig (6) shows FFT based welch periodiogram for power density estimation of HRV signal.

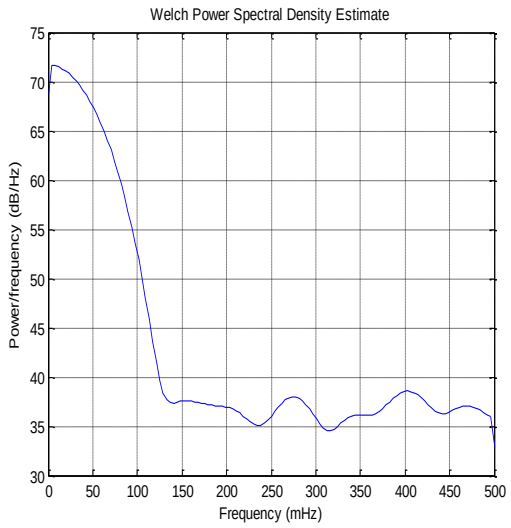

Fig -6: PSD spectrum of HRV signal

3.3 Nonlinear analysis

Linear analysis methods unable to reveal the long range organization and complexity present in heart rate variation .Non-linear measurements can easily significant the unpredictability of a time series, which results from the complexity of the mechanisms that regulate HRV. Some non-linear feature are as follows:

3.3.1 Poincare plot

The Poincare plot is a nonlinear method to assess the dynamics of HRV .it is graphical representation in which each RR interval is plotted against next RR interval. it is type of delay or scattered plots .The Poincare parameter used in this paper are SD1,SD2,SD1/SD2.SD1 and SD2 are defined as the standard deviation of the distance of each point calculated from two lines having expression y=x and y=x+Rm, where Rm is the mean of RR interval. The Poincare plot in HRV is widely used to detect and monitoring many important and critical diseases. Here this is chosen for comparison of the normal and arrhythmia affected samples [9]. Fig (6) shows the Poincare plot of healthy subject.

3.3.2 Correlation Dimension

Correlation dimension (CD) shows the measure of complexity. The more variables required to predict the time series, the greater its complexity. It describes the minimum number of variables required to construct a model of system dynamics [10].

3.3.3 Detrended Fluctuation Analysis

It is a scaling analysis method that extracts the correlation between successive R-R over different time scale. Results of this analysis are slope α1 and slope α2, which describes small fluctuations, long-term fluctuations respectively. Using DFA short-term scaling exponent reflect the baroreceptor reflex, while long-term scaling exponent reflect the regulatory mechanisms that limit fluctuations of the beat cycle. Studies have shown that DFA may provide more powerful information on the risk for fatal cardiovascular events [10].

3.3.4 Approximate Entropy (ApEn)

ApEn gives the knowledge of the irregulation and disorder in heart rate signal. Large values of ApEn represent low predictability of fluctuations in consecutive RR intervals. ApEn value falls with decrease in RR variation [10].

3.3.5 Sample Entropy

This variable is measure of regularity and complexity present in the system. Greater value of spectral entropy represent greater irregularities and lesser values shows more regularities in the system. Sample entropy (SampEn) is improved tool compared to ApEn for measuring complexity and study of cardiovascular physiology [10].

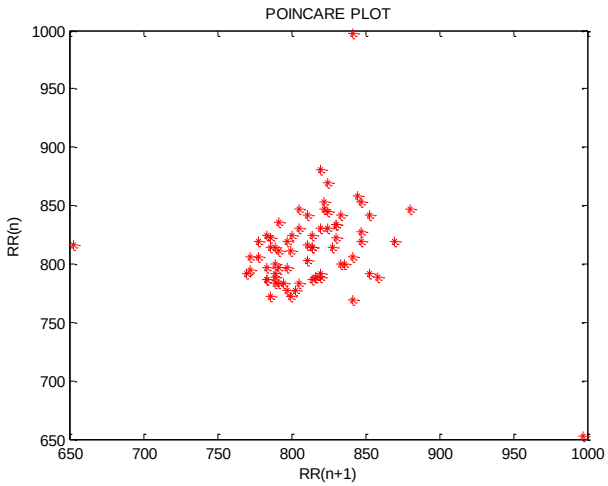

Fig -7: Poincare Plot

4. RESULT

Table 1 shows values of mean and standard deviation of RR interval, RMSSD and as a time domain features. In nonlinear analysis SD ratio as a parameter of Poincare plot and sample entropy are calculated for HRV analysis of ECG signals obtained from MIT-BIH arrhythmia database.

Table -1: Feature Extraction of HRV Signal

Sample No.	Mean RR interval(msec)	SDnn (msec)	RMSSD (msec)	SD Ratio	Spectral Entropy
100	812.290	37.894	55.737	1.0853	1.5852
101	849.801	50.497	26.557	0.274	1.2189
102	855.595	33.321	29.557	0.5013	1.1471
103	724.220	90.291	147.403	1.6057	2.6554
104	665.530	84.344	105.147	0.797	2.9665
105	701.752	15.759	21.993	0.9828	0.92253
106	955.510	68.053	70.016	0.6065	1.6784
107	762.321	13.231	15.257	0.714	0.74475

4. CONCLUSION

In this work, Wavelet transform have been used and performed well for ECG signal processing or noise removal. Some features extracted for HRV analysis of arrhythmia affected samples. From the obtained parameters, we can propose that higher values of mean shows that the values R-R distance were higher in the samples which also indicates lower values of heart rate. Greater values of standard deviation shows the variability between heart rate is much higher i.e. the HRV is higher in the arrhythmias affected samples. The values of RMSSD and SD ratio is higher for abnormal signals than for normal signals.Variation in heart rate is good sign for health but the variation should not be vary in a broad range. In future work we can extract more feature in frequency domain also as these extracted features are not enough to analyzing HRV. Large number of data can be classified using any classifier such as ANN, SVM.

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