Non-Linear Feature Extraction for Heart Rate Variability: An Overview

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ABSTRACT
Extensive Research has been done to extracting non-linear features for Heart Rate Variability. Non-Linear Dynamics has many methods which will give better accuracy than linear methods. Human Heart Fluctuates in very complex manner HRV is mainly characterized by linear ,non-linear manner. Heart Beat Signal are chaotic in nature which are very complex which is impossible to predict. To extract non-linear patterns from HRV data is very challenging task as compare to the linear pattern. In this paper we presents a brief survey about some important methods which are useful to extract non-linear features such as Phase Space Reconstruction, Lyapunov Exponent, Fractal Dimensions, Recurrence Quantification Analysis.

Keywords
HRV, ECG, Non-Linear Dynamics, Phase Space, Lyapunov, Recurrence Plot..

1. INTRODUCTION
Heart is one of the major components in human body. Heart continuously pumps oxygenated blood throughout the body. Our Heart Beats approximately 70,000 to 1, 00,000 per day. The Heart has four chambers two atria and two ventricles which are place on both side right and left side of heart. Heart has one pacemaker which is called SA node which sends electrical signals from the atrium it to contract and pump blood into the the ventricle. Heart Rate Variability is the time interval between heartbeats also called as R-R interval. ECG is used to measures the electrical activity of heart. ECG is Electrocardiogram which has some characteristics. ECG wave is generally called as PQRST waves. These waves are generated by the polarization and depolarization of heart.

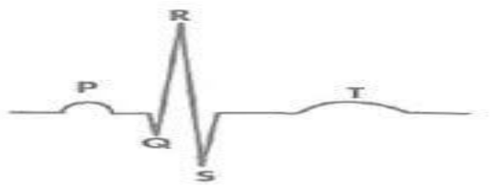

Fig 1.1 PQRST Wave

Heart Rat Variability is very important because it observes the activity of brains control system which is called as Autonomic Nervous System. Now most of the researchers are focusing on the study of Heart Rate Variability[1]. Analysis of non-linear features of HRV data is very complex task most of the researches are working on non-linear extraction of HRV patterns which will play a big roll in the development of medical science. In recent years non-linear dynamics used in number of medical application [2].

The non-linear analysis and chaos theory has been applied to many medical application[3].There are many methods are used from non-linear dynamics which will read the behavior of ECG signals such as Phase Space Reconstruction, Correlation Dimensions , Lyapunov Exponents, Recurrence Quantification Analysis etc.

This paper gives a brief survey about the non-linear methods which are used in characterization of HRV patterns Section 2 is about the Literature survey of non-linear dynamics and Section 3 is for Conclusion.

2. LITERATURE SURVEY
Linear methods which are used in medical applications are not more powerful to detect the HRV patterns. Linear methods cannot be very complex HRV data. In the recent years Non-linear dynamics has some methods which will analyze very complex data which are presents in HRV[4]. Non-linear methods are very different from linear methods. Major Advantage of Non-linear dynamics is that able to generate more details signal which will give better accuracy to detect the HRV patterns. There are many methods are used in non-linear feature extraction such as Phase Space Reconstruction , Correlation Dimension, Lyapunov Exponents, Recurrence Quantification Analysis.

2.1 Phase Space Reconstruction
Phase Space Reconstruction sometimes called as State Space Reconstruction which uses Taken Theorem[5] which uses time delay and embedding dimension methods. This methods are used to construct the attractor of dynamic system. Attractor shows the subset of Phase Space which are attracted and remains within for lifetime.

Phase Space Reconstruction is used to measures systems parameters such as Lyapunov Exponents, Dimensions etc. Takens reconstructed the phase space which is equivalent to original phase space form scale time series [6] using the methods of delays. The Phase Space Reconstruction is express as

$$Y_n = [x_n, x_{n+\tau} \ldots x_{n+(d-1)\tau}]$$

Where τ represents time delay and d represents embedding dimensions. Lyapunov Exponents and Fractal Dimensions are the dynamical features in the phase space they can only be determine from the Phase Space Reconstruction.

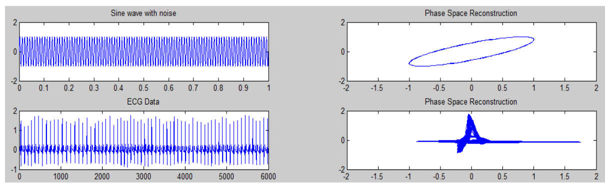

Fig 1.2 Phase Space Reconstruction

Here we are taking two signals one is Sin wave with noise and one is ECG data we apply the phase space reconstruction on both signal with Time Delay is 10 which will show above results.

2.2 Lyapunov Exponent

Lyapunov Exponent measures the two nearby point on trajectories which will diverge or converge from each other. The positive Lyapunov exponents shows that there is chaos in the system. By following way we can calculate average largest Lyapunov Exponent. At first, we need to select starting point from the reconstructed phase space and then find then find all the closest points which are nearer to this point as compared to predetermined distance e. Now in second step, as the system evolves we need to calculate the average distance between two trajectories which are formed by initial starting point and remaining neighboring points.

If we plot the graph of these average value of distance by taking their logarithm against time which gives the slope of line ,will be the expected largest Lyapunov exponent. The average largest Lyapunov exponent is also calculated by repeating the same procedure for different starting points and take the average of same. This will help to remove the dependency on starting point for calculated values.

Exponent one of them is Wolf et al which finds Lyapunov Exponent from time series data in which equation of motion are unknown λmax [7]. Using Wolf et al algorithm only single neighboring trajectory can be evaluated, which not gives better results for classification of any signal. To overcome this drawback Kanz's algorithms was used.[8].

Then, the maximal Lyapunov exponent is estimated as

$$\lambda_{max} = \frac{1}{t_m - t}\sum_{k=1}^{M}\log_2\frac{L'(t_k)}{L(t_{k-1})}$$

where M gives total number of replacement steps.

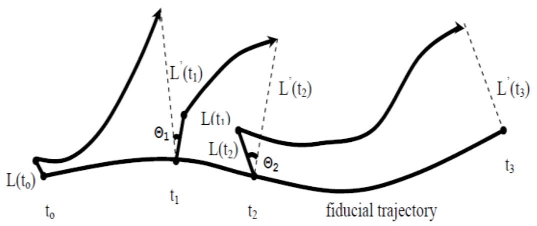

Fig 1.3 Lyapunov Exponent

2.3 Fractal Dimensions

The Attractor which is present in Phase Space which is Fractal in nature called as Strange Attractor. A Fractal object is an object which one part is similar to the whole in some way which is called self similar in nature. HRV also have the self similar patterns. other example are Sierpinski triangle, Koch flack ,tree etc.

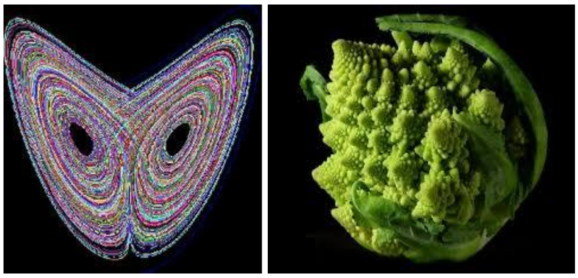

Fig 1.4 Fractal Structure

An ECG signal of human heart is a self similar objects so it must have fractal dimensions for these reason we used fractal analysis. There are many methods are used to find the dimensions one of the most popular method is boxcounting method[9].

The box counting method is a simple way to assign dimensions. The box counting dimension is given as

$$X\,0 = \lim_{r\to 0}\frac{\ln N(r)}{\ln(1/r)}$$

Correlation dimension [10] X2, describes the geometric structure of the current system and is given by:

$$X2 = \lim_{r\to 0}\frac{\log 2Cm(r)}{\log 2r}$$

where m represents dimension of the phase space, and Cm(r) gives Correlation Integral.

2.4 Recurrence Quantification Analysis

Recurrence plot is an important tool to visualize non-linear dynamics in time series data. Recurrence plot shows or describes the recurrence of phase space trajectory to a specific state which is basic important property of dynamical system. Recurrence plot has been applied in various biological applications[11].Recurrence Plot is expressed as

$$R_{i,j} = \Theta(a_i - \|D_i - D_j\|);$$

where ai gives the cutoff distance ,|| || represents the norm and ϴ represents the heavy side function[12] . The large scale and small scale patterns will be characterized by the recurrence plot e.g. is diagonal line, horizontal line and vertical line.

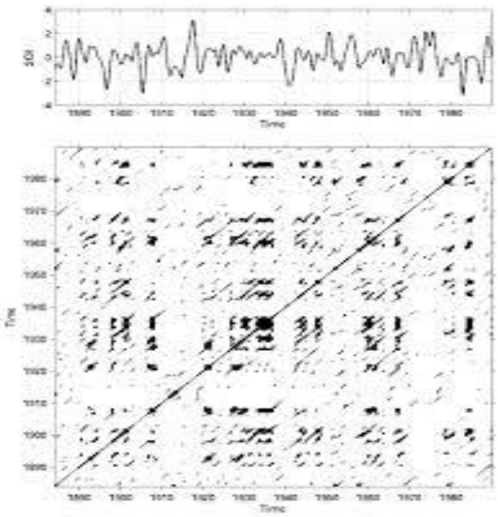

Fig 1.5 Recurrence Plot of Signal

Recurrence Quantification Analysis was developed to quantify and recurrence plot which is based on the diagonal structure and the recurrence point density in the recurrence plot [13]. Some important measures or computations depend on distribution of the length of underlying diagonal structure are calculated by RQA. Recurrence Rate, Maximal Length of Diagonal Structure (Lmax), Determinism, Entropy, Trapping Time, Laminarity and Maximal Length of Vertical Structure all are measured by Recurrence quantification analysis.

3. CONCLUSION

Heart Beat Signals are chaotic in nature which are very complex and impossible to predict. To extract and detect non-linear features from HRV data which is very challenging task, most of the scientist still working on better feature extraction of HRV data ,which will give better accuracy than linear methods. This paper presents a brief literature survey for detecting non-linear feature of Heart Rate Variability using some important methods such as Phase Space Reconstruction, Lyapunov exponents, Fractal Dimensions and Recurrence Quantification Analysis.

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