Quantification of Heart Rate Variability (HRV) Data using Symbolic Entropy to Distinguish between Healthy and Disease Subjects

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ABSTRACT
Heart rate variability (HRV), is defined as the variations in heart rate about its mean value. The human heart is a non linear system as the heart rhythm is modulated by the Autonomic nervous system (ANS).The extracted and analyzed HRV signal parameters are highly useful in diagnosis. .Entropy based methods, present a good performance as irregularity measures as well as properties that make them suitable for physiological data analysis The objective of this work is to develop and implement an algorithm for symbolic entropy and further compare it with Approximate Entropy (ApEn), and Correlation Dimension by analyzing three sets of subjects. Three cases that are taken for the analysis are the first case is with healthy subjects, second case is subjects with some cardiac related problems and third case is with thyroid affected and depressed affected subjects. It may be concluded that Symbolic Entropy is best suited for small datasets and clearly demarks the healthy and disease subjects such as Atrial Fibrillations(AF), Congestive heart failure(CHF) and Premature ventricular Complex(PVC) subjects and also for subjects having seizures as compared to ApEn For case of thyroid the values are same as ApEn For Asthma subjects the Symbolic entropy is not suitable to demark

General Terms
HRV Analysis, Symbolic Entropy, Nonlinear measures

Keywords
HRV, Symbolic Entropy, Approximate Entropy, ANS, Thyroid

1. INTRODUCTION
Heart rate variability (HRV), is defined as the variations in heart rate about its mean value. The human heart is a non linear system as the heart rhythm is modulated by the Autonomic nervous system (ANS).The extracted and analyzed HRV signal parameters are highly useful in diagnosis. The HRV analysis may contain indications of current behavior and warnings about the diseases. Therefore HRV has become a universal tool to study the neural control of the heart. The heart rate fluctuations are composed of linear, non-linear, periodical and non-periodical oscillations patterns. The analysis of HRV can be done in time domain, frequency domain, non-linear methods and using geometric methods Different parameters are used in each of the domains and they are given different weight age based on their accuracy of detecting cardiovascular diseases and symptoms. Dynamic analysis of HRV gives independent information that cannot be detected by linear analysis techniques [2] A E Aubert et. al(2002) proposed nonlinear methods for the study of Athletes and the results indicated the possible relation of non-linear measures and autonomic regulation of cardio vascular function Linear methods cannot quantify the dynamic structures of the signal sufficiently. Hence usage of non-linear analysis techniques are increasing as cardiac systems exhibit non-linear functioning. Some of the nonlinear measures are Correlation Dimension (CD), Detrended Fluctuation Analysis (DFA), approximate entropy (ApEn), Sample entropy (SampEn), Largest Lyapunov exponent (LLE), Fractal dimension (FD) and Hurst exponent (H) etc

2. BACK GROUND
Various methods to estimate the system complexity from data are evaluated the underlying deterministic process may not be implied by Correlation Dimension applied for finite values. Approximate Entropy (ApEn) can estimate complexity of a system with a minimum of 1000 data values in both deterministic and stochastic processes. [11]

Entropy refers to the information content .With reference to a dynamical system it is rate at which information is produced. Entropy is suitable for the physiological signal analysis which usually involves short and noisy data sets specifically the Heart rate time series data sets. Approximate Entropy (ApEn) a complexity measure is introduced by Pincus. et. al(1991) gave inconsistent results.[12]The limitation of ApEn is the inconsistent results and dependency on data length is overcome by Sample Entropy(SampEn)introduced by Richman. .Joshua's and Moorman (2000) the SampEn will not do the self matches and it is independent of data length. For larger values of data length 'N' and threshold 'r' both the values of ApEn and SampEn will be the same.[12] ApEn and SampEn were used to assess HRV and complexity of time series was calculated[1]

It was found that traditional algorithms indicated higher complexity for pathological subjects as compared to healthy subjects this may be due to inherent multiple time scales present in the healthy dynamics to overcome this Multi Scale Entropy(MSE) is introduced by Costa.et.al (2002)MSE clearly separated healthy and Pathologic group and consistently yielded higher values for simulated long-range correlated noise compared to uncorrelated noise [8] Entropy measures reflect both variance and correlation properties. The combination of Zhang's complexity and Pincus Complexity methods developed

into Menthe MSE values are high for healthy subjects indicating the complexity and low for AF and CHF indicating lower complexity, the limitation of MSE is it requires larger data length.[9] Jing Hu .et.al2006)proposed a new Multiscale analysis of HRV based on scale dependent Lyapunov exponent (SDLE) which accurately distinguished between healthy subject and cardiac heart failure subject. Hang Ding et.al (2007) carried out a new HRV analysis by means of quantifying the variation of non-linear patterns (VNDP) which is based on Recurrence Quantification Analysis (RQA) to quantify the dynamic patterns. Then use of Mutual Information (MI) and entropy (EN) to characterize VNDP and next linear discriminant analysis to exploit association within MI and EN. VNDP method overcomes non stationary problem and exploits non static properties in HRV

.Ismail Sadiq et.al(2010) studied Fuzzification for the HRV analysis using ECG in timedoman,frequency domain and statistical domains According to Fuzzification laws the RR intervals that get high scores around a pre-defined values are considered normal In Li Helong et.al (2008) developed a new methodology of HRV in time - frequency analysis, which is based on Hilbert – huang transform in 2006 M. G. Signorini et.al (2006)performed non-linear analysis of HRV signal for characterization of cardiac heart failure patient and also have proposed new regulating index Gaussian Entropy which is the modification of ApEn and SampEn. They understood that the reduction of time series length leads in saving the computing time needed to estimate these indexes.

Joan E Deffeyes et.al (2009) used symbolic entropy to find the patterns of the hand movement of an infant. This method requires less number of data points ,it has been adopted to estimate the Symbolic entropy of healthy and Pathologic subjects to see whether it can give mark able difference

3. METHODOLOGY & DATA ANALYSIS

3.1 Data Acquisition

The healthy and Pathologic data for the analysis. is acquired from Physionet [15] and the Thyroid,, asthma and depressed subjects data is acquired from Power Lab.. The data of 22 subjects is analyzed out of which four healthy, four CHF, four AF, one PVC ,two thyroid, two asthma, two seizure, and three are depressed subjects The ApEn AND Correlation Dimensions are estimated for data length of 1500 and 4000 respectively

The algorithm for Symbolic Entropy [6] is given below which is implemented using Lab view and Matlab

3.2 Symbolic Entropy algorithm

1. Data of very short length (about 52 data points) is taken .

2...The mean of these points is estimated and is taken as

the threshold

3. Each and every element of the data series is compared with the threshold If the data element value is greater than the threshold , then the data element is rewritten as'1 ' Else the data element is rewritten as '0'

4. Coded group of three bits of the obtained data by making the groups i_j = i ,i+1 to i+2 for every 'j' value up to total length N -2 of the data series ,where initial values of i=0 and j =1

5. Estimated the Shannon's Entropy of the coded groups and computed symbolic entropy

6. Computed the normalized symbolic Entropy

are assembled.

4. RESULTS & DISCUSSION

For the 22 subjects the ApEn , Symbolic Entropy and CD are estimated and the mean value of these parameters is computed. The computed mean values are tabulated in the table1

Table 1 shows the mean values of ApEn, Normalized Symbolic Entropy & Correlation Dimension of healthy and disease subjects

Subject Type	Mean ApEn	Mean Normalised Symbolic Entropy	Mean CD
Healthy	1.3	5.3	3.4
AF	1.6	6.9	3.8
CHF	1.1	3.9	1.5
PVC	1	3.8	4.8
Thyroid	1.2	5.6	3.4
Asthama	1.4	5.4	0.04
SIE	0.8	4.9	0.9
Depression	0.59	3.4	1.7

The mean values of ApEn, Symbolic Entropy and Correlation Dimension (CD) are computed and plotted as a function of subject types as shown in figure1.From the figure1 and Figure2 it is clearly seen that mean Normalized Symbolic Entropy is significantly higher for AF subjects and significantly lower for CHF and PVC subjects as compared to Healthy subjects. From figure 1 it is seen that the Mean ApEn value of AF subjects is higher and for PVC and CHF subjects it is lower as compared to healthy subjects. The difference is large in case of Normalized Symbolic Entropy for subjects affected by Thyroid, seizures, and depression the ApEn value is lower compared to healthy subjects. The lower value of ApEn, Symbolic Entropies indicates the reduced complexity of HRV and the disease.

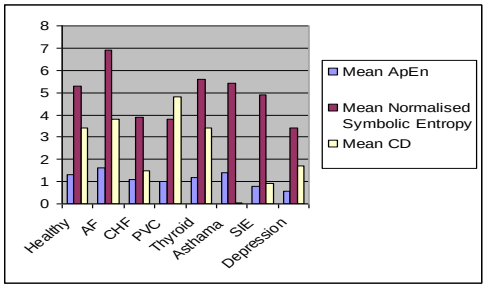

Figure1.Shows the Mean values of ApEn, Symbolic Entropy and CD

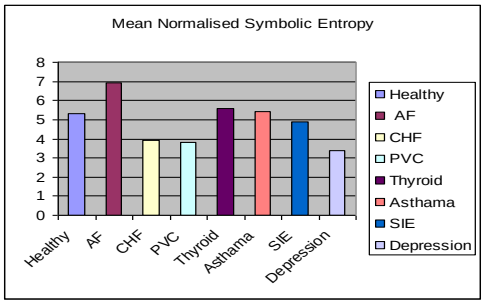

Figure2, Shows the mean Symbolic Entropy of Healthy and Disease subjects

The variation of CD as a function of subjects is shown in figure3. Which clearly shows significantly lower values of CD for Depressed, Seizures and Asthma Subjects. The CD value is significantly high for PVC subjects. As shown in figure3

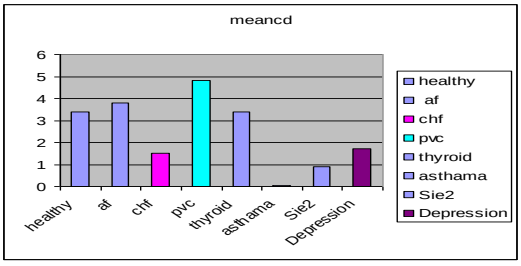

Figure3.Mean CD values of different subjects

5. CONCLUSIONS

Symbolic Entropy can be used for distinguishing healthy ,AF and CHF subjects It is also useful for very short length of data analysis. The values of ApEn, Normalized Symbolic Entropy and CD can be used together to clearly distinguish AF,CHF, PVC, Thyroid, Depression and Asthma subjects compared with Healthy subjects.

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