

# Analysis and Characterisation of Heart Rate Variability (HRV) Data of Different Sets of Subjects Using Nonlinear Measure (Approximate Entropy)

CH.RenuMadhavi and A.G.Ananth

**Abstract**—The human heart is a nonlinear system because the heart rhythm is modulated by the Autonomic nervous system (ANS). The modulation of the heart rate about its mean value is called Heart rate variability (HRV). Nonlinear analysis of HRV is helpful to assess the cardiac health noninvasively. The analysis of HRV data of different sets of subjects is done using ApEn. The autonomic dysfunction also causes cardiac malfunction. The Subjects involved in meditation is taken as one set. The other set is depressed subjects. The third set is congestive heart failure (CHF) subjects. The fourth set is healthy subjects. Also The effect of ANS on cardiac functioning is investigated, before and after the meditation for the set of meditation subject and also for the set of depressed subjects. The cardiac health status is also investigated for the set of Congestive heart failure (CHF) subjects and healthy subjects. It has been found that the ApEn values indicated improved cardiac health after meditation. The ApEn values of depressed subjects is lower than that of healthy subjects. The high values of ApEn for healthy subjects suggest that the functioning of heart is dynamic. The lower ApEn values of the depressed subjects observed indicate the presence of the Autonomic dysfunction, which in turn effected cardiac function indirectly causing heart to exhibit less dynamism. The CHF data showed the ApEn values lower than healthy subjects indicating cardiac ill health.

**Index Terms**—Heart rate variability, Nonlinear, Approximate entropy, meditation, depressed

## I. INTRODUCTION

It is known that Electrocardiogram (ECG) represents the electrical activity of the heart. This electrical activity is generated by SinoAtrial (SA) node which is a biological pacemaker present in the heart. The SA node is controlled by ANS which modulates the normal heart rhythm through sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). So the heart is not a linear system, can be effected by nonlinear contributions. Therefore, it is considered as a complex system.

Heart rate is the reciprocal of the time interval between two consecutive R peaks of ECG. Typical value of heart rate is 72 beats per minute. The variation of Heart rate from its mean

value is called Heart Rate Variability (HRV). The HRV can show the presence of disease and gives indications about the threatening diseases. Hence for the study of the Cardio-autonomic abnormalities HRV has become an important noninvasive tool. HRV analysis is helpful to estimate the cardiac health and the state of autonomic nervous system which is responsible for affecting the cardiac functionality. [1].

HRV analysis is done using Time domain methods, Frequency domain methods, nonlinear methods and Geometrical methods. The time domain methods are simple, but can not distinguish between the SNS and PSN components of HRV. Frequency domain methods estimate the power spectral densities by using both parametric and nonparametric methods. The nonparametric method of analysis is done by applying Fast Fourier Transforms (FFT) or periodograms. The frequency domain can show the cause producing the effect in terms of the frequency components and power spectral density. These methods have a limitation of spectral leakage, which will hide the weak signal present in the data, this limitation is overcome by using parametric power spectral estimation methods namely Autoregressive (AR) modeling [1].

The linear methods of analysis apply timeseries analysis, where the parameters such as mean of the data, standard deviation, variance are estimated.

Spectral analysis is helpful to see the sympathetic component in low frequency range, which is from 0.04 Hz - 0.15 Hz. The parasympathetic component can be seen in high frequency, whose range is 0.15 Hz - 0.4 Hz.

The geometrical methods of analysis is done by using Poincare plots and recurrence plots. To draw Poincare plots it is required to take all the  $RR_i$  interval data on X axis and  $RR_{i+1}$  interval data on Y axis. The graph is plotted for  $RR_i$  Verses  $RR_{i+1}$ . The shape of the graph thus obtained is used to find whether the subject is normal or abnormal.

Recurrence plots also are used for the graphical representation about the status of the heart. Generally the patterns of graphs obtained will be different for different data. Looking at the Recurrence plot also the health of the heart can be predicted as whether it is normal or abnormal.

The processes generated by biological systems are described more effectively by various Nonlinear measures. [1] such as correlation dimension (CD), Detrended fluctuation analysis (DFA). Approximate Entropy

CH.RenuMadhavi is with the Dept, of Instrumentation, R.V.College of Engineering, Bangalore, India (renumadhavi@yahoo.com).

A.G.Ananth is with the Dept of Telecommunication, R.V. College of Engineering, Bangalore, India (antisro@yahoo.com).

(ApEn), Sample Entropy (SampEn), Largest Lyapunov Exponent (LLE), Fractal dimension (FD), Hurst exponent (H). The geometrical methods applied for the visualization of HRV as a graph are Poincare plots and Recurrence plots. The pattern of the plots indicates the cardio autonomic state. [1] ApEn is the measure of complexity of the time series data. If ApEn is larger the system is complex, if its value is smaller the system is said to be regular. [2, 3, 4].

Application of nonlinear analysis to ECG started two decades ago. Extensive work has been carried out nonlinear analysis of HRV. The nonlinear nature of physiological signals such as ECG suggests the application of nonlinear techniques for the diagnostic and classification of the biological system [1]. ApEn can be used as parameter to measure the complexity of a biological system [2, 3, 4].

Nonlinear techniques were applied for the classification of various types of cardiac abnormalities [1,10,11,12] it was suggested that linear and nonlinear methods are applicable to various cases with HRV such as blood pressure, myocardial infarction, cardiac arrhythmias, diabetes, renal failure, gender and age, drugs, smoking, sleep in infants [1,10,11,12]

Recent results have suggested that the fluctuations in time between beats in a healthy heart may be due to an intrinsic variability and the nonlinear nature of the autonomic nervous system control exhibiting a complex behavior. ApEn, SampEn, LLE, D2, Standard deviation 1 (SD1) Standard deviation 2 (SD2) were used as nonlinear measures for PVC, VF, AF subjects along with healthy subjects and further classified the data. [15]

The non linear analysis of HRV has significant role in the assessment of cardiac health status. In this work the effect of nonlinear entropy measure ApEn of HRV on healthy and different disease subjects is investigated. Further the effect of meditation on HRV is studied.

## II. DATA ANALYSIS AND METHODOLOGY

For the present analysis the ECG signals were obtained from different sources. The sources of ECG data acquisition are the Powerlab instrument and the meditation data derived from Physionet [18].

ECG signals of pre and post meditation were acquired from seven healthy subjects using the PowerLab instrument. The data is collected from lead 2 at a sampling frequency of 500 Hz. The RR intervals were separated using the inbuilt filters in the instrument and then applied as input data to the program for estimation of ApEn.

The sample of the ECG intervals got from the Power Lab systems is as shown in figure 1 below.

Time (s)	RRR	Interval	Rate	OT	Interval	First Beat	Last Beat	Used	Edited
1	1.254	0.6465	92.5212	0.312084	2	5	4	0	
2	3.988	0.66	90.9091		6	8	0	0	
3	13.153	0.59675	100.545	0.314087	10	13	4	0	
4	15.523	0.6325	94.6617	0.301289	14	17	4	0	
5	18.146	0.67725	88.9336	0.124569	18	21	4	0	
6	20.86	0.67475	88.9218	0.138677	22	26	4	0	
7	23.48	0.594	101.01	0.312117	26	29	4	0	
8	26.617	0.61075	98.2389		30	33	4	0	
9	28.291	0.6485	92.5212	0.143872	34	37	4	0	
10	30.944	0.64875	92.3432	0.294237	38	41	4	0	
11	33.488	0.63325	99.4613	0.374891	42	45	4	0	
12	35.997	0.6415	93.5308	0.298666	46	49	4	0	
13	38.494	0.66575	90.1239	0.426288	50	53	4	0	
14	41.178	0.65925	91.0125	0.134117	54	57	4	0	
15	43.821	0.68875	87.1143	0.340563	58	61	4	0	
16	46.619	0.7005	85.6531	0.275692	62	65	4	0	
17	49.264	0.66225	90.9002	0.307414	66	69	4	0	
18	52.017	0.6795	88.9302	0.336919	70	73	4	0	
19	54.737	0.66575	90.1239	0.367657	74	77	4	0	
20	57.384	0.66025	92.2722	0.320156	78	81	4	0	
21	59.989	0.65475	92.2595	0.355144	82	85	4	0	
22	62.701	0.68675	86.1141	0.376242	86	89	4	0	
23	65.475	0.68325	87.8156	0.314742	90	93	4	0	
24	68.208	0.693	86.9801		94	97	4	0	
25	70.951	0.66	92.3077		98	101	4	0	
26	73.498	0.61775	97.1267	0.111385	102	105	4	0	

Figure 1 shows the snap shot of powerlab acquired data

ECG signals of three depressed subjects and three healthy subjects were acquired using the PowerLab instrument

The five different types of data are used for the present analysis. The first type is the pre and post meditation of seven healthy subjects. The second type of data is the data of three healthy subjects derived from powerlab.

The third type of data is the data of three depressed subjects derived from powerlab. The fourth type of data is the congestive heart failure (CHF) data derived from Physionet [18], and the fifth type is the meditation data derived from Physionet [17].

Four sets RR intervals of pre and post meditation were acquired from Physiobank [17]. The nonlinear complexity measure is done by implementing the algorithm for ApEn proposed by Pincus [2, 3, 4] using MATLAB

The nonlinear measure estimated for the data acquired is Approximate Entropy (ApEn). The heart rate dynamics can be quantified using number of nonlinear measures one of them is ApEn. The ApEn can be applied to short length of data hence it is selected.

ApEn is a nonlinear measure that signifies the complexity of the applied time series data. The calculation of ApEn requires three parameters namely N, length of the data, r the threshold and m the embedding dimension. The value of m can be 1 or 2 and r can be 0.15- 0.2.

The values of ApEn determines whether the data is random or deterministic. Lower the value of ApEn the data is deterministic and higher the value of ApEn the data is random.

ApEn is calculated by first finding the frequency with which all the 'm' point patterns in the sequence are close to each other, let this frequency be 'k1', and finding the frequency with which all the 'm+1' point patterns in the sequence are close to each other, let it be 'k2', then finding the difference between k1 and k2 gives the value of ApEn. The value of k1 is estimated by calculating the natural logarithm of correlation integral of m point patterns in the sequence, for i=1 to N-m+1, take the average of the correlation integrals. To compute k2 the same procedure as done for k1 is repeated but now m+1 point patterns need to be considered for the calculation of correlation integral. The ApEn is estimated as the difference between k1 and k2.

### III. RESULT AND DISCUSSION

The ApEn values of subject before and after meditation are computed for the data acquired from Powerlab has been shown in figure2. The figure shows that the ApEn values of pre meditation subjects indicates a higher value and increased to little more higher value for post meditation subjects.

It is evident from the figure that the ApEn values determined for post- meditation subjects increased when compared to premeditation subjects. The values of ApEn computed for data obtained using powerlab are presented in table1.

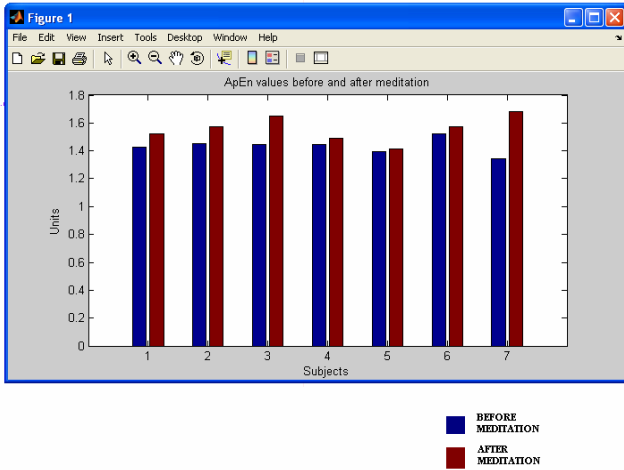


Figure2: shows ApEn values before and after meditation of powerlab data

The mean ApEn values are computed for healthy subjects before and after meditation as shown in figure2a

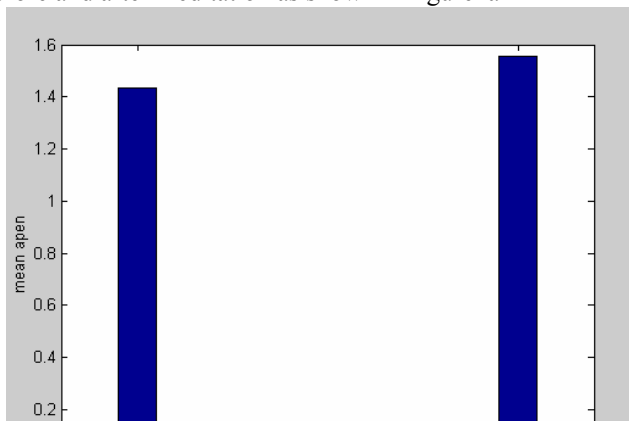


Figure 2a : shows mean ApEn values before and after meditation of powerlab data

The figure shows a high mean value for premeditation data and an increase in its value after meditation. Showing the evidence of improved health

TABLE 1 COMPUTED VALUES OF APEN OF POWERLAB DATA

Sample	ApEn Premeditation	ApEn Post meditation
1	1.425804	1.521591
2	1.454506	1.570543
3	1.447770	1.648860
4	1.447763	1.492151
5	1.396951	1.415407
6	1.521463	1.571821
7	1.343834	1.684213
<b>Mean</b>	<b>1.4340</b>	<b>1.5578</b>

These results can be used to monitor the variation in heart dynamics. For premeditation healthy subjects ApEn value is high and the functioning of the heart is very dynamic and HRV is non regular. For the post meditation healthy subjects the ApEn values increased still higher indicating that the dynamism of the heart is more

The ApEn values of subjects whose data is acquired from Physionet [17] are computed after performing the physical activity (meditation). The ApEn values are computed for pre and post meditation cases and the results are tabulated in table2 shown below , and indicated in the figure3.

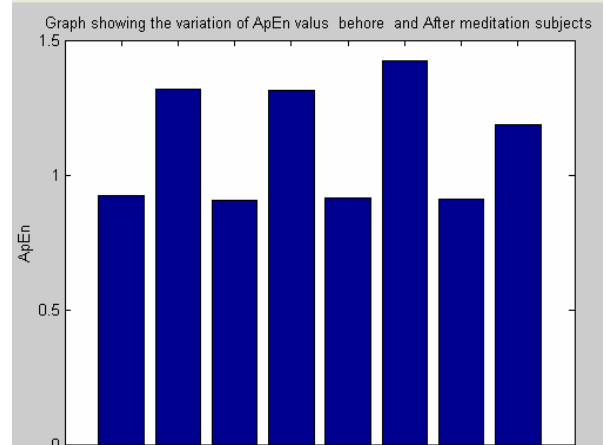


Figure3: shows ApEn values before and after meditation of physionet data

It is evident from the figure that the ApEn values determined for premeditation are low and for post meditation subjects the values increased.

The mean ApEn values computed for pre and post meditation for physionet data is shown below in figure3a

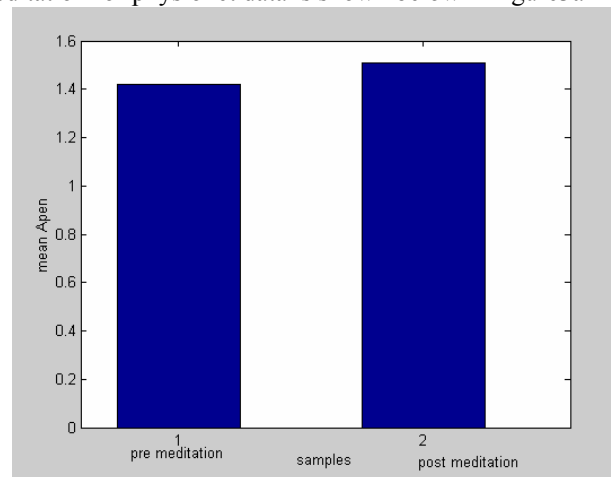


Figure3a: shows mean ApEn values before and after meditation of physionet data

From figure it is clearly seen that the mean ApEn value is less before meditation and increased after meditation indicating an improvement. The lower value of ApEn before meditation suggests that the subjects heart is less dynamic, and the increased value of ApEn after meditation indicates improved heart dynamism.

TABLE 2 COMPUTED VALUES OF APEN OF PHYSIONET DATA[1]

sample	ApEn Premeditation	ApEn Post meditation
PH1	0.9215	1.3178
PH2	0.90466	1.3153
PH3	0.91423	1.4230
PH4	0.9116	1.1882
mean	0.9129	1.311

It can be observed from the table 2 that the Approximate entropy value increased after meditation. The mean value of post meditation is more than the mean of premeditation.

The values of ApEn for premeditation is lower compared to postmeditation in this case.

In order to emphasize the significance of the results the ApEn values for both healthy and depressed subjects is computed. As shown in figure4 It is observed from the figure that the ApEn value is significantly high for healthy subjects as compared to depressed subjects. This result signifies the role played by ANS in controlling HRV and indicating its indirect effect. on heart

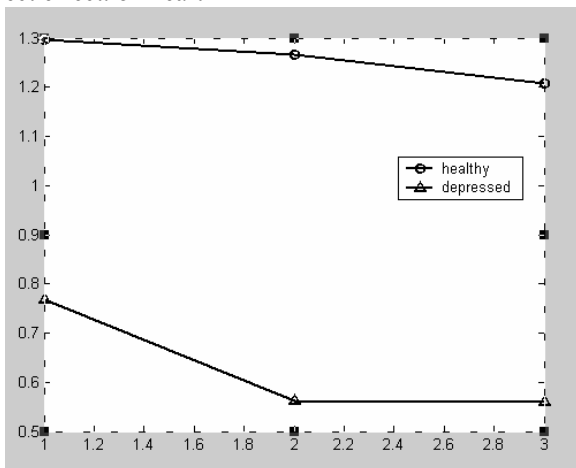


Figure4 shows ApEn values of healthy subjects against depressed subjects

Further it can be seen from the figure 5 that ApEn values are higher for healthy subjects and lower ApEn for Congestive heart failure(CHF) subjects..

Graph showing the variation of ApEn between Congestive Heart Failure and Healthy subjects

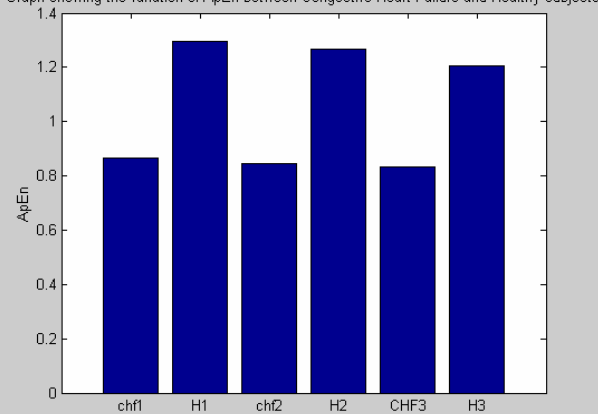


Figure5 shows Apen values of achf subjects and healthy subjects [18]

It is evident from figure that these results can be used to monitor healthy or unhealthy status of a heart. Further it is observed that ApEn value is high and the functioning of the heart is very dynamic for healthy subjects, and less dynamic for the CHF subjects.

The mean ApEn value of CHF subjects is found to be less compared to healthy subject's mean ApEn value.

The mean ApEn values are estimated for healthy subjects, depressed subjects, healthy subjects involved in physical activity, Subjects whose health state is unknown but involved in physical activity and CHF subjects is shown in figure6.

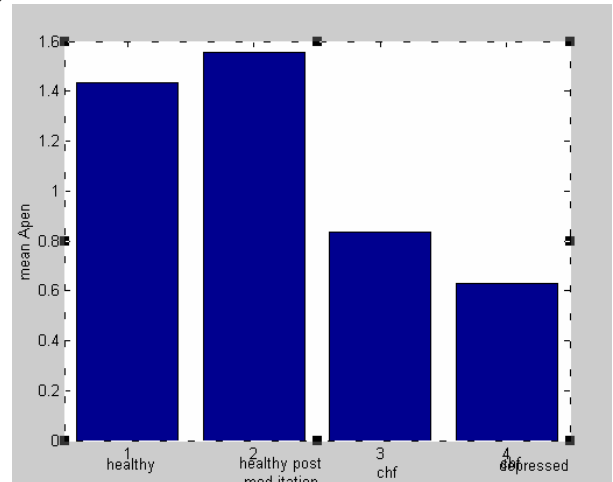


Figure6. Mean values of apen for healthy, post med, chf and depressed subjects

It is clearly seen from the figure that the mean ApEn value of a healthy subjects is high and the value increased still high after meditation. Also it is evident from the figure that the mean ApEn value of CHF subject is low and it further reduced to a lower value for depressed subjects.

#### IV. CONCLUSIONS

(1) The analysis of HRV data of healthy subjects suggested a high value for ApEn Indicating the complexity of HRV thus shows that heart is healthy agreeing with the earlier works

(2) ApEn values computed for the known subjects who are healthy indicated high ApEn values before meditation and increased little higher after meditation. This observation suggests that the functioning of the heart is improved further after meditation

(3) The ApEn values computed for the meditation data obtained from Physionet, where the details of the subjects is unknown. The results indicated a Lower ApEn value for pre meditation and increased to higher values after meditation. The increased values of ApEn after meditation indicates improved heart health. The initial low value indicating the less dynamism in the heart activity may be the subjects are not healthy.

(4) The ApEn values of depressed subjects exhibited a lower value compared to the healthy. This lower value indicates the indirect effect of ANS dysfunction effecting the cardiac function.

(5) It is evident from the results that the ApEn values of

CHF subjects are lower compared to healthy subjects agreeing with the earlier works

The analysis of the HRV data in using ApEn as a nonlinear measure is helpful to identify noninvasively health status (normal/abnormal) of the subjects, further it is observed that the health status improved due to meditation for a healthy subject and also for unhealthy subjects. The ApEn values of depressed subjects attributed to the ANS dysfunction. The mean ApEn value of the depressed subjects is the lowest of all values calculated.

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