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QUANTITATIVE DETECTION OF VENTRICULAR TACHYARRHYTHMIA: A FRACTAL APPROACH

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ABSTRACT

ECG time series show self-similar fractal pattern. Therefore to study heart with respect to ECG signal, fractal analysis is important. Ventricular Tachyarrhythmia is a serious heart disease. In this work, ECG signals are acquired from normal subjects. Ventricular Tachyarrhythmia ECG time series data are collected from MIT-BIH Physionet database. In this paper, we have tried to distinguish between normal and Ventricular Tachyarrhythmia ECG signals by looking at the Fractal Dimension. For this purpose, we have implemented Hurst's Rescaled range analysis method.

KEYWORDS: *ECG time series, Fractal pattern, Ventricular Tachyarrhythmia, Fractal Dimension, Hurst's Rescaled range analysis*

I. INTRODUCTION

Electrocardiogram (ECG) is a record that represents the electrical activity of the heart. The relevant parameters of ECG signal, P, QRS and T waves reflect the rhythmical electrical depolarization and repolarization of the myocardiogram associated with the contractions of the atria and ventricles. The shape and duration of each feature of ECG signal are significant diagnostic parameters [1-2]. Time domain and frequency domain features of ECG signals can be extracted using Digital Signal Processing (DSP) techniques. It has been seen that if there is fibrillation present in the ECG signal then this is indicated by the presence of distinct peaks in the range of 3 Hz-7 Hz in the frequency band of its frequency spectrum [3-4]. ECG signals have very low amplitude and the information contained in these signals gets corrupted by noise. Noise elimination from ECG signals is a challenging task. Savitzky Golay filter works well in noise elimination from ECG signals [5-7].
Ventricular Tachycardia (VT) is a broad complex tachycardia, defined as three or more successive ventricular beats at heart rate above 120 beats per minute [8]. Episodes can be sustained, or can degenerate into ventricular fibrillation. Sustained VT normally occurs at heart rate of 150-250 beats per minute, but the diagnosis can be difficult [8]. Symptoms of VT can vary from mild palpitations to dizziness, syncope and cardiac arrest [8].
Ventricular Fibrillation (VF) is the commonest initial arrhythmia causing cardiac arrest and appears as a chaotic rhythm on the ECG signal [8]. Studies on scatter plots of Normal, Ventricular Tachyarrhythmia and Atrial Fibrillation ECGs can be done using DSP techniques [9-11]. Normal and abnormal ECGs can be effectively studied in terms of Power spectrum Density [12]. These DSP techniques are effective tools for detecting cardiac diseases. ECG signals are non-linear and non-stationary signals and they have shown self-similarity pattern i.e. fractal pattern [13-15]. In this paper, attempts have been made to identify Ventricular Tachyarrhythmia from ECG time series in terms of Fractal Dimension.

Fractal patterns are seen all over the universe—in nature, in the form of trees, snowflakes, thunderstorms; in Physiology, as random human heart beat, in geology, as anomalous earthquake, etc. Fractal means 'fraction' of an object which would represent the whole system [16]. If one takes a smaller part of the system and magnifies it, the smaller portion would show the same complexity as that of the whole system. Thus, fractals can be named as "scale invariant". Fractals are classified into two categories: "Monofractal" and "Multifractal". Monofractals are simpler as compared to multifractal. Monofractal shows same type of complexity in every direction; thus it appears to be same on every scale; whereas Multifractal does not appear to be same on every scale [15].

Fractal incorporates the concept of "Fractional Dimension". Generally classical geometry shows that regular forms have integer dimensions. For example, a line has dimension = 1, a rectangle has dimension = 2 and so on. However, structures in nature are usually irregular. Compared with a smooth classical geometric form, a fractal form appears to be non-related [17]. Therefore studying fractal has become a growing area of interest.

The history of fractals began by the research of Gaston Julia, and continued with findings of Benoit Mandelbrot. Benoit Mandelbrot was one of the first to discover fractals. He was examining the shapes created by Gaston Julia, by iterating a simple equation and mapping this equation in the complex plane, where Gaston Julia, a mathematician in 1920's could not describe these shapes using Euclidean geometry, "(Barnsley 1993)" [16].

To study the seemingly irregular self similar pattern we need to use "Statistical Analysis". For this, methods like- "Averages", "Standard Deviation" "Distribution Function", "Power spectrum of non stationary signals", " Standard Partition function method", "Wavelet Transformation modulus maxima method" [18-19] were introduced. But the problem with "Averages", "Standard Deviation" "Distribution Function" methods are that they cannot distinguish between two different sources of data set. "Power spectrum analysis" method is applicable only to stationary signals. "Standard partition function" method needs the signal to be stable and temporal, but ECG signals are not so and "Wavelet transform modulus maxima" method requires large computation. Later on, Hurst developed Rescaled Range Analysis method [20-22] which is a statistical method to analyze long range data set by choosing discrete set of time series. There are many other methods namely ANN, DFA, MF-DFA etc which can also be used to study the fractal geometry.

Therefore, studying ECG signal using Rescaled Range Analysis method is important. Hence, in this paper, we will implement Rescaled Range Analysis method to study the Fractal Dimension of Normal and Ventricular Tachyarrhythmia ECG signals.

II. DATA SELECTION

ECG signals are recorded using POLYPARA module with a sampling rate of 200 samples per second from 35 subjects who are not suffering from any cardiac diseases. Ventricular Tachyarrhythmia ECG signals are collected from MIT-BIH Physionet database [23-24]. This database is a large and growing archive of well-characterized digital recordings of physiologic signals and related data.

The database [23] includes 35 eight-minute ECG recordings of human subjects who experienced episodes of sustained ventricular tachycardia, ventricular flutter, and ventricular fibrillation.

Record cu01 was obtained from a long-term ECG (Holter) recording (played back at real time for digitization); the other records were digitized in real time from high-level (1 V/mV nominal) analog signals from patient monitors. All signals were passed through an active second-order Bessel low-pass filter with a cutoff of 70 Hz, and were digitized at 250 Hz with 12-bit resolution over a 10 V range (10 mV nominal relative to the unamplified signals). Each record contains 127,232 samples (slightly less than 8.5 minutes) [23].

III. MATHEMATICAL ANALYSIS

Rescaled Range Analysis

The rescaled range analysis is simple yet robust non-parametric method for fast fractal analysis. This is performed on the discrete time series data set x_t of dimension N by calculating the mean $\tilde{x}(N)$;the standard deviation S(N) and the cumulative departure X(n,N), where,

$$\tilde{x}(N) = \sum \frac{x_t}{N} \tag{1}$$

$$S(N) = [\frac{1}{N}\sum (x_t - \tilde{x}(N))^2]^{\frac{1}{2}} \tag{2}$$

Range of cumulative departure of the data is

$$R(N) = \max[x(n,N)] - \min[x(n,N)] \tag{3}$$

Where cumulative departure is given by

$$X(n,N) = \sum (x_t - \tilde{x}(N)), \quad 0 \leq n \leq N \tag{4}$$

The associated R/S analysis for the ECG signals is discussed in detail in the Result section of this paper. It is computed as

$$\frac{R}{S} = n^H \tag{5}$$

The slope of the plot of log (R/S) vs. log (n) gives rise to H. The magnitude of H indicates whether a time series is random or successive increments in time series.
The fractal dimension D [25-26] is determined as

$$D = 2-H. \tag{6}$$

The correlation ‘ρ’ [26] between two successive steps or increment is given by

$$\rho = 2^{2H-1}-1 \tag{7}$$

If H = 0.5 then ρ = 0. For this the time series represents random walk and each observation is totally independent of the prior observations. If ρ is positive then 0.5<H<1, meaning the time series is persistent and has long memory effect, that is the preceding observations has a positive correlation with the successive observations. On the other hand if ρ is negative then 0<H<0.5, meaning the observations are non-persistent and the each value has negative correlation with the previous value [21].

IV. RESULTS AND DISCUSSIONS

The plots for normal ECG and diseased ECG e.g. Ventricular Tachyarrhythmia are shown in Fig-1 and Fig-2 respectively.

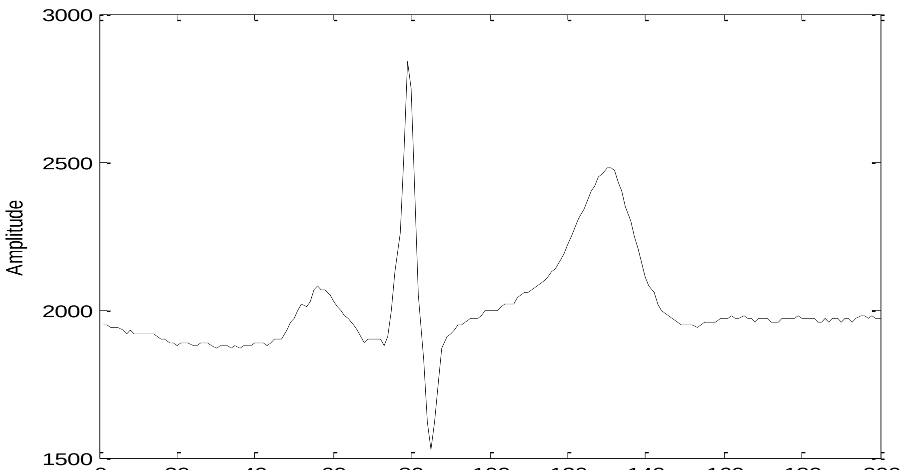

Fig-1: Normal ECG

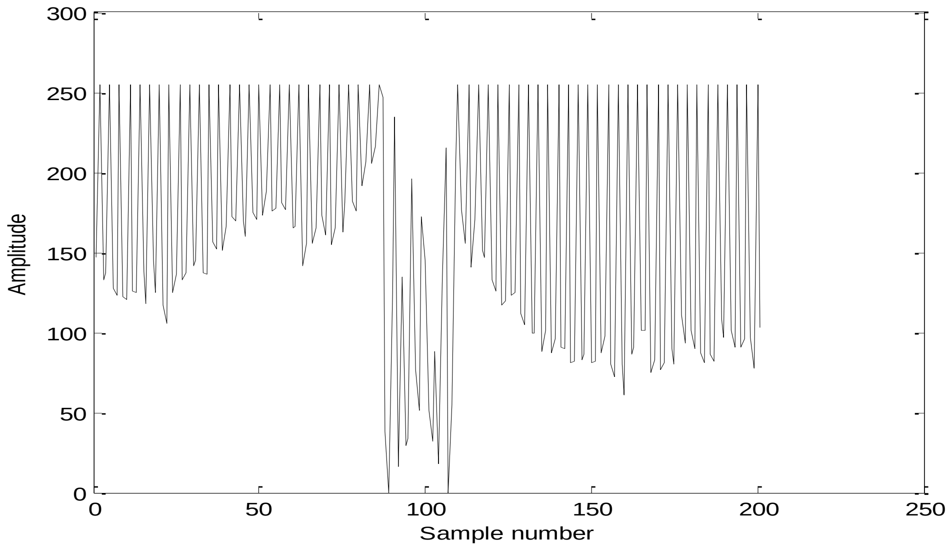

Fig-2: Ventricular Tachyarrhythmia ECG

Both normal and Ventricular Tachyarrhythmia ECG time series are loaded on MATLAB platform. Rescaled range analysis method as explained in the earlier section is applied to these time series. For this method, we choose a set of dimension N (which is 200, in our case). Mean $\tilde{x}(N)$, Standard Deviation S(N), Range R(N), Cumulative Departure X(n ,N) are found using eqns. 1, 2, 3, and 4 respectively. Subsequently, (R/S) value is calculated. A graph $\log_{10}$(R/S) vs. $\log_{10}$(N) is then plotted. Hurst exponent is then found from the slope of this graph using eqn. 5.

The graph $\log_{10}$(R/S) vs. $\log_{10}$(N) for a normal ECG time series is shown in Fig-3 as a sample plot.

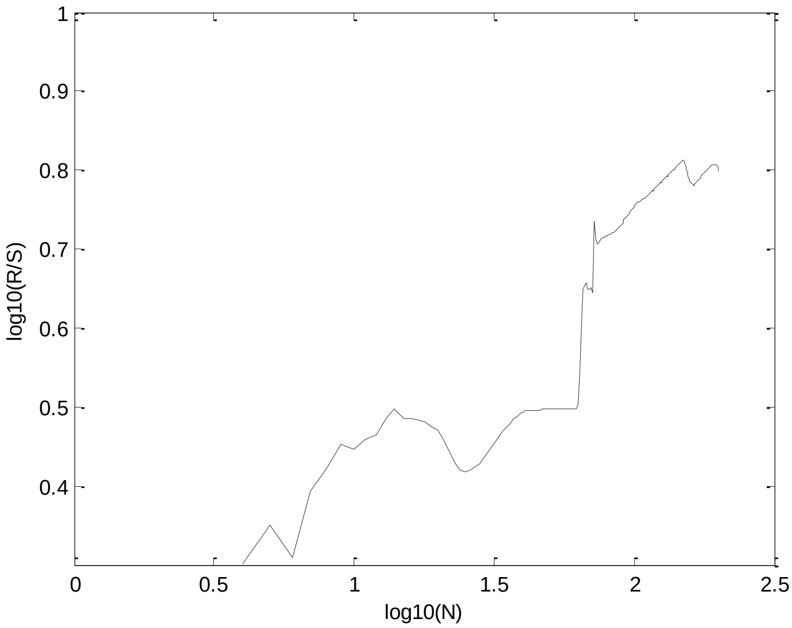

Fig-3: log $_{10}$(R/S) vs log $_{10}$(N) for a normal ECG time series

Similarly, the graph $\log_{10}$(R/S) vs. $\log_{10}$(N) for a Ventricular Tachyarrhythmia ECG time series is shown in Fig-4 as a sample plot.

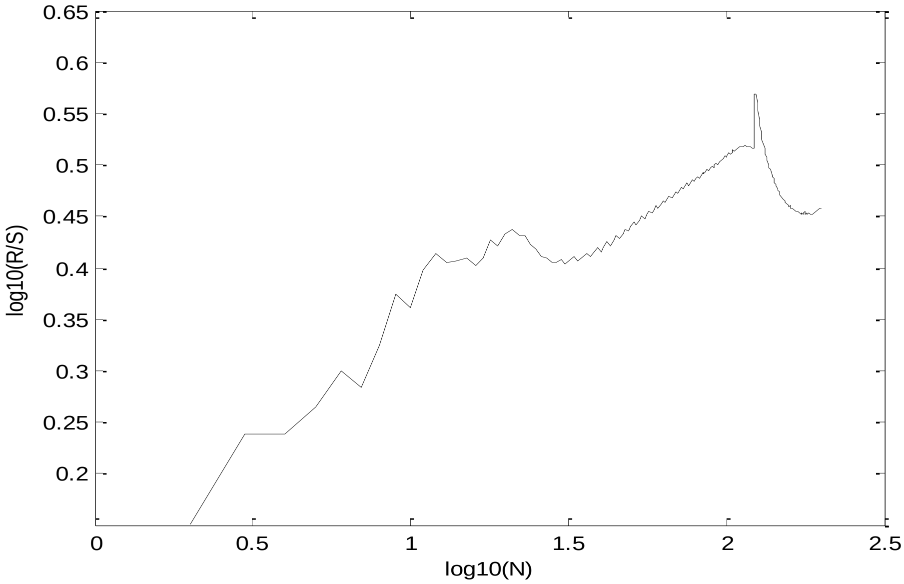

Fig-4: log $_{10}$(R/S) vs log $_{10}$(N) for a Ventricular Tachyarrhythmia ECG time series

Fractal dimension of each data set is obtained using eqn.6, which is D = 2-H. We also found the correlation between two successive steps by using eqn.7 which is $\rho = 2^{2H-1}-1$.

Fractal dimension values obtained for Normal and Ventricular Tachyarrhythmia ECG time series are tabulated in Table-1 and Table-2 respectively as sample results

Table 1: For Normal ECG Time Series

Set no	H	D	ρ
1	0.3603	1.6397	-0.1761
2	0.3603	1.6397	-0.1761
3	0.4053	1.5947	-0.123
4	0.3569	1.6431	-0.1799
5	0.3475	1.6525	-0.1905
6	0.3962	1.6038	-0.134
7	0.3603	1.6397	-0.1761

Table 2: For Ventricular Tachyarrhythmia

Set no.	H	D	ρ
cu01	0.2447	1.7553	-0.2981
cu02	0.2574	1.7426	-0.2856
cu03	0.2629	1.7371	-0.2801
cu04	0.2346	1.7654	-0.3078
cu05	0.2355	1.7645	-0.3069
cu06	0.2684	1.7316	-0.2746
cu07	0.2281	1.7719	-0.314

From Table-1 and Table-2, it can be observed that Hurst Exponent for all the normal and Ventricular Tachyarrhythmia ECG time series is less than 0.5. Thus, there is a negative correlation. Also from these two tables it can be observed that Fractal Dimension values are lying in between 1 and 2 (implying that all the data sets are having neither straight line nature nor rectangular nature). Moreover, all the log plots show that there is no linear dependency. This ensures the fact that, all the ECG time series i.e. Normal and Ventricular Tachyarrhythmia, show multifractal nature.

Frequency Distribution plot of Fractal Dimension for 35 normal ECG signals is shown in Fig-5

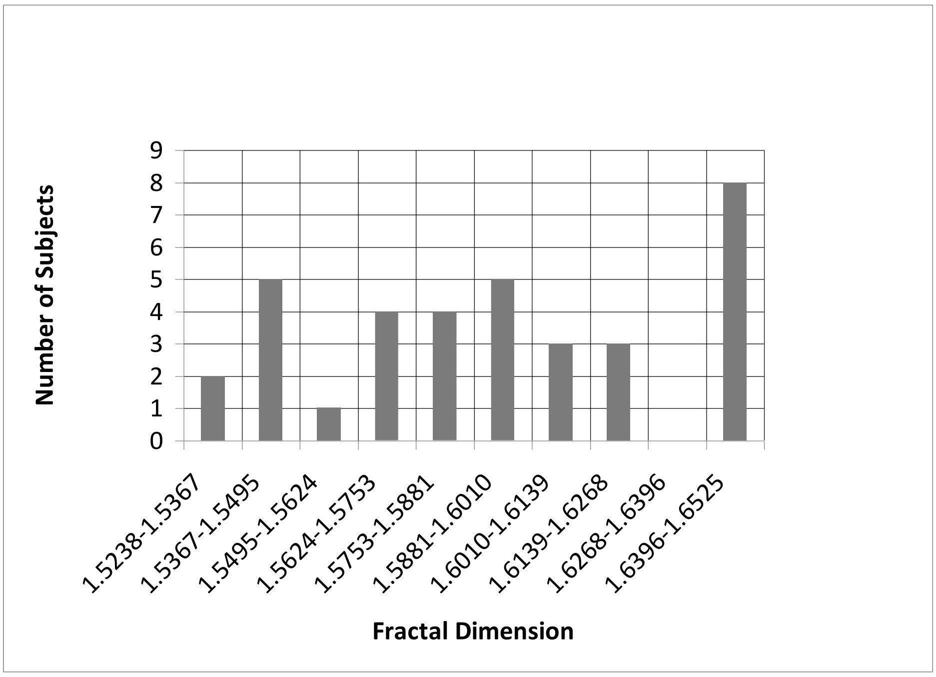

Fig-5: Frequency Distribution for Normal ECG Signals

From Fig-5, it is observed that, Fractal Dimension class interval lying in between 1.6396-1.6525 is having more number of subjects as compared to other class intervals of Fractal Dimension for normal ECG time series.

Frequency Distribution plot of Fractal Dimension for 35 Ventricular Tachyarrhythmia ECG signals is shown in Fig-6

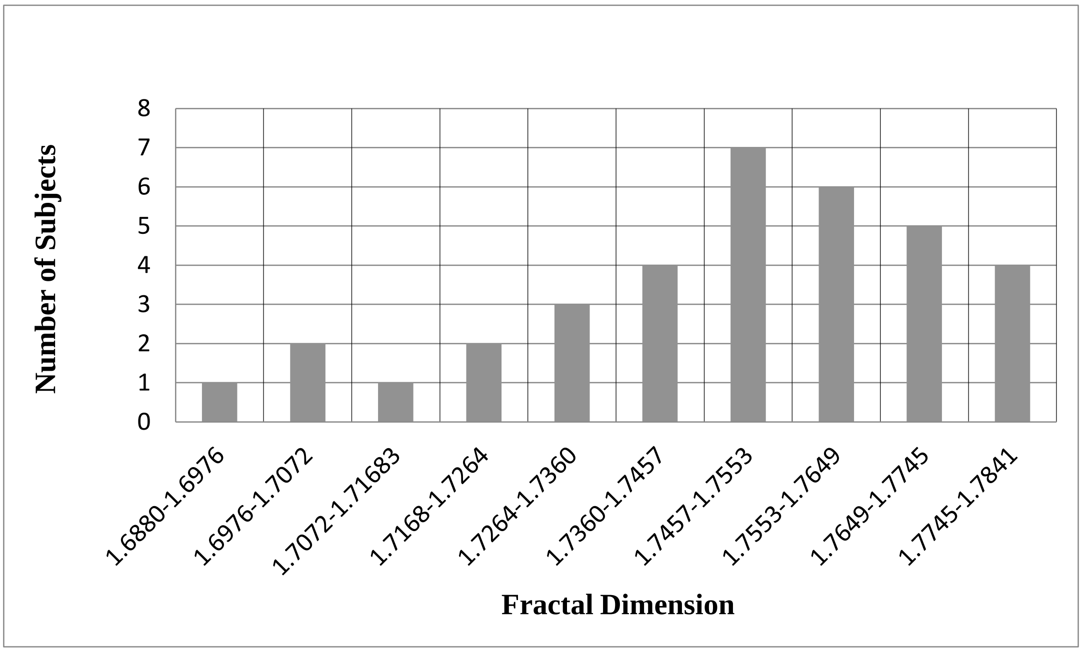

Fig-6: Frequency Distribution for Ventricular Tachyarrhythmia ECG Signals

From Fig-6, it is observed that, Fractal Dimension class interval lying in between 1.7457-1.7553 is having more number of subjects as compared to other class intervals of Fractal Dimension for Ventricular Tachyarrhythmia ECG time series.

Mean and Standard Deviation are obtained from the whole data set considered in this work and these results are tabulated in Table-3 for normal and Ventricular Tachyarrhythmia ECG time series. These results are compared.

Table-3: Fractal Dimension For Normal And Ventricular Tachyarrhythmia Ecg Time Series

Set type	Mean	Standard Deviation	Minimum Limit	Maximum Limit	Mean-Std.	Mean +Std.
Normal	1.5920	0.0386	1.5238	1.6525	1.5534	1.6306
Ventricular Tachyarrhythmia	1.7481	0.0235	1.6880	1.7841	1.7246	1.7716

V. CONCLUSION

Fractal Dimension of Ventricular Tachyarrhythmia ECG time series lies in between 1.7481± 0.0235. Whereas, the Fractal Dimension of normal ECG time series is 1.5920 ± 0.0386. It is observed that the Fractal Dimension value is higher for the case of Ventricular Tachyarrhythmia ECG time series as compared to that of normal ECG time series. Moreover, the variation of Fractal Dimension amongst the data set for Ventricular Tachyarrhythmia ECG time series is small as compared to that of normal ECG time series. This analysis indicates that Fractal Dimension is a very sensitive parameter and it does have clinical significance. So, this range of Fractal Dimension (i.e. 1.7481 ± 0.0235) for Ventricular Tachyarrhythmia ECG time series can be used as a disease index to identify this disease.

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