Detection of Some Major Heart Diseases Using Fractal Analysis

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Abstract

This paper presents a new method to analyze three specific heart diseases namely Atrial Premature Beat (APB), Left Bundle Branch Block (LBBB) and Premature Ventricular Contraction (PVC). The problem is introduced from the discussion of Fractal Dimension. Further, the fractal dimension is used to distinguish between the Electrocardiogram (ECG) signals of healthy person and persons with PVC, LBBB and APB from the raw ECG data. The work done in this paper can be divided into few steps. First step is the determination of the rescaled range of an ECG signal. Then there comes the necessity of calculating the slope of the rescaled range curve. Through this methodology we have established a range of fractal dimension for healthy person and persons with various heart diseases. The way towards determining the range of fractal dimension for those ECG data taken from MIT-BIH Arrhythmia Database has been explained. Again, the obtained range of fractal dimension is also presented here in a tabular fashion with proper analysis

Keywords: Rescaled Range Analysis, PVC, APB, LBBB

1. INTRODUCTION

Premature Ventricular Contraction, also known as extra systole is a relatively common condition where the heart beat is initiated by the heart ventricles rather than the sino atrial node, the normal heartbeat initiator.

The term atrial premature beat describes beat arising from the atrium and occurring before the expected sinus beats. Premature beats can occur randomly or in a pattern. P-wave morphology differs from sinus beats and varies, depending on the origin of the impulse in the atria. In general beats arising in the high atria have upright P-waves in leads II, III and a VF and those originating in the low atria have inverted P-waves in those leads. Depending on the prematurity of the atrial impulse and refractoriness of the AV node and His-Purkinje system, the P-wave may conduct with normal or prolonged PR interval with narrow or aberrant QRS complex or may block and not be followed by a QRS complex. It has been empirically noted that alcohol in excess, fatigue, cigarettes, fever, anxiety and infectious diseases of all sort may result in atrial premature beats and elimination of these factors may correct the disorder. APB also occurs in some patients with CHF and in some with myocardial ischemia. They may also be noted in patients with underline myocardial disease, in those with pulmonary disease and systemic hypoxia. Premature beats are usually perceived by patients as “palpitations”, and sometimes are of concern to patients who noticed skipped beats or fluttering that is frightening. Often atrial premature beats cause no symptoms and are not recognized by the patients. Then APB requires no specific therapy. If they are a source of aggravation or concerned to the patient and one of the above mentioned factors can be identified and should take immediate Medicare.

Premature and abnormal P-wave morphology as compared to the sinus P-wave activity (the premature P-wave may be obscure or it may be buried in the P-wave).

Premature P-wave may or may not be conducted and when conducted would be followed by a QRS wave that often has a normal duration but sometimes it is prolonged.

In a bundle branch block (either left or right) a block of excitation in one of the branches will cause the effective side to be excited i.e. depolarized later and this fact will be revealed in a prolongation of the duration of the QRS. So in BBB, the ventricles will be excited serially, the effected side being excited lastly. Excitation first appears on the surface of the thin walled right ventricles owing to the nature of the conduction system and differing thickness of ventricular myocardium. In the ECG signal the right sided V leads show a large, broad, downward wave. Left sided V leads show a large broad upward wave. QR is prolonged and downward in V5-V6.

So detecting APB, PVC and LBBB precisely have important clinical significance.

2. RELATED WORKS

Frequently a time varying signal is required to analyze to extract characteristic of interest. For example, medical diagnosis often requires the analysis of time varying cardiac, respiratory or brain signals in order to detect cardiac, pulmonary, or mental problems. In general, most temporal processes are analyzed using Fourier transform technique (frequency domain); chaos dynamic (position-velocity phase plane) and other complex mathematical techniques have been applied to signal analysis [4].

Heart failure patients can also be identified by computing certain statistics of the sequence of heart beats such as the Allan factor (AF) and its generalization [1].One method has been applied in [5] for the diagnosis of neuromuscular diseases and can be suitably applied for microcomputer-based on-line analysis of EMG signals. In [7] an electrocardiogram (ECG) beat classification system based on wavelet transformation and probabilistic neural network (PNN) is proposed to discriminate six ECG beat types. With observations it opted for computer-aided diagnosis of heart diseases based on ECG signals. In [8] a functional model of ANN is proposed to aid existing diagnosis methods which investigates the use of Artificial Neural Networks (ANN) in predicting the Thrombo-embolic stroke disease. For ascertaining the robustness of the proposed algorithm; evaluation of the entire MIT-BIH arrhythmia database has been attempted in [9], but the view and purpose was way too different from that of ours. With the best of our effort we couldn't come up with similar works using ECG signal for detailed fractal analysis.

3. SIGNIFICANCE OF OUR WORK

A common drawback of the related methods described above is that they are often complex, not easily amenable to analyze and require some data preprocessing procedures, such as filtering etc. Thus there remains a need for simple and practical method for analyzing such time varying electrical signals.

ECG signal is a self-similar object. So, fractal analysis can be implemented here for proper utilization of the gathered info. It obviously opens scope to analyze the MIT-BIH Arrhythmia Database with different view points. Scope for further medical research and clinical advancement remain wide open through this.

4. WHAT IS FRACTAL AND FRACTAL ANALYSIS

Fractals are of rough or fragmented geometric shape that can be sub divided in parts, is of which are reduced copy of the whole [2]. Fractal dimension is number very often non integer, often it is the only one measure of fractals. It measures the degree of fractal boundary fragmentation or irregularity over multiple scales. It determines how fractal differs from Euclidian objects.
Images and shapes within images which cannot be represented by Euclidian geometry have been analyzed by fractal geometry. Unlike conventional geometry, which deals with lines, triangles, circles, spheres and cones, fractal geometry is concerned with broken or fractured shapes as so commonly found in nature.

A collection of mathematical procedure used to determine fractal dimension (or any other fractal characteristic) or set of fractal dimensions with smallest error.

4.1 Self similarities and fractal analysis

Fractal is strictly self similar if it can be expressed as a union of sets, each of which is an exactly reduced copy of the full set (Sierpinski triangle, Koch flack). The most fractal looking in nature does not display this precise form.

Natural objects are not union of exact reduced copies of whole. A magnified view of one part will not precisely reproduce the whole object, but it will have the same qualitative appearance. This property is called statistical self-similarity or semi-self similarity.

As ECG signal of a human heart is a self similar object. So it must have a fractal dimension. So we have used fractal analysis. And to determine the fractal dimension rescaled range method has been used here.

4.2 Rescaled range analysis

Hurst developed the rescaled range analysis, a statistical method to analyze long records of natural phenomena [3]. There are two factors used in this analysis; firstly the range R, this is the difference between the minimum and the maximum accumulated values of cumulative sum of X (t, τ) of the natural phenomenon at discrete integer-valued time t over a time span τ, and secondly, the standard deviation is S, estimated from the observed values X_i (t). Hurst found that the ratio R/S is very well described for a large number of natural phenomena by the following empirical relation.

$$[\ R(\tau) / S(\tau)\ ] \ \alpha\ \tau^{H}$$

Where τ is the time span and H is the Hurst component. The coefficient C is taken equal to 0.5 by Hurst. R and S are defined as:

$$R(\tau) = \max_{1 \le t \le \tau} X(t, \tau) - \min_{1 \le t \le \tau} X(t, \tau)$$

$$S(\tau) = \left\{ 1/\tau \sum_{t=1}^{\tau} [\zeta(t) - (\zeta)_{\tau}]^2 \right\}^{1/2}$$

Where,

$$(\zeta)_{\tau} = 1/\tau \sum_{t=1}^{\tau} \zeta(t)$$

and,

$$X(t,\tau) = \sum_{u=1}^{t} [\zeta(u) - (\zeta)_{\tau}]$$

4.3 Relation between the rescaled range and fractal dimension

The relation between the Hurst exponent and the fractal dimension is simply D=2-H. We have calculated the individual calculations for each interval length. A straight line is fitted in the log-log plot.

$$\text{Log } [R(\tau)/S(\tau)] = c + H \text{ Log } (\tau)$$ Where H = slope.

So fractal dimension, D=2-H. With the help of these equations we can easily evaluate fractal dimension in the rescaled range analysis.

The results for the R/S analysis depend on the number of sub-interval, the minimum and maximum lags. It is not clear how important the number of sub interval is. Mandel Brot and Wallis noted that the smallest lags (under 30) cannot be expected to be on the line and should not be in the procedure. In the analysis, we choose not to use overlapping sub intervals so that extra dependency between these sub-intervals occurs to find the fractal dimension.

4.4 Analysis of the procedure in brief

We have implemented the rescale range by using MATLAB codes. The source of the ECGs included in the MIT-BIH arrhythmia database is a set of over 4000 long term Holter recording that were obtained by the Beth Israel Hospital Arrhythmia laboratories between 1975 and 1979 [6]. Here, a sample of the analysis procedure is shown through PVC patient. At first we are showing the ECG signal of a patient with Premature Ventricular Contraction (PVC).

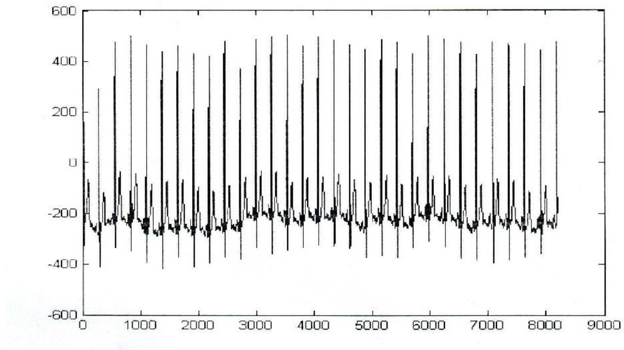

FIGURE 1: ECG Signal of a PVC Patient.

Then we determined the rescaled range of this ECG signal for different slot size (analogous to the sub-interval) utilizing MATLAB code. After that, we got the following table:

Slot Size, T	Log_2 (T)	Log_2 (R/S)
1024	10	12.0865
512	9	11.4365
256	8	10.8452
128	7	10.3248
64	6	9.9850
32	5	9.3542

TABLE 1: Rescaled Range of ECG Signal for Different Slot Size

From this table we have got the following graph:

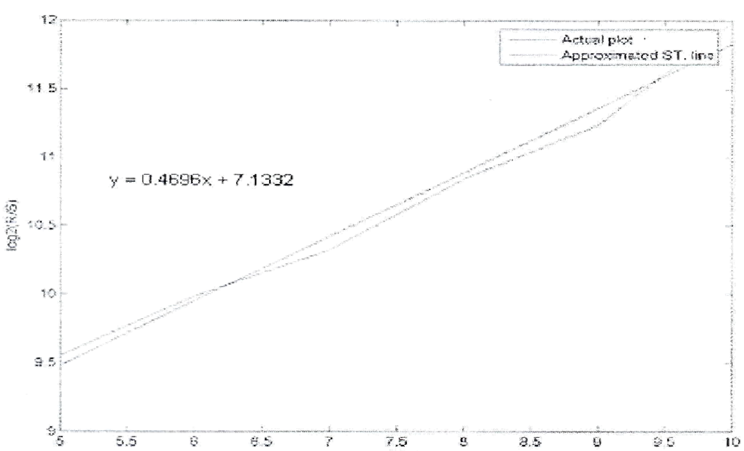

FIGURE 2: Fitted Straight Line by Log-Log Plot

Slope being, H=0.5164, fractal dimension thus remains, D=2-H=1.4836

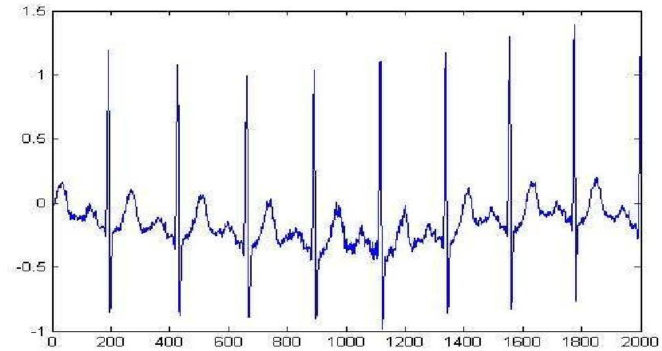

FIGURE 3: ECG signal of APB patient (MIT-BIH 209)

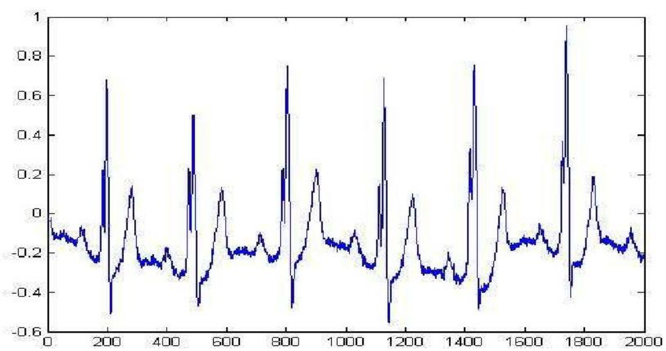

FIGURE 4: ECG signal of LBBB patient (MIT- BIH 111)

Like the example shown above, this approach was applied to MIT-BIH Arrhythmia database file 209 for patient with Atrial Premature Beat (APB) in Fig 3 & Left Bundle Branch Block (LBBB) in Fig 4. Again, it can also be successfully used to tell about the fractal dimension range for the other database files.

Thus, our above mentioned methodology can be suitably applied to MIT-BIH database and in this way a distinct range of fractal dimension was found out for the cases mentioned.

4.5 Obtained result and discussion

Here, we have determined the range of fractal dimension for patients with premature ventricular contraction, left bundle branch block, atrial premature beats along with healthy persons.

Like the shown example, our methodology was applied to other MIT-BIH Arrhythmia database for providing a thorough analysis. Again, it can successfully tell about the fractal dimension range using the other database files of MIT-BIH for PVC patient like 106, 116, 119, 200, 201, 203, 207, 208, 210, 213, 214, 215, 217, 221, 223, 228, and 233. In the same way, for APB case it also accomplishes its goal of reaching a proper fractal dimension range analyzing the samples like 207,209,222,232 etc.

Thus, our above mentioned methodology can be suitably applied to MIT-BIH database and thus a distinct range of fractal dimension was found out for the cases mentioned.
The ranges are tabulated here below:

Sample ECG signal	Range
Healthy Person	1.65-1.67
Patients with PVC	1.48-1.53
Patients with APB	1.54-1.58
Patients with LBBB	1.71-1.74

TABLE 2: Distinct range of fractal dimension for sample ECG signal

5. CONSLUSION

In this paper it has been tried to present a different method for the detection of heart diseases from a newer perspective. ECG signal being a self-similar object; can well be considered for fractal analysis. We have used rescaled range method to determine the specific range of fractal dimension for each specific disease. And we found that the range of fractal dimension for healthy person is 1.65-1.67, for PVC patients it is 1.48-1.53, for APB patients it is 1.54-1.58 and finally for LBBB patients the range is 1.71-1.74. So, the methodological analysis does provide a significant clinical advantage.

6. FUTURE WORK

This paper went for fractal analyzing the MIT-BIH arrhythmia database for heart disease detection. Such an approach should further encourage the researchers in algorithm development on these as it is a widely used database. So, suitably ranging the MIT-BIH arrhythmia database on the basis of fractal dimension should obviously encourage and smooth further research.

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