New Representation of Heart Rate and Evaluation of Extracted Geometric Features

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Abstract

In this paper, a novel method for representation of heart rate has been introduced which is obtaining by using RR interval time series signal to plot the Triangle mapping consist of all the ordered pairs: (RR_i, abs ($\overline{RR} - RR_i$)), $i = 1, \dots, N$ where $\overline{RR}$ is the mean of RR intervals. We obtained a triangle from the distribution of these points and by analyzing it, we could extracted some geometric features which were evaluated in distinguishing four groups of subjects (Arrhythmia, Congestive Heart Failure (CHF), Atrial Fibrillation (AF) and Normal Sinus Rhythm (NSR)) obtained of Physionet database. The results show that these features discriminate arrhythmia from NSR subjects by p<3E-4; CHF from NSR by p<8E-4; AF from NSR by p<8E-4; CHF from arrhythmia by p<2E-2; CHF from AF by p<8E-4; and arrhythmia from AF by p<7E-4.

1. Introduction

A time series of RR interval is the time between successive R-waves and the variation in the time series of consecutive heartbeats is referred as Heart Rate Variability (HRV) [1].

Heart rate is an indicator of heart's condition [2]. Assessment of heart rate has been shown to aid clinical diagnosis and intervention strategies. It has been proved that nonlinear analysis of it might provide more valuable information for the physiological interpretation of heart rate fluctuations [3]. However, the variety of contradictory reports in this field indicates that there is a need for a more rigorous investigation of methods as aids to clinical evaluation. The nonlinear analysis of HRV is a valuable tool in both clinical practice and physiological research reflecting the ability of the cardiovascular system [4].

While linear tools are well suited for making steady state measurements, the non stationary feature of the HRV makes it a prime candidate for applying chaos theory [5]. One of the chaos tools that has been used extensively in the initial development of HRV has been the phase space Poincare plot, sometimes also referred to as Lorenz plot [6]. But standard analyses of Poincare plot are linear statistics and hence the measures do not directly quantify the nonlinear temporal variations in the time series contained in the poincare plot. Moreover, it has some limitation to investigate all the physiological mechanisms in a time series [7]. So for distinguishing the behavior of different arrhythmia, accessing to more information of HRV dynamics is necessity.

For this purpose, in this paper, we introduced a novel mapping for heart rate which we named Triangle Phase Space Mapping (*TPSM*). Then, we extract geometric features in this new map to detect new aspects of HRV dynamics.

For evaluating these features in new map (*TPSM*), we try to use them for distinguishing four groups of subjects (Arrhythmia, Congestive Heart Failure (CHF), Atrial Fibrillation (AF) and Normal Sinus Rhythm (NSR)).

2. Triangle Phase Space Mapping

In this section, first we introduced our novel mapping: Triangle Phase Space Mapping (*TPSM*). Then, base on point's distribution in this new space, we extract new geometric features such as Angles, Area of the triangle, the slope of the line, the length of them and so on which are explained in details in the following and then they have been used for distinguishing different groups of subjects which is followed by statistical analysis.

2.1. Construction of TPSM

For constructing this new mapping using RR time series, we used the mean of *RR* intervals which is defined as:

$$mean(RR) = \overline{RR} = \frac{1}{n+1}\sum_{i=1}^{n} RR_i \qquad (1)$$

in which RR = {RR_1, RR_2, …, RR_n}.
So *TPSM* consists of all the ordered pairs:

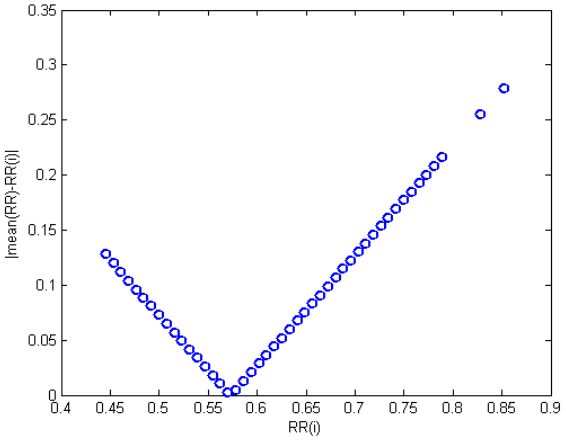

Figure 1. The distribution of points in *TPSM*

$$(RR_i, |\overline{RR} - RR_i|) \qquad (2)$$

in which i = 1, 2, 3, …, n.

The distribution of points in this new map is shown in Fig. 1.

By analyzing the point's distribution in this new map, we could obtain a triangle which for the all kinds of HRV has special features. This triangle is shown in Fig. 2.

For all kinds of HRV data, normal or abnormal, the obtained triangle is a right angled triangle. Because its interior angle *C* is 90˚. Also the slope of the sides *a* and *b* is respectively *1* and *-1*.

2.2. Extraction geometric features in *TPSM*

The first step in geometrical analysis of *TPSM* is finding the coordination of three vertices of the triangle. There are a lot of ways for measuring the following geometric features of a triangle. But the methods we used in this paper are as follows:

The vertices *A* and *B* has occurred where their horizontal coordinates are respectively minimum and maximum and *C* occurred where $|\overline{RR} - RR_i|$ is minimum. These relations are:

$$\begin{gathered} A(\min(RR), |\overline{RR} - \min(RR)|) \\ B(\max(RR), |\overline{RR} - max(RR)|) \\ C(RR_C, |\overline{RR} - RR_C|) | |\overline{RR} - RR_C| = \min(|\overline{RR} - RR_i|) \end{gathered} \qquad (3)$$

After finding the coordinates of three vertices, we can find the slope of the sides. As mentioned before, the slope of sides *a* and *b* are clear. So it's enough to find the slope of side *c* (m_c).

$$m_c = \frac{y_B - y_A}{x_B - x_A} \qquad (4)$$

in which *x* and *y* are the coordinates of triangle vertices.

For calculating the length of the sides, we used the relation for finding the distance between two points. So we have:

$$\begin{gathered} a = \sqrt{(x_B - x_C)^2 + (y_B - y_C)^2} \\ b = \sqrt{(x_A - x_C)^2 + (y_A - y_C)^2} \\ c = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \end{gathered} \qquad (5)$$

Now, by knowing the lengths of all three sides of triangle, the three internal angles can be calculated as follows:

$$\begin{gathered} A = \cos^{-1}\left(\frac{b^2 + c^2 - a^2}{2bc}\right) \\ B = \cos^{-1}\left(\frac{a^2 + c^2 - b^2}{2ac}\right) \\ C = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right) = 90^{\circ} \end{gathered} \qquad (6)$$

Of course, because the angle *C* is 90˚, the angles *A* and *B* are complementary. It means that *A+B = 90.*˚ So it's sufficient to just measure angle *A*.

The perimeter of the triangle is defined by adding three sides of it:

$$P = a + b + c \qquad (7)$$

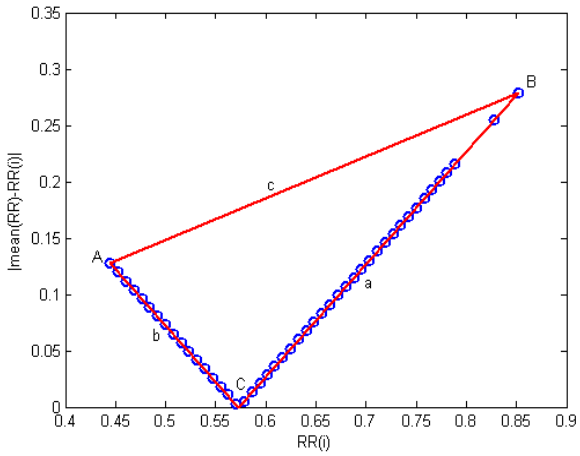

Figure 2. Estimation a triangle for point's distribution in TPSM

By knowing the coordinates of the three vertices of the triangle, the area can be computed as $^1/_2$ times the absolute value of the determinant:

$$S = TriangleArea = \frac{1}{2}\left|det\begin{pmatrix} x_A & x_B & x_C \\ y_A & y_B & y_C \\ 1 & 1 & 1 \end{pmatrix}\right| \quad (8)$$

$$= \frac{1}{2}\ |(x_A - x_C)(y_B - y_A) - (x_A - x_B)(y_C - y_A)|$$

The last geometric feature extracted from *TPSM* is measuring the quality of the triangle which is obtained as follows:

$$q = \frac{4\sqrt{3}S}{a^2+b^2+c^2} \quad (9)$$

3. Discrimination of heart arrhythmia

In order to validate the proposed features, coefficients *A*, *B*, and *C*, we have used them to discriminate four groups of subjects (Arrhythmia, Congestive Heart Failure (CHF), Atrial Fibrillation (AF) and Normal Sinus Rhythm (NSR)). For each groups, we calculate these features separately.

The data from MIT-BIH Physionet database [8] are used in the experiment. In this study, we have used 15 long-term ECG recordings of subjects in normal sinus rhythm from Physionet Normal Sinus Rhythm database [8]. Furthermore, we have also used NHLBI sponsored Cardiac Arrhythmia Suppression Trial (CAST) RR-Interval Sub-study database for the arrhythmia data set from Physionet. Subjects of CAST database had an acute myocardial infarction (MI). The database is divided into three different study groups among which we have used the Encainide (e) group data sets for our study. From that group we have chosen 15 subjects belong to subgroup baseline (no medication) [8]. Also, we have used 15 long-term ECG recordings of subjects with CHF from Physionet Congestive Heart Failure database along with 15 ECG recordings of subjects with Atrial Fibrillation from Physionet Atrial Fibrillation database [8]. The original long term ECG recordings in every four groups were digitized at 128 Hz [8].

4. Results

For comparing the results and evaluate the proposed parameters, we have used statistical analysis which are explained in details in next section.

Table 1. *p-Value Results for TPSM Features (Angle, Sides)*

Groups	*TPSM* Features			
	A	*a*	*b*	*c*
NSR, CHF	0.0033	0.7131	0.0028	0.0009
NSR, CAST	0.0024	0.0088	0.0005	0.0003
NSR, AF	0.4082	0.0008	0.0536	0.0077
CHF, CAST	0.9633	0.0274	0.5813	0.5813
CHF, AF	0.0008	0.0015	0.0021	0.0051
CAST, AF	0.0007	0.1543	0.0008	0.0011
Total	1.06E-4	4.81E-4	5.38E-5	2.52E-5

4.1. Statistical analysis

In this study, we have used Kruskal-Wallis test to define the level of significance of our proposed features.

Kruskal-Wallis test is a nonparametric version of the classical one-way ANOVA, and an extension of the Wilcoxon rank sum test to more than two groups. The assumption behind this test is that the measurements come from a continuous distribution, but not necessarily a normal distribution. The test is based on an analysis of variance using the ranks of the data values, not the data values themselves.

In our study, this test has been used to evaluate the hypothesis for each feature separately. The *p* values obtained from Kruskal-Wallis analysis for all features are shown in Table 1 and Table 2.

In case of $p < 0.05$ to be considered as significant, we can see that *TPSM* features would show the significant difference between groups which *p* value is shown in Table 1 and Table 2.

The results show that these parameters don't depend on the type of arrhythmia and are able to distinguish different groups (Fig. 3). They discriminate CHF from NSR by *p<8E-4*; AF from NSR by *p<8E-4*; CAST from NSR by *p<3E-4*; CHF from CAST by *p<2E-2*; CHF from AF by *p<8E-4*; and CAST from AF by *p<7E-4*. It's shown in this tables that these features are able to classify all four groups by *p<E-5*.

Table 2. *p-Value Results for TPSM Features (Slope, Perimeter, Area, Quality)*

Groups	*TPSM* Features			
	m_c	*P*	*S*	*q*
NSR, CHF	0.0033	0.0008	0.0015	0.0008
NSR, CAST	0.0024	0.0003	0.0003	0.0024
NSR, AF	0.4082	0.0088	0.0169	0.9268
CHF, CAST	0.9633	0.5813	0.3581	0.8903
CHF, AF	0.0008	0.0051	0.0274	0.0002
CAST, AF	0.0007	0.0011	0.0015	0.0015
Total	1.06E-4	2.39E-5	6.57E-5	5.50E-5

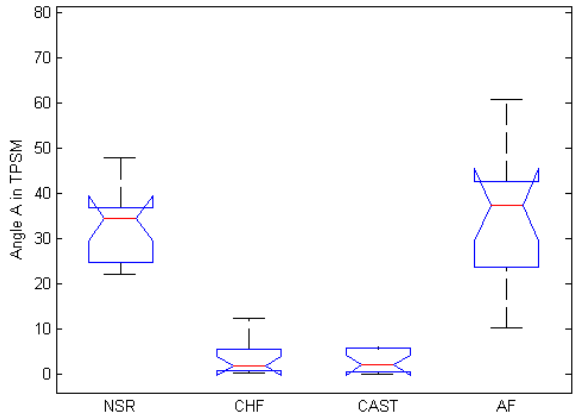

Figure 3. Box-Whiskers Plot of angle *A* in TPSM

5. Discussion

In this novel method, we have used the function between current data of time series in relation to the mean of whole data. It was shown that this new mapping was able to differentiate four groups of subjects significantly. The triangle model of it enable the user to test different geometric analysis on it and extract different features which each one may reflect different aspects of HRV behavior. Another advantage of this triangle mapping is that the points in this map overlapped with each other as a kind of compaction and so this map deletes the extra and useless information and just keeps the useful ones.

Hence, it seems that this kind of mapping may be used as an efficient method for pathology detection. So it would be evaluated in most cases and compared with clinical results to detect its more advantages in cardiac arrhythmia diagnosis.

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