New Feature Set for Better Representation of Dynamic of RR Intervals in Poincare Plot

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Abstract

Traditional features extracted from Poincare plot (e.g., SD1 and SD2) ignore temporal information and only quantify point distribution. In this article, a new feature set is proposed to capture the dynamic of point distribution in the Poincare plot. For quantification of temporal information in Poincare plot, extracted ADP features (angle, direction, and position) from point distribution in the Poincare plot were used with K- Nearest Neighbor (KNN) classifier for classification of four cardiac condition obtained from Physionet database (normal sinus rhythm, myocardial infarction, congestive heart failure, and atrial fibrillation). KNN was trained on 70% of data as a train set, and the accuracy was evaluated on 30% of data as a test set. Accuracy of classification were 94.8% and 95.58% for training and test set, respectively. Furthermore, ADP features were used for creating a new map that represents the temporal information of points in Poincare plot.

1. Introduction

Heart Rate Variability (HRV) is the variation in the time series of RR intervals [1] and is an indicator of heart's condition [2]. It has been proved that nonlinear analysis of HRV provides more valuable information for the physiological interpretation of heart rate fluctuations compared to linear HRV measures [3]. One of the useful nonlinear analysis of HRV is Poincare plot, plot of each RR interval against next RR interval [4]. Woo et al. were the first group who used Poincare plot for evaluating the differences between healthy subjects and heart failure patients [5]. Poincare plot is a geometrical representation of RR time series to demonstrate patterns of heart rate dynamics resulting from nonlinear processes [6]. Tulppo et al. [7] fitted an ellipse to the point distribution in the Poincare plot and defined two standard descriptors (SD1 and SD2) for quantification of the Poincare plot geometry. These standard descriptors represent the minor axis and the major axis of the ellipse and guide the visual inspection of the distribution. Brennan et al. proved that although Poincare plot is a nonlinear representation of RR intervals, but SD1 and SD2 cannot describe these nonlinear behavior and are linear and statistic parameters [8]. Furthermore, these descriptors ignore temporal information and only quantify point distribution [9].

In addition to geometric features that was proposed by our team previously [10-13], a new feature set is proposed in this article to capture the temporal information in a Poincare plot by considering the angle between consecutive points, the direction of the trajectory, and the position of points in relation to the line of identity. These features were used to create ADP Map (angle, direction, and position map) for a new representation of RR points.

Performance of proposed feature set was evaluated in distinguishing four cardiac condition including normal sinus rhythm (NSR), acute myocardial infarction (MI), congestive heart failure (CHF), and atrial fibrillation (AF).

2. Method and Data

2.1. Method

For extraction of the new feature set and creating new map, quantification of temporal information/dynamics of the points in Poincare plot were the focus of this article. For capturing dynamic information, three features were calculated between every three consecutive points in Poincare plot: angle, direction of the trajectory, and the location of middle point in relation to the line of identity. For visualization purpose, these features were used to create a 3D map (ADP map).

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2.1.1. Angle

For defining the angle between every three consecutive points, points in Poincare plot were connected in their temporal orders as is shown in Figure 1 and the angle between two sequential vectors was measured.

For measuring the angle between two vectors, first length of two vectors which connects the two sequential points should be measured. This can be obtained by measuring the distance between two points as:

$$D_i = \sqrt{(RR_i - RR_{i+1})^2 + (RR_{i+1} - RR_{i+2})^2} \qquad (1)$$

and then the angle between two consecutive vectors is defined as:

$$\alpha_i = \cos^{-1}\left(\frac{D_i^2 + D_{i+1}^2 - \left((RR_i - RR_{i+2})^2 + (RR_{i+1} - RR_{i+3})^2\right)}{2D_i D_{i+1}}\right) \qquad (2)$$

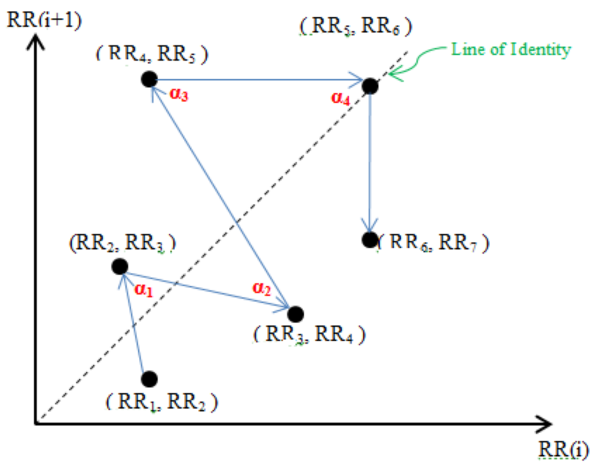

Figure 1. Definition of angle between every three consecutive points in Poincare plot.

2.1.2. Direction

The direction of trajectory for every three consecutive points can be one of the following conditions (Figure 2):

1. The points are on straight line.
2. The points have clock-wise orientation.
3. The points have counter clock-wise orientation

Finding one of the specific condition mentioned above is defined as follows:

$$Dir_i = \begin{vmatrix} RR_i & RR_{i+1} & 1 \\ RR_{i+1} & RR_{i+2} & 1 \\ RR_{i+2} & RR_{i+3} & 1 \end{vmatrix} = \begin{cases} 0; & \text{on straight line} \\ >0; & \text{counter clock-wise orientation} \\ <0; & \text{clock-wise orientation} \end{cases} \qquad (3)$$

In this study, only the sign of Dir_i is important. So if the points are in counter clock-wise orientation, Dir_i is coded as +1 and if they are in clock-wise orientation, Dir_i is coded as -1.

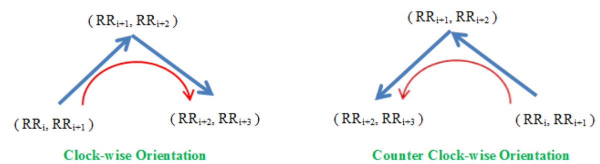

Figure 2. The direction of trajectory for three consecutive points in Poincare plot.

2.1.3. Position of Middle Point in Relation to the Line of Identity

As is shown in Figure 1, the line of identity passes through the origin at an angle of 45° with horizontal axis [14]. For defining the position of middle point in every three consecutive points in relation to this line, the distance of point to the line $y=x$ is determined as follows:

$$d_i = \frac{RR_{i+1} - RR_i}{\sqrt{2}} \qquad (4)$$

If d_i is positive, the point is above the line of identity. Negative d_i shows that the point is below the line of identity and if d_i is zero, the point is on the line of identity. Position of the point was represented by color as third dimension in new ADP map (Figure 3, red, green, and blue were used if middle point was above, on, and below unity line, respectively).

2.1.4. ADP Map

ADP map will be used for a better representation of points' temporal behavior in Poincare plot. For creating this map, first the two parameter *Angle* and *Dir* were combined by their multiplication. Since *Dir* is *-1* or *+1*, the sign of *Angle* would become positive or negative. We plot this new feature versus *i* which is the temporal index of points in Poincare plot. The location of the point in relation to the line of identity was added as a third dimension by color. Point above the line of identity, below the line of identity, and on the line of identity were represented by blue, red, and green, respectively.

As it is shown in figure 3, the first three points in Poincare plot have the angle 163°, and since these points are in counter clock-wise orientation, the parameter *Dir* is *+1* and since the middle point is above the line of identity, it is shown by red color.

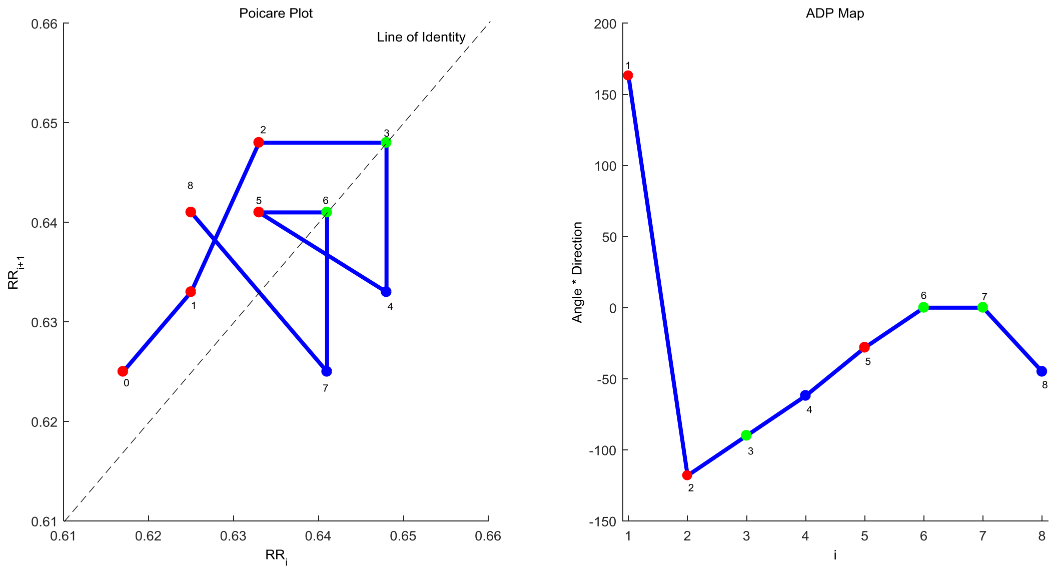

Figure 3. Poincare plot and ADP map of nine consecutive points
(Left figure: Poincare plot; Right figure: ADP Map)

2.2. Statistical Analysis and Classification

Kruskal-Wallis, a non-parametric version of the classical one-way ANOVA, was used to compare the proposed features between four cardiac conditions. Level of significance was set to 0.05. Extracted ADP features (angle, direction, and position) were used with K- Nearest Neighbor (KNN) classifier for classification of four cardiac condition. KNN was trained on 70% of data as a train set, and the accuracy was evaluated on 30% of data as a test set.

2.3. Data

In this study, RR intervals for acute myocardial infarction (MI, n=14), Congestive Heart Failure (CHF, n=14), Atrial Fibrillation (AF, n=14), and Normal Sinus Rhythm (NSR, n=14) were extracted from Physionet for evaluation of the proposed feature set.

The data from Physionet database [15] are used in the experiment. In this study, 14 long-term ECG recordings of subjects in normal sinus rhythm were extracted from Physionet Normal Sinus Rhythm database [15]. Furthermore, NHLBI sponsored Cardiac Arrhythmia Suppression Trial (CAST) RR-Interval Sub-study database for the acute myocardial infarction (MI) data set from Physionet was used for extracting MI data. This database is divided into three different study groups among and the Encainide (e) group data sets was used to extract 14 MI subjects belong to subgroup baseline (no medication) [15]. Also, 14 long-term ECG recordings from Physionet Congestive Heart Failure database along with 14 ECG recordings from Physionet Atrial Fibrillation database were used to create CHF and AF data set, respectively [15]. The original ECG recordings for all groups were digitized at 128 Hz [15].

3. Results

For comparing the results and evaluating the proposed feature set, statistical analysis was used first. Then KNN classifier was used to classify these four groups of arrhythmia by using extracted features. Mean and standard deviation of ADP features are reported in Table 1. The *p*-values from Kruskal-Wallis analysis are shown in Table 2 for ADP features. Angle was significantly different between MI and AF (p-value=0.02) as well as CHF and AF (p-value<0.05). Except MI and CHF, direction was significantly different in other cardiac group pairs (p-value<0.05).

Accuracy, sensitivity, and specificity for KNN classifier for test set is reported in Table 3. Accuracy of classification for four groups was 94.8% and 95.58% for training and test set, respectively.

4. Conclusion

In this article, a new feature set and map were proposed for capturing temporal information/dynamic of points in Poincare plot. The promising result of this study suggests that new feature set can complement traditional quantifiers of Poincare plot.

Table 1. Mean and standard deviation of ADP feature set across groups with different cardiac condition (NSR: Normal Sinus Rhythm, MI: Acute Myocardial Infarction, CHF: Congestive Heart Failure, AF: Atrial Fibrillation).

	ADP Feature Set		
	Angle	Direction	Position
NSR	72.01±10.71	-0.01±0.02	-0.18e-4±0.35e-4
CHF	62.63±15.38	-0.81±1.48	-0.04e-4±0.08e-4
MI	67.10±13.89	-1.80±2.97	-0.04e-4±0.65e-4
AF	78.81±14.40	-0.01±0.02	-0.01e-4±0.43e-4

Table 2. *P-value for ADP features, significant parameters are highlighted in bold (NSR: Normal Sinus Rhythm, MI: Acute Myocardial Infarction, CHF: Congestive Heart Failure, AF: Atrial Fibrillation).*

Groups	*ADP* Features		
	Angle	Direction	Position
NSR & MI	0.33	**<0.05**	0.08
NSR & CHF	0.09	**<0.05**	0.06
NSR & AF	0.19	**0.02**	0.06
MI & CHF	0.33	0.43	0.18
MI & AF	**0.02**	**<0.05**	0.67
CHF & AF	**<0.05**	**0.01**	0.46

Table 3. *Classification performance for test set*

	Accuracy	Sensitivity	Specificity
NSR	94.11	100	91.66
CHF	100	100	100
MI	88.23	75	92.30
AF	100	75	100

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