Blood Pressure Classification by Analyzing the Behavior of Heart Rate Variability in Poincare Plot

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Abstract

Blood pressure is the amount of pressure exerted by the blood on the walls of the vessels. In this research, the impact of three different blood pressure levels (e.g., High, Normal, and low) on the extracted features of the Poincare plot of heart rate variability (HRV) is studied. After extracting RR intervals from ECG, Global Occurrence Matrix (GOM) and Co-occurrence Matrix (COM) parameters demonstrating the dynamic in the Poincare plot were obtained. First, the extracted features in three blood pressure levels were compared, and then the k-nearest neighbor classifier was used to distinguish three classes of high, normal, and low blood pressure. The results show that the GOM and COM features significantly differed between different blood pressure stages, with a mean accuracy of 91%.

1. Introduction

Cardiovascular diseases are still the first cause of death in the world[1]. One of the most important and perhaps the most influential factors in the occurrence and development of cardiovascular diseases and heart and brain strokes is having high blood pressure or, as it is commonly called, "blood pressure" [2]. High blood pressure is one of the factors that usually happens gradually. However, it gradually leaves its destructive effects on the heart, large and small blood vessels, kidneys, retina, and other organs [2]. Since the main task of the heart is to send blood to the muscles, brain, and other organs, any factor that creates a barrier in front of this task will increase the work of the heart.

Blood pressure is the amount of pressure exerted by the blood on the walls of the vessels and is one of the vital signs [3]. Pressure is a physical concept. Pressure refers to the "power" of a moving fluid. Blood pressure in the areas near the heart is higher and decreases in proportion to the distance from the heart [4]. Blood pressure is different in different parts of the circulatory system. The most common way to measure blood pressure is through a sphygmomanometer, which uses the height of mercury to measure the blood pressure circulating in the veins [5].

Normal blood pressure in humans while resting is in the range of 90 to 120 mmHg (systolic) and 60 to 80 mmHg (diastolic) [2]. Typically, if the blood pressure is consistently higher than 130 systole and 80 diastoles, it is considered pathology and disease. The complication of increased blood pressure beyond normal is called hypertension and high blood pressure [5]. Lower blood pressure is also called hypotension. High blood pressure, if not treated, causes damage to the arteries and vital organs of the body, that's why it is called the silent killer.

Blood pressure naturally rises due to stress and physical activity, but a person with high blood pressure has higher than normal blood pressure even when resting. In this article, we try to evaluate and detect three different blood pressure levels using an analysis of the Poincare plot of RR intervals. For this purpose, after HRV signal processing, we extracted different features defined in the Poincare plot of RR intervals to recognize the blood pressure level compared to the normal one.

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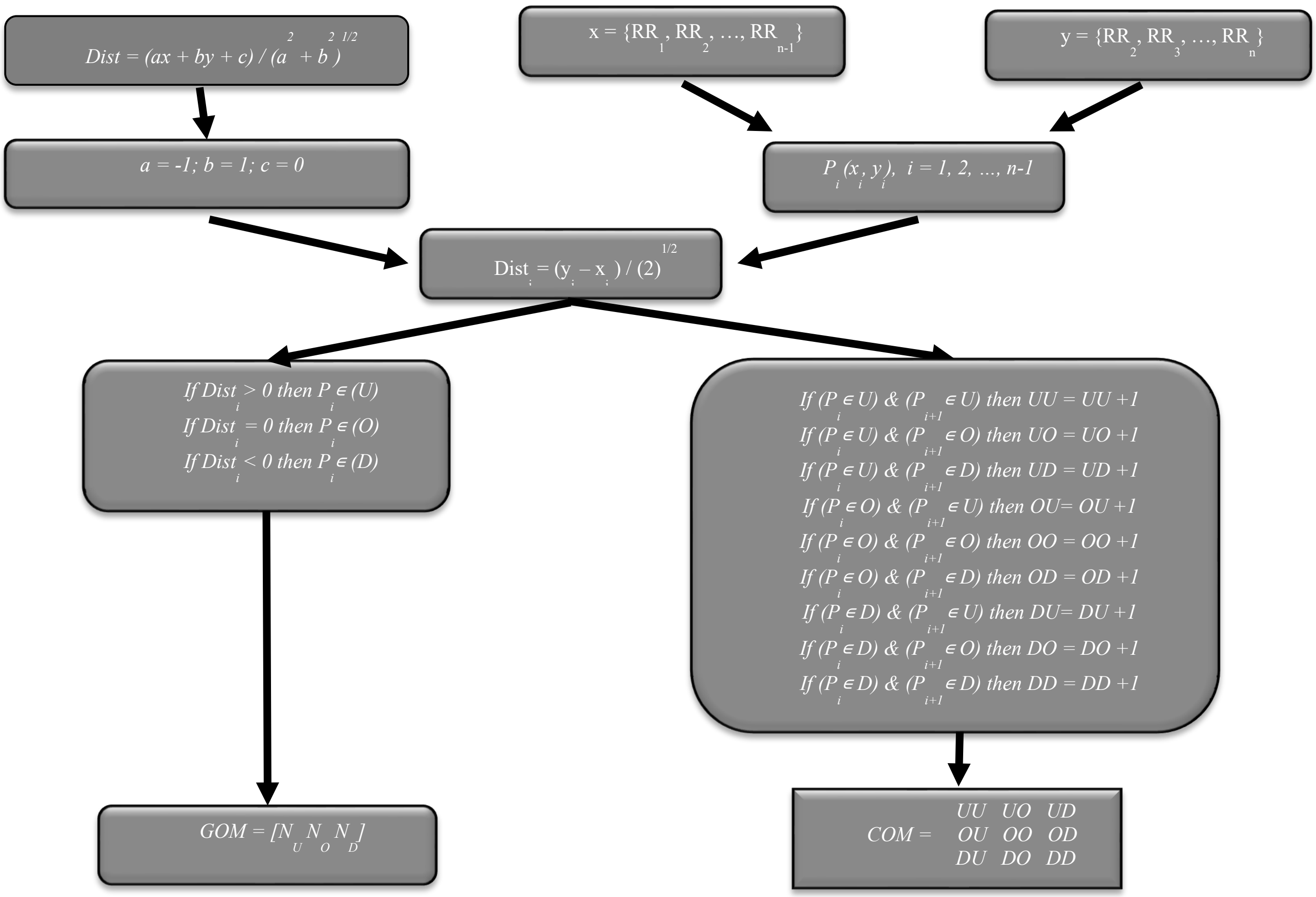

Figure 1. Definitions of extracted features (GOM: Global Occurrence Matrix and COM: Co-occurrence Matrix)

2. Poincare Plot of RR Intervals

Given a time series RR = {RR_1, RR_2, …, RR_n} the standard Poincare plot is constructed by locating points from the time series on the coordinate plane according to the pairing (x_i, y_i) in which,

$$x = \{x_1, x_2, \ldots, x_{n-1}\} = \{RR_1, RR_2, \ldots, RR_{n-1}\} \quad (1)$$

$$y = \{y_1, y_2, \ldots, y_{n-1}\} = \{RR_2, RR_3, \ldots, RR_n\} \quad (2)$$

and i = 1, 2, 3, …, n-1 and *n* is the length of the RR time series [6].

2.1. Global Occurrence Matrix (GOM)

Moharreri et al. evaluated the behavior of the point related to the identity line [7]. The identity line (y = x) in the Poincare plot has a simple physiological interpretation: the points on this line correspond to equal consecutive *RR* intervals, the points above it correspond to decreasing heart rate, and the points below this line to increasing heart rate [6, 8]. They defined two global and local analyses of points against the identity line. In the global method, *GOM*, they contemplate all points in the Poincare plot and count the number of points above, under, and on the identity line based on the point's distance to the line of identity [7]. The summary of algorithm is summarized in Figure 1.

2.2. Co-Occurrence Matrix (COM)

For Co-occurrence Matrix (COM) features, Moharreri et al. considered two following points P_i and P_{i+1}. Therefore the analysis corresponds to at least three consecutive RR intervals in the RR interval time series. [7]. So, in *COM*, nine different behaviors dependent on points' classes in relation to each other and line of identity had been counted that are explained in detail in [7, 9], Figure 1.

3. Data

Sixty subjects with high (n = 20), low (n=20) and normal (n = 20) blood pressure participated in the study. The lead II of Electrocardiogram was recorded for five minutes, and the systolic and diastolic blood pressure were recorded at the end of the experiment. PowerLab system (Model: ML4866) was used for data acquisition. The laboratory conditions (e.g., temperature and light) were kept fixed for all participants as far as possible. The mean temperature was about 24°C, and subjects were asked to close their eyes during data acquisition. A bandpass filter was used to remove power line interference, and a single-stage median filtering was used to eliminate baseline wander. After QRS detection, RR intervals were extracted for HRV analysis, and then the extracted features of the Poincare plot were used for analyzing and distinguishing three groups of blood pressure.

Based on the values of measured blood pressures, the subjects are classified into three classes as follows [10]:

- IF the systolic BP<90 & diastolic BP<60 THEN blood pressure is LOW.
- IF the 90<systolic BP< 120 & 60<diastolic BP<80 THEN blood pressure is NORMAL.
- IF the systolic BP>120 & diastolic BP>80 THEN blood pressure is HIGH.

4. Results

First, we have used statistical analysis to compare the results and evaluate the proposed parameters. Then we used K- Nearest Neighbor (KNN), Multi-Layer Perceptron (MLP), and Self Organizing Map (SOM) to classify these three groups by extracted features. All these stages are explained in the following.

4.1. Statistical analysis

Kruskal-Wallis test, a nonparametric version of the classical one-way ANOVA, has been used to identify features significantly different between groups. This test assumes that the measurements come from a continuous distribution but not necessarily a normal distribution. Statistical results for GOM and COM features are reported in Tables 1 and 2. For p<0.05, highlighted by '*' in Tables 1 and 2, COM and GOM differ significantly between groups.

Table 1. Kruskal-Wallis test for GOM features

GOM	**High & Normal**	**High & Low**	**Normal & Low**
U	<0.05*	<0.05*	<0.05*
O	0.205	<0.05*	0.395
D	<0.05*	<0.05*	0.736

Table 2. Kruskal-Wallis test for *COM* features

GOM	**High & Normal**	**High & Low**	**Normal & Low**
UU	0.191	<0.05*	0.108
UO	0.609	<0.05*	0.150
UD	<0.05*	<0.05*	0.102
OU	0.626	0.011*	0.035*
OO	0.014*	<0.05*	0.233
OD	0.064	0.041*	0.516
DU	<0.05*	<0.05*	0.213
DO	<0.05*	0.787	<0.05*
DD	<0.05*	<0.05*	0.594

4.2. Classification

Extracted features, *GOM* and *COM*, were used with KNN classifier, MLP, and SOM neural network for detecting the level of blood pressure. All the classifiers were trained on 70% of data as a train set, and performance was evaluated on 30% of data as a test set. For the KNN classifier, the parameter *K* was considered as three. The MLP Neural Network with two layers is used for classification. The first layer has twelve neurons as input features, the output layer has three neurons as three classes of blood pressure (Low, Normal, High), and the hidden layer has 50 neurons. The SOM network starts with 40 neurons. The results are shown in Table 3. The results show that the MLP neural network classifier has the best results compared to others.

Table 3. Classification results for detecting the level of blood pressure

	Accuracy	Sensitivity	Specificity
KNN	85	88	80
MLP	**91**	**90**	**93**
SOM	70	73	78

5. Discussion

In this article, the temporal behavior of RR interval points in the Poincare plot has been evaluated to detect three blood pressure levels (e.g., low, normal, and high). The results of utilizing the occurrence sequence of RR intervals and extracted features from it, GOM and COM, showed some physiological meanings of heart behavior in different blood pressure levels. For example, feature D (the number of points under the line of identity) increases in the high blood pressure group compared to the normal group, which means the heart rate is higher in this group. The results show that HRV is a good tool for detecting and classifying high, low, and normal blood pressure.

References

[1] Grassi G, Mark A, and Esler M The Sympathetic Nervous System Alterations in Human Hypertention. Circulation Research 2015; 116 976-990.

[2] Schroeder EB, Liao D, Chambless LE, Prineas RJ, Evans GW, and Heiss G Hypertension, Blood Pressure, and Heart Rate Variability. Hypertension 2003; 42(6) 1106-1111.

[3] Wnek G, and Bowlin G, *Encyclopedia of Biomaterials and Biomedical Engineering*: CRC Press, 2008.

[4] McCombie DB, Reisner AT, and Asada HH, Adaptive Blood Pressure Estimation from Wearable PPG Sensors Using Peripheral Artery Pulse Wave Velocity Measurements and Multi-Channel Blind Identification of Local Arterial Dynamics, in 28th Annual International Conference of the Engineering in Medicine and Biology Society (IEEE-EMBS), 2006, pp. 3521-3524.

[5] Mancia G, and Grassi G The Autonomic Nervous System And Hypertension. Circulation Research 2014; 114 1804-1814.

[6] Piskorski J, and Guzik P Geometry of The Poincaré Plot of RR Intervals and Its Asymmetry In Healthy Adults. Physiological measurement 2007; 28 (3):287.

[7] Moharreri S, Parvaneh S, Jafarnia Dabanloo N, and Nasrabadi AM, Utilizing Occurrence Sequence of Heart Rate's Phase Space Points In Order to Discriminate Heart Arrhythmia. 17th Iranian Conference of Biomedical Engineering (ICBME) 2010.

[8] Guzik P, Piskorski J, Krauze T, Wykretowicz A, and Wysocki H Heart Rate Asymmetry By Poincaré Plots of RR Intervals. Biomedizinische Technik 2006; 51 (4):272-275.

[9] Jafarnia Dabanloo N, Attarodi G, Moharreri S, Parvaneh S, and Nasrabadi AM, Emotion Recognition Based on Utilizing Occurrence Sequence of Heart Rate's Phase Space Points. pp. 52-55.

[10] Program NHBPE The Seventh Report of The Joint National Committee on Prevention, Detection, Evaluation, And Treatment of High Blood Pressure. 2004;

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