# HEART RATE VARIABILITY ANALYSIS USING POINCARÉ PLOT OF R-R INTERVALS

PHÂN TÍCH LOẠN NHỊP TIM SỬ DỤNG PHƯƠNG PHÁP POINCARÉ PLOT
PHÂN TÍCH CÁC KHOẢNG R-R

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**Abstract -** Heart rate variability (HRV) analysis attempts to assess cardiac autonomic regulation through quantification of sinus rhythm variability. The sinus rhythm times series is derived from the QRS to QRS (RR) interval sequence of the electrocardiogram (ECG), by extracting only normal sinus to normal sinus interbeat intervals. HRV refers to the beat-to-beat alterations in heart rate. HRV analysis is based on the concept that, fast fluctuations reflect the changes of sympathetic and vagal activity which results in variability of intervals between R waves i.e. "RR intervals". In the current work HRV was assessed by traditional linear time and frequency-domain indexes, in parallel with the non linear indexes. Both linear time and frequency domain parameters, and nonlinear parameters discriminate the different levels. Poincaré plot analysis is a promising method in statistical evaluation and arrhythmia cases.

**Key words -** heart rate variability;HRV; Poincaré plot; SD1/SD2 ratio; RR intervals.

**Tóm tắt -** Phân tích loạn nhịp tim (HRV) nhằm mục đích đánh giá sự tự điều chỉnh của tim thông qua việc định lượng biến đổi nhịp xoang. Chuỗi thời gian nhịp xoang là khoảng thời gian từ phức hợp QRS đến phức hợp QRS tiếp theo (khoảng RR) của điện tâm đồ (ECG), được xác định bằng cách chỉ lấy ra các khoảng nhịp xoang bình thường đến nhịp xoang bình thường của các nhịp liên tiếp. Phân tích loạn nhịp tim dựa trên khái niệm cho rằng những biến động nhanh chóng phản ánh những thay đổi của hoạt động của hệ thần kinh giao cảm - mê tẩu tạo ra những thay đổi về khoảng cách giữa các sóng R tức là "khoảng thời gian RR". Trong công trình nghiên cứu này, loạn nhịp tim được đánh giá bằng các chỉ số trong miền thời gian, tần số cũng như phi tuyến với nhiều đặc trưng khác nhau. Phương pháp phân tích Poincaré plot có nhiều hứa hẹn trong đánh giá và thống kê các trường hợp loạn nhịp tim.

**Từ khóa -** loạn nhịp tim; HRV; Poincaré plot; tỉ số SD1/SD2; khoảng thời gian RR.

## 1. Introduction

Electrocardiograms (ECGs) are used by medical professionals to monitor the heart of a patient. These devices usually operate with 12 leads connected to the patient's skin in a prescribed pattern. An ECG can be used to detect abnormal cardiovascular symptoms, measure heart rates (HR), and monitor heart diseases. The aim of this paper is to evaluate HRV signals using Poincaré plot analysis.

In the study of biomedical signals we are always searching for new methods of analysis. The most popular are linear methods, like Fourier transform, but in recent years we have observed increased interest in new, nonlinear methods, like eg. methods originating from chaos theory. In this paper we share the results of the application of an interesting and simple nonlinear method – Poincaré plot. The Poincaré plot of RR intervals is one of the techniques used in heart rate variability (HRV) analysis. It is both a useful visual tool which is capable of summarizing an entire RR time series derived from an electrocardiogram in one picture, and a quantitative technique which gives information on the long term HRV.

## 2. Methods

### *2.1. Data acquisition and signal processing*

This database includes beat annotation files for 20 long-term ECG recordings of subjects aged 34 to 79, with congestive heart failure (NYHA classes I, II, and III). Subjects included 8 men and 2 women; gender is not known for the remaining 9 subjects. Further details about the larger study group are available in the first reference cited above. A number of additional studies have made use of these recordings; see the additional references below.

The individual recordings are each about 23 hours in duration. The original ECG recordings (not available) were digitized at 128 samples per second, and the beat annotations were obtained by automated analysis with manual review and correction. The original analog recordings were made by Rochelle Goldsmith, at Columbia-Presbyterian Medical Center, New York.

### *2.2. Poincaré Plot Method*

Standard HR and its variability analysis have been performed in parallel to Poincaré plots of RR intervals during every testing condition and overall Poincaré plot. Minimal and maximal HR frequency, the difference between of them (ΔRRr) and total HR variability (ΔRRt) as a measure of reflex and tonic HR control, correspondingly, were measured. Correlation between of standard and new parameters was analyzed.

In HRV, an ECG recording is taken and processed to locate the times of the heartbeats. This is done by locating the R waves in the ECG recordings, as they are the largest deflection and the wave that is able to be most precisely located. The times between successive R waves, the so-called RR intervals, is the time series that is a result of this process.

The Poincaré plot is a scatter plot of the current R-R interval plotted against the preceding R-R interval. Poincaré plot analysis is a quantitative visual technique, whereby the shape of the plot is categorized into functional classes. The plot provides summary information as well as detailed beat-to-beat information on the behavior of the heart. Points above the line of identity indicate R-R intervals that are longer than the preceding R-R interval, and points below the line of identity indicate a shorter R-R interval than the previous. Accordingly, the dispersion of point's perpendicular to the line of identity (the "width") reflects the level of short-term variability. This dispersion can be quantified by the standard deviation of the distances the points lie from the line of identity. This measure is equivalent to the standard deviation of the successive differences of the R-R intervals [standard deviation of successive differences (SDSD) or root-mean-square of successive differences (RMSSD)] [1]. The standard deviation of points along the line of identity (the "length") reflects the standard deviation of the R-R intervals (SDRR)

Poincaré plots appear under different names in the literature: scatter plots, first return maps, and Lorenz plots being prominent terms. A distinct advantage of Poincaré plots is their ability to identify beat-to-beat cycles and patterns in data that are difficult to identify with spectral analysis [2], [3].

Considering the complex control systems of the heart it is reasonable to assume that nonlinear mechanisms are involved in the genesis of HRV.

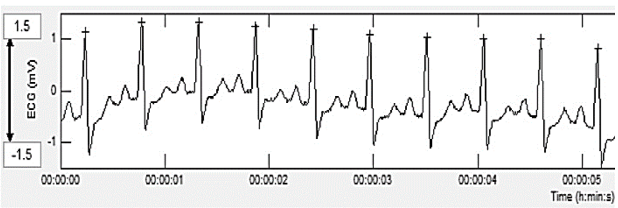


***Figure 1**. ECG signals*

The nonlinear properties of HRV have been analyzed using measures such as Poincaré plot [4], [5], approximates and sample entropy [6], [7], detrended fluctuation analysis [8], [9], correlation dimension, and recurrence plots. During the last years, the number of studies utilizing such methods has increased substantially. The downside of these methods is still, however, the difficulty of physiological interpretation of the results.

Poincaré plots are return maps in which each result of measurement is plotted as a function of a previous one. It is a simple and effective concept.

The idea is as follows:

Let us denote the data by: $x_0$, $x_1$, $x_2$, $x_3$, $x_4$, . . .. The return map will bea plot of the points ($x_0$, $x_1$), ($x_1$, $x_2$), ($x_2$, $x_3$), ($x_3$, $x_4$),....

A shape of the plot describes the evolution of the system and allows us to visualize the variability of time series $x_n$[10], [11].

There are standard descriptors used in quantifying Poincaré plot geometry, namely SD1 and SD2 [12], [13]. We can obtain them by fitting an ellipse to the plot shape (Figure 2). Descriptors SD1 and SD2 represent the minor and the major semi-axes of this fitted ellipse. A description of SD1 and SD2 in terms of linear statistics is shown in some research [4]. SD1 is the standard deviation of the distances of points from axis 1 and determines the width of the ellipse (short-term variability). Descriptors SD1 can be defined as:

$$SD1 = \frac{\sqrt{2}}{2} SD(x_n - x_{n+1}) \quad (1)$$

SD2 equals the standard deviations from axis 2 and length of the ellipse (long-term variability). Descriptors SD2 can be defined as:

$$SD2 = \sqrt{2SD(x_n)^2 - \frac{1}{2} SD(x_n - x_{n+1})^2} \quad (2)$$

where SD is a standard deviation of the time series.

The instantaneous beat-to-beat variability of the data was derived from SD1 index. Details of SD1 analysis were described previously. The SD1 index was plotted against work rate and the first intensity at which the SD1 index reached values equal to or lower than 3ms was defined as the HRV threshold. The mean HR of each stage was also calculated and plotted against work rate to estimate the HR at HRV threshold. The maximal work rate and maximal HR computed during the incremental tests were also compared in the pre- and post-training.

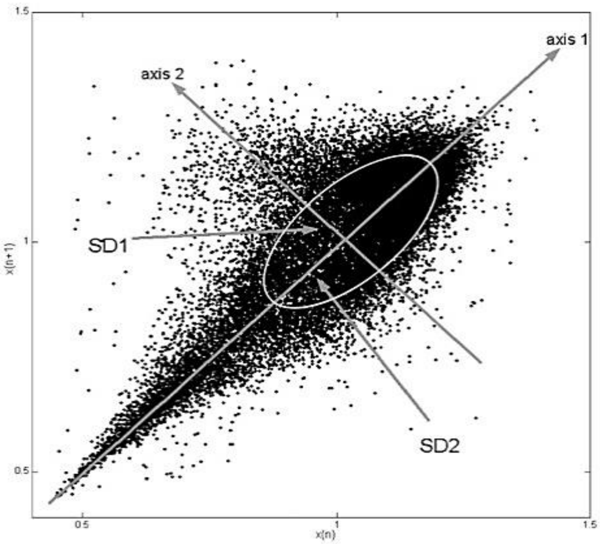


***Figure 2.** The idea of an ellipse fitted to the Poincaré plot and descriptors SD1and SD2.*

## 3. Results

All CHF signals were obtained from Physionet (Rochelle Goldsmith, of Columbia-Presbyterian Medical Center, New York; and Phyllis Stein, of Washington University School of Medicine, St. Louis). Its includes beat annotation files for 29 long-term ECG recordings of subjects aged 34 to 79, with congestive heart failure (NYHA classes I, II, and III). Subjects included 8 men and 2 women; gender is not known for the remaining 10 subjects. The Normal SinusRhythm database includes 18 long-term ECG recordings of subjects found to have had no significant arrhythmias; they include 5 men, aged 26 to 45, and 5 women, aged 20 to 50.

As mentioned above, R-R intervals were extensively studied by means of Poincaré plot, so we present only basic information about it. R-R intervals are the series of time intervals between the beats of heart [12].

There are interpretations of SD1 and SD2 in these kindsof studies. SD1 is an instantaneous beat-to-beat variability and SD2 acontinuous beat-to-beat variability [12], [13], [14]. The SD1/SD2 ratio represents the randomness in the heart rate variability time series.

RR-intervals and Poincaré plot are shown in Figure 3. Values of SD1, SD2 and their ratio for R-R intervals (normal sinus rhythm) are presented in Table I.

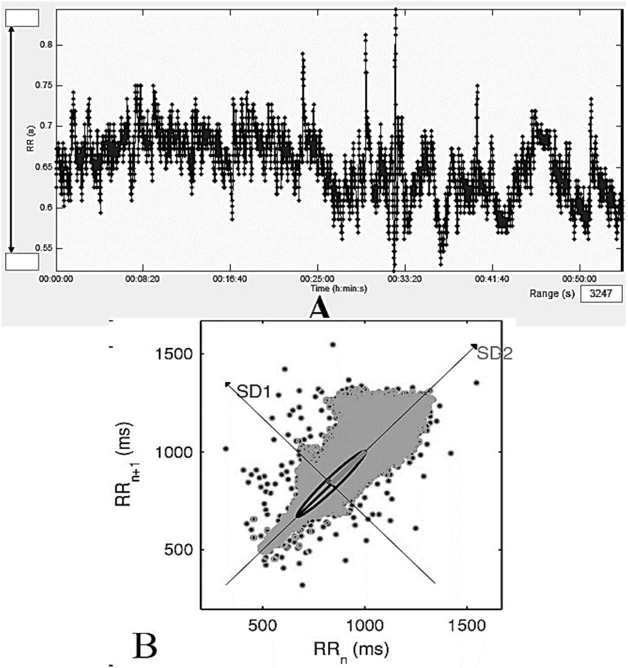


***Figure 3.*** *A) R-R intervals from a healthy subject (normal sinus rhythm) and B) Poincaré Plot.*

***Table I.*** *Values of descriptors SD1, SD2 and SD1/SD2 ratio for R-R intervals from 10 healthy subjects.*

| Subject | Poincaré Plot SD1 [ms] | Poincaré Plot SD2 [ms] | SD1/SD2 ratio |
|---|---|---|---|
| 1 | 37.1 | 238.8 | 0.16 |
| 2 | 41.1 | 184.7 | 0.22 |
| 3 | 23.3 | 243 | 0.10 |
| 4 | 79.6 | 319.1 | 0.25 |
| 5 | 29.8 | 235.5 | 0.13 |
| 6 | 44.4 | 262.5 | 0.17 |
| 7 | 97 | 256 | 0.38 |
| 8 | 30.8 | 217.3 | 0.14 |
| 9 | 57.4 | 214.7 | 0.27 |
| 10 | 32.2 | 167.6 | 0.19 |

Based on a review of the state of the art of software related to the HRT analysis [16], we motivate the development of this open source software platform which could be an interesting tool both for studying HRT or performing clinical experiments for research purposes. We present the results of the application of our package to two ECG databases from Physionet of patients suffering from healthy subjects and Congestive Heart Failure(CHF).

We performed a discriminated analysis using the SD1/SD2 ratio in order to distinguish between CHF subjects and healthy subjects. The SD1/SD2 ratio were compared against standard HRV indexes in a group of healthy subjects and in a group of CHF.

Figure 4 and figure 5 shows the results of calculation Poincaré plot parameters from CHF patients. By the SD1 and SD2 indexes, we calculate the SD1/SD2 ratio of CHF subjects for comparison with healthy subjects. The Poincaré Plot Scatter plotted base on SD1 and SD2 indexes of CHF subjects.

We can see the difference of SD1/SD2 ratio of healthy subjects and CHF subjects from Table I and Figure 5. The SD1/SD2 ratio of healthy people is usually smaller than 0.4, and the one of CHF is approximate from 0.8 – 1.0 (Figure 5)

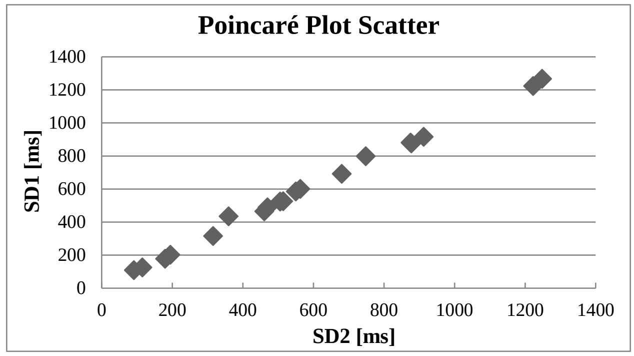


***Figure 4**. Scatter of Poincaré plot SD1 and SD2 of CHF subjects.*

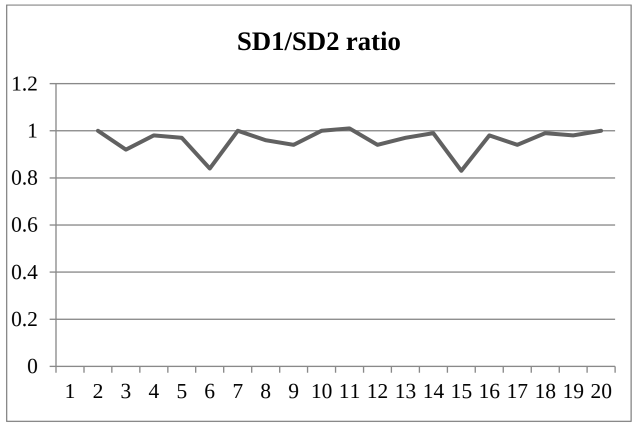


***Figure 5**. The Poincaré results of 20 CHF subjects.*

## 4. Disscussions

In a Poincaré plot due to complex dynamic behaviors, the SD1/SD2 statistics yield mixed results. In other studies, it was found to be effective in the assessment of both arrhythmia and CHF against normal sinus rhythm [11].In future, it may be used as an efficient tool for cardiovascular risk detection [11].

The magnitude of SD1 and SD2 values depend on the number of R-R intervals. Thus, if we have only SD1 or SD2 index is not enough to determine that the patient has heart problems.

The SD1/SD2 ratio of group of healthy people have similar low value and in the ranged of 0.1 to 0.4. The SD1/SD2 ratio of group of patients have similar higher value and in the ranged of 0.8 to 1.0. So we can based on the SD1/SD2 ratio for preliminary classification of persons at risk of HRV with healthy people, will be useful for screening patients.

The rate between SD1 and SD2 of the patients are linear correlated (Figure 4), the value of SD1 and SD2 indexes are not much disparity. Also with healthy people, Poincaré plot scatter is dispersed, the value of SD1 is very small compared to SD2 (Table I)

The studies performed to verify whether there is a correlation between SD1, SD2, and SD1/SD2 ratios and nonlinear indexes (e.g. Lyapunov Exponent, Correlation

Dimension, DFA method...) of heart rate variability either in cases of disease or in healthy conditions [10]. They claim that a high relationship with nonlinear indexes and low relationship with linear indexes suggests nonlinear fractal features.

## 5. Conclusions

The research about the geometry of Poincaré plot of RR intervals and redefined SD1 [13], which allowed them to define two new useful descriptors. They have shown that there is an asymmetry in the Poincaré plot and called it heart rate asymmetry. This paper is very interesting from a theoretical point of view.

Poincaré plot is a nonlinear method that can help us to analyze signals qualitatively and quantitatively. It reflects the variability of data. It seems that too low or too high SD1/SD2 ratio values are connected with illness, with respect to the biomedical signal. This requires further study. We hope that other signals, not only R-R intervals, will be investigated by means of Poincar´e plot. Through such investigation, a new interpretation of this method can emerge in biomedical signal studies.

The Poincaré plot is a promising technique of HRV analysis. It constructed from long-termECG recordings of RR intervals might be useful in the analysis of specific cases of HRV as atrial diagnostics, atrial flutter and other supraventricular dysrhythmias. It is so simple, that it can be used by anyone with a basic knowledge of computer.The current study is believed to serve a prelude to further studies involving evaluation of various cardiovascular risk.

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