Experimental Study of Heart Rate Variability by Wrist-Pulse Wave

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Abstract

In previous clinical diagnosis, heart rate variability (HRV) extraction was performed by electrocardiogram (ECG) signals. A HRV analysis system was designed to explore whether the Wrist-pulse wave can be used instead of ECG for heart rate variability analysis. The front end part of the system realized the synchronous acquisition of ECG signals and wrist pulse waves. The terminal PC extracted the pulse peak interval and the ECG signal interval sequence, and calculated the HRV time domain and frequency domain respectively nonlinear parameters.25 healthy adults were selected as experimental samples to calculate the HRV and PRV parameters extracted from the wrist PPG. The HRV results extracted by the traditional ECG were used as reference groups, and compared by mathematical statistics. It is result that the parameters of pNN50, HF and LF/HF in the HRV index obtained from the two sites were different, and there was no sufficient consistency. The other parameters could be substituted for each other.

Keywords

Wrist-pulse wave, Heart Rate Variability, Time and Frequency domain, Nonlinear.

1. Introduction

Heart Rate Variability (HRV) refers to the small fluctuations of tens of milliseconds between successive cardiac intervals [1], which can be regarded as the regulation of the sinus node rhythm by the autonomic nervous system. Experts and doctors believe that HRV is an important indicator of human health. As a sign of physiological flexibility and behavioral flexibility [1], in healthy individuals, the heart maintains a certain elasticity, which reflects our ability to adapt effectively to external stress and environmental requirements. ability. Electrocardiogram (ECG) extraction of HRV has been regarded as the gold standard in the field of clinical medicine [2]. The existing HRV detection method is through the ECG signal, and the measured patient needs to wear a holter monitor to record the heartbeat RR interval changes throughout the day, but many actions of the patient will be limited.

The PhotoPlethysmoGraphy (PPG) signal can reflect the blood flow changes in the blood vessels caused by the heart beat, and the continuous change of the same characteristic time point of the pulse waveform can be obtained to obtain the variability of the pulse signal period during the heart beat (Pulse Rate Variability, PRV) [3]. Since the various features of the PPG waveform correspond to the heartbeat cycle, the variability feature of the pulse signal cycle has the potential to be consistent with the heart rate variability feature. Studies at home and abroad have confirmed that fingertip PPG signals can be used in place of ECG for heart rate variability analysis[4]. Photoelectric volume pulse wave surgery can provide a non-invasive method to measure the heart beat interval of the human body. PPG signal acquisition is very simple, only a small optical sensor is needed to contact the skin surface. At least two viscous ECG electrodes are attached to the body compared to conventional HRV analysis, and PPG measurement techniques minimize the effects on the subject. If the HRV (PRV) can be extracted from the wrist pulse signal collected by a single point, the PPG signal is relatively high in signal-to-noise compared to the traditional ECG signal extraction method, and the acquisition process is simple and comfortable, and the anti-interference ability is stronger[5].

2. Experimental Methods And Objects

2.1 Experimental Equipment And Subjects

Figure 1 is a block diagram showing the overall structure of the system used in this experiment. The whole system consists of two parts: the ECG pulse integrated acquisition device and the upper computer analysis platform. The acquisition device is responsible for synchronous measurement of wrist pulse wave and ECG signals, physical data processing and transmission. One pulse wave is output by the port OUT1 of the green heart rate monitoring module SON1205. The digital pulse wave is obtained by the A/D sampling of the single chip microcomputer, and the ECG signal of another route ADS1292R is sent to the single chip microcomputer through the SPI interface. The STM32L151 is used as the core chip to control the ECG and pulse group frames to be sent to the host PC through the serial port. The terminal PC analysis platform uses MATLAB and statistical software to perform off-line analysis of PPG and ECG synchronization signals. The platform mainly implements data analysis, digital filtering, ECG R wave detection, pulse peak identification, HRV (PRV) time-frequency domain and nonlinear parameter calculation.

Twenty-five healthy adult volunteers (20 males and 5 females) were selected as the test. The average age was 24.3 years. Each subject remained in a relaxed sitting state. During the test, the limb movement was avoided as much as possible, and the sample was kept at 250 Hz. The rate was recorded for 5 min of PPG and ECG synchronization data. The system collects the pulse and ECG data of the sample through experiments and analyzes the characteristic parameters of HRV and PRV in time domain, frequency domain and nonlinearity through quantitative comparison.Use statistical calculation methods to explore a more accurate relationship between HRV and PRV indicators.

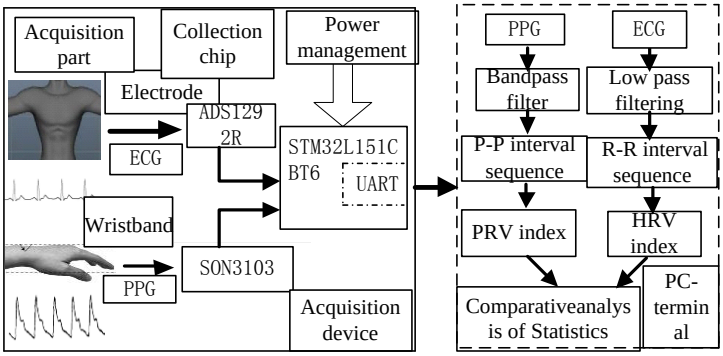
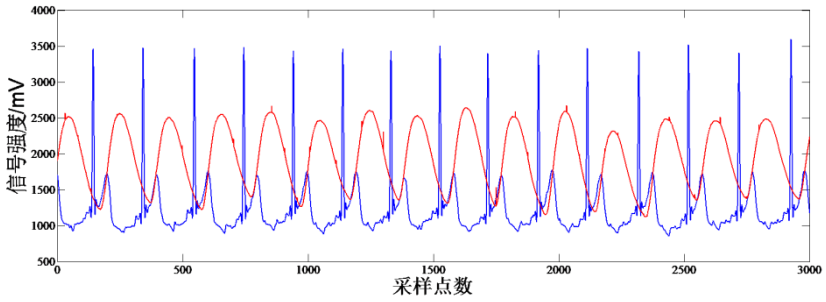


Figure.1 System block diagram

2.2 Data Acquisition And Preprocessing

After the program runs, initialize the clock, I/O port, external interrupt, ADC is set to continuous conversion mode, DMA channel is enabled to cycle mode, and the ADS1292R chip is configured. Firstly, the wrist pulse wave signal is output from the OUT1 port of the SON1205 sensor module as the single chip AD. The converted analog input signal, the ADC of the I/O port of the microcontroller always performs pulse data acquisition, and then the original pulse is moved to the memory by DMA, and the ECG signal is amplified by the ECG acquisition module and converted into digital by the AD. At the same time, a 4ms timer interrupt is turned on, and the data in the memory is read periodically during the interrupt, so that the pulse and the electrocardiogram are simultaneously sampled at a sampling rate of 250 Hz. The host computer received the original sign of 5 minutes with strong high frequency interference and other noise. After the ECG signal is low-pass filtered, the R-wave of the ECG signal can be located using a differential threshold algorithm to determine the R-R interval. The pulse wave interference of the wrist is small, and only the singular point can be removed. The peak point is located by using the pulse waveform point by point method to obtain the corresponding P-P interval. Figure 2 shows the ECG pulse synchronization signal. The HRV consists of a series of R-wave intervals between two QRS complexes in the ECG waveform. In the same way, the PRV signal can be obtained by using the peak time interval of two adjacent pulse waves to form a data set.



(Red Blue represent PPG ECG signal respectively)
Figure 2 ECG, PPG timing synchronization signal

2.3 HRV signal acquisition

There are usually two types of methods for HRV signals: interval spectra and count spectra. In this paper, the interval spectrum method is used to obtain the HRV signal. The experiment collects the 5 min ECG and pulse signals of the subject in the sitting state, selects the specific recognition algorithm to accurately detect the characteristic points of the original data, and sets the timing of the adjacent ECG R wave (pulse peak). Coordinates are used as the difference, and the interval between 5 minutes is taken to form the HRV (PRV) signal. Since the tester during the measurement process may generate interference waveforms due to weak motion of the instrument, there is an error in the extracted heartbeat interval values, which affects the final HRV–PRV comparison analysis result. Therefore, a preset threshold is needed to determine whether the RR (PP) interval sequence is within a preset range, thereby eliminating abnormal data [6]. The RR (PP) interval normally collected during the experiment should meet the following conditions:

$$AVE(RR)/1.2 < RR < AVE(RR) * 1.2 \quad (1)$$

AVE (RR) represents the average of all RR (PP) intervals, and RR is the instantaneous heartbeat interval. Figure 3 is the same sample.

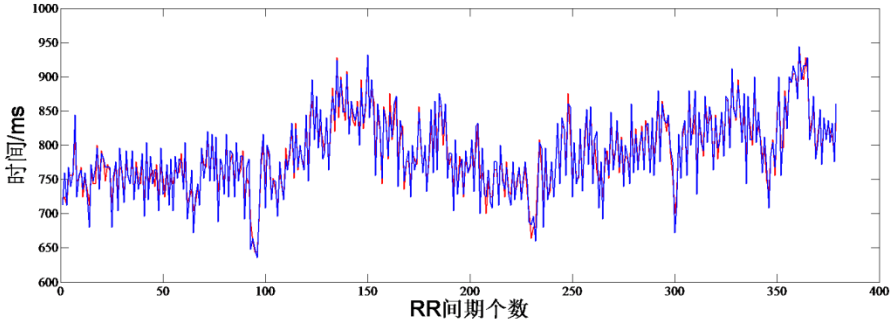


Figure 3.HRV (PRV) signal, blue red represent for HRV and PRV respectively

2.4 HRV signal analysis method

2.4.1 Time Domain Analysis

This experiment focuses on the resting and short-term measurement of the physiological activities of the heart. For consecutively recorded normal sinus beats, time-domain analysis was performed by chronologically arranging RR values. Including normal sinus RR interval mean RR, normal sinus rhythm RR interval standard deviation (SDRR) was used to assess the overall change of HRV, and the root mean square root (RMSSD) of consecutive adjacent normal RR intervals was used to reflect The fast-changing component in HRV, the difference between the adjacent RR intervals in all RR intervals is greater than 50ms, and the percentage of all RR intervals (pNN50). The parameters of each time domain parameter are as follows:

$$\overline{RR} = \frac{1}{N}\sum_{i=1}^{N} RR_i \quad (2)$$

$$SDRR = std(RR_i) \tag{3}$$

$$RMSSD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} DRR_i^2} \tag{4}$$

$$pNN50 = P(|DRR_i| > 50ms) \tag{5}$$

In the above formula, N represents the total number of heart beats in the RR interval, and RRi represents the i-th RR interval time, in units of ms. Where DRRi is the length of two adjacent sinus cardiac intervals, in ms.

2.4.2 Frequency Domain Analysis

Frequency domain analysis is to analyze the heart rate power spectrum in order to explore the speed and amplitude of heart rate variability. The frequency domain analysis method is to perform a fast Fourier transform (FFT) or an autoregressive parametric model (AR) operation on a relatively stable RR (PP) interval [7], and obtain the frequency (Hz) as the abscissa, the power spectrum. The power spectrum with density as the ordinate is analyzed. The study found that complex heart rate beat signals can be described according to different frequency bands, and the effects of various physiological factors can be separated and analyzed. The heart rate variability power spectrum of a normal person is generally 0 to 0.5 Hz, and the heart rate variability power spectrum is divided into the following three frequency bands:

Very low frequency band (VLF): 0.003 ~ 0.04 Hz, VLF reflects the heart rate change receptor temperature regulation.

$$VLF = \int_{0.003Hz}^{0.04Hz} f(\lambda)d(\lambda) \tag{6}$$

Where f(τ) is the power spectral density function

Low frequency band (LF): 0.04 to 0.15H, LF reflects the regulation of sympathetic nerves.

$$LF = \int_{0.04Hz}^{0.15Hz} f(\lambda)d(\lambda) \tag{7}$$

High frequency band (HF): 0.13 to 0.5 Hz, HF only reflects the regulation of the vagus nerve.

$$HF = \int_{0.15Hz}^{0.4Hz} f(\lambda)d(\lambda) \tag{8}$$

The LF/HF ratio reflects the equilibrium state of the autonomic nervous system.

2.5 Statistical principles and methods

Pearson's Correlation, also known as product-difference correlation, is a method of calculating linear correlation proposed by British statistician Pearson in the 20th century. The linear regression parameters of the two sets of sequences can be obtained through Pearson correlation coefficient calculation. But this method can not fully explain the linear relationship between the two variables when the data volume is small. There are obvious differences in HRV (PRV) parameters extracted from ECG and wrist-pulse wave.

We need to use a more precise and intuitive method to measure its consistency. In the experiment, Bland-Altman diagrams of some parameters are drawn by Medcalc software, and the consistency of time-frequency domain and non-linear parameters of HRV (PRV) is evaluated. The definition of Bland-Altman is as follows:

Bias (Bias) means the difference between the two calculation methods (HRV-PRV) represents the system error [8]. The standard deviation of bias (SD) represents random error or variability. Bias (+1.96SD) is used to evaluate the consistency of LOA: AL (acceptance limit) represents the mean of the two measurement methods. It is determined by the range of two parameters of the experimental test sequence and the reference sequence. BAR (Bland-Altman ratio) is defined as the ratio of SD to AL [9]. When 0 < BAR < 0.1, it shows that the two methods have good consistency. When 0.1 <

BAR < 0.2 is within the range, it shows that the two methods have general consistency. When the ratio of BAR > 0.2 is larger than the range, it shows that the two methods are not fully consistently.

3. Experimental results and discussion

3.1 Calculation results of HRV (PRV) parameters

Heart rate variability parameters (Mean + Std form) and Pearson correlation coefficients were calculated using statistical software SPSS19.0 for 5 min ECG and wrist PPG signals of 25 volunteers. The results are shown in Table 1. Bland_Altman analysis method is used to make more accurate and intuitive consistency analysis of HRV (PRV) results in time-frequency domain as shown in Table 2.

Table 1 25 volunteers comparison of HRV-PRV index analysis results

HRV Index	ECG	Wrist-PPG	Pearson
SDNN(ms)	50.84±12.95	52.68±11.35**	0.9462
pNN50(%)	0.23±0.15	0.28 ±0.16**	0.9264
RMSSD(ms)	47.90±14.93	51.79± 14.61**	0.9611
MEAN_RR(ms)	841.89± 65.10	843.48±62.58**	0.9543
TP(ms2)	1928.83±760.81	2077.17±797.76**	0.9666
LFP(ms2)	530.55±262.58	523.71±244.48**	0.8842
HFP(ms2)	413.18±312.84	530.36±347.20**	0.8219
LF/HF	2.05±1.42	1.51±1.13**	0.9685
VAI(angel)	1.12±0.07	1.10±0.06*	0.9365
HRD	0.060±0.017	0.062 ±0.015**	0.9664
HLE	5.24 ±0.45	5.12± 0.42**	0.9193

Notes: **p<0.01，*p<0.05.

Table 2 consistency of partial parameters of HRV-PRV

Index	Bias	linar.m	linar.b	SD	R2	Consistency limit		BAR
						Lower	upper	
MEAN_RR(ms)	-0.019	0.976	19.562	0.092	0.998	-4.54	5.56	0.009
SDNN(ms)	2.731	1.024	1.509	2.454	0.955	-7.54	2.08	0.092
pNN50(%)	5.50	0.940	6.946	6.240	0.854	-0.18	0.07	0.514
RMSSD(ms)	-4.291	0.957	6.341	4.090	0.923	-12.3	3.73	0.170
TP(ms2)	-148.3	1.014	122.259	204.77	0.934	-450.2	253.3	0.179
LFP(ms2)	6.499	0.967	28.492	122.91	0.947	-125.2	74.5	0.188
HFP(ms2)	114.37	0.915	149.141	191.78	0.827	-256.35	118.37	0.447
LF/HF	-0.537	0.773	-0.073	0.4303	0.876	-0.31	1.38	0.624

Notes: m, B are the coefficients of linear regression equation of HRV-PRV parameter index, m is the slope of fitting regression equation, B is the intercept, R^2 is the determinant of regression linear model, and BAR ratio can be quantified by consistency analysis results.

The scatter plot and regression curve are drawn by calculating HRV parameter index as abscissa and PRV index as longitudinal coordinate. Fig 4,5,6,7 are scatter plots and regression curves of SDDN,pNN50,HFP,LF/HF respectively. Combining with the parameters in Table 2, it is found that the parameters of heart rate variability and pulse rate variability are generally consistent, but some parameters are not fully consistent. The BAR values of pN50, HF and LF/HF are 51.4%, 44.7% and 62.4%, respectively. It shows that the two measurement methods lead to the inconsistency of the three sets of indicators, and this parameters can not be substituted for each other in the study. The reason for this may be that the high-frequency components of PRV signal are affected by human spontaneous or regulatory respiration. One solution is to use the direct linear transformation method or to consider the effect of respiratory rhythm, which can minimize the standard errors of the two calculation variability parameters.

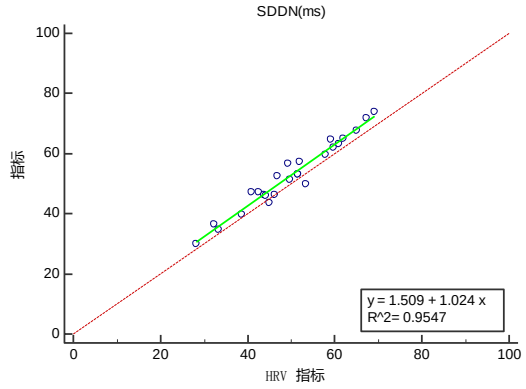


Fig. 4 SDDN linear regression curve

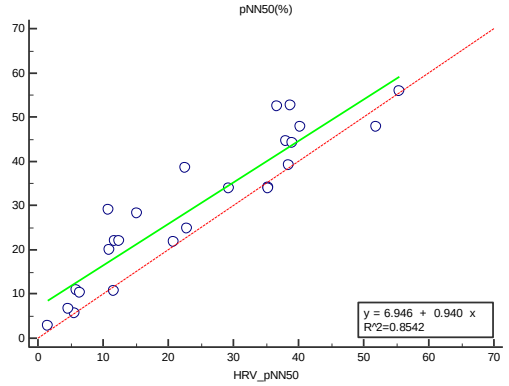


Fig. 5 pNN50 linear regression curve

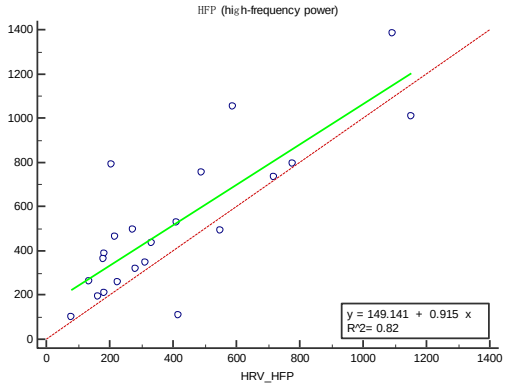


Fig. 6 HFP linear regression curve

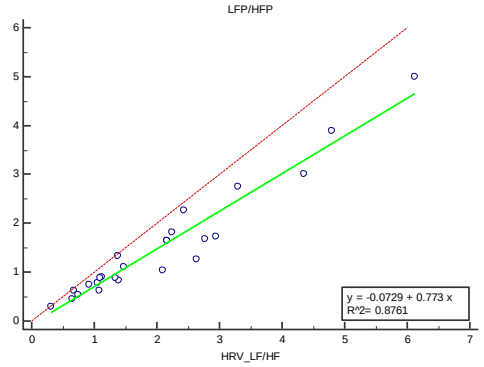


Fig. 7 LFP/HFP linear regression curve

4. Prospects

The experiment explores that some parameters of pulse rate variability can replace heart rate variability to objectively evaluate autonomic nervous system function, and also provides theoretical basis for the application of pulse rate variability analysis in intelligent wrist watch and wrist rings and other devices to analyze HRV. Real-time monitoring of HRV parameters can be achieved through wireless connection of wearable devices and mobile terminals, which can facilitate rapid assessment of cardiovascular diseases. Future research directions may turn to the comparison of parameters of pulse rate variability and heart rate variability under high pressure and anxiety.

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