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Research on Blood Pressure Measurement Method Based on Oscillographic Method

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Abstract

Blood pressure is an important parameter reflecting human physiological condition. A portable wrist electronic blood pressure measurement system was designed by using STM32F103RCT6 and MP3V5050GP pressure sensor. Variable amplitude coefficient method is used to determine blood pressure, which overcomes the disadvantage of poor individual adaptability of single amplitude coefficient method. The blood pressure signal is obtained by software filtering method, and the static pressure curve is more close to the linear deflation through the peak value fitting method. The peak value of the whole pulse wave is determined by Gauss fitting curve, which makes the calculation result more accurate by the variable amplitude coefficient method based on the amplitude of oscillating pulse wave. Compared with the standard auscultation method, the average error of this method is within 5mmHg, which conforms to ANSI / AAMI / ISO standard.

Keywords

Blood pressure measurement, band pass filter, Gaussian fitting, pulse wave.

1. Introduction

Blood pressure refers to the pressure that the blood is pumped into the blood vessel when the heart contracts, and it is an important physiological index reflecting human health [1]. The normal range of systolic pressure (SP) and diastolic pressure (DP) were 90-140mmHg and 60-90mmHg respectively. The specific values were related to gender, age and other factors. Blood pressure measurement methods are generally divided into invasive and noninvasive measurement. Invasive pressure measurement method is used in human arterial blood vessels, adding blood pressure sensor, although the measurement is accurate, but the measurement conditions are complex, causing certain trauma to the human body, which is generally used under special conditions [2-3]. In the noninvasive pressure measurement method, some auxiliary sensors are added to the measurement part to collect the physiological signals of the corresponding parts and carry out the algorithm processing and analysis. Finally, the blood pressure value can be calculated. This method is non-invasive and portable, and the deviation of measurement results is within several mmHg, which is widely used at present.

2. Organization of principle

2.1. Measuring principle

The oscillogram is also called vibration method [4]. Its basic principle is to use air pump, solenoid valve, cuff and pressure sensor to form a closed measuring system to air the cuff, thus blocking blood flow in the artery of wrist or arm. In the process of deflation or inflation, the cuff pressure also fluctuates due to the weak vibration of the pulse. The signal of the oscillating pulse can be collected by pressure sensor. According to clinical medical experiments and theories,

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these collected wave signals have functional relationship with systolic and diastolic pressure, so blood pressure can be calculated [5-6]. There are two ways to collect, the deflation mode and the inflation mode. In this paper, the pulse wave signal is collected by the inflatable method. The specific steps are as follows: put on the cuff on the wrist and sit still, keep the arm level with the heart, and collect the blood pressure signal during the process of slowly inflating the air pump (about 5 ~ 10mmHg/s).

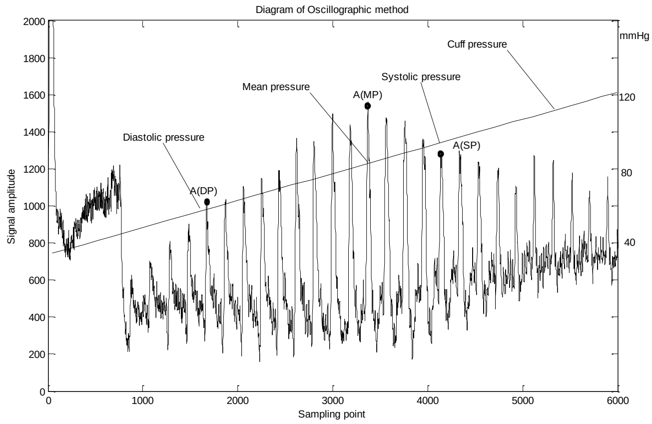

Fig. 1 The schematic diagram of oscillographic method

At this time, there is only weak oscillation signal in the cuff. When the pressure in cuff is close to the amplitude of diastolic pressure oscillation, the amplitude is the largest when it is close to the average pressure. As the pressure in the cuff increases, the amplitude of oscillation decreases gradually. When the amplitude is close to the contraction pressure, the amplitude decreases obviously, and then it is weak signal, as shown in Fig.1. After inflation of about 180 mmHg, the arterial blood flow was blocked and the solenoid valve was opened to complete the signal acquisition.

2.2. Selection of blood pressure criterion

Waveform characteristic method and amplitude coefficient method are commonly used in Oscillographic method. Characteristic method is according to the blood pressure value will appear oscillation pulse amplitude value big change. Because there are many interference factors in actual measurement, the selection of characteristic inflection point of feature method often has large deviation, which affects the fitting of envelope line, and has poor adaptability, which is gradually replaced by other methods [7].

The amplitude coefficient method is to determine the blood pressure value according to the proportional relationship between the corresponding pressure value (average blood pressure value) at the maximum amplitude of oscillatory pulse wave and systolic and diastolic blood pressure [8]. As shown in Figure 1, let the value at the largest amplitude of oscillation wave be A(MP), A (SP) at systolic blood pressure, and A (DP) at diastolic pressure, then the proportional relationship is as follows.

$$\mathrm{A(SP)}/\mathrm{A(MP)} = K1, \quad \mathrm{A(DP)}/\mathrm{A(MP)} = K2 \tag{1}$$

The range of K1 value is generally 0.40 ~ 0.75, and K2 value is generally 0.45 ~ 0.90. The systolic and diastolic blood pressure can be calculated according to the relationship between the maximum amplitude of oscillatory pulse wave and the proportional coefficient. Combining the sampling frequency and the number of peaks, the pulse rate is calculated [9].

The amplitude coefficient method is simple and practical, but can't adapt to individual changes [10]. The results show that the normalized coefficients of oscillatory waves at systolic and diastolic blood pressure change with the change of mean pressure [11]. The variable amplitude coefficient method selects different values of normalization coefficient K1 and K2 according to different mean pressure, which has strong individual adaptability. In this paper, the method of

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variable amplitude coefficient is used to measure human blood pressure. The experimental results show that the average error between the two methods is less than 5mmHg.

Table 1: Normalization coefficient table

MP range (mmHg)	normalization coefficient (SP) K1	MP range (mmHg)	normalization coefficient (DP) K2
120~135	0.52	120~140	0.85
110~120	0.57	60~120	0.78
70~110	0.58	50~60	0.60
Less than 70	0.64	Less than 50	0.50

3. Design of system

3.1. Overall design of system circuit

The overall circuit diagram of the hardware is shown in Figure 2. The main modules include power supply module, blood pressure signal control module, algorithm processing module, display module and storage module.

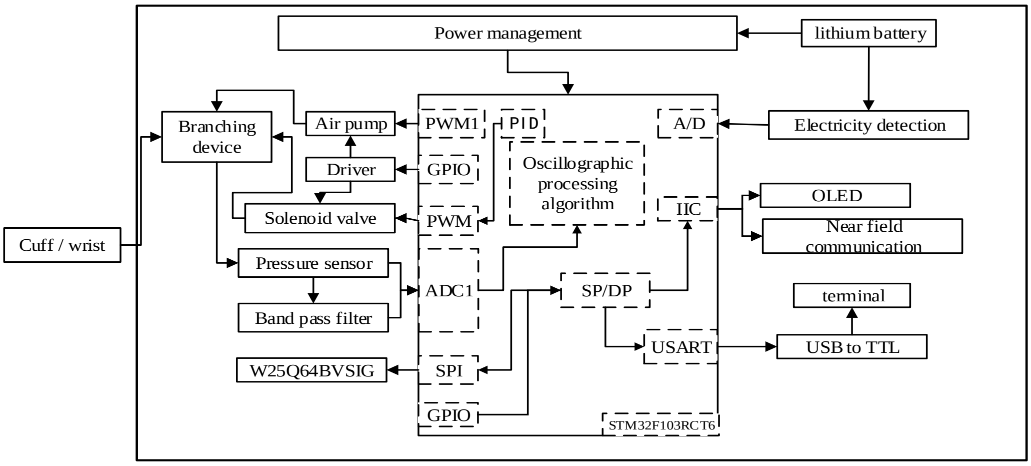

Fig.2 overall circuit diagram of blood pressure system

The power management module is mainly responsible for the power supply of the whole system. The A / D conversion is used to detect the power of lithium battery and send out the signal whether to charge the battery. The blood pressure signal control part is mainly composed of air pump, cuff, solenoid valve, pressure sensor and driving circuit. This is to form a closed circuit, which can realize the control of charging and discharging. The STM32F103RCT6 is selected as the main control chip to complete the logic control and algorithm processing of the whole system. Data is transmitted to OLED screen by IIC protocol, such as systolic blood pressure, diastolic blood pressure, heart rate, etc. In the storage part, serial flash is controlled by SPI protocol to expand the memory of the system and save the data.

3.2. Signal acquisition process

The collection part is composed of air pump, solenoid valve, branching device, cuff and pressure sensor to complete the inflation or deflation of cuff. DQB030-A air pump is selected in this design, the power is 0.6W, and the tightness is less than 3mmHg/min, which can meet the demand of blood pressure measurement. DQF1-3A solenoid valve is selected, and its working pressure range is 0 ~ 350mmhg. It takes less than 3 s to deflate from 300 mmHg to 15 mmHg, and the venting speed can meet the demand of venting. Because the physiological signals of human body are low-frequency small signals, the signal-to-noise ratio is low. MP3V5050GP pressure sensor is selected in this paper, which has signal operational amplifier and adjustment function, and can be compensated on chip. The pressure value of 0 ~ 375mmhg is directly converted into 0.06 ~ 2.82V electrical signal, which matches the design requirements of electronic sphygmomanometer.

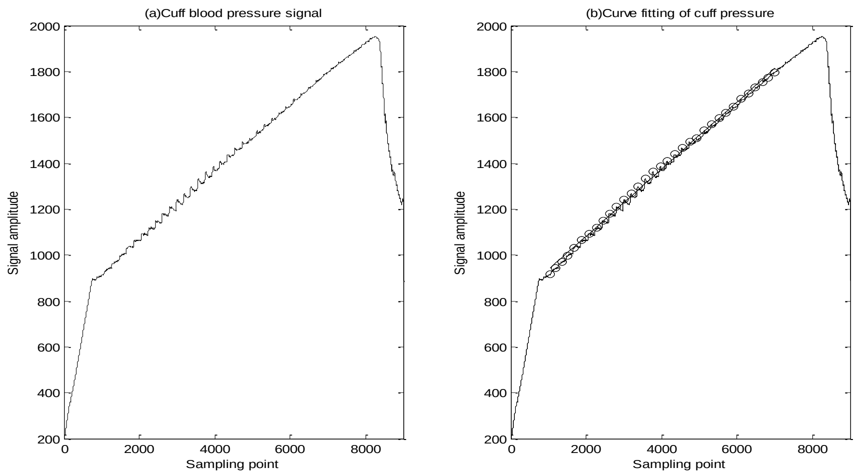

Fig.3 Mixed signal and cuff fitting signal

In the pressurization stage, the solenoid valve is closed, the air pump is controlled by 100Hz PWM wave, and the duty cycle is controlled between 20% and 26%, so as to realize constant pressure at 5 ~ 10mmHg/s. The analog-to-digital conversion of the pressure sensor and processor completes the data acquisition, and the acquisition frequency is 250Hz. The mixed signal is collected as shown in Fig.3 (a). In the decompression stage, the solenoid valve is opened to realize rapid deflation.

3.3. Cuff pressure curve fitting

The PWM wave is used to control the solenoid valve to realize the uniform linear deflation of the system. Due to electromagnetic interference, wrist jitter, incomplete separation of pulse wave and static pressure and other factors, the cuff pressure signal collected in the process of deflation also has a weak fluctuation. The nonlinearity of cuff static pressure will lead to large error in the calculation of air pressure value. In order to reduce the computing load of MCU, the least multiplication is chosen for linear fitting. The principle of least square linear fitting is as follows.

Let's suppose the linear expression y = A + Bx. Let n groups of data, the difference between the peak data (x_i, y_i) and the straight line y is di, so that (d_{12} + d_{22} +...+ d_{n2}) is the minimum. That is to say, the method of finding the best value A and B is called the least square method. The values of A and B are shown below.

$$A = \bar{y} - B\bar{x}, \quad B = \frac{\overline{xy} - \bar{x}\,\bar{y}}{\overline{x^2} - \bar{x}^2} \tag{2}$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i; \quad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i; \overline{x^2} = \frac{1}{n}\sum_{i=1}^{n} x_i^2; \overline{xy} = \frac{1}{n}\sum_{i=1}^{n} x_i y_i \tag{3}$$

Combining the values of A and B, the fitting curve can be obtained as shown in Fig.3 (b).

3.4. Mixed signal separation and signal noise processing

The pressure signal is the absolute pressure that the air pump adds to the cuff. When the air pressure in the cuff is reduced to a certain degree, it also contains the vibration pressure of the artery. The pressure caused by pulse vibration is far less than the absolute pressure of the whole cuff, as shown in Fig. 3 mixed signal. The vibration signal can be ignored when extracting the cuff pressure signal. It is the key to separate blood pressure signal from the mixed signal. Considering the high frequency interference, the static pressure signal is equivalent to the DC signal, the processing speed of single chip microcomputer and the pulse wave frequency of human body are generally around several hertz. The digital band-pass filter simulated by software is selected. The formulas of low-pass filter and high-pass filter are as follows.

$$V_{01}(k) = aV_i(k) + (1-a)V_{01}(k-1), (a = \frac{t}{R_1C_1}, f_l = \frac{a}{2\pi t}) \tag{4}$$

$$V_{02}(k) = (V_{01}(k) - V_{01}(k-1) + V_{02}(k-1))b, b = R_2C_2 / R_2C_2 + T_2 \tag{5}$$

The static pressure signal of the cuff can be obtained by passing the mixed signal through a 10 Hz low-pass filter. Because the pressure signal of air pump is equivalent to DC signal, the frequency of human pulse wave is generally between 1 ~ 10Hz. After verification, it can pass through the 0.8Hz high pass filter, and the sampling rate FS is 250Hz, where a is 0.0252 and b is 0.975. After removing the baseline drift, the signal figure is shown in Fig. 4.

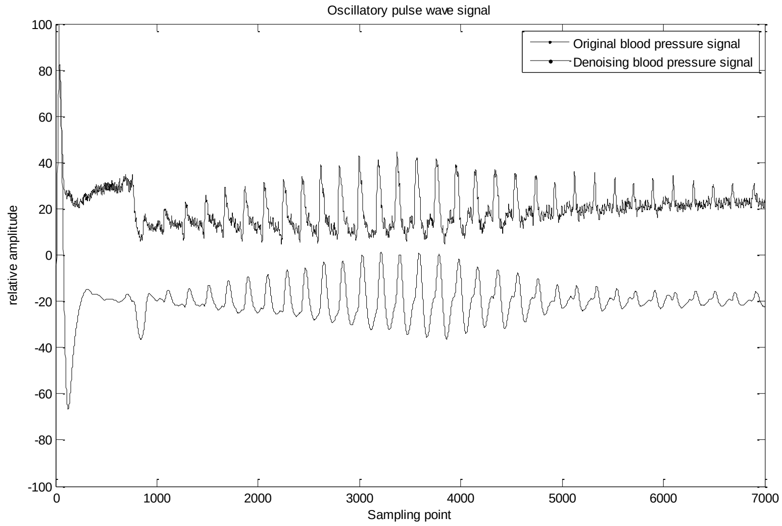

Fig. 4 Oscillatory pulse wave signal

3.5. Envelope fitting of oscillatory pulse wave

In order to find a suitable fitting algorithm for the peak of oscillatory pulse wave, polynomial fitting and Gaussian fitting are carried out and compared.

Polynomial fitting, because the overall envelope is similar to the shape of quadratic function, quadratic polynomial fitting is used. The fitting function is $y = ax^2 + bx + c$, and the fitting curve is shown in Fig. 5 (a).

The results show that the overall amplitude of standard oscillatory pulse wave presents a certain normal distribution, and the peak distribution is more uniform. Let the modified peak group data be (x_i, y (x_i)), and the length of the whole set of data is n, as shown in the fitting formula.

$$y(x_i) = A \times \exp(-\frac{(x_i - u)^2}{(2\times\sigma^2)}),\ i = 1, 2, \cdots, N,\ A = \exp(\frac{-a_1^2}{4\times a_2 + a_0});\ u = \frac{-b_1}{2\times b_2};\ \sigma = \sqrt{\frac{-1}{b_2}} \tag{6}$$

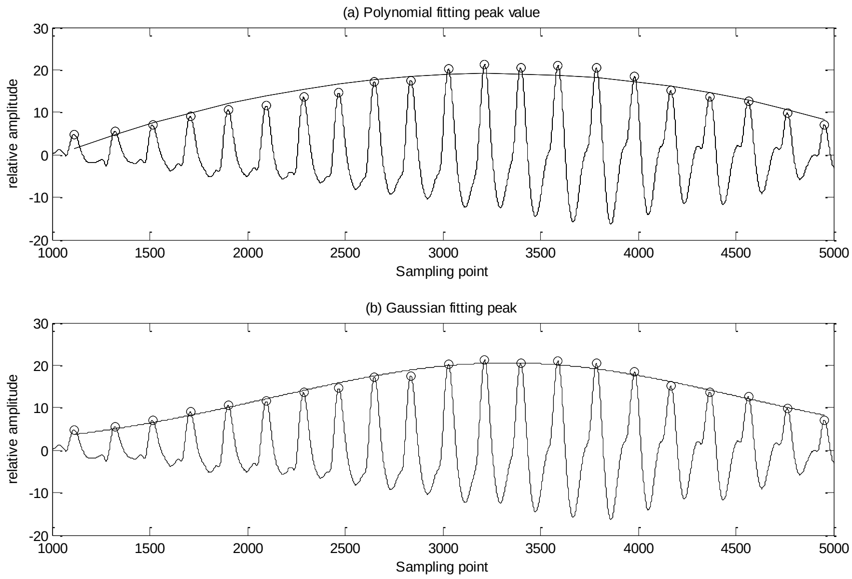

Fig.5 Ftting comparison curve

Table 2 : Error analysis of fitting curve

Fitting curve	SSE	R-square	RMSE
Polynomial fitting	0.8939	0.9227	0.1646
Gaussian fitting	0.0545	0.9731	0.0426

Through calculation and comparison, the envelope curve is fitted in Fig. 5, and the fitting error analysis results are shown in Table 2. It can be seen from the table that the Gaussian fitting function is closest to the actual distribution of oscillatory pulse wave. In this paper, Gaussian fitting peak curve is selected.

3.6. Blood pressure calculation

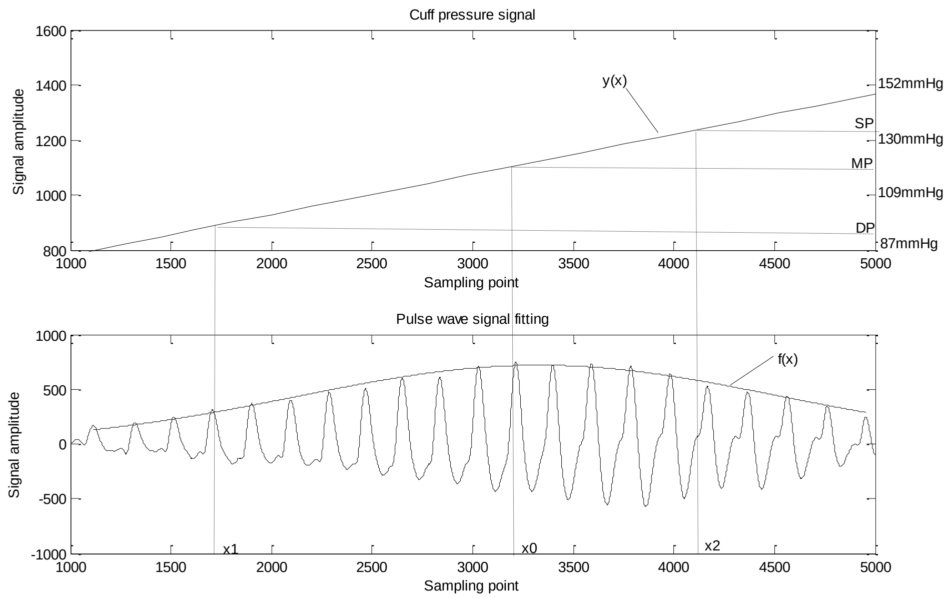

Fig.6 Schematic diagram of blood pressure calculation

The peak envelope curve f (x) was obtained by Gaussian fitting the peak value of pulse wave. Linear fitting y (x) of cuff static pressure curve. The effect picture is shown in Figure 11. The maximum value point x0 is determined by the maximum value of Gauss fitting curve f (x). The

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corresponding point of x0 is the average pressure MP, as shown in the figure. According to the variable amplitude coefficient method, the calculation formula of systolic and diastolic blood pressure is determined as shown in the formula.

$$y(x1)=k1y(x0),\begin{cases}k1=0.52,120<y(x0)\theta<135\\k1=0.57,110<y(x0)\theta<120\\k1=0.58,70<y(x0)\theta<110\\k1=0.64,y(x0)\theta<70\end{cases},\quad y(x2)=k2y(x0),\begin{cases}k2=0.85,120<y(x0)\theta<140\\k2=0.78,60<y(x0)\theta<120\\k2=0.60,50<y(x0)\theta<60\\k2=0.50,y(x0)\theta<50\end{cases}\tag{7}$$

Where θ is the conversion coefficient between the pressure sensor data collected by the processor and the air pressure value. In this paper, MP3V5050GP air pressure sensor and ADC1 acquisition of STM32F103RCT6 are selected. The coefficient is 0.10949. The systolic blood pressure and diastolic blood pressure can be obtained by calculating the function values of the corresponding points of x1 and x2.

4. Experimental results

After debugging the hardware of physical system and MATLAB successfully, the stored data are processed and calculated. Blood pressure measurement parameters are shown in Table 3. According to the table, the maximum monitoring error of systolic and diastolic blood pressure is 4.8 mmHg, and the standard deviation is 2.5 mmHg. According to AAMI / ISO standard [12], it can meet the requirements of clinical use.

Table 3 : Systolic / diastolic blood pressure error measurement results

Test	Systolic/diastolic blood pressure error value (mmHg)										Error mean	Standard deviation
	1	2	3	4	5	6	7	8	9	10		
A	5/4	3/4	6/3	7/2	4/5	3/6	2/7	6/2	6/5	3/5	4.5/4.3	1.7/1.6
B	1/6	7/0	8/4	5/2	6/4	2/3	4/5	6/2	4/1	5/7	4.8/3.4	2.2/2.2
C	5/2	5/4	3/3	2/3	4/5	6/1	1/1	7/2	8/6	2/4	4.3/3.1	2.3/1.7
D	5/4	7/5	6/3	2/4	5/6	8/4	3/5	2/4	3/1	1/2	4.2/3.8	2.3/1.5
E	2/1	6/3	3/4	1/3	1/0	6/2	6/2	8/6	5/8	6/3	4.4/3.2	2.5/2.3
F	4/5	6/8	1/2	1/3	4/4	4/3	3/1	4/6	2/2	6/5	3.5/3.9	1.8/2.1
G	3/1	2/4	3/0	7/6	4/4	8/6	1/4	5/3	6/5	3/4	4.2/3.7	2.2/1.9
H	3/4	7/5	3/1	2/1	5/1	4/5	3/4	6/2	8/9	5/4	4.6/3.6	2.0/2.5
I	5/3	3/6	6/8	4/3	2/3	6/2	3/7	5/7	6/3	4/1	4.4/4.3	1.4/2.5
J	6/5	4/5	3/3	5/3	8/6	6/3	3/5	4/5	4/0	3/2	4.6/3.7	1.7/1.8

5. Conclusion

In the whole design of blood pressure measurement system with variable amplitude coefficient method, it is particularly important to select the signal acquisition, interference processing and blood pressure determination method. These factors will directly affect the accuracy of blood pressure. This paper introduces the hardware and software design of wrist blood pressure measurement system. The innovation and improvement of this paper have the following two parts: 1) the static pressure curve is fitted by the peak point, which makes the static pressure line closer to the linear deflation. 2) The baseline drift of the peak value is processed to effectively prevent the influence of hand shaking and motor interference in the measurement process. It makes the calculation results of variable amplitude coefficient method based on

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average pressure amplitude more accurate. In the general study of electronic sphygmomanometer, this method has feasibility and practical value in engineering.

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