RESEARCH ARTICLE OPEN ACCESS

Research on blood oxygen and heart rate detection algorithm based on infrared detection

Dong-Jie Yang*, Bo Yang**
*(College of Information Science and Engineering, Hunan Normal University, China）
** (College of Information Science and Engineering, Hunan Normal University, China)
Corresponding Author: Bo Yang

ABSTRACT
Blood oxygenation and heart rate detection based on infrared detection technology is one of the basic technologies of modern wearable devices and medical monitoring. In order to obtain fast and accurate blood oxygen and heart rate, this paper studies the algorithm for acquiring heart rate and blood oxygen. First, the pulse wave signal is collected based on hardware and software design. The pulse wave is then converted to a bipolar signal by a time domain method and a frequency domain method. The spectrum of the pulse wave is obtained by moving average filtering and fast Fourier transform. Finally, real-time heart rate and blood oxygen data are calculated based on the spectral waveform data. The experimental results show that the algorithm studied in this paper runs very well, and both methods can obtain actual heart rate and blood oxygen data.
Keywords - blood oxygen,fast Fourier transform,heart rate,infrared technology,pulse wave signal

---

Date Of Submission: 25-07-2019 Date Of Acceptance: 06-08-2019

I. INTRODUCTION

With the continuous development of human society, people are more and more concerned about their own health. When there is something wrong with the body, many large medical devices[1] are inconvenient and expensive, so people cannot timely detect their own health. In addition, heart rate and blood oxygen, as two important physiological parameter indicators of the human body, play an important role in human life and health. By obtaining physiological parameters such as heart rate[2], blood oxygen[3], respiratory rate, blood pressure, blood sugar, etc., people can assess their health status. Once the abnormality is found, they can seek medical advice and adjust their living habits in a timely manner, and away from cardiovascular and cerebrovascular diseases.

For patients, wearing a portable device with the above-mentioned physiological parameters can facilitate the patient to observe the condition in real time, and when an abnormal situation such as sudden cardiac arrest or sudden rise, sleep apnea, etc. occurs, the patient's family can also be alerted to save lives in time. The real-time monitoring of heart rate and blood oxygen signal data can facilitate timely treatment in the early stage of the disease, reduce the incidence of various diseases, and provide an important guarantee for our life and health[4].

Heart rate refers to the number of beats of the heart in each unit of time. Generally speaking, it refers to the speed of heartbeat in a certain period of time. It is an important physiological parameter that describes the function of the heart. SpO2 refers to the ratio of oxyhemoglobin in the human blood to all hemoglobin binding. It is closely related to human respiratory activity and is an important physiological parameter to describe whether the respiratory and circulatory system is normal or not.

The contents of each part of the paper are as follows. Firstly, a systematic description of the research background and significance is given. Then, the basic principle of measuring heart rate and blood oxygen by pulse wave labeling method, and the operation steps of how to obtain the signal are introduced, then use the time domain method and the frequency domain method to calculate the digital signal processing of heart rate, and the formula derivation and final value of blood oxygen. Finally, it summarizes the research results and shortcomings, and points out the further research from which aspects can make the algorithm of this paper more accurate and generality.

II. PRINCIPLE AND METHOD

The Lambert-Beer law is the basic law of spectrophotometry. It describes the relationship between the intensity of light absorption at a certain wavelength and the concentration of light absorbing material and the thickness of its liquid layer[5].Its formula is as follows: $I = I_0 * \mathrm{e}^{-kcd}$ (1)

c is the concentration of the substance,k is the absorption coefficient,d is the thickness.

According to lambert-beal's law, the PPG signal reflects a periodic body rhythm. By calculating the number of cycles of PPG signals over a period of time, you can calculate the heart rate over that period of time. So that's how you calculate the heart rate from the time domain of the PPG signal.

Another way to calculate heart rate is by spectrum analysis. The AC component of the PPG signal is caused by the flow of blood through the arteries, while the DC component is caused by other tissues, skin, and bones.The frequency point with the largest amplitude in the range of 0.7 to 5 Hz represents the maximum AC component caused by blood flow.Assuming this frequency is f, then the heart rate is 60*f, its unit is bpm.

According to Lambert-Beer's law and the theory of spectral diffusion theory, we can get a description of the behavior of light in human tissue.

$$I = I_0 * E * e^{-(\varepsilon_1 c_1 d + \varepsilon_2 c_2 d)} \quad (2)$$

I_0 represents the incident light intensity, E represents the attenuation coefficient of other tissues, ε_1 and ε_2 represent the absorption coefficients of HbO2 and Hb, respectively, c_1 and c_2 represent the concentrations of HbO2 and Hb, and d is the optical path.

$$I_{\max} = I_{AD} + I_{DC} = I_{DC} e^{-(\varepsilon_1 c_1 + \varepsilon_2 c_2)\Delta d} \quad (3)$$

Taking the natural logarithm on both sides. After calculation, we can get the following formula.

$$\frac{I_{AC}^{\lambda_1} / I_{DC}^{\lambda_1}}{I_{AC}^{\lambda_2} / I_{DC}^{\lambda_2}} = \frac{\varepsilon_1^{\lambda_1} c_1 + \varepsilon_2^{\lambda_1} c_2}{\varepsilon_1^{\lambda_2} c_1 + \varepsilon_2^{\lambda_2} c_2} \quad (4)$$

The formula for

$$SpO2 = \frac{C[HbO2]}{C[HbO2] + C[Hb]} \times 100\%$$

blood oxygen is as follows.
(5)

Using formula (4) and (5), the following can be

$$SpO2 = \left(\frac{\varepsilon_2^{\lambda_2}}{\varepsilon_1^{\lambda_1} - \varepsilon_2^{\lambda_1}} \times \frac{I_{AC}^{\lambda_2} / I_{DC}^{\lambda_1}}{I_{AC}^{\lambda_2} / I_{DC}^{\lambda_2}} - \frac{\varepsilon_2^{\lambda_1}}{\varepsilon_1^{\lambda_2} - \varepsilon_2^{\lambda_2}} \right) \times 100\%$$

deduced[6].
(6)

Usually, we write it like this.

$$SpO2 = (A * R - B) \times 100\% \quad (7)$$

The main chips used for signal acquisition include STM32 and heart rate blood oxygen sensor[7].First, designing schematic diagram, then processing the schematic diagram in the factory, finally getting the circuit board. Inputting and debugging the corresponding program, then we can do the experiment.

When a person's finger is close to the sensor, the light emitted by the 660 nm red LED and the 880 nm infrared LED is incident on the skin and the blood in the tissues and blood vessels under the skin, and the red and infrared light is reflected and irradiated onto the photodiode. After the analog to digital converter, the current magnitude is quantified. After being digitally filtered, the acquired samples are stored in the FIFO. Finally, the external MCU can acquire this data through I2C bus communication.

III. RESULTS AND DISCUSSION

After receiving the sampling data of the red LED and the infrared LED in the serial port, the data is plotted to obtain the Fig.1 and Fig.2.

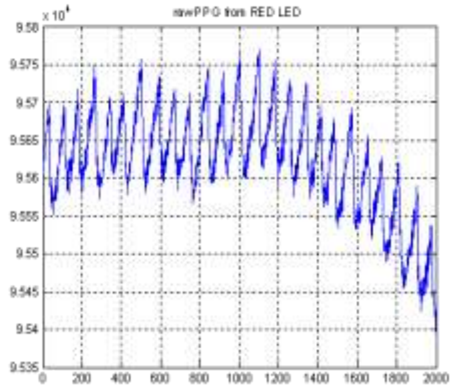

Figure. 1. Red light PPG signal diagram

Fig.3 shows the signal to be converted from a unipolar signal to a bipolar signal in order to reduce its DC component to observe subsequent noise reduction effects.

The filtering method used in this paper is the moving average filtering[8]. The current signal value is itself and the following three signal values, that is,

the arithmetic mean of a total of four quantities, and the last three signal values remain unchanged.

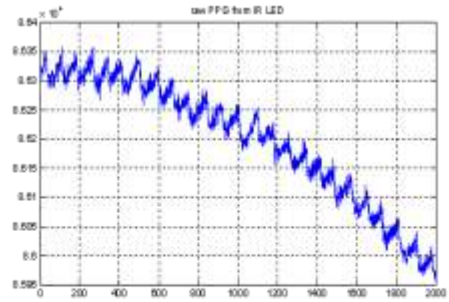

Figure. 2. Infrared light PPG signal diagram

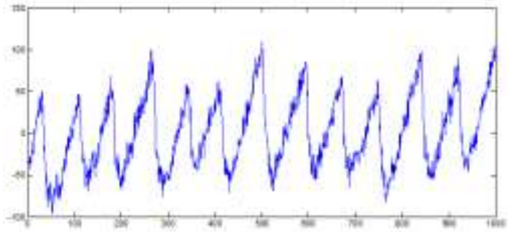

Figure. 3. PPG signal diagram after reducing DC component

Fig.4 shows the filtered signal. According to the figure, after filtering, the PPG signal removes the glitch and becomes smoother.

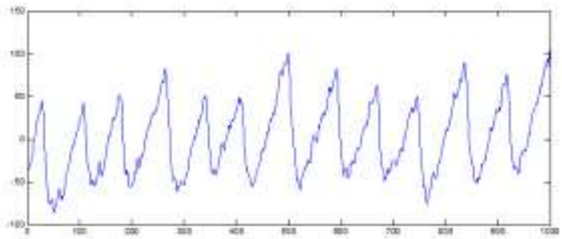

Figure. 4. Bipolar PPG signal after moving average filtering

In order to determine that a certain maximum value is the correct feature point of the PPG signal, it is necessary to have an in-depth understanding of the shape and cause of the pulse wave.

The main morphological features of a single pulse wave are as follows: at the maximum is a peak, after the peak, the signal amplitude drops rapidly to the trough, during which a large amount of blood flows from the heart to the blood vessel. The blood volume in the blood vessels increases rapidly, so the total amount of blood absorbed by the light signal also increases rapidly, resulting in a rapid decrease in the intensity of the received light signal[9].

For the above characteristics of the pulse wave, statistical analysis was performed on the pulse wave with 11 complete cycles in Fig. 3. And the obtained data is shown in Table 1.

Table.1

Pulse wave characteristic analysis

Serial number	Rising length before feature point	Falling length after feature point
1	5	8
2	4	11
3	5	15
4	2	13
5	1	12
6	3	18
7	7	14
8	9	11
9	1	12
10	1	12
11	1	14

All of the feature points can be successfully found using the above criteria, but due to the unstable condition during the rapid bloodletting of the heart, errors may occur when the amplitude of the individual points rises.

In order to eliminate the misjudgment point, the following method is also needed in the above criterion: assuming that a point satisfies the above-mentioned determination condition, then starting from this point, if it drops 7 bits continuously, this point is the wrong characteristic point. Otherwise, it is the correct feature point.

Fig.5 and Fig.6 show the graphs before and after eliminating the error feature points.

And then we can calculate the heart rate.The formula of heart rate is as follows.

$$Heart\ rate = \frac{N * F_s * 60}{d} bpm \quad (8)$$

Fs is Sampling frequency.

The first feature point number is 28,and the last feature point number is 1975,which is 1946 points apart. There are 24 complete pulse cycles between the first feature point and the last feature point. The sampling frequency of the PPG signal is 100 Hz.

So the heart rate during this time is as follows.60*24*100/1946=74bpm.

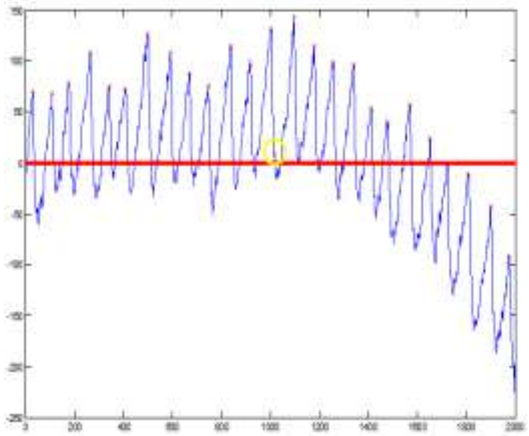

Figure. 5. Error feature points

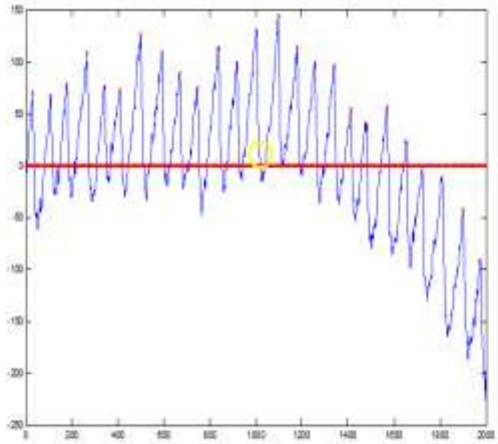

Figure. 6. Correct feature point

Discrete Fourier transform is a mathematical transformation that can map finite-length discrete sequences into its finite-length discrete frequency domain. Fig.7 and Fig.8 shows the conversion of PPG sequences from 2000 samples into a spectrogram.

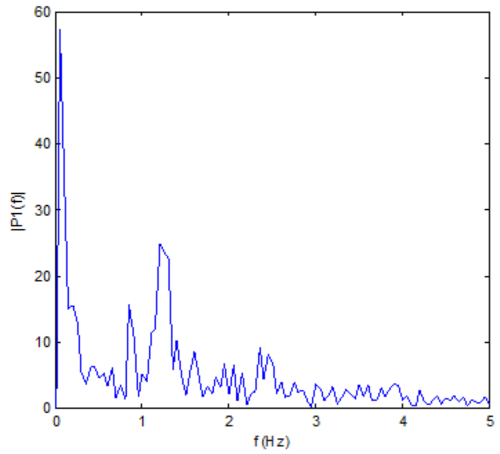

Figure. 7. Spectrum diagram of PPG signal

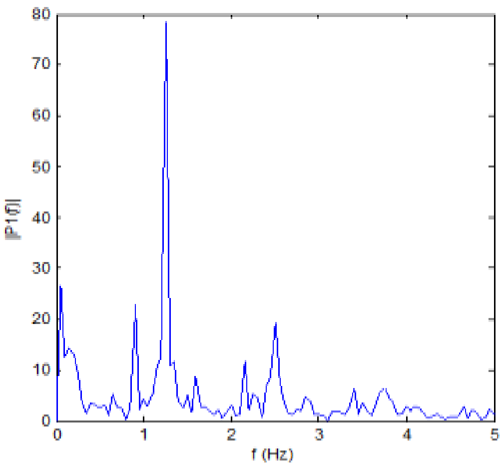

Figure. 8. Spectrum diagram of PPG signal

As can be seen from the spectrum, in the range of 0.7~5Hz, the maximum amplitude is found at frequency 1.2Hz in Fig.7 and 1.25Hz in Fig.8.So the heart rate is as follows.

1.2HZ*60s=72bpm.1.25HZ*60s=75bpm

Table 2 shows the four heart rates of the PPG signal with a length of 2000 points in the time and frequency domains. During the test time, the heart rate of the test subject was measured at about 75 bpm, which was in good agreement with the data in the table below. It can be seen that both the time domain method and the frequency domain method are effective methods for measuring heart rate.

Table.2

Heart rate data

Serial number	Time domain method(bpm)	Frequency domain method(bpm)
1	76	74
2	73	76
3	74	75
4	75	75

First, R was calculated according to the signal waveform of red and infrared light, and then blood oxygen was collected according to the standard detection instrument. Then, according to the data obtained by the experiment, the data is fitted by the linear regression equation, and finally ,the data of A and B were obtained[10].

Fig.9 shows a set of red and infrared light PPG signal. Through calculation, we can get the following data.

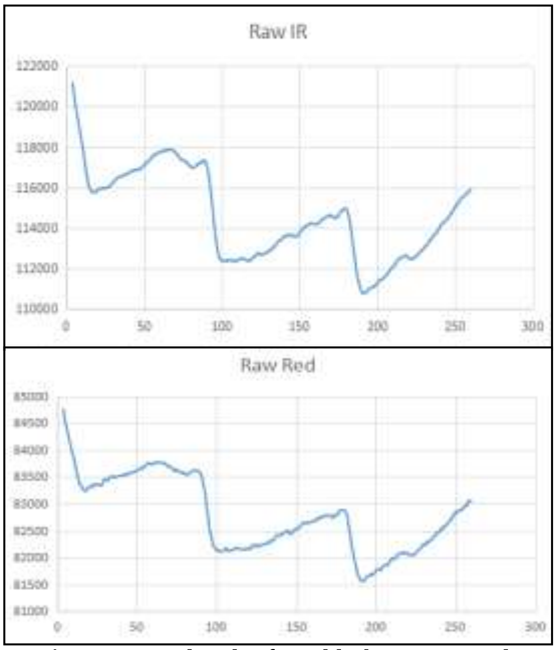

Figure. 9. Red and infrared light PPG signals

$$R = \frac{\frac{1154.07}{81735.93}}{\frac{3714.514}{111208.486}} = \frac{0.014119}{0.033401} = 0.4227$$

The blood oxygen data at this time is 97.2%.In the experiment, we tested four different age groups, and the test results are shown in Table 3 and Table 4 and Table 5 and Table 6.

Table.3
Test data for R and SPO2

	Serial number	R	SpO2(%)
childhood	1	0.5908	94.8
	2	0.5736	95.5
	3	0.4482	96.0
	4	0.5678	95.3
	5	0.5749	95.1
	6	0.5972	94.3
	7	0.5845	94.8
	8	0.5453	95.8
	9	0.4775	96.1

The formula for obtaining blood oxygen by fitting data is as follows.SpO2=-9.962R+100.8.

Table.4
Test data for R and SPO2

	Serial number	R	SpO2(%)
youth	1	0.5730	94.8
	2	0.5683	95.1
	3	0.4365	97.1
	4	0.5432	95.8
	5	0.4736	96.8
	6	0.5159	96.3
	7	0.4649	97.0
	8	0.5569	95.1
	9	0.5532	95.3

The formula for obtaining blood oxygen by fitting data is as follows.SpO2=-17.37R+105.

Table.5
Test data for R and SPO2

	Serial number	R	SpO2(%)
Middle aged	1	0.5185	96.8
	2	0.5588	96.1
	3	0.5625	95.8
	4	0.5418	96.3
	5	0.5649	95.3
	6	0.4329	97.1
	7	0.4722	97.1
	8	0.6519	94.8
	9	0.6326	95.1

The formula for obtaining blood oxygen by fitting data is as follows.SpO2=-11.7R+102.5.

Table.6
Test data for R and SPO2

	Serial number	R	SpO2(%)
elderly	1	0.4729	95.2
	2	0.4695	95.8
	3	0.5266	95.3
	4	0.5673	94.8
	5	0.6650	94.3
	6	0.4480	96.1
	7	0.4569	96.0
	8	0.5333	94.8
	9	0.6232	94.5

The formula for obtaining blood oxygen by fitting data is as follows.SpO2=-7.861R+99.36.
Averaging four sets of data and get the final formula as follows.SpO2=-11.7R+102.

IV. CONCLUSIONS

In this paper, the two methods of time domain method and frequency domain method are used to measure heart rate. The time domain method designs the algorithm for locating feature points by analyzing the characteristics of individual pulse wave signals. The definition of the feature point was corrected after the wrong feature point was found. The frequency domain method is less affected by the motion artifacts of the PPG locality, and the heart rate can be calculated as long as the frequency point with the largest amplitude in the spectrum is found.

It can be seen from the experimental results that the heart rate and blood oxygen data are ideal, indicating that the research algorithm is suitable for the research of this thesis. Of course, the tester is not extensive, and gender, age, skin color, race, environment and other factors will lead to data deviation, but after repeated calculations, these errors are within the scope of the experiment, it can be said that this research can be achieved the needs of the people. In the experiment, more data sources should be selected to ensure more accurate algorithm.The experimental results are also very good, this algorithm can contribute to the wearable heart rate and blood oxygen equipment[11].

REFERENCES

[1]. Dr. Shantanu K. Dixit, Miss. Ashwini A. JoshiA Review Paper on Design of GPS and GSM Based Intelligent Ambulance Monitoring.International Journal of Engineering Research and Applications(IJERA)ISSN:2248-9622,Vol.4,Issue 7,PP101-103, July 2014.

[2]. Dogan A , Tunc E , Varol E , et al. Comparison of the four formulas of adjusting QT interval for the heart rate in the middle-aged healthy Turkish

men.[J]. Ann Noninvasive Electrocardiol, 2015, 10(2):134-141.

[3]. K. Navya , Dr. M. B. R. Murthy.A Zigbee Based Patient Health Monitoring System.International Journal of Engineering Research and Applications (IJERA)Vol.3,Issue 5,PP483-486,Sep-Oct 2013.

[4]. Li H , Xu Y , Li X , et al. Epidermal Inorganic Optoelectronics for Blood Oxygen Measurement[J]. Advanced Healthcare Materials, 2017:1601013.

[5]. H. -X. Zhang, Zhu Y S, Wang Z M. Complexity measure and complexity rate information based detection of ventricular tachycardia and fibrillation[J]. Medical & Biological Engineering & Computing, 2000, 38(5):553-557.

[6]. Teng X F, Zhang Y T. Blood Oxygen Saturation Measurements[M]// Wiley Encyclopedia of Biomedical Engineering. 2006.

[7]. Rajeshwari S, Arpitha P, Meghana P,Sushmitha C:Android Based Body Temperature, Heart Beat and Drouse Sensor Monitoring Using and SMS Based Telemedicine System.International Journal of Engineering Research and Applications(IJERA)ISSN:2248-9622,Vol.7, Issue 5,PP75-78, May 2017.

[8]. SUBRAMANIAN H,IBEY B L,X U W J,et al .Real-time separation of perfusion and oxygenation signals for an implantable sensor using adaptive filtering[J].IEEE Transactions onBiomedical Engineering,2005,52(12):2016-2023.

[9]. Swamy TN, Rashmi KM.Data Acquisition system based on FPGA.International Journal of Engineering Research and Applications (IJERA)ISSN:2248-9622,Vol.3,Issue 2, pp. 1504-1509,March -April 2013.

[10]. Yan YS ,Zhang YT ,A model-based artifact reduction method for thenon-invasive estimation of blood oxygen saturation[C] ,IEEE/EMBS International Summer School on Medical Devices and Biosensors (ISSS -MD),2004:90-92.

[11]. P. V. Rama Raju.Smart health monitoring system using internet of things (IoT).International Journal ofEngineeringResearchandApplications(IJERA)ISSN:2248-9622,Vol. 9,Issue 3, pp. 73-77,March 2019.

Bo Yang" Research on blood oxygen and heart rate detection algorithm based on infrared detection" International Journal of Engineering Research and Applications (IJERA), Vol. 09, No.08, 2019, pp. 33-38