A PPG-based Wireless Sensor System Design for Portable Medical Monitoring

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ABSTRACT

Based on the serious threat of cardiovascular diseases to human beings nowadays, the traditional blood pressure and blood oxygen measurement methods are relatively complex and poorly portable. To solve this problem, this paper is devoted to the study of a portable wireless sensor system for medical monitoring based on PPG. This system is based on photoplethysmographic (PPG) to collect human pulse wave signals, using photoelectric sensor MAX30101 to collect human pulse wave signals. The microcontroller STM32 is embedded and programmed using Keil uVision5 platform to find the heart rate and blood oxygen parameters, and the heart rate-blood pressure model is used to find the blood pressure parameters based on the Queensland Vital Signs dataset. Bluetooth module is used to communicate the device with the mobile phone to transmit the human health parameters to the mobile app in real time. This scheme can provide some reference value for the health parameter monitoring devices used in daily life..

KEYWORDS

PPG; Wireless sensor; Blood pressure; Blood oxygen; Heart rate

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1 Introduction

(1) Research background and significance

Cardiovascular disease (CVD) has always been the leading cause of death for both urban and rural residents in China. According to the China Cardiovascular Health and Disease Report 2022 published by the Chinese Journal of Circulation, CVD accounted for 45.86% of human deaths in 2020 [1]. In 2023, human beings have entered the era of coexistence with COVID-19. A study by Zuyi Yuan et al. at the First Affiliated Hospital of Xi'an Jiaotong University showed that SARS-CoV-2 viruses damage and attack the vascular system from the cellular level [2].The 2013 ESH/ESC Guidelines for Arterial Management recommend that patients with hypertension should have their heart rate and oximetry measured at the same time as their blood pressure [3].

The prevalence and specificity of cardiovascular diseases pose difficulties for real-time monitoring. Nowadays, the application of wireless sensor technology in the medical field proposes a solution in this field, which becomes the trend of future medical development. As wireless sensor technology continues to mature, its advantages such as low power consumption, low cost, and strong anti-interference ability are increasingly favoured by various industries. Many problems in the medical field will be solved creatively.

(2) Current status of research at national and international level

Currently scholars have conducted much research in the field of healthcare monitoring system. Foreign scholars Hajer Abed et al. proposed a new design of wearable smart T-shirt which used sensor to monitor respiratory profile and thus determine the health status of human body and provides additional results for different tests on male and female subjects [4]. However, the system was costly. Mohsin Alabassby et al. used the open source hardware platforms Arduino to design a healthcare monitoring system using electrode pads to capture heart rate and body temperature [5]. It reduces the cost of the system, but the portability is not enough. In China, the Bio-Circuits and Systems Laboratory at Shanghai Jiaotong University has proposed the adoption of PPG for continuous measurement of blood pressure using a finger-clip sensor [6]. The complexity of the system was reduced, but the portability needs to be further improved.

It can be seen that the main problems of current civilian medical monitoring systems are high manufacturing costs and poor portability. In recent years, scholars have started to use PPG to measure human health parameters, and PPG has attracted much attention because of its low cost of equipment, smaller size of equipment and more comfortable to wear.

(3) Research content and innovations

This paper is based on the PPG to collect the human pulse wave signal through the photoelectric sensor, through the signal processing such as filtering the signal, the use of microcontrollers for embedded programming to find the blood oxygen heart rate, and then through the heart rate of blood pressure modelling, and then complete the design of the system. Dedicated to improving the problem that most of the existing monitoring equipment is expensive and not very portable, to design an inexpensive and portable non-invasive wireless sensor system for medical monitoring. Finally this paper shows an outlook on its use in wireless sensors.

2 System Design

(1) System design process

The system performs the necessary pre-processing of the PPG signal in order to capture the required PPG signal. The flow of the system design is as follows:

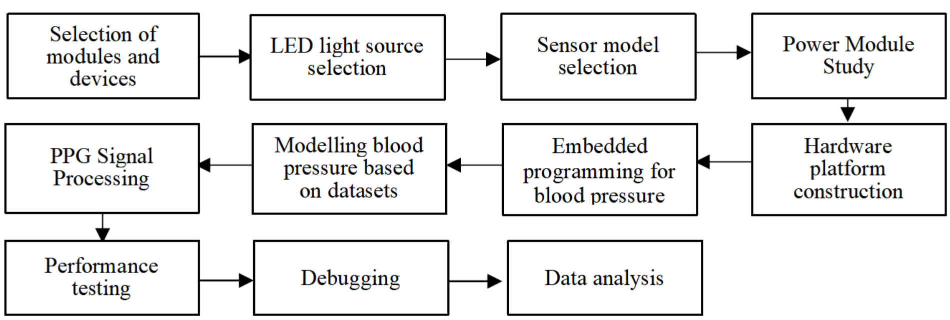

Figure 1. The system design flowchart.

(2) System hardware design

This blood pressure oximetry measurement system is mainly divided into hardware part and software part. The hardware part of this device consists of acquisition module, processor and wireless communication module and feeder module.

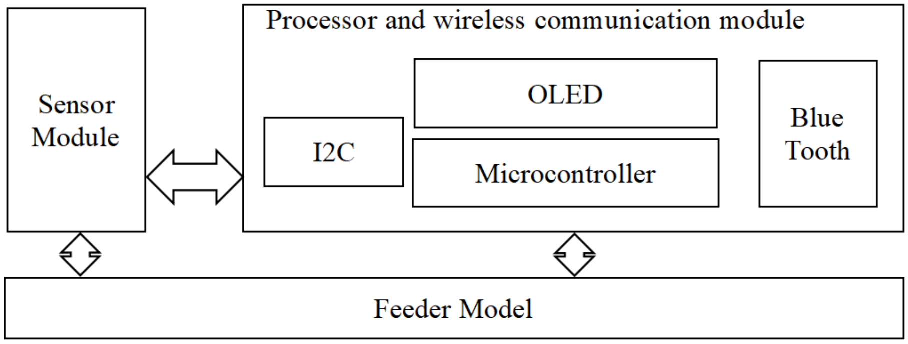

Figure 2. The system hardware schematic.

The acquisition module uses the MAX30101 photoelectric sensor, which can accurately feel the attenuation of light and thus achieve the conversion of the signal, and then achieve the acquisition of PPG signals. The processor and wireless communication module contains a microcontroller module, a display module and a Bluetooth module. The microcontroller module uses the STM32WB wireless microcontroller which supports Bluetooth 5.0 and IEEE 802.15.4 wireless standards. The display module uses OLED display to show the human health parameters in real time. Bluetooth module is used to communicate with mobile phones.

The power module uses a current boost chip using model ETA1061 to meet the voltage accuracy requirements of the MAX30101 chip.

(3) System software design

The software part of this paper is based on the embedded development environment of Cortex M4 core. The algorithm flow includes device initialisation, sensor parameter setting, signal acquisition, signal processing, peak and trough detection, blood pressure model modelling and blood pressure, blood oxygen calculation.

3 System Simulation and Analysis

(1) Oxygen monitoring model

Since oxygenated haemoglobin and haemoglobin are clearly reflected at red and infrared light, two LED light sources (660 nm red light, 880 nm infrared light) of the MAX30101 photoelectric sensor were used in this project for the collection of blood oxygen saturation. Calculate the AC of red light divided by the DC of red light, and the AC of infrared divided by the DC component of infrared, respectively, and divide the two to get the R value:

$$R = \frac{AC_{red}/DC_{red}}{AC_{ired}/DC_{ired}} \quad (5)$$

Based on the Lambert-Beer law [7] it can be introduced that the formula for the calculation of oxygen saturation can be approximated as:

$$SaO_2 = R * B_1 + B_2 \quad (6)$$

Where, B_1,B_2 are related to the absorption coefficients of Hb and HbO_2, which can be obtained by fitting the formula by the parameters. However, a lot of research shown that the effect of using quadratic function calculation is more accurate than the effect of using primary function [8] , MAXIM company uses quadratic function for fitting can be obtained from the empirical formula of blood oxygen saturation:

$$SpO_2 =- 45.060 * R * R + 30.354 * R + 94.845 \quad (7)$$

(2) Blood pressure monitoring model

In a healthy body, heart rate and pulse rate are highly compatible. If a person has a medical condition that causes an irregular heart rate, the pulse rate will be slightly lower than the heart rate, however, the correlation between the two is always highly correlated. Pulse rate is the frequency of the pulse beat and is generally expressed as the number of beats per minute (BMP). Let the difference between the peak times of two pulse waves be A, and the formula for calculating pulse rate be:

$$\mathrm{PR} \approx \mathrm{HR} = \frac{60}{\mathrm{T}_2 - \mathrm{T}_1}\mathrm{s} \quad (8)$$

In order to obtain sufficient data to look for the relationship between other human health parameters (e.g., heart rate, blood oxygen, etc.) observed with systolic and diastolic blood pressure, using the Queensland Vital Signs dataset as a reference. In this paper, the correlation between blood pressure and pulse rate was calculated using Pearson's correlation coefficient formula. The correlation coefficients between systolic blood pressure and heart rate or blood oxygen were calculated as:

Table 1. Correlation coefficient between blood pressure and heart rate or blood oxygenation.

	SBP	DBP
HR	0.6084	0.6803
Blood oxygenation	-0.0437	-0.0832

It is evident that heart rate and blood pressure show a significant correlation. In this paper, heart rate and systolic and diastolic blood pressures were modelled using MATLAB software, and all data used were from the Queensland Vital Signs dataset.

Based on the calculation of the correlation between heart rate and high and low blood pressure as well as oxygen saturation and high and low blood pressure, it can be seen that the correlation between oxygen saturation and high and low blood pressure is very low, while heart rate is significantly correlated with HBP. Therefore, in this paper, only heart rate is used as the dependent variable for the modelling of systolic and diastolic blood pressure. Figure 3 shows the fitted curves of SBP and DBP versus heart rate.

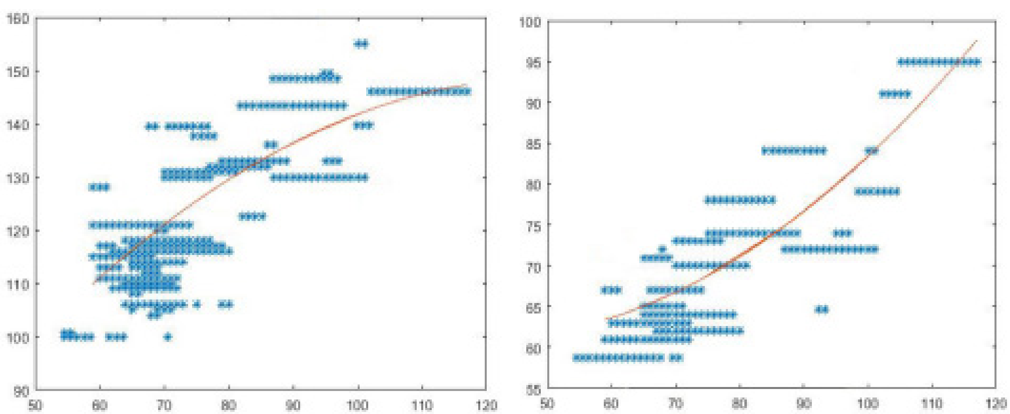

Figure 3. The fitted curves of SBP and DBP versus heart rate.

Finally, the SBP is modelled as:

$$SBP=-0.0077*HR^2+2.0079*HR+18.4225 \quad (10)$$

The DBP is modelled as:

$$DBP=0.0061*HR^2-0.4756*HR+70.3279 \quad (11)$$

Both SBP and DSP are measured in mmHg.

(3) Research result

In order to verify the accuracy of the results of the software designed in this paper to measure blood pressure, this paper measured the test SBP and test DBP using this device at the same time with an electronic sphygmomanometer produced by Jiangsu Yuyue Medical Devices Co Ltd, which was recorded as the actual SBP and the actual DBP. a correlation analysis was carried out between the real blood pressure values and the measured blood pressure values.

Two sets of data were tested in this paper, one set of human data in resting state and one set of human data after slight exercise. A total of 12 subjects participated in the test, all of whom volunteered to participate and all of whom were in good health. This paper shows five of the most representative sets of results.

Table 2. Measurements when the body is in a relaxed state.

	HR	Real SBP	Test SBP	Real DBP	Test DBP	Real SPO2	Test SPO2
1	90	130	136	72	76	100	100
2	63	111	114	61	64	100	100
3	79	130	128	70	70	100	100
4	71	116	122	62	67	100	100
5	64	106	115	59	64	100	100

The correlation coefficients R of the systolic and diastolic blood pressure data for the true and measured values were 0.9123 and 0.7477 , respectively, which are highly correlated.

As shown in Table 2, the data calculated by this model are more accurate when the heart rate is between 80-90 beats per minute. Whereas, this device produces higher errors when the heart rate is too high or too low, especially when it is too low. Further improvements will be made to work on this issue in the future. When the heart rate is in the range of 60-70 the HBP produces an error of about 10 mmHg.

The correlation R of the SBP and DBP data for the true and measured values were 0.6472 and 0.7741 respectively.As seen in the table, the error for systolic blood pressure was 11 mmHg and for diastolic blood pressure was 17 mmHg.

Table3. Measured when the body is in a state of slight exercise.

	HR	Real SBP	Test SBP	Real DBP	Test DBP	Real SPO2	Test SPO2
1	101	145	142	72	84	99	100
2	90	130	136	62	76	100	99
3	110	135	146	74	91	99	99
4	94	136	139	64	79	100	100
5	91	132	137	60	77	100	99

It can be seen that the accuracy of blood pressure measurement using this device decreased after exercise, which may be due to the increase in motion artefacts after exercise affecting the extraction of key nodes of the pulse wave signal, and further improvements will be made to the device in this regard in future studies.

(4) Error analysis

From the research results, it shows that there are some differences between the experimental results and the real results, which may be constituted by the following reasons:

- The finger should be placed in the exact position to ensure that the finger completely covers the light-emitting position, and contact noise due to finger bending or moving should be avoided in order to improve the accuracy of the measurement data.
- Exercise generates many EMG signals and other noises, and it is likely that the useful signals will be drowned in these noises, thus affecting the accuracy and leading to an increase in the error during exercise.
- In this paper, only heart rate is used as a parameter in the modelling of the blood pressure model, but there are actually articles that demonstrate that other parameters also affect blood pressure. The dataset used in this paper is very comprehensive, and there are some anomalies in the data due to various reasons, so inaccuracies in the model can also lead to errors.

4 Conclusion

In this paper, a portable medical monitoring wireless sensor system based on PPG is designed for the problems of poor portability and complexity of measuring blood pressure and blood oxygen in the traditional way. The hardware of the system consists of an acquisition module, a processor and wireless communication module, and a feeder module. For the software part, heart rate-blood pressure modelling is performed based on the Queensland Vital Signs dataset. In the software part, the pulse wave signal is extracted based on the PPG using the photoelectric sensor MAX30101, and the key parameters are extracted after filtering and other signal processing of the extracted pulse wave. Based on the extracted pulse wave parameters, heart rate and blood oxygen calculations are performed, and blood pressure calculations are performed based on the heart rate substituted into the heart rate-blood pressure model. Eventually achieve the function that can continuously monitor blood pressure and blood oxygen. This device can provide a certain reference value for the daily use of health parameter monitoring equipment.

Since this device uses Bluetooth module to communicate with mobile phones, it has certain reference value in the application of wireless sensor network in medical system, this device can be used as a user node of a wireless sensor network, and when the device monitors the abnormalities of human health parameters, it sends these abnormal signals to the owner of the network in order to achieve the purpose of protecting the user's health.

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About the Author

Xuechun Leng is postgradute of University of Birmingham, and her research field is signal processing.

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