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ORIGINAL RESEARCH ARTICLE

Design of a portable low-power wearable heart rate and blood oxygen monitoring system

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ABSTRACT

Heart rate, blood oxygen and body temperature are all important physiological information of human body, and designing a small and portable system measurement device will have a large social and clinical economic benefit. An attempt was made to design a portable monitoring device with STM32F103C8T6 as the controller. The heart rate, blood oxygen and body temperature data are collected by MAX30102 and GYMCU90615 modules and the data are sent to an Android smart phone via Bluetooth module for analysis and display, realizing an Android-based heart rate, blood oxygen and body temperature monitoring system. The system has been tested and verified to be stable and reliable.

Keywords: heart rate and blood oxygen detection; body temperature detection; STM32F103C8T6; Android; Bluetooth communication

1. Introduction

Heart rate and blood oxygen saturation are important physiological indicators of the human body[1], reflecting the health status of the body. With the development of information technology, the popularity of smart health wearing devices has increased dramatically[2,3]. Xue et al. designed a wearable blood oxygen saturation monitoring device based on Bluetooth low-power technology, which can continuously detect human blood oxygen saturation and pulse rate[4] with the characteristics of low power consumption and wearable, but the detection accuracy of the device is affected when the output blood oxygen saturation of the simulator is lower than 75%. Zhang et al. investigated the heart rate detection method for existing wearable devices and found that the human heart rate varied greatly under different activity states, but no corresponding App program was given for real-time detection[5]. Xu et al. introduced a blood oxygen analog acquisition circuit based on TI's AFE4400 integrated chip. Their study mainly simplified the circuit design, reduced system power consumption and circuit size, and improved the portability of the hardware, but slightly lacked in the development of the whole system network operation[6]. With the development of network cloud platform technology, some products with the function of detecting human physiological parameters are also developing in the direction of wearable and network real-time monitoring. For

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example, Xiaomi's wearable product Xiaomi Bracelet can provide highly accurate heart rate and sleep quality monitoring; the low-cost finger clip device produced by some domestic manufacturers can detect blood oxygen saturation and heart rate, and display data through OLED screen.

The Android-based heart rate, blood oxygen and temperature monitoring system designed by the author has the features of portability, low power consumption and wireless transmission. The system consists of two parts: hardware side and software side. The hardware side consists of sensor module, Bluetooth communication module, STM32 core circuit and power regulator circuit. The sensor module consists of MAX30102 heart rate and blood oxygen module and GY-MCU90615 infrared temperature module, which sends the collected data to the Android terminal through Bluetooth module, parses the data and displays it on the interface. The specific system design is shown in **Figure 1**.

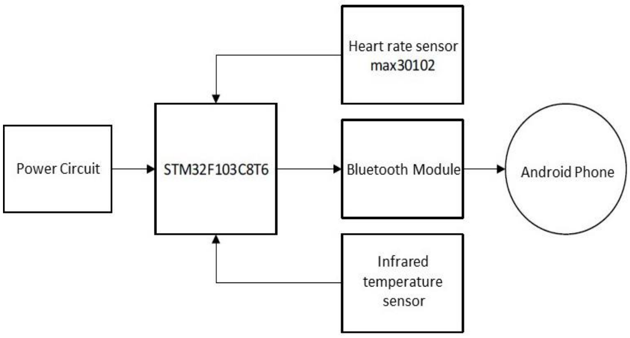

Figure 1. System design framework.

The finished device can help users to measure their body's oxygen saturation, heart rate and other physiological indicators more accurately anytime and anywhere, so as to better grasp their physical condition. From medical analysis, two physiological indicators, blood oxygen saturation and heart rate, are important data for hospital diagnosis and treatment, blood oxygen saturation of 95 and above is normal, and heart rate between 60 and 100 per minute is normal. When the user's measurement results do not meet the above two indicators several times in different time periods, it indicates that there are physical abnormalities, and it is recommended to consult a doctor for detailed investigation.

2. Detection principle

2.1. Heart rate oximetry principle

As the most common means of monitoring measurement, the optical volumetric method is simple, easy to wear, and highly reliable. The basic principle is to use the difference in light transmission generated by human tissue during vascular pulsation for heart rate and oxygen saturation measurement, and the sensor used consists of two parts: A light source and a photoelectric transducer[7,8], which is fixed to the patient's finger, wrist, or earlobe by a strap or clip. The light source is generally a light-emitting diode with specific wavelengths selective for oxyhemoglobin (HbO_2) and hemoglobin (Hb) in arterial blood (generally red light near 660 nm and infrared light near 940 nm are chosen)[9]. When the light beam passes through the human peripheral vasculature, the light transmission is changed due to the change in blood volume caused by the pulsation of the artery, and the light reflected by the human tissue is received by the photoconverter, transformed into an electrical signal and amplified and output. Since the pulse is a signal that changes periodically with the beating of the heart, the arterial blood volume also changes periodically, so the change period of the electrical signal of the photoelectric converter is the pulse rate. Meanwhile, according to the definition of blood oxygen saturation (SaO_2), it is expressed as:

$$\mathrm{SaO_2} = \frac{C_{\mathrm{HbO_2}}}{C_{\mathrm{HbO_2}} + C_{\mathrm{Hb}}} \times 100\% \qquad (1)$$

Figure 2 shows the degree of absorption of different frequencies of light by oxyhemoglobin (HbO_2) and hemoglobin (Hb).

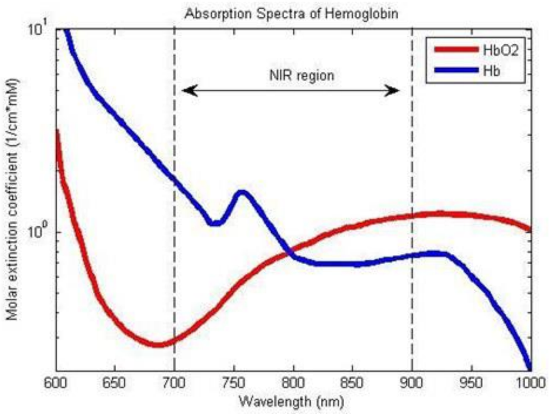

Figure 2. Absorption spectra of HbO_2 and Hb.

2.2. Body temperature detection principle

Infrared temperature measurement is widely used in non-contact temperature measurement equipment[10]. And its principle is to convert the infrared radiation energy emitted by the object into an electrical signal, the magnitude of the infrared radiation energy corresponds to the object's own temperature, and the temperature of the measured body is determined, according to the value of the transformed electrical signal.

3. Hardware system design

3.1. Signal acquisition module

As shown in **Figure 3(a)**, the MAX30102 from Maxim is a high-sensitivity blood oxygen and heart rate biosensor[11]. It integrates LED and driver, light sensing and AD conversion, ambient light interference cancellation and digital filtering parts, leaving only a digital interface, which greatly reduces the design burden of developers.

As shown in **Figure 3(b)**, GY-MCU90615 is a low-cost infrared temperature module with the advantages of low power consumption and small size. Its working principle is to read infrared temperature data by microcontroller and output by serial communication. The circuit connection of the acquisition module is shown in **Figure 4.**

(a) (b)

Figure 3. Blood oxygen heart rate acquisition module, temperature measurement module.

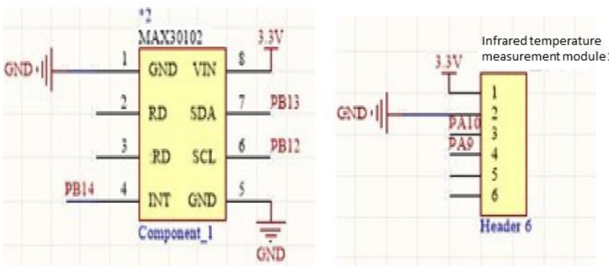

Figure 4. Acquisition module circuit connection.

3.2. Bluetooth module

HC-05 is a high-performance master-slave Bluetooth module can be used directly as a serial port. The physical and circuit connections are shown in **Figure 5**.

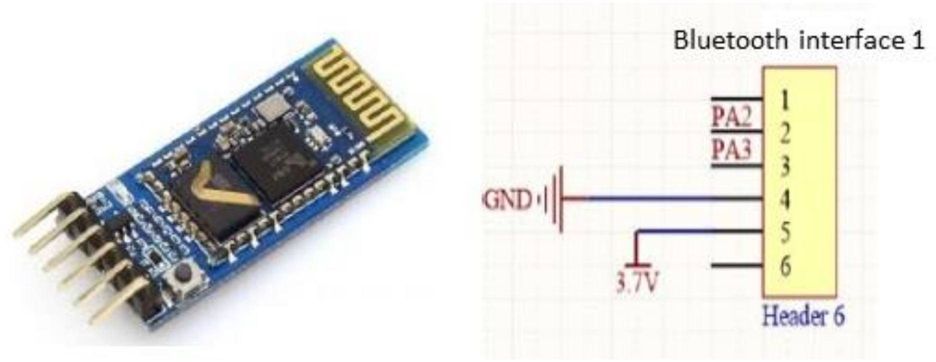

Figure 5. Bluetooth module and circuit connection.

3.3. Power circuit

In the subsequent circuit design, considering the voltage of the supply battery is around 3.7 V, the TPS7333 chip is chosen to regulate the voltage, which is stable within 0.3–0.4 V. The power supply circuit is shown in **Figure 6**.

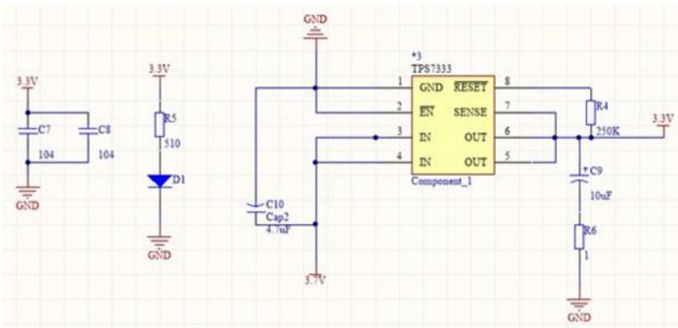

Figure 6. Power circuit.

3.4. Main control chip circuit

The STM32 core circuitry consists of four main parts: (1) reset circuit, (2) crystal circuit, (3) serial port download, and (4) I/O port.

The STM32 is externally connected to two crystals to provide a clock source for its internal system. An 8 M high-speed external clock (HSE) provides the system with a more accurate master frequency; the other is a 32.768 M low-speed external clock (LSE), which is used to provide accurate clock functions. The specific schematic of the system core board is shown in **Figure 7**.

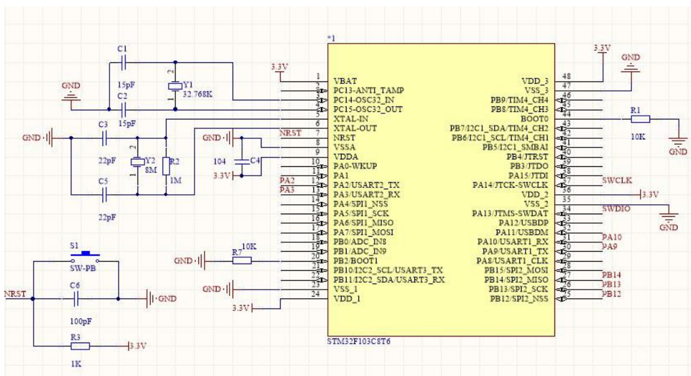

Figure 7. System core circuit.

4. Software development and algorithms

4.1. Communication Protocol

The communication protocol is the main factor that affects the stability of the system[12]. The author's design requires two serial ports, USART1 and USART2, one interrupt port, and two I^2C analog ports for the lower computer side. Among them, the USART1 serial port is connected to the infrared temperature measurement module and the USART2 serial port is connected to the Bluetooth module.

The MAX30102 module uses the I^2C communication protocol, and for stability, the software emulation of I^2C is used; from **Figure 5**, the USART2 function pins PA2 (TXD) and PA3 (RXD) are used as the communication interface between the lower and upper computers, with a baud rate of 9,600 bps. The GY-MCU90615 module communicates with the STM32 through the USRAT1 serial port. The number of fixed packets is 9 frames and the protocol is as follows.

(1) Frame header: Byte0 and Byte1 fixed frame header 0x5A. (2) Data bits: Byte2 indicates the data type of this frame. Byte3 indicates the amount of data (2 groups of 4 bytes of data for one parameter). Byte4 indicates the high 8 bits of the target data. Byte5 indicates the low 8 bits of the target data. Byte6 indicates the high 8 bits of the ambient temperature data. Byte7 indicates the low 8 bits of the ambient temperature data. (3) End of frame: Byte8 in the range 0x00-0xFF is the checksum (the sum of the previous data accumulation, only the lower 8 bits are kept).

The frame determines the correctness of the data header, frame tail and frame length, and the required data is extracted from the correct data bits of the frame set and parsed to complete the data conversion.

4.2. Lower computer firmware development

The main function integrates the heart rate and blood oxygen acquisition and infrared temperature measurement programs. The main logic is to read the serial number firstly, determine the data sent by the serial port can correctly parse, and then send a query instruction; after that, the interrupt trigger of heart rate blood oxygen detection was checked. If the interrupt was triggered, the heart rate blood oxygen module could work normally. Then, the red light and infrared light were read, and 100 groups were read each time and stored in an array. After reading, AD conversion was performed. Since the sum of the read values is less than 500 groups in the initial stage, the data cannot be displayed for about 5 s. After that, the module works normally and performs mean filtering on the 500 groups of collected data. The heart rate and blood oxygen values collected are judged to be normal, and the collected values are confirmed to be valid before the group frames are sent. After the sending is completed, the data shifting of the array is performed, in which the previous data are discarded and only 500 data in the array are saved forever.

The infrared temperature measurement module works by means of serial communication. The principle is that the module sends the command 0xa5+0x15+0xBA to the device, and the device then returns a piece of data, of which the valid data can be taken. In this program, the command query method is used, which means that the command needs to be sent each time for the sensor to return the value.

4.3. Brief description of the algorithm

The algorithm for heart rate and blood oxygen detection is ported from the official Maxim library. The main functions used in the program are:

voidmaxim_heart_rate_and_oxygen_saturation

$$
\begin{aligned}
(&\text{uint32t} * \text{pun\_ir\_buffer}, \text{int32\_t n\_ir\_buf} \\
&- \text{fer\_length}, \text{uint32\_t} \\
&* \text{pun\_red\_buffer}, \text{int32\_t} \\
&* \text{pn\_spo2}, \text{int8\_t} \\
&* \text{pch\_spo2\_valid}, \text{int32\_t} \\
&* \text{pn\_heart\_rate}, \text{int8\_t} \\
&* \text{pch\_hr\_valid})
\end{aligned}
$$

Put the read parameters of red light and IR light into the array and fill the array names of red light and IR light into the corresponding array parameter names. The parameters **pn_heart_rate* and **pn_spo2* are variables for the output results. **pn_heart_rate* outputs the heart rate and **pn_spo2* outputs the blood oxygen concentration. **pch_spo2_valid* and **pch_hr_valid* are used to determine the validity of the acquired heart rate and blood oxygen, if it is 1, it means the corresponding parameters acquired are valid; if it is 0, it means the acquired values have too much error and are judged as invalid. The invalid value is indicated by -999, and only the valid value is output.

4.4. Upper computer software development

The upper computer APP is written in Android Studio, mainly divided into four parts: Bluetooth connection, data processing, UI refresh, and curve plotting. The specific software main flow is shown in **Figure 8**.

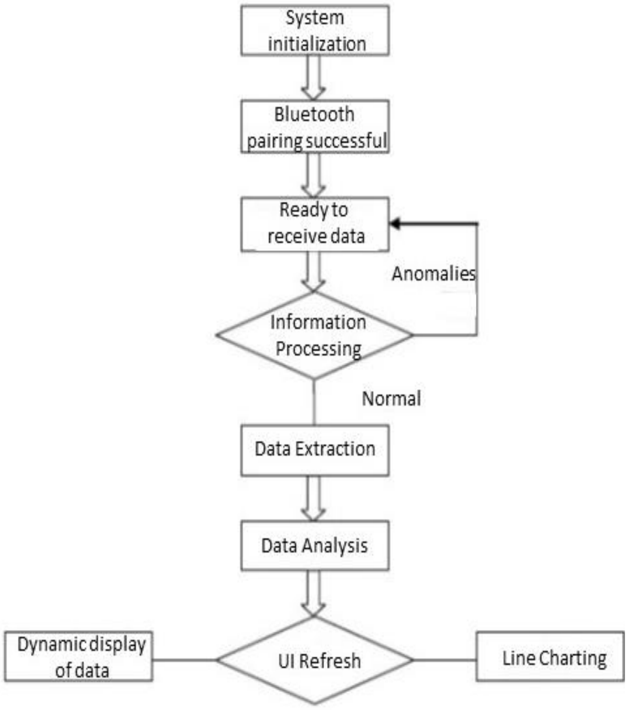

Figure 8. Software master process.

The Bluetooth connection requires that the phone has been paired with the Bluetooth module. The data processing is mainly to parse the frame data, and the UI refresh is done by a handler mechanism, which determines which part of the UI to refresh based on the msg parameter sent by sendHandlerMessage. After getting the parsed data, the github component is called to draw the curve.

As shown in **Figure 9**, the APP has a main interface (a) and two types of sub-pages for all monitoring (b) and single monitoring (c), which are used to display the current value of the signal and its change curve.

Figure 9. Android UI and functions.

5. Test results

As shown in **Figure 10**, the test conditions were indoor, 26 °C, and the test subjects were in normal physical condition (not strenuously exercising). The main reason for choosing to collect the human static data indoors[13] is that there are fewer disturbing factors such as noise and light, which are more conducive to extracting valid data.

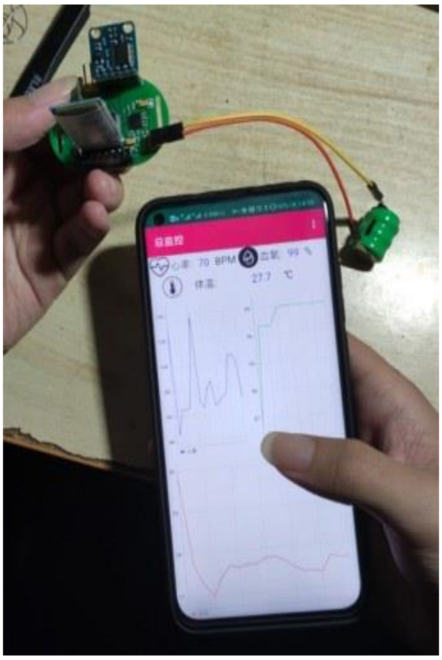

Figure 10. System testing.

When the battery of the device is powered on, the LED of the Bluetooth module is flashing, and the Android APP is opened for testing, when the flashing frequency of the LED of the Bluetooth module is reduced, it indicates that the communication between the upper computer and the lower computer is successful. The heart rate, temperature and blood oxygen concentration values collected by the lower computer are displayed in real time on the Android terminal, and are shown in the form of a line graph. Since the system has received less than 500 sets of data in the first 5 s, it cannot be displayed.

Figure 11–13 show the screenshots of each test interface, in the case of good contact between the device and the human body, the collection of data is normal and relatively stable. By comparing the data of the same period with the more mature portable heart rate and blood oxygen detection products on the market, such as Xiaomi bracelets, it meets the expected results.

Figure 11. Heart rate interface.

Figure 12. Oximetry interface.

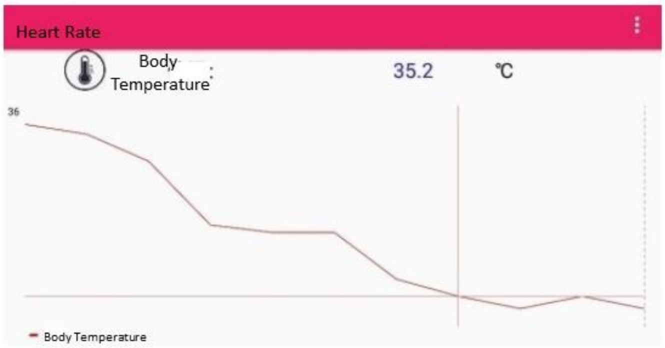

Figure 13. Body temperature interface.

6. Conclusions

The design of heart rate, blood oxygen and temperature monitoring system based on Android system is briefly introduced, aiming to provide an intelligent monitoring device for home and other environments. After testing, the system can detect the signals more accurately and display the data and change curve in real time on the Android terminal, with the features of low cost, easy to carry[14], simple operation, and wireless transmission.

Conflict of interest

The authors declare no conflict of interest.

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