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Design of Portable PPG Heart Rate Detection System Based on Single Chip Microcomputer

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ABSTRACT
Reliable pulse wave acquisition and heart rate tracking are critical to the evolution of portable pulse diagnosis tools, especially for point-of-care and daily monitoring scenarios. Existing acquisition modules frequently impose a trade-off: analog-intensive front ends hinder miniaturization and increase power draw, whereas more compact, fixed-function designs often foreclose the later addition of complementary sensing modalities such as pressure-based metronome. This study introduces an STM32-based photoplethysmographic (PPG) heart rate detection system built around a fully integrated optical sensor. Pulse waveform data are converted to the digital domain on sensor and streamed directly to the micro-controller via an I²C link, with heart rate values refreshed in real time on an OLED display. The architecture addresses prior limitations in two concrete ways. First, the all-digital signal chain eliminates the need for discrete analog conditioning components, yielding a significantly smaller footprint and lower cost without compromising waveform fidelity. Second, the board incorporates a reserved signal-conditioning path centered on an operational amplifier, which provides the necessary gain and band-limiting for future pressure-pulse sensors. This deliberate provision preserves both the portability of the current unit and the flexibility required for subsequent hardware expansions, effectively decoupling core functionality from peripheral augmentation. The paper details the hardware design rationale and confirms operational integrity of the principal modules through empirical testing. The resulting platform constitutes a low-cost, lightweight front-end solution that directly supports the iterative development and refinement of new-generation pulse diagnostic instruments.

KEYWORDS
Photoplethysmography, Heart rate detection system, Single-chip microcomputer, Portable detection

1. Introduction

Cardiovascular disease is one of the major diseases that threaten human health. Heart rate is a core physiological parameter that reflects the cardiovascular function status, and its daily monitoring is of great significance for early prevention and health management of diseases. Pulse wave signals contain rich cardiovascular physiological information. By analyzing the shape, rhythm, and intensity of pulse waves, we can obtain key health indicators such as heart rate and blood oxygen saturation [1]. Traditional Chinese medicine pulse diagnosis is a traditional medical diagnostic method that determines the status of the body's internal organs by touching the pulse of the inch mouth. However, traditional pulse diagnosis methods have limitations such as strong subjectivity, excessive reliance on doctors' experience, and difficulty in quantification [2]. With the development of electronic technology and sensor technology, combining modern signal detection technology with traditional Chinese medicine pulse diagnosis theory to achieve digitalization and objectivity of pulse diagnosis has become a current research highlight [3].

At present, pulse wave detection technology is mainly divided into two categories: pressure type and photoelectric type. Pressure sensors obtain pulse waves by detecting changes in blood vessel pressure, but they have problems such as structural complexity and poor wearing comfort. The photoplethysmography (PPG) technology utilizes the absorption characteristics of blood towards specific wavelengths of light, and obtains pulse wave signals by detecting changes in light intensity through photoelectric sensors. This technology has advantages such as noninvasiveness, low cost, and easy integration, and has been widely used in portable heart rate monitoring devices [4]. In terms of embedded control, the STM32 series micro-controller has become the preferred solution for portable detection system design due to its rich peripheral resources, high cost-effectiveness, and mature development environment [5].

This work presents a photoplethysmographic heart rate detection system built around the STM32 micro-controller. An integrated optical sensor captures the pulse waveform, and the resulting digital signal is conveyed directly to the micro-controller via an I²C interface. Heart rate values are displayed in real time on an OLED screen. The paper describes the system architecture, hardware circuitry, and associated software design. Simulation-based testing confirms the viability of the core functional modules, establishing a practical front-end foundation for future refinement of pulse diagnostic instrumentation.

2. System detection principle and overall design scheme

2.1 Principle of photoelectric capacitance pulse wave detection

The photoplethysmography method is based on Lambert Beer's law. When light of a specific wavelength is irradiated onto human tissue, it is absorbed and reflected by body tissues such as skin, muscles, and blood. Because hemoglobin in human arterial blood has a strong ability to absorb light, and arterial blood volume varies periodically with heartbeat, the intensity of reflected or transmitted light received by the photo-detector will also exhibit periodic fluctuations. This fluctuation signal is the PPG signal [6].

When the heart contracts, the arterial blood volume increases, the absorption of light increases, and the intensity of light received by the detector decreases. When the heart relaxes, the arterial blood volume decreases, the absorption of light weakens, and the intensity of light received by the detector increases. By detecting periodic light signals and converting them into electrical signals, a waveform synchronized with the heartbeat can be obtained. The calculation of heart rate is based on the period of pulse waves. By detecting the time interval T between the peaks of two adjacent pulse waves, the real-time heart rate value HR can be calculated by $HR=60/T$ [7].

2.2 Overall System Design Architecture

This system adopts a modular design approach, and the overall architecture is divided into two parts: hardware layer and software layer. The main control core of the hardware layer is the micro-controller, which includes the minimum system module, pulse wave signal acquisition module, human-computer interaction module, wireless transmission module, and power module. For future system development and expansion, the system also reserves an OPA based analog signal conditioning interface, which can be used for signal processing of pressure pulse sensors.The software layer includes data acquisition programs, signal prepossessing programs, heart rate calculation programs, display programs, and Bluetooth transmission programs. The workflow of the system is as follows: Firstly, the PPG signal of the fingertips is collected by sensors, and the digital signal is directly obtained through the I2C interface and transmitted to the main control micro-controller. In the main control micro-controller, the signal is prepossessed and the heart rate value is calculated through software algorithms. Finally, the calculated result is displayed on the OLED screen. At the same time, the heart rate data is transmitted wireless to the mobile phone through the Bluetooth module. The overall architecture of the system is shown in **figure 1**.

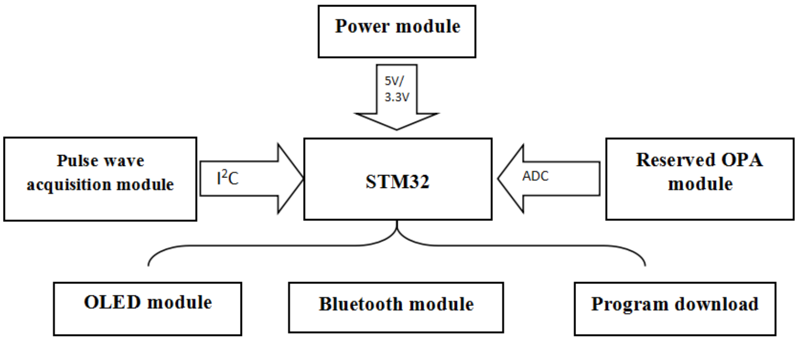

Fig.1 Overall System Framework Diagram

3. Hardware circuit design of the system

3.1 Minimum System Module

This system uses STM32 as the main control chip, which has rich peripheral resources such as GPIO, I2C, USART, etc. It has low cost and low power consumption, fully meeting the system control requirements. The minimum system consists of a main control chip, crystal oscillator circuit, reset circuit, and BOOT configuration circuit. This system is configured to start from user Flash.

3.2 Pulse wave signal acquisition module

MAX30102 integrated photoelectric capacitance pulse wave sensor is selected for pulse wave acquisition. The device integrates red LED, infrared LED, photo-detector, optical components, ambient light suppression circuit, and 18 bit ADC internally. The output signal communicates directly with the main control through the I2C interface without the need for external analog conditioning circuits [8].

In terms of circuit connections, the VIN pin of MAX30102 is connected to a 3.3V power supply, GND is connected to ground, and the pins of SCL and SDA are respectively connected to the PB6 and PB7 pins of STM32. Implement register configuration and data reading through I2C bus. The INT interrupt pin is an optional connection used to trigger a data ready interrupt. At the contact area between the sensor and the finger, mechanical structure design is used to ensure good optical path isolation and reduce interference from ambient light.

3.3 Reserved analog signal conditioning module

In order to meet the requirements of various types of sensors (such as pressure pulse sensors) for the new pulse diagnosis instrument, the designed system reserves an OPA based analog signal conditioning module. This interface can be connected to pressure sensors in the future to achieve synchronous collection of pulse signals from "inch, off, and ruler" channels. The specific circuit design includes two-stage amplification and second-order active filtering, which can be flexibly configured according to the actual sensor characteristics.

3.4 Human Computer Interaction and Wireless Transmission Module

The human-machine interaction adopts an SSD1315 driven OLED display screen, which communicates with STM32 through the I2C interface. This module has low power consumption and can still display clearly under strong light, making it suitable for portable devices.

The wireless transmission adopts HC-05 Bluetooth module, which communicates with STM32 through USART serial port. The connection method between the module and the main control is as follows: TXD of HC-05 is connected to PA3 (RX) of STM32, RXD is connected to PA2 (TX) of STM32, VCC is connected to 5V power supply, and GND is grounded. By configuring the working mode of the module, wireless transmission of heart rate data can be achieved, and data reception and display can be completed in conjunction with the Bluetooth debugging assistant on the mobile phone.

3.5 Power Supply and Download Interface Module

The system is powered by a USB Type-C interface with an input voltage of 5V. The power circuit is equipped with input and output filtering capacitors (10 μ F and 0.1 μ F in parallel) to suppress power ripple and ensure power supply stability.

The HC-05 Bluetooth module and reserved OPA analog interface are directly powered by 5V input from USB to ensure normal operation. The program downloads and debugging use ST Link emulator, which connects the SWDIO and SWCLK pins of STM32 through the SWD interface to achieve program burning and online debugging. This system can be based on breadboards and DuPont lines to build hardware prototypes, facilitating module debugging and circuit modification, and meeting the requirements of early scheme verification.

4. Program design of system software

4.1 Overall process of the main program

The system software is developed based on the STM32 standard library and adopts a front-end and back-end system architecture. After power on, the program first performs initialization operations: configure the system clock to 72MHz, initialize GPIO, I2C1, USART2, OLED, and HC-05. After initialization is completed, the system enters the main loop and performs tasks such as data acquisition, signal processing, heart rate calculation, and display transmission in a loop. The main program flowchart is shown in **figure 2**.

4.2 Pulse wave data acquisition and prepossessing

Data collection is achieved by reading the internal FIFO register of MAX30102 through the I2C interface. The internal FIFO of the sensor can store 32 sets of sampling data, each set of data containing 18-bit ADC values for both infrared and red channels. The main control checks whether there is new data in the FIFO by querying, and reads 6 bytes each time as a complete set of sampling points.

The original pulse wave signal contains baseline drift and high-frequency noise, which requires prepossessing. This system uses the sliding average filtering algorithm to suppress random noise: a sliding window with a length of 5 is set, and every time new data is collected, the window slides forward one bit, and the arithmetic mean of the data within the window is calculated as the filtering output for the current point. To address the issue of baseline drift, a first-order high pass filter is used for suppression, with a cutoff frequency set to 0.5Hz, to filter out low-frequency interference such as breathing.

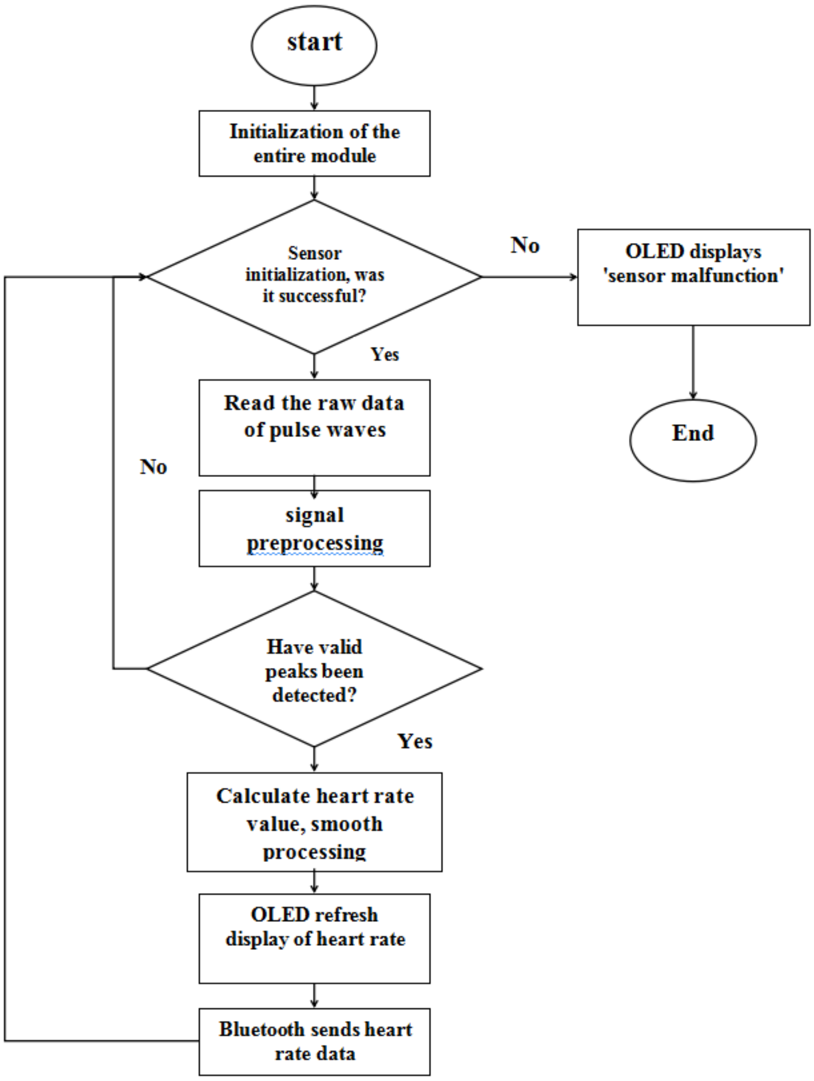

Fig. 2 Flowchart of the System Main Program

4.3 Calculation of heart rate values

The calculation of heart rate value adopts the time-domain peak detection method. Firstly, peak recognition is performed on the prepossessed pulse wave signal: a dynamic threshold is set, and when the signal rises above the threshold and subsequently decreases, the point is recorded as a candidate peak. Exclude pseudo peaks by checking the minimum interval between adjacent peaks. For each valid peak detected, record its corresponding timestamp and calculate the time interval ΔT from the previous peak, resulting in an instantaneous heart rate value of $60/\Delta T$.

To improve the stability of heart rate measurement, a moving average method is used to smooth the instantaneous heart rate: cache the last 5 heart rate values, remove the maximum and minimum values, calculate the arithmetic mean, and use it as the final heart rate value. When no valid peak is detected for 10 consecutive seconds, the heart rate value displayed as "--" indicates detection failure.

4.4 Display and Bluetooth transmission

The display program sends commands and data to the OLED through I2C to refresh the screen. The screen is divided into three display areas: the top displays the "HR:" label and real-time heart rate values; Display a simple pulse waveform in the middle, update waveform data at regular intervals, and create a dynamic scrolling effect; The bottom displays the Bluetooth connection status and system running time. The screen refresh rate is set to 2Hz, balancing display smoothness and system load.

The Bluetooth transmission program sends data externally through USART2. The sending frequency is synchronized with the heart rate update frequency, sending once per second. The mobile phone can use any Bluetooth serial port assistant to receive data and display heart rate values through custom protocol parsing.

To illustrate the architecture of the proposed system with clarity, a schematic diagram of the design is presented in **figure 3**.

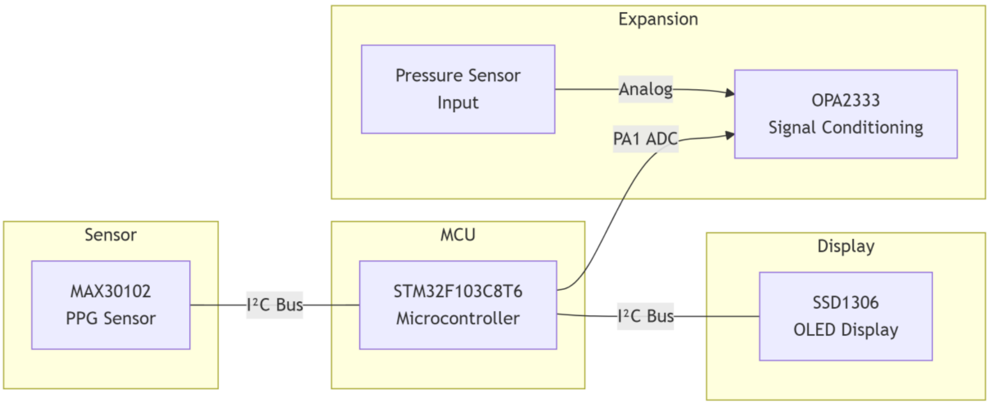

Fig. 3 Simulated system circuit diagram

5. Simulation experiment

To verify the accuracy and reliability of the heart rate detection algorithm in this system, a comparative experiment was conducted using medical grade heart rate detection equipment as the standard. Verify the heart rate detection accuracy of the system at different time periods and physiological states, providing data support for the daily health monitoring application of the system and the front-end acquisition function of the pulse diagnosis instrument.

5.1 Experimental scheme

1.Experimental subjects: Two healthy college students were selected as subjects: subject A was male, 21 years old; Subject B is a female, 20 years old. Both subjects have no cardiovascular disease, no long-term medication history, and no behaviors that affect heart rate such as vigorous exercise, alcohol consumption, or staying up late within 24 hours before the experiment. Their resting heart rates are within the normal adult reference range (60-100 beats per minute).

2.Reference equipment: The Yuyue Medical Electronic Blood Pressure Monitor (certified by the National Medical Device Administration and with high heart rate measurement accuracy) is selected as the standard reference equipment. This device is a routine clinical vital sign detection device, and the measurement results have clinical reference value.

3.Experimental procedure: The experimental period is 24 hours, which means that measurements are taken synchronously at four time points every day: 6:00 (morning rest), 12:00 (noon rest), 18:00 (evening rest), and 24:00 (nighttime rest). At each time point, the subjects remained seated for 5 minutes, and after reaching a resting state, measurements were conducted synchronously with the control device using this system. This system collects fingertip photoplethysmography pulse waves to calculate heart rate values, and synchronously measures bronchial artery heart rate values with the control device. Each group is measured 3 times, and the arithmetic mean of the 3 measurement results is taken as the final measurement value. The heart rate data detected by this system and the control device are recorded.

4.Evaluation indicators: Using the measurement results of the control equipment as reference values, calculate the absolute and relative errors of the measurement values of this system, and evaluate the detection accuracy of the system.

5.2 Experimental results and analysis

The heart rate monitoring results of subjects A and B within 24 hours are shown in Table 1.

Table 1: Heart rate monitoring results of subjects A and B.

	time	System measurement values (times/min)	Equipment measurement values （times/min）
A	6:00	64	68
	12:00	76	80
	18:00	79	82
	24:00	63	65
B	6:00	62	65
	12:00	79	77
	18:00	76	79
	24:00	62	64

From the experimental data, it can be seen that at four different times, the heart rate measurement results of two subjects using this system have good consistency with the measurement results of medical grade equipment. From the data, we can see that the error between the two measurement results is very small, which also confirms the reliability of the signal preprocessing algorithm and peak detection heart rate calculation method of this system. Therefore, the designed PPG heart rate detection system based on STM32 micro-controller has good stability and accuracy. The designed heart rate detection system can meet the needs of daily heart rate monitoring and front-end signal acquisition of pulse diagnosis instruments, and has practical application significance.

5. Conclusion

In order to meet the portable application requirements of pulse diagnosis instruments, we have designed a PPG heart rate detection system based on STM32 microcontroller. The designed system uses MAX30102 sensor as the pulse wave digital acquisition core, displays data through OLED, and completes wireless transmission through HC-05 Bluetooth module; At the same time, an OPA based analog signal conditioning interface has been reserved, laying the foundation for the subsequent integration of pressure pulse sensors and the implementation of traditional Chinese medicine's "inch, close, ruler" three part pulse acquisition.

This article elaborates on the overall architecture, hardware circuit design, and software program design of the system, and verifies its feasibility through experiments. The designed system has the characteristics of low cost, low power consumption, and high modularity, providing a reference for the development of new pulse diagnosis devices.

In future research work, one is to improve the detection accuracy and anti-interference ability of the system; The second is to further extract the time-domain and frequency-domain characteristic parameters of pulse, improve the functions of pulse diagnosis instruments, and promote the objective and standardized development of traditional Chinese medicine pulse diagnosis.

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Conflicts of Interest: The authors declare no conflict of interest.

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