

## STM32-Based Heart Rate Variability Detection

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### Abstract

Real-time monitoring of psychological stress is critical to maintaining physical and mental health. Although traditional ECG methods can provide accurate stress assessment, their complexity and high cost limit daily use. To address this issue, this paper designs a heart rate monitoring system based on the STM32F103C8T6 microcontroller, which provides an easy and cost-effective solution for stress monitoring. The system simplifies operations and reduces costs by detecting peak heartbeat signals to estimate interbeat interval (IBI) and analyse heart rate variability (HRV). The system uses the XD-58C PulseSensor for accuracy, including an OLED display for real-time data and a threshold range to ensure validity. Heart rate data can be uploaded to a PC platform for visualisation via serial communication, enabling users to track health trends. The system has been tested for ease of use, broad applicability, stable performance and high utility value to help individuals manage their mental health and as a preventive medicine tool to reduce the risk of disease and improve public health.

### Keywords

Stress Monitoring; STM32F103C8T6; Interbeat Intervals; Heart Rate Variability.

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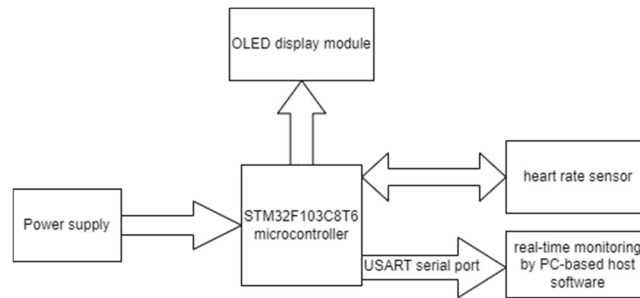
### 1. Introduction

With the accelerated pace of modern life, psychological stress[1]has become a widespread issue affecting all societal groups. Studies indicate that persistent psychological stress can lead to mental health problems such as anxiety and, in severe cases, negatively impact overall physical and mental well-being, making the development of real-time and simple psychological monitoring methods particularly important [2]. Heart rate (HR), defined as the number of heartbeats per minute, is not perfectly regular but exhibits slight variations, known as heart rate variability (HRV), which reflects differences in interbeat intervals (IBI) [3]. HRV is a crucial measure for assessing cardiac health and autonomic nervous system (ANS) function [4]. Traditional HRV measurements rely on contact-based devices such as electrocardiograms (ECG) or blood pressure analysis, which, despite their ability to continuously record IBI for HRV estimation, are complex and costly to operate. To address these limitations, this paper proposes a heart rate monitoring system based on the STM32F103C8T6 microcontroller, utilizing the XD-58C PulseSensor as the heart rate detection module to enable accurate measurement and transmit data to a host computer for monitoring and analysis. This allows users to monitor their health in real time, identify potential risks promptly, and effectively reduce the likelihood of diseases.

### 2. Overall System Design

The heart rate monitoring system based on the STM32 microcontroller consists of two main parts: hardware design and software development. On the hardware side, the system utilizes a heart rate sensor to collect physiological signals and transmits these data to an OLED display for real-time visualization through a control circuit. Additionally, to enable further data analysis and monitoring,

the system sends the collected heart rate information to upper computer software via serial communication. On the software side, the STM32 microcontroller coordinates the operation of each hardware component to ensure accurate data acquisition, processing, and transmission. Meanwhile, the PC-based host computer software receives data from the microcontroller and provides a user-friendly interface for real-time monitoring. The overall design framework of the system is illustrated in Fig. 1.

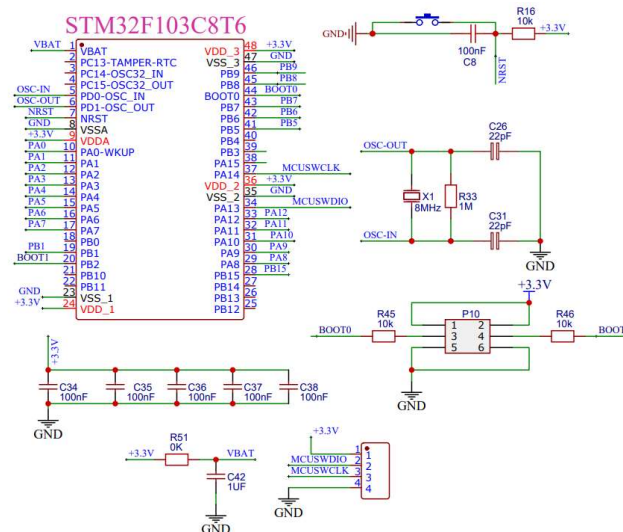


**Fig. 1** Overall system design framework

## 2.1 System Hardware Design

### 2.1.1 STM32 Master Control

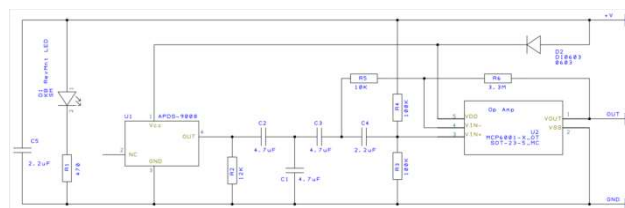
The STM32F103C8T6 microcontroller, based on the high-performance Cortex-M3 core, serves as the main controller of the system. With its rich feature set, efficient processing power, and low power consumption. Equipped with 64 KB of Flash memory, the STM32F103 supports a wide operating voltage range from 2V to 3.6V and operates stably in extreme temperatures ranging from -40°C to 85°C. It features a maximum operating frequency of 72 MHz, excellent interrupt handling capabilities, and 37 general-purpose I/O ports, 16 of which can be configured as external interrupt lines, enhancing system response efficiency and interactivity [5]. The integrated peripheral modules, such as timers, ADCs, and DACs, reduce the need for external components, simplify circuit design, and ensure excellent backward and forward compatibility for easy upgrades and maintenance. In summary, the STM32F103's high performance, low cost, low power consumption, wide environmental adaptability, and high integration make it a core component for building an efficient and stable human health monitoring system. These features ensure the system's reliability and practicality, laying a solid foundation for its wide range of applications. The minimum system circuit is shown in Fig. 2.



**Fig. 2** STM32F103C8T6 MCU Minimum System Circuitry

### 2.1.2 Heart Rate Detection Module (XD-58C PulseSensor )

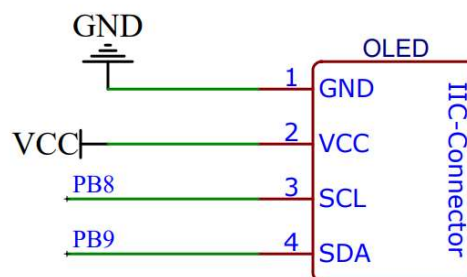
The XD-58C PulseSensor is a photoreflective analog sensor designed for heart rate measurement, featuring integrated amplification and noise cancellation circuits to improve signal quality and accuracy [6]. By placing a finger on the sensor’s white area, users can detect heart rate through changes in light transmission caused by vascular pulsation. As the heart contracts and relaxes, blood flow variations alter light transmittance, which is captured by a photodetector and converted into an electrical signal. The sensor filters and amplifies this signal, outputting an analog voltage proportional to heart rate frequency. The STM32F103 microcontroller digitizes this voltage using its ADC function and calculates heart rate (BPM) and inter-beat intervals (IBI) through an algorithm. With its high-performance circuitry, ease of use, and strong anti-interference capabilities, the XD-58C PulseSensor provides stable and accurate data. Combined with the STM32F103’s processing power and peripheral interfaces, the system enables high-precision data acquisition and processing, making it suitable for personal health management, sports monitoring, and medical applications. Its internal circuit design is shown in Fig. 3.



**Fig. 3** Heart Rate Sensor Circuit

### 2.1.3 OLED Displays

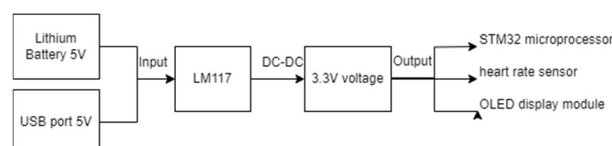
The system utilizes the STM32F103C8T6 series microcontroller as its core, paired with a 0.96-inch OLED display featuring an IIC interface to present the collected user information in real time. The circuit design for this functionality is illustrated in Fig. 4. spacing.



**Fig. 4** OLED Display Circuit

### 2.1.4 Power Module

The power module of the system is designed to supply power to the STM32 microprocessor module, heart rate signal acquisition module, and OLED display module. To enhance the system's practicality, two power supply schemes are implemented: one utilizes battery power, while the other integrates with the widely used USB power supply. The system's voltage conversion output and power distribution to each module are illustrated in Fig. 5.



**Fig. 5** Power Module Design Block Diagram

To ensure the stable operation of all modules in the system, a uniform 3.3V supply voltage is adopted in the design. Since the lithium battery pack provides a 5V input voltage, voltage conversion is necessary. The low-dropout linear regulator chip LM1117-3.3, produced by TI, was selected for this purpose. This chip features current limitation, thermal protection, and a built-in Zener-regulated bandgap reference voltage circuit, ensuring an output voltage accuracy of  $\pm 1\%$  or better. The circuit design for this voltage conversion is illustrated in Fig. 6.

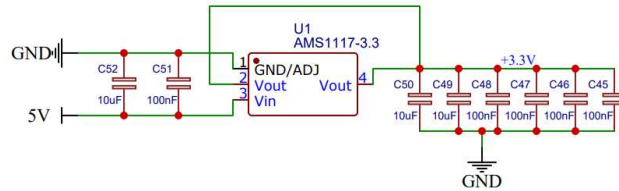


Fig. 6 LM117 Voltage Regulator Schematic

## 2.2 System Software Design

### 2.2.1 Master programming

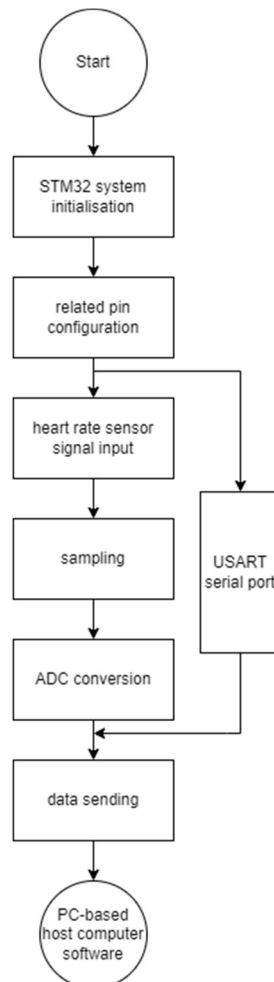
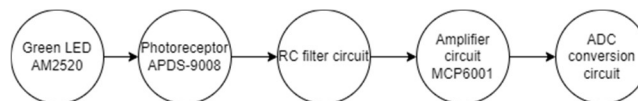


Fig. 7 Main program workflow

The STM32 microcontroller connects to the XD-58C PulseSensor module via a single-wire interface. The heart rate signal acquisition in this system is achieved using the light-emitting component AM2520 and the photoreceptor APDS-9008, complemented by a filtering and amplification circuit to ensure accurate signal capture. The output of the heart rate measurement module is connected to the PA1 port of the STM32 microcontroller, where the analog signals are transmitted for digital

conversion (AD conversion). After digitization, the microcontroller calculates the heart rate (BPM, Beats Per Minute) and the inter-beat interval (IBI, Inter-Beat Interval) using corresponding algorithms. The processed data is then displayed in real time on the OLED display. Additionally, the system utilizes the USART serial port for communication between the microcontroller and the PC, sending the collected data to the host computer for visual representation. The workflow of the main program is illustrated in Fig. 7.

The external auxiliary circuit of the heart rate measurement sensor is primarily divided into two main parts: the first part includes the LED light-emitting circuit and the APDS-9008 light-sensing circuit, while the second part consists of an RC filtering circuit and an amplification circuit based on the low-power operational amplifier MCP6001. The detailed design of these circuits is illustrated in Fig. 8.



**Fig. 8** Heart Rate Sensor Flowchart

### 2.2.2 Upper Computer Design

The STM32 microcontroller and the PC-based host computer communicate heart rate data and intervals via a serial port at a baud rate of 115200. In the host computer software, a dynamically updated heart rate waveform graph is displayed at the top, while the latest heart rate values and intervals are shown at the bottom, enabling real-time monitoring of heart rate changes. The interface of the host computer is illustrated in Fig. 9.



**Fig. 9** Heart Rate Sensor Flowchart

## 3. Test

### 3.1 Experimental Procedure

To investigate the effect of psychological stress on heart rate variability (HRV), a stress-induced experiment was designed. The psychological stress monitoring system is portable, and resistant to external light interference, allowing for easy monitoring by placing the index finger or wrist on the sensor surface. The experiment was conducted under different physical conditions and environmental stressors, involving six mentally healthy subjects aged between 22 and 48. None of the subjects had taken any psychotropic drugs, and they remained seated and still for 10 minutes prior to the experiment. The experimental procedure was as follows:

- **Baseline Measurement:** Subjects maintained a state of deep relaxation for 5 minutes in a quiet, temperature-controlled environment. During this period, the index finger of the right hand was placed on the sensor module to collect baseline HRV data, which served as a reference for stress effects on the body.

- **Intervention Tasks:** Subjects performed two intervention tasks: a 4-minute arithmetic task and an 8-minute moderate-intensity exercise. Instantaneous HRV changes were recorded at 2-minute intervals during these tasks.
- **Recovery Period:** After each intervention, a 15-minute rest period was provided to ensure subjects fully recovered to baseline HRV levels.

This experiment, which accurately captures the effects of psychological stress on HRV, while ensuring the safety and comfort of each subject.

### 3.2 Results of the Experiment

Psychological stress was assessed in 6 subjects using the above experimental method and the results of HRV test of the subjects are shown in Table 1.

**Table 1.** HRV test results

Serial Number	Baseline Value	Count		Campaigns			
1	131	130	128	123	118	101	99
2	98	98	96	96	88	79	68
3	82	79	78	77	70	61	54
4	59	57	58	56	50	48	45
5	46	45	43	42	31	23	18
6	32	32	30	31	27	19	15

### 3.3 Health Advice

To enhance physical health, it is recommended to optimize sleep quality by ensuring 7 to 8 hours of quality rest each night, engage in regular physical activity such as aerobic exercise at least three times a week to improve fitness, and maintain mental health by managing stress positively and avoiding excessive anxiety. Additionally, adopting a balanced diet by reducing oily food intake and increasing the consumption of fresh vegetables and fruits is essential, along with scheduling regular health check-ups, particularly for heart health, to identify and address potential issues early. These practices collectively promote long-term physical and mental well-being while reducing the risk of health-related problems.

## 4. Summary

Due to the high-pressure lifestyle in modern society, the number of people facing health issues is increasing year by year, with psychological stress emerging as one of the primary health challenges. To address this, the system employs a hardware framework based on the STM32F103C8T6 microcontroller, the XD-58C PulseSensor heart rate detection module, an OLED display, and other components, integrated with host computer software to develop a comprehensive heart rate monitoring system. This system effectively collects the user's heart rate data, analyzes heart rate variability (HRV), and provides a host computer platform for data reception and visualization. By enabling users to view and analyze their health trends in real time, the system offers a practical solution for monitoring and managing psychological stress and overall well-being.

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