Intelligent Wristband Design Based on STM32 Microcontroller Unit

Ziwang Tao[1, 2, 3], Juan Zhao[1, 2, 3, *], Feng Wang[1, 2, 3], Seiichi Kawata[1, 2, 3], and Jinhua She[4,**]

[1] School of Automation, China University of Geosciences, Wuhan 430074, China

[2] Hubei Key Laboratory of Advanced Control and Intelligent Automation for Complex Systems, Wuhan 430074, China

[3] Engineering Research Center of Intelligent Technology for Geo-Exploration, Ministry of Education, Wuhan 430074, China

[4] School of Engineering, Tokyo University of Technology, Hachioji, Tokyo 192-0982, Japan

Abstract. Health is becoming increasingly important and a healthy lifestyle has become a fashionable trend. Against this background, an intelligent wristband based on the STM32 microcontroller unit (MCU) is designed to provide comprehensive health monitoring and management functions, including time display, temperature, heart rate, and blood oxygen measurement. It also reacts to the user's exercise safety and health in real time. The wristband immediately triggers an audible and visual alarm if the data is out of the set range. Finally, Bluetooth technology connects to a mobile phone application (app), allowing users to conveniently view various health data and make adjustments via their phones. This intelligent system gives users a more intuitive understanding of their health status, achieving personalized and intelligent health management.

Keywords: Intelligent wristband; STM32; Health monitoring

1 Introduction

With the accelerated pace of modern life and increased health awareness, intelligent wearable devices have become a popular health management tool. The design of an intelligent wristband based on the STM32 MCU combines advanced technology and convenience to provide comprehensive health monitoring and management functions.

Xia et al. [1] designed a smart wristband based on an STM32 MCU to achieve the

---

This work was supported in part by the National Natural Science Foundation of China under Grant 62106240; China Postdoctoral Science Foundation under Grant 2022M722943; Fundamental Research Funds for the Central Universities, China University of Geosciences (Wuhan), under Grant CUG240635; the "CUG Scholar" Scientific Research Funds at China University of Geosciences (Wuhan) under Grant 2022029; the Natural Science Foundation of Hubei Province, China, under Grant 2020CFA031; the 111 Project under Grant B17040; and JSPS (Japan Society for the Promotion of Science) KAKENHI under Grants 23K25252 and 24K03325.

* Corresponding author, email: zhaojuan0859@cug.edu.cn

** Corresponding author, email: she@stf.teu.ac.jp

functions of exercise monitoring and heart rate detection. Zhu et al. [2] designed a smart wristband with WiFi localization and automatic billing. Zeng et al. [3] designed a wristband that was tested to have more than 98% accuracy in step counting, heart rate, and temperature detection. Zhan et al. [4] designed a wristband using a built-in accelerometer to recognize emotions. Qu et al. [5] used a six-axis inertial measurement module and a convolutional neural network to recognize activity patterns.

These designs greatly enhance the utility of the device through versatile integration and expandability. However, they cannot finely analyze the user's exercise status and synchronize the data remotely and are also flawed in terms of real-time and data transmission stability. This paper proposes a new intelligent wristband with STM32 MCU as the core controller to monitor the user's real-time exercise status, heart rate, exercise time, and mileage detection. In addition, it can connect with mobile phone app through Bluetooth modules to analyze the data synchronously, which improves the science and convenience of health management. The design meets daily wear needs and has high practical value and market prospects.

2 Hardware Design

2.1 Overall System Architecture

The design consists of an STM32 MCU, a sensor module, an OLED display module, a Bluetooth module, a mobile app, an alarm module, and a power module. The overall block diagram of the system is shown in Fig. 1.

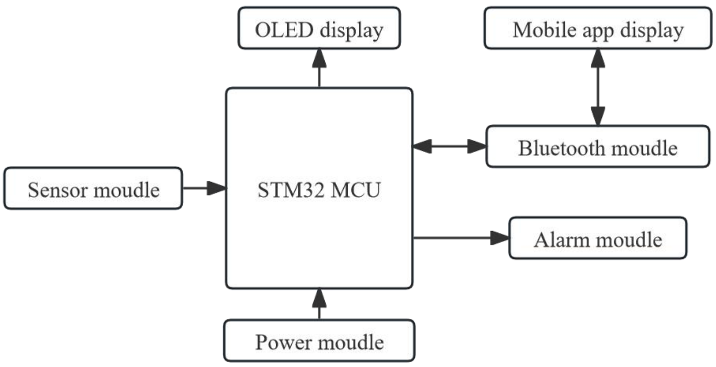

Fig. 1. Overall system architecture diagram

The data collected by the sensor module is calculated and processed by the MCU and then transmitted to the OLED display and mobile phone app for display, respectively. Meanwhile, the alarm module monitors the user data and triggers an alarm when the data exceeds the set range.

2.2 MCU Module Design

To achieve the versatility of this design, an MCU that can handle complex calculations and high-speed communication is required, and the STM32F103C8T6 chip is used as the control center for this design. Compared with the STC51, the STM32 MCU has more features. Firstly, the STM32 has a complete development ecosystem, including many development tools, boards, and software libraries. The STC51 is based on the Intel 8051 series core with an 8-bit architecture, while the STM32 MCU is based on the ARM Cortex-M series core with a 32-bit architecture, which allows it to process more data at the same time. This gives the STM32 an advantage in handling complex tasks and high-speed communications, making it a perfect fit for our design.

2.3 Pedometer Module Design

A 3-axis acceleration sensor is required for step and distance detection, especially fall detection. A 3-axis capacitive acceleration sensor called the ADXL345 was selected as the pedometer module for this system, and the central detection part of the ADXL345 is a G-CELL sensor, which acquires the acceleration in the mutually orthogonal directions of its X, Y, and Z axes.

The G-CELL sensor can be simplified as three capacitive pole plates. The capacitive plates inside the sensor also move when its carrier moves, changing the internal capacitance. This change in capacitance value is converted into a final voltage output value through a series of signal-processing steps to complete the acceleration measurement. First, the capacitance-to-voltage conversion converts the capacitance value into a voltage signal. Next, this voltage signal is amplified to increase its amplitude to be easily detected and processed. Finally, this signal is filtered to remove noise and unwanted frequency components to improve the accuracy and reliability of the measurement [6].

2.4 Heart Rate Oximetry Module Design

For efficient and reliable health monitoring that is suitable and convenient, the MAX30102 was chosen for this design. The MAX30102 measures heart rate and blood oxygen using the photovoltaic volumetric method. This method uses the volume changes in skin microvessels caused by heartbeats to indirectly estimate heart rate and oxygen saturation by measuring changes in light absorption or scattering in the skin [7]. A schematic diagram of the MAX30102 is shown in Fig. 2.

The communication between MAX30102 and the MCU adopts the IIC communication method. The VIN pin (Fig. 2) serves as the power input and the pull-up level for the IIC bus, connected to a 5 V power supply.The SCL pin is connected to the clock of the IIC bus. The SDA pin is connected to the data of the IIC bus to transmit the data to the MCU, which gets the value of the converted light intensity. Then, the corresponding heart rate and blood oxygen can be obtained by writing the corresponding algorithms.

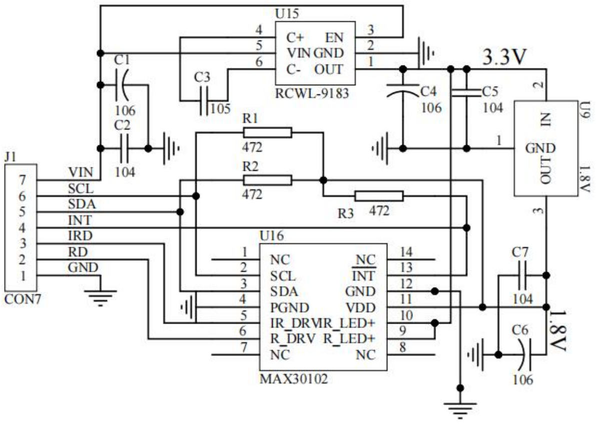

Fig. 2. MAX30102 schematic

2.5 Temperature Measurement Module Design

The reason for choosing DS18B20 as a temperature sensor is its digital communication method based on a single bus interface. DS18B20 requires only one IO port to connect to the MCU, and it can directly output digital signals to ensure the accuracy and reliability of temperature measurement results.

The temperature measurement principle of the DS18B20 is based on the internal inclusion of two crystal elements with a large temperature sensitivity difference, which have a large difference in temperature coefficient so that they produce a different oscillation frequency difference as the temperature changes[8]. By measuring this frequency difference, the DS18B20 can calculate the current temperature.

2.6 Clock Module Design

To keep the circuit interface simple and time accurate, this design uses the DS1302 as the clock module. The schematic diagram of the DS1302 module is shown in Fig. 3.

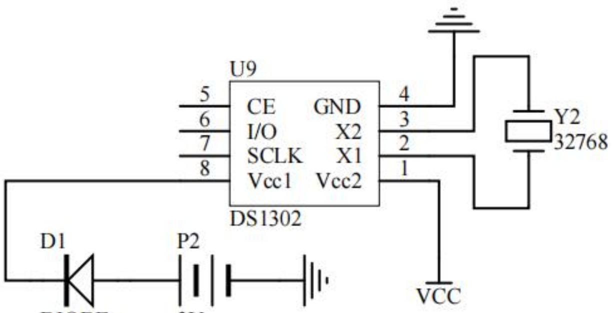

Fig. 3. DS1302 schematic

The DS1302 features high performance and low power consumption, and the clock can be accurate to the second. It also incorporates a crystal oscillator circuit that eliminates the need for an external oscillator component, thus simplifying the overall system design[9]. The X1 and X2 pins are connected to an external 32.768 kHz crystal. The SCLK pin is the serial clock input. The I/O pin is used for transmitting data and receiving information.

2.7 PCB Design

For the circuitry of each module in the system, the PCB is drawn in Altium Designer software. The overall PCB diagram of the completed hardware is shown in Fig. 4.

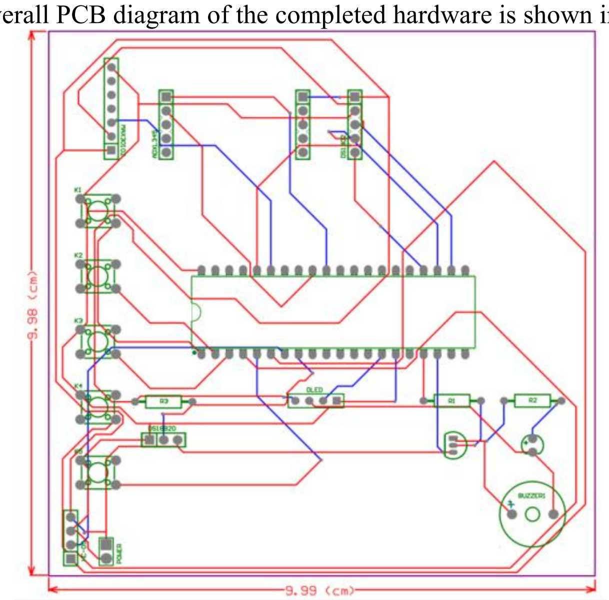

Fig. 4. System hardware PCB

3 System Software Design

3.1 Overall Process of System Software

Following the system's activation, the pin configuration and IIC interface of the STM32 must be initialized. Subsequently, the data detected by the ADXL345, MAX30102, and DS18B20 sensors must be obtained. Then, the data are converted into decimal values and transmitted to the mobile phone app via Bluetooth HC-05 serial port for display. The DS1302 displays the time and date, and the data are displayed on the OLED screen after initializing the OLED screen. Ultimately, the system determines whether the heart rate, blood oxygen, and temperature are within the normal range. An alarm will be generated if these data are out of the set ranges.

3.2 Pedometer Module Software Design

The flowchart for the ADXL345 pedometer module is shown in Fig. 5.

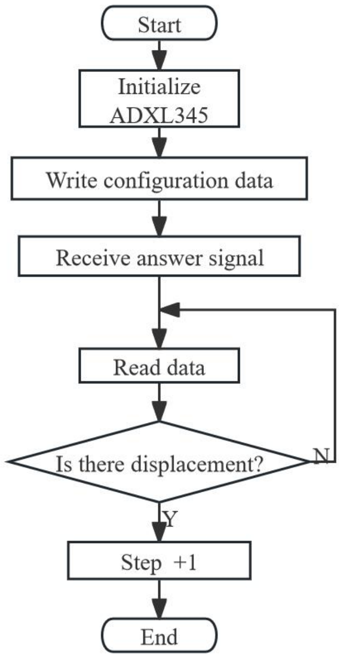

Fig. 5. Pedometer module program flowchart

The ADXL345 is initially configured to the operational state. Next, the initial signal is written to the ADXL345 to facilitate communication. Then, a stop and answer signals are written to confirm that the device is receiving the initial signal. Then, an answer signal is written from the ADXL345 to ensure proper communication. Finally, the data is read from the ADXL345 sensor. The readings should be compared to a set threshold to determine whether displacement occurred. If a displacement is detected, the step counter should be incremented by one.

3.3 Heart Rate and Blood Oxygen Detection Module Software Design.

The flowchart of the heart rate module program is shown in Fig. 6. This flow chart shows a basic workflow for measuring heart rate and blood oxygen using the MAX30102 sensor. The flow begins with the system start-up. First, the IIC communication interface is initialized. Next, the initialization configuration is carried out. Finally, the MAX30102 sensor is initialized. Once initialization is complete, the system retrieves data from the MAX30102 sensor and finally the process ends by processing this data to calculate heart rate and blood oxygen levels.

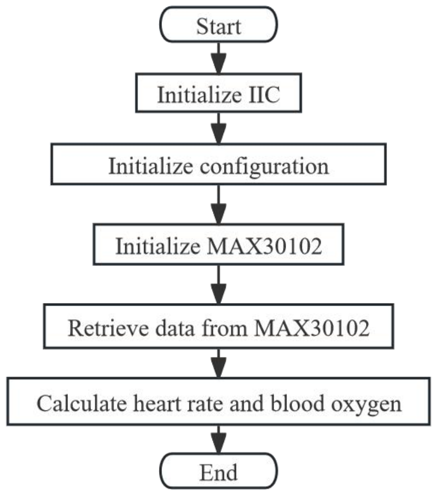

Fig. 6. Flowchart of heart rate module

3.4 Clock Module Programming

The initialization of the SPI interface and the configuration of the requisite pins are the first steps undertaken by DS1302. The DS1302 registers are updated with the current time and date through a write operation. Subsequently, the real-time and date data are obtained by reading the registers at regular intervals. Subsequently, the data undergoes processing and is displayed by the requisite specifications. The entire process must adhere to the communication protocol of the DS1302, encompassing the transmission of the initiation command, address, and data, as well as the execution of the requisite operations by the response of the clock chip.

3.5 Temperature Acquisition Module Software Design

The DS18B20 temperature measurement flowchart is shown in Fig. 7. The temperature data from the DS18B20 is represented in BCD code, which is converted to decimal temperature data. At this point, the temperature data contains two decimals, but no output is generated. Therefore, the actual temperature is one percent of the detected temperature. At 12-bit resolution, the lowest bit of the temperature data represents 0.0625° C. If the detected data is positive, multiply the measured data by 0.0625. If a positive number is detected, multiply the measured data by 0.0625 to obtain the true temperature value.

4 System Testing and Analysis

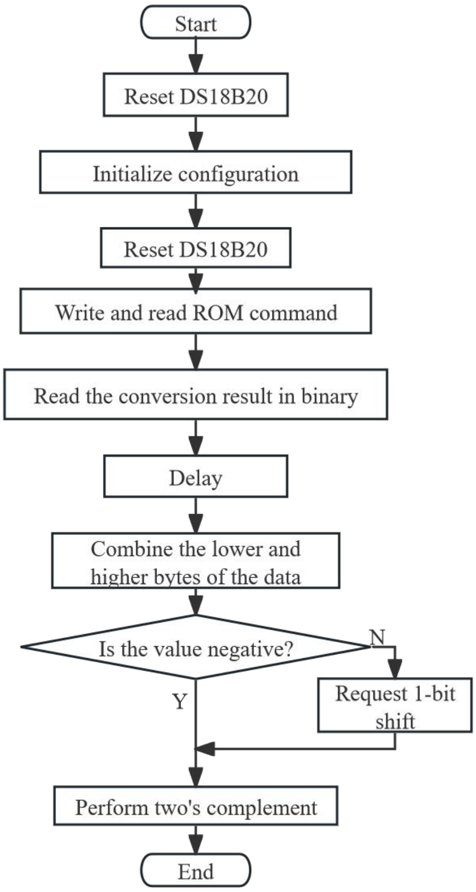

Fig. 7. DS18B20 temperature measurement flowchart

4.1 Overall System Functionality Testing

The welded system is illustrated in Fig. 8.It is necessary to make the relevant settings in Keil5 software to adapt the STM32 MCU and select the STLINKV2 downloader to burn the program.

Once the system is powered on, the user should open the mobile phone app to connect Bluetooth. The display will initially show the time and date and begin to collect ambient temperature data. When the user places their finger on the MAX30102 heart rate sensor and waits for a certain period, the system will detect and display the heart rate and blood oxygen values. Additionally, if the user picks up the entire board and shakes it either up and down or left and right, the number of steps is increased and displayed on the mobile phone app. The test results for each of the above modules are shown in Fig. 9.

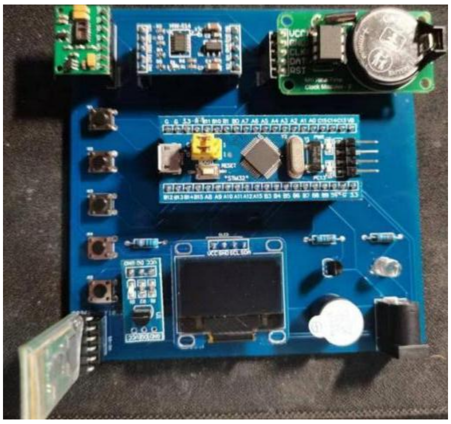

Fig. 8. Soldered board

Fig. 9. Sensor data acquisition function test diagram

4.2 Inspection Data Testing

Ten tests were carried out using the wristband to measure body temperature, heart rate, and steps. For comparison, a thermometer was used to measure body temperature, and the M2239B1 device was used to measure heart rate, where steps are the data displayed on the wristband after walking 100 steps. The test data after the ten tests are shown in Tables 1 and 2. In the first test, the wristband measured a heart rate of 90 beats per minute. Meanwhile, the M2239B1 device recorded a heart rate of 86 beats per minute. The temperature measured by the wristband was 36.3°C, while the thermometer showed 36.7°C. Besides, the wristband registered 98 steps while the actual count is 100.

After testing, the system function runs normally, the error of heart rate is ±2 BPM, the error of body temperature is ±0.3 ℃, the error of step number is ±2, the average blood oxygen concentration is 98%, which is in the human body between the normal blood oxygen concentration value. It can meet the needs of daily health monitoring and compensate for the shortcomings of the traditional thermometer and heart rate monitor with a single measurement index.

TABLE 1. Comparison of heart rate results

Number	Wristband (BPM)	M2239B1 (BPM)	Difference (BPM)	Wristband (℃)	Thermometer (℃)	Difference (℃)
1	86	90	-2	36.3	36.6	-0.3
2	93	93	0	36.4	36.5	-0.1
3	89	92	-2	36.5	36.7	-0.2
4	85	88	-1	36.9	36.7	0.2
5	95	93	1	36.2	36.0	0.2
6	96	91	-2	36.8	36.5	0.3
7	88	82	-1	36.8	37.1	-0.3
8	90	86	-1	36.5	36.3	0.2
9	92	91	-1	36.9	37.1	-0.2
10	88	90	-2	36.6	36.3	0.2

TABLE 2. Step count measurement results

Number	Steps	Difference
1	100	0
2	97	-3
3	100	0
4	101	1
5	98	-2
6	98	-2
7	100	0
8	99	-1
9	102	2
10	99	-1

4.3 Personalization Test

The user presses the switch button to enter the exercise interface and then presses the plus button to start the exercise. The user can record the mileage and exercise time and display it on the mobile phone app, as shown in Fig.10A. The user then sets the exercise time and mileage limit, as shown in Fig. 10B.

A.Record interface B.Alarm limit setting

Fig. 10. Campaign settings screen

When a fall event is detected, the system will alarm, as shown in Fig. 11.

5 Summary

In response to the demand for health detection of an individual's daily exercise, this paper designs an intelligent wristband based on the STM32 MCU, which can detect the user's heart rate and blood oxygen, temperature measurement, pedometer, and exercise status. The primary objective of this paper is to present the following:

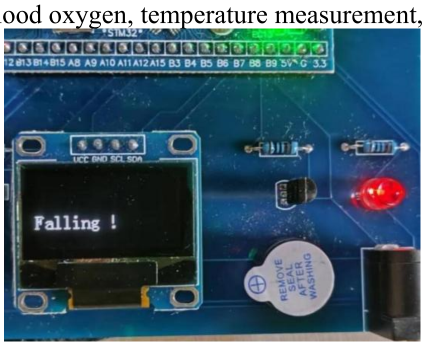

Fig. 11. Falling test

(1) Feature-rich design. The intelligent wristband shows its versatility by integrating temperature measurement, oximetry, heart rate measurement, pedometer, exercise mileage, time detection, and an emergency alarm. These features make the wristband meet daily health monitoring needs and provide critical data support during exercise and in emergency situations. This comprehensive functionality greatly enhances both the user experience and the overall utility of the device.

(2) Intelligent and personalized systems. The wristband connects seamlessly to the mobile app via Bluetooth technology, allowing users to synchronize and view all test data in real time. This includes not only basic temperature, blood oxygen, and heart rate monitoring data, but also detailed exercise analysis such as step count, exercise

mileage, and exercise time. Users can conveniently view their health data on the mobile app and personalize their health management and exercise plans based on this data. The mobile app also provides personalized settings options, allowing users to set personalized reminders and alarms based on their health goals and lifestyle habits. In addition, the app can provide personalized advice and feedback for different exercise types and intensities to help users optimize exercise results and improve health management.

(3) Health monitoring systems. After detailed testing, the intelligent wristband shows great accuracy in measuring temperature, blood oxygen, heart rate, and other health data. The test results show that these data are very close to the results of standard measuring devices, indicating that the wristband can provide reliable health monitoring information. Accurate health data not only helps users understand their health status promptly but also supports scientific health management and decision-making, thus effectively improving users' health.

References

1. Miao Xia, Xiaoyan Chen, and Jianliang Li.: Design of Smart Bracelet Based on STM32 Microcontroller. Proceedings of International Conference on Artificial Life and Robotics 27, 1080–1084 (2022).
2. Yang Zhu, Yanning Yang, Chenle Dong, Shudong Feng, and Yongxing Du.: Design of Playground Smart Bracelet Based on STM32F103C8T6. Computer Measurement and Control 32 (1), 1–13 (2024).
3. Guiling Zeng, Sudie Ye, and Ping Wang.: Design of Smart Bracelet Based on STM32 Microcontroller. Journal of Xi'an College of Arts and Sciences (Natural Science Edition) 26 (3), 72–76 (2023).
4. Zhan Zhang, Yufei Song, Liqing Cui, Xiaoqian Liu, and Tingshao Zhu.: Emotion Recognition Based on Customized Smart Bracelet with Built-in Accelerometer. PeerJ: The Journal of Life & Environmental Sciences 4, e2258 (2016).
5. Junsuo Qu, Ning Qiao, Haonan Shi, Chang Su, and Abolfazl Razi.: Convolutional Neural Network for Human Behavior Recognition Based on Smart Bracelet. International Journal of Fuzzy Systems 38 (5), 5615–5626 (2020).
6. Michelle Annice Tjitra, Nagisa Eremia Anju, Dodi Sudiana, and Mia Rizkinia.: A Wireless Noninvasive Blood Pressure Measurement System Using MAX30102 and Random Forest Regressor for Photoplethysmography Signals. Computers 13 (5), 125 (2024).
7. Zimeng Gao.: Design of Temperature Control System. International Journal of Networked and Distributed Computing 7 (9), 37–41 (2023).
8. Pei R , Cao Y .: Design of Multi-Channel Temperature Acquisition System Based on STM32. Journal of Artificial Intelligence Practice 6(1), (2023).
9. Chunyu Zhang.: Research on The Function Test Method of Perpetual Calendar Chip DS1302. Microprocessor 40(05),13-16, (2019).