

Non-contact Health Detection Device based on Millimeter Wave Radar

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Abstract

With the deepening implementation of the "Healthy China 2030" strategy, health issues have increasingly garnered widespread attention. Understanding one's health status primarily involves monitoring the normality of basic physiological parameters. For instance, conditions such as fever or pneumonia may manifest as an elevated heart rate and more rapid, deepened breathing. Timely acquisition of basic human physiological information has thus become a critical requirement in the modern medical industry. To address these challenges, this project proposes designing a non-contact health detection system leveraging STM32 and millimeter-wave technology. The millimeter-wave radar is employed to capture micro-motion signals generated by chest movements during breathing and heartbeat. STM32 serves as the core processing unit to analyze the collected data. An OLED display then presents real-time information, including heart rate, respiratory rate, and human body distance. Simultaneously, this data is transmitted to mobile devices via WiFi or Bluetooth modules. On smartphones, phase signal-based charts of heart rate and respiratory rate are generated, enabling intuitive visualization of current health metrics. Furthermore, the highly integrated nature of its modules significantly reduces the system's size, allowing broader access to basic human physiological information with greater convenience for a wider population.

Keywords

Millimeter - Wave Radar; STM32 Single-chip Microcomputer; Non - contact Detection; Health Detection.

1. Introduction

With the continuous advancement of the 'Healthy China 2030' strategy and the acceleration of the global aging society, non-contact health monitoring technology is gradually becoming a key breakthrough direction in the field of medical health. Although traditional contact detection equipment can provide high-precision data, due to its poor wearing comfort, long-term use can easily lead to skin allergies, and cannot meet the needs of special scenarios and many other problems, its limitations have become increasingly obvious. In this context, the non-contact detection technology based on millimeter wave radar has gradually become a research hotspot in the field of health monitoring by relying on the unique advantages of 'non-wearing, non-intrusive and anti-environmental interference'. The technology can realize the detection of health indicators without wearing any equipment, which greatly improves the user 's sense of experience, and also provides a new solution for health detection in special environments.

However, the current millimeter-wave radar detection system faces two major challenges. On the one hand, the stability of the millimeter-wave radar echo signal is poor, and it is susceptible to environmental factors such as temperature and humidity, resulting in a certain degree of fluctuation in the echo signal, which affects the correctness of the measurement results. On the other hand, the existing systems generally have the problem of excessive volume, and the demand for high power consumption, miniaturization and low power consumption is very urgent. Most of the traditional equipment needs to use PC and industrial computer as terminals for data processing, which is difficult to meet the long-term detection needs in the family environment.

In this paper, a non-contact health detection system is designed for related problems. The system is based on STM32 and millimeter wave radar. STM32, as the core control unit, has the characteristics of high cost performance, rich interface and low power consumption. With 60 GHz millimeter wave radar, this system can carry out detection work at a distance of 0.4 to 1.5 meters. With the help of WiFi / Bluetooth module, the detection data can be transmitted to mobile phone APP or cloud in real time to achieve remote detection. The experimental results show that the device has accuracy and reliability, and has application value in respiratory rate and heart rate detection. This system has broad market prospects in the field of home detection and remote tracking detection of chronic disease patients.

2. Related Work

STM32 is one of the mainstream 32-bit micro controller series launched by STMicro electronics. It is based on the ARM Cortex-M core. Because of its high performance and low power consumption, as well as high cost performance and ecological maturity, it is widely used in the field of embedded system development.

STM32 has a series of rich models, from the entry-level such as F103C8T6 to high-performance like H7 series. It has a wide range of applications in the field of intelligent hardware, industrial control, consumer electronics and so on. The single-chip microcomputer model used in this study is STM32F103C8T6. At the hardware level, the main frequency of this single-chip microcomputer 72MHz can meet the requirements of real-time control. It has 64KB Flash storage space and 20KB SRAM running memory. It also has many rich external ports : 37 GPIOs, 3 USARTs, 2 SPI / I2C, 12-bit ADCs, and universal timers. These features enable it to support UART serial communication, SPI driver peripherals, I2 C connected sensors, and ADC to collect analog signals, which meets the basic peripheral requirements of most embedded scenarios [1,2].

STM32F103C8T6 is selected as the core processing unit, and HLK-LD6002 60GHz millimeter wave radar is used to carry out distance measurement and collect data such as heart rate and respiration rate [3]. MQ2 is used to detect harmful gases in the environment, and SHT30 is used to detect the temperature and humidity of the environment. All the above data are finally displayed by OLED display, processed by STM32 microcontroller, and sent to mobile phone applications by WiFi / Bluetooth module.

1. Circuit power supply : the working voltage of the whole circuit is stable at 5V, the working voltage of millimeter wave radar is 3.3V, and the power supply requirements are more stringent, so it is selected again to carry out step-down and remove ripple processing work.

2. Millimeter wave radar : With the help of HLK-LD6002 60GHz millimeter wave radar, the data acquisition of distance, heart rate and respiration rate can be achieved.

3. Environmental factor measurement : With the help of MQ2 smoke detection module and SHT30 module, the harmful gas, temperature and humidity and other related information in the environment are detected.

4. WiFi / Bluetooth module: STM32F103C8T6 processor acts as CPU by means of communication with mobile phones and other host computers.

5. Data processing : The STM32F103C8T6 processor is used as the CPU, which is responsible for processing the data collected by each module.

6. Data display. After completing the relevant calculation operations, the OLED screen equipped with the device can obtain various information such as current heart rate, respiration rate, phase difference, distance, and temperature and humidity.

As shown in Figure 1, the framework part :

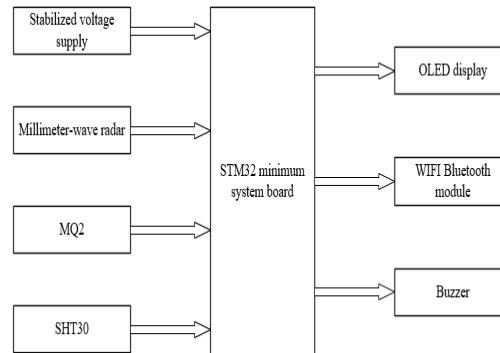


Fig 1. Framework display

2.1. Hardware Scheme Device Selection

2.1.1. Selection of Main Control Module

STM32 chooses ARM Cortex-M architecture as the core microcontroller of human fall detection system. This architecture has the advantages of high performance and low power consumption. STM32 has rich software ecology and can provide a large number of ready-made open source libraries and examples. After performance comparison, STM32F103C8T6 microcontroller is more in line with the needs of this project because of its own characteristics.

2.1.2. Millimeter Wave Radar Selection

HLK-LD6002 is selected, which is developed by Shenzhen Hailingke Electronics Institute. It uses FMCW technology and two-transmitter and two-receiver mode. Its operating frequency is between 58-62GHz, and the detection distance is 0.4-1.5m. This module can perform non-contact monitoring of respiration and heartbeat. The typical value of accuracy reaches 90 %, and it will not be interfered by environmental factors such as temperature and humidity, illumination, and airflow. The data is output by serial port ASCII, the power supply requirement is 3.3V, and the size is 15 × 40mm. It supports pin insertion and patch connection. It also reserves multiple sets of IO ports for secondary development, and the price is relatively cheap, which is more in line with the needs of this study.

2.2. System Hardware Principle Diagram

The hardware structure of the human fall detection device mainly includes STM32 microcontroller module, HLK-LD6002, MQ2 gas detection module, SHT30 temperature and humidity detection module, DX-WF24-A dual-mode Bluetooth module and OLED display module. STM32 is the main control module of the system, which undertakes the work of real-time data acquisition. HLK-LD6002 60GHz millimeter wave radar module is responsible for collecting the main heart rate and respiratory rate data. The principle of the hardware system is shown in Figure 2.

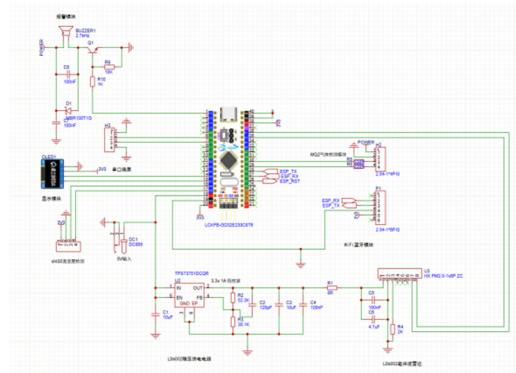


Fig 2. Hardware Schematic Diagram

2.3. Main Function Module Circuit Diagram

2.3.1. Power Circuit Design

The main circuit of the system uses a 5V power supply, and its input end is the DC005 interface, which is connected to the external 5V power plug. The pin 1 and the plug power supply end are turned on to supply a 5V voltage for the subsequent circuit. Both pin 2 and pin 3 are grounded to form a power circuit to ensure that the circuit can obtain a stable 5V power supply. Here, it mainly supplies power to the single-chip microcomputer, because the single-chip microcomputer 's sensor and RF chip all need 5V power supply, so as to ensure the normal operation of the system. The power demand of the remaining modules is 3.3V, which can be directly powered by the single chip microcomputer. The power supply circuit is shown in Figure 3 :

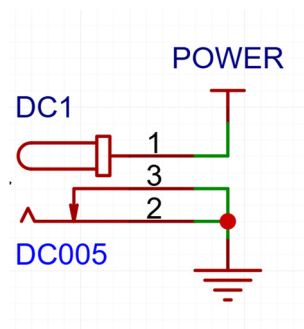


Fig 3. Total power circuit design

The main responsibility here is to supply power to the single-chip microcomputer. The sensors and RF chips equipped with the single-chip microcomputer require a voltage of 5V to ensure its normal operation. The remaining modules of the circuit require a power supply of 3.3V, which can be obtained directly by means of the single-chip microcomputer. The power supply, however, HLK-LD6002 60 GHz millimeter-wave radar has high requirements for power supply, so it is necessary to specially design a buck circuit.

2.3.2. 3.3V Step-down Circuit Design

This step-down circuit uses a TPS73701DCQR voltage regulator chip to convert the input voltage into a stable 3.3V output, and the output has a low ripple characteristic, providing a stable power supply for the HLK-LD6002 60GHz millimeter-wave radar. The schematic diagram is shown in Figure 4.

C1, a 10μF capacitor, is used as the input filter capacitor, which can filter out the clutter generated by the power input and improve the stability. FB is the feedback pin. With the help of the voltage divider circuit composed of R2 and R3, the output voltage is adjusted and stabilized

to ensure the output accuracy. The output filter network composed of C2, C3 and C4 can reduce the output ripple, improve the purity of the power supply, and ensure the stable operation of the post-stage circuit. R1 is the zero-ohm resistance of 0Ω, which can be used to disconnect or connect the circuit during debugging, so as to facilitate the test of different power supply paths or reserve expansion function.

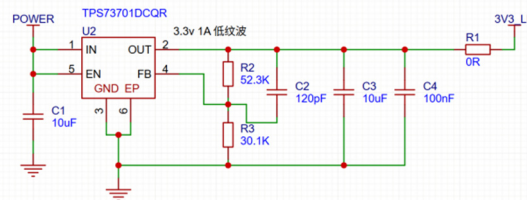


Fig 4. FTSP73701DCQR regulator chip schematic diagram

2.3.3. HLK-LD6002 60GHz Millimeter Wave Radar Circuit Design

This module selects the HLK-LD6002 60GHz millimeter wave radar produced by Hailingke Company, and its related diagram can be seen in Fig.5

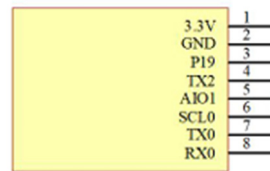


Fig 5. HLK-LD6002 60GHz millimeter wave radar schematic diagram

Pin 1 is called 3V3 POWER INPUT, which is used to access 3.3V power supply, pin 2 is GND, pin 3 is GPIO19, which can be used for Boot1 function, etc. As for the specific function, it can be configured according to the user 's secondary development. Pin 4 is GPIO20, which can be used as TX2 pin for data transmission and other functions. Pin 5 is AIO1, which belongs to analog input and output pin, which can be used to connect external analog equipment or collect and output analog signals. Pin 6 is GPIO07, which can be used as SCL0 pin for clock line in I2 C and other communication protocols. It can also be used for other functions. Pin 7 is TX0, which is connected to the sending pin of the external serial port to send the data of the module to the external device. Pin 8 is RX0, which is connected to the receiving pin of the external serial port to receive the data sent by the external device to the module.

Millimeter wave radar transmits millimeter wave signal, receives the signal returned by the human body and analyzes the data. When the transmitted millimeter wave signal contacts the human body, the human chest will produce radial displacement due to heartbeat and respiration. The amplitude is about 0.1 ~ 1mm, and the speed is about 0.1 ~ 5mm / s.This periodic motion causes the echo signal to produce periodic modulation, forming a micro-Doppler effect [4]. It is assumed that the chest motion is a simple harmonic motion, and its mathematical model is Formula (1).

$$x(t) = A \cdot \sin(2\pi f_h t + \phi_0) \tag{1}$$

Where A refers to the vibration amplitude, that is, the displacement generated by the chest, f_h represents the heartbeat frequency, the unit is Hz, Φ_0 represents the initial phase, and the echo signal generated by these conforms to the formula (2).

$$\phi(t) = \lambda 4\pi x(t) = \lambda 4\pi A \sin(2\pi f_h t + \phi_0) \tag{2}$$

Among them, $\lambda = c / f_c$ is the radar wavelength, where $c = 3 \times 10^8 \text{ m/s}$ represents the speed of light, and $f_c = 60 \text{ GHz}$ represents the radar center frequency [5,6]. Then, the phase information of the echo signal is extracted by means of orthogonal demodulation technology, such as I / Q demodulation, to obtain a composite signal containing heart rate and respiratory rate. In view of the difference between heartbeat frequency and respiratory frequency, the frequency component corresponding to heartbeat can be separated by band-pass filter, and then the peak frequency is calculated by fast Fourier transform or autocorrelation algorithm, and finally converted into heart rate [7-9].

2.3.4. MQ2 Harmful Gas Detection Circuit Design

The MQ-2 smoke sensor uses tin dioxide, which has a low conductivity in clean air and belongs to the surface ionic N-type semiconductor. When the MQ-2 smoke sensor is in an environment of 200 to 300 degrees Celsius, tin dioxide will adsorb oxygen in the air to form negative ion adsorption of oxygen, which reduces the electron density in the semiconductor and increases the resistance value. When the sensor is in contact with smoke, if the barrier at the grain boundary changes due to the action of smoke, the surface conductivity will change. With the help of this characteristic, the information of smoke can be obtained. The greater the smoke concentration, the higher the conductivity, the lower the output resistance, and the greater the output analog signal. The detection range of MQ-2 smoke sensor is more extensive. It is commonly used in gas leakage monitoring devices in homes and factories. It is suitable for the detection of liquefied gas, benzene, alkane, alcohol, hydrogen, smoke and so on. The internal circuit diagram of the smoke sensor is shown in Fig.6.

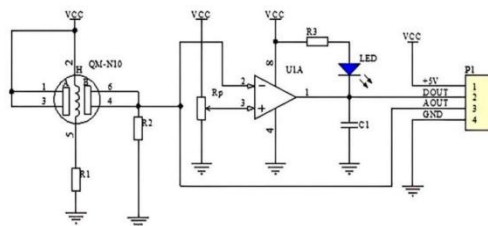


Fig 6. Internal circuit diagram of smoke sensor

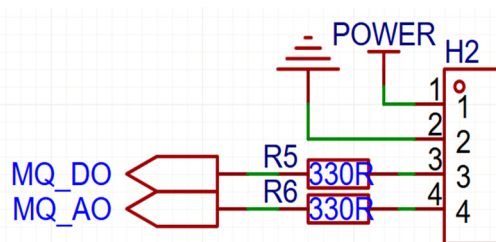


Fig 7. The schematic diagram of MQ2 harmful gas detection circuit

As a gas sensor, the resistance value of QM-N10 will change according to the change of surrounding gas concentration. It is the key core component to detect gas concentration. R1 provides heating current for QM-N10 sensor to ensure that the sensor is at normal working temperature and can accurately detect gas. R2 and QM-N10 are connected in series to convert the resistance change of the sensor into voltage signal, which is conducive to subsequent circuit processing. The potentiometer Rp is used to adjust the reference voltage of the comparator and set the alarm threshold of the gas concentration. The comparator ULA will compare the input voltage from R2 and QM-N10 and the reference voltage adjusted by Rp. When the gas concentration changes, the input voltage exceeds the reference voltage, the output level will flip

and trigger the alarm. LED is used as an alarm indicator. When the comparator outputs a specific level, the LED will be lit to indicate that the gas concentration is abnormal. P1 is the external interface, which involves the output alarm signal, power supply, digital output pin DOUT, analog output pin AOUT, which is convenient to connect with STM32 single chip microcomputer, to achieve more complex control or data transmission. The external schematic is shown in Fig.7.

2.3.5. SHT30 Temperature and Humidity Measurement Circuit Design

SHT30 is a high-precision digital temperature and humidity sensor module. The module uses Sensirion's CMOSens[®] technology to integrate capacitive humidity sensing elements and bandgap temperature sensing elements. It has high reliability and long-term stability. Its temperature measurement range is -40°C to 125°C , the accuracy can reach $\pm 0.3^{\circ}\text{C}$, the humidity measurement range is 0 to 100 % RH, and the accuracy is $\pm 2\%$ RH. The working voltage is between 2.4 V and 5.5 V, and it supports I2C communication interface, which is convenient to connect with single chip microcomputer, microcontroller and other equipment. The digital signal output is easy to process and facilitate system integration [10].

This module has the characteristics of low power consumption, fast response speed and strong anti-interference ability. It can quickly detect the changes of environmental temperature and humidity. It is suitable for automatic adjustment of temperature and humidity in the field of smart home, as well as environmental monitoring such as weather station and indoor air quality detection, and industrial automation. The production line environment monitoring is also suitable for the Internet of Things scenarios such as intelligent buildings. It can provide accurate and reliable temperature and humidity data support for various applications, and can achieve environmental optimization and intelligent control. The schematic diagram of HT30 temperature and humidity detection circuit is shown in Fig.8.

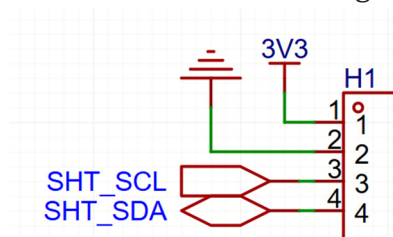


Fig 8. SHT30 temperature and humidity measurement circuit schematic diagram

The power supply of the module is borne by 1 and 2 pins. Pin 3 is the clock line of I2C communication, and its function is to synchronize data transmission. Pin 4 is the data line of I2C communication, which is mainly used to transmit temperature and humidity data and receive instructions from the main control equipment, so as to achieve the purpose of communication with the single chip microcomputer and obtain accurate temperature and humidity data. The module is suitable for environmental monitoring, smart home and other related scenarios.

3. Software Design

3.1. Software Main Program Architecture

STM32 microcontroller takes C language as the main programming language. In order to ensure the accuracy and efficiency of software design, Keil uVision5 is used to carry out the design work. The software has excellent window management function. This function is flexible and diverse, which greatly improves the convenience of program monitoring. In the whole program design process, it can give real-time design error prompts, ensure timely detection and correction of problems, and ensure software quality and stability.

According to the specific requirements of the whole system, the software will initialize all the pins of STM32 when starting, and initialize the millimeter wave radar, temperature and humidity sensor, gas sensor and wireless module in parallel, and configure the communication interface and working parameters. After that, the respiratory, heart rate and distance data of millimeter wave radar, the environmental data collected by temperature and humidity sensor and the concentration state of gas sensor will be obtained in sequence. Analyze the radar signal, that is, separate the breathing and heartbeat, calibrate the temperature and humidity, update the gas alarm sign, and then use OLED to display multi-page data, including environmental parameters, physiological indicators and debugging information. The fused data is packaged in JSON format, and finally sent to the mobile phone APP by WiFi or Bluetooth, so as to support remote monitoring until the end of the power outage program. The whole main program flow is shown in Figure 9.

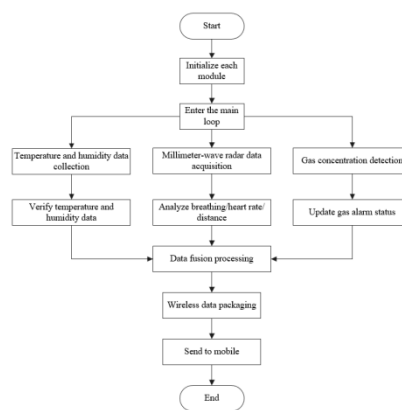


Fig 9. Main program flow chart

3.2. Millimeter Wave radar Program Design

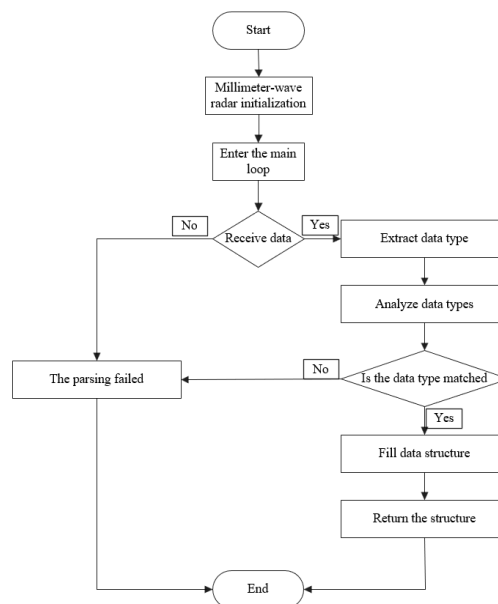


Fig 10. Millimeter wave radar program flow chart

First of all, the initialization operation of the single-chip microcomputer is carried out. This operation is mainly aimed at the data structure body used to store the analytical results. The expansion is like emptying the historical data, setting the initial value, etc., and then checking

the integrity of the data. That is, to check whether the original data contains a valid frame header, but also to check whether the data length is consistent with the format, and whether the checksum is correct, with the help of these checks to ensure that the data does not appear damaged or transmission error. Then the data content is extracted, and the key information is extracted from the data on which the verification is based, such as data type, data segment length, etc., so as to provide the corresponding basis for the subsequent analysis work, and then the data content is analyzed. According to the data type, such as heart rate, respiratory rate, distance, etc., the binary data is converted into actual physical quantities, such as floating-point values, and then filled into the structure [11]. Finally, the result is returned. If all steps are successfully completed, the parsing success and valid data are returned. If there is a failure in any link, such as verification not used, type mismatch, etc., then the parsing failure is returned. The process is shown in Figure 10.

3.3. MQ2 Program Design

The first thing to do is to carry out the initialization operation. This operation will first check the data _ fun function pointer of the sensor node to see whether it is empty, and also check whether the sensor address is a valid value. Next, the data measurement work will be carried out. Before the measurement, the measurement mode should be set to support single measurement mode (sht3x _ shot _ set _ mode) and periodic measurement mode (sht3x _ peri _ set _ mode). In the periodic mode, the SHT3X _ FETCH _ DATA command is used to obtain the cache data. Then read and check the data, first read the 6 bytes of data, the 6 bytes of data including temperature 2 bytes, CRC1 bytes, humidity 2 bytes and CRC1 bytes, then use the CRC-8 check algorithm, its polynomial is 0x31, to verify the integrity of the data, to calculate the checksum by bytes and compare with the original CRC, and finally calculate the temperature and humidity values, With the help of temperature conversion formula: $T = \frac{\text{rawtemp} * 175}{65535} - 45$, This formula is applicable to the range of 45 °C ~ 125 °C. Humidity conversion formula: $RH = \frac{\text{rawhum} * 100}{65535}$, This formula is suitable for the range of 0 % RH ~ 100 % RH [12]. According to these two formulas, the temperature and humidity are calculated respectively, and the obtained data are returned to the structure, and the whole process is ended. The process is shown in Figure 11:

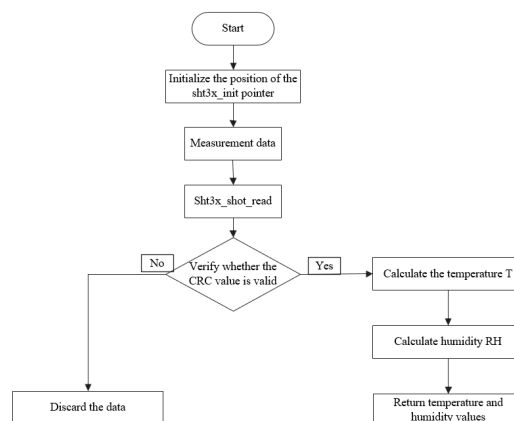


Fig 11. MQ2 program flow chart

4. Experiments and Analysis

4.1. Respiratory Heart Rate Detection Debugging

During the simulation test, the results obtained from the system test are compared with the popular watches with the function of measuring heart rate on the market. For the counting method of respiration, the stopwatch is used to count once by one breath. Since the beginning, it has been counted until the data of the system appears. Then the average number of times per minute is calculated, and then compared with the data of the system. The circuit board radar module is facing the human body and is measured at multiple positions between 0.4 meters and 1.5 meters. Finally, the contents of Table I are listed as follows.

During the measurement operation, the tester sits quietly on the chair and wears a test watch on his hand. After three measurements are carried out for each group, the average value is obtained. After observation, it can be found that when the system is measured in a common indoor environment, the error is within the range of [± 5 times / min], which meets the expected requirements of the system design.

Table 1. Heart rate measurement data comparison table

Distance(m)	0.40	0.80	1.00	1.25	1.50
The heart rate measured by this system (times / min)	73	71	83	84	83
Heart rate measured by smart watch (times / min)	74	73	81	83	81
Error	-1	-2	+2	+1	+2

Respiratory frequency measurement test, the test results are shown in Table II . In the process of respiratory measurement, the system has a long test time and a relatively slow data generation. The results obtained after the modification and optimization of the millimeter wave code are not obvious, but the overall measurement results and actual errors are within the range of [± 7 times / min], which meets the expected requirements.

Table 2. Respiratory rate measurement data table

Distance(m)	0.40	0.80	1.00	1.25	1.50
Respiratory rate measured by this system (times / min)	25	22	24	21	23
Actual respiration rate (times / min)	27	25	26	25	24
Error	-2	-3	-2	-4	-1

5. Conclusion

In this paper, a non-contact health detection device is designed. The device is based on STM32 and millimeter wave radar, which can be applied to people 's daily life. It detects heart rate and respiratory rate, and can provide support for the prevention of various diseases. When constructing the system hardware, we completed the selection of components, the design of the circuit and the programming work related to each module one by one. After hardware debugging, it is proved that the designed health detection system has basic functions.

The system carries out data processing by STM32 single-chip microcomputer, uses MQ2 and SHT30 to measure environmental related information, HLK-LD6002 is responsible for measuring human respiration and heart rate, and sends the phase data to the single-chip

microcomputer after retaining the phase data. The OLED liquid crystal will display three pages at intervals. The first page presents temperature and humidity, MQ related data and host computer link status. The second page shows heart rate, respiratory rate, distance and other information. The third page shows total phase, respiratory phase, heart rate phase and minimum alarm distance. With the help of DX-WF24-A, the information is transmitted to the set mobile phone APP to realize online data monitoring. At the same time, the icon is drawn according to the phase information, which is vividly displayed.

Acknowledgments

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