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ORIGINAL RESEARCH ARTICLE

Wearable grain silo working environment sensing and safety alarm system

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ABSTRACT

A set of wearable granary working environment sensing and security alarm system is developed to ensure the safety of granary staff. The gas sensor, piezoelectric ceramic chip, infrared transmitting and receiving tube and photosensitive resistance are used as the core components of each circuit module to collect the gas concentration signal, human respiration intensity signal, pulse intensity signal and light signal in the granary. AD0809 module chip is used to convert analog data into digital data and send it to MCU for information processing to make alarm judgment. At the same time, PTR2000 module is used to transmit the sensor data to the upper computer. The upper computer determines whether to alarm through data comparison, and transmits the alarm signal to the mobile phone through Wi-Fi in real time. Each module cooperates with each other, information real-time transmission to complete the detection of granary environment and danger alarm. The test results show that the system can meet the safety operation requirements of large and medium-sized state-owned grain depot.

Keywords: sensor; alarm system; AD0809 chip; Keil C51

1. Introduction

With the expansion of grain storage in grain depots and the wide application of chemical fumigation agents, grain depot workers often face the dangers of landslides, hypoxia, poisoning of harmful residual gases, etc. when entering the warehouse[1]. In order to address these issues, this project designs and develops a portable granary working environment and life activity sensing system for workers and other dangerous situations. The sensor itself and the connected wireless transceiver module can be used to implement automatic alarms inside and outside the warehouse, maximize the safety of workers entering the warehouse, and achieve part of the grain condition detection function.

2. System overall structure

The overall structure of the system is shown in **Figure 1**, including various sensors, signal acquisition, conditioning circuits and local alarms. Generally, it can be divided into four modules: gas detec-

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tion, respiratory and pulse monitoring, illumination detection and wireless communication[2]. The signal acquisition and conditioning circuits then process the data collected by the sensors and after preliminary amplification, conditioning, shaping and digitization of the signal, transmits the signal to the communication host of the monitoring center in the current limited transmission mode through the communication extension where it is connected with the host computer through the RS232 interface. The host computer then receives the signal sent by the communication host and conducts a real-time online analysis. Once the signal value is found to exceed the safety standard, the host computer will send an alarm command to the lower computer to trigger the local alarm. As a result, the sounding of the room alarm will go off and at the same time, the emergency situation will be reported to the relevant personnel in the form of a short message through Wi-Fi.

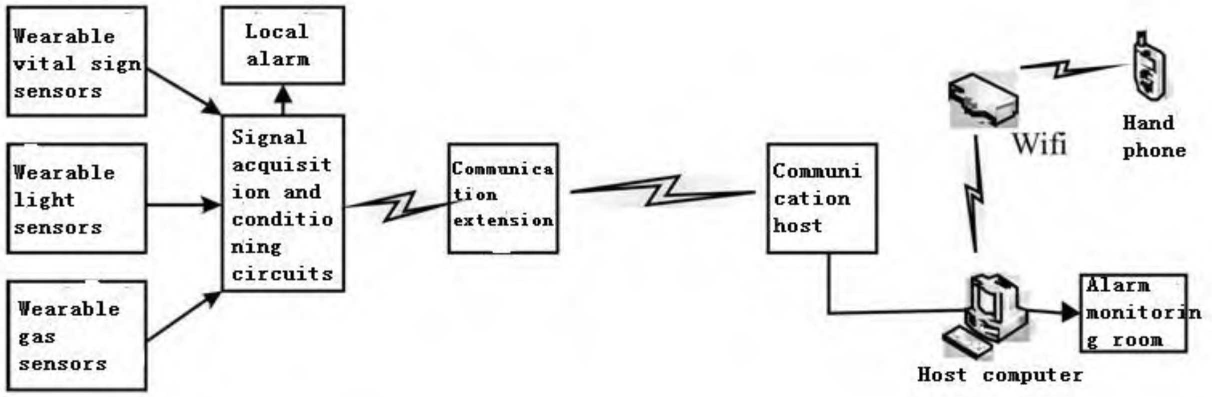


Figure 1. General diagram of system structure.

3. Hardware system design

3.1. Gas detection module

The gas detection module is divided into a fumigation gas detection module and an oxygen and carbon dioxide gas detection module[3].The design ideas of these two modules are the same, and the structure diagram of the gas detection module is shown in **Figure 2**.The gas detection module consists of gas sensors[4] and an AD0809 analog-to-digital conversion chip. The gas sensor can collect and analyze the concentration of fumigation gas or oxygen and carbon dioxide gases in the granary in real-time. When different gas concentrations are collected, outputs of different voltages and currents values will be sent by the sensors. At this point, the micro controller is unable to recognize the analog values and hence, it is necessary to convert the analog value output by the sensors into a digital value by selecting the use of AD0809 chip during the analog-to-digital conversion which will be activated by the microcontroller. After the activation of the chip AD0809, the analog voltage or current value is converted into a digital value. After the conversion, the AD0809 chip sends an interrupt request to the microcontroller where the microcontroller responds to the interrupt request reads these digital values in real-time, and compares the read digital values with the standard digital values to determine the gas concentration.

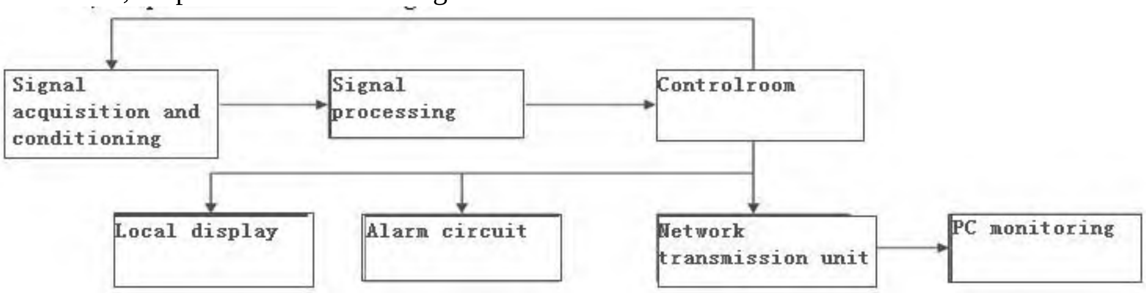


Figure 2. Working diagram of gas concentration detection module.

3.2. Respiration and pulse monitoring module

Design of respiratory monitoring module

The breath detection sensor is designed with a piezoelectric ceramic sheet as the core. When exhaling, a certain pressure will be applied to the piezoelectric ceramic sheet which will generate a signal output. When inhaling is performed, the pressure is then removed and the piezoelectric ceramic sheet will have no signal output. This way, the time length of one breath can be determined by measuring the output signals of two adjacent piezoelectric ceramic sheets and calculating the breathing frequency of a person.

The block diagram of the respiratory monitoring module is shown in **Figure 3**[5]. When the piezoelectric ceramic sheet senses exhalation, a rising edge pulse signal will be generated, and the rising edge will generate a timer interrupt for the microcontroller. At this time, the microcontroller starts timing. As the exhalation continues, the piezoelectric ceramic sheet continues to output a high-level signal. When inhaling, no force is applied to the piezoelectric ceramic sheet. During this time, the piezoelectric ceramic sheet continues to output a low-level signal until the next exhalation where the output signal of the piezoelectric ceramic sheet changes from low to high again. The change is then detected by the microcontroller and generates an interruption to the timer, and the timer is turned off. The microcontroller then determines the breathing frequency according to the time recorded by the timer and compares it with the normal breathing frequency set in the program. When the calculated breathing frequency is no longer in the normal range, the microcontroller will then start the alarm.

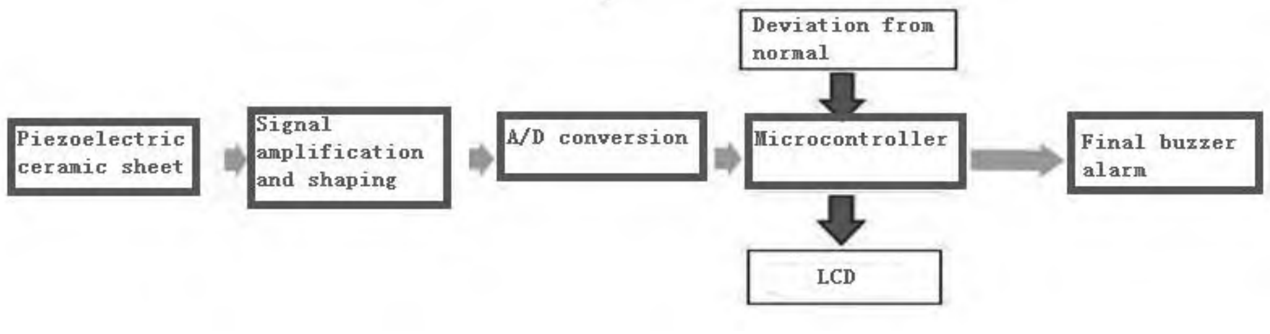


Figure 3. Structure diagram of the respiratory monitoring module.

Design of pulse monitoring module

The pulse measurement uses a reflective photoelectric switch sensor, which consists of an infrared emitting diode and a receiving diode. Measurement is made when a finger is placed between the transmitting diode and the receiving diode. When the blood flow changes, the intensity of the light received by the receiving diode also changes, and this change is consistent with the beat of the heart. The receiving diode converts the received light signal into an electrical signal, which is collected and processed by the microcontroller to calculate the pulse rate of the person.

The structure of the pulse monitoring module is shown in **Figure 4**[6]. The pulse sensor uses a reflective photoelectric switch as the core device. The device is a device that can convert between optical and electrical signals. After the optical signal reflected by the finger sensor is photo-electrically converted, it outputs about 2mVof electrical pulse information that is first filtered by an RC low-pass to filter out clutter and interference, then amplified by the integrated operational amplifier module and shaped by the NOT gate shaping circuit. Finally, the input is sent to the input and output ports of the microcontroller.

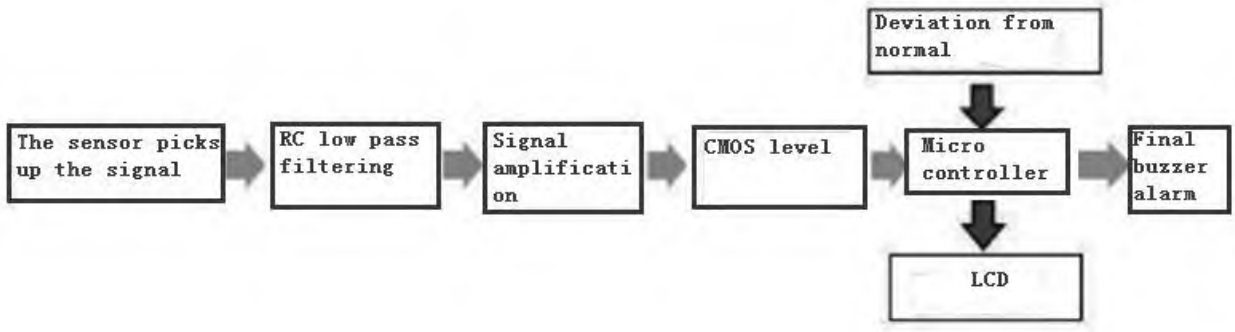


Figure 4. Structure diagram of the pulse monitoring module.

The microcontroller performs related processing on the input, calculates the number of human pulse beats per minute, and displays it through the LED light, while the other channel is input to the timing counting module for real-time and intuitive display. If the detected data deviates from the data range of the normal value, a real-time alarm will be given to the buzzer control through the microcontroller.

3.3. Illumination detection module

After entering the granary, the staff will work in a brightly lit environment. If the body is caught in the food, the chest and abdomen are compressed, and the person cannot breathe normally and if the time passed is too long, they will suffocate and die. This means that if the person were to fall into the food, the personnel do not immediately lose consciousness or even die. Since there is still some oxygen left in the body when it is just immersed, the body generally does not have symptoms within a minute. The people outside must also try to rescue the trapped people in the shortest time possible. This requires that when the sensor cannot receive the light signal, it will immediately send an alarm to the outside world. Sometimes if the staff works at night and encounters a power outage, the sensor will also not receive light at this time. If the alarm is issued again at this time, a false alarm will occur. Therefore, a drivable light source can be added to the original system, so that when there is sudden darkness, the microcontroller can drive the light source to emit light after receiving several light and dark data and continue to receive several additional data. If it is still light and dark, it will immediately issue an alarm.

This avoids false positives. The illumination detection module is mainly composed of illumination acquisition, microcontroller, A/D conversion, and three light sources, as shown in **Figure 5**[7].

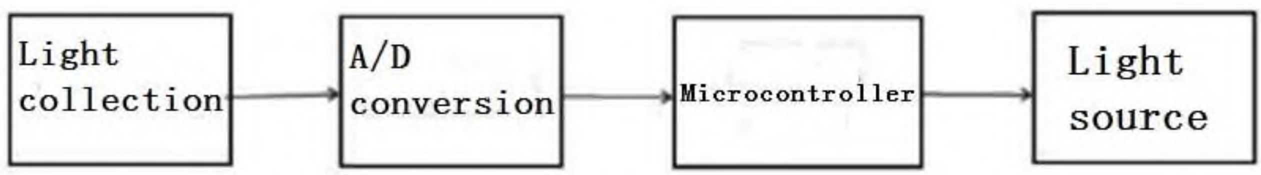


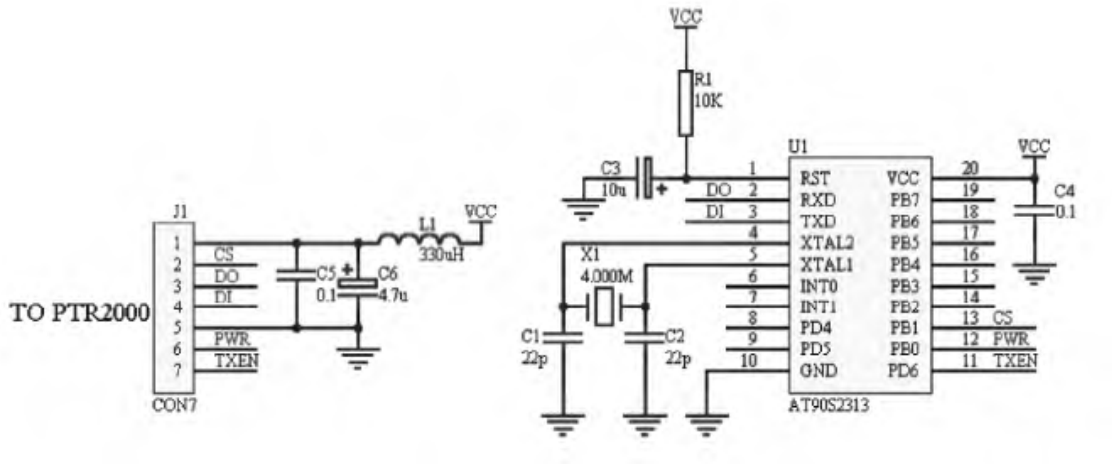
Figure 5. Overall block diagram of the illuminance sensing system.

The light collection uses a photo resistor as the light collection element, together with a diode and 555 timers to form a collection amplification voltage regulation circuit. Two transient steady-state outputs in the circuit are used to generate an analog signal output to the next module. In addition, the resistance value of the photo resistor will change with the intensity of the light, which in turn makes the multivibrator in the circuit generate different clock cycles. At the same time, the output waveform frequency will also change. After that, the digital-to-analog conversion is performed and the microcontroller handles the calculation.

3.4. Wireless communication module

PTR2000 is an ultra-small, ultra-low power, high-speed 19.2k wireless transceiver and data transmission MODEM with receiving and transmitting features. The operating frequency is the international common data frequency band 433MHZ using DDS+PLL frequency synthesis technology. The frequency stability is excellent and can be directly connected to the CPU Serial port use (such as 8031). Additionally, it can also be connected to the computer RS232 interface, which makes software programming more convenient. The PTR200 is mainly used in remote control, telemetry, industrial data acquisition systems and other fields[8].

A signal is transmitted to the communication host of the monitoring center in an infinite transmission mode through the PTR2000 wireless communication module, and the communication host is connected to the host computer through the RS232 interface. The host computer then receives the signal sent by the communication host and conducts real-time online analysis. Once the signal value was found to exceed the safety standard, the host computer will send an alarm command to the lower computer to stimulate the local alarm. At the same time, the alarm in the monitoring room which is directly connected to the upper computer alarms, reports the emergency to the relevant personnel in the form of short messages through Wi-Fi. The interface circuit between the PTR2000 series and microcontroller is shown in **Figure 6**.



Note: (1) The first pin of AT90S2313 is the reset pin (low-level reset). (2) The second pin of AT90S2313 is the serial input pin; the third pin of AT90S2313 is the serial output pin. (3) PWR, TXEN, CS of the wireless module can be connected to any I/O of AT90S2313 for control. (4) It is recommended to use tantalum capacitors for C6.

Figure 6. PTR2000 series and microcontroller interface circuit.

Figure 7 shows the connection circuit between PTR2000 and the computer serial port.

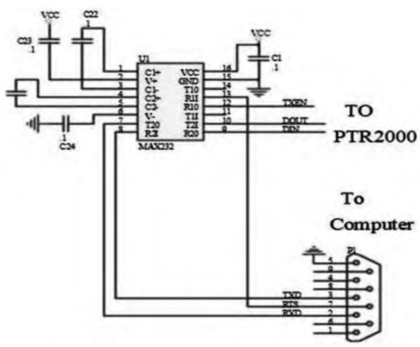


Figure 7. The connection circuit between PTR2000 and computer serial port.

Description: PTR2000 will send the received data to the computer serial port after 232 level conversion. Although it is permissible to connect the PTR2000 to a PC after 232 level conversion, it may take up a large amount of computer resources. Hence, in the actual design process, it is possible to consider adding a single-chip microcomputer between the PTR2000 and the computer. The working block diagram of the wireless communication module is shown in **Figure 8**.

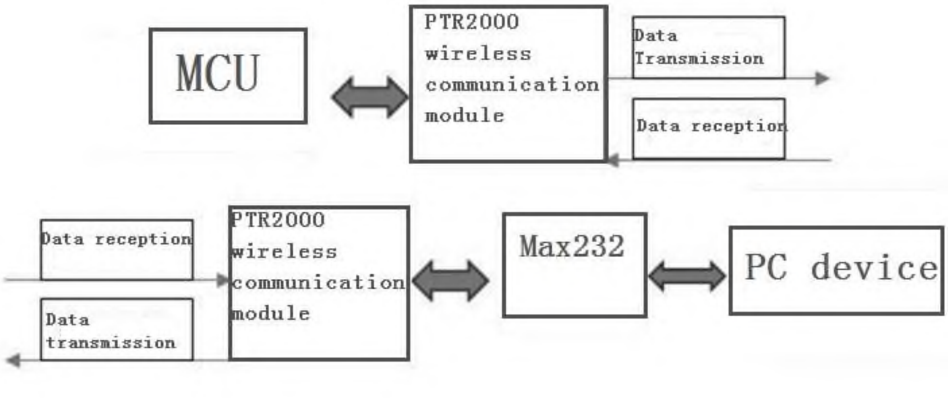


Figure 8. Working diagram of the infinite communication module.

4. Software programming

The design mainly adopts the programming of STC89C52, in which the system adopts modular design where each functional module collects information, converts it into a digital signal and inputs it into STC89C52 microcontroller and uses the microcontroller to perform analysis and calculation.

The modules include pulse respiration detection module, oxygen and carbon dioxide sensor module, illuminance sensor module and fumigation gas transmission module. Each module collects information and transmits the data to the STC89C52 microcontroller for analysis and calculation. If the signals exceed the safety range, it will drive the alarm module and notify the host computer. The program flow chart is shown in **Figure 9**.

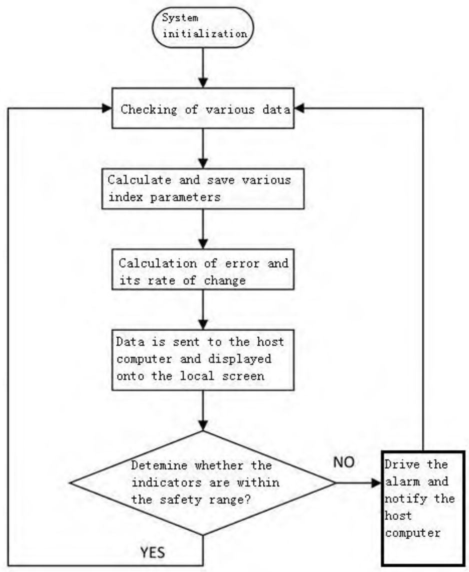


Figure 9. Program flow chart.

When the system starts, it first initializes and programs each module to ensure smooth operation, starts the timer interrupt and external interrupt, ensures the reception and response of data are in the working mode, records data changes at any time, determines whether the field situation is safe under the data analysis program of each module and sends the data to the host computer if necessary.

System software is mainly written in C language. Compared with assembly language, C language has better readability, structure, maintainability and portability, which is conducive to the modular design. Keil C51 is a 51 series compatible microcontroller C language software development system produced by American Keil Software. Keil provides a complete development solution including a C compiler, macro assembler, linker, library management and a powerful emulation debugger. These parts are combined through an integrated development environment (μVision)[9].The software part of this system adopts Keil uVision4 integrated development environment for program design, compilation and debugging. Since the microcontroller used is the STC89C52RC, the download programming and burning software of the microcontroller uses the STC-ISP designed for the STC series microcontroller.

5. System Test

After the design is completed, the wearable granary working environment sensing and alarm system is tested through experiments, and the results showed that the system has a good effect in detecting the granary environment. Before the test, the hardware is repeatedly checked whether there are problems such as short circuit, multi-line, and low line, and check whether the performance indicators of the components and the selection of components meet the range requirements. After the hardware inspection is completed, the source program is burned to the microcontroller to detect whether each function meets the basic requirements of the system in the environment. If it deviates from the expected result, the system is debugged until the expected result is reached.

5.1. Detection of oxygen and carbon dioxide detection sensor system

The detection was carried out by placing the O_2 and CO_2 sensor system into a sealed box filled with inward oxygen and carbon dioxide and continuously adjusting the molar mass density ratio of oxygen and carbon dioxide, and observing that when the ratio of oxygen and carbon dioxide reaches a preset value, the system can give off an alarm.

5.2. Detection of illuminance detection sensor system

The light sensor system was placed in an environment with adjustable light intensity constantly adjusted. When the light intensity reaches a preset value, the system will give off an alarm, indicating that the light intensity detection sensor alarm system can meet the basic requirements.

5.3. Detection of pulse and respiration detection sensor alarm system

According to the exhalation of the human body, the exhaled gas will produce a certain pressure on the piezoelectric ceramic sheet, while inhalation does not affect the piezoelectric ceramic sheet. The two processes then prompt the piezoelectric ceramic sheet to produce different output signals, which determines the passing of the test. The signal output of the piezoelectric ceramic sheet was measured to calculate the time length cycle of one breath of the human body and then through the calculation, the breathing frequency rate of the human body per minute is measured. When the respiratory rate exceeds the preset value range, the system will give off alarms, indicating that the pulse and respiration detection sensor alarm system can meet the basic requirements.

5.4. Detection of fumigation gas detection sensor alarm system

The phosphine fumigation gas and air were filled into the sealing device and the concentration ratio of fumigation gas and the air was continuously adjusted. When the value reaches the preset value, the system gives off an alarm, indicating that the internal power of the fumigation gas detection and sensing alarm system meets the basic requirements.

6. Conclusions

The safety and reliability of the working environment of the granary have always been an important issue. As people have increasingly higher requirements for the working environment, a reliable safety system is naturally required to ensure the safety of the staff.

The wearable granary working environment sensing and safety alarm system is therefore developed to solve this issue. Through the division of labor and cooperation of the team members as well as through the analysis and discussion of different technical issues, the design of this system has been completed. A lot has been gained throughout the design process where some important conclusions were finally reached.

Aiming at the possible existence of harmful fumigation gas in the granary, we have carried out the research and design of the detection and sensing system of harmful fumigation gas. In this, it is difficult to completely remove harmful gases through exhaust ventilation, but if the concentration is low, no alarm signal will be generated which indicates that the accuracy of the sensor is particularly high. However, the detection of harmful gases is still very important. Thus, when designing the gas sensor and processing circuit, we chose a more reliable detection device and optimized the processing circuit to solve this problem. The concentration of oxygen and carbon dioxide in the granary is also a very important index, as the concentration of oxygen will be directly related to the storage of grain. Since the oxygen concentration in the granary has been in a stable fluctuation range, the cost of the sensor can be reduced by selecting an instrument that allows some errors in measuring the concentration of oxygen and carbon dioxide. In the research and design of wearable sensing systems, we aimed to be more functional and more portable, while at the same time paying more attention to the real-time nature of wearable devices. Having considered the real-time requirements of the system, wireless communication was used in data transmission, which also reduces part of the cost and brings more portability to people in use.

This design realizes real-time monitoring of gas concentration and vital sign sensors in the granary and reliable transmission of information through wireless communication technology, which greatly improves the safety of the granary, improves work efficiency, and is more conducive to scientific grain storage, which is also a trend in the future development of the warehousing industry.

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