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Research on Coal Mine Gas Monitoring System

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Abstract: *In coal mining and transportation, in order to prevent mining workers from being exposed to harmful gases for a long time, the construction area needs to conduct real-time monitoring of harmful gases to ensure the job security of mining workers. Needs to conduct real-time monitoring of harmful gases to ensure the job security of mining workers. To solve this problem, this article designs a multi gas monitoring system, using STM32F103 as the main control chip, and designs a multi parameter monitoring system for four types of gases, temperature, and humidity, which can achieve excessive and humidity, which can achieve excessive alarm and real-time data collection functions on the upper computer. After debugging and experimentation on after debugging and experimentation on the prototype, the results show that the system has good performance, can achieve the expected goals, and has strong feasibility.*

Keywords: *STM32, Multiparameter Monitoring, Harmful Gases*

1. Introduction

Fossil energy has been the main source of energy for human beings, and it has made excellent contributions to the development of human industry [1]. However, in the process of energy extraction, the leakage of hazardous gases is unavoidable, which greatly affects the life safety of extraction workers. In order to minimize the occurrence of safety accidents in mining projects, it is very important to test the concentration of hazardous gases and the environmental parameters of the work site [2].

Coal mine gas monitoring technology is developing very rapidly, it is widely used in coal mining, petrochemical, medical diagnosis, national defense science and technology and many other fields.[3]Coal mine gas monitoring technology is developing rapidly. The development of gas detection technology is very rapid, gas detection equipment is very suitable for real-time monitoring in coal mines and other special environments. [4]In the actual mine environment, the gas detection equipment is very suitable for real-time monitoring. In the actual mine environment, the human body has not only a hazardous gas, in addition to CH4, there are other toxic gases in the air, to the production and life of human beings has brought great harm.

The scientific research history of gas monitoring can be traced as far back as 1815 when the British invented the gas detector, the gas detection lamp [5], and since then, countries around the world have carried out research on gas monitoring. In 1998, P. Werle[6] of the University of Heidelberg designed a vertical external-cavity surface-emitting laser for monitoring oxygen concentration. A representative modern gas detection device is the development of a sensor for the detection of gas mixtures in engine exhaust by Oliver Diemel[7] of Germany in 2019, which allows rapid monitoring of engine exhaust components and gases in the cylinder.

China has continuously made new progress in gas detection, continuously improved the types of gas detection and the accuracy of detection.[8] At the same time, we have introduced and absorbed relevant foreign technologies, and gradually mastered the wireless network communication technology and multi-sensor fusion technology of gas monitoring system, thus promoting the development of the overall gas detection industry in China.[9] In 2007, China's first set of automobile exhaust emission monitoring system based on TDLAS technology, online real-time greenhouse gas monitoring system, and urban underground gas network leakage monitoring system were launched successively.[10] In 2020, Liu Ningwu et al.[11] et al. developed a small multi-component gas detection system for simultaneous determination of CO, N2 O, and CH4 . The design uses a 76-meter Heriot gas chamber, which effectively increases the absorption length of the light path. Field tests showed that the developed gas sensor has good detection performance for atmospheric environment, soil and respiratory gases, etc. In 2022, Yu Di et al.[12] developed an intrinsically safe circuit board level signal processor using DSP. The method used both DLAS data processing method and WMS data processing method and integrated them organically, thus expanding the dynamic detection range of the system; on this basis, the Lagrangian interpolation and the least squares method were utilized to suppress the background of the DLAS, which improved the resolving power of the DLAS by three times and reduced its sensitivity from 1.5 ppmv to 0.5 ppmv.

Today's rapid development of microelectronics technology, the use of microcontrollers to achieve the monitoring of gas has become the mainstream direction of the future. The gas monitoring system introduced in this paper is a microcontroller-based system. The extremely low-power microcontroller STM32F103VET6 was chosen as the main controller, and the hardware and software design of the system was carried out, and the gas monitoring experiments were carried out on the prototype of the system under safe experimental conditions, and the results showed that the system was able to realize the high-precision, high-reliability, and high-stability detection of gases.

2. Overall Design of The Gas Monitoring System

The gas monitoring system designed in this paper is divided into four main modules:

(1) Sensor monitoring module: the sensor is the source of information of the gas monitoring system, this paper selects the combustible gas sensor (methane), carbon monoxide sensor, carbon dioxide sensor, oxygen sensor, and temperature and humidity sensors, through which the sensors detect the chemical signals such as the concentration of the corresponding substance content and convert it into electrical signals. (2) Signal Conditioning Module: The weakness signals received by each sensor are tuned and processed, amplified and filtered, and sent to the A/D conversion module of STM32, where the corresponding concentration values are obtained using the corresponding algorithms, and the obtained information is fitted and filtered. (3) Main control module: STM32F103 microcontroller is utilized to control the whole system. (4) Peripheral Function Module: The function of the gas monitoring system is not only to monitor the concentration but also to have OLED screen display, threshold setting and alarm system. The overall block diagram of the system is shown in Figure 1.

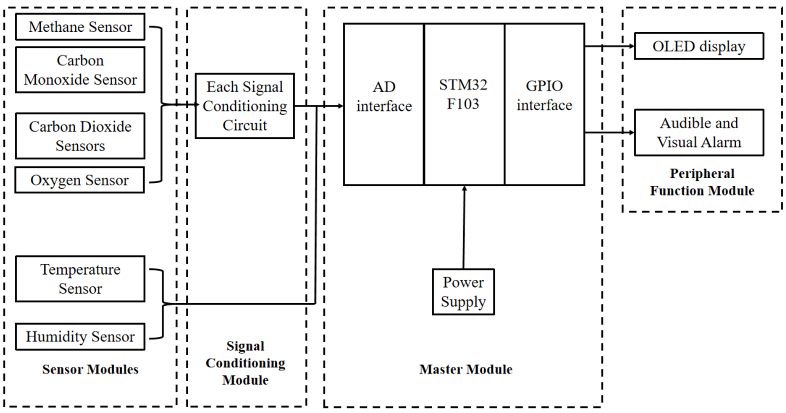

Figure 1: Overall structure of the system

3. Hardware design of the gas monitoring system

3.1. STM32F103

In this paper, STM32F103 is chosen as the main controller of the system. This model has many advantages such as excellent performance, rich resources, fast operation, high integration, small size, large number of IO interfaces, low power consumption, affordable price and good stability. The minimum system circuit diagram of the master control module is shown in Figure 2.

3.2. Gas Detection Sensors

The gas sensor is the key component of the monitoring system, and its detection accuracy and stability directly affect the testing effect of the whole monitoring system. The gases detected in this paper mainly consist of four kinds, methane, CO, CO_2 and O_2. The following are the detection sensors of the four gases and their circuit diagrams.

Methane gas sensor in this paper is selected by the Jingxun Changtong company produced by the sensor, its working principle is infrared absorption, with good linearity, high resolution, the advantages of small temperature drift. When the system is running, the signal collected by the sensor is very weak, so the signal needs to be optimized to meet the conversion standard of STM32. The detection principle of methane gas signal acquisition is catalytic combustion, so the signal conditioning of the methane sensor needs to add a resistor to the outside of the sensor so that it forms a Whisden bridge with the "black element" and "white element" in the sensor, which produces a voltage output signal. The schematic diagram of the methane sensor signal conditioning circuit is shown in Figure 3.

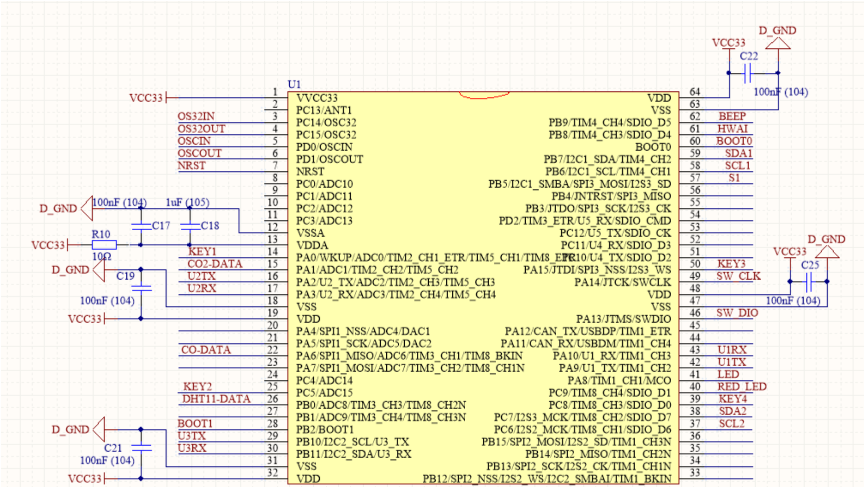

Figure 2: STM32 minimum system circuit diagram

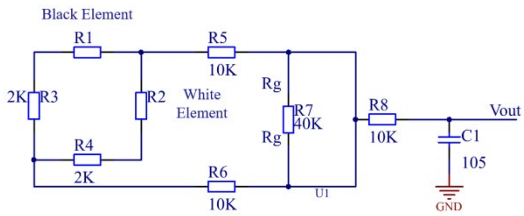

Figure 3: Schematic diagram of methane signal conditioning circuit

The CO sensor selected for this paper is a Chicory Electronics Inc.ZE16-CO type module. Its working principle is electrochemical method, which has the advantages of fast response, quick reply, high environmental requirements and good stability. The CO sensor is conditioned using a new programmable control chip developed by Texas Instruments, the circuit diagram of which is shown in Figure 4.

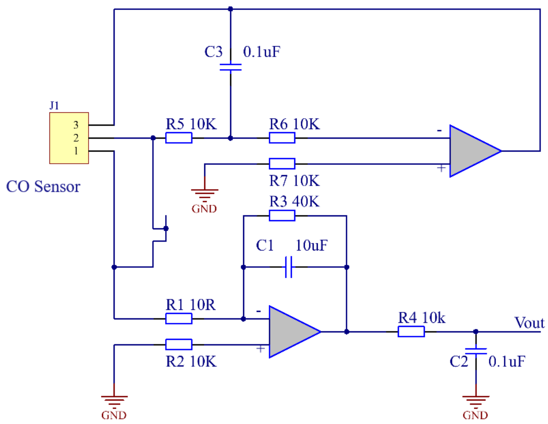

Figure 4: CO signal conditioning circuit diagram

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The CO_2 sensor selected in this paper is a kind of NDIR non-dispersive infrared absorption sensor developed by Jingxun Changtong Company, which has the advantages of strong anti-interference ability, good explosion-proof performance, low energy consumption and good stability. Due to external factors, the output signal of CO_2 is unstable, so it is necessary to filter the signal, and its circuit diagram is shown in Figure 5.

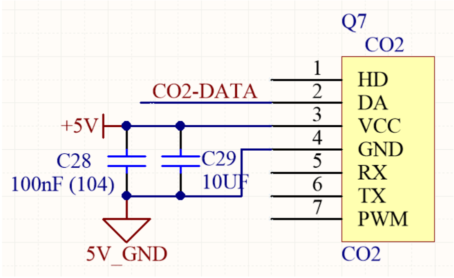

Figure 5: CO_2 Signal Conditioning Circuit Diagram

The O_2 sensor used in this paper is a mine oxygen detector produced by Jingxun Changtong Company, which has the advantages of stable performance, high sensitivity and low price.JXM-O_2 It has the advantages of stable performance, high sensitivity and low price. The O_2 sensor adopts a two-electrode electrochemical detection principle, in the process of the sensor work, O_2 and its working pole on the chemical reaction, and in its working pole to form a weak current proportional to the O_2 content. According to this principle, this paper uses a piece of AD8606 chip to constitute the O_2 signal conditioning circuit, whose circuit diagram is shown in Figure 6.

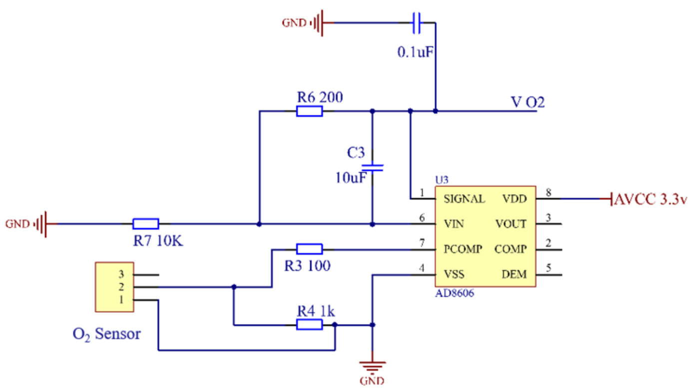

Figure 6: O2 Signal Conditioning Circuit Diagram

3.3. Temperature and Humidity Sensors

The DHT11 sensor is used for temperature and humidity monitoring, which has the advantages of high reliability, strong anti-interference ability and very low power consumption. The air temperature and humidity acquisition circuit is shown in Figure 7.

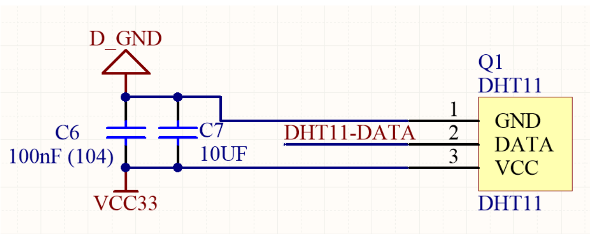

Figure 7: Air temperature and humidity acquisition circuit

3.4. Peripheral Function Module Design

In order to enrich the function of the gas monitoring system, this paper designs two peripheral functions, OLED display and sound and light alarm function. The following is the circuit design of the two functions.

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The OLED display module has an internal OLED driver circuit that can control the display pins by connecting to the STM32's interface. In addition, the screen can be operated on the OLED module to display the display information processed by the microcontroller in an OLED LCD. The circuit diagram of the OLED is shown in Figure 8.

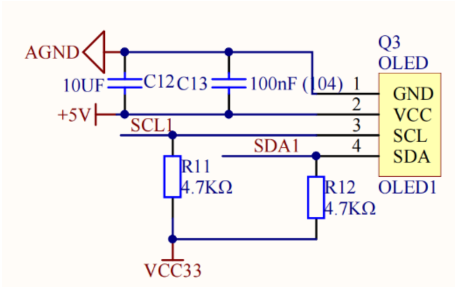

Figure 8: OLED Display Circuit

The sound and light alarm circuit is an important function of the gas monitoring system designed in this paper, in case of dangerous gas exceeding the set threshold, an alarm will be issued and a light will be illuminated to warn. The circuit diagram is shown in Figure 9.

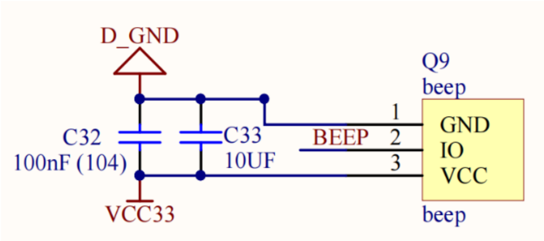

Figure 9: Audible and visual alarm circuit

3.5. PCB Board Design

The hardware circuit is accomplished through Altium Designer 18 software with a double-layer panel structure. According to the previously designed sensor circuit and peripheral function circuits, the circuit is integrated into a PCB board, and the PCB board circuit diagram and physical diagram are shown in Figure 10.

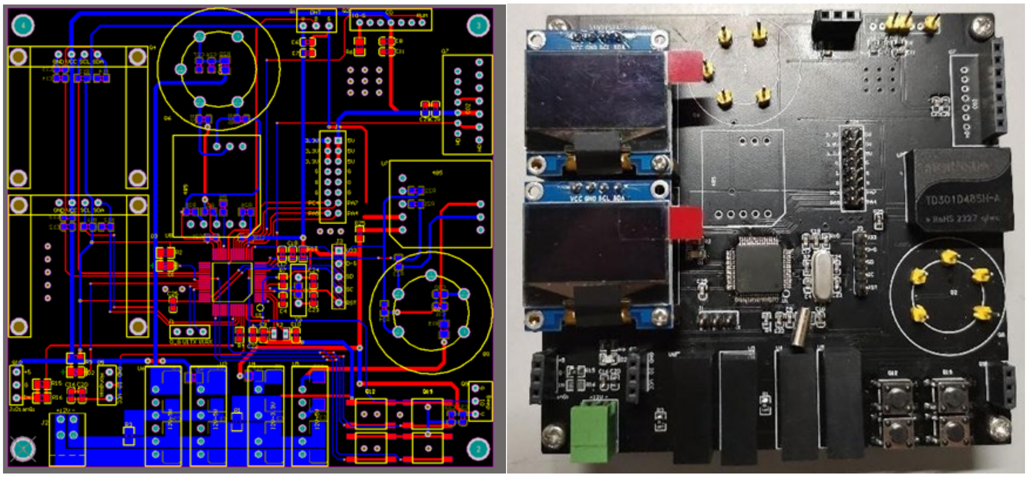

Figure 10: PCB board circuit diagram and physical drawing

4. Software Design of The Gas Monitoring System

The software design of the gas monitoring system mainly focuses on the implementation of the system's display function program and the sound and light alarm program. The program flow charts of the two functions are shown in Figure 11 and Figure 12.

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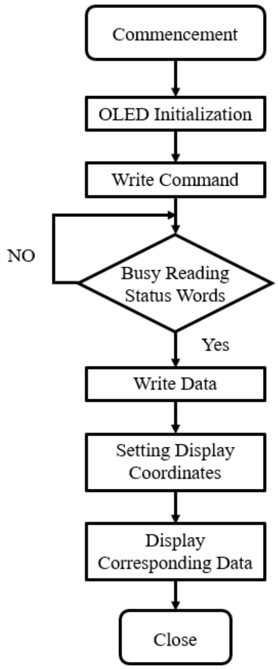


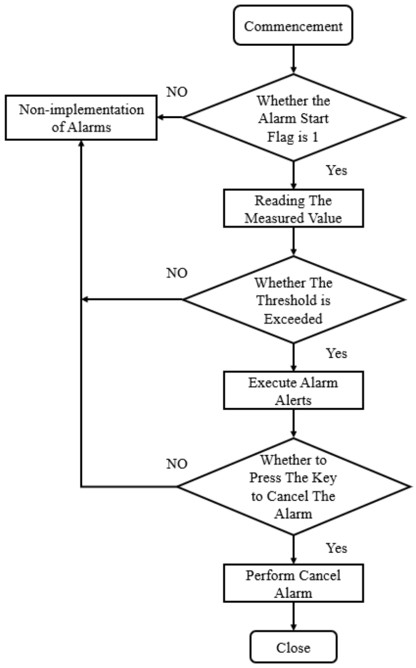


Figure 11: Flowchart of on-screen display program (Left)

Figure 12: Flowchart of sound and light alarm program (Right)

5. Experiments and results of the gas monitoring system

According to the wiring ports on the PCB board, the devices of each module are connected to the PCB board with DuPont wires to form a complete gas monitoring system. The physical diagram is shown in Figure 13.

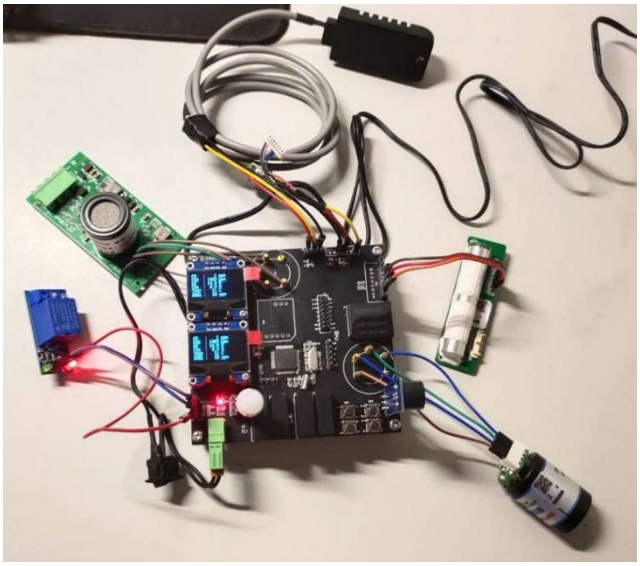


Figure 13: Physical diagram of the gas monitoring system

Before doing the experiment, a safe experimental environment needs to be built. As shown in Figure 14 is the schematic diagram of the overall structure of the gas distribution test device.First of all, it is necessary to carry out zero calibration of the instrument, after the instrument is energized for 30min, put the instrument into the standard gas container, and then inject high-purity nitrogen into the gas container, set the flow rate of 200ml/min. When all the indexes of the detection device tends to be stable, adjust the displayed values of methane, CO, CO_2 , O_2 to zero. After the operation is completed, the experiment can be started.After the calibration of the device was completed, an error experiment was performed using two standard airs with different contents, and after the displayed data stabilized, the data was recorded as shown in Figure 15. The relative error of the experimental data was calculated to be within± 0.05% or less, which is within the allowable error range of each sensor, proving that the system can maintain a relatively good accuracy.

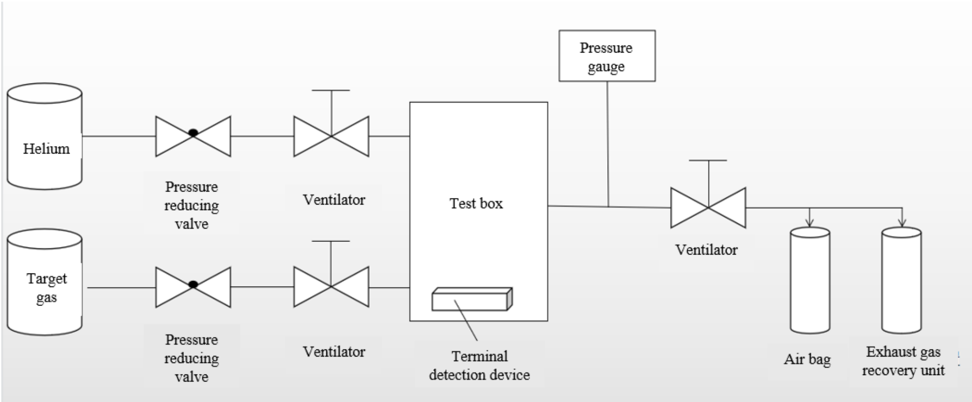
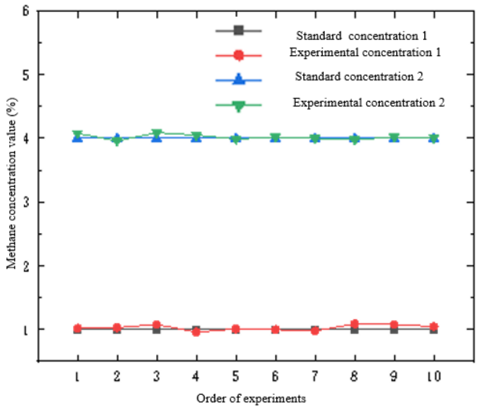
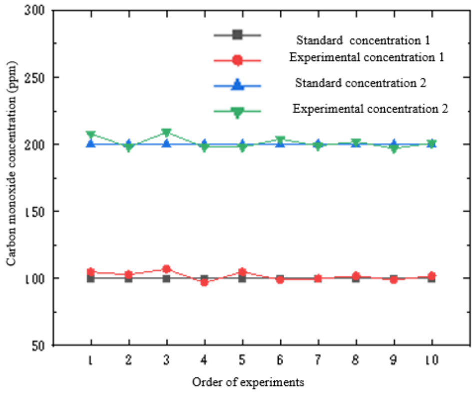


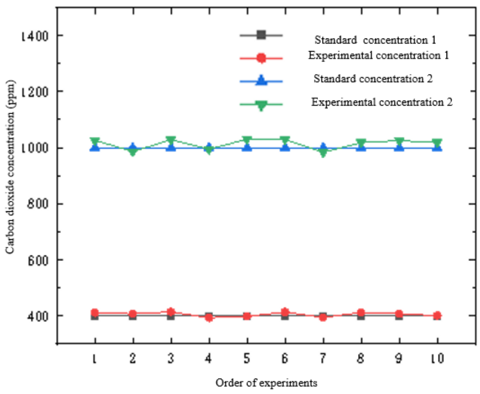
Figure 14: Schematic diagram of the structure of the gas distribution test device



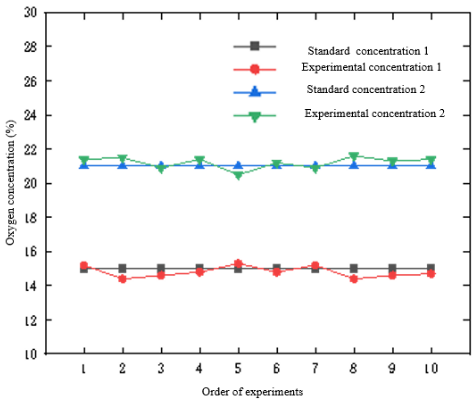
(a) Methane concentration profile



(b) CO concentration profile



(c) CO_2 concentration profile



(d)O_2 concentration profile

Figure 15: Plot of error experiment results

6. Conclusions

In this paper, we design a gas monitoring system based on microcontroller, and choose STM32F103 as the main controller of the system; in hardware, we choose four gas sensors for measuring methane, CO, CO2 , O2 as the detecting devices, and design the conditioning circuit of each sensor to amplify the signals and input them into the STM32; we add the DHT11 sensor to detect temperature and humidity, and set up two peripheral functions, namely the OLED display and audible and visual alarm; in software, we realize the program of OLED display and audible and visual alarm; we make the PCB board of the

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whole system; in software, we realize the program of OLED display and audible and visual alarm. OLED display and sound and light alarm two peripheral functions are set, and the PCB board of the whole system is made; in the software aspect, the programs of OLED display and sound and light alarm functions are implemented. Finally, the modules are connected to the PCB board to form a prototype gas monitoring device, and the experimental environment is set up to carry out error and stability experiments, which show that the gas monitoring device designed in this paper has good accuracy and stability.

Acknowledgements

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References

[1] Li Weidong, Wang Lianfu, Liu Daowen, et al. Current status and development trend of dust concentration monitoring technology in China's coal industry[J]. Mining Safety and Environmental Protection, 2005(S1):66-67+125.
[2] Li Runqiu, Shi Shiliang, Luo Wenke. Characteristics and coupling law of coal mine gas explosion [J]. China Journal of Safety Science, 2010, 20(02):69-74+178.
[3] Jing Yuanjie. Research on the measurement method of multivariate mixed gas concentration and the development of detector [D]. Harbin: Harbin Institute of Technology, 2021.
[4] J. Li. Design and development of gas concentration field detection system based on TDLAS technology [D]. Beijing: North China Electric Power University, 2020.
[5] Zheng Shifei. Design and realization of gas detector based on FPGA [D]. Hefei: Hefei University of Technology, 2020.
[6] Lian Jiuxiang. Research on key technology of gas detection based on TDLAS technology [D]. Nanjing: Southeast University, 2020.
[7] Diemel O, Honza R, Ding C P, et al. In situ sensor for cycle-resolved measurement of temperature and mole fractions in IC engine exhaust gases [J]. Proceedings of the Combustion Institute, 2019, 37(2): 1453-1460.
[8] Liu B. Coal mine underground environment monitoring system based on wireless network [D]. Beijing: Beijing Jiaotong University, 2010.
[9] Li L, Niu S, Qu Y, et al. One-pot synthesis of uniform mesoporous rhodium oxide/alumina hybrid as high sensitivity and low power consumption methane catalytic combustion micro-sensor[J]. Journal of Materials Chemistry, 2012, 22(18): 9263-9267.
[10] Bao-Long Zhang. Research on CO concentration detection system based on TDLAS [D]. Xi'an: Xi'an University of Science and Technology, 2019.
[11] Liu N, Xu L, Zhou S, et al. Simultaneous Detection of Multiple Atmospheric Components Using an NIR and MIR Laser Hybrid Gas Sensing System[J]. ACS Sensors, 2020, 5(11): 3607-3616.
[12] Wang P, Chen C, Wang Y, et al. A Prototype of CH4 and CO2 Sensing System Using State Parameters Correction Applied to Gas Geochemical Exploration[J]. IEEE Transactions on Instrumentation and Measurement, 2020.