Design and research of tunnel ventilation system based on STM32

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Abstract. Tunnel ventilation system has always been an important field in tunnel construction, with the main purpose of ensuring air circulation inside the tunnel and ensuring the safety of personnel and equipment inside the tunnel. This article introduces the concept and working principle of tunnel ventilation system. In addition, in terms of operation, this article proposes comprehensive management measures and discusses the measures that should be taken in different situations and emergency response methods.In summary, this paper focuses on the design and operation of tunnel ventilation systems, which has certain reference value for practical applications.

Keywords: STM32, microcontroller, sensor, intelligent tunnel ventilation.

1. Introduction

During the tunnel excavation construction process, the oxygen content in the tunnel gradually decreases due to factors such as surrounding rock conditions, drilling and blasting, operation of various mechanical equipment, and breathing of construction personnel. Various toxic and harmful gases (such as CO, CO_2, SO_2, and NO_x) and dust concentrations gradually increase. At the same time, as the tunnel continues to be excavated, the humidity and temperature of the working face will also continue to rise. In order to ensure the safety of construction personnel, ensure the normal operation of various mechanical equipment, ensure safety and efficiency during the construction process, and maintain a good air environment, it is quite necessary. So there are three purposes for transporting fresh air outside the tunnel to the excavation face through air duct transportation and other methods, to provide sufficient oxygen for the workers inside the tunnel, replace toxic and harmful gases and blasting dust, and provide a suitable construction environment inside the tunnel [1].

The combination of harmful gas concentration and temperature measurement and control with the Internet of Things eliminates the need for large-scale wiring and surveillance, does not change the original layout of the laboratory, and reduces the cost of renovation [2].

2. Overall Design

2.1. Overall functional analysis of the system

The focus of this design is on hardware circuit design and software program design. It is required to achieve temperature, humidity, and gas concentration detection, alarm exceeding limits, and control the exhaust of the fan. This design mainly includes sensor circuit module, alarm circuit module, motor module, GSM SMS alarm module, and OLED display module. Control by STM32 to achieve functions such as concentration detection, over limit alarm, and fan exhaust.

2.2. Overall design concept of the system

This design uses STM32 as the main control CPU, and collects the concentration and temperature of harmful gases through sensors and temperature sensors for carbon monoxide, methane, sulfur dioxide, and smoke, and sends signals to the CPU. Next, the CPU processes the signal and sends it to the OLED screen for display through the iic communication protocol, Simultaneously use ESP8266 to transmit harmful gas concentration, temperature and other information to the cloud platform, and the cloud platform will display the data on the WeChat mini program. When the temperature or harmful gas concentration exceeds the threshold, the alarm information will be sent by the CPU to the alarm circuit and fan module. The relay of the alarm circuit will be turned on, the buzzer and red LED will be turned on, and the green LED will be turned off; Fan module startup; The GSM SMS alarm module sends SMS messages to preset numbers. If you want to change the threshold for temperature and harmful gas concentration alarms, you can use the keyboard module to change it. These operations make the tunnel ventilation system intelligent. The overall system diagram is shown in Fig 1.

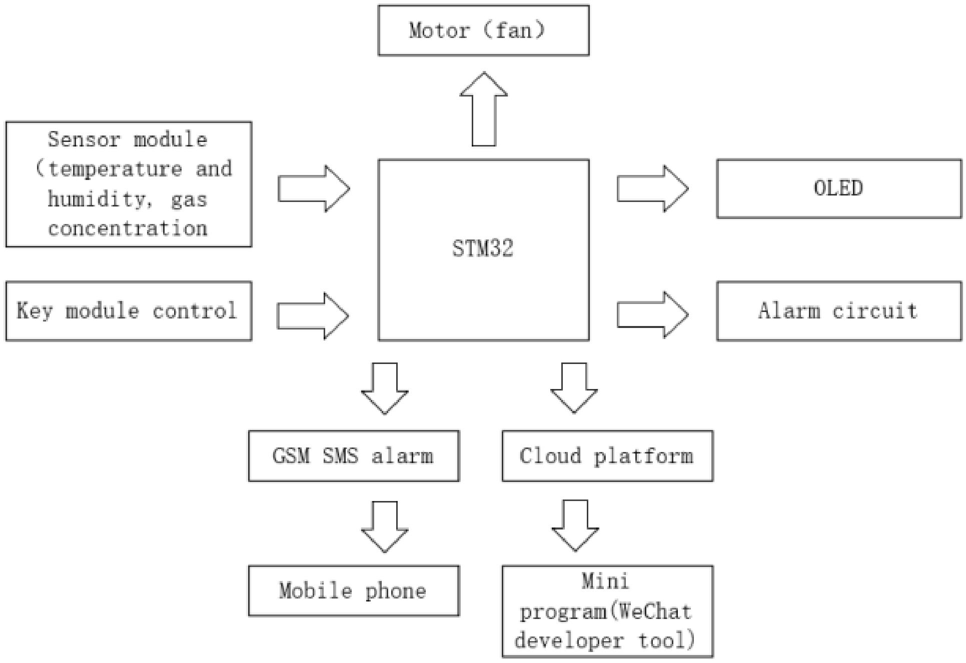

Fig 1. General block diagram of intelligent ventilation system for tunnel construction

2.3. System development environment

The programming software for this design is Keil5. The burning software application mcu-isp is implemented using the WeChat developer tool and JavaScript code to achieve manual terminal control.

3. Hardware design

3.1. Hardware structure design

This project power supply part uses a 5VDC power supply that can be used by the STM32 core board to supply electricity to the entire equipment. There are five main parts connected to the STM32 core board, namely sensor detection circuit, motor start circuit, OLED display circuit, sound and light alarm circuit, and GSM short message alarm circuit. The sensor detection circuit consists of four harmful gas sensors: carbon monoxide, nitrogen oxide, sulfur dioxide, and smoke, as well as temperature sensors. The sensors transmit electrical signals to the CPU for processing through gas and temperature sensitive resistors. The CPU transmits the processed data signals to OLED and ESP8266, and displays temperature and concentration data of harmful gases on OLED screens and Wechat App, allowing users to have a clear understanding of the current construction environment data. When the temperature or concentration of a harmful gas exceeds the threshold, the CPU sends signals to the fan start circuit, sound and light alarm circuit, and GSM SMS alarm circuit, respectively, to turn on the fan, buzzer, and red light flashing, and send SMS messages to the user.

3.2. STM32 Core Circuit

This design selects STM32F103C8T6 packaged in VFQFPN as the main control CPU. STM32 is a 32-bit high-performance MCU produced by Italian Semiconductor based on the ARM Cortex-M3 core. It has the advantages of high performance, low energy consumption, rich peripherals, and a convenient interrupt response system [3]. The core circuit diagram of STM32F103C8T6 is shown in Fig 2.

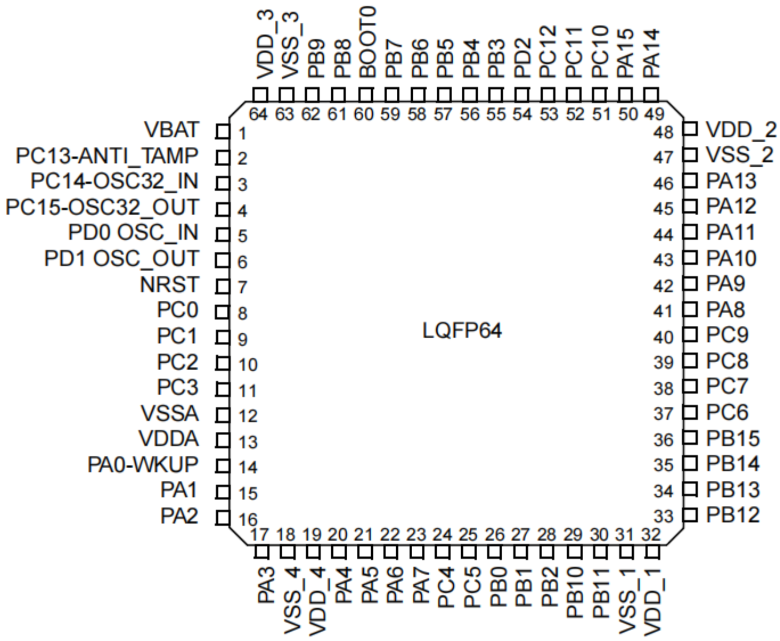

Fig 2. STM32F103C8T6 core circuit diagram

3.3. Sensor Circuit Design

3.3.1 gas concentration sensor

This design adopts four types of hazardous gas and flammable and explosive gas sensors, namely MQ2 smoke sensor, MQ7CO sensor, MQ9CH4 sensor, and 2SH12SO2 sensor, which are highly dangerous during tunnel construction. The MQ9CH4 sensor will be used as an example in the following text. The working principle of the MQ9CH4 sensor is that the surface resistance Rs of the sensor is obtained by outputting the effective voltage signal VRL on the load resistor RL in series with it. The relationship between the two is:

$$R_S/R_L = (V_C - V_{RL})/V_{RL} \tag{1}$$

The internal testing circuit of the MQ9CH4 sensor is composed of two parts, one is the heating circuit, which has a time control function (high voltage and low voltage cyclic operation). The second is the testing circuit, which can reflect the changes in surface resistance of gas sensing components. The sensitive layer of MQ-9 gas sensing element is made of very stable tin dioxide. Therefore, it has excellent long-term stability, and its service life can reach 5 years under normal usage conditions.

The sensor circuit transmits the collected data signal to STM32, which receives and processes the data signal. Therefore, pin 2 RXD sends the collected gas data signal and connects it to the TXD of STM32 to receive and process the data signal. The circuit of this sensor is shown in Fig 3.

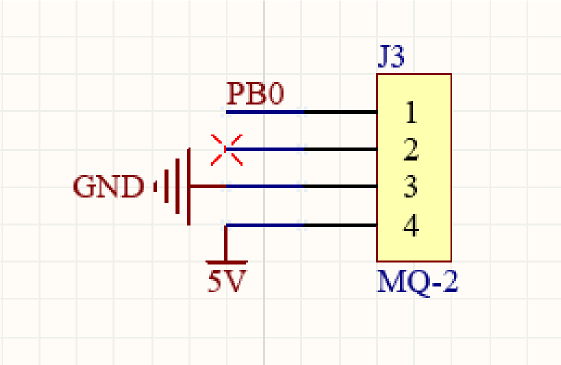

Fig 3. Gas concentration sensor circuit

3.3.2 temperature and humidity sensor

This design adopts DHT11 temperature and humidity sensor. The sensor includes a resistive humidity sensing element and an NTC temperature measuring element, and is connected to a high-performance 8-bit microcontroller. The DHT11 temperature and humidity sensor has the advantages of corresponding speed, strong anti-interference ability, and high cost-effectiveness. One of its advantages is its small size and high power, so DHT11 sensors are widely used in various fields [4].

DHT11 adopts a single bus bidirectional serial communication protocol, and each acquisition requires the microcontroller to initiate a start signal. Then, DHT11 sends a response to the microcontroller and starts transmitting a 40 bit data frame, with the high bit in front. The data format is: 8-bit humidity integer data+8-bit humidity decimal data+8-bit temperature integer data+8-bit temperature decimal data+8-bit check digit

The default value for the decimal part of temperature and humidity is 0, which means that the data collected by the microcontroller is integers, and the checksum is the lower 8 digits of the result obtained by adding the data with 4 bytes. The circuit of this sensor is shown in Fig 4.

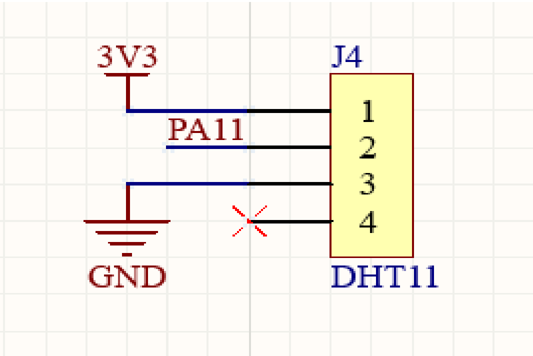

Fig 4. Temperature and humidity sensor circuit

3.4. Design of Sound and Light Alarm Circuit

3.4.1 LED alarm circuit

The working principle of the LED alarm circuit circuit is that STM32 supplies high level to PA4, the collector junction is positively biased, the transistor is on, the relay electromagnetic switch is turned on, and the red LED lights up. The advantages of using a transistor as a switch are low cost and easy to use. The LED alarm circuit is shown in Fig 5

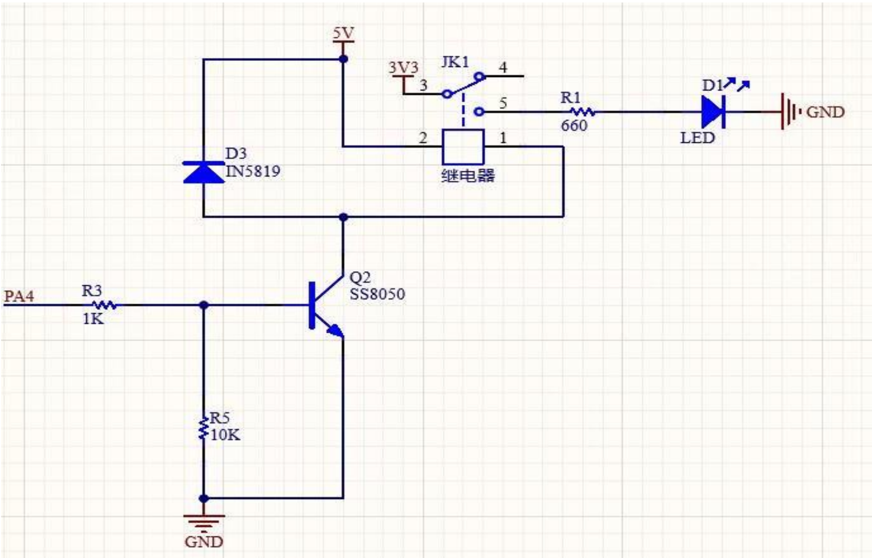

Fig 5. LED alarm circuit

3.4.2 Buzzer alarm circuit

The alarm circuit of the buzzer module in this design consists of three wires, one pin connected to the positive pole of VCC, one wire connected to the negative pole of VCC, and the middle wire connected to the IO port of the microcontroller for communication [5]. The working principle of the buzzer alarm circuit is that STM32 provides a high level to PA5, the collector junction is positively biased, the transistor is on, and the buzzer emits an alarm. The buzzer alarm circuit is shown in Fig 6.

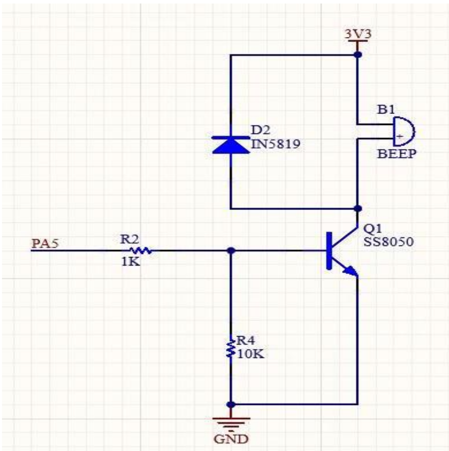

Fig 6. Buzzer alarm circuit

3.5. Motor drive circuit design

The motor drive circuit uses the L9110 chip as the control chip. The working principle of L9110 is to use IB configuration to multiplex push-pull output PMW, IA configuration to use universal push-pull pull low, and the motor rotates forward, while the motor reverses. When L9100 is used as a motor control chip, the OAOB pin is connected to the motor, and the IAIB is connected to the STM32 forward and reverse signal output pins PB7 and PB9. As a motor driver chip, L9110 has high flexibility, and its two output terminals can directly drive the motor forward and backward. This chip has good anti-interference performance. The L9110 pin connection is shown in Fig 7 below.

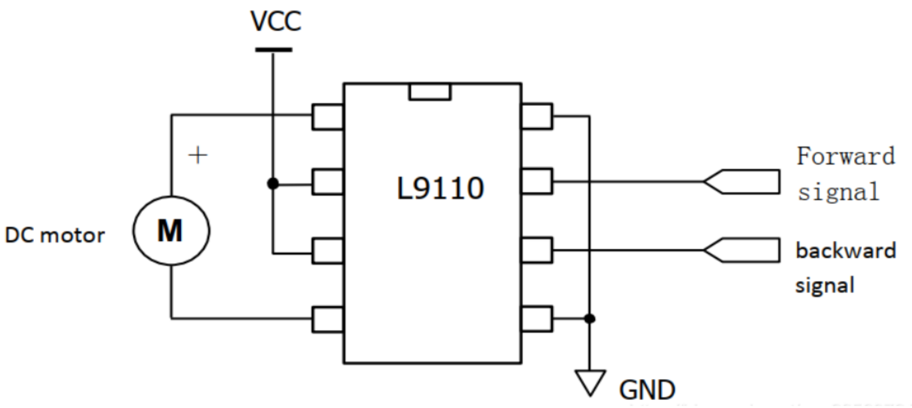

Fig 7. L9110 pin connection diagram

3.6. Design of GSM SMS alarm circuit

GSM uses the global mobile communication system network established by mobile companies and China Unicom on a large scale for SMS data transmission. The module leads out pins TX and RX, which are respectively connected to pins PB10 and PB11 in the system main control chip through a level adaptive circuit. Then, the system main control chip sends AT instructions and the required information to achieve asynchronous serial communication with the main control chip [6]. Its connection to the computer requires the 232 interface in the module, and its connection to the microcontroller is: TXD and RXD of SIM900A are connected to RXD and TXD of STM32, respectively. The recommended power interface is a 1.5A or higher DC power supply. The GSM SMS alarm circuit is shown in the Fig 8.

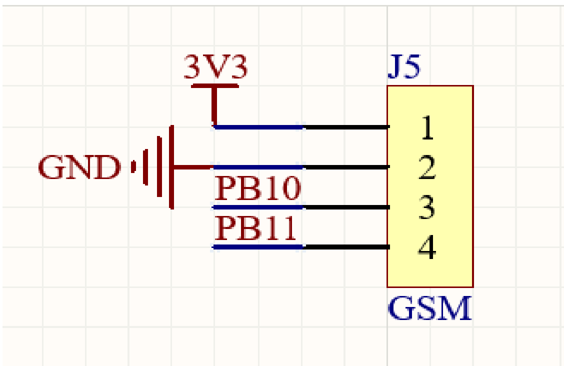

Fig 8. GSM SMS alarm circuit

4. Software design

4.1. Overall software process design

This system uses STM32 as the core processor and can be connected to various modules. The software compilation design lies in the initialization configuration of the system. After the system works, the sensors, buttons, and display screens of each module are initialized first. Then, the physical signals are converted into electrical signal parameter values through the corresponding sensors, and then converted into the corresponding target concentration through formulas [7]. The sensor detection module transmits data to the cloud platform and further reaches the mini program terminal, while also displaying the data on the OLED screen. Then compare the concentration of harmful gases with the threshold. If the threshold is exceeded, the fan will start, the buzzer will alarm, the status light will turn red, and GSM will send a text message alarm; On the contrary, the fan, buzzer, GSM, and status lights remain in their original state. The overall process design of the program is shown in Fig 9.

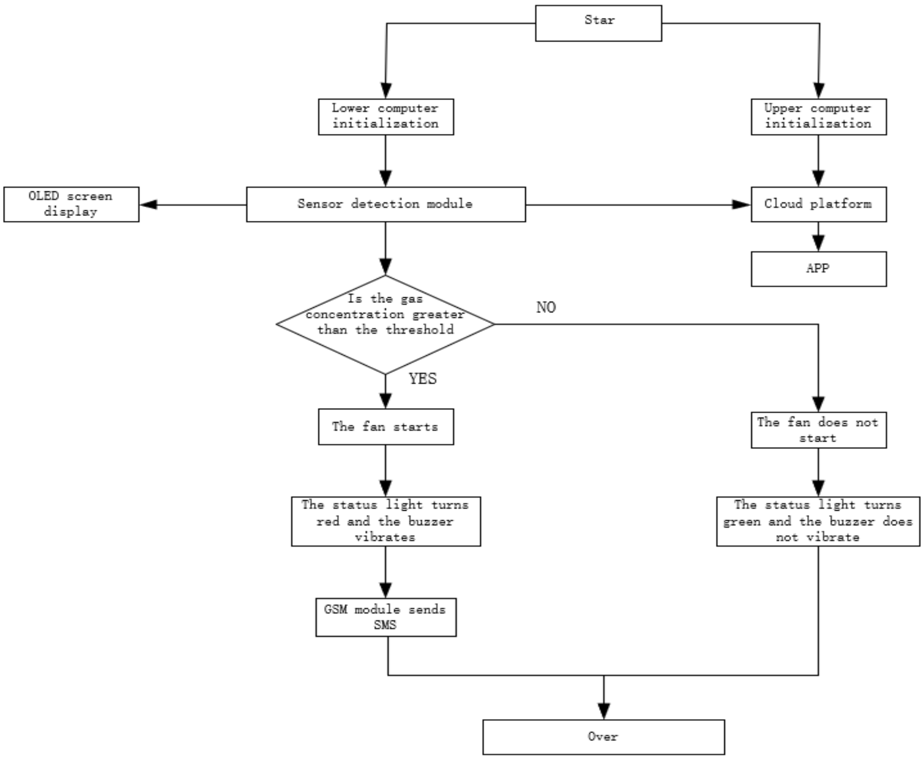

Fig 9. Program overall process design

4.2. OLED Display Program Design

OLED screens have two modes of operation, namely SPI and IIC communication modes. The IIC communication mode reduces the number of chip pins and costs due to the interface directly above the components. The length of the bus can reach 25 feet and can support multiple components at a transmission rate of 10Kbps [8]. The IIC timing diagram of SSD1306 is shown in Fig 10.

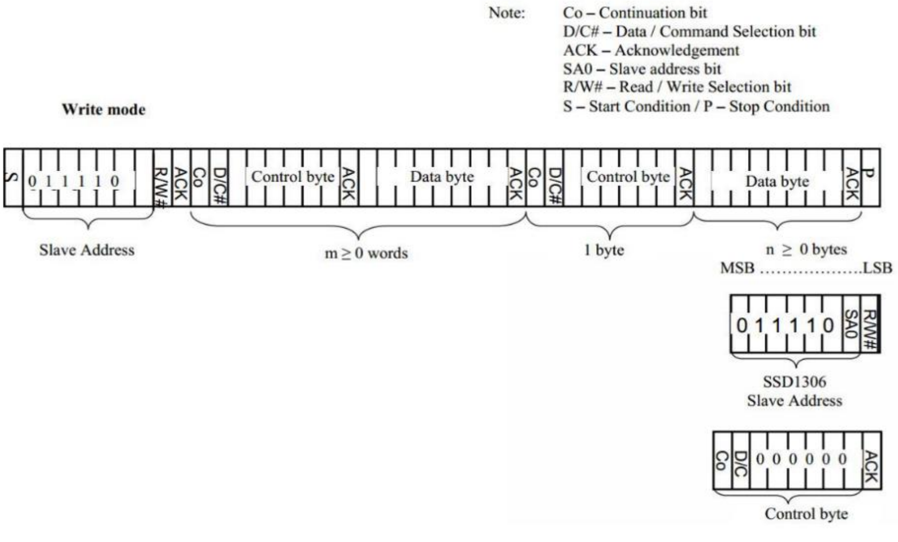

Fig 10. Timing diagram of IIC of SSD1306

According to the sequence diagram of IIC of SSD1306, the operation sequence for writing data to SSD1306 using the IIC protocol is as follows: first, send the start signal, and then set the RW # bit and SDA position to 0. Wait for SDA to switch from high level to low level. When D /C=0, write data bytes. When D /C=1, write command bytes. Wait for the SDA to change from high level to low level, and then write a command byte. Wait for SDA to switch from high level to low level. If the host sends an end signal to end the communication and release the bus when the communication ends.

4.3. Wireless Network Programming

Local WIFI operates in the lower computer mode. When the lower computer is turned on, STM32 can send data to the lower computer through a serial port. The lower computer transmits the data to the upper computer through the TCP/IP protocol, which is the cloud platform and mini program terminal in this design. At this point, data can be directly read from the serial port. The ESP8266 module supports three working modes, namely STA working mode, AP working mode, and STA+AP working mode [9]. When initializing the lower computer, it is usually achieved using the 'AT' command. It should be noted that before starting STM32, it is necessary to start the mini program terminal and initialize the upper computer. After receiving the command, the lower computer will return the execution result to STM32. The STM32 local end and remote end communicate through a master-slave transparent transmission method between Wi-Fi modules, which is essentially serial communication. The remote end uses the serial port components inside Wechat App to associate the corresponding signals with slot functions and detect the received content of the serial port [10].

4.4. Wechat APP programming

Wechat App is an app written using the JavaScript programming language on the Wechat developer platform. The lower computer sends the detected data to the cloud platform through a wireless network, and the cloud platform sends the data to Wechat App, thereby achieving information transmission from the lower computer to the upper computer. Wechat App is mainly divided into three parts: the control program for the lower computer, the data display program, and the cloud platform connection program. The control program of the lower computer is mainly achieved through the interruption of STM32. The small program sends an interruption signal to the cloud platform, which sends an interruption signal to STM32. STM32 controls the fan switch, thus achieving intelligent control of the tunnel ventilation system.

5. Conclusions

This design is based on the STM32 tunnel ventilation design system. The core is the STM32 microcontroller, which realizes the detection of temperature, humidity, and harmful gas concentration in the tunnel, as well as the function of over threshold alarm and automatic control of the motor to control harmful gas concentration and temperature below the threshold. In addition, manual control can also be achieved through Wechat App. The entire system occupies less space, and the model can be moderately optimized in tunnels, such as fan power, fan blade size, etc. The advantage of its system lies in its high intelligence and simple operation. Suitable for implementing intelligent ventilation systems in tunnels. It is of great significance for ensuring construction safety, promoting traffic development, energy conservation and emission reduction, and has a very broad prospect.

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