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Research on the vehicle safety protection system "Drive with confidence"

Hongjing Yuan[1,a], Zhengquan Zheng[1,b], Qing Chang[1,c,*]

[1]Department of Information and Mechanical Engineering, Jinshan College of Fujian Agriculture and Forestry University, Fuzhou, China
[a] 1121686091@qq.com, [b] 1347208419@qq.com, [c] 514281473@qq.com
**Corresponding author*

Abstract: *"Drive with confidence" - Vehicle Safety System is a project born in response to the continuous growth of China's economic and urbanization process, as well as the increasing number of fatalities caused by frequent traffic accidents. With the frequent occurrence of traffic accidents, people's attention to the automotive industry has shifted from car performance to car safety. With the development of technologies such as in-vehicle mobile communication, the development and application of smart devices are becoming increasingly popular. This article primarily focuses on the application of sensor technology, CAN bus technology, vehicle information acquisition technology, GNSS positioning technology, and data fusion of 5G mobile communication for developing an intelligent safety system that implements sensor alarms and facilitates the quick evacuation of passengers in the event of a fire accident through window breaking. Its main functions include smoke, temperature, humidity, CO2 concentration detection within the vehicle, reading of passenger vehicle driving data, transmission of information to onboard terminal modules, remote backend monitoring, and automatic window breaking functionality. Experimental results indicate that various sensors perform well, and all onboard hardware modules function properly. The supervisory backend can receive real-time information from the system terminals and monitor vehicle positioning and speed status information. Both automatic and manual window breaking can be realized.*

Keywords: *Drive with confidence, Vehicle Safety System, CAN bus, GNSS positioning technology, terminal modules, automatic window breaking functionality*

1. Introduction

In the rapidly evolving world of technology, people's demands for vehicles are no longer limited to simple transportation. Therefore, automotive companies are increasingly considering factors such as comfort and luxury in the manufacturing of modern vehicles. While the integration of advanced electronics, fuel systems, and larger cargo space provides convenience for passengers, it also increases the risk of rapid fire spread in the event of a fire. Due to the confined space and high driving speeds, accidents involving vehicles often result in severe consequences, with significant losses in terms of human lives and property. These incidents have a profound impact on society and often become a focal point of concern for various stakeholders. Analyzing the characteristics of major vehicle accidents, such incidents are frequently accompanied by direct fires or indirect fires after collisions[1]. This is also the reason why vehicle accidents pose challenges for escape and result in substantial loss of life and property.

Research on the practical application of intelligent fire alarm systems in domestic settings has shown a thriving development trend since the beginning of the 21st century. In the year 2000, Wang Xihuai and others proposed the use of a multi-sensor detection approach for ship fire alarm systems, employing multi-sensor integration and multi-parameter fusion methods to achieve multi-level fire alarms on ships. In 2011, Peng Haixia and colleagues emphasized the significant role of fire automatic alarm systems in building fire early warning and other scenarios, successfully developing an integrated detection and alarm fire automatic alarm system[2]. With the advancement of internet applications, in 2018, Tao Zengjie and others designed a fire alarm intelligent system based on the Internet of Things (IoT) technology. This research not only improved the speed of fire detection but also proposed different levels and perspectives of fire monitoring. By integrating IoT technology, the system benefited from the advantages of networking, thus enhancing the accuracy of alarm results[3]. In 2019, Feng Xiaoxiang and others based on low-power wide-area network communication technology, designed and developed a wireless fire alarm control system for fire IoT vehicles[4]. This system achieved dynamic monitoring of fire risks in logistics vehicles, real-time collection of sensor information, and uploading to servers, which holds significant importance for the development of the logistics industry[5].

In addition to deploying fire alarm systems, it is necessary to consider how to safely and effectively create escape routes in the event of a vehicle fire accident, such as incorporating an automatic window-breaking device. Although vehicles are equipped with window-breaking tools, such as safety hammers, their window-breaking capability is often limited, requiring multiple strikes and consuming time and effort[6]. Currently, there are a few improved window-breaking devices available in the domestic market, which primarily utilize high-energy spring storage, miniaturized explosive impact, or electromagnetic emission principles to enhance window-breaking ability. However, research on intelligent automatic window-breaking is limited but highly significant. In order to address the issue of low efficiency in window-breaking hammers, Xu Zhiwei designed a new type of window-breaking device in 2010. In 2011, Pan Caixia and her team built a bus automatic escape system with the PAC System RX3i controller as its core. The proposal of this solution has advanced exploration into installing automatic escape systems on public transportation vehicles and holds great market potential[7].

Technological advancements and the mature application of various technologies, including the Controller Area Network (CAN) bus, fire detection sensors, and modern mobile communication technology, have made it possible to integrate a vehicle fire accident window-breaking system triggered by fire hazard signals[8]. In the 1990s, Bosch, a German company, introduced the CAN communication protocol, primarily targeted at the automotive industry. Since then, the high reliability and superior performance of CAN bus communication have expanded its usage in various fields such as industrial equipment, medical devices, and ships. In 2012, Szabo et al. designed an autonomous motion robot control system based on the CAN bus, demonstrating the high reliability of CAN communication with microprocessors and expanding its application in the field of intelligent robotics[9].

This article describes the development of an intelligent safety system aimed at facilitating the rapid evacuation of passengers during a fire incident by breaking windows, along with sensor-based alarm functionalities. The main features of this system include detecting smoke, temperature, humidity, and CO2 concentration inside the vehicle, as well as collecting driving data. The collected information is then transmitted to the onboard terminal module and a remote backend monitoring system. The experimental results demonstrate the excellent performance of the sensors, and the onboard hardware modules operate normally. The backend monitoring system is capable of receiving real-time information from the system terminals and monitoring the position and speed status of the vehicle. Additionally, the system can automatically or manually break the windows to aid evacuation.

2. Hardware design of vehicle broken window escape system

2.1. Overall hardware structure of vehicle broken window escape system

The overall structure of the system hardware is shown in Figure 1.

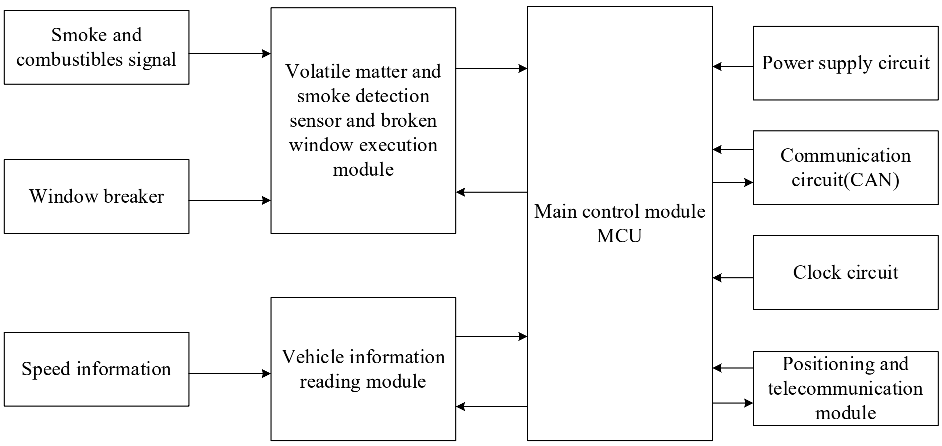

Figure 1: Overall structure diagram of system hardware

The hardware part of the vehicle fire accident window-breaking escape system studied in this article consists of the selection of various functional module chips and the design of hardware circuits for each

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module. The hardware modules of this system include the onboard terminal control module, flammable volatile substance and smoke detection sensor, window-breaking execution module, vehicle information reading module, and positioning and remote communication module

Data transmission between the hardware modules is carried out through the CAN bus. Additionally, considering the stability and reliability requirements of the system operation, the hardware modules have been designed using methods to resist electromagnetic interference. In the design of the system power circuit, the voltage of medium to large-sized passenger vehicles' batteries is generally 24V. Therefore, appropriate DC-DC buck modules were chosen to design voltage reduction circuits, converting 24V to 12V and 12V to 5V, to meet the operating voltage requirements of different units[10].

2.2. System vehicle terminal control module circuit design

The circuit design of the hardware modules begins with the selection of the microprocessor, which is the most crucial and fundamental part of the system. There are numerous microprocessors available in the market today for automotive applications. In this study, the selection of the MC9S12G48 chip from NXP was based on actual requirements. This chip is a mature product widely used in the automotive electronics field. The chosen package type is a 32-pin LQFP package. The main functional parameters of this chip are as follows:

1) CPU: It utilizes a 16-bit central processing unit core with a operating frequency of 25MHz.

2) Memory: It has 48K bytes of flash memory and 4K bytes of RAM.

3) Analog-to-Digital Converter: It features 8 channels of 10-bit precision analog-to-digital conversion, with a conversion time of 3 microseconds.

4) Timers: It includes 6 channels of 8-bit precision for input capture or output compare.

5) Pulse Width Modulation (PWM) Module: It consists of 6 channels of 8-bit precision PWM.

6) Communication Interfaces: It includes one Serial Peripheral Interface (SPI) peripheral interface, one MSCAN module interface, and two SCI module interfaces.

The functional allocation of the peripheral pins of the main control chip is shown in Figure 2.

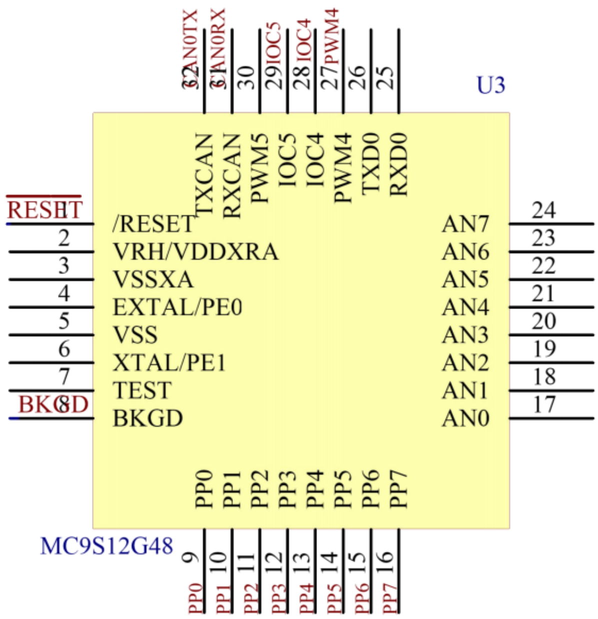

Figure 2: Main control chip MC9S12G48 pin function distribution diagram

2.2.1. CAN communication interface circuit design

The TJA1040 CAN transceiver is an interface commonly placed between the CAN controller and the physical bus. It supports a maximum data transmission rate of 1 Mbps and is fully compatible with the ISO 11898 standard protocol. It is a new generation product based on the high-speed CAN transceiver TJA1050. Its advantages can be listed as follows: it is compatible with input levels of 3.3V or 5V,

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supports up to 110 communication nodes, has strong resistance to electromagnetic interference, and features a low-current standby mode and bus remote wake-up function. The CAN transceiver interface circuit schematic for the onboard terminal control module is shown in Figure 3, where P2 is the interface used for debugging with the positioning and remote communication module.

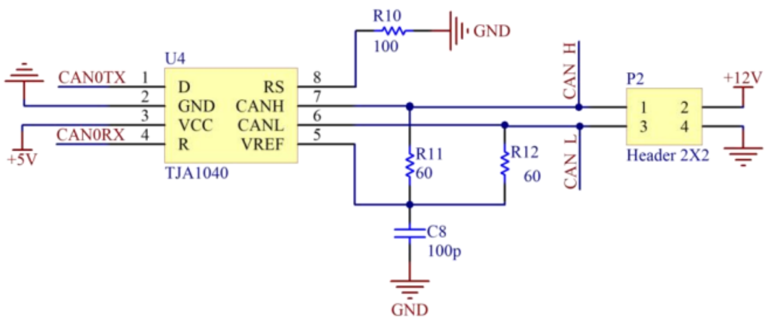

Figure 3: CAN transceiver circuit schematic diagram

2.2.2. Clock, reset circuit design

The quality of the clock signal plays a crucial role in the proper functioning of a microcontroller system. For the onboard terminal control module, an external passive crystal oscillator with an oscillation frequency of 4MHz is chosen for the clock circuit. The two pins of the passive crystal oscillator are connected to the 4th pin (EXTAL) and the 6th pin, respectively[11]. To enhance the anti-interference capability of the clock circuit without affecting the precision of the crystal oscillator, each of the two pins of the passive crystal oscillator is connected to ground through a 20pF capacitor. The reset circuit ensures that in case of any abnormality during program execution, a power-on reset is triggered to initialize all modules of the system, thereby enabling normal system operation. The schematic diagram of the reset circuit and the crystal oscillator circuit is shown in Figure 4.

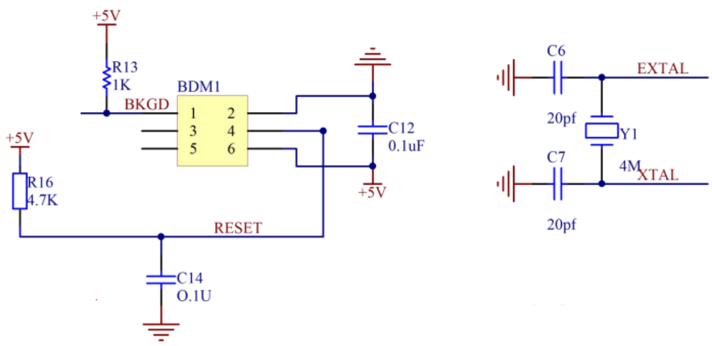

Figure 4: Reset and crystal oscillator circuit schematic diagram

2.2.3. Sound and light alarm circuit design

The design of the audiovisual alarm circuit is intended to alert the driver to the location of the specific triggering sensors (flammable volatile substance and smoke detection sensors) and the window-breaking execution module inside the vehicle compartment. Four common-anode tricolor LEDs are set in the main control module for alarm indication. The first LED indicates the power status of the main control module, with the blue LED illuminated upon module power-up. The second, third, and fourth LEDs respectively indicate the detection status of the sensors located in the front, middle, and rear positions of the vehicle compartment[12]. Upon power-up, the blue LED remains constantly lit. Once an alarm occurs in the corresponding position, the corresponding LED starts flashing in red. The illumination of the tricolor LEDs is controlled by the MMUN2211LT1 transistor. Under normal system conditions, the main control chip of the onboard terminal control module outputs a high level to the base of the transistor controlling the blue LED, thereby turning on the circuit for blue LED illumination, while the transistor controlling the red LED remains off. During an alarm situation, the main control chip outputs a low level to the base of the transistor controlling the blue LED, interrupting the circuit for blue LED illumination. At the same time, the main control chip outputs a PWM level to the base of the transistor controlling the red LED, causing the red LED to flash. The design of the buzzer alarm circuit is similar to that of the audiovisual alarm circuit, with the main control chip outputting high and low levels to control the conduction of the

MMUN2211LT1 transistor and thus the buzzer circuit. Additionally, a buzzer mute circuit is designed to deactivate the buzzer alarm by pulling down the voltage of pin PP6 of the main control chip via a switch. The relevant circuit schematic is shown in Figure 5.

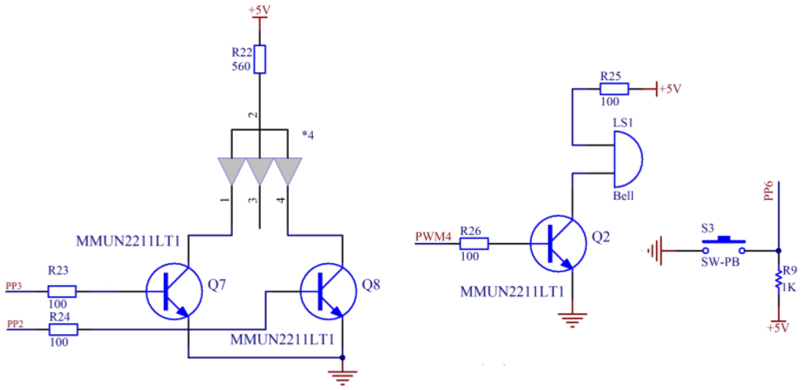

Figure 5: Acousto-optic alarm circuit schematic diagram

2.2.4. Manual window breaking circuit

Under normal circumstances, after the onboard terminal control module is powered on, the +5V voltage holds the PP7 interface of the main control chip at a high level through a pull-up resistor. Once the S2 push button switch is pressed, the PP7 interface potential is pulled low, triggering the main control chip to send a forced window-breaking message to the window-breaking module, thereby completing the circuit for the operation of the power window breaker. The circuit diagram is shown in Figure 6. The purpose of the manual window-breaking circuit design is to ensure that in the event of a vehicle fire where automatic window-breaking is not possible, the vehicle windows can be shattered by pressing the S2 push button switch.

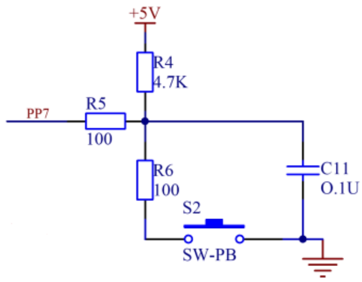

Figure 6: Manual broken window circuit

2.3. Flammable volatile matter and smoke detection sensor and broken window execution module circuit design

2.3.1. Flammable volatile matter and smoke detection sensor circuit

The interfaces of the ZPE02 flammable and explosive gas detection module include +12V power ports (one on each side for reliable power supply). The communication interfaces RXD and TXD are connected to the TX and RX pins of the MC9S12G48 microprocessor, respectively. The module has three alarm output level interfaces: OUT_L, OUT_M, and OUT_H. By default, they have low-level active output and are connected to the PWM4/IOC4 and IOC5 pins of the MC9S12G48 microprocessor, the latter being used as an IO channel. Under normal conditions, OUT_M outputs a low level, and the built-in alarm indicator of the module blinks at a frequency of 1 second. In all other cases, it outputs a high level. When a low alarm is detected (both sensors have low concentration alarms), the indicator blinks at a frequency of 600 milliseconds, OUT_L outputs a low level, and the rest of the time it outputs a high level. When a high alarm is detected (at least one sensor has a high concentration alarm), the indicator blinks at a frequency of 300 milliseconds, OUT_H outputs a low level, and the rest of the time it outputs a high level. The ZH03B laser dust sensor, which serves as the smoke sensor in the system, has two types of alarm output: serial port and PWM. Since the RX and TX pins of the main control chip are already occupied, the PWM alarm output is used. The output pin is connected to the PP6 pin of the main control chip used as an input interface. When the smoke sensor alarms, the PWM output port of the sensor outputs

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a high level. The peripheral interface circuits of the two sensors and the logic level transformation of the various alarm output interface pins of the ZPE02 flammable and explosive gas detection module are shown in Figure 7.

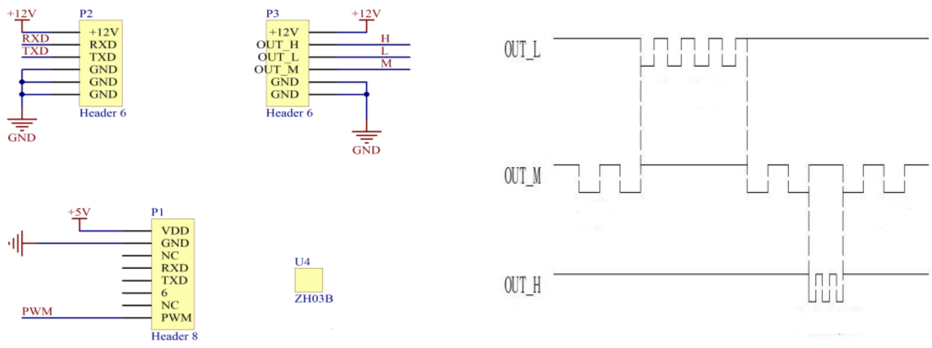

Figure 7: Schematic circuit diagram of sensor interface and logic level diagram of pin function

2.3.2. Window breaker switch control circuit

In the design of the window breaker switch control circuit, the IRF7341 MOSFET is chosen as the switch to control the conduction of the window breaker circuit. This MOSFET features ultra-low on-resistance, ensuring the reliability and real-time operation of the switch circuit, making it widely used in the automotive electronic control field. In the window breaker switch control circuit, the P4 interface terminal is used as the positive terminal and connected to the positive terminal of the window breaker, providing a 12V operating voltage. The negative terminal is connected to the negative terminal of the window breaker. Under normal conditions, the MOSFET is in the cutoff state. The gate of the conducting MOSFET is connected to the PP1 pin of the microprocessor, which outputs a control voltage level. When the PP1 pin outputs a high level, the MOSFET is turned on, and the circuit of the window breaker is completed, driving the window breaker to work. The schematic diagram of the window breaker switch control circuit is shown in Figure 8.

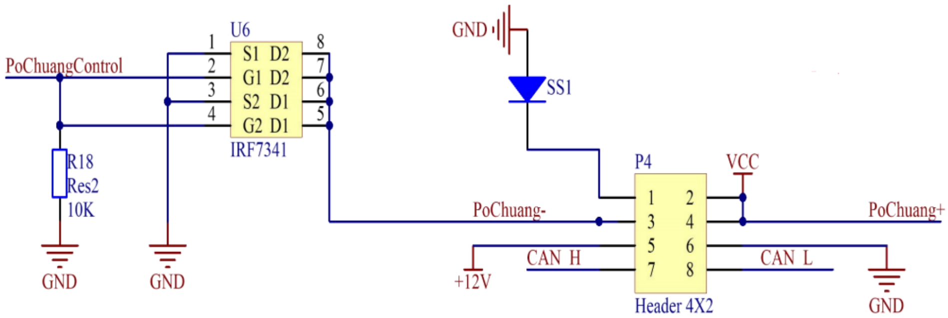

Figure 8: Window breaker switch control circuit schematic diagram

2.4. Positioning and telecommunication module

According to the overall system requirements, the positioning and remote communication module MCU needs to receive system alarm data from the main control module, vehicle information data collected by the vehicle information acquisition module, and GNSS positioning information, and then upload these data to the monitoring backend to achieve real-time monitoring of the bus. Therefore, the hardware part of the peripheral circuit needs to include the CAN receiver peripheral circuit, GNSS module, and 4G module peripheral circuits. The module uses an LQFP48 package STM32F103C8T6 chip as the microprocessor of the minimum system. This chip has a total of 48 pins, and its main functional features are as follows: it uses a high-performance ARM® Cortex™-M3 32-bit RISC core with a working frequency of 72MHz; 64K bytes of flash memory, 20K bytes of SRAM; 2 12-bit ADCs, 3 general-purpose 16-bit timers and 1 PWM timer, as well as advanced communication interfaces: up to 2 I2C interfaces and SPI interfaces, 3 USART interfaces, 1 USB interface, and 1 CAN interface. The functional allocation of the peripheral pins of the main control chip is shown in Figure 9.

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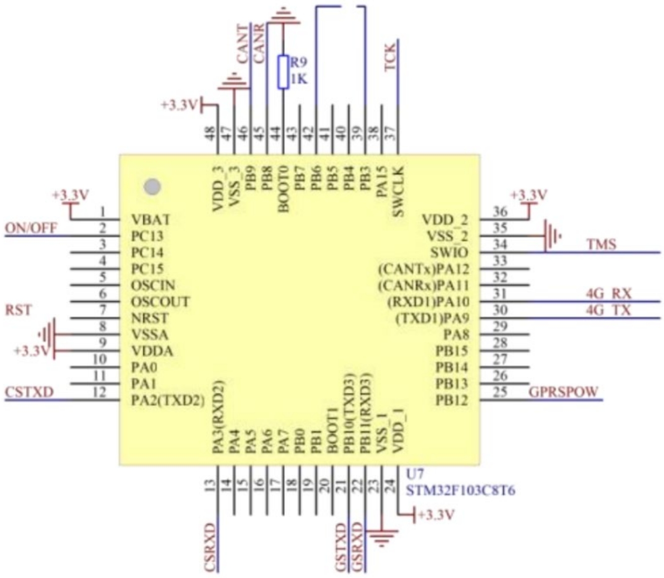

Figure 9: Pin function distribution diagram of main control chip

3. System software development

3.1. Vehicle terminal control module program development

After the module is powered on, the microcontroller will only start running from the main function, and the initialization functions of the program are also included therein. Initialization functions are essential for the proper functioning of the program and play a crucial role in the program. The initialization function flow and their purposes in the vehicle terminal module are shown in Figure 10.

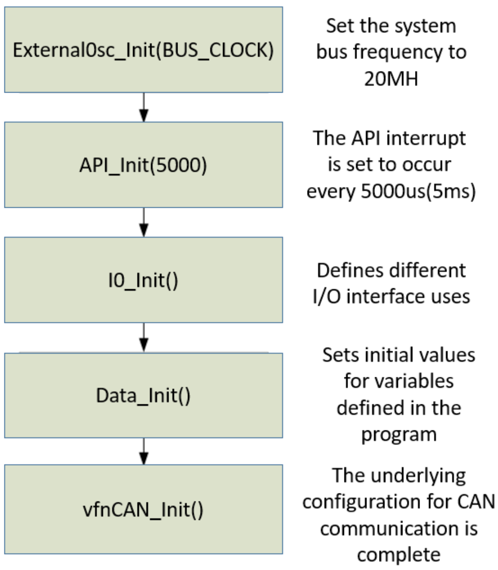

Figure 10: The process of initialization function of vehicle terminal module

3.2. Flammable volatile matter and smoke detection sensor and broken window execution module program development

The development process of the flammable volatile gas and smoke detection sensor, as well as the window-breaking execution module, is similar to that of the vehicle terminal control module. Firstly, in the main function, initialization sub-functions are called to sequentially complete the program's system bus clock configuration, API interrupt frequency setting, I/O interface function configuration, variable and flag initialization, CAN communication initialization, and other initialization processes. Then, interrupts are enabled, and the program will cyclically execute the task scheduler function vfnTask_Scheduler(). Finally, when the microcontroller is reset, the program will be executed again. The program block diagram for the flammable volatile gas and smoke detection sensor, as well as the window-breaking execution module, is shown in Figure 11.

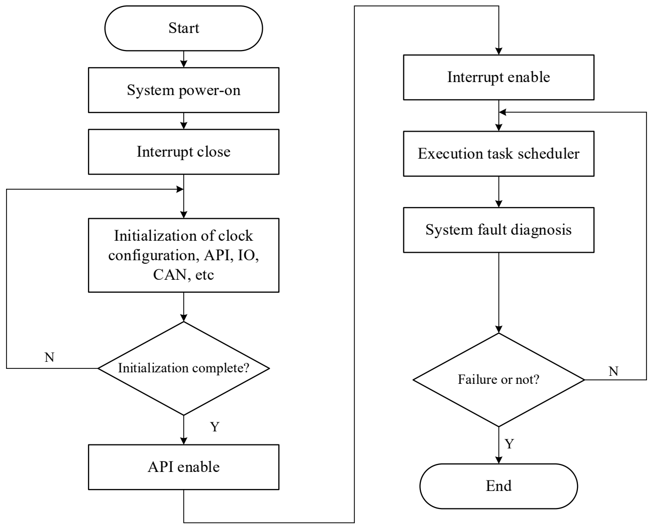

Figure 11: Block diagram of sensor and broken window execution module

In this study, flammable volatile gas and smoke detection modules are installed at the front, middle, and rear positions inside the vehicle, with IDs of 0x702, 0x703, and 0x704, respectively. The program checks the smoke detection every second and the presence of flammable volatile gas every 0.5 seconds. If either of these two conditions is detected, the corresponding information will be uploaded to the controller to be written into the data segment of the outgoing message. In normal conditions inside the vehicle, the data segment of the message will be filled with zeros, indicating that no alarms have been detected.

3.3. Communication module program development

The functionality to be implemented by the positioning and remote communication module is to receive data from the CAN bus and GNSS positioning information, and send them to the monitoring platform through the 5G module. The GNSS positioning information acquisition and 5G transmission are performed by the Quectel EC20 dual-function module, which is connected to the MCU via the USART serial port. The software flow begins with the initialization of GPIO, CAN, USART, and other ports. The EC20 module's 5G function is used to establish a wireless network connection. Once the network connection is successful, the program starts receiving and storing data from the CAN bus and GNSS positioning. The received data is then packaged and sent to the monitoring backend. If the transmission fails, the program immediately interrupts and retries the data reception until successful transmission, and then proceeds to the next data reception and transmission cycle.

4. System test

4.1. Positioning and remote communication module testing

During the testing of the GNSS positioning functionality of the onboard terminal, it is necessary to place the antenna outside the window to ensure the quality of signal acquisition. The connection with a personal computer is achieved through a USB-to-serial converter. The USB serial debugging tool and GNSS latitude and longitude observation tool display the data as shown in Figure 12. The data displayed by the serial port tool indicates that the module's positioning functionality is normal. Among them, the sentence "112031.0,3448.6836N,11340.1161E,1.9,112.0,2,328.01,0.0,0.0,230321,04" contains the extracted data required by this system. According to the parsing protocol, the data can be interpreted as follows: the test time is 11:23:04 in Beijing time, the date is March 23, 2021, and the location is represented by the module's original latitude and longitude coordinates: 34°48'42.40"N, 113°40'6.52"E.

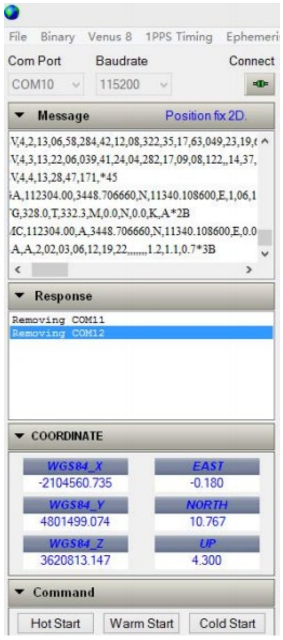

Figure 12: GNSS positioning function serial port tuning attempt

4.2. Vehicle terminal control module data sending and receiving test

During the test, after the system is powered on, the flammable and explosive gas detection module and smoke sensor are stimulated by butane in a lighter and cigarette smoke. The indicator lights of the vehicle terminal control module are observed, and the manual window break button is pressed to observe whether the window break command message is sent and whether the window breaker circuit connected to the LED is conducting. The CAN bus data stream is observed through the CAN test software window to confirm the effectiveness of the flammable volatile substance and smoke detection sensors, as well as the proper functioning of the vehicle terminal control module's sending functionality.

4.3. System real car window test

The system's on-road testing was conducted at Zhonglian Recycling Resources Co., Ltd. in Xinmi City, Henan Province, China. Firstly, the various modules of the system were installed inside the test bus. Then, the flammable substance detection and window break module sensors were stimulated to test whether the monitoring backend could receive the alarm information from the terminal in the system. Finally, remote window break commands were sent from the monitoring backend to verify the reliability of the system's remote window breaking functionality. The on-road testing scenario and the system information received by the monitoring backend are shown in Figure 13.

Figure 13: System test scene layout and broken window renderings

5. Conclusion

The aim of this project is to realize an intelligent vehicle fire accident window-breaking system. By accessing the vehicle's OBD port, information such as vehicle speed is retrieved. Leveraging the 5G communication network, this gathered information, sensor alarm data, and location coordinates are sent to the monitoring backend. The system achieves detection of hazardous volatile substances, early smoke alarm for fire incidents inside the vehicle, and uploads the information to the regulatory backend. To

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enhance system reliability, manual window-breaking by the driver and remote window-breaking commands from the backend are included. Following a modular design approach, the system terminal module consists of the terminal control module, volatile substance and smoke detection sensors, window-breaking execution module, vehicle information retrieval module, and positioning and remote communication module. The circuit schematics design for each hardware module of the system has been optimized.

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