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Application of Electrical Product Design in Residential Security Systems

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Abstract: Based on the mastery of basic principles of electrical product design, the Capstone educational philosophy, which is oriented towards learning outcomes, is practiced through practical steps such as on-site research and physical production. Against the backdrop of people's increasing emphasis on security, this paper designs a community security system based on the STM32F103C8T6 microcontroller, which combines various sensors such as flame sensors, human infrared sensing modules, and RFID detection modules to monitor fires and external personnel. Relays, buzzers, and other modules implement intelligent access control and alarm functions. In practice, it can meet the intelligent security needs of modern communities, enhancing residential safety and convenience.

Keywords: Electrical Product Design; STM32; Residential Security System; Smart Access Control; Video Surveillance

1. Introduction

The electrical product design course integrates engineering practice and innovation ability cultivation, covering multiple aspects such as functional analysis of electrical products, design process, material and process selection, drawing of electrical schematic and structural diagrams, product standards and specifications. This course is a collaborative effort between schools and enterprises for the electrical engineering and automation major. Under the guidance of enterprise engineers, students gain a deep understanding of the real product development process and technical points, thereby achieving efficient transformation from classroom knowledge to engineering application. In the context of the Capstone project offered in the electrical major, students delve into the real product development process and technical points of enterprises to design an electrical product.

As China's urbanization process continues to accelerate, residential communities, as the core setting for residents' lives, have seen an upgrade in their security needs, shifting from traditional "passive protection" to "active early warning and intelligent control" [1]. With the enhancement of residents' safety awareness, traditional security modes such as single manual patrol, access control duty, or independent sensor monitoring have gradually revealed drawbacks such as insufficient real-time performance, delayed early warning, and fragmented management. For example, manual patrol has issues with high labor costs and numerous blind spots at night, while independent flame alarms can only sound early warnings locally and cannot achieve remote synchronous reminders. These deficiencies make it difficult to meet the modern residential community's demand for "all-weather, all-round, and fully-linked" security. The rapid development of embedded technology and low-power wireless communication technology provides technical support for the intelligent transformation of residential community security systems [2].

The intelligent security device for elderly users based on STM32 in literature [3] integrates a camera module, GSM/GPRS module, smoke sensor, flame sensor, and infrared sensor. It has reference value for the integration of buzzer local warning function in residential community security.

2. Overall Design Scheme

This system uses the STM32F103C8T6 microcontroller as its core, with a 12V lithium battery as the power supply module. It outputs 3.3V and 5V voltages through LM1117-3.3V and LM1117-5V voltage regulation modules, respectively, to power the STM32 microcontroller, various sensor modules, and modules such as ESP8266 and ESP32-CAM, ensuring stable operation of all system hardware and avoiding voltage fluctuations that could affect the normal functioning of security features. The flame sensor collects real-time flame concentration signals within the residential area and transmits the data to the STM32 microcontroller through both analog and digital outputs. The human body infrared sensing module (HC-SR501) detects human movement within the area and outputs a high-level signal to the STM32. The RFID detection module (RC522) reads the card number information of the swiping personnel and transmits it to the STM32 via SPI protocol for permission comparison. The STM32 processes these sensor data to accurately determine whether there are abnormal situations such as fire hazards, personnel intrusion, and illegal card swiping.

The STM32 microcontroller serves as the core of the system. On one hand, it establishes a connection with the ESP8266 wireless transmission module through the serial port, and achieves bidirectional data interaction with the APP via Wi-Fi: it receives user card registration instructions, flame alarm threshold setting instructions, and manual control instructions issued by the APP, while simultaneously sending monitoring data collected by sensors and abnormal event information, such as unregistered card swiping and flame exceeding the limit, to the APP, facilitating real-time viewing and remote control by management personnel. On the other hand, it communicates with the ESP32-CAM camera module through the UART interface, controlling it to capture real-time images of key areas in residential areas and transmit the camera data to the APP, enabling remote video surveillance.

Upon receiving the card number transmitted by the RFID module and determining it as a registered user, the STM32 sends a control signal to the relay module. The relay engages, driving the door lock motor to operate, thus achieving the door-opening function. If the card number is determined as unregistered or if excessive flame concentration or abnormal personnel intrusion is detected, the STM32 triggers the buzzer module to emit audible and visual alarms. Additionally, the system switches between manual and automatic modes through physical buttons: in automatic mode, the STM32 automatically monitors flame conditions and the entry and exit of external personnel, uploading the data; in manual mode, relevant control functions are implemented through APP operations. As shown in Figure 1.

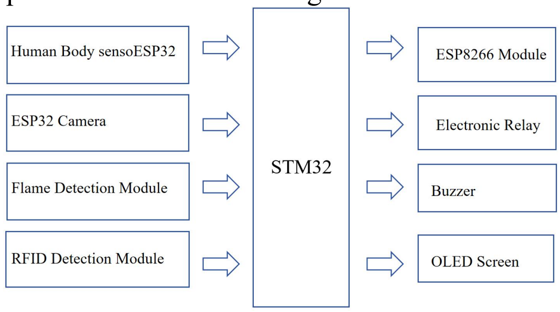

Figure 1. Design Scheme Diagram

3. System Hardware Design

As the core control unit, STM32F103C8T6 possesses processing capabilities suitable for security access control scenarios and abundant pin resources for coordinating the work of various peripheral modules. It can efficiently drive hardware components such as flame sensors, RFID modules, and relays to work together. Furthermore, by connecting an external ESP8266 module, it can flexibly implement wireless communication functions, fully meeting the design requirements of this system.

OLED display module: Its pins are connected to PB12 and PB13, utilizing the general-purpose I/O ports of STM32 to display and output access control status, system parameters, and other content. ESP8266-01S wireless transmission module: The TX and RX pins are respectively connected to PA3 and PA2 of STM32, facilitating data interaction between the access control system and the host computer or mobile phone APP, such as uploading card swipe records and receiving remote configuration instructions. Human body infrared detection module: The DAT pin is connected to PB14, transmitting the detected human body infrared sensing signals to STM32 to trigger access control responses. Infrared flame detection module: The signal output pin is connected to PA4, passing the detected flame signals to STM32 for fire warning, linkage access control, and other fire-fighting equipment. Relay module: The control pin is connected to PB15, with STM32 outputting level signals to control the relay's engagement/disengagement, achieving on/off control of the access control door lock. Button module: The button pins are connected to PC13 and PC14, enabling the execution of corresponding functions by detecting changes in button voltage levels. Buzzer module: The control pin is connected to PB9, with STM32 outputting signals to drive the buzzer, emitting audible and visual alarms in case of anomalies [4,5]. RFID module: Its related pins PA0, PA1, PA5, PA6, and PA7 communicate with STM32 to achieve read-write operations on RFID cards, which are used to identify the validity of access cards and read information stored within the cards. Each pin has a clear division of functions and works in coordination to ensure stable system operation and fulfill various functions of the residential community security access control system. As shown in Figure 2.

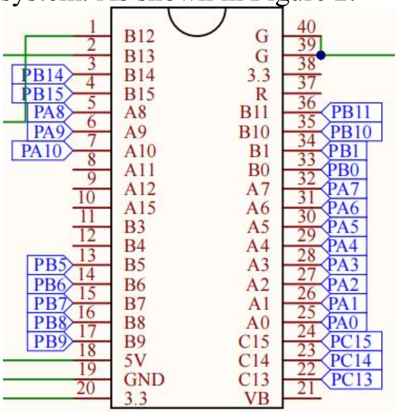

Figure 2. STM32F103C8T6 Pin Circuit

At the same time, reset circuits, crystal oscillator circuits, human body infrared sensing module circuits, RFID detection module circuits, camera module circuits, wireless transmission module circuits, relay module circuits, and buzzer module circuits are designed [6].

4. System Software Design

The main program of the system serves as the core execution logic of the residential community security system, responsible for coordinating the collaborative work of various modules to achieve functions such as security monitoring, access control, and remote interaction. When the program starts, it first performs system initialization and simultaneously evaluates two conditions: personnel intrusion and flame danger. If personnel intrusion or flame danger is detected, an alarm warning is triggered; if not detected, the alarm warning is turned off.

The system uploads security monitoring data to the APP terminal, and then determines whether the RFID card used for swiping belongs to an administrator card. If it is an administrator card, the alarm warning is disabled; otherwise, the alarm warning remains in place. The program executes button-related instructions, such as switching between manual and automatic modes, and receives instructions sent from the APP, such as adding an administrator card number or modifying the flame threshold. Ultimately, the microcontroller system switches to the corresponding mode or changes the flame threshold to complete the instruction response. After all functions are executed, the program "returns" to the monitoring and judgment phase, entering the next round of looping to ensure continuous system operation. The main program flow is shown in Figure 3.

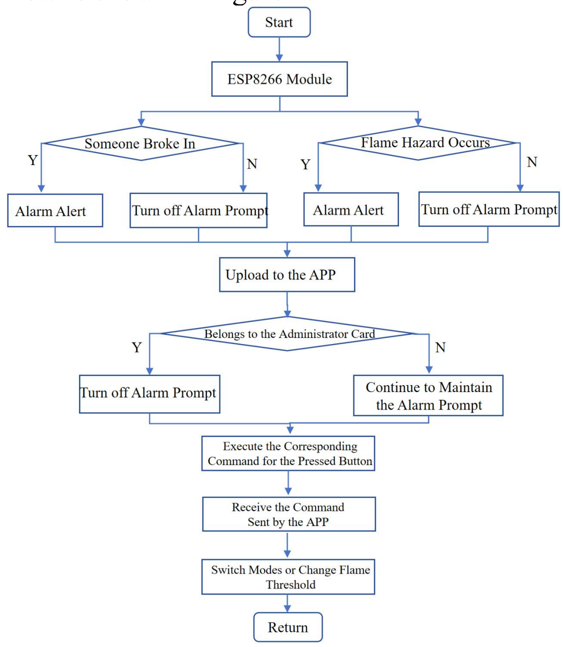

Figure 3. Main Program Flowchart

The human body infrared sensor subprogram is designed to detect whether there are personnel activities in the residential area; the RFID detection module subprogram is used for identity recognition at the entrance of the residential area; the camera module subprogram is used to capture real-time images of key areas in the residential area; the wireless transmission module subprogram is used to achieve bidirectional data interaction between the system and the mobile APP terminal; the relay module subprogram is used to control the on/off state of the entrance door lock in the residential area; and the buzzer module subprogram is used to alert when the security system in the residential area detects abnormal situations [7,8].

5. System Physical Debugging

5.1 Hardware Debugging

The hardware debugging and software debugging of the system are closely interrelated.

First, eliminate obvious hardware faults, and then debug in conjunction with the software. The ultimate goal of designing the security system for this community is to achieve practical functions such as security monitoring and intelligent access control in real-world scenarios. Therefore, after completing the system scheme design, hardware design, and software design, it is necessary to test and verify the functions of each module. Power on the system, measure the potential of each key node, and check whether it is consistent with the design requirements. If the potential is abnormal, troubleshoot the power supply voltage regulation circuit, filter capacitor, and other parts. Then, use a simulator for online debugging, test the I/O port, peripheral devices, crystal oscillator circuit, and reset circuit separately, and correct any errors found in a timely manner [9,10].

Finally, connect the STM32's program download interface to an external downloader to prepare for software debugging. Use programming software to program the written test program into the STM32 microcontroller, and verify whether the various hardware modules can initially achieve basic functions under program control.

5.2 System Operation Effect

The power indicator lights of each module in the system are illuminated normally, indicating that the entire system's circuit is functioning properly without any short circuits. After power-on, the OLED screen displays automatic or manual mode, with the flame threshold set to 50. When someone is detected approaching, an alarm is triggered after a 10-second delay, as shown in Figure 4.

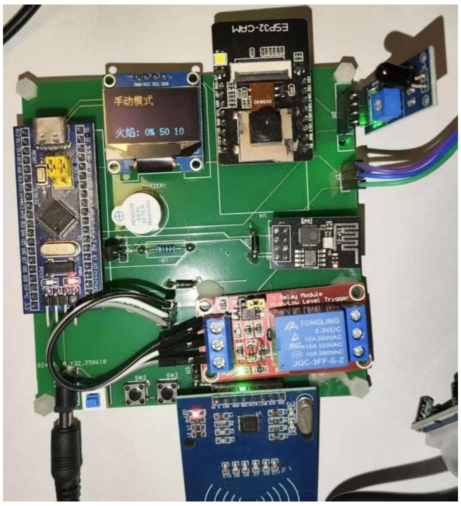

Figure 4. Physical Object Diagram

By pressing a button, the system can be switched to card reading mode. In this mode, the system reads the card number through the RFID module and displays it on the OLED screen, facilitating users to manually enter the card number for registration in the APP. Switching the system to manual mode allows for manual triggering of system alarm activation and deactivation. In the APP, users can directly read the flame values and the normal or abnormal status of the system, as well as adjust the system flame threshold and switch the system's operating mode through the APP. After the microcontroller system enters the card swiping mode, place the RFID card above the sensor, and the sensor reads the card code. When the flame sensor detects a flame, it triggers a flame alarm, and the camera module captures the flame situation immediately, allowing users to view the current flame situation.

6. Conclusion

This design is based on the STM32-based community security system, providing an intelligent and efficient solution for community security management.

1) The hardware part utilizes STM32F103C8T6 as the main control core, integrating a flame sensor and a human infrared sensor to achieve environmental and personnel monitoring. It employs an RFID detection module and a relay to construct an intelligent access control system, and is paired with an ESP32-CAM camera module and an ESP8266 wireless transmission module to complete remote video and data interaction. Local alerts and mode switching are implemented using a buzzer and physical buttons.

2) Finally, a joint test of software and hardware is conducted to verify the stability and functionality of each hardware component, ensuring that indicators such as RFID card number reading accuracy, flame concentration acquisition precision, and video transmission delay meet standards. Additionally, actual residential community scenarios are simulated to ensure that after the triggering of abnormal events, APP reminders, relay door lock responses, and other aspects meet design requirements.

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