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Design and Implementation of STM32-based Intelligent Fire Response System for Fire Protection

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Abstract

With the acceleration of urbanization, the fire safety problem is becoming more and more serious, especially for special groups of people such as the elderly, the disabled, children and the sick, the fire risk increases significantly. In this paper, we design an intelligent fire fighting system based on STM32, using STM32 as the core controller, integrating various sensors such as temperature and humidity sensors, smoke sensors and flame sensors, and realizing the efficient data transmission and processing through the AliCloud platform. The system is equipped with automatic alarm, automatic spraying, remote monitoring and intelligent voice control, which can significantly improve the fire warning and response capability and provide safety for special people.

Keywords

STM32; Fire Safety; Intelligent Fire Protection; Special Populations.

1. Introduction

Fire is one of the serious public safety problems in modern society, especially in the context of accelerated urbanization, fire accidents occur frequently, which brings great threats to the safety of people's lives and property[1]. According to statistics, special populations such as the elderly, the disabled, children and the sick are less capable of escaping from fire accidents and face higher risks[2]. The traditional fire protection system relies on manual monitoring and alarming, which has problems such as slow response time, false alarms and missed alarms[3]. With the development of IoT, cloud computing and smart sensor technologies, intelligent fire protection systems have become an important means to improve fire warning and emergency response capabilities[4].

In this study, an intelligent fire fighting fire response system based on STM32 microcontroller is designed, integrating temperature and humidity sensors, smoke sensors and flame sensors, and realizing efficient data transmission and processing through the AliCloud platform. The system has the functions of automatic alarm, automatic spraying, remote monitoring and intelligent voice control, which can significantly improve the fire warning and response ability and provide safety for special people.

2. Overall System Design

The system takes STM32F103C8T6 microcontroller as the core and integrates various sensor modules (temperature and humidity sensor, smoke sensor, flame sensor), alarm module, automatic spraying module, voice recognition module and WIFI communication module. The overall system structure is shown in Figure 1.

The whole system detects environmental conditions such as flame, smoke, and temperature and humidity, processes the data through the STM32F103C8T6 microcontroller, and sends the alarm and control signals to the cloud platform and the mobile APP through the WIFI module.The system also

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includes voice recognition for additional control and responds to fire emergencies using actuators such as water pumps and LED lights. In the event of a fire, a buzzer will immediately sound an alarm to alert the occupants of the house. At the same time, the automatic sprinklers will turn on the pump to suppress the fire and the mobile app will alert the user with a fire alarm. At the same time, the LED lights in the house will be turned on to guide the house occupants to evacuate quickly and away from the fire scene.

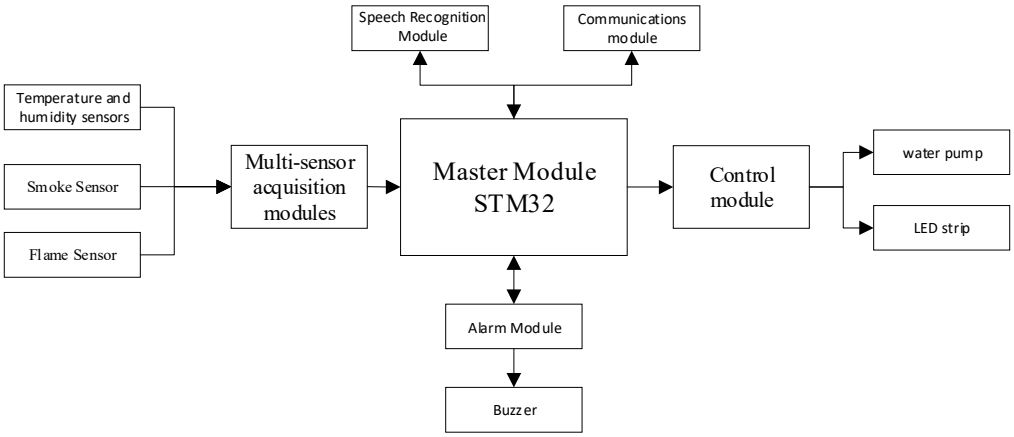

Figure 1. Overall system structure diagram

3. Hardware Designs

3.1 STM32 Core Circuitry

The system adopts STM32F103C8T6 as the core controller, which is characterized by high performance, low power consumption, and rich peripheral interfaces, and is able to meet the needs of multi-sensor data acquisition and processing.STM32, as the master of the control system, is the core of the whole system. By writing the corresponding code to it, it replaces the external load and accesses the cloud platform to connect to the web page and the mobile terminal.The interface circuit diagram of STM32F103 core board is shown in Figure 2.

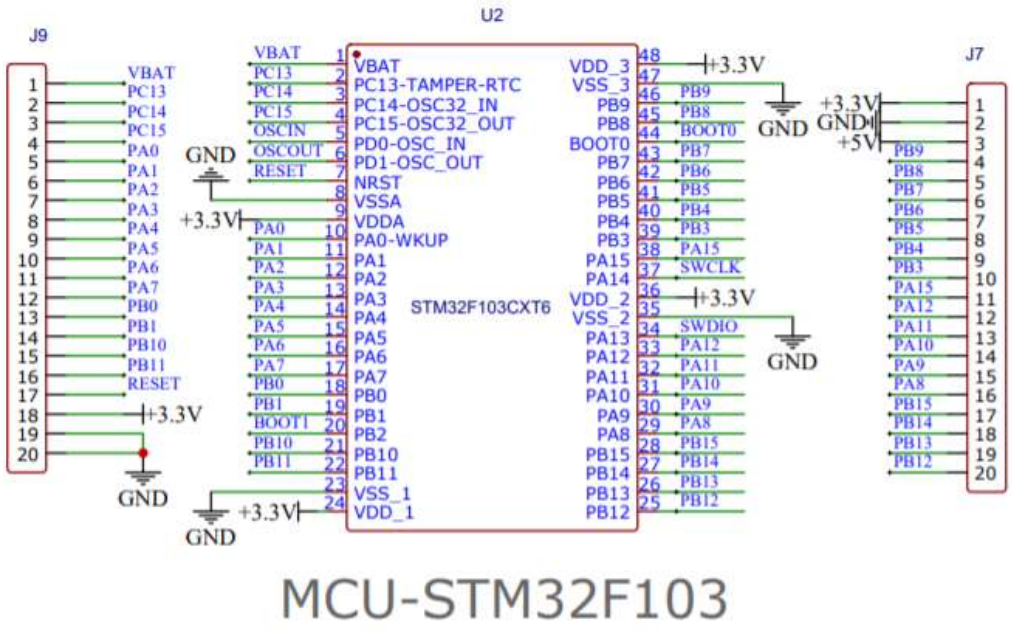

Figure 2. STM32 core board interface schematic

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3.2 Sensor Modules

The system integrates three sensors: the DHT11 temperature and humidity sensor, the MQ-2 smoke sensor and the flame sensor. These sensors are used to monitor the ambient temperature and humidity as well as to detect smoke and flame in the early stages of a fire, respectively, providing critical data to support fire warning and emergency response.

3.2.1 DHT11 Temperature and Humidity Sensor

The DHT11 Digital Temperature and Humidity Sensor is a composite sensor containing calibrated digital signal outputs, using dedicated digital module acquisition technology and temperature and humidity sensing technology to ensure the product has very high reliability and excellent long-term stability[5]. It has a measurement range of 20%~90% relative humidity and 0~50°C. In this system, DHT11 is used for real-time monitoring of environmental temperature and humidity to provide auxiliary data support for fire warning, Specific pin descriptions are shown in Table 1, and the temperature and humidity sensor circuit is shown in Figure 3.

Table 1. Pin Descriptions

Pin	Name	Exegesis
1	VDD	Power supply 3-5.5VDC
2	DATA	Serial Data, Single Bus
3	GND	Ground, Power Negative

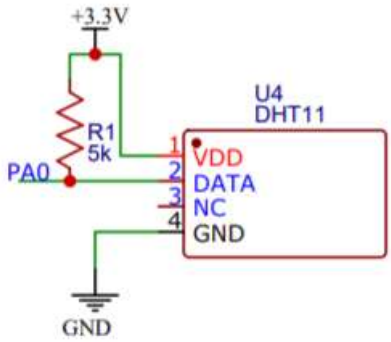

Figure 3. Circuit diagram of DHT11 temperature and humidity sensor

3.2.2 MQ-2 Smoke Sensor

MQ-2 is a smoke sensor based on tin dioxide semiconductor gas-sensitive material, capable of detecting a wide range of combustible gases and smoke[6]. It outputs an analog signal by detecting changes in the concentration of gases in the environment, and when the gas concentration exceeds the set threshold, the sensor outputs a high level signal, which is used to trigger the alarm device. In this system, MQ-2 is used to monitor the smoke concentration in the environment in real time, and can detect the presence of smoke in the early stage of fire in time.

3.2.3 Flame Sensor

Flame sensors work by detecting a specific wavelength of light (usually UV or infrared) emitted by a flame. The operating principle is based on the photoelectric effect, and when a flame is detected, the sensor outputs a digital signal to trigger an alarm device. Flame sensors are able to respond quickly in the early stages of a fire, providing an important basis for fire warning. In this system, the flame sensor is used to detect the flame at the early stage of fire and works in concert with the smoke sensor to improve the accuracy of fire warning.

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3.3 WIFI Communication Module

This design uses a WIFI module to connect to the real-time data detected by the Aliyun Record Detection Module.The WIFI module is the ESP-01S WIFI module, which is compact in size and suitable for space-limited applications, and integrates WIFI functionality and a processor that reduces the need for external components.The ESP-01S WIFI module has a low-power feature that allows it to be used in applications with limited space. Communication through the serial port allows configuration and control using AT commands.The ESP-01S module features low power consumption, making it suitable for applications that run for long periods of time.

3.4 Speech Recognition Module

The voice recognition module used in this system is LU-ASR01, which is a powerful voice recognition module. Its working principle is to convert voice signals into digital signals, and then use voice recognition algorithms to convert the digital signals into text. Through voice control, users can issue commands quickly in emergency situations, improving the system's operational convenience and response speed, especially for special groups such as the elderly, the disabled, children and the sick, which provides great convenience.

3.5 Control Modules

3.5.1 Automatic Sprinkler Module

The automatic sprinkler module of this system mainly pumps water through a DC micro-pump, and when a flame is detected, the module will automatically turn on to inhibit the spread of the flame to achieve the purpose of extinguishing the fire. The integration of the automatic sprinkler module also enables the fire protection system to realize intelligent and automated management, through the preset fire response strategy for accurate spraying, avoiding the delay and risk of misoperation of the traditional manual operation, and through the cloud platform for remote monitoring and management, to ensure that the system is always in the best working condition, and to enhance the overall reliability of the fire protection system and the ability to respond to emergencies.

3.5.2 LED Module

The LED strip plays an important role of auxiliary lighting and safety indication in this system, including two strips of white and green color. When there is a fire or the smoke concentration is too high, the LED will light up automatically. Its main functions include providing emergency lighting in the event of a fire so that personnel can evacuate and escape smoothly; LED strips installed in key locations such as evacuation corridors, stairwells, and exits will light up in the event of a fire, forming an obvious band of light that guides personnel to evacuate in the correct direction, reduces the risk of getting lost in the smoke and dark environment, and improves the efficiency of escape[7].

3.6 Alarm Module

The buzzer plays a vital role as an alarm module in an intelligent fire protection system. It is capable of emitting a high-decibel alarm sound when the system detects a fire signal, quickly alerting those present to the fire danger and taking emergency evacuation or fire-fighting measures. With its high loudness and clear alarm sound, the buzzer ensures that it can be heard in a variety of environments, greatly enhancing the timeliness and effectiveness of fire alarms.

4. Software Design

4.1 System Software Architecture

The system software is based on STM32 microcontroller and AliCloud IoT platform, and adopts the front and backend framework to realize efficient task scheduling. After the hardware initialization is completed, the system connects to the AliCloud platform through the WIFI module and enters the cycle running state. The main program executes the tasks of serial port reception, sensor data reading, data release and control logic sequentially according to the preset time base. The serial port receiving program receives data from the WIFI module through interrupts and parses JSON-formatted control

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commands to realize the remote control function. Sensor data is published to the AliCloud platform in JSON format through the ESP-01S module for users to monitor in real time. The system supports both automatic and manual modes: in automatic mode, sensor data triggers alarm and fire-fighting operations; in manual mode, users can control the equipment remotely via APP. The control logic, as the core of the system, performs the corresponding operations according to the sensor data and control instructions to ensure the high efficiency of fire monitoring and emergency response. The main program flowchart of the controller is shown in Figure 4.

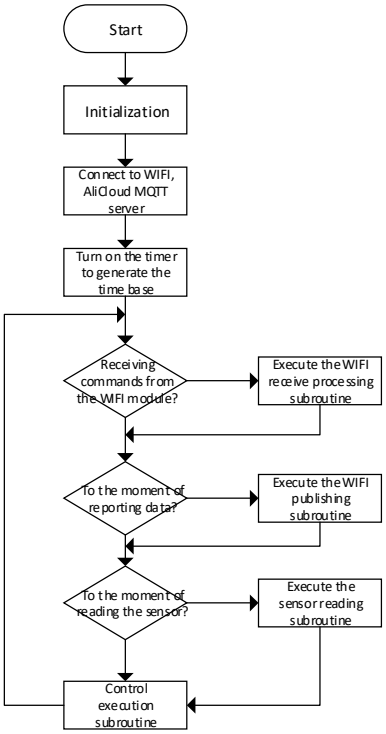

Figure 4. Flowchart of main program

4.2 APP Design

APP is developed based on Android Studio, using Java language and MQTT protocol to realize data transmission and device control.APP communicates with hardware system through AliCloud IoT platform to realize real-time data transmission and interaction. Its functional modules include real-time monitoring, remote control, alarm notification, historical data query and system settings. The real-time monitoring module displays sensor data such as temperature and humidity, smoke concentration, and flame status; the remote control module allows users to start or shut down devices such as water pumps, lights, and alarms through the APP; the alarm notification module sends an alert to users when an abnormality is detected; the historical data query module provides a history of sensor data for users to analyze the trend of fires; and the system setup module allows users to configure parameters such as sensor The APP interface is simple and intuitive, and ensures real-time interaction with the hardware system through the data flow mechanism, providing users with an efficient and convenient fire monitoring and emergency response experience.

5. System Testing and Analysis

5.1 Voice Control Testing

In the voice control test, the voice announcement was set to a female voice when the system was initialized, and the wake-up word of the smart housekeeper was set to “Scholar”. After powering on, the speaker announces “Welcome to use Smart Butler, wake me up with ‘Scholar’”, indicating that the system starts normally. When the user speaks the wake-up word “Scholar”, the voice module is

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activated and the microcontroller enters the voice mode and replies “I am here”. If there is no further instruction within 10 seconds, the system will automatically exit the voice mode and announce “I am standing down, use ‘Scholar’ to wake me up”. In voice mode, the system can recognize and execute a variety of control commands, such as voice commands “open the water valve” or “spray water” to start the water pump, or “turn on the lights” and “turn off the lights”. “turn off the light” to control the lighting equipment, at the same time, the system will confirm the results of the operation through voice feedback. In addition, the system also supports triggering or canceling alarms through voice commands, and prompts users through the mobile APP, realizing the convenient voice interaction control function. Photographs of the real thing are shown in Figure 5.

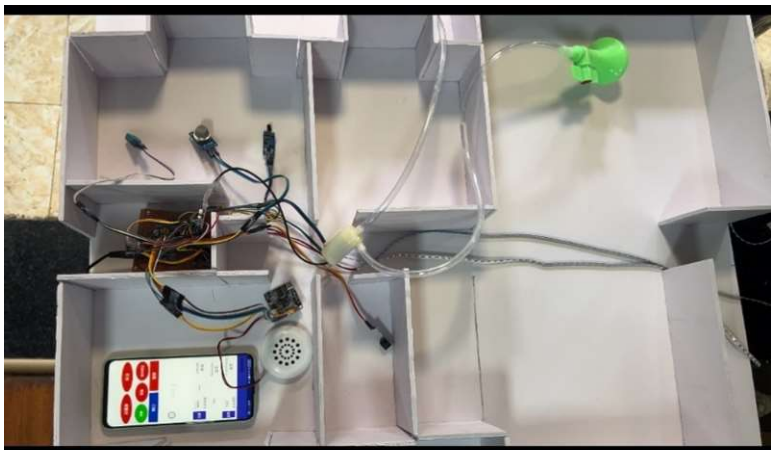

Figure 5. Physical photograph

5.2 APP Remote Control Test

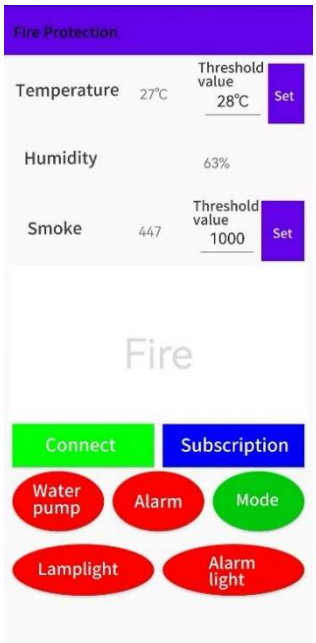

Figure 6. Application Main Screen

In the mobile APP control test, we first ensure that the power supply of the MCU is connected and complete the initialization of each module, and confirm that the device is successfully online through the AliCloud platform. Subsequently, the control test is conducted through the APP interface, whose function is similar to voice control, but supports manual setting of temperature and smoke thresholds. When the environmental parameters exceed the set thresholds, the buzzer automatically alerts the user.APP provides two modes of automatic and manual switching, and is equipped with an alarm

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light control function, where green color indicates normal operation, and the light is automatically lit when the fire or smoke exceeds the thresholds, and the user can manually switch it on and off as well. The status of each module is visualized by red and green buttons, red is off and green is on, as shown in Figure 6 main interface of the app.

6. Conclusion

The STM32-based intelligent fire protection system designed in this paper realizes efficient and intelligent fire monitoring and emergency response through multi-sensor integration, AliCloud platform and MQTT protocol. The system is equipped with automatic alarm, automatic spraying, remote monitoring and voice control, which can significantly improve the fire warning and response capability and provide safety for special populations. In the future, we will further optimize the system performance, introduce image recognition technology, and expand the smart home functions.

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