ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

INTELLIGENT FIRE PROTECTION ECOSYSTEM

Team #16

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1 Introduction

In today's rapidly evolving urban landscape, ensuring the safety and security of buildings against fire hazards remains a paramount concern. Traditional fire protection systems, while effective to a certain extent, often fall short in addressing the dynamic challenges posed by modern infrastructure and diverse fire risks. Recognizing the need for a more intelligent and comprehensive approach to fire safety, our project endeavors to introduce the Intelligent Fire Protection Ecosystem.

1.1 Objective

The objective of our project is to address the shortcomings of traditional fire protection systems by introducing the Intelligent Fire Protection Ecosystem. Traditional fire detection and alarm systems often lack the sophistication needed to accurately detect different gases and respond to fire incidents in a timely manner. The use of a single sensor is prone to false alarms. Users are notified of fire information in a single way, making timely response difficult.

Our proposed solution aims to enhance the capabilities of conventional fire alarm equipment by integrating traditional sensor technologies and leveraging WiFi connectivity through the ESP8266 chip. By doing so, we seek to achieve more precise and reliable fire detection capabilities, allowing for early detection of smoke, hazardous gases, and temperature variations. Through a mobile application interface, users can receive real-time warnings and monitor changes in gas concentrations, empowering them to take proactive measures to mitigate fire hazards and ensure the safety of occupants and assets.

1.2 Background

The context of the problem is the inability of traditional fire protection systems to effectively respond to the ever-changing challenges posed by the modern built environment, with limited scope and means of data transmission. According to Illinois Fire Departments, there were over 1.4 million incidents, 92 civilian lives were lost and over $476 million in property damage resulted from fires, according to the Office of the Illinois State Fire Marshal. and over $476 million in property damage resulted from fires in 2022[1].As urbanization and technological advances continue to reshape our cities, the need for smarter, more responsive fire safety solutions is increasingly evident. According to the United States Fire Department, there is a fire in a residential area every 85 seconds and these fires account for almost 80 percent of all fire-related deaths[2, 3].Traditional systems, which rely on simple detection methods and manual intervention, are mainly classified into

photoelectric smoke detectors and ionization smoke detectors[4].However, the detection of a single type of gas, alarm threshold adjustment is difficult, not real-time feedback of toxic or flammable gas concentration, but also easy to produce false alarms because of a single sensor, so in a detector integrated multiple sensors and real-time feedback is very necessary.

1.3 Physical Design

The physical design of the Intelligent Fire Protection Ecosystem is depicted in Figure 1. It illustrates the integration of our solution within a building environment, along with relevant external systems such as mobile devices for remote monitoring and control. The dotted lines indicate connections between our system and external components, emphasizing the seamless interaction between them.
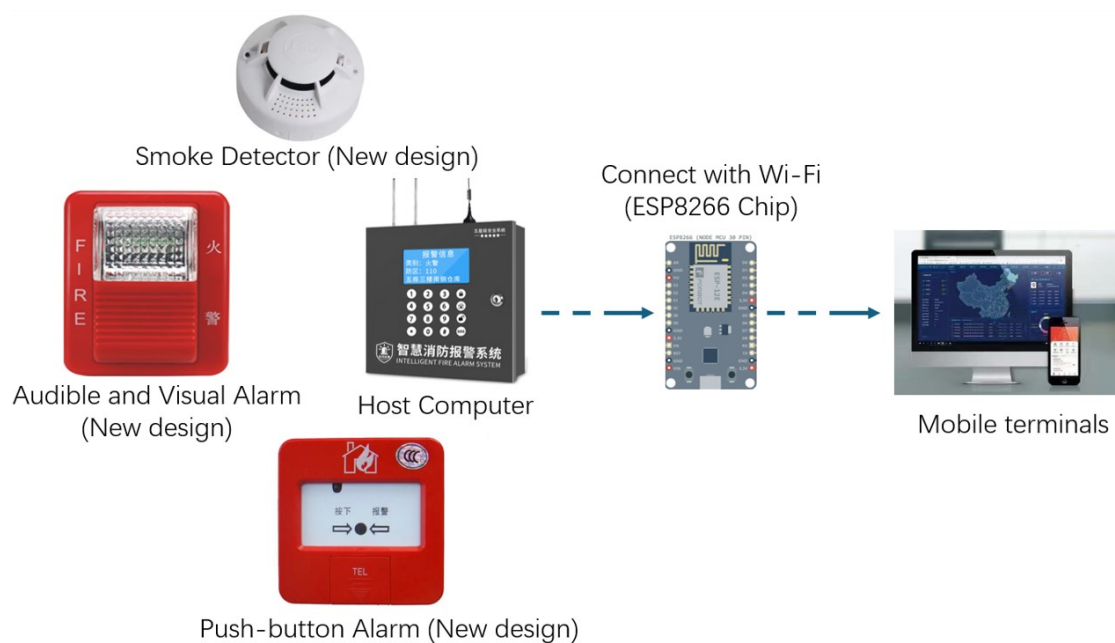

Figure 1: Physical Design for Intelligent Fire Protection Ecosystem

1.4 High-level requirements list

1. **Fire Detection Accuracy:**
   The system must highly accurately and intelligently detect at least three different causes (e.g., high temperatures, combustible gases, etc.) of fire accidents and minimize false alarms by displaying the change in gas concentration (LEL) in real time on a mobile device.

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2. **Remote Monitoring and Control:**
   Remote monitoring and control functionalities must exhibit a response time of less than 5 seconds, enabling users to swiftly assess and manage fire-related emergencies from a distance.

3. **Power:**
   The batteries of the equipment must be able to provide sufficient power, the power consumption of the electronic equipment needs to be strictly controlled, and there is no need to replace the batteries for at least 3 months because the equipment needs to be thoroughly checked every 3 months according to the program to ensure safety.
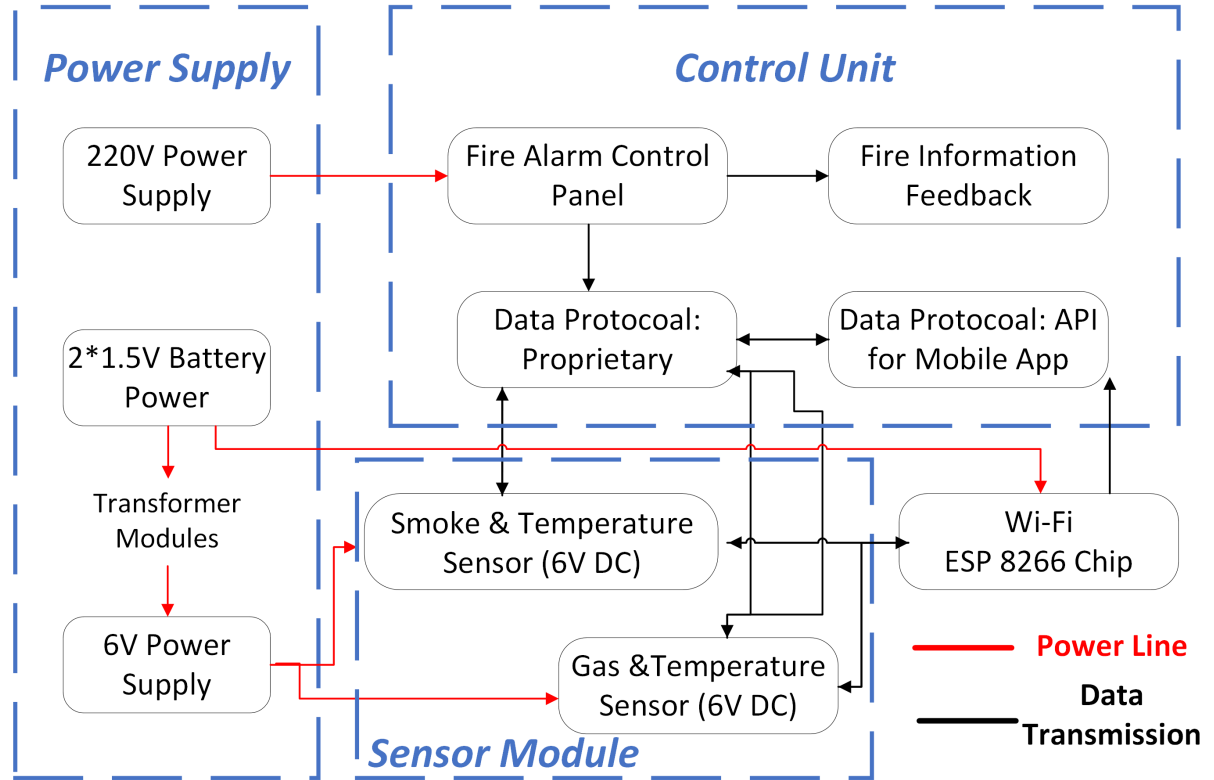
2 Design

2.1 Block Diagram

Figure 2: Block Diagram

Power Supply: This subsystem provides power to the entire fire protection system. It accepts 120V AC input power and distributes it to the various subsystems. Each subsystem may have its own voltage requirements.

Fire Alarm Control Panel: This subsystem serves as the central hub of the fire detection system. It receives signals from the smoke sensor and other detection devices, activates response mechanisms, and interfaces with external devices. The control panel operates on a data protocol that may be proprietary to the manufacturer.

Fire Information Feedback: This subsystem provides users with real-time information about the fire status, sensor data, and instructions via a mobile application. It interfaces with the control panel through an API specifically designed for

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communication with the mobile app.

Smoke Sensor: This subsystem detects smoke particles in the environment and sends signals to the fire alarm control panel. It operates on a 6V DC power supply.

Gas Sensor: This subsystem detects hazardous gases in the environment and may also send signals to the fire alarm control panel. It operates on a 6V DC power supply.

2.2 Function Overview&System requirements

2.2.1 Smoke Sensor Subsystem

The smoke sensor in this ecosystem functions by continuously monitoring the environment for smoke particles. When detected, it sends a signal to the central system to initiate an alert. This sensor interfaces with the central monitoring system, through a wireless connection, to ensure that smoke detection is quickly communicated and actioned upon.

Requirement: Input voltage: DC 5V Power consumption (current):150mA. DO output: TTL digital quantities 0 and 1(0.1 and 5V). A0 output: 0.1-0.3V (relatively pollution-free), the highest concentration voltage is about 4V.

2.2.2 Manual Alarm Button Subsystem

The manual alarm button allows individuals to activate the fire alarm system manually in the event of a fire. This immediate human input bypasses the need for automatic detection and can be crucial in cases where a fire is observed before the sensors are triggered. This button is wired (or though WIFI) directly to the fire alarm control panel to ensure a swift response once activated.

Requirement: Provide instant 0/1 signal to the fire control host.

2.2.3 Fire Alarm Control Panel Subsystem

The fire alarm control panel is the central hub of the fire detection system. It receives signals from various detection devices, such as the smoke sensor, and activates the necessary response. This includes triggering alarms and notifying the relevant parties, such as the fire department or building management. The panel is also responsible for monitoring the status of the entire system and can often be interfaced with a computer or mobile device for remote monitoring and control.

Requirement: It should ensure continuous monitoring of system status, support interfacing with external devices for remote monitoring and control, and include fault detection mechanisms for timely maintenance. User-friendly interface, compatibility with existing infrastructure, reliability, and compliance with standards are essential considerations for its design and functionality.

2.2.4 Sound and Light Alarms Subsystem

These alarms are the physical warning devices that are activated in the event of a fire. They produce loud sounds and flashing lights to alert occupants of the danger and prompt evacuation. They are directly controlled by the fire alarm control panel, which sends a signal to them when a fire has been detected. This ensures that everyone in the building is made aware of the emergency.

Requirement: These devices are designed to operate on a 24V DC power supply, which is the standard in fire alarm systems for safety devices. And they are controlled by signal switches to operate when needed.

2.2.5 Fire Information Feedback

Users can monitor the status of the fire, view sensor data and receive instructions via an phone app. It acts as a user interface, providing immediate access to the system's status. This can involve an API (Application Programming Interface) that allows the app to communicate with the central control system. The API receives requests from the app and sends responses back, including fire alerts, status updates, and sensor readings.

Requirement: The Fire Information Feedback Subsystem must provide a user-friendly mobile application interface for real-time monitoring of fire status, sensor data viewing, and receipt of instructions. It should seamlessly integrate with the central control system through an API, facilitating prompt communication of fire alerts, status updates, and sensor readings to users. Robust user authentication and data security measures are essential, ensuring secure access to some private information.

2.3 Tolerance (Risk) Analysis

The most critical and potentially risky aspect of the fire protection system lies in the accurate detection of fire incidents by the smoke sensors. Ensuring the feasibility of this critical subsystem function requires rigorous mathematical analysis or simulation to assess its performance under various environmental conditions and

potential sources of interference. Factors such as smoke particle size, density, and distribution patterns, as well as ambient lighting conditions and air flow dynamics, can significantly impact the effectiveness of smoke detection. Conducting sensitivity analysis and Monte Carlo simulations can help identify critical parameters and assess the system's robustness to variations in these factors. Additionally, failure mode and effects analysis (FMEA) can be utilized to identify potential failure modes and develop mitigation strategies to enhance the reliability and resilience of the smoke detection subsystem. By thoroughly analyzing the tolerance of the smoke detection function to uncertainties and potential failure modes, we can mitigate risks and ensure the overall effectiveness of the fire protection system.

3 Ethics and Safety

Because our ESP8266 chip ultimately needs to rely on the software platform on the mobile terminal to link with the fire protection equipment we designed, the use of intelligent fire protection equipment and software may collect and transmit sensitive data, such as location information, environmental parameters, and so on. According to e IEEE Code of Ethics, #1[5], "to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment." The design process should ensure that the privacy of user data is protected from unauthorized access and data leakage, and that users are informed about how data is collected, used, and protected.

Regarding the new design of smoke alarms, push button alarms and audible and visual alarms, these products need to comply with the Chinese standard for self-contained smoke alarms: GB 20517-2006[6], which has provisions for high temperature and corrosion resistance, so polyvinyl chloride (PVC) material is used in the official products to meet the requirements and to facilitate the manufacture and reduce the cost.

Unfortunately, PVC is hazardous to the environment and is a difficult material to degrade. In order to meet the IEEE Code of Ethics, #1[5],"to hold paramount, the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable We believe that equipment should be manufactured and used in a way that minimizes its impact on the environment. We believe that equipment should be manufactured and used in a way that minimizes its impact on the environment. For example, we need to use environmentally friendly materials and manufacturing processes for packaging, and modular designs that allow for easy disassembly and replacement of components, as well as ensuring that the equipment can be safely recycled at the end of its lifecycle.

According to our opinion and design, our products do not exist with race, religion, gender, disability, age, national origin, sexual orientation gender identity, or gender expression, which is mentioned in the IEEE Code of Ethics, #7[5]

References

[1] J. Pritzker, "the 2022 annual report for the office of the illinois state fire marshal," vol. 32, p. 31, Feb. 2023.

[2] A. Cowlard, A. Bittern, C. Abecassis-Empis, and J. Torero, "Fire safety design for tall buildings," *Procedia Engineering*, vol. 62, pp. 169–181, 2013.

[3] J. Ma, W. Song, W. Tian, S. M. Lo, and G. Liao, "Experimental study on an ultra high-rise building evacuation in china," *Safety science*, vol. 50, no. 8, pp. 1665–1674, 2012.

[4] J. Nie and H. Du, "Overview of specialized smoke detector detection circuits," , vol. 12, no. 06, pp. 39–41+46, 2012.

[5] Ieee.org, "Ieee ieee code of ethics," 2020. [Online]. Available: https://www.ieee.org/content/dam/ieee-org/ieee/web/org/about/corporate/ieee-code-of-ethics.pdf

[6] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China, "National standard of the people's republic of chinafire detection and alarm systems-smoke alarms," 2006. [Online]. Available: https://openstd.samr.gov.cn/bzgk/gb/newGbInfo?hcno=11BFFB6E7366D62926036872F2DEC1BA