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IoT-Based Multi-Sensor Fire Detection and Automated Suppression System with Electrical Isolation

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***Abstract:** This article describes the creation of an Internet-of-Things (IoT)-based system to automate the detection and extinguishing of fire in multi-story buildings to make them reliably safe from fires in real-time. The system uses three sensors, DHT11, MQ2, and IR; a fire will only be identified as having occurred if all three sensors have simultaneously detected an abnormal condition. The real-time monitoring of the three-sensors will be performed by an ESP32 microcontroller, which will disconnect the electrical load through the use of an electrical relay and activate a water-spray system for fire suppression. A prototype building was constructed with four floors, including eight electrical loads connected in parallel and powered by a battery. When a fire is detected, the ESP32 will disconnect the electrical supply using a relay (to avoid the chance of a short circuit) and turn on a motorized water pump to put out the fire. The system allows for real-time monitoring of the situation by using the Adafruit IO dashboard; notification systems, including email, are utilized to alert the user via IFTTT webhooks. Electrical isolation will prevent an electrical short circuit and ensure personnel are not harmed while the water is dispensed. Testing the performance of the entire system resulted in an average response time of less than 1.5 seconds and zero false alarms. The proposed system can be used as an automated, reliable, and low-cost approach to protecting smart building from fire.*

***Keywords:** Fire Detection, ESP32, IoT, Multi-Sensor Fusion, Adafruit IO, IFTTT, Relay Control, Electrical Isolation, Automated Suppression*

I. INTRODUCTION

Fire remains one of the most destructive hazards to life and property in residential, commercial, and industrial environments. The risk and impact of fire incidents have increased due to rapid urbanization, higher electrical consumption, and the widespread use of combustible materials. Conventional fire detection systems typically rely on a single sensor, such as heat or smoke detectors. These systems often suffer from high false alarm rates and unreliable performance under environmental conditions such as dust, humidity, and temperature variations.To overcome these limitations, multi-sensor fire detection systems have been developed by integrating temperature, smoke, and flame detection. This approach significantly improves detection accuracy, reduces false alarms, and enables faster response, aligning with modern automated and real-time safety requirements.

This paper presents an Internet of Things (IoT)-based multi-sensor fire detection and automated suppression system using DHT11 (temperature), MQ2 (smoke), and IR(flame) sensors. The ESP32 microcontroller continuously monitors sensor data and confirms fire only when all three conditions are satisfied using logical AND-based decision making, thereby improving reliability.Upon fire detection, the system automatically activates a buzzer, disconnects the electrical supply through a two-channel relay, and triggers a water-pump-based suppression system. The system is implemented on a four-floor prototype model with eight loads connected in parallel and powered by a battery backup, ensuring uninterrupted operation during power outages. A key feature of the system is electrical isolation, where power is disconnected before water suppression is activated, preventing short circuits and ensuring user safety. Additionally, IoT integration using Adafruit IO enables real-time monitoring, while IFTTT provides email-based remote alerts.

II. LITERATURE REVIEW

Studies have demonstrated that conventional single sensor systems (heat or smoke detection) have high false alarm rates and don't consistently perform well. Milenkovic explained that smoke-based fire detection systems are not able to differentiate whether the smoke is from an actual fire or some other source of smoke, therefore resulting in many false alarms.

To provide a solution for these issues, multiple sensor systems have been developed and researched by many professors across the globe. In their study, Chen et al. showed a 35% decrease in false alarms as a result of using both smoke and temperature sensors to detect fire.

Two-sensor systems do not allow for detection of flames, which can create problems for those trying to detect fires. In their study, Kumar and Sharma presented a system that incorporated three sensors into the fire detection process temperature, smoke, and flame detection which had a near-zero false alarm rate under controlled environments and provided a detection mechanism with no additional fire suppression or safety systems. New developments in IoT have created systems that allow for remote monitoring and alerting. Sriskanthan and Tan developed a system that used the GSM network to send alerts, while Ali et al. created a real-time dashboard using MQTT. Low-cost alerting systems can be developed using IFTTT-based notification systems and do not require complex systems for notification.

The research conducted on automated suppression systems demonstrates the need for electrical safety. Studies show that safe operation of the device requires isolating the electrical supply before water discharges so that equipment is protected and users are safe from electric shocks.While this development has greatly improved the reliability and safety of automated suppression systems; unfortunately, most existing installed systems separate these functions into three separate modules. In contrast, the proposed system takes a holistic approach by combining multi-sensor detection, automatic suppression, relay type electrical isolation, and IoT monitoring into a single integrated solution.

III. SYSTEM ARCHITECTURE

A. Overall Design

The three principles that underpin the system design are:

1) notification mechanism (a person must first receive confirmation of 'fire');
2) electrical isolation (there will be no electrical power to devices prior to engaging water-based fire suppression system(s));
3) ongoing monitoring of system parameters via IoT so that systems can be assessed in real time.

These principles ensure reliability & less chance of false alarm, & safe & automated operation. The sensor unit consists of three sensors (DHT11 (temperature), MQ2 (smoke) and Flame) that send continuous signals to an ESP32 microcontroller. The ESP32 processes signals received from sensors and processes them using a logical 'AND' based mechanism to confirm that a fire exists.

A 2-channel relay module is used, where one channel controls the electrical load cutoff and the other controls the water pump. The system first disconnects the electrical supply and then activates the pump after a short delay, ensuring safe operation.

All sensor data will also be transmitted using Wi-Fi to the Adafruit IO cloud so that users can continuously monitor the system through a dashboard accessible by mobile and/or PC.

B. Sensing Layer

The sensor layer is composed of 3 different sensing devices to monitor the three aspects of fire. The three sensors are the DHT11 which measures the temperature of ambient air, the MQ2, which against combustible gasses and traces of smoke, and the flame sensor which detects infrared energy emitted by flames.

The DHT11 is a direct digital device, while the MQ2 sensor is an analogue device supplying current to another device connected to the ESP32's ADC (analogue to digital converter). Likewise, the flame sensor provides a digital signal that indicates the presence of flame. Using multiple types of sensors allows accurate detection of fires and a reduction in false alarms due to each type of sensor detecting various characteristics associated with a fire.

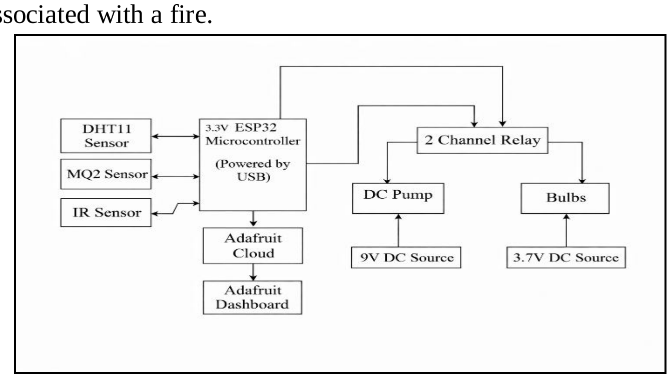

Fig. 1 Block Diagram of IoT Multi-Sensor Fire Detection System

C. Processing and Control

The processing and control layer utilizes the ESP32 microcontroller as its central processing unit (CPU) with integrated Wi-Fi capability. The ESP32 wirelessly reads the values from the sensors on a continuous basis and determines fire conditions using only logical AND decisions. Using logical AND decision-making processes, a fire is confirmed when a sensed temperature value, smoke value, and flame value are above their defined thresholds at the same time. Using the multiple types of sensors to detect confirmed fires enhances the reliability of the entire system. The ESP32 will initiate a buzzer if fire detection occurs and will be connected to a 2-channel relay module to de-energize the electrical load connected to relay one, and then after a short period of time programmed in the ESP32, relay two will activate and start the water pump. This sequential operation of the relays allows for fire suppression and minimizes the risk of an electrical hazard occurring.

D. Electrical Load System

The building is modeled as having 4 floors and 8 parallel electrical loads all powered by a battery-backed supply so that should there be a failure of any of the loads or an interruption to the power supply to the building will not disrupt the continuous operation of the building. The electrical load is controlled through the first channel on the relay module, automatically shutting off the power to the load as soon as the fire is detected, providing a high level of safety to the occupants prior to the fire suppression termination occurring.

E. Fire Suppression Mechanism

The fire suppression system consists of a water pump powered by a separate battery and controlled through the second channel on the relay module. After a brief delay following the cutoff of electric power to the building, the water pump is then activated to spray water in an effort to suppress the fire. This sequential control of the suppression system serves to provide for adequate fire suppression and at the same time provides an additional degree of safety by separating the electric and water systems' interaction from occurring simultaneously.

F. IoT Monitoring and Alerts

The system supports real-time monitoring of the system from a dashboard using the Adafruit IO Platform, along with sensor data and status information of the overall system. During fire events, email alerts are generated using IFTTT (If This Then That) webhooks. Alert notifications are only generated during transitions from state to state to ensure that the alerts are not sent multiple times and that efficient communication with the building's occupants occurs.

IV. IMPLEMENTATION

A. Hardware Assembly

The use of a breadboard to build the prototype was an important aspect because it allowed for flexible connections, which could be changed easily during testing. The ESP32 development board was placed in the center of the breadboard as a means of minimizing the amount of wiring and creating an efficient interface between all components and the board. The sensors (DHT11, MQ2, and flame sensor) were arranged on the breadboard to provide accurate environmental readings. Each of the components was connected to one another using jumper wires in order to maintain a stable and organized connection. The two-channel relay module was connected to the ESP32 via GPIO pins.

The relay module was located separately from the ESP32 to provide electrical insulation between the control and power side of the circuits. The load of the system consists of eight bulbs connected in parallel using a 12V battery as the power source. This configuration used to ensure that if one of the bulbs fails, the other bulbs will continue to operate. The ESP32 and the sensors receive power from a regulated power source (USB or the onboard regulation) to ensure they operate properly in all situations. The water pump will be powered from a 9V battery that is controlled from the second channel of the relay module. This independent power source will ensure that the suppression system can continue to operate even if the main electrical supply becomes disconnected.

B. Firmware Design

The firmware is developed using the Arduino Framework on-board the ESP32 touch screen graphical user interface. The main control loop will continuously read data from the sensors: a DHT11 (temperature and humidity), MQ2 (smoke and gas), and IR Sensors (flame detection).

The control loop evaluates whether a fire has been detected or is considered to be imminent by comparing each sensor value against pre-determined thresholds. A logical AND based decision structure will allow all three sensor values to have to be present for the system to confirm that there is a fire event. The ESP32 will be put into a latched alarm condition once a fire has been detected and it will not allow the system to be activated again until it has been manually reset.

The ESP32 now controls a dual channel relay card in a sequential fashion. The relays are wired in such a way that when the first relay is triggered (the electrical load is disconnected), it will trigger the water pump after a pre-programmed time delay. To improve safety and prevent potential electrical hazards while suppressing fires, the second relay will not engage until the first relay has been activated and there has been an allowable time for the suppression system to be activated.

The ESP32 is set up for IoT communication using MQTT to send/receive sensor information and system status data to/from the Adafruit IO cloud service. Email alerts will be sent by the system using the IFTTT web-based trigger to send an HTTP request to the e-mail address specified in the IFTTT action.

Non-blocking communications will also provide reliable means of transmitting sensor data so continuous data processing will occur from the sensors even while the ESP32 is communicating through the IoT system. In addition to ensuring continuous sensor data processing, if the connection to the IoT system is lost, the ESP32 will automatically attempt to reconnect using an exponential back-off method.

C. Dashboard Configuration

To provide real-time tracking of system parameters, the Adafruit IO dashboard will be configured to include widgets that display an object being monitored for temperature (0-100°C), smoke level (ADC values), flame detection status, as well as relay states (for electrical load and pump control), along with an event log to record the activity of the system.

Data will be transmitted every 5 seconds, which corresponds to the maximum limits allowed by the Adafruit IO Free Tier. The dashboard can be accessed via either a web browser or mobile device, therefore it will allow you to monitor and visualize the status of the system remotely.

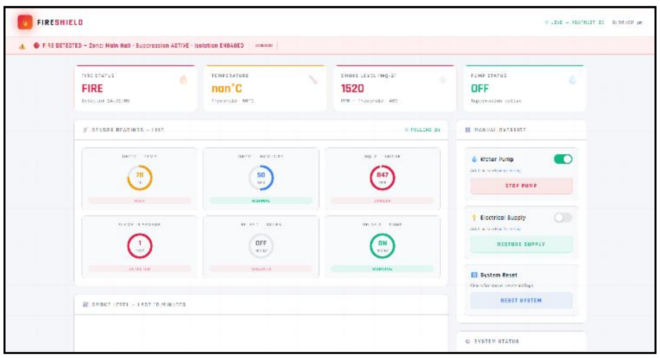

Fig. 2 Dashboard Developed

V. RESULTS AND DISCUSSION

The testing of the new system took place under controlled conditions using 3 different stimuli: flame from burning incense sticks, smoke from burning incense sticks, and varying amounts of heat. Sensors were tested both independently and together to measure accuracy of detection, time it takes to detect, and reliability of the system. Table I contains the results of this testing.

Test Scenario	Detection	Alarm
Smoke only	No	None
Heat only	No	None
Flame only	No	None
All sensors	Yes (<1.5 s)	Yes

Table I - System Performance Summary

In terms of results, no sensor activation resulted in an alarm; therefore, the AND method of using multiple sensors eliminates false alarms due to environmental conditions such as smoke, heat variance or background light. When all three conditions occurred at once, fire was detected by the system in approximately 1.5 seconds consistently, thus ensuring a fast response.

Once the fire was detected, the ESP32 went through a series of steps: 1st) turn off power to affected area, 2nd) turn on water pump, and 3rd) sound alarm. This indicates that safety logic has been properly implemented with electrical disconnection/ isolation prior to water-based suppression. Table II gives an overview of the communication behavior for IoT in addition to detection performance.

Feature	Platform Used	Observation
Real-time Monitoring	Adafruit IO	Continuous data visualization
Data Update Interval	MQTT	~5 seconds
Alert Mechanism	IFTTT	Email notification
Alert Response Time	IFTTT	Few seconds to <1 minute
System Accessibility	Web/Mobile	Remote monitoring enabled

Table II - IoT Communication Performance

The Adafruit IO dashboard allows for ongoing supervision of the IoT system while IFTTT allows for prompt notifications via e-mail. Due to fluctuations in network conditions, notification delays may vary but will typically occur automatically and nearby. The system operated consistently and reliably throughout testing, as no unintended activations were reported.

Fig. 3 Normal Supply Load Conditions (Left) Under Fire Conditions (Right)

Relay based operation of the system provided safe operation of water discharge and verified the overall meaningfulness of the project. Overall, the results of this project indicate that the system will provide a level of response that is correct, timely, and dependable for smart fire safety solutions.

VI. CONCLUSION

This paper presents a multi-sensor fire detection and automated suppression system using multiple sensors that communicates over the Internet of Things(IoT). The Fire Detection and Suppression System utilize temperature, smoke, and flame sensors along with logic to verify that there is indeed a fire present, which reduces false alarms and eliminates the need for human verification. The system detects fires in less than 1.5 seconds.

To enhance the reliability and safety of the utility supply to the fire protection equipment, we designed the system to disconnect the supply before powering up the water suppression system. The water suppression system can be powered from battery-backed parallel loads, ensuring that it operates during a power failure as long as the battery backup is functional. Also, since the two circuits (control and suppression) use separate power sources, when one fails, it provides continuity to the other. The integration of Adafruit IO and IFTTT into the system provides the ability to monitor in real-time and send alerts outside of the facility with limited infrastructure that can improve situational awareness during an emergency.

The proposed system represents a reliable, cost-effective, and scalable solution to smart fire safety applications. Additionally, future enhancements for the proposed system could include increasing the number of nodes in the system, adding gas detection devices such as CO and CO_2, and implementing advanced data techniques for detecting a fire with greater accuracy.

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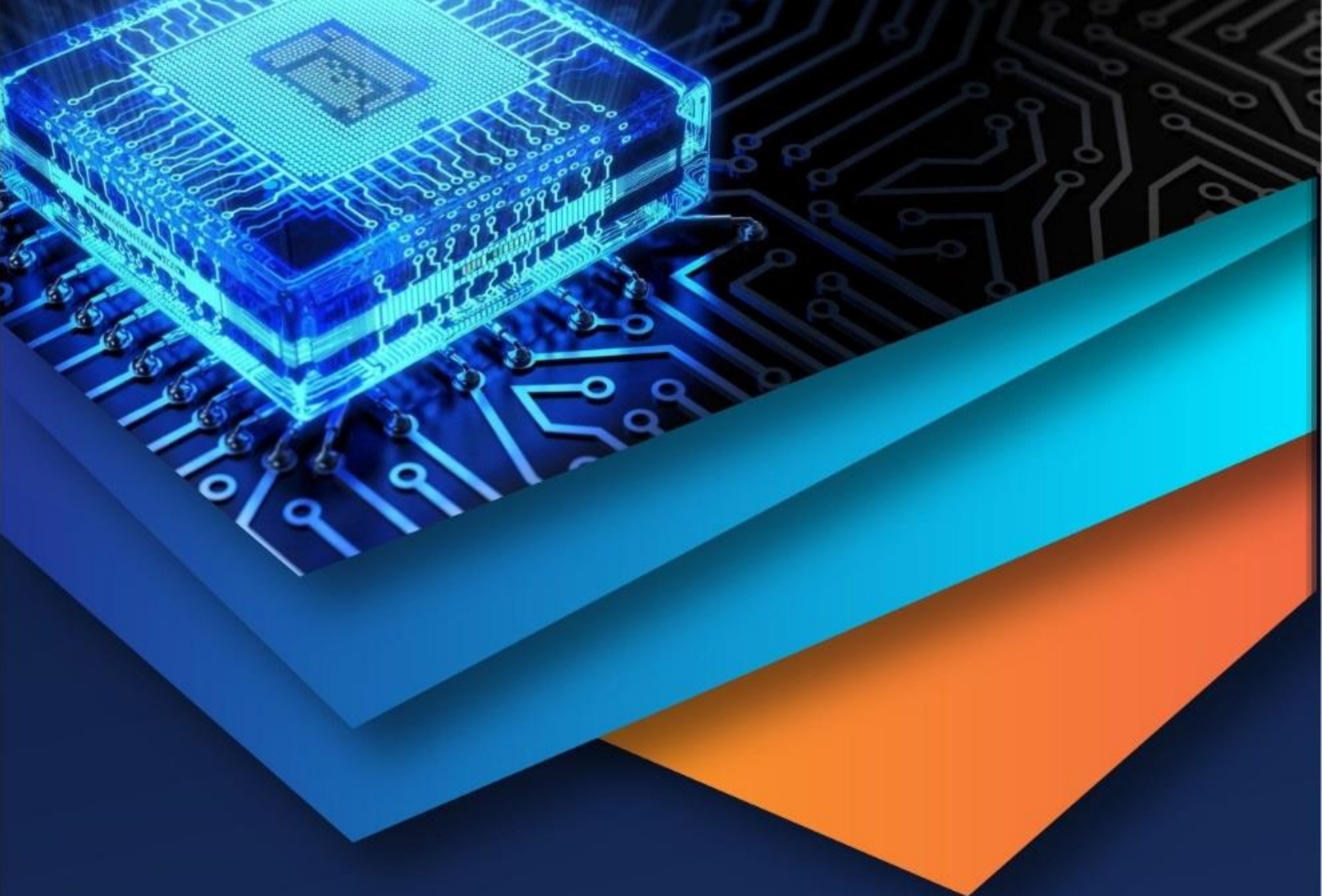

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