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AI-DRIVEN FIRE DETECTION AND SUPPRESSION SYSTEM WITH REAL-TIME REMOTE MONITORING

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ABSTRACT

Fire detection and suppression are essential for the safety of monitored environments. Our project aims to develop an intelligent solution using artificial intelligence AI to optimize these processes. We integrate algorithms to process signals from gas and flame sensors via Arduino and use AI to analyze camera signals to improve accuracy. When a fire detected, a signal sent to an automatic extinguisher for immediate intervention. Additionally, we have designed a remote monitoring platform in Python, enabling real-time system management from a control center. This platform offers proactive management and instant visibility into the status of monitored environments, thereby enhancing overall security. A thorough analysis confirms that our Fire detection System FDS is robust and effective for fire detection and management, ensuring rapid and precise responses, and thus contributing to the safety and peace of mind of users. This system is particularly suited for deployment in high-risk and high-occupancy buildings such as hotels, shopping markets, office complexes, industrial facilities, and residential apartments, ensuring enhanced safety and peace of mind for users.

I. INTRODUCTION

Technological advancements have led to the development of various automatic fire detection and suppression systems aimed at protecting lives and property [1-3]. However, despite their widespread use, these systems face challenges such as false alarms and inaccurate detections, compromising their reliability and effectiveness [4],[5]. False alarms can cause unnecessary panic and resource mobilization, while inaccurate detections can lead to delayed responses, resulting in significant damage and losses [6-8]. To address these challenges, this study proposes an intelligent approach using artificial intelligence (AI) techniques to enhance fire detection and suppression. The integrated solution utilizes algorithms to process and encode signals from various sensors, including gas and flame sensors, via the Arduino platform. It also employs AI processing to analyze signals captured by cameras, thereby improving the accuracy of fire detection and automatically triggering suppression measures. Additionally, this research introduces a remote monitoring platform using Python programming, enabling real-time monitoring and management of the fire detection and suppression system from a centralized point. The primary objective of this study is to resolve issues related to false alarms and inaccurate fire detection while enhancing the overall efficiency and reliability of automatic fire detection and suppression systems.

II. ADVANCEMENTS IN AI-INTEGRATEDD FIRE DETECTION AND SUPPRESSION SYSTEMS

Contemporary advancements in security system development integrate extensive automation across residential buildings, offices, and enterprises, aiming to automate life support management and operational functions. This evolution has led to integrated security systems (ISS) with comprehensive functionalities, automating engineering system management within buildings. Fire alarm systems (FAS) are globally mandated components for all structures. Artificial intelligence (AI) utilizing trained neural networks (NN) shows promise in designing integrated fire alarm and evacuation control systems. NNs, interconnected artificial neurons, resolve complex problems through signal transmission and image classification [9-11]. Researchers apply NNs for pattern recognition and fire classification, using mathematical, empirical, and theoretical methods [12-17] AI effectively classifies fire scenarios using object-monitoring data, enhancing real-time decision-making by identifying critical fire characteristics. However, adapting NN learning algorithms to dynamic changes, such as combustion processes, remains a challenge.

There are several examples of projects with the same concept as our project:

II.1 PROJECT FIRE-GRID

The Connected Firefighter Platform integrates cloud-based connectivity for seamless data transmission [18],[19], enhancing communication and decision-making during firefighting. It manages device and incident data, personnel, and equipment records, offering real-time monitoring locally via Fire-Grid Monitor and remotely through Remote Monitoring. Automated data generation supports post-scene evaluation, training, and maintenance, optimizing firefighting effectiveness.

II.2 DRONE-BASED FIRE MONITORING AND SUPPRESSION

Firefighting drones provide early detection and access to inaccessible areas, crucially saving lives. They deploy fire-extinguishing balls using remote sensing and drones from safe locations [20-25]. These drones detect flame length, enhancing firefighting efficiency, with AI-enabled models using computer vision for smoke and fire detection, leveraging advanced camera systems.

II.3 SMART BUILDING FIRE SAFETY SYSTEMS

Smart buildings integrate cyber-physical systems to enhance daily user routines and optimize building management across health, energy, and security domains [26-29]. These systems operate interactively or autonomously, aiming to address recurring building issues and enhance safety through AI, IoT, and automated response technologies, surpassing traditional fire safety methods by predicting, detecting, and responding to fire hazards efficiently.

II.4 WILDFIRE PREDICTION AND MANAGEMENT

Wildfire prediction and management employ advanced technologies such as predictive analytics using weather, fire history, and vegetation data to forecast fire behavior and spread. Remote sensing through satellite imagery and drones enables real-time detection and assessment, with AI analyzing data to enhance decision-making [30-34]. IoT integrates sensors and cameras for early warning systems, while GIS maps fire-prone areas to plan effective evacuations. These technologies, including automated drones and AI-driven robots, improve fire containment efforts, complemented by community preparedness programs to bolster fire safety and resilience..

III. PROPOSED SYSTEM ARCHITECTURE AND OPERATIONAL WORKFLOW

Due to identified shortcomings in fire detection and extinguishing systems, a solution proposed to mitigate false alarms and ensure swift fire detection in residential, commercial, and industrial sectors, thanks to the architectural design of this system. This automatic system provides a solution to well-known issues in the fire detection and extinguishing systems market. It relies on an intelligent approach, utilizing artificial intelligence (AI) for detection, as well as processing and encoding signals from sensors (such as gas and flame sensors) via the Arduino software. Additionally, it incorporates AI processing for analyzing signals captured by the camera. This solution also offers a remote monitoring platform, facilitated by the use of Python.

Our system integrates three main components: detection, extinguishing, and a control unit. Detection features gas and flame sensors alongside a camera for quick risk assessment. Automatic extinguishers in the system ensure immediate response to fires. The control unit acts as a central platform for fire management, facilitating efficient coordination and swift action during incidents.

Connected sensors, managed by a microcontroller (Arduino Python), process data through specialized algorithms to make informed decisions. Notifications issued via a web portal and local alert system for timely response. The system's block diagram (Figure 1) illustrates sensor data processing, camera integration, and essential components.

Software algorithms dedicated to fire detection interpret sensor and camera inputs to activate or deactivate alerts. In fire emergencies, signals trigger automatic doors for extinguisher activation. The system functions autonomously, potentially supported by a central control unit for remote management. AI integration enhances camera capabilities for precise and rapid-fire detection.

A schematic depicts sensor and camera connections with microcontrollers and the control unit, ensuring scalable deployment across large areas if needed.

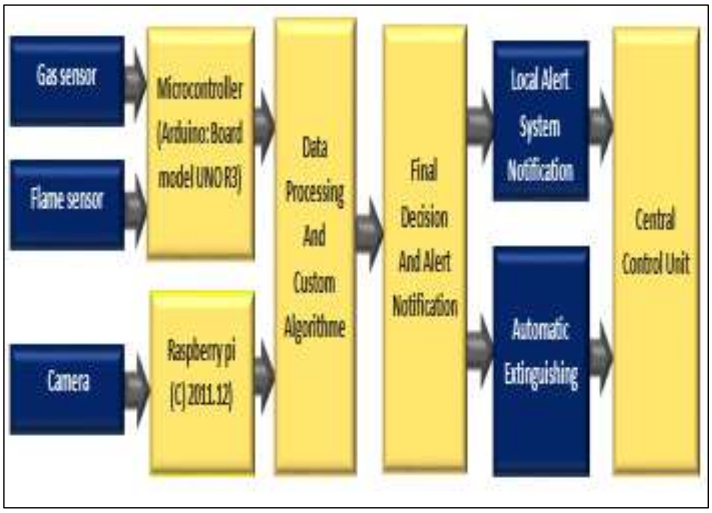

Figure 1: Block diagram of the system.
Source: Authors, (2025).

III.1 DETECTION

Our Fire Detection System (FDS) integrates the MQ135 gas sensor, KY-026 flame sensor, and a camera managed by Python (AI) on a Raspberry Pi microcontroller, all connected to an Arduino Uno R3. This setup sends signals to the serial monitor for cross-validation with camera data, minimizing false alarms and enhancing reliability for prompt fire detection and response.

III.2 GAS SENSOR

We selected the MQ135 sensor for our FDS project due to its ability to detect a wide range of gases including LPG, smoke, carbon monoxide, ammonia, nitrogen oxides, alcohol, benzene, and carbon dioxide. Its high sensitivity, detecting concentrations as low as 10 to 300 ppm for ammonia, 10 to 1000 ppm for benzene, and 10 to 300 ppm for alcohol, makes it ideal for early fire detection.

III.3 FLAME SENSOR

We chose the KY-026 flame sensor for our FDS project based on its high infrared sensitivity (760 to 1100 nm), dual analog and digital signal outputs, and adjustable detection threshold. Operating on 0 to 15 V DC power, it offers a versatile 60-degree detection angle and compact size, facilitating easy integration into diverse environments. This sensor's primary function swiftly and accurately detect flames, enabling prompt fire response.

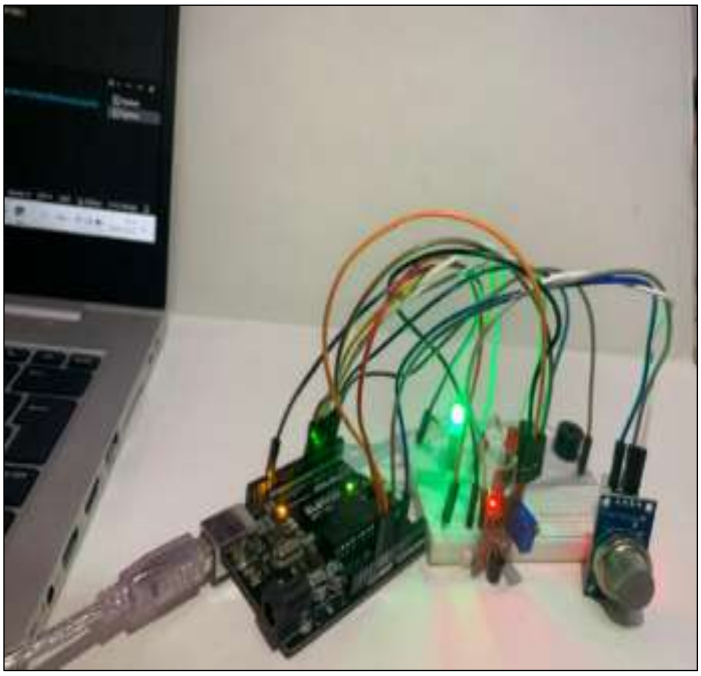

Figure 2: System In A Safe Condition with No Fire Detected.
Source: Authors, (2025).

III.4 LED AND BUZZER

In our FDS project, we use LEDs and a buzzer to ensure a quick and effective response in case of a fire alert. The LEDs provide an immediate visual indication of the presence of smoke or abnormal heat, allowing occupants quickly become aware of the danger. The buzzer emits a loud and distinctive sound to alert people, even if they are not in direct view of the LEDs. This combination of visual and auditory indicators ensures comprehensive coverage, increasing the likelihood of a fast and safe evacuation, thereby minimizing risks to human lives and property.

III.5 ARDUINO ARCHITECTURE

As part of our FDS project, the use of the Arduino Uno R3 proves to be crucial. This versatile tool, based on an Atmega328P architecture, features 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal oscillator, a USB connection, a power jack, and a reset button. These characteristics allow for efficient processing of data from various sensors, particularly those for gas and flame detection. The architecture of the Arduino Uno R3 facilitates the quick and precise processing of incoming signals thanks to its interrupt capabilities and analog-to-digital conversion. In the event of detecting flammable gases or flames, the Arduino Uno R3 activates an LED to indicate the presence of danger and triggers a buzzer to alert the occupants.

III.6 CAMERA

In our Fire Detection System (FDS), a USB Digital PC Webcam (model OEM-CS0138) enhances accuracy by capturing infrared radiation to detect temperature variations and hotspots, enabling early fire detection. This 720p, 30 fps camera with a high-sensitivity CMOS sensor allows real-time monitoring and rapid response, crucial for minimizing damage and ensuring safety.

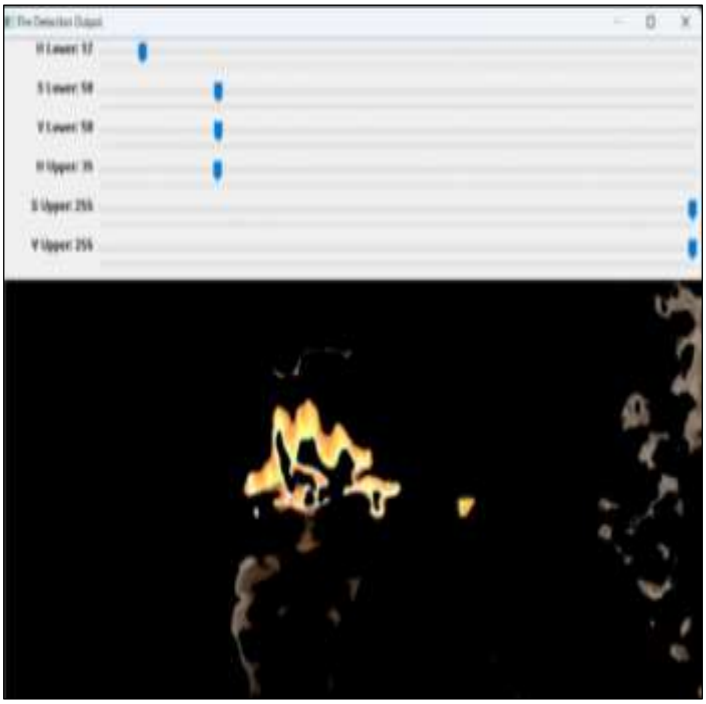

Figure 3: Triggering of an alarm after the detection by the camera.
Source: Authors, (2025).

III.7 ARDUINO SOFTWARE (IDE 2.3.2)

In our FDS project, the use of the Arduino Integrated Development Environment (IDE) is of paramount importance for effectively managing the data captured by our gas and flame sensors. Through this integrated development environment, we can precisely program and calibrate our sensors reliably detect potentially hazardous gas levels and the presence of flames. The Arduino IDE, as officially supported software by the Arduino platform, provides a user-friendly interface for writing, editing, and compiling the code required for our detection system. Compatible with both C and C++ languages, this environment enables us to develop sophisticated algorithms to interpret sensor data and trigger appropriate actions in the event of fire detection, such as activating alert LEDs or buzzers. By fully integrating the Arduino IDE into our development process, we ensure a professional and efficient approach to realizing our project.

III.8 RASPBERRY PI ARCHITECTURE

The architecture of the Raspberry Pi, first launched in 2011-2012, stands out for its unique combination of computing power and versatility, making it an ideal choice for our FDS project for automatic fire detection. Equipped with a high-performance ARM processor and ample RAM, the Raspberry Pi provides the resources needed effectively execute the complex artificial intelligence algorithms required for thermal image analysis. Its extensive connectivity, including USB ports, GPIO interfaces, and wireless connections, facilitates the integration of various modules and sensors, including cameras, essential for our application. Furthermore, its compact size and low power consumption make it suitable for large-scale deployments while ensuring efficient resource management.

III.9 PYTHON SOFTWARE (3.12 (64 BITS))

Python 3.12 (64 bits) plays a pivotal role in programming the camera for our FDS project, which dedicated to automatic fire detection. With its clear syntax and extensive library ecosystem, Python provides an ideal development environment for integrating artificial intelligence into our detection system. Leveraging specialized libraries such as Open CV and Tensor-Flow, Python simplifies the manipulation and analysis of thermal images captured by the camera. The breadth of Python's features enables the implementation of sophisticated machine learning algorithms and image processing techniques to detect thermal anomalies associated with fires. Moreover, Python's portability across various platforms, including the Raspberry Pi, makes it an optimal choice for our project, offering flexibility and performance for precise and rapid-fire detection.

III.10 VISUAL STUDIO CODE SOFTWARE

Visual Studio Code (VS Code) proves to be an essential element in the programming process of the camera for our FDS project focused on automatic fire detection. With its array of sophisticated features and intuitive user interface, VS Code provides an optimal development environment for code creation, debugging, and deployment. The versatility of VS Code in programming languages, notably its strong compatibility with Python, a widely used language in artificial intelligence projects, makes it a strategic choice for our application. The available extensions for VS Code allow seamless integration of AI-specific tools and libraries, such as TensorFlow or PyTorch, which are crucial for thermal image analysis.

III.11 EXTINGUISHING

In our project, we integrated automatic fire extinguishers with our advanced detection system, using sensors to identify smoke or heat and automatically activating the extinguishers to minimize property damage and ensure occupant safety. These extinguishers feature ultra-fast activation, extensive suppression capacity, and compatibility with various agents like water, foam, chemical powders, and inert gases. Equipped with mechanisms for optimal distribution, they provide continuous protection, reduce fire reaction times, and enhance system reliability and efficiency. This integration ensures a rapid, coordinated emergency response, maximizing safety and minimizing losses.

III.12 SURVEILLANCE PLATFORM

Our FDS system features an integrated surveillance platform that offers real-time visibility into the status of monitored environments, enabling proactive management and prompt intervention in case of fire. This enhances overall site security and ensures efficient responses. In-depth analysis confirms that our FDS system is a comprehensive and robust fire detection and management solution, capable of delivering rapid and accurate responses. This significantly contributes to the safety of monitored environments, providing users with peace of mind.

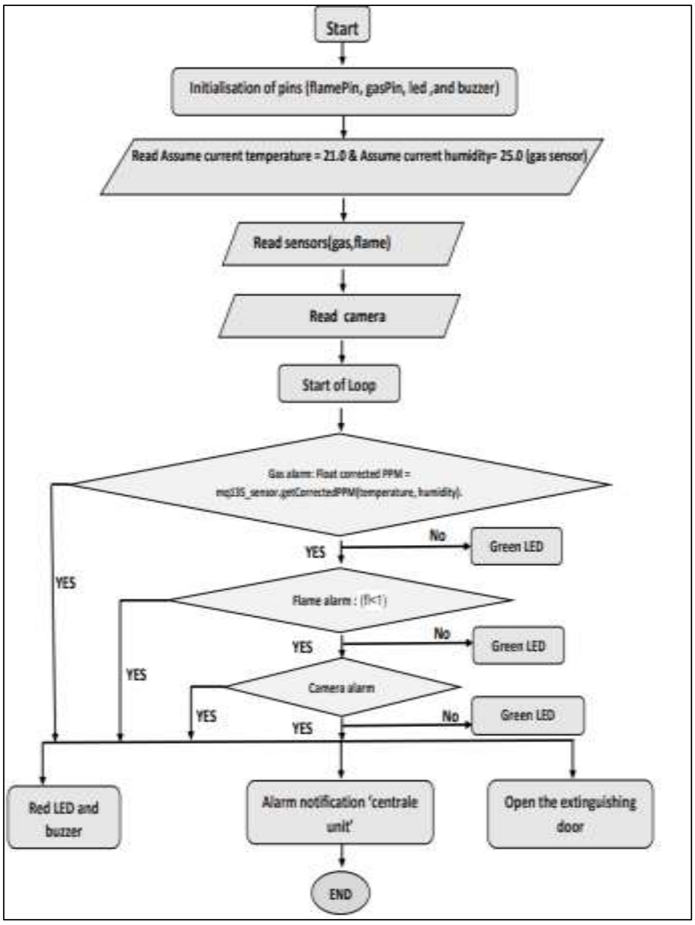

Figure 4: FDS Code flowchart.
Source: Authors, (2025).

Figure 5: Platform design.
Source: Authors, (2025).

IV. TESTING AND RESULTS

The analysis of the results of our FDS project highlights several key aspects of its operation and effectiveness. Firstly, comprehensive testing of the sensors demonstrated the system's reliability in real-time data collection, which is essential for accurate fire detection. The correlation between sensor data and camera signals enhanced continuous surveillance and the system's ability to react promptly. During this phase, the sensors underwent a series of tests to evaluate their reliability in real-time data collection. These tests verified the accuracy of measurements and the sensors' effectiveness in detecting fire signals.

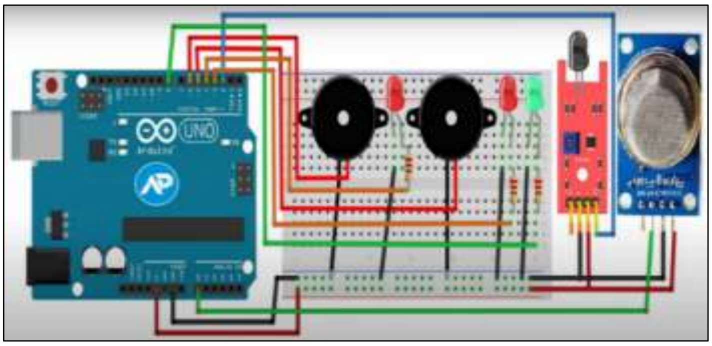

Figure 6: fire detection system circuit diagram.
Source: Authors, (2025).

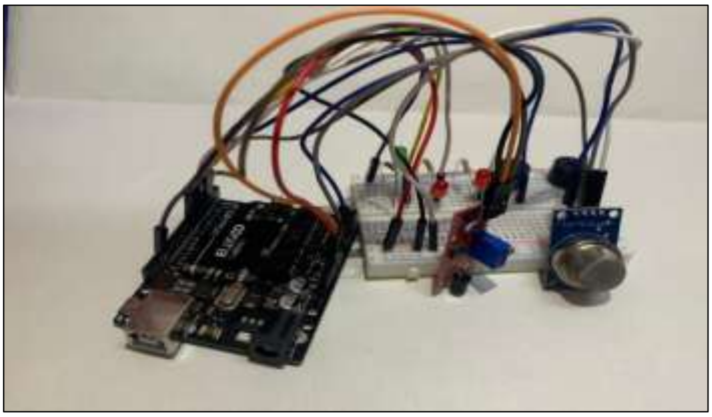

Figure 7: The Actual Installation of Our Project.
Source: Authors, (2025).

IV.1 SIGNAL RECORDING

The system configured to record distinct signals based on the presence or absence of a fire. This functionality was crucial for triggering appropriate emergency measures, such as visual and auditory alerts, as well as automatic activation of extinguishers, ensuring a swift response in case of fire.

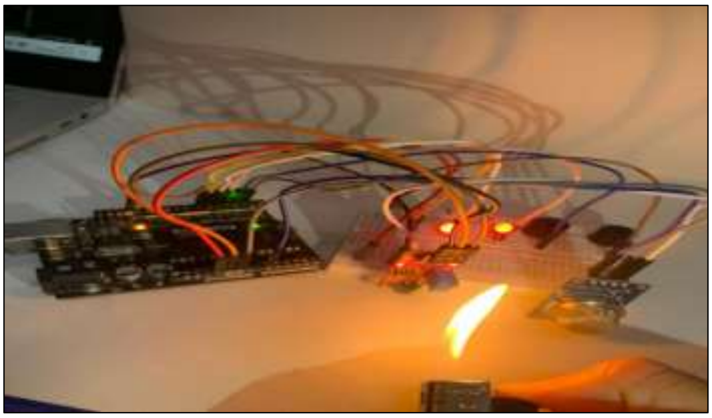

Figure 8: Fire alarm detection.
Source: Authors, (2025).

IV.2 INTEGRATION OF SURVEILLANCE PLATFORM

Integrating the surveillance platform enabled proactive management of the situation by providing users with real-time visibility into the status of each monitored environment. This feature facilitated prompt and efficient intervention in the event of a fire, thereby enhancing overall site security. The in-depth analysis of the results confirms that our FDS system is a comprehensive and robust solution for fire detection and management. Its ability to deliver a rapid and accurate response significantly contributes to the safety of monitored environments, providing users with peace of mind.

Figure 9: In terms of security status.
Source: Authors, (2025).

The security status is indicated by a green color in the absence of anomalies and a red color in case of fire detection, accompanied by an alarm sound. However, the yellow room was not identified correctly, requiring a system reevaluation.

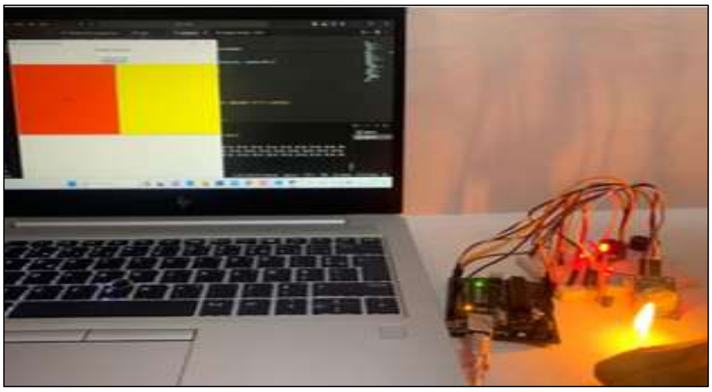

Figure 10: Fire detection.
Source: Authors, (2025).

V. FUTURE WORK

In our project, we plan to add various improvements and future proposals to further develop it, increase its efficiency, and enhance its functionalities. To improve the effectiveness and functionality of our Fire Detection System (FDS) project, we must focus on several key areas. First, it is essential to explore advancements in sensor technology to increase the accuracy and responsiveness of fire detection, by integrating more sensitive sensors or adopting emerging technologies like machine learning algorithms for more precise detection. Next, integrating the FDS with smart building systems can enhance automation and response capabilities, such as automatically shutting down heating systems, unlocking emergency exits, or sending notifications to building occupants. Additionally, developing a robust remote monitoring and control system is crucial, allowing users to access real-time data and control the FDS from anywhere through a mobile application or web interface. Implementing predictive analytics algorithms to anticipate potential fire hazards based on historical data and environmental conditions represents a proactive approach to fire prevention. Furthermore, exploring options for integrating the FDS with local emergency services to accelerate response times in the event of a fire is necessary, including automatically alerting fire departments and providing them with real-time data.

Finally, the FDS should be designed to be scalable and adaptable to different types of buildings and environments, requiring the development of modular components that can be easily customized and expanded to meet the specific needs of different applications. By focusing on these areas for future work, we can continue to improve fire safety and protection in various environments..

VI. DISCUSSIONS

The following assembly represents the electronic circuit operation of our project. Once the sensor data is collected, it is compared to signals recorded by the camera. This correlation strengthens system surveillance by providing a coherent overview of the monitored environment, enabling rapid and accurate fire detection. The system is configured to record distinct signals based on the presence or absence of a fire. This functionality is crucial for triggering appropriate emergency measures, such as visual and auditory alerts, as well as the automatic activation of extinguishers, ensuring a swift response in case of fire.

The integration of the camera plays a pivotal role in enhancing detection accuracy by capturing real-time visual data, which complements the information gathered by other sensors. The thermal camera, in particular, provides critical insights by detecting heat signatures that might indicate a fire, even in its early stages. This capability is essential for early intervention, potentially preventing small incidents from escalating into major fires. Additionally, the implementation of the FDS (Fire Detection System) platform facilitates remote monitoring and control, offering a comprehensive interface for real-time management. The platform is designed to allow users to access live feeds from the cameras and sensor data from any location, providing immediate insights into the status of the monitored environments.

This real-time visibility is crucial for proactive management, as it enables users to quickly assess and respond to potential fire threats. The combination of sensor data, camera inputs, and the FDS platform creates a robust system for fire detection and management. The in-depth analysis of the results confirms that our FDS system is a comprehensive and reliable solution, capable of delivering rapid and accurate responses to fire incidents. This system significantly contributes to the safety of monitored environments, providing users with peace of mind by ensuring that any fire threat is detected and addressed promptly and effectively.

VII. CONCLUSIONS

This study has demonstrated the effective design and successful integration of an advanced fire detection and management system. Utilizing an integrated approach with cutting-edge sensors and a proactive surveillance platform, our system has shown its ability to swiftly and accurately detect fires while minimizing false alarms. The results have confirmed the reliability and efficiency of our solution, highlighting its potential to enhance the security of monitored environments and provide a prompt and appropriate emergency response. These advancements represent a significant contribution to ongoing efforts aimed at improving fire safety and risk management.

VIII. AUTHOR'S CONTRIBUTION

Conceptualization: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra.
Methodology: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra.
Investigation: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra..
Discussion of results: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra..
Writing – Original Draft: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra..
Writing – Review and Editing: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra..
Resources: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra..
Supervision: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra..
Approval of the final text: Metahri Dhiyaeddine, Dekar Amina, SettingsKadi Halima Bouchra..

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