



Fireguard AI: Advanced Fire Detection and Evacuation Path Guidance System Using IoT and Artificial Intelligence

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Abstract: Fire accidents in buildings are a serious threat to human life and infrastructure, especially when the current fire evacuation systems in buildings are lack intelligent and adaptability. So, the solution proposes these system FireGurard AI. Traditional methods of detecting fire are using isolated sensors and alarm mechanism, which often delayed the response and inefficient evacuation. FireGuard AI integrate IOT sensors with deep-learning based computer vision (YOLO V8) for intelligent detection and evacuation planning. A Mobile application is developed to guide the evacuation safely during emergency. The proposed system detects the fire through the CCTV video streams of the building by a YOLO model, then the risk level is evacuated by physical agent which is integrated with IoT sensors and a camera module. The sensor data and visual analysis is to fixed to assess risk level and guide the occupant through safe evacuation path by mobile app and physical actuation like voice assistance, and lights. Using adaptive decision making large experimental evacuation shows that the system improve detection accuracy, reduce false alarm and enhance evacuation efficiency compared to traditional approaches. This proposed solution provides cost effective and intelligent framework for next generation fire system for smart buildings.

Keywords: Fire detection, YOLO V8, Emergency guidance, Path Planning, Evacuation planning, A* path finding algorithm.

I. INTRODUCTION

Accidents due to fire in residential, commercial, and industrial buildings is a serious threat to human life and property, especially in crowded places such as hospitals, shopping centers, offices, and academic institutions. The major reason for fires is due electrical failures, gas leakage, overheating, or even human error, which may spread quickly if not detected at an early stage. Also, the presence of thick smoke, harmful gases, and high temperatures makes evacuation more difficult, resulting in panic, which may lead to serious consequences. Thus, early detection is essential to reduce damage and ensure maximum safety. Conventional methods of detecting fires, such as smoke detectors, heat detectors, and alarm units, are used in most buildings. However, these devices start responding only when a fire is well established, while false alarms may result due to dust, steam, or temperature changes. Also, conventional alarm systems do not provide adequate information about the location of the fire or the best route to take while evacuating a building. Even if exit plans are available, they may not prove to be effective if there is congestion while evacuating.

However, recent advancements in technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and computer vision have provided opportunities for intelligent fire detection and response systems. In this context, this project proposes a fire detection and evacuation route guiding system based on AI technologies. The proposed system will be referred to as FireGuard AI and will utilize CCTV-based image analysis and IoT-based environmental sensors to detect fire and smoke in real-time and guide people to safe exits using a mobile application.

II. RELATED WORKS

A. IoT-Based Fire Detection and Evacuation Systems

The application of IoT in fire safety systems has been extensively studied to facilitate real-time detection and response. In early systems, IoT-based distributed sensor systems are employed to monitor various parameters such as temperature, smoke, and gas levels to detect fire threats. Faritha Banu et al. proposed an intelligent IoT-based evacuation system, which includes an intelligent system for guiding evacuees to safety through sensor integration and decision-making processes [1]. Although the system reduces the response time for evacuating the building, it suffers from the drawback that IoT-based detection systems may trigger false alarms or fail to detect fires in complex situations.



B. AI-Based Fire and Smoke Detection

Significant improvements have been made in Artificial Intelligence, especially in deep learning. This has improved the accuracy of fire detection. Convolutional Neural Network-based models are commonly used to detect fire and smoke patterns in images. Arpit Jadon et al. proposed a lightweight deep learning model known as FireNet, which has been optimized for real-time IoT applications [3]. This model has high accuracy in detecting fires with minimal computational complexity. Most AI-based fire detection systems have been designed to detect fire only. There has been no inclusion of evacuation procedures. Such AI-based fire detection systems have been designed to work independently.

C. Intelligent Evacuation Path Planning

Evacuation path planning is a significant research area where various optimization algorithms and simulation-based strategies have been applied to solve this problem. Hong-Hsu Yen et al. proposed a time-aware and temperature-aware evacuation algorithm, where safe evacuation routes are dynamically computed in multi-story buildings during emergency situations [5]. This algorithm considers various environmental factors, such as temperature variation and fire spread, to improve evacuation efficiency. In addition, Selain K. Kasereka et al. proposed an evacuation path planning algorithm based on an agent-based simulation approach, where people are classified according to their mobility and behavioral characteristics during emergency situations [2]. This approach improves evacuation strategies by considering human factors, but this algorithm is mostly based on a simulation approach and lacks real-time adaptability.

Ali Mohammadiounotikandi et al. proposed a fire evacuation and control system based on hybrid intelligent algorithms and IoT technology [6]. This algorithm is useful in improving decision-making, but it is considered to be computationally complex and less applicable in real-time situations.

D. AI and IoT Integrated Evacuation Systems

The integration of AI and IoT has resulted in the development of smart evacuation systems that improve user interaction and intelligence in evacuation systems. Huixian Jiang proposed a mobile-based fire evacuation system that enables real-time evacuation using AI and IoT [7]. The system improves interaction with people and enables evacuation processes; however, the system relies on a model and lacks adaptive learning features.

E. Comparative Analysis

From the existing literature, it can be observed that IoT-based systems are mainly focused on environmental monitoring and alarm generation, whereas AI-based systems are mainly focused on accurate fire and smoke detection through vision-based models. In addition, evacuation path planning methods are mainly focused on improving route optimization, whereas these methods are limited to simulation environments and are not adaptable in real-time. Although there are some studies that are focused on combining AI and IoT for efficient evacuation support, these methods are also limited to some extent due to the absence of dynamic decision-making, continuous monitoring, and user guidance. Thus, there is a need to develop a unified system that can efficiently integrate real-time fire detection, intelligent analysis, dynamic path planning, and mobile-based guidance. The proposed FireGuard AI system efficiently addresses all these challenges by incorporating real-time detection, IoT-based sensing, path generation, and mobile-based guidance within a unified framework.

III. PROPOSED SYSTEM

The system provides intelligent AI driven fire evacuation guidance system in a smart building during emergency situation. It is the combination of computer vision, IoT, real time monitoring and Artificial intelligence. The CCTV cameras placed in different locations of a building continuously monitor that area and by using deep learning model (YOLO V8), it detects the fire smoke, and human presence. Is there is fire detected it sends signal to the processor through MQTT after reaching the signal the processor sent alert message to the mobile phone and signal to the robotic agent on sealing. At that instant the robotic agent moves to the location of fire detected.

These robotic agents consist of various sensors such as PIR sensor, smoke sensor, temperature sensor, flame sensor and cameras. These robotic agent helps to conform the real fire, avoid false detection and showing how severe the condition of that area at that time. Then the agent send signal to the processor to generate safest and easiest way to escape from the building and these paths send to the mobile application for helping the occupants to easily escape from the building. And also the mobile application automatically send location and alert message to fire evacuation team.

This system aims to provide intelligent and faster fire detection and decision making and real-time monitoring and evacuation guidance system to improve the safety of occupants in a building compared to traditional fire alarm system.



IV. SYSTEM ARCHITECTURE

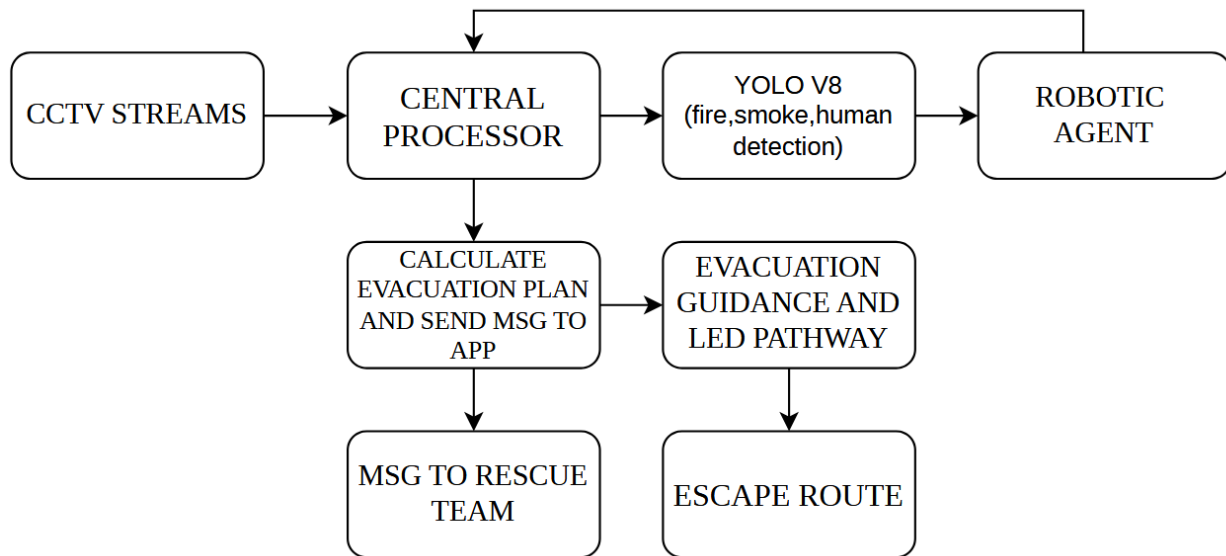


Fig. 1 Block Diagram

The architecture of the system Fireguard AI is designed for intelligent fire detection and smart evacuation path guidance. These systems consist of 4 layers Input layer, Central processing and decision engine layer, Agent controller layer and Output layer. The input layer consists of CCTV cameras placed in various locations of the building to detecting the fire and human presence in that surveillance area. It continuously monitors the environment also. These streams from the surveillance camera send to central processor, here central processor is used as mini-PC it analyses the room in real time.

The agent controller layer consists of ESP32, temperature sensor, flame sensor, smoke sensor, PIR sensor, and intelligent camera module. The processor send signal to the DC motored rail agent, if the fire detected. The agent analyses the data of the fire detected location to conform the fire detected or not. The temperature sensor helps to detect the increase in temperature, smoke sensor is to detect the smoke level, flame sensor is to detect the fire flames, And the PIR sensor helps to detect the person in that agent surveillance location.

The central processing and decision engine layer is responsible for analyzing the camera streams for detecting fire by using YOLO V8. YOLO V8 is a deep learning model it is trained model by using thousands of images for the accuracy of real fire image. And after detecting fire it sends a signal to the agent through MQTT (Message Queuing Telemetric Transport) It is a communication platform for allowing 2 ways of communication. After receiving the analyzing dada of robotic agent, the processor calculates the safe evacuation path by using A* /Dijkstra algorithm is an algorithm helps to identify the easiest way to escape from the building, it works through building plan converted into grid that calculate the easiest path from starting node to ending node, this algorithm is a pathfinding and graph traversal algorithm.

The output layer is receiving the evacuation path in mobile application. The mobile application is developed by using flutter with dart language as frontend and python as backend language. The usage of flutter helps to develop the application for Android and IOS easily. It allows same codebase for these too. And it is very helpful for developing features like real time alert, live mapping and AI guidance. And also, sensor data and CCTV streams are shown in these application helps the user for analyzing the situation of the building. If the sensor data exceeds the threshold value the mobile application automatically send location and alert message to the fore rescue team.

V. METHODOLOGY

The methodology proposed system develops an AI driven fire evacuation system that give guidelines to escape from a building safely by using a ceiling mounted agent and a mobile application. It is combined with computer vision, IoT, continuous monitoring and response mechanism to improve the safety of people during fire emergency situation.

Unlike from normal fire alert system in a building this system actively, detect the fire using AI Vision, Sends the data to the ceiling mounted agent, Agent evaluates the condition on the sites, it computes the safe path and guide the people to evacuate safely. Fig.1 shows the working flow of the system.



A. AI Based Fire detection

The initial stage of the system is fire detection .It uses surveillance cameras fixed at different locations of the building ,these surveillance cameras connected with the main processor and continuously monitoring the location .The live video streams from the camera are sent to the processor it analyses there is fire or smoke through the indication patterns of fire flames ,smoke patterns etc. using a trained deep learning model based on YOLO V8.When the detection is exceeds the predefined threshold and there is human presence there the system triggers the alerts.

B. Alert and Agent Activation

After fire detection AI Vision triggers emergency buzzer and glow the warning lights. The processor sends activation signal to ESP32 microprocessor through MQTT for smooth two-way communication. When the signal reaches the robotic agent. It starts to move through the sealing mounted rail by using DC geared motors towards the fire detected location and prioritize to move towards the high fire confidence location

C. On-Site Monitoring

Once the agent reaches the location it monitors the current condition of the location and sent data to the main processing unit, based on the agent data the processor made decisions. The agent consists of multiple sensors such as temperature sensor, smoke sensor, flame sensor and PIR sensors. Temperature sensor is to checks the intensity of the heat ,smoke sensor to measure the air toxicity ,Flame sensor is to confirm whether it is actual fire and PIR sensor is to detect whether any human is trapped or not .These are used to avoid the false information in the AI Vision and to identify there is any people trapped or not when any of the person trapped the system immediately send message to the fire escape team.

D. Decision Making

Now the system is in AI base decision making stage with the streamed visual data and onsite sensing data .By combining visual data's from the surveillance camera and sensors on the agent such as smoke sensor, flame sensor ,PIR sensors , Smoke sensors, it identifies the condition according to the severity of the fire .If the fire is identified small according to the scanned data the system continuous its monitoring .If the fire detected is very high the evacuation planning process is initiated by the system and a path finding A* algorithm is used to calculate the safest evacuation plan .According to the building structure and location of fire identified form the surveillance camera it structure is converted into grid format(like matrix) because the path finding algorithm uses the matrix then to calculate the safest and easiest path .It provides the safest exit path and blocks the unsafe path to secure the people till safe exit .

E. Evacuation Guidance

The system provides 2 different methods to make people escape from building, one is by using LED strips placed in corridors ,pathways that illuminates in the computed safe exit .Another is by providing the map of how to escape safely form the building inside mobile application and it also shows the risk level classification that is high medium or low for helping the people to understood the urgency of the situation .The mobile application also consist of emergency contact and emergency message sending option the message consist of location of the person also for taking immediate action from the Rescue team.

F. Continuous Monitoring

After evacuation, the FireGuard AI system continues to monitor to ensure complete safety and support rescue activities. It continues to track human movement, fire spread, smoke, and temperature. The camera modules use YOLOv8 to detect any remaining people, and IoT sensors continuously provide information regarding the environment. This information is then sent to the control dashboard and mobile app to visualize in real-time. The system provides alerts for abnormal situations, like a sudden rise in temperature or re-ignition of fire. This real-time information enables rescue teams to take quick action. So, continuous monitoring extends the functionality of the system to include post-fire surveillance and rescue.

VI. RESULT AND DISCUSSION

The proposed FireGuard AI system was implemented and tested under various real-time and simulated fire scenarios to assess its effectiveness in fire detection, alarm generation, and evacuation route planning. The system utilizes IoT sensing, deep learning (YOLOv8), and a mobile app interface to provide efficient and intelligent response to emergencies.

The experimental results demonstrate that the system is able to detect fires with high accuracy and minimal response time. The vision module, based on YOLOv8, was able to recognize the regions of fire and smoke under various environmental conditions, including illumination and occlusion. The incorporation of temperature and smoke sensors also improved the detection accuracy, as false alarms are eliminated, as observed in traditional alarm systems.



The response time of the system was measured by calculating the response time at various stages, including detection, processing, alarm generation, and notification. The experimental results demonstrate that the overall response time is well below a few seconds, as opposed to traditional systems that utilize threshold detection techniques.

From Table 1, it is clear that the response time of the system is less than 6 seconds, and this is considered to be a good response time for a real-time system in fire emergency situations. This is mainly due to the efficient processing of the system by the AI model.

STAGES	TIME(Seconds)
Fire Detection	1.0-2.0
Data Processing	0.10-0.30
Alert Generation	0.5-0.7
Mobile Notification	1.0-1.7
Total Response Time	3.5-4.5

Table 1. Response Time Analysis

In addition, further evaluation was carried out to test the system's response to various environmental conditions, and the results are presented in Table 2.

TEST CONDITION	DETECTION (%)	OBSERVATION
Normal Lighting	95	Fast Detection and High Accuracy
Low Lighting	96	Small Delay in Detection
Heavy Smoke	93.5	Sensors Improve Reliability
High Temperature	96.5	Stable Performance
Blind Spot View	90	Reduced Vision Accuracy

Table 2. System Performance under various conditions

From Table 2, it is clear that the system possesses high accuracy for different scenarios; however, a decrease in the performance level is noticed for scenarios with dense smoke and vision obstruction. This is mainly because the vision module relies on the presence of features. However, the inclusion of IoT sensors makes up for this limitation to a great extent.

In addition to the detection capability, the system was also tested for the evacuation path planning capability. The dynamic algorithm was able to generate safe routes by skipping the areas affected by the fire and leading the people towards the nearest exit safely. The computation time for the path was found to be less than 2 seconds.

The interface of the mobile application was also tested in terms of performance. The application was able to send out alerts with a high success rate, providing real-time navigation assistance to users. Moreover, the user interface was found to be efficient, along with accurate location tracking, which enabled efficient evacuation guidance.

Based on the results obtained, it can be concluded that the proposed system outperforms conventional fire alarm systems in terms of accuracy, response time, and intelligent evacuation. Some limitations were found, such as a decline in performance in a highly obstructed environment. However, the system was found to be efficient in providing a robust solution for smart fire safety management.

VII. FUTURE SCOPE

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