VAWKUM Transactions on Computer Sciences
http://vfast.org/journals/index.php/VTCS@ 2025, ISSN(e): 2308-8168, ISSN(p): 2411-6335
Volume 13, Number 1, January-March 2025 pp:99-110

Artificial intelligence based real-time smoke and fire detection and security management algorithms

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Keywords:*Peak hours, smart, Energy saving, Power system, Load management.*

Journal Info:
Submitted:
March 16, 2025
Accepted:
March 20, 2025
Published:
March 26, 2025

Abstract

Smart fire detection is essential for people's safety and property. The effective utilization of innovative technologies provides fast fire detection before intensification. Automatic fire systems commonly utilize passive sensors that are damaged by sunlight and environmental conditions. To address this problem, this study provides AI-based fire and smoke detection system that uses a You Only Look Once (YOLO) smart object detection algorithm integrated with a deep learning convolutional neural network architecture(CNN) and Android Studio to achieve the desired requirements. This prototype uses Common Objects in Context (COCO) datasheets for YOLO modelling. The incorporated camera continuously monitors the consumer for immediate notification. The system uses Android applications to monitor the parameters. The application architecture uses the Django framework to communicate the developed system with the Android application and the YOLO model. The Android application was designed using Android studio software to provide online information via cloud-based systems. Compared with conventional fire detection systems that consist of heat, flame, gas, and smoke sensors with high power consumption, installation, and preventive maintenance. The designed system considers AI fire detection algorithms using images and video forms. Further advancements in this state-of-the-art technology can improve the industrial application of early fire detection.

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DOI: 10.21015/vtse.v13i1.2092

1 Introduction

Design and construction of an AI-based smart security system integrated with IoT technology for innovation in domestic applications. This study thoroughly reviewed different AI- and IoT-based systems for video-based home security systems. The major components include IoT components, software integration with IoT technology, and AI-based video processing systems. The integration and implementation of each component selection are based on proper selection to achieve an efficient security system. The proposed system provides an innovative solution to improve domestic security systems [1].

This work demonstrates an Internet of Things (IoT)-based system for an innovative domestic automatic fire detection system. This study thoroughly discussed the implementation of a domestic fire extinguishing system integrated with an ESP8266 microcontroller to control water for early detection and monitoring via cloud-based systems. The system contains a servo motor to control water for fire extinguishing and fire sensors to detect flames. System construction includes both software and hardware implementation [2].

The artificial intelligence and big data field related to the computer engineering field. This work examines different methodologies to improve the big data management. By utilizing these assessment, the AI implementation with data management improves the system efficiency. The centralized data base management system integration with AI technology demonstrates the time management [3].

The motive of this study is to focus event management system via utilizing android application to manage and monitor the event. The monitoring and controlling includes the creation and deletion of events and collect the data for the proposed event[4].

Unusual accidents and events occur in human life and structures, and fire damages the entire infrastructure. Video-based fire detection has attracted considerable attention for its innovative monitoring over long distances. The latest fire detection systems have been integrated with an IoT-based system to communicate with fire stations. The system uses a deep neural network for the automatic analysis of fires using a video tool. This study provides a model-based design to improve fire parameters [5].

The current major difficulties in fire detection systems are the use of single photos and smoke sensors for detection, which are affected by sunlight and gases that cause fire fault detection. The conventional system is not capable of properly detecting real fire alarms. AI-based fire detection systems detect minor and major fires and smoke using cameras. AI based cameras implemented to monitor and control the area from fire [6].

Automatic fire systems improve human properties by implementing innovative technologies. The fire detection system plays an important role in the presence of a minimum number of people. This system used the YOLOv7 model to design the system. This system attains an inspiring performance with a 98% accurate detection of fire and smoke. The system is inspired by the Artificial intelligence techniques to efficiently detect the fire [7].

Fire discovery and quenching systems are important in our daily lives to minimize the cause of damage due to fire. The implementation of sensors in forests to detect fires using the latest technologies. The proposed system uses image processing and deep-learning algorithms to detect fires. This study thoroughly reviewed research articles published from 2013 to 2023 to explore the existing and latest systems. Real-time satellite- and camera-based detection is the current advanced technology for fire detection [8].

The loss of human life, climate change, and natural disasters are all caused by fire accidents. Efficient detection and quenching reduce the cause of fire. This study utilized artificial intelligence-based methods to detect real-time fires. This system uses a 7187 fire image data sheet for deep learning, and you only look once at the YOLO technique to advance the performance. The YOLO technique achieved a 95% accuracy. The hardware setup includes a Raspberry Pi microcontroller, Pi camera, and drone. YOLOv7n model was installed in a hardware setup for real-time fire monitoring [9].

Forest fires represent a major global challenge. To reduce these effects, perfect and early detection of forest fires is required. Artificial intelligence-based technologies have been utilized for fire detection. The study thoroughly evaluated various existing systems to detect fires early. This study also evaluated the use of 5G technology in communication [10].

Natural disasters are a significant challenge worldwide. The urgent requirement for fire detection must be implemented using artificial intelligence-based technologies. Use of drones to assist early fire detection. This method uses machine learning and deep learning algorithms for forest fire detection and monitoring [11].

Pakistan's power system has deficiencies and a lack of advancement in technology, especially IoT-based technology. The utilization of imported fuel damages the country's economy. The microcontroller-based solution designed in this study deactivates unnecessary loads during peak hours[12].

This study demonstrates a video detection system using convolutional neural networks(CNN). The main objective of this study is to detect fires using CCTV cameras. The Google Net architecture detects fire early. The study uses fire datasets with practical outcome and model working efficiently [13].

Forest fires have become a major global problem. Early fire detection systems for wild and forest fires are lacking. To overcome these major problems this study, provide the IoT and sensor based solution using anomaly vision algorithm [14].

Forest fires are out of control owing to their high intensity. The satellite-based system considered in this study was used for real-time monitoring of wildfires. The proposed model provides aerial ground fusion detection using a vision-positioning system. This system identifies early detection of fire locations using AI algorithms. The outcome shows that the observations with different lights distances ranges from 4% to 15% with ground based detection [15].

Forest fires are a major cause of climate change and related disasters. This study demonstrated the early detection of forest fires. The conventional detection system failed to detect the fire damage early. This study uses a convolutional neural network-based model to efficiently detect fires early[16].

This study considered fire and smoke detection for real-life applications. The algorithm utilized in this study was a YOLO-type system for object detection. This study defined the application of an early detection system for domestic purposes.[17].

Advancements in the IoT and artificial intelligence-based fire and smoke detection systems are required for human safety and property damage. The conventional system uses complex analog devices compared to the latest methods. This study demonstrates current deep learning-based algorithms with a minimal cost-effective solution. This study uses the YOLO version 8 algorithm, which efficiently overcomes the current challenge [18].

Forest fires damage biological diversity and human lives. The quick detection of smoke and fire improves the efficiency of fire extinguishing systems. Deep learning methods have been used to sense fire and smoke. In this study, the latest YOLO-based methods were applied to detect smoke and fires. The YOLO model achieved efficient performance with 80% fast detection [19].

The risk of wildfires can cause significant damage to humanity. The YOLO v8 model can detect early forest fires and smoke. The system uses the ghost convolution method to optimize fires using computer vision resources. To enhance the resolution of small fire systems, a Spatial Context Awareness Module is used. The results show that the system works properly, with high accuracy and early detection[20].

Accurate detection and monitoring of fires requires improvements in conventional methods. Fast detection of fire and smoke in both interior and exterior environments is required to save human lives and property. The proposed model provides a YOLO object detection system to quickly detect smoke and fire. This study evaluated the performance of the proposed YOLO model, and the findings showed that the integration of this system improves real-time fire detection [21].

Current fire risk situations in industrial and domestic construction face major challenges across the globe. The deployment of a fire man is not an option to save human life and property. This study addresses the issue of utilizing machine learning and Internet-of-Things (IoT)-based technologies to develop fire robots. The objective of this study was to detect fires early using an automatic fire detection and extinguishing system. The system is inspired by the latest technology, artificial intelligence, to monitor fires using cameras and controllers. The system uses a CNN to perform fire detection [22].

The system considers wild fire detection using the You Only Look Once (YOLO) algorithm. Compared with the convolutional neural network method, the YOLO method works efficiently for early fire detection. YOLO algorithm uses innovative technology to detect fires using images and video [23].

The industrial zone plays an essential role in nation financial development. The fire tragedies in industrial zone damages the people live and properties. To address this major issues this study focuses deep learning algorithms to detect the fire. This system provides smart monitoring system to detect the fire and smoke using the latest YOLO model[24].

1.0.1 Comments to the literature review

To create the proposed system, the literature review discusses relevant previous studies to express a particular area of research. For this purpose, the articles cited above were considered for implementing and constructing the required system. The existing study integrated a CNN with the latest YOLO model to detect fires and smoke early and accurately. The system is integrated with a cloud-based system to monitor and control water management to extinguish fires. The latest system automatically informs fire stations using deep neural networks by detecting fires using cameras. A conventional system is not capable of detecting real fire and smoke alarms. The implementation of an AI camera-based system improved the efficiency of fire and smoke detection. 98% detection is improved by utilizing the artificial intelligence YOLO model. The system was inspired by the latest deep-learning technologies. Deep learning methodologies using Roboflow software for fire and smoke detection via computer vision technology. Android Studio was utilized for application development to monitor the parameters. The backend system utilizes the Django framework for data analysis and communication between the systems and mobile applications.

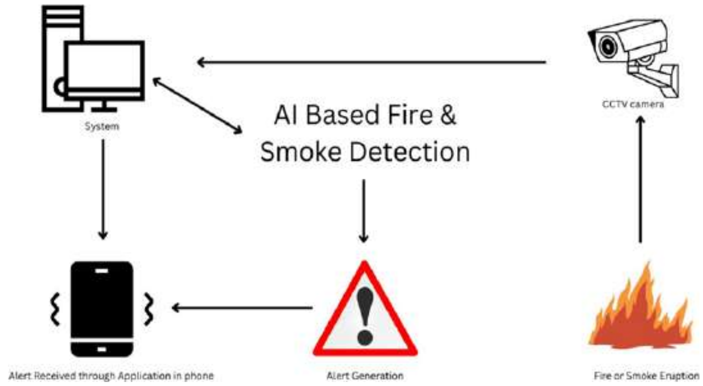

Figure 1. Proposed System Architecture

2 MATERIALS AND METHODS

2.1 Proposed System

The designed system uses closed-circuit television CCTV integrated with artificial intelligence YOLO-based algorithms to detect fires and smoke. Camera footage uses live footage data to detect fires and smoke. The computer vision system uses live footage to visualize fire and smoke, and the web application displays live footage. The use case list of actions provides interactions with a unified modeling language as a system to achieve early detection. The use case list of action provides interactions with unified modeling language as a system to achieve the early detection. When the camera is run, it captures the video frame, and the artificial intelligence algorithm starts detecting fire and smoke individually. Figure 1 shows the proposed system.

2.2 Software Setup

2.3 Roboflow

The system uses a Roboflow deep-learning tool that facilitates computer vision. This algorithm provides the freedom to produce computer vision applications, and both object detection and arrangement models are supported. The figure 2 shows the data sheet for AI based fire and smoke detection.

2.4 Android Studio

Android Studio is authorized software developed by Google that uses integrated development environment (IDE) technology for Android app development.

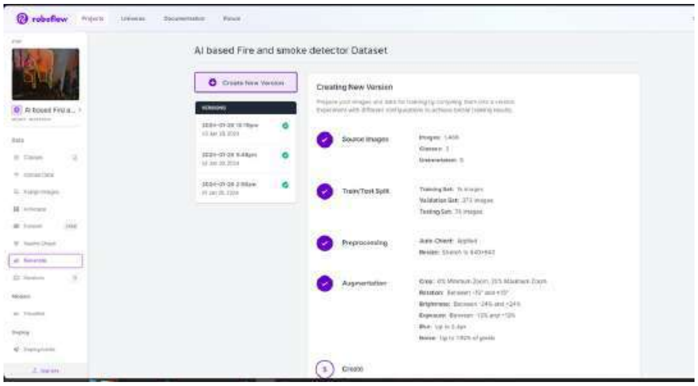

Figure 2. Roboflow data sheet for fire and smoke detection

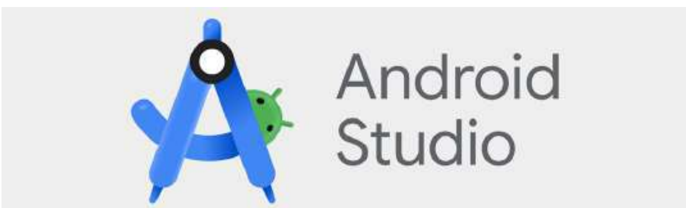

Figure 3. Android Studio interface

This is a comprehensive set of tools for creators to debug, code, test, and design Android applications.

2.5 Methodology

Microsoft Visual Studio is a free open code-editing platform. This system was used to develop programming and computer vision support systems. The designed system utilizes the YOLO algorithm to detect fire and smoke, and the addition of Django utilizes the front- and back-end real-time emergency alert development. Google Colaboratory uses cloud-based data analysis and machine learning. Colab offers editing and sharing of Google Drive integrated with machine and deep learning libraries.

2.5.1 Live Video Capture

The system uses a camera to capture the video and an artificial intelligence algorithm to detect the fire and smoke, respectively, and utilizes a camera as the main component for the fire and smoke detection part for continuous coverage and monitoring, as shown in figure 4.

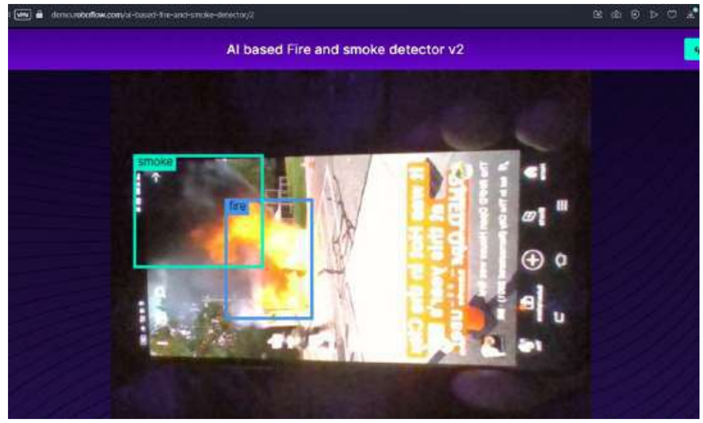

Figure 4. Live video detection

2.5.2 Object Detection Model(YOLOv7) with CNN Architecture

The fire and detection process is performed via the arrangement of YOLO and CNN integration for the innovation and early detection of fire by implementing the latest technologies. The CNN is accountable for mining the data from the image, YOLO architecture is utilized for prediction and probabilities, and uses a deep CNN network to detect the fire and smoke via the image and the architecture of the CNN, as shown in figure 5.

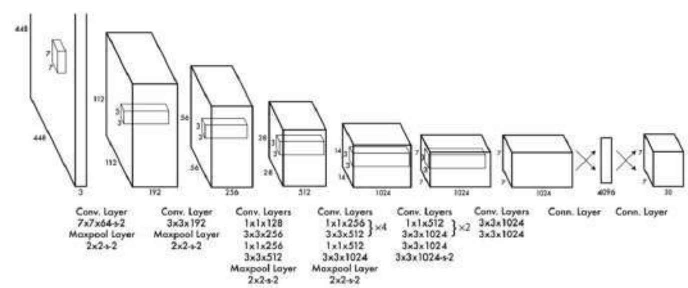

Figure 5. CNN Architecture

2.5.3 Alerting Mechanism

The alert system reports to the user via a web application for real-time data monitoring. The application utilizes an alert system designed using the Android Studio app for integration with a fire and smoke detection system. This system provides a real-time alert to take instant action. The web and mobile applications are integrated into the cloud server to send alerts and notifications to both devices. Figure 6 shows the alert application design using Android Studio.

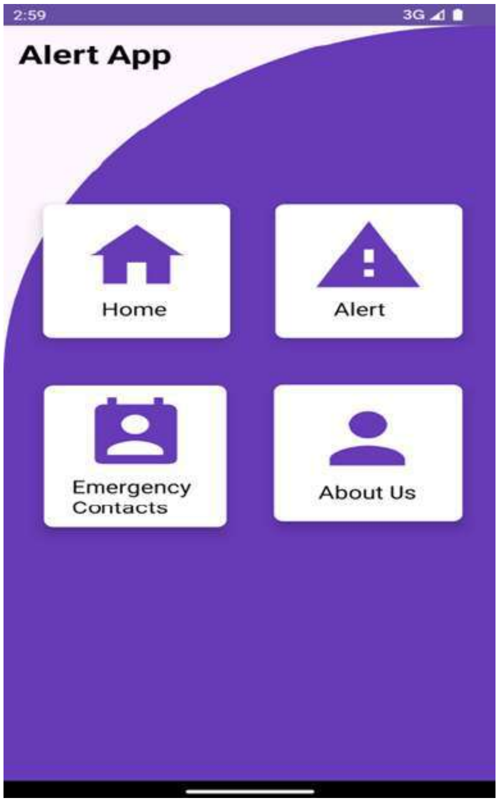

Figure 6. Android Studio based alert mechanism

2.5.4 Django Framework Backend

The backend system utilizes the Django framework for data analysis and communication between systems and mobile applications. Figure 7 shows the software implementation for running the Django framework server

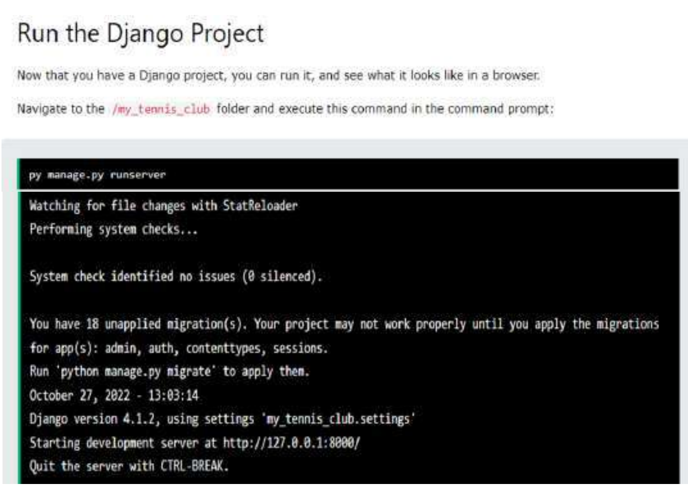

Figure 7. Run the server

2.5.5 Mathematical formulations

2.5.6 Convolution Operation

For a 2D input image f and a 2D kernel g, the convolution operation can be defined as:

$$(f * g)(x, y) = \sum_{i=-k}^{k} \sum_{j=-k}^{k} g(i, j) \cdot f(x + i, y + j)$$

Where f(x,y) is input image, g(i,j) is filter and k is size of the filter.

2.5.7 ReLU Activation Function

$$\mathrm{ReLU}(z) = \max(0, z)$$

2.5.8 Fully Connected Layer

$$z = b_0 + \sum_{i=1}^{p} w_i x_i$$

The mathematical formulation uses a convolution neural network to linearly transform and provide a complex model within the data relation. The function for each convolution and connected layer helps the model develop an expressive representation of the data.

2.5.9 System flow

Fig. 8 shows the overall flow of the fire and smoke detection system.

3 RESULTS AND DISCUSSION

In the result phase, the artificial-intelligence-based fire and smoke detection system functioned properly. The functionality testing was performed to verify the results and error analysis. The operational performance, efficient, design and procurement specifications were verified. The system efficiently detects fire and smoke

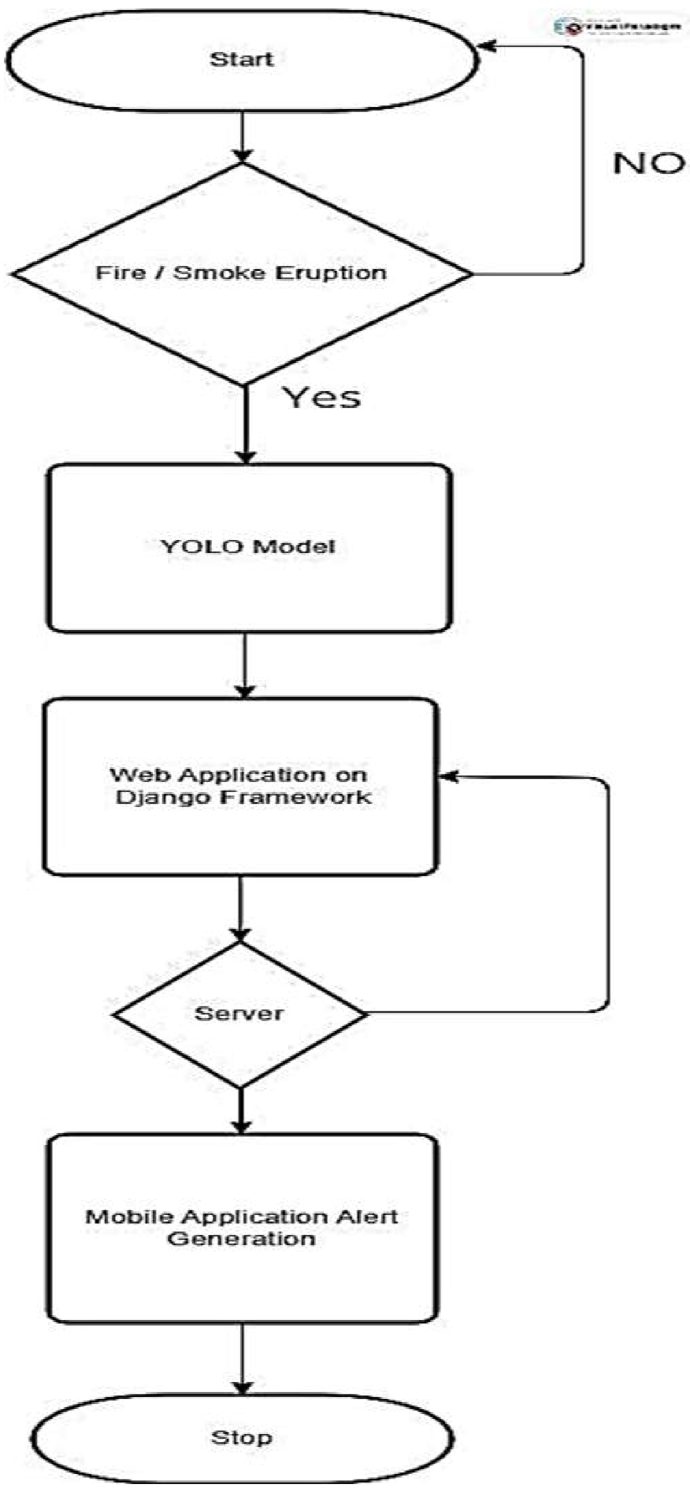

Figure 8. Fire and smoke detection system flow

early. The main purpose of this system is to quickly detect fire and monitor real-time data via web and mobile applications.. The YOLO algorithm initially pre-trains its first 20 convolution layers using ImageNet and then adapts the model for object detection, incorporating temporary average pooling and fully connected layers. The system distributes the input image into an S × S grid, where individually cell is accountable for sensing objects. During training, YOLO assigns one predictor per detect based on the maximum Intersection over Union promoting specialization among predictors for various object characteristics. Non-maximum suppression (NMS) is employed post-processing to refine detection, eliminating redundant bounding boxes and ensuring one box per object. The training graphs are shown in figure 9 and figure 10 shows the detection of fire and smoke via the CCTV footage for the design system.

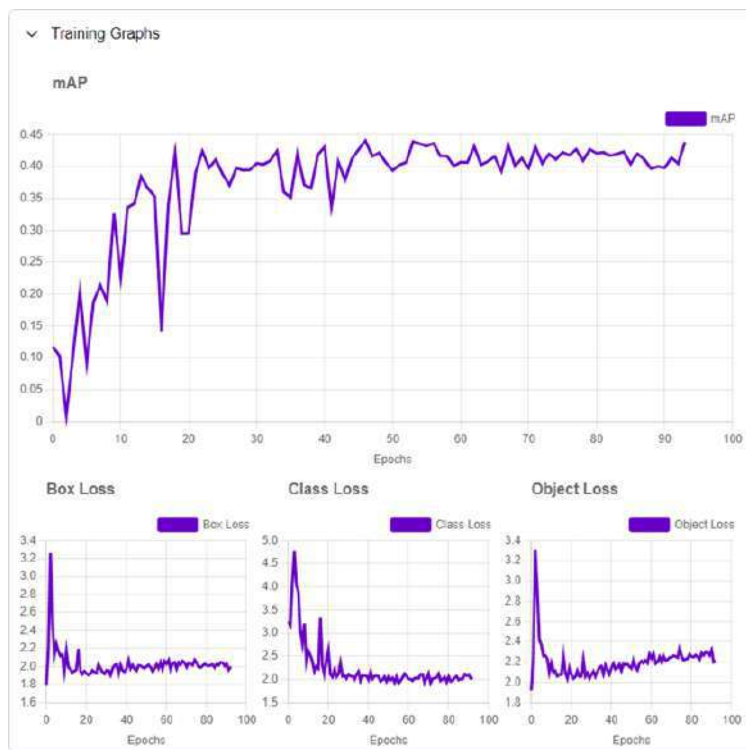

Figure 9. Training graphs YOLO model

Figure 10. Fire and smoke detection interface

3.0.1 Login webpage

Figure 11 shows the login web page for real-time monitoring of the system. This system was inspired by artificial-intelligence-based technologies.

Figure 11. Web page interface

3.1 Access the Alert Page

The figure 12 shows the access details for the design system. The alert system utilizes android studio software to design the project. For the real time monitoring system integrated with YOLO computer algorithm to manage.

3.2 Testing

In the testing phase, the functionality of the application was tested by assessing the operation and efficacy of the system. The validation was observed in this phase to check the accuracy of the system. To detect smoke and fire cameras integrated with the YOLO algorithm for fire and smoke detection. This algorithm reduces false detections with timely decision making. To check the detection efficiency of fire and smoke accidents, the system continuously uses a camera for live capturing and generating alerts. The main motive for testing and validation was to verify the specifications. The first phase of testing was to verify the operational, performance, design, and execution considerations. The following tables list the test parameters of the design system.

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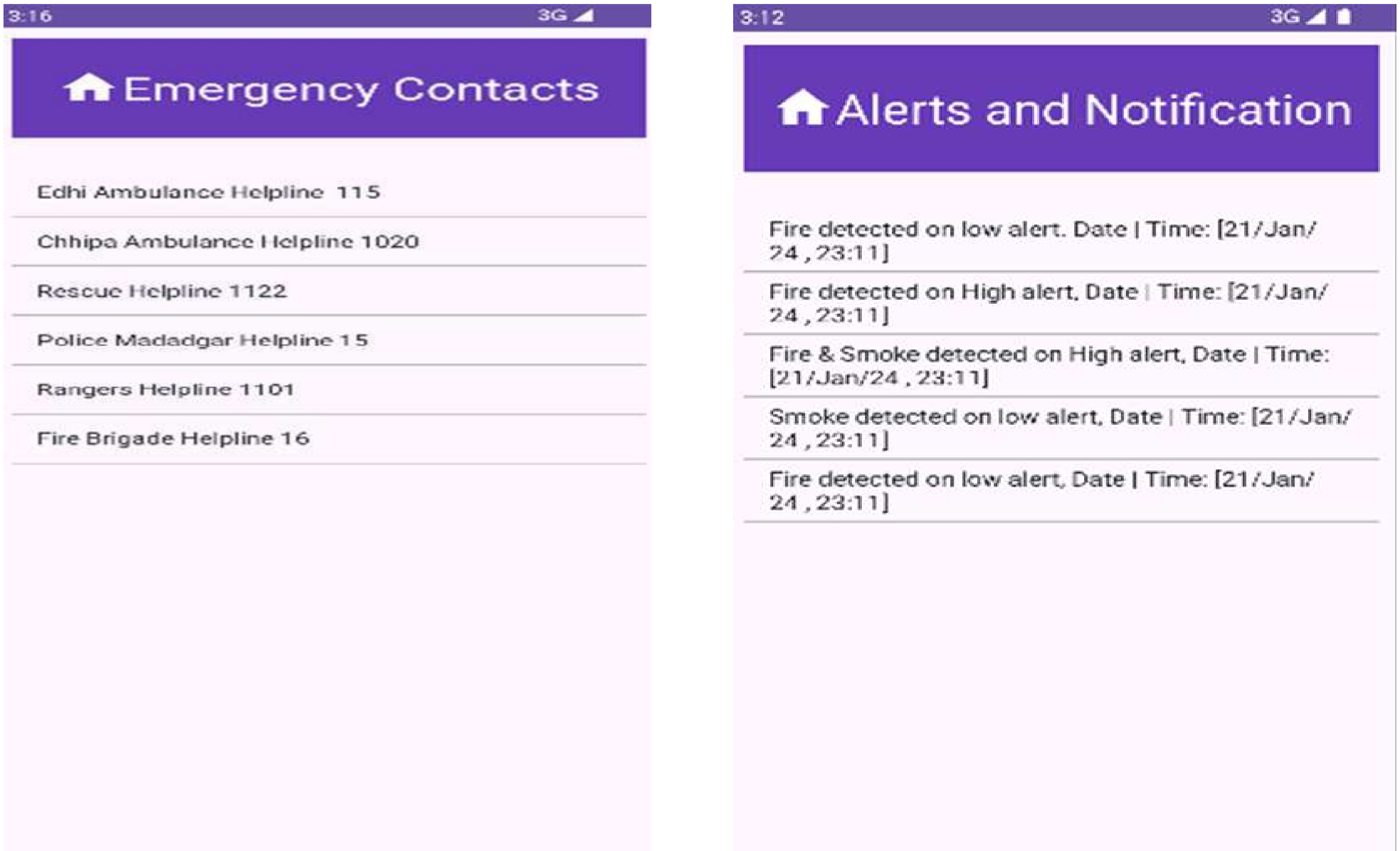

Figure 12. Alert notification interface

3.2.1 Test Case 1

Test Case Title: Testing Mobile application is running

3.2.2 Test Case 2

Test Case Title: Testing Live Video on Roboflow

3.2.3 Test Case 3

Test Case Title: Testing the Front-end development Server

3.2.4 Test Case 4

Test Case Title: Testing Mobile Alert Notifications.

3.3 Comparative Analysis

The performance comparison with conventional fire and smoke detection systems elaborated in table 5 to summarize performance metrics.

Preconditions	Check application is open after installation.
Actions	It runs on the Android mobile.
Expected Result	Open an Application.
Result	Pass

Table 1. Test Case 1

Preconditions	Check by starting a real-time video detection.
Actions	It detects Fire and Smoke simultaneously.
Expected Result	It will detect the Fire or Smoke.
Result	Pass

Table 2. Test Case 2

Preconditions	Check the Django server running.
Actions	Start the server to host the Web app.
Expected Result	Server will start.
Result	Pass

Table 3. Test Case 3

Preconditions	Check the application displays alerts.
Actions	After detecting fire, the app will notify.
Expected Result	Application will push alerts.
Result	Pass

Table 4. Test Case 4

Table 5. Comparative Analysis

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S. No	**Features**	**IoT Based Detector**	**Smoke Detector**	**Sensor Based Smart Detection**	**AI Based Fire & Smoke Detector**
1	Detect Smoke	Yes	Yes	No	Yes
2	Detect Fire	Yes	Depends on smoke density	Yes	Yes
3	Time Taken in Detection	Until smoke reaches the detector	Until smoke reaches the detector	Until temperature exceeds the limit	Immediate detection
4	Cost	Cost multiplies with the number of detectors installed	Cost multiplies with the number of detectors installed	Cost multiplies with the number of detectors installed	The cheapest tool comparatively
5	Terrain Based Detection	Cannot operate in windy, foggy, or sandy regions	Cannot operate in windy, foggy, or sandy regions	Cannot operate in windy, foggy, or sandy regions	Wherever the CCTV is operational the detector will work

4 CONCLUSION AND FUTURE WORK

In conclusion, the results show that the designed system works efficiently, and the design of fire and smoke detection provides major requirements for the safety of human lives and damage. By utilizing previous studies, the system was successfully constructed to identify fire and smoke early. The smart fire and smoke detection system is helpful for implementing the latest detection system. This system was designed to improve the performance of the fire and smoke detection system. The system uses YOLO algorithm integrated with android studio to efficiently monitor the real time parameters. The web and mobile application provide user friendly interface to visualize the parameters using computer vision technologies. The proposed system architecture features a seamless integration of a camera with the YOLOv7 model for real-time fire and smoke detection. The camera captures the environmental feed, and the YOLOv7 model implemented within the system analyzes the images to identify potential fire or smoke incidents. Upon detection, the system triggers an immediate alert and communicates crucial information to the mobile app. This two-tiered approach ensures a swift and efficient response mechanism, where the robust detection capabilities of the YOLOv7 model combined with the instant alerting system contribute to the overall effectiveness of the system. The integration of these components forms a cohesive and intelligent architecture that is designed to enhance fire safety by promptly notifying users of potential hazards. In the future, the development of this system using Java will improve its efficiency. The integration of an advanced cloud-based structure improved the stability and efficiency of the selected fire and smoke detection system. Cloud computing streamlines data storage and processes data remotely from any location.

Author Contributions

Khurram Iqbal: Practical and Material Supervision. **Syed Saad Ali**: Hardware and Software development. **Abdul Ahad**: Data collection. **Ghulam Mohiuddin Khan:** Interpretation of Data. **Ahmed Hamza Khan**: Testing and Validations **S. M. Yousuf Qasim:** Revision the work

Compliance with Ethical Standards

The authors declare that they have no conflict of interest. Consent was obtained from all authors included in the study.

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