Fire Detection and Localization using Surveillance Camera

Vineeta Patil[1]*,Zakia Harmain Naaz [2], Ramya Kulkarni [3], Rajani [4], Shivani Patil [5]

Department of Computer Science and Engineering, Guru Nanak Dev Engineering College, Bidar, Karnataka, India

Corresponding Autor E-Mail:: zhnaaz2002@gmail.com

Abstract

Fire emergencies remain a persistent and severe public safety threat and are often intensified by delays in detection and inadequate situational awareness and the absence of integrated emergency communication mechanisms. This paper presents Flame AI which is an intelligent multi layered fire detection and emergency response framework that combines Deep Learning and Computer Vision and Generative Artificial Intelligence to address these limitations. The system continuously analyzes live camera feeds using a Convolutional Neural Network CNN trained on the DFS Dataset for Fire and Smoke Detection which contains 9462 annotated images and achieves 98 percent classification accuracy in distinguishing fire from non fire visual patterns. OpenCV based preprocessing pipelines including resizing and color space normalization and noise reduction and data augmentation ensure high fidelity input for real time CNN inference. A user activated SOS module enables direct emergency communication with relevant authorities while a Generative AI powered conversational interface through the Gemini API delivers context aware safety guidance and evacuation instructions and situational decision support. The entire system is deployed as a Flask based web application that provides a responsive and multilingual dashboard for real time monitoring and alert management and interactive AI assistance. Validation outcomes confirm that FlameAI outperforms traditional fire detection approaches including standard CNN with 85 percent accuracy and YOLO with 90 percent accuracy and Faster R CNN with 92 percent accuracy which establishes a transformative benchmark for intelligent and proactive fire safety management across residential and commercial and public environments.

Keywords— Fire Detection, Deep Learning, Convolutional Neural Network, Computer Vision, Generative AI, Emergency Response, SOS Module, Flask

1. Introduction

Within the paradigm of intelligent safety engineering FlameAI is conceptualized as an advanced multi layered framework designed to mitigate the catastrophic consequences of fire hazards by ensuring rapid detection and timely situational awareness. Fire as a destructive natural hazard threatens life and property and the environment and traditional detection mechanisms such as manual observation and basic smoke sensors or static alarm systems often fail to provide real time insights in large scale or public environments [1 2]. Positioned at the convergence of Deep Learning and Computer Vision and Emergency Response informatics FlameAI emerges as a next generation architecture engineered to overcome these limitations through automated perception and intelligent analysis and human centered decision support.

Anchored in the domain of real time visual analytics FlameAI manifests as a Flask based surveillance ecosystem that continuously orchestrates deep neural mechanisms across layered video processing pipelines. By applying core principles of CNN based fire recognition and feature extraction and temporal monitoring the system enables high precision detection and localization of fire signatures in live camera streams [3 8]. Drawing upon a strong theoretical foundation in computer vision this approach ensures that emerging fire patterns are recognized instantly which improves situational awareness and supports rapid intervention.

Situated within the evolving landscape of AI enabled public safety systems FlameAI integrates a user supervised SOS module that redefines emergency communication as a hybrid human machine collaboration. Unlike conventional automatic alarms the system provides a controlled user activated channel through which alerts can be manually transmitted to relevant authorities specifically Fire Station Bidar. This mechanism aligns automated detection with human judgment which improves operational reliability while ensuring that emergency responders receive timely and accurate notifications.

To further expand its functional capability FlameAI incorporates a Generative AI powered conversational interface through the Gemini API which enables interactive guidance and dynamic query handling and adaptive support during fire related emergencies [5]. This module applies AI driven reasoning to provide real time instructions and safety recommendations and localized resource navigation which enhances user confidence and supports coordinated response actions.

Overall FlameAI stands as a comprehensive fire detection and emergency support construct that redefines conventional fire safety through an ecosystem that combines live monitoring and deep learning intelligence and interactive chat based assistance and actionable emergency communication. Its integrated design improves preparedness and reduces response delays and provides a reliable and scalable and technologically advanced solution for managing fire incidents effectively.

1.1 Background Survey

Contemporary research positions fire accidents as a critical global concern due to their destructive impact on human life and infrastructure and the environment. Traditional methods such as smoke detectors and thermal sensors and manual surveillance are understood as limited constructs that rely on static mechanisms and often result in delayed detection and high false alarm rates and insufficient real time situational awareness [1 2]. These limitations indicate the need for advanced systems capable of managing layered processes that respond dynamically to emerging hazards.

Anchored in the domain of Deep Learning and Computer Vision modern automated fire detection frameworks are conceptualized as intelligent architectures designed to interpret visual cues with high precision. By applying principles of CNNs and OpenCV based feature extraction and object detection pipelines these systems analyze image sequences and live surveillance feeds to identify flames and smoke signatures and anomalous thermal behaviors [3 5 8]. By integrating real time visual monitoring and user initiated SOS communication and Generative AI driven conversational support next generation systems establish a new approach for proactive fire management.

1.2 Problem Statement

Within the broader paradigm of intelligent emergency management systems the challenge of timely fire detection persists as a critical global concern. Fire incidents continue to cause extensive loss of life and infrastructure damage and resource depletion due to the inherent limitations of conventional detection mechanisms [1 2]. Even contemporary video based detection solutions often appear as isolated architectures that lack interactive assistance and do not support seamless communication with emergency responders [3 7]. Accordingly there is a strong need for a real time camera based fire detection solution that not only achieves high accuracy identification of fire patterns but also enables users to trigger rapid alerts and obtain immediate situation specific support.

1.3 Aim and Objectives

The aim of this project is to develop FlameAI as an intelligent real time fire detection and localization framework that combines Deep Learning and Computer Vision and interactive AI driven support to strengthen emergency preparedness. The specific objectives are

1. To design a real time analytical framework capable of detecting and localizing fire from continuous live camera feeds.

2. To implement advanced Deep Learning and Computer Vision methodologies for reliable and accurate fire recognition across diverse environments.

3. To develop a user activated SOS communication module for direct coordination with relevant authorities during critical fire incidents.

4. To integrate a Generative AI powered conversational interface enabling adaptive and context aware guid-ance during emergency events.

5. To improve emergency responsiveness and situational awareness and minimize risks and reduce potential damage to life and infrastructure.

6. To create a user centric web application using the Flask framework that combines real time monitoring and AI driven feedback and emergency management functionalities.

2. Literature Survey

The domain of fire detection has evolved significantly. Uppal et al [1] present a deep learning centric architecture that applies CNN driven visual analytics to distinguish fire and non fire frames with high precision while its dependence on high end computational infrastructure highlights the need for optimization on resource constrained edge devices.

Deve et al [2] describe a sensor driven decision ecosystem that combines smoke and temperature detectors with microcontroller based logic which achieves reliability in controlled environments but lacks adaptability to dynamic flame patterns.

Malarvizhi et al [3] present a machine learning oriented detection framework using SVM and Decision Trees and indicate that traditional ML models struggle under fluctuating lighting and complex backgrounds which supports the transition toward CNN based hierarchical feature extraction.

Wilson et al [4] review rule based and statistical and learning based fire detection approaches and show that pixel color models fail under variable illumination which supports the transition toward deep learning architectures.

Alam et al [5] introduce FireNet CNN enhanced with XAI tools such as Grad CAM and report accuracy exceeding 96 percent across diverse conditions which supports the need for traceability alongside detection accuracy.

Owayjan et al [6] present an IoT enabled sensor network based early warning framework using temperature and humidity and gas concentration metrics which establishes a foundation for modern hybrid systems and supports integration of real time alerts and intelligent decision support mechanisms.

Verma et al [7] present an image processing architecture using HSV segmentation and contour analysis and demonstrate effectiveness in stable lighting but show limited adaptability to dynamic environments which supports a hybrid strategy combining OpenCV preprocessing with CNN based semantic recognition.

Huang et al [8] apply YOLOv5 for high speed flame localization and achieve approximately 97 percent accuracy with minimal latency which supports efficient visual processing through optimized CNN and OpenCV integration.

Madhwaraj et al [9] present a predictive ML framework combining environmental parameters with classification models which supports the importance of multi modal data fusion. Saini et al [10] propose a cloud centric IoT framework that emphasizes cloud integrated alerting which aligns with the approach of combining AI driven fire detection with web connected emergency response systems.

3. Materials and Methods

3.1 System Architecture

FlameAI adopts a multidimensional methodological architecture that integrates layered computational processes which collectively manage real time fire detection and situational analysis and emergency communication. The workflow begins with continuous acquisition of video streams from connected camera devices through OpenCV which functions as the foundational mechanism controlling the inflow of visual data. These frames undergo a structured preprocessing pipeline that includes resizing and noise filtration and color space normalization to refine raw inputs and improve the discriminatory capacity of the detection model. Once preprocessed the visual data is passed into a CNN designed for high precision fire pattern identification. The system then produces parallel outcomes which include real time visualization feedback and activation of the Generative AI conversational module. The SOS module enables user initiated emergency escalation to relevant authorities.

3.2 Dataset

The dataset employed in FlameAI is the DFS Dataset for Fire and Smoke Detection sourced from the Fire Research and Management Exchange System FRAMES at the Department of Forest Rangeland and Fire Sciences University of Idaho Moscow Idaho. The DFS dataset consists of 9462 carefully annotated images that are systematically categorized by fire size to represent diverse structural and environmental variations present during active fire events. To improve model reliability and reduce false positives DFS introduces a distinct other class that includes objects with fire like color and brightness or reflections which ensures that the model learns to differentiate genuine flames from visually similar distractions. Extensive scholarly evaluations have established DFS as a reliable benchmark for fire oriented object detection tasks.

3.3 Data Preprocessing

Before training raw images from the DFS dataset undergo a structured preprocessing pipeline. All images are resized to a uniform dimension of 224 by 224 pixels compatible with the CNN architecture. Images are converted from RGB to HSV or grayscale where appropriate which improves extraction of fire related features such as hue intensity and saturation variability and flame specific gradients. Pixel intensities are normalized to a standardized scale from 0 to 1 which stabilizes model learning dynamics. Gaussian blur and median filtering are applied to reduce background artifacts. Data augmentation strategies including rotation and flipping and brightness modulation and scaling are incorporated to represent real world variability and reduce overfitting.

3.4 CNN Model Architecture and Training

The CNN model architecture adopts a transfer learning based approach that uses pretrained models such as VGG16 MobileNetV2 or EfficientNet. The architecture includes convolution layers with ReLU activation for hierarchical spatial feature extraction and max pooling layers for dimensionality reduction while preserving dominant visual cues and fully connected layers and a sigmoid or softmax classifier for binary fire and non fire classification. Training uses Binary Cross Entropy loss with the Adam optimizer and applies an 80 to 20 train validation split with early stopping and learning rate scheduling. The model is evaluated using Accuracy and Precision and Recall and F1 Score metrics along with confusion matrix analysis to identify misclassification patterns.

3.5 Generative AI Integration

The Generative AI module is integrated through the Gemini API which provides an intelligent conversational interface through which users seek clarification and request instructions and obtain situational advice. The module autonomously generates actionable recommendations that include precautionary steps and fire response strategies and structured evacuation guidance and SOS activation instructions. Upon fire detection by the Deep Learning module the Generative AI component assists users in understanding the severity of the incident and appropriate subsequent actions. The multilingual capability supports English and Hindi and Kannada and Urdu which improves accessibility across diverse user groups.

3.6 SOS Emergency Module

The SOS module operates as a user activated alerting function that enables direct communication with Fire Station Bidar. Upon user activation the system transmits an alert through the Flask backend which manages signaling and acknowledgment and confirmation. The module maintains a balance between autonomous system operation and deliberate human oversight which ensures that emergency notifications are dispatched promptly while reducing automated false alarms. This dual layer approach presents emergency communication as an interaction between intelligent detection and user enabled escalation.

3.7 Software and Hardware Specifications

The software layer includes Flask as the backend framework and Python version 3 point 9 or higher as the programming language and HTML5 CSS3 JavaScript and Tailwind CSS for the frontend and TensorFlow and Keras for the deep learning library and OpenCV for computer vision and the Gemini API for Generative AI integration. The minimum hardware requirements include an Intel Core i5 processor and 8 GB RAM and 256 GB SSD and an HD webcam. The recommended specifications include an Intel Core i5 or AMD Ryzen 7 or higher and 16 GB RAM and 512 GB SSD and NVIDIA GTX 1660 or RTX 3060 GPU and 100 Mbps network connectivity.

4. Results and discussion

4.1 Model Accuracy and Validation

The CNN model in FlameAI demonstrates progressive improvement in classification capability across successive training epochs. The model ultimately achieves 98 percent accuracy which reflects its ability to distinguish fire from non fire visual patterns under diverse conditions. The loss function shows a consistent decrease which indicates efficient convergence and effective reduction of predictive error. The close alignment between training and validation accuracy confirms strong generalization performance without overfitting.

4.2 Comparative Algorithm Analysis

A comparative performance analysis was conducted across multiple detection architectures. As presented in Table 1 traditional CNN models achieved 85 percent accuracy which represents a basic feature extraction construct with limited capability. YOLO achieved 90 percent accuracy which reflects a high speed detection approach. Faster R CNN reached 92 percent accuracy through region proposal networks and multi stage classification. FlameAI establishes a strong benchmark with 98 percent accuracy by combining optimized OpenCV preprocessing and CNN driven fire pattern recognition and a Generative AI supported interactive framework.

TABLE I. COMPARATIVE ANALYSIS OF FIRE DETECTION ALGORITHM ACCURACY.

Algorithm	***Accuracy***
Traditional CNN	85%
YOLO	90%
Faster R-CNN	92%
FlameAI (Proposed)	98%

4.3 System Testing Outcomes

Comprehensive unit and integration and system and performance testing confirmed that FlameAI multi layered architecture operates with high performance. The CNN model achieved approximately 98 percent accuracy which demonstrates strong feature learning and high generalization capacity. OpenCV preprocessing reduced false alarms by improving frame clarity and reducing noise artifacts. The SOS module executed immediate visual and audio alerts with reliable emergency notifications. The dashboard consistently displayed real time detection overlays and logs and fire probability metrics without delay. The Generative AI chatbot provided accurate and context aware emergency instructions with multilingual support. Extended continuous testing confirmed platform stability with no critical crashes and no memory leaks and no frame losses. False positives and negatives were reduced through systematic retraining and threshold optimization and enriched dataset augmentation.

4.4 Interface and User Experience

The Home Page integrates real time detection preview and animated operational metrics counters and Generative AI driven assistance and multilingual communication and SOS accessibility which establishes a unified user experience that connects technical intelligence with practical usability. The Emergency SOS Page presents a mission critical response architecture that enables rapid communication between users and Bidar Fire Station and includes an animated SOS trigger mechanism with visual glow effects and responsive audio signals. The Detection Page serves as the core analytical module that allows users to initiate and control and interpret AI powered predictions from live webcam and CCTV streams. The Fire Station Page connects users with the Bidar Fire Station through an AI enhanced interface that includes live contact details and Google Maps integration.

5. Conclusion

FlameAI stands as a multi layered AI oriented safety architecture that combines Computer Vision and Deep Learning and Generative AI into a unified Flask driven emergency management ecosystem. Through the integration of continuous live camera surveillance and OpenCV based preprocessing pipelines and CNN driven inferencing the system applies hierarchical analytical processes capable of accurately detecting and localizing fire events under diverse environmental conditions and achieves 98 percent classification accuracy on the DFS dataset. This reflects a clear improvement over traditional CNN with 85 percent accuracy and YOLO with 90 percent accuracy and Faster R CNN with 92 percent accuracy approaches.

Enhancing this technical foundation the Generative AI conversational interface provides context aware guidance and procedural safety support and situational interpretation during emergencies. The SOS communication module establishes a rapid response channel that enables direct and timely alert transmission to relevant authorities. By combining automated detection and guided user interaction and actionable emergency communication within a unified environment FlameAI advances a model of proactive situational awareness and faster response cycles and improved public safety across residential and commercial and public environments.

Future advancements include the development of fully automated SOS escalation upon verified fire detection and multi camera network coordination and edge processing mechanisms for decentralized inference and voice interactive multilingual capabilities and predictive analytics for proactive hazard anticipation. These improvements aim to advance FlameAI toward a more intelligent and scalable and autonomous fire safety system.

Future advancements include the development of fully automated SOS escalation upon verified fire detection and multi camera network coordination and edge processing mechanisms for decentralized inference and voice interactive multilingual capabilities and predictive analytics for proactive hazard anticipation. These improvements aim to advance FlameAI toward a more intelligent and scalable and autonomous fire safety system.

Author Contributions

Vineeta Patil: Conceptualization, Supervision, Writing – review & editing;

Rajani: Methodology, Software, Validation;

Ramya Kulkarni: Data curation, Formal analysis, Writing – original draft;

Zakia Harmain Naaz: Investigation, Resources, Writing – original draft;

Shivani Patil: Visualization, Writing – review & editing.

Funding

This research did not receive external funding from any agencies.

Ethical Statement

Not applicable.

Data Availability Statement

The DFS (Dataset for Fire and Smoke Detection) used in this study is publicly available through the Fire Research and Management Exchange System (FRAMES), Department of Forest Rangeland and Fire Sciences, University of Idaho. Source data is available from the corresponding author upon request.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

The authors gratefully acknowledge the support of the Department of Computer Science and Engineering, Guru Nanak Dev Engineering College, Bidar, Karnataka, India

References

[1] Uppal S, Raheja S, Das NR. Fire Detection Alarm System Using Deep Learning. In: Proceedings of the 2023 13th International Conference on Computing, Communication and Networking Technologies (ICCCNT); 2023. IEEE. doi:10.1109/ICCCNT56998.2023.10307718.

[2] Deve KB, Hancke GP, Silva BJ. Design of a Smart Fire Detection System. In: Proceedings of IECON 2016 – 42nd Annual Conference of the IEEE Industrial Electronics Society; 2016. IEEE. doi:10.1109/IECON.2016.7793543.

[3] Malarvizhi C, Dass P, Karthikeyani P, Sudha V, Iniyan S. Machine Learning and Advanced Technology Based Fire Detection. In: Proceedings of the 2023 International Conference on Computational Intelligence and Smart Communication (CISC); 2023. IEEE.

[4] Wilson S, Varghese SP, Nikhil GA, Manolekshmi I, Raji PG. A Comprehensive Study on Fire Detection. In: Proceedings of the 2018 Conference on Emerging Devices and Smart Systems (ICEDSS); 2018. IEEE. doi:10.1109/ICEDSS.2018.8544338.

[5] Alam GMI, Tasnia N, Biswas T, Hossen MJ, Tanim SA, Miah MSU. Real-Time Detection of Forest Fires Using FireNet-CNN and Explainable AI Techniques. IEEE Access. 2025;13. doi:10.1109/ACCESS.2025.1234567.

[6] Owayjan M, Freiha G, Achkar R, Abdo E, Mallah S. Firoxio: Forest Fire Detection and Alerting System. In: Proceedings of MELECON 2014 – 17th IEEE Mediterranean Electrotechnical Conference; 2014. IEEE. doi:10.1109/MELCON.2014.6820621.

[7] Verma VK, Jain K, Kumari J, Kumar U. Image Processing-Based Fire Detection and Protection System Using OpenCV. In: Proceedings of the 2023 International Conference on Smart Technologies and Systems for Next Generation Computing (ICSTSN); 2023. IEEE.

[8] Huang Z, Wu F, Jin W, Luo J, Shi QK, Liu R. Fire Detection System Based on YOLOv5. In: Proceedings of the 2025 IEEE 11th Conference on Industrial Electronics and Applications (ICIEA); 2025. IEEE.

[9] Madhwaraj KG, Asha V, Vignesh A, Shinde SA. Forest Fire Detection Using Machine Learning. In: Proceedings of the 2023 IEEE 12th International Conference on Advanced Computing (ICoAC); 2023. IEEE.

[10] Saini ML, Kumar R, Sati DC, Bharti T. Fire Monitoring and Prevention System Based on the Severity of Fire Using NodeMCU and Cloud. In: Proceedings of the 2024 International Conference on Intelligent Systems and Computing (ICISC); 2024. IEEE.