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Automated Fire and Smoke Monitoring System Using Vision-Based Techniques

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KEYWORDS

Fire Detection, Smoke Detection, YOLOv8, Deep Learning, Computer Vision, Real-Time Monitoring, Telegram Alert, OpenCV

ABSTRACT

Fire accidents pose a severe threat to human life, property, and the environment, making early detection a critical safety need. Traditional sensor-based systems relying on heat, smoke concentration, or manual CCTV monitoring often fail in large or open environments and are prone to false alarms caused by dust, steam, or temperature fluctuations. To address these limitations, this project proposes a vision-based fire and smoke monitoring system that leverages deep learning to enable faster and more accurate detection. The system captures live video through a webcam and processes each frame in real time using YOLOv8, a CNN-based object detection algorithm trained on a custom dataset of fire and smoke images. Detected instances are validated using confidence thresholding and Non-Maximum Suppression (NMS) to ensure precise localization and eliminate duplicate detections. Upon detection, the system instantly sends an automated alert along with a snapshot image to the user via the Telegram Bot API, implemented using Python threading to avoid any processing delays. The entire system is built using Python, OpenCV, PyTorch, and YOLOv8, and operates on standard laptop hardware without requiring any specialized infrastructure. This solution enables early-stage fire and smoke detection with high accuracy, real-time response, and minimal human intervention, making it a practical and scalable alternative to conventional fire monitoring systems.

1. INTRODUCTION

In recent years, the increasing occurrence of fire-related incidents in residential, industrial, and public environments has highlighted the critical need for efficient and early fire detection systems. Traditional fire detection methods, such as smoke detectors and heat sensors, are widely used but often suffer from delayed response times and limited detection capabilities, especially in large or open areas. These systems primarily rely on physical changes in the environment, which may not always provide timely warnings, leading to severe damage and potential loss of life.

With advancements in computer vision and artificial intelligence, vision-based monitoring systems have emerged as a powerful alternative for real-time hazard detection. These systems utilize cameras and intelligent algorithms to continuously analyze visual data, enabling early identification of fire and smoke before they escalate into dangerous situations. By leveraging deep learning techniques, such systems can recognize complex patterns and features associated with fire and smoke, significantly improving detection accuracy and response time.

Fig 1: Automated Fire and Smoke Monitoring System

The Automated Fire and Smoke Monitoring System using Vision-Based Techniques is designed to address these challenges by integrating deep learning-based object detection with real-time video processing. The system utilizes the advanced YOLOv8 (You Only Look Once) algorithm to detect fire and smoke from live video streams captured through a webcam. YOLOv8 is known for its high-speed processing and accuracy, making it suitable for real-time applications where immediate response is crucial.

The system continuously analyses each frame of the video feed and identifies potential fire or smoke hazards based on trained model predictions. When a detection is made with a confidence level exceeding a predefined threshold, the system triggers an alert mechanism. A snapshot of the detected frame is captured and sent to the user via the Telegram messaging platform, along with a detailed notification message. This ensures that users receive instant updates, allowing them to take timely action and prevent further escalation of the hazard.

To enhance system performance and ensure smooth operation, multithreading is implemented to handle alert notifications without interrupting the real-time video processing. Additionally, a cooldown mechanism is incorporated to prevent repeated alerts within a short time interval, thereby improving system efficiency and user experience.

Overall, this project demonstrates a cost-effective, scalable, and intelligent solution for early fire detection using modern computer vision techniques. By combining deep learning, real-time monitoring, and instant communication, the system aims to improve safety standards and provide a reliable tool for hazard prevention in various environments.

1.1 OVERVIEW OF FIRE AND SMOKE DETECTION SYSTEMS

Fire and smoke detection systems play a crucial role in ensuring safety by providing early warnings of potential hazards. These systems are widely used in homes, industries, commercial buildings, and public spaces to prevent fire-related disasters. Conventional systems primarily rely on sensors that detect smoke particles, heat levels, or gas emissions. While these methods are effective in certain conditions, they often face limitations such as delayed detection, false alarms, and restricted coverage areas.

Fig 2: Overview Of Fire And Smoke Detection Systems

Vision-based detection systems offer a modern approach by using cameras and image processing techniques to identify fire and smoke visually. Unlike traditional sensors, these systems can monitor large areas continuously and detect hazards at an early stage. By analyzing visual patterns such as color, motion, and texture, vision-based systems can accurately distinguish fire and smoke from other objects in the environment. The integration of deep learning algorithms has further enhanced the capabilities of these systems. Models trained on large datasets can recognize complex features and variations in fire and smoke, improving detection accuracy and reliability. This advancement has made vision-based detection systems a promising solution for real-time hazard monitoring.

2. LITERATURE SURVEY

[1] YOLOv3: An Incremental Improvement

YOLOv3 is a real-time object detection algorithm that improves accuracy and speed compared to earlier versions. It uses a deep neural network (Darknet-53) and predicts objects at multiple scales, making it effective for detecting small and large objects. It is widely used in applications like surveillance and fire detection.

[2] Ultralytics YOLOv8 Documentation

YOLOv8 is the latest version of the YOLO model designed for object detection, segmentation, and classification. It provides high accuracy, fast performance, and easy implementation using pre-trained models. It is commonly used in modern AI applications for real-time detection tasks.

[3] The OpenCV Library

OpenCV is an open-source library used for image and video processing. It provides tools for object detection, image enhancement, and real-time video analysis. It is widely used in computer vision projects for handling visual data.

[4] Deep Learning

Deep learning is a subset of machine learning that uses neural networks to learn patterns from data. It is used for tasks like image recognition, speech processing, and object detection. It forms the foundation for models like YOLO.

[5] PyTorch Documentation

PyTorch is a deep learning framework used to build and train neural networks. It supports dynamic computation graphs and GPU acceleration, making it suitable for research and real-time AI applications.

[6] Telegram Bot API Documentation

The Telegram Bot API allows developers to create bots that can send messages, alerts, and media. It is used in applications to provide real-time notifications, such as sending alerts when fire is detected.

[7] Computer Vision: Algorithms and Applications

This resource explains the principles and techniques of computer vision, including image processing, feature detection, and object recognition. It helps in understanding how machines interpret visual data.

[8] Research Articles on Vision-Based Fire Detection

These articles focus on using deep learning and computer vision techniques to detect fire and smoke in images and videos. They discuss methods to improve accuracy and reduce false alarms in real-time systems.

3. PROPOSED METHODOLOGY

The proposed system introduces an intelligent vision-based approach for detecting fire and smoke using deep learning techniques. It utilizes the Ultralytics YOLOv8 model to analyze live video streams captured through a webcam and identify fire or smoke in real time. Unlike traditional systems, this approach relies on visual data rather than physical sensors. The system processes each frame of the video feed and applies a trained deep learning model (best.pt) to detect fire and smoke with high accuracy. When a detection is made with a confidence level greater than 60%, the system immediately triggers an alert mechanism.

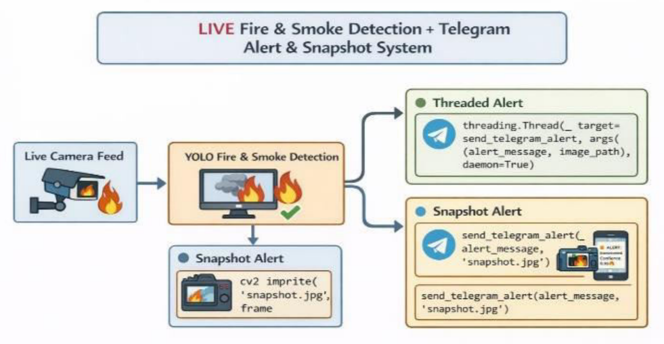


Fig 3: Block Diagram

One of the key features of the proposed system is its ability to send real-time notifications through the Telegram platform. When a hazard is detected, the system captures a snapshot of the frame and sends it along with a detailed alert message, including the type of hazard and confidence score. To ensure smooth and uninterrupted performance, the system uses multithreading for handling alert notifications. This prevents the video processing pipeline from slowing down or freezing during alert transmission. Additionally, a cooldown mechanism is implemented to avoid repeated alerts within a short time interval, improving system efficiency and user experience. Overall, the proposed system provides a fast, accurate, and reliable solution for early fire detection, making it suitable for real-time surveillance applications.

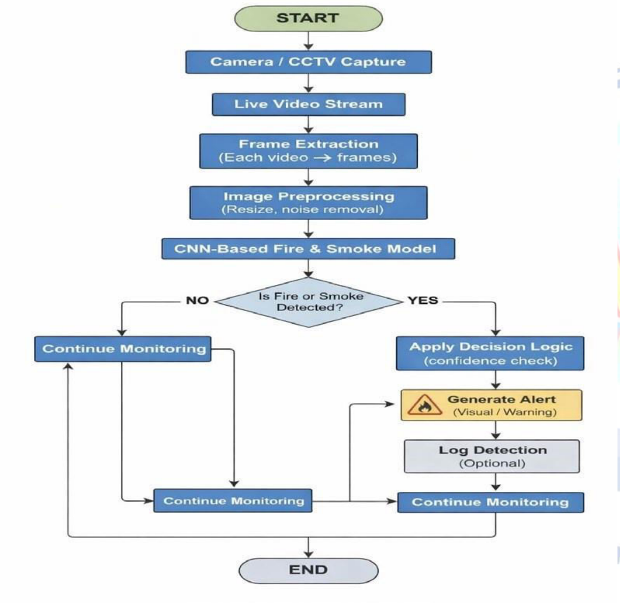


Fig 4: Purposed System

3.1 SYSTEM ARCHITECTURE

The working process of the system follows a structured sequence of steps:

1. The webcam captures live video continuously.
2. Each frame is extracted and processed using OpenCV.
3. The YOLOv8 model analyzes the frame for object detection.
4. The system identifies fire or smoke and calculates confidence scores.
5. If the confidence exceeds the threshold (60%), the system proceeds to alert generation.
6. A snapshot of the detected frame is captured and saved.
7. A notification message along with the image is sent to the user via Telegram.
8. A cooldown timer prevents repeated alerts within a short interval.
9. The annotated video is displayed in real time with detection labels.

This workflow ensures accurate detection, fast response, and efficient system operation.

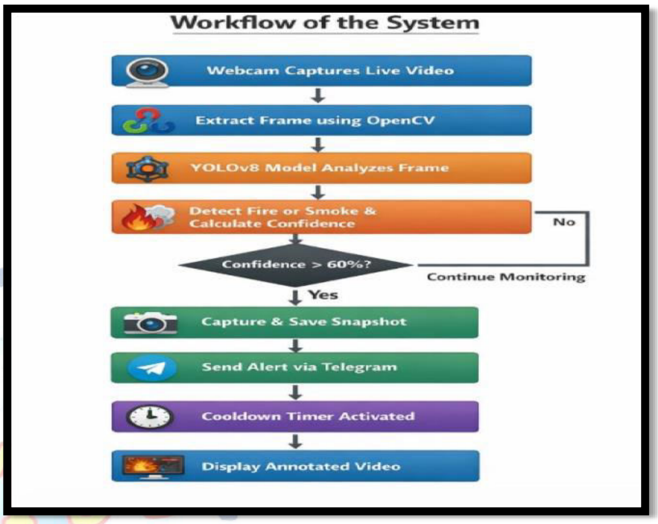
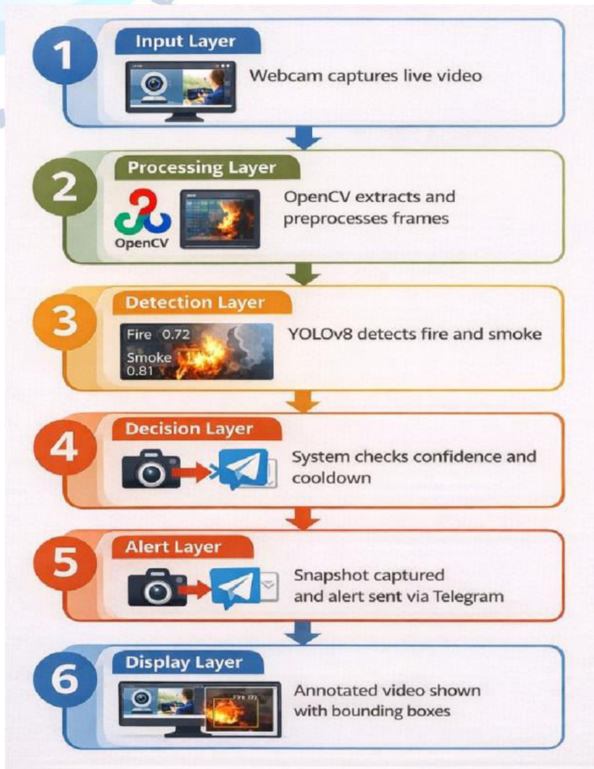


Fig 5: Workflow Of the System

SYSTEM ARCHITECTURE DIAGRAM



3.2 USE CASE DIAGRAM

The use case diagram represents the interaction between the user and the system.

Actors:

- User

Use Cases:

- Start System
- Monitor Video
- Detect Fire/Smoke
- Receive Alerts
- View Output

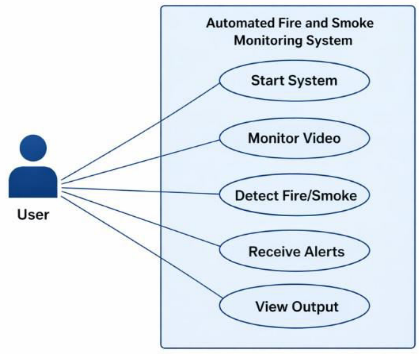


Fig 6: Use Case Diagram

3.3 CLASS DIAGRAM

The class diagram represents the structure of the system by showing classes and their relationships.

- **Camera Module:** Handles video capture
- **Detection Module:** Performs YOLO inference
- **Alert Module:** Sends Telegram alerts
- **Processing Module:** Handles frame processing
- **Main Controller:** Coordinates all modules

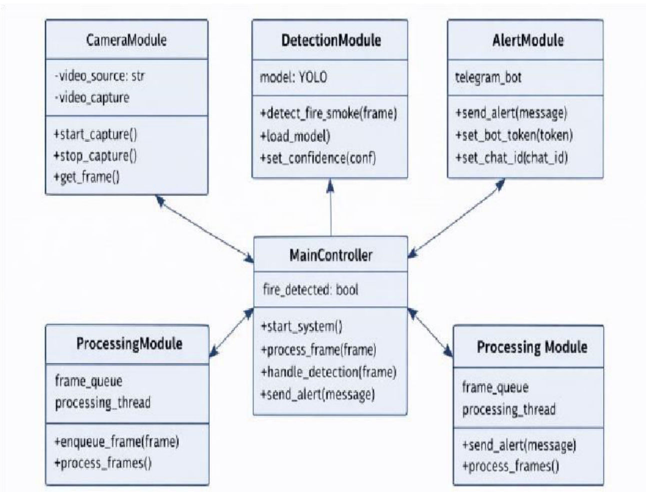


Fig 7: Class Diagram

3.4 DATASET

The system uses a pre-trained YOLOv8 model (best.pt) for detecting fire and smoke.

- The model is trained on labeled images of fire and smoke
- It can recognize patterns and features associated with hazards
- Provides bounding boxes and confidence scores

If trained manually:

- Dataset includes fire and smoke images
- Training performed using Ultralytics YOLO framework

Fig 8: Dataset

RESULTS

The system generates real-time outputs using annotated video frames and alert notifications. It captures live video through a webcam and processes each frame using the YOLOv8 model to detect fire or smoke. Detected objects are highlighted with bounding boxes along with labels and confidence scores for easy monitoring. When a hazard is detected, an alert message with the confidence score is sent to the user via Telegram. Additionally, a snapshot of the detected frame is captured, saved locally, and shared with the alert. This ensures quick response and provides clear visual confirmation of the hazard.

5. CONCLUSION

The Automated Fire and Smoke Monitoring System uses deep learning and computer vision to detect fire and smoke in real time. It is based on the YOLOv8 algorithm, which provides high accuracy in identifying hazards from live video streams. The system improves early detection compared to traditional methods by continuously analyzing visual data. It also sends instant alerts with images through Telegram, enabling quick response. Features like multithreading and a cooldown mechanism ensure smooth operation and prevent repeated alerts. Overall, the system is a reliable and cost-effective solution for enhancing safety.

FUTURE ENHANCEMENT

The system can be improved by supporting multiple camera inputs to monitor larger areas. Integration with cloud platforms can enable remote access and better scalability. A mobile application can be developed for real-time notifications and easy monitoring. Accuracy can be enhanced by training the model on a larger and more diverse dataset. The system can also be connected with IoT devices like alarms and sprinklers for automatic response. Overall, future improvements can make the system more efficient and suitable for real-world applications.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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