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Revolutionizing Fire Safety: Real-Time Fire Detection in Buildings using YOLOv8

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***Abstract*–The research ambit of the present study aims to develop improved real-time fire detection systems in buildings, which can reduce threats to human life, property, and the environment. Fire incidents are considered some of the most dangerous events that lead to great economic losses and put people in jeopardy almost every year. Most conventional fire detection systems are not able to warn users instantly. They live with delayed information and reduced accuracy and thus aggravate the damages due to fire even further. Hence, we proposed a solution that relies on using YOLOv8 deep learning model for real-time fire detection. The system is trained with a custom-made dataset, which includes different scenarios such as bright, dark, smokey, and noisy environments, to make it perform well in all these conditions. We integrated an automated alarm and a system for emergency call notifications that would immediately get alerts to administrators on the occurrence of a fire. Experimental results showed that the model trained obtained an average precision of 91.2%, which proves its high accuracy and reliability. The main contributions of this research work include a cost-effective, high-speed fire detection system, improved detection sensitivity in harsh environments, and integration of IoT-based remote alert mechanisms. It will take future smart buildings toward advanced and real-time fire safety systems and greatly improve safety and response efficiency.**

***Index Terms*—Real-Time Fire Detection, Fire Safety Systems, YOLOv8, Object Detection Deep Learning, Computer Vision, Building Safety, Smart Buildings, IoT-Based Fire Detection**

I. INTRODUCTION

Fire is a significant threat to life, property, and security. It may be caused by defective wiring, overloaded circuits, cooking equipment and smoking, where electrical causes are the leading factor in 12% office fires. The National Fire Protection Association (NFPA) estimates that 350,000 dwelling structure fires nationally require the assistance of fire departments each year, resulting in direct losses of around $7 billion. Compared to the 12,300 civilian fire injuries and more than 2,500 human fire deaths that occur each year, the destruction of property is insignificant [11]. Deep learning has been proven to be a powerful tool in fire detection, having robust image recognition capabilities. Real-time performance is lost in two-stage detection techniques such as Faster R-CNN and Mask R-CNN, despite their great accuracy. Yolov8 algorithm is used to detect fire in smart cities [1]. SVM, Random forest, CNN, CNN-GRU, CNN-LSTM, Faster R-CNN, and SSD are used to detect forest fires [12] One-stage algorithms with high speed and efficiency include YOLO and SSD. YOLOv5 was introduced in 2020, and the latest version, called YOLOv8, represents a compact, fast, and accurate detection system. The version used for this paper is the YOLOv8m, which is put to work in detecting fires within residential buildings. Trained on house fire images, YOLOv8 gives an overall much-enhanced detection speed and accuracy, though both low-light and occlusion scenarios still require further improvement.

Fire causes severe loss of life and property, with over 24,000 fires and 98 deaths reported in Bangladesh in 2022 [15]. Traditional fire detection systems, like smoke detectors, are usually slow and often give time for the fire to spread before any action is taken. The most recent real-time classification model for detecting fire in photos and videos is entitled YOLOv8. It is fast, precise, customizable with specific datasets, and economical. A YOLOv8-based fire detection and alarm system could save lives by allowing early evacuation and a faster response from firefighters, revolutionizing fire safety with its speed and reliability. In summary, the objectives of this system are to provide:-

- Real-time detection: Instantly detect fires in buildings, labs, hotels, and more.
- Real-time alerts: Alert admins to evacuate on time, reducing casualties.
- Cost-effective: Offers a low-cost, high-speed fire detection solution.
- Better safety: More reliable and effective fire detection means greater protection.
- Continuous improvement: Optimize the system with YOLOv8 advancements for world-class fire safety.

II. STUDY OF THE EXISTING SYSTEMS

Several studies have explored fire detection methods using advanced technologies, each with specific focuses and limitations. Pincott, J. and Ahn, Y. uses CCTV footage for training their model[13][14]. B. Swarajya Lakshmi[3] used YOLOv3 for image-based fire detection, but it struggles with low-light accuracy and relies on an outdated model. Nayankumar Dhome et al. proposed a SqueezeNet-enhanced YOLOv3 for live camera detection[4], which also faces similar challenges. Dou, Z. uses YOLOv5s for detect the fire[16]. Mukhiddinov et al. developed a YOLOv4-based system for visually impaired individuals[5] but reported issues in dark scenes and basic indoor navigation. Using Arduino and sensors [6], Suwarjono et al. created an indoor fire observing system; however, it is temperature-dependent and does not provide real-time detection. M. Udin Harun Al Rasyid et al. created a smart home fire monitoring system using sensors and fuzzy logic[7], which failed to identify the fire source. In [2], Wei He et al. utilized YOLOv5s for natural gas station fire detection, but it lacks optimization for lighting and motion variations. In [5], Abdusalomov et al. improved a fire warning system with YOLOv5m but encountered issues with blurry images. Sourav Kumar Bhoi et al. introduced IoT-based fire detection with KNN and decision trees[8], limited by a small dataset. A slow-detecting sensor-based detector for fires was created by Rishika Yadav and Poonam Rani [9]. A system to recognize fires under video monitoring was proposed in [10] by Md. Mahamudul Hasan et al., although it has trouble with noisy images. These limitations highlight the need for improved real-time, accurate, and versatile fire detection solutions.

III. Methodology

- Initiate Webcam:- At first the system will detect and initialize the web camera to start the system. It can be a surveillance camera or CCTV in which the model will run.
- Read Input:- Using a web camera the system will perform tracking and detect any fire movements and will analyze the overall event and will react to this event. The model will not take any steps until it detects any fire.
- Detect Fire:- If any fire pollution occurs under the surveillance camera or CCTV it will immediately raise a warning or alarm to monitor. It can detect a very small-scale fire to large-scale fire, so before getting damaged by fire at the early stage it will initiate the alarm system to the monitor.

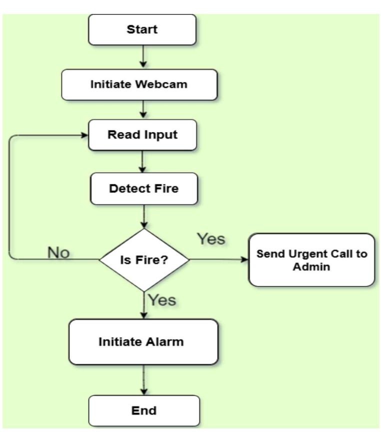

Fig. 1. Architectural view of the system: How the built systems work

- Send Emergency Call to admin:- In case the admin is not present on the spot he/she will be able to know if any fire incident occurs. For this reason, this system will send emergency calls to the admin as a remote fire alarm.
- Initiate Alarm & Play Sound:- This part will raise sound immediately after detecting any fire. It will play sound at least 3/4 times at a time.

IV. MODEL TRAINING OF THE FIRE DETECTION SYSTEM

The overall workflow of how the model has been trained is shown below.

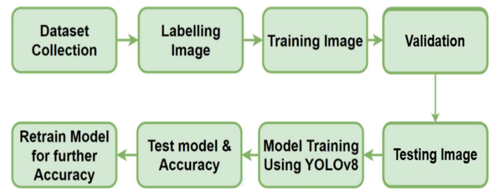

Fig. 2. Workflow Flow of then model with step-by-step explanation.

Every step in the fire model training process has been explained thoroughly:

A. Dataset collection:

We distributed the overall dataset as 80% for training, 10% for testing, and 10% for validation purposes. A self-built dataset was developed using fire video data taken from actual building monitoring systems to realistically capture building and yard environments promptly with mobility to detect fire.

Fig. 3. Sample Images of Dataset, including various types of fire.

We have prepared our dataset by various types of fire images, the approximate ratio is shown below:-

B. Dataset Folder Structure:

Among 3000 images, the folder structure for the training set is 2400 images, the validation set is 300 images, and the testing set is 300 images.

TABLE I
DATASET RATIO OF VARIOUS FIRE IMAGES

Fire Condition	Dataset ratio of each type per 100 frames		
	Training[%]	*Testing[%]*	*Validation[%]*
Noisy Image	70	15	15
Smoky Fire	75	15	10
Flame Fire	75	15	10
Bright Fire	80	10	10
Indoor Fire	80	10	10
Vehicle Fires	70	15	15

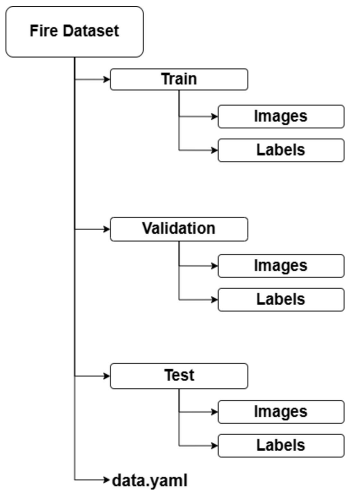

Fig. 4. Dataset folder structure: how images were classified [YOLOv8 based]

C. Preprocessing of the dataset:

This research provides an economically feasible, speedy method for fire detection and alert systems enhancement in buildings. The dataset was preprocessed by resizing images to 640x640 pixels and cropping them before converting them into JPG format. The augmentation of data included rotations, flips, and random cropping to increase variability and improve model robustness. The application of the LabelImg tool also provided accurate labelling of fire by drawing around where fire exists in the image and labelling it fire so that maximum precision is guaranteed in the inclusion of fire-related images for training the model.

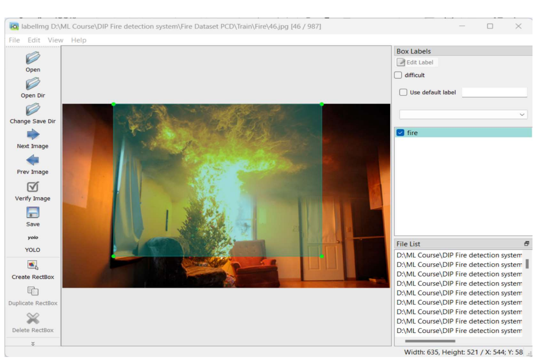

Fig. 5. Labeling of the fire images while preparing the dataset

D. Models Evaluation:

Moreover, we evaluate the trained model's mean average precision and inference speed in the real-world scenario, as depicted in the image. This testing phase is very important to us since it gives us a chance to see how the models will perform on unseen data and how effective they are in recognizing the various types of building fires. Each time the machine learning model, YOLOv8, predicts a new input of data as a fire, a module called Alert System is immediately invoked. The computer display will automatically sound an alarm in this case.

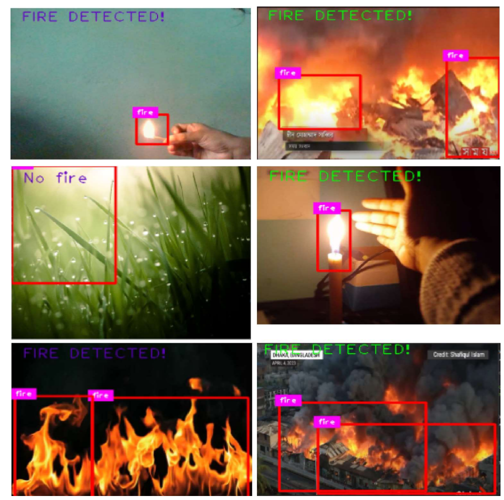

Fig. 6. Testing the model in a real-life environment to test its accuracy

V. RESULT AND DISCUSSION

The test dataset is fed into the model when the model has finished training, and Figure 7 displays the results of the testing stage. The confidence in the fire class designation is shown in the figure as the value in the target box. The YOLOv8 algorithm can determine the target more precisely when the colour difference between the flame and the scene is high or small in the station complex environment in the 600 test photos searched online during the experiment. When the image of the sun or another well-known image of this type is also detected as fire, an inspection has been missed.

A. Method for Determining Accuracy

$$\text{Accuracy} = \frac{\text{Number of Correct Predictions}}{\text{Total Number of Predictions}} \times 100$$

Fig. 7. Technique to estimate accuracy

The Number of correct predictions denotes the summation of true positive and true negative, whereas the total number of predictions denotes the sum of all samples including false positives, false negatives, real positives, and true negatives.

B. Estimated accuracy in a real-world scenario

Our trained model has been evaluated in both bright and dark environments, as well as in real-world scenarios. The model is quite sensitive to bright environments because we uploaded it to a camera where the lens reflects light. We discovered that the detection accuracy in bright light environments is 70%, whereas the detection accuracy in dark environments is somewhat higher, at about 82%.

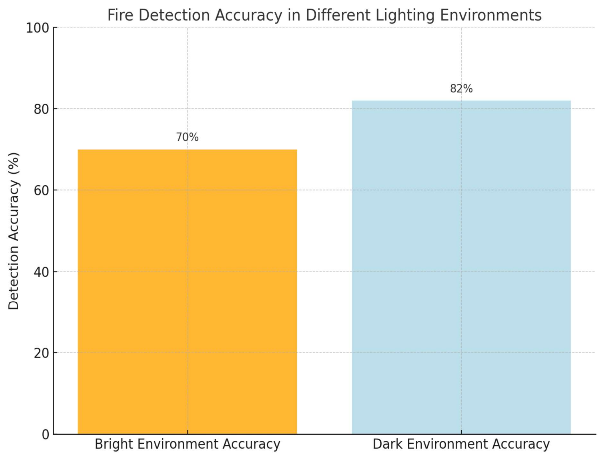

Fig. 8. Fire Detection accuracy in both light and dark environment

In this section, we have shown a comparative analysis of other existing systems along with the method they used to develop their system. In Table III the accuracy of different authors is demonstrated where the highest obtained accuracy is 82.4% in [2] , where in our system overall accuracy is 96% for the bright environment.

C. Analysis in comparison to the current system

In several studies, we discovered certain significant shortcomings that our trained model has addressed; we have included a few of these.

TABLE II
ANALYSIS IN COMPARISON TO THE CURRENT SYSTEM

	Our contribution compared to existing limitations		
Author	***Methodology***	***Findings***	***Our contribution***
Adav, R. and Rani, P[16]	Image Processing, GSM modem	Problems in noisy images	Improved detection of noisy image
Hasan, M.M. and Razzak, M.A[27]	Arduino, temperature sensor, gas sensor	Slow speed of detecting fire	Enhance detection speed

VI. CONCLUSION AND FUTURE WORK

A real-time fire detection technique for properties relying on the YOLOv8 network model is proposed to accomplish the objective of accuracy and real-time detection and alleviate the manual nature of tiresome detection labour. Some advantages of the method in this paper are shown by experimental testing, which proves that it can satisfy the video picture real-time criteria with an average precision of 91.2. The algorithm still has some problems and requires further research due to the limitations of environment and other conditions. In the future, the system will be enhanced to address challenges in low-light conditions and the training dataset will be expanded to improve performance. Additionally, motion and texture characteristics of fire will be incorporated into the study to further refine fire recognition capabilities.

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