

Machine Learning–Based Fire Detection for Highways

Abstract

Highway fires are a serious safety concern because they can spread quickly and cause major damage to vehicles, infrastructure, and the environment. Detecting fires early is extremely important, since even short delays can make situations much more severe. Traditional fire detection methods, such as heat and smoke sensors, often do not work well in open highway environments due to environmental factors and delayed response times. This research presents a machine learning–based fire detection system that uses computer vision to identify fire hazards from highway camera footage in real time. A convolutional neural network based on the MobileNetV2 architecture was trained using labeled fire and non-fire images. The system also includes an automated alert mechanism to notify users when a fire is detected. The results show that the model is able to detect fires with high accuracy and low latency, suggesting that this approach can be an effective solution for improving highway fire safety.

Keywords: machine learning; fire detection; computer vision; convolutional neural networks; highway safety

1. Introduction

Highway fires have become an increasing problem as traffic volume, vehicle usage, and fuel transportation continue to grow. Fires caused by vehicle crashes, engine failures, or hazardous materials can escalate very quickly and pose serious risks to drivers, emergency responders, and nearby environments. In many cases, the amount of damage caused by these fires depends on how quickly they are detected and how fast emergency services can respond.

Most traditional fire detection systems rely on heat or smoke sensors. While these systems can be effective in enclosed areas such as buildings or tunnels, they are much less reliable in open highway environments. Factors such as wind, weather conditions, and large open spaces can delay detection or cause false alarms. As a result, fires are often detected only after they have already grown to a dangerous level.

Recent advances in artificial intelligence, especially in computer vision, provide new opportunities for improving fire detection. Visual-based systems can analyze video data directly and identify fire-related features such as flames and smoke at early stages. This research focuses on developing and evaluating a machine learning–based fire detection system that uses deep learning to improve detection speed, accuracy, and overall reliability on highways.

2. System Objectives

The main objective of this research is to develop a real-time fire detection system that can identify highway fires using visual data from cameras. The specific goals of the system are:

- To design a computer vision pipeline that processes video frames in real time
- To train a deep learning model that can accurately classify fire and non-fire scenes
- To integrate an automated alert system that immediately notifies users when a fire is detected
- To evaluate the system's performance based on accuracy, response time, and practical usability

By meeting these objectives, the system aims to overcome the limitations of traditional fire detection methods while remaining efficient and scalable.

3. Methodology

The system was developed using a step-by-step methodology that includes data collection, model training, system integration, and alert design.

3.1 Data Acquisition and Preprocessing

A binary image dataset was created using fire and non-fire highway images. These images were collected from open-source datasets and selected to include different environments, lighting conditions, and camera angles. Each image was labeled to support supervised learning.

Before training, all images were resized to 224×224 pixels and normalized to ensure consistent input. Data augmentation techniques, such as rotation, zooming, and horizontal flipping, were applied to increase dataset diversity and help the model perform better on unseen data.



Figure 1. Examples of fire and non-fire images used in the training dataset

3.2 Model Architecture and Training

The model used in this project is based on the MobileNetV2 convolutional neural network architecture, which was chosen for its balance between accuracy and efficiency. Pretrained ImageNet weights were used, and the base layers of the model were frozen to preserve previously learned visual features.

A custom classifier was added on top of the base model to perform binary classification. The model was trained using the Adam optimizer and binary cross-entropy loss. Training and validation accuracy and loss were tracked throughout the process to monitor performance and prevent overfitting.

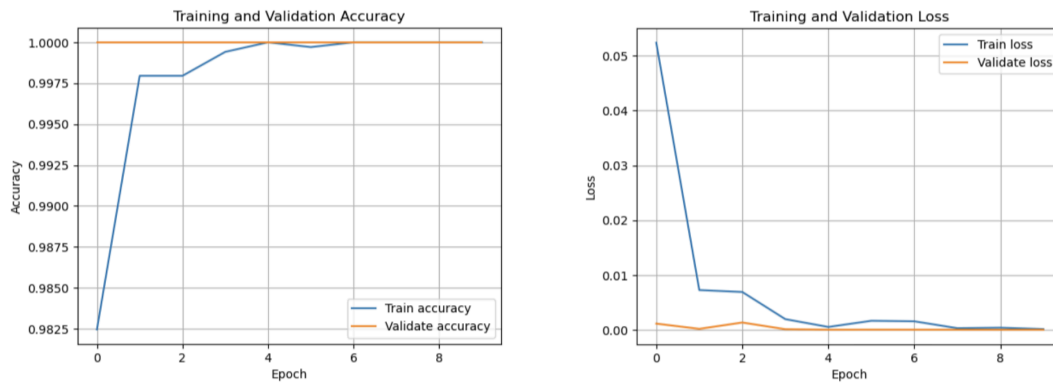


Figure 2. Training and validation accuracy and loss

3.3 System Integration and Alert Mechanism

After training, the model was integrated into a system that processes video streams frame by frame. Each frame is evaluated independently, and a confidence threshold is used to decide whether a fire is present. This helps reduce false detections caused by noise or unrelated visual patterns.

Once a fire is detected, the system triggers an alert mechanism that includes audible alarms and notification signals. This feature is designed to support fast response times, which are critical for minimizing damage and improving safety.

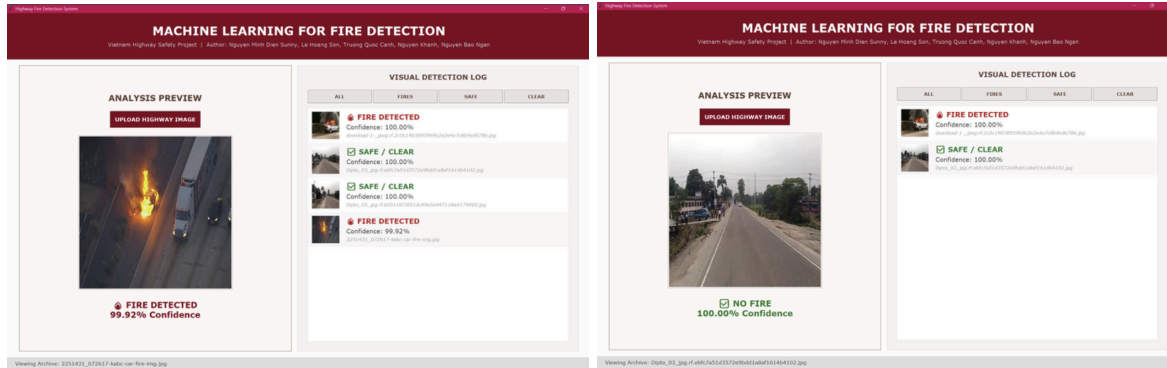


Figure 3. Example of system output and alert when fire and non-fire is detected

4. Results and Evaluation

The trained model achieved high accuracy on both the training and validation datasets, demonstrating its ability to reliably distinguish between fire and non-fire scenes. Validation results also indicated low overfitting, suggesting that the model can generalize well to new data.

Compared to human monitoring, the AI-based system offers faster and more consistent response times. It can continuously monitor multiple camera feeds without fatigue, making it suitable for large-scale highway surveillance.

5. Discussion

The results demonstrate that machine learning and computer vision can significantly improve highway fire detection. By detecting visual signs of fire at early stages, the system allows for quicker intervention and reduces the risk of severe damage. Using a lightweight CNN architecture also makes the system practical for real-time applications.

However, the system still has limitations. The dataset used in this project is relatively small, which may limit performance in rare or extreme scenarios. In addition, further optimization is needed for full real-time integration with live highway camera feeds.

6. Future Work

Future improvements will focus on expanding the dataset to include more fire scenarios, weather conditions, and highway environments. Additional features, such as predictive

analytics, could help identify areas with higher fire risk. Further integration with traffic management and emergency response systems could also improve overall effectiveness.

7. Conclusion

This research presents a machine learning–based fire detection system designed for highway environments. By combining computer vision, deep learning, and automated alerts, the system addresses many of the weaknesses of traditional fire detection methods. The results show strong performance and highlight the potential of this approach to improve public safety and reduce fire-related damage. With continued development and testing, this system could play an important role in future intelligent transportation safety solutions.