Deep Learning-Based Early Forest Fire Detection System for Environmental Disaster Management

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***Abstract*—One of the most hazardous natural disasters, forest fires may seriously harm wildlife, the environment, and even human lives. The likelihood of wildfires has increased dramatically due to climate change and rising global temperatures. The goal of this project is to create a forest fire detection system that automatically detects fire in photos by utilising deep learning techniques, notably Convolutional Neural Networks (CNNs). This system's objective is to give an early warning approach by precisely and swiftly identifying fire through the analysis of visual data. The algorithm learns to differentiate between fire and non-fire scenes after being trained on a dataset that includes pictures of both types of scenes. If put into practice, the system's ability to detect fire in real-time through image recognition techniques may assist stop wildfires from spreading. This solution is lightweight and simple to install because it was completed entirely with software and no additional hardware components. The results demonstrate that deep learning can be quite effective in wildfire identification, even though this is still a simple prototype. This strategy might be incorporated into a bigger system to more efficiently monitor and manage forest fires with additional accuracy and performance enhancements.**

***Index Terms*—Convolutional Neural Networks (CNN), Image Classification, TensorFlow, Keras, Real-Time Fire Alert System.**

I. INTRODUCTION

One of the most significant natural resources on the planet is the forest. In addition to supporting biodiversity and regulating the temperature, they also supply oxygen and are home to many species, including people in some areas. But because of deforestation, global warming, and human carelessness, forest ecosystems are now more susceptible to wildfires. Once started, these fires spread quickly and have the potential to do enormous damage in a matter of hours. Nature and human life have long been seriously threatened by forest fires. In recent years, wildfires have become much more frequent and intense due to the increasing effects of climate change. In addition to destroying enormous tracts of forest and wildlife; these fires also contribute to global warming by releasing toxic chemicals into the sky.

To prevent these fires from spreading and causing irreparable damage, early identification is essential. The frequency and intensity of forest fires have alarmingly increased during the last few years worldwide. Among the notable events are the terrible Maui flames (Hawaii, 2023), which devastated entire villages and claimed lives, and the Canadian wildfires (2023), which burnt millions of hectares and sent smoke across North America and even portions of Europe. The bushfires in Australia, which began in late 2019 and lasted into 2020, burned around 18 million hectares of land and caused an unparalleled loss of biodiversity and species. In India, frequent forest fires have also damaged delicate ecosystems and uprooted families in areas like Uttarakhand and Himachal Pradesh, frequently during the arid summer months. Forest fire detection has historically been accomplished through the use of techniques such as sensor-based systems, human observation, and satellite surveillance. However, particularly in isolated or densely forested areas, these methods frequently have drawbacks such as slow reaction times, high costs, and restricted coverage. With the speed at which technology is developing in the modern world, there is a need for more intelligent and efficient methods of hazard detection. This research introduces

Convolutional Neural Networks (CNNs), a deep learning-based method for identifying forest fires. Images of fire and non-fire make up the labelled dataset used to train the algorithm. After training, it can recognise the presence of fire and classify fresh photos with accuracy. This project's primary goal is to create a dependable, effective, and scalable software-based real-time fire detection system. This initiative aims to improve environmental protection and forest management by decreasing manual labour and increasing detection speed. Forest fire detection has historically been accomplished through the use of techniques such as sensor-based systems, human observation, and satellite surveillance. However, particularly in isolated or densely forested areas, these methods frequently have drawbacks such as slow reaction times, high costs, and restricted coverage. With the speed at which technology is developing in the modern world, there is a need for more intelligent and efficient methods of hazard detection.

This research introduces Convolutional Neural Networks (CNNs), a deep learning-based method for identifying forest fires. Images of fire and non-fire make up the labelled dataset used to train the algorithm. After training, it can recognise the presence of fire and classify fresh photos with accuracy. Python was used for the implementation, which runs well on Google Colab and includes libraries like TensorFlow, Keras, and OpenCV. This project's primary goal is to create a dependable, effective, and scalable software-based real-time fire detection system. This initiative aims to improve environmental protection and forest management by decreasing manual labour and increasing detection speed.

II. LITERATURE SURVEY

Using an upgraded YOLOv5 model combined with global attention and sophisticated convolutional algorithms, this study suggests a better fire detection strategy. Some of the sample artificial intelligence, machine learning and deep learning models for prediction for fire detection are described in details [1-9]. In line with the goal of precise and prompt fire recognition, the suggested method greatly increases detection precision and recall, making it appropriate for real-time small-scale fire identification [10]. They introduced SegNet, a CNN-based wildfire detection system tailored for real-time UAV imagery. The model successfully improves early fire detection by increasing pixel density and decreasing noise, which is a goal that our effort employing CNN for quick fire recognition shares [11].

The FIgLib dataset, which comprises 25,000 labelled photos of wildfire smoke, was presented in this paper along with the creation of SmokeyNet, a spatiotemporal deep learning model. In real-time smoke detection, SmokeyNet aims for human-level accuracy, which is comparable to our project's objective of accurate image-based fire identification [12]. Using the CWGID dataset and EfficientNet-B0, a satellite-based wildfire detection system was created that achieved an accuracy of over 92%. Supporting the approach, the paper demonstrates how CNN performance for fire recognition can be improved by using large, labelled image datasets [13]. Fire detection using modified versions of ResNet-50 and Xception achieved 99–100% accuracy on two benchmark datasets. Our CNN-based method is directly related to the enhancements, which highlight the effectiveness of deep CNN architectures in forest fire detection [14].

In an effort to lower human risk, this study automates fire detection from aerial data using deep learning techniques based on UAVs. Similar to our effort, it focuses on integrating autonomous surveillance and vision-based recognition systems for early disaster warning [15]. A review of satellite imagery-based AI-powered fire detection systems that examine different deep learning models is provided. For precise smoke and flame prediction, it highlights CNNs and picture segmentation methods [16]. A lightweight deep learning method for detecting forest fires, the FireNet-CNN model achieved an accuracy of over 99%. It confirms the efficacy of CNN models in offering accurate fire categorisation, enhanced by explainable

AI technologies [17]. A modified deep CNN model for real-time video-based forest fire detection is presented in this study. The model parallels the main goals of our fire classification system by minimising false alarms while attaining high accuracy through feature fusion and transfer learning [18]. Secure Data Storage and Sharing in Multi-Cloud Environment

In the cloud storage is also described to store the predicted data in a secured way [19-22]. In order to achieve effective aerial picture analysis, this study investigates wildfire identification using lightweight CNN architectures such as MobileNetV2 and ShuffleNet. With a lower computational cost matching cross-dataset studies validate their efficacy [23, 24].

III. METHODOLOGY

A methodical and structured strategy that included data preparation, model creation, training, evaluation, and testing in order to create a forest fire detection system that is dependable and responsive. The goal was to automatically differentiate between photos with and without fire using Convolutional Neural Networks (CNNs). This project detects fire in photos using a Convolutional Neural Network (CNN) method. The dataset is divided into two categories: Both Fire and No Fire. In order to enhance model generalisation, the data is first loaded and pre-processed by scaling all photos to 128x128 pixels, normalising the pixel values, and enhancing the data via zooming and horizontal flipping. The photos are effectively loaded in batches for training and testing using Keras' Image Data Generator. TensorFlow and Keras are used to construct the CNN model, which consists of several layers: dense layers for classification, max pooling layers to minimise spatial size, a dropout layer to avoid overfitting, and convolutional layers for feature extraction. The last output layer determines whether an image contains fire (1) or not (0) using a sigmoid activation function. Accuracy is used as the evaluation metric, and the model is constructed using the Adam optimiser and binary cross-entropy loss function. After 10 training epochs, the model's performance is evaluated using test data. Furthermore, a prediction algorithm is employed to ascertain whether a fire is visible in a particular photograph. The system plays an alert beep and displays a "Fire" label if a fire is detected. It just shows "No Fire" It just shows "No Fire" if there is no fire detected. This procedure offers a dependable method for early forest fire detection by showcasing a full pipeline from data collection, pre-processing, model training, prediction, and alarm generation. Step-by-Step Implementation Process:

Step 1: Gathering Information
Initially, a collection of photos depicting forest fire scenarios and photos without fire had to be gathered. These came from publicly accessible websites such as Kaggle and other fire detection datasets. The two folders "Fire" and "No Fire" were created by hand from the photographs, and these served as the basis for training the model.

Step 2: Preparing the data
Several pre-processing methods were used to get the photos ready for model training:

- For consistency, every image was resized to a standard size.
- To expedite training and accelerate model convergence, pixel values were normalised.
- To improve the model's generalisation, data augmentation methods such as flipping, zooming, and rotation were applied to broaden the dataset's diversity

Step 3: Loading the Dataset
Batch processing was used to load the photos into the model. Training and testing portions of the dataset were separated. The model was trained using the training data, and its performance was assessed using the testing data. The dataset loader also handled real-time augmentation while supplying the data to the model.

Step 4: CNN Model Construction
The purpose of a convolutional neural network (CNN) is to categorise pictures as either "fire" or "no fire." The model was developed with numerous layers, each having a specific function:

- Convolutional layers for feature extraction (detecting edges, colours, patterns, etc.)
- Using pooling layers to simplify and concentrate on the most important aspects
- Dropout layers to enhance generalisation and avoid over fitting
- Dense layers for ultimate categorisation

Step 5: Model Compilation and Training
A loss function appropriate for binary classification was utilised to construct the model, and an adaptive optimiser was employed to effectively update the weights. Accuracy and loss measures were used to track the model's performance across several iterations, or epochs, during training.

Step 6: Assessment of the Model
Following training, the unseen test dataset was used to evaluate the model's performance. The model's performance in distinguishing between fire and non-fire images was examined using evaluation criteria like accuracy, precision, recall, and F1-score.

Step 7: Real-Time Prediction and Alert
To test new images, a prediction function was developed. If the model is able to identify fire in an image, it will display the label "Fire" and sound an audio alert. This real-time response can be implemented in surveillance systems to detect fires early.

IV. RESULTS AND DISCUSSION

The results produced by the forest fire detection system confirm that the trained Convolutional Neural Network (CNN) model is effective. The model effectively classified test photos into "Fire" or "No Fire" classes after being fed them, as shown in the output screens that are attached. Real-time usability is improved by the system's intuitive interface, which not only shows the prediction result over the image but also sounds an alert when fire is detected. For fire images: An active fire detection is indicated by a beep sound alert, which acts as a real-time warning (as viewed from the audio playback bar). The output message is easy to see as the label "Fire" appears beneath the image in huge type sown in Fig 1. For pictures of No Fire Users may easily understand the output without having to study the raw prediction numbers because the label "No Fire" is displayed beneath the image shown in Fig 2.

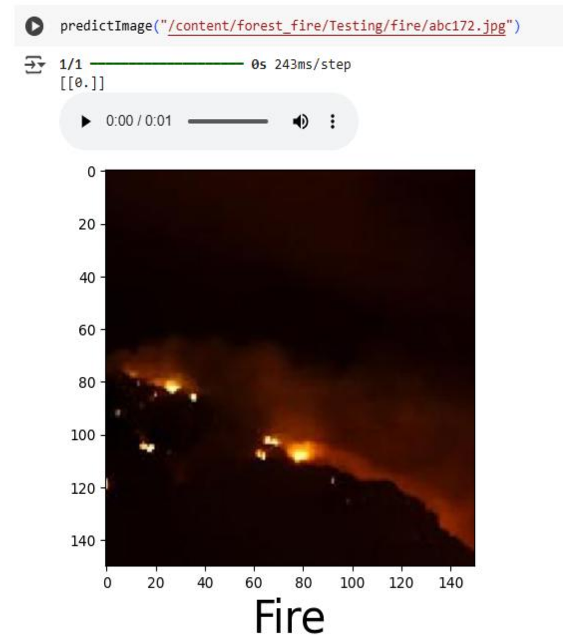

Fig 1. System Detect the “Fire”

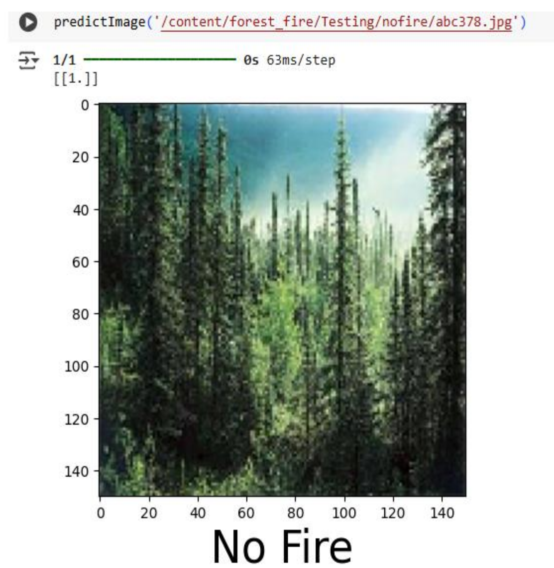

Fig 2. System Detect “No Fire”

V. CONCLUSION

Through the use of Convolutional Neural Networks (CNNs), this project effectively illustrates the use of deep learning in early forest fire detection through image classification. The model is a useful and scalable solution for real-time fire monitoring, assisting in minimising environmental damage and facilitating quicker response. With further advancements, this system has great potential for integration into surveillance drones, forest monitoring networks, and disaster management frameworks. The results demonstrate that deep learning can be quite effective in wildfire identification, even though this is still a simple prototype. This strategy might be incorporated into a bigger system to more efficiently monitor and manage forest fires with additional accuracy and performance enhancements.

VI. FUTURE SCOPE

Early fire detection accuracy can be increased by integrating IOT devices and sensors (temperature, humidity, and gas) with optical detections. By creating a smartphone application that allows firefighters and forest officials to view the locations of fires in real time on a map and receive quick alerts. Real-time data processing, alerting, and extensive monitoring may be guaranteed by implementing the model on scalable cloud infrastructure.

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