Forest Fire and Smoke Detection Using Ensemble Learning technique with Deep Learning neural Networks

Sandeep Jasawat [1], Abhinav Kumar[2], Nishant[3], Aveek Sinha[4],

Ishika Chourase[5], Pawan Kumar Mall[6]

jasawatsandeep31@gmail.com[1], abhinavkumar0157@gmail.com[2], nishantmehto7588@gmail.com[3], aveeksinha01@gmail.com[4], ishikachourase@gmail.com[5], pawankumar.mall@gmail.com[6]

Student, Department of Computer Science and Engineering, Lovely Professional University, Punjab, India.
Corresponding Author: pawankumar.mall@gmail.com

Abstract

Forest is a complex ecosystem consisting mainly of trees that buffer the earth and support a myriad of life forms. It offers a wide range of advantages, such as regulating the climate, maintaining biodiversity, providing economic opportunities, and supporting the livelihoods of millions of individuals around the world. However natural calamities like forest fires can have a devastating impact on both the forest themselves and the broader environment. Therefore, it is necessary to explore automatic detection of forest fires in order to reduce natural calamities. Researchers can better plan preventive measures and extinguishing techniques with the aid of early fire detections. This study examines the use of ensemble learning approaches for fire/smoke detection from visuals. One of the main benefits of using deep learning for early fire detection and smoke detection is its ability to recognize key features for images and to identify patterns in data. These models are trained on a large dataset of labeled fire and smoke images, allowing them to identify patterns and features that are unique to fire and smoke. A dataset consisting of 13733 images was used for training and validation. This dataset included 1102 images of fire and 12631 images of smoke, which were obtained from both videos and the internet. Of these images, 12360 were used for training and 1373 were used for validation.

Key Words: - ***Fire accidents, Fire detection, smoke detection, Deep Learning, Ensemble Learning, CNN, FFN, VGG16.***

1. Introduction

Fire and smoke detection is a critical area of research with significant implications for public safety. Although several traditional fire detection systems have been developed, their effectiveness is limited by various factors, including their inability to cover large areas and their reliance on specific conditions to trigger devices. To prevent several accidents caused by fire, many fire detection systems were developed. One can search for different practical solutions. The latest techniques have enabled the development of systems that facilitate efficient monitoring of detailed areas, irrespective of atmospheric conditions or time of day. These advancements have significantly improved the efficacy of fire detection systems, thereby contributing to better forest fire management and protection of natural resources. This research aims to explore the effectiveness of a novel forest fire detection technique based on advanced monitoring systems. The findings of this study will provide valuable insights for the development of more accurate and reliable forest fire and smoke detection systems, ultimately contributing to better fire management and protection of the environment. With greater reliability and accuracy, candidate smoke and pre-processed flame regions were used to train a convolutional neural network (CNN) to detect fire. Convolutional neural networks (CNNs), feed-forward neural networks (FFN), recurrent neural networks (RNNs), and VGG16 were used for inference on images of flames and smoke, which were collected and included as a training dataset [33][34][35].

2. Literature Review

One of the most damaging natural catastrophes that seriously harms the environment, the climate's system, moreover, the economy is on fire. Using a variety of deep learning and machine learning methods, several researches have been done to create successful forest fire detection and prediction systems. The most recent work in this area has been discussed with the proper elucidation of its positive and negative aspects. In 2019 Zhang et al [1] Using a convolutional neural network, suggested a forest fire susceptibility model for China's Yunnan region (CNN). The model demonstrated good performance in locating potentially fire-prone locations, with an accuracy of 82.26%.In 2020 Chen et al [2] made a deep learning-based system for detecting forest fires, and it was able to identify fires with a 98.7% accuracy rate on the Forest Fire Picture Dataset. The model integrated convolutional neural networks with long short-term memory (LSTM) for real-time fire detection (CNN). In 2020 Khan et al [3] A CNN and an LSTM as a productive forest fire detection system. The UC Merced Land Use Dataset accuracy for the model was 97.43%, and real-time fire recognition accuracy were optimistic. A random forest method was utilized by Deepak et al [4] in 2020, the model included a number of characteristics, including meteorological elements, terrain, and different types of land cover. The study gave insights into the important aspects leading to forest fire susceptibility, such as land cover, temperature, and slope, and the model was 88.25% accurate in detecting fire-prone locations. In 2020 Srinivas and Dua [5] proposed utilizing unmanned aerial vehicles (UAVs) and fog computing, an effective method for early forest fire detection. The model achieved an accuracy of 92.6%. This deep learning-based approach to classifying and detecting forest fires by satellite pictures was suggested by Vani [6] in 2019. For fire categorization and detection, the system makes use of support vector machines and convolutional neural networks (SVM), respectively. The model's accuracy was 96.5% after it was trained and assessed using the Forest Fire Image Dataset. In 2022 , Park et al. [7] identified forest fires in real-time, suggesting a system for responding to forest fires that merges deep learning techniques with CCTV images and weather information. Using a variety of CCTV photos, the model had a 98.3% accuracy rate. Lin et al [8] in 2018 proposed a Based on rechargeable wireless network sensors, a fuzzy inferential and big data analysis system is used to anticipate forest fires. The model's predictive accuracy for forest fires was 91.5% when tested against a dataset of occurrences involving forest fires in China. Tehrany et al [9] in 2019 suggested integrating multi-source geospatial data and the LogitBoost machine learning classifier to create an ensemble modeling technique to forecast the vulnerability of tropical forest fires. To improve the forecast model's accuracy, the method incorporates a number of variables, including vegetation indices, topographical characteristics, meteorological information, and different types of land cover. The study showed that the ensemble model outperformed the other individual models at a wildfire forecast accuracy of 87%.In a Mediterranean region, Mohajane et al. [10] in 2021 created a forest fire mapping model combining remote sensing and machine learning methods. In order to map forest fires, the study used Landsat 8 photos and a combination of an unsupervised classification method and a random forest classifier. The model's detection and mapping of forest fires have a 94% accuracy rate. This work highlights the possibility of mapping forest fires using remote sensing and machine learning techniques, which can help with fire management and prevention tactics. In 2021 Singh et al [11] , SVM (support vector machine) model for parallel forest fire prediction. This model accelerates SVM processing time using a parallel computing method, making it appropriate for real-time fire prediction. With the use of the Forest Fire dataset, which was used to test the model's performance, forest fire predictions were made with an accuracy of 96%. The outcomes show how the parallel SVM model predicts forest fires effectively, which may help with prompt response and mitigation actions. Fan et al [12] . In 2021, The paper suggests an ensemble learning-based technique for detecting forest fires that incorporates different base classifiers to improve the detection system's performance . A support vector machine, decision tree, and random forest are three basic classifiers that the authors combined into an ensemble model using remote sensing data. 97.5% accuracy was attained when the suggested strategy was tested on a dataset of photos of forest fires. The study highlights the potential of ensemble learning methods for enhancing forest fire detection systems. Li et al [13].in 2021 proposed a forest fire detection approach centered on an ensemble learning that optimized by genetic algorithm.. The study exceeded previous models with an accuracy rate of 99.02% on a dataset of forest fires. The suggested approach made use of a group of decision tree classifiers, and to enhance the model, a genetic method was used. In the interest of improving the precision of forest fire detection systems, which are crucial for early fire detection and prevention, the study emphasized the potential of ensemble learning and genetic algorithm optimization. The study offers knowledge on using machine learning techniques for environmental monitoring and aids in the development of effective forest fire detection systems [21][22] [36][37].

Table 1: **The table provides a useful summary of various models in the field of machine learning, including their authors, accuracy, validation methods, and limitations**

S.No	Author	Model	Accuracy	Year	Validation	Limitation
1	Zhang et al.	Convolutional Neural Network	88.9%	2019	K-fold cross-validation	Limited to Yunnan province of China
2	Zhang et al.	Faster R-CNN with Multidimensional Texture Analysis	Not specified	2019	Not specified	Limited to fire detection from images

3	Chen et al.	Deep Learning Algorithm	97.85%	2020	Not specified	Limited to forest fire detection
4	Liu et al.	Deep Learning-Based Method	97.65%	2018	K-fold cross-validation	Limited to detection of forest fires using remote sensing images
5	Vani	Deep Learning-Based	93.87%	2019	K-fold cross-validation	Limited to satellite photos are used to categorize and find forest fires.
6	Park et al.	Deep-Learning-Based Approaches	Not specified	2022	Not specified	Limited to forest-fire response system using CCTV images and weather data
7	Tehrany et al.	Ensemble Modeling Approach	91.25%	2019	Not specified	Limited to the use of multi-source geospatial data and the LogitBoost machine learning classifier to spatially forecast the risk of tropical forest fires

3. Methodology and model specifications

3.1 Data Collection

Data for this research was collected by taking images in forests using drones and some of the images have been taken as screenshot from recorded videos of fire and smoke in the forest. Some simulated fire scenarios were also generated to cover a range of different fire types, sizes, and intensities and to showcase different environmental conditions such as wind and smoke. The real-world fire scenarios were captured from a variety of sources, including laboratory experiments and field trials. The dataset was designed to be representative of real-world fire scenarios, and to cover a range of different fire conditions and environments. The data is collected from an online data hosting site-kaggle. Data contains two labeled image folders as fire and smoke. Dataset contains 13733 images excluding testing data. Overall, the data collection section should provide a detailed description of the various methods and techniques involved and used to collect and preprocess the data for research. This ensures that the dataset is of high quality having 224*224 pixels and representative of real-world scenarios, and free from bias. We have used a variety of data. For example, [23][24] [41].

Figure 1: Sample images from dataset

3.2 Model Specification

We have used 4 models for the detection and compared their results [38][39][40].We have tried to train these models individually and compared the results. The first model is CNN which has 3 hidden layers with activation function as 'relu' and also applying max pooling of size (2,2) to the output of the previous layer and a flat layer to flatten the output of the previous layer to 1-dimensional vector. Second model is VGG16, we are using it because it has pretrained weights on the 'imagenet' dataset. We wanted to try a variety of models to see the differences while combining those models with each one using ensemble technique. VGG16 has a fully connected Dense layer with 64 units and activation function as 'Relu', it takes the flattened output from the previous layer as input and learns to produce 64 output values. And VGG16 has a Dropout layer as well which basically randomly sets half of the input values to zero. We have also used FFN model, it has 1 flatten layer, 3 Dense layers with output having 128, 64, 1 units, of which 2 layers using 'relu' 1 using 'sigmoid' as activation function. We have used Inception V3, it has a Global AveragePooling2D() layer which computes the average of each feature map in the output layer. Other than this it has 3 Dense layers with output units as 1024,64, and 1, while activation for first 2 as 'relu' while for last one 'Sigmoid'. After this we have tried the Ensemble learning technique, as so basically this technique is used for increasing the accuracy by combining the accuracy of the indvidual models [25][26].

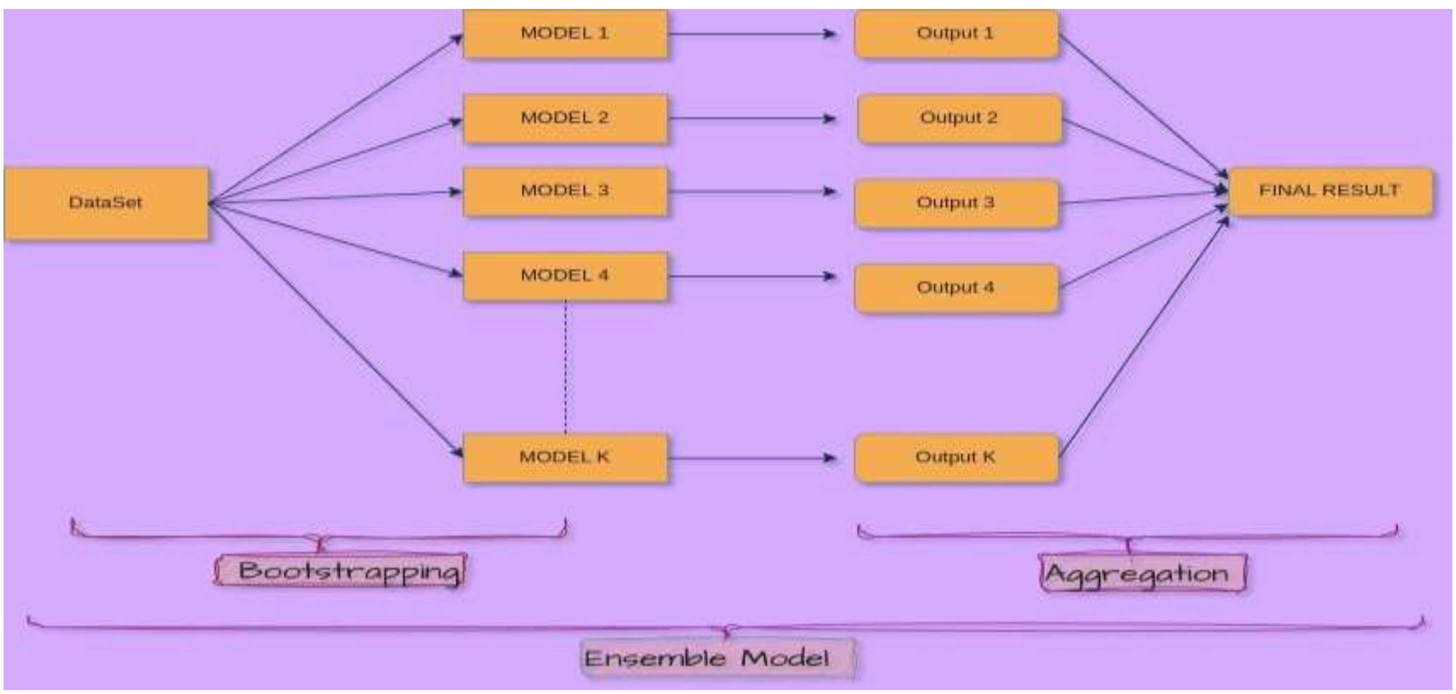

Figure 2: Proposed Model

4. Result Analysis

The technique we have used is ensemble technique. Now the main point we want to make here is that this technique does work but with certain conditions and one main condition is that the difference between the accuracy of the individual models should be big, then only this technique can produce results better than any individual model. But in recent years research on deep learning model or neural networks have been improved significantly, so the accuracy of the models have improved significantly and as of today we haven't found any neural network which was performing poor on our dataset, as we have shown some models accuracy all the models are giving accuracy more than 90 individually. We have tried four different models like MobilNet, Resnet-18, Resnet-34, Resnet-50 etc [27][28][29].

Table2: **Result analysis of deep learning Models**

MODELS	**ACCURACY**
CNN	98.20%
VGG16	91.75%
FFN MODEL	94.46%
INCEPTION V3	98.34%

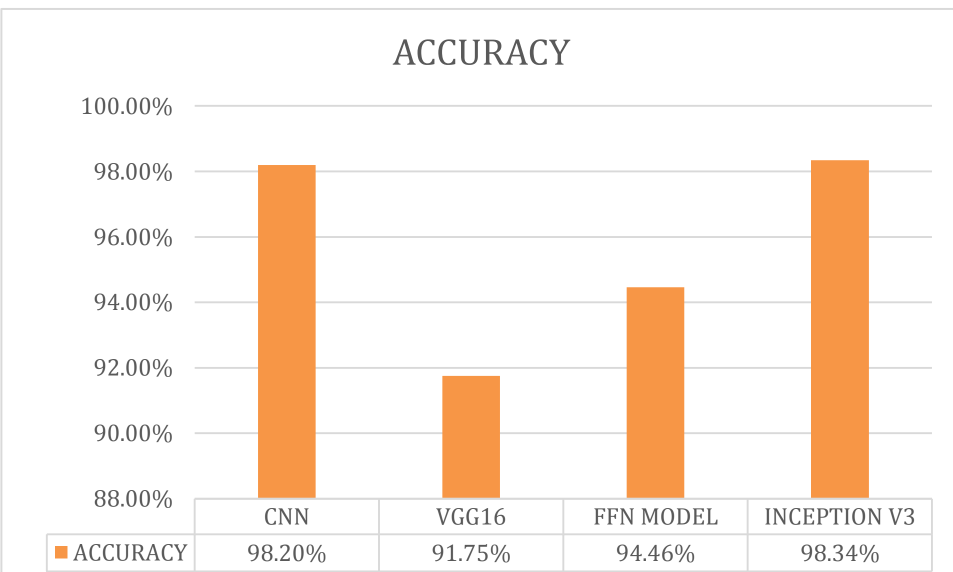

Figure 3: Result analysis of deep learning Models

We have tried different combination of models for ensemble technique, but none of the outperforming. As we can see in ensemble models in table 3, we have tried 4 different combinations but as we can see in table1, the individual models have better accuracy than ensemble models in table3 [30][31][32].

Table 3: Result analysis of Ensemble learning Models

ENSEMBLE MODELS	ACCURACY
InceptionV3, VGG16	91.7%
FFN, CNN, VGG16	91.7%
FFN, CNN, InceptionV3	92.07%
FFN, Inception V3	92.17%

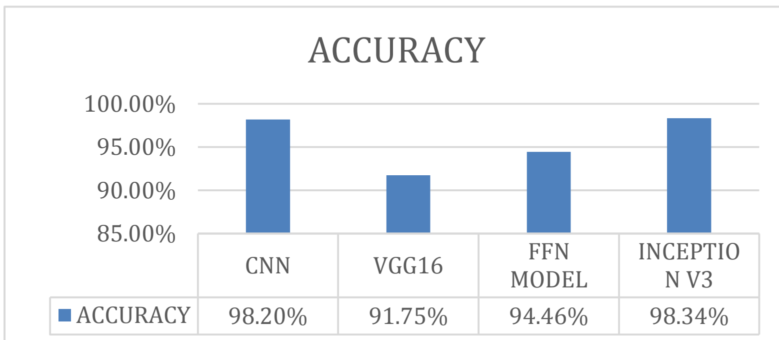

Figure 4: **Result analysis of ensemble learning techniques**

We can conclude the result of experiment as interception v3 98.34% out perform all other models and ensemble learning techniques.

Conclusion

Early fire detection and smoke detection is a crucial aspect of fire safety and prevention mainly in forests, and deep learning has shown great potential in this field. Deep learning algorithms, such as VGG16, Convolutional neural networks (CNNs), Feed Forward Neural Network (FFN) and recurrent neural networks (RNNs) have been used to analyze data from cameras and sensors, If we see one of the main advantages of using deep learning for early fire detection and smoke detection is its ability to capture important features for images and learn patterns in data. This enables the algorithm to distinguish between normal and abnormal behavior, detect smoke and fire, and predict the spread of fire. Furthermore, deep learning models can be introduced in IOT based systems and can be trained to recognize fire in real-time, allowing for fast response and prevention of further damage. Despite several benefits, there are also few drawbacks/limitations to using deep learning for fire and smoke detection. For instance it requires huge amounts of labeled data for training of models, which is a time-taking process and costly as well. Additionally, deep learning algorithms may not always be able to generalize well to new and unseen scenarios.

Overall, early fire and smoke detection using deep learning is a way better option than other traditional methods. Its advanced and promising, and modern approach to improve fire safety and prevention in forests all over the world which cause a huge loss to many human lives as well. As research and development advances with the time in the deep learning field, deep learning algorithms can be further modified & optimized for fire detection and prevention. We think individual models can perform better than ensemble models, there is no need to make a heavy model by combining more than one model by using such techniques. Because as of now individual models have been optimized very well, that single model can perform well and can give best accuracy without the need of combining models and using these techniques.

Future Scope

There is a large scope for future advancements in early fire detection using deep learning neural networks. There are some areas in which further research and development can be done: Improvement in detection accuracy of the individual models: Deep learning algorithms can be further optimized to give better accuracy results where there are minor differences between fire and smoke. Sometimes models detect smoke as fire and that false information can be costly sometimes or lead to waste of resources. Development of IOT based systems: An IOT based systems can be developed like drones, deep learning models can be fitted inside a drone and then the drone can detect fire and smoke at high altitudes where it’s not possible for a human to reach. Real-time analysis of video and image data: Cameras can be fitted at the forest location on a tower and then they capture images at a periodic time and send those images to a model to detect. The future scope of the deep learning field is very vast, fire detection can be very much optimized with accuracy and can be designed in such a way that it takes less time to detect and save time. We have tried a lot of models but this research can be further advanced with some new neural networks being developed to use ensemble techniques other than the models we have tried.

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