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Forest Fire Detection and Prevention - Based on Machine Learning

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Abstract: Forest fires are a significant danger to ecosystems, to biodiversity, and for human lives worldwide. Traditional methods of forest fire detection and prevention frequently, they fail to tackle the complexity and magnitude of these disasters. Recently, there has been a growing emphasis on leveraging Artificial Intelligence (AI) and Machine Learning (ML) techniques to enhance forest fire detection and prevention. This study offers a comprehensive review of recent advancements in AI and ML-based approaches for forest fire detection and prevention. We have analyzed various methodologies, datasets, and challenges associated with implementing AI/ML in this domain. This system can detect the presence of fire in the forest with 97.40% accuracy using the RCNN model.

Keywords: CNN • Sensors • UAV • Artificial Neural Network

Introduction: Fires in forests are among the most significant natural disasters that threaten ecosystems, biodiversity, and human settlements worldwide. These fires not only devastate millions of acres of forests annually but also result in severe ecological, economic, and social consequences. The frequency and intensity of forest fires have been exacerbated by climate change, land-use practices, and human activities, making them a pressing global concern. Traditional methods of forest fire detection and prevention have faced numerous challenges in effectively mitigating the risks associated with these disasters. Conventional approaches primarily rely on human surveillance, such as lookout towers, patrols, and aerial reconnaissance, which are often limited in their coverage, scalability, and timeliness. Furthermore, the increasing complexity and scale of modern forest fire incidents necessitate more advanced and proactive strategies for detection and prevention.

Recently, there has been a growing emphasis on leveraging Artificial Intelligence (AI) and Machine Learning (ML) techniques to overcome the limitations of traditional forest fire management systems. AI/ML technologies offer the potential to revolutionize forest fire detection and prevention by leveraging vast amounts of data, sophisticated algorithms, and real-time analytics. These techniques enable automated analysis of various data sources, including satellite imagery, sensor networks, weather data, and social media streams, to enhance early detection, prediction, and response to forest fire events.

The integration of AI/ML in forest fire management holds the promise of improving the accuracy, efficiency, and effectiveness of detection and prevention efforts. By harnessing the power of AI algorithms, it is possible to develop intelligent systems capable of detecting nascent fire outbreaks, predicting fire behavior and spread, and optimizing resource allocation for firefighting and evacuation operations. Moreover, AI/ML techniques offer opportunities for proactive risk assessment, adaptive decision-making, and community engagement in forest fire management initiatives. Basu et al (2018) revealed that 80% of the losses caused by fire could have been prevented with prompt detection. The solution to this problem lies in an IoT-powered fire identification and surveillance system depended on Node MCU.". In this task a fire finder system utilizing Node MCU is assembled, interfacing with different temperature sensors, signal, smoke sensor, Zhang et al (2009) reported Cluster-oriented (WSN) wireless sensor network model for instantaneous forest fire detection was suggested. A new idea using a cluster-driven (WSN) wireless sensor network for instantaneous detection of forest fires was introduced among others. In the research, Saikumar and Sriramya (2019) developed an IoT-driven fire monitoring and detection system utilizing the Arduino platform here a fire detection system is developed using an Arduino board UNO, connected to a temperature sensor, buzzer and smoke detector. Ranjith et al (2019) in their research, uncontrolled fires driven by weather conditions, wind, and dry vegetation can rapidly spread, burning vast areas and destroying everything in their path, resulting in severe harm to both natural environments, human resources. Sharma et al (2017) proposed a scheduling system that triggers an immediate alert to the user upon detecting fire or smoke. They used an Arduino Uno from the Arduino family, interfaced with an Ethernet module to connect the system. The system also features an LCD display that shows the status, indicating if smoke or overheating has been detected.

Methodology: The suggested system is designed for deployment in forest regions susceptible to yearly fires, can predict the probability of a fire and identify its presence. To cover a large forest area, numerous nodes are strategically placed to monitor environmental conditions. Once a fire is confirmed, the system sends an alert to the nearest node, enabling prompt action from the relevant authorities.

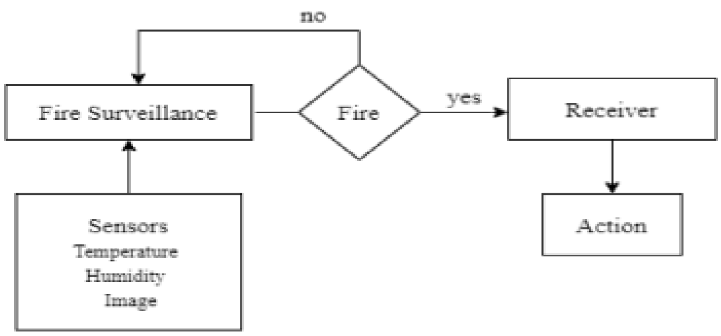

Fig.1: Forest Fire Monitoring System Overview

The fire monitoring system confirms the occurrence of a fire after analyzing temperature and humidity, along with video footage captured by UAVs (Unmanned Aerial Vehicles) operating autonomously

Temperature and Humidity Surveillance:

Sensor Networks: Deploying sensor networks equipped with temperature and humidity sensors across forested areas enables real-time tracking of environmental conditions. AI/ML algorithms can process data from these sensors to identify unusual temperature and humidity patterns that could signal the presence of a fire or create favorable conditions for its spread.

Weather Stations: Weather stations equipped with temperature and humidity sensors are commonly used for environmental monitoring. These stations can be installed at various locations within forests to gather localized data. Automated weather stations offer instantaneous data on temperature, humidity, wind speed, and many different atmospheric conditions.

Remote Sensing: Techniques like satellite and aerial images provide a broader perspective on temperature and humidity conditions across extensive geographic regions. Satellite-based sensors can capture thermal infrared radiation to estimate surface temperatures, while multispectral sensors can provide information about vegetation health and moisture content, which indirectly relates to humidity levels.

Wireless Sensor Networks (WSNs): Autonomous sensors in WSNs are spatially distributed and communicate wirelessly to monitor environmental conditions. These networks are particularly useful for real-time monitoring in remote or rugged terrain where traditional wired infrastructure is impractical.

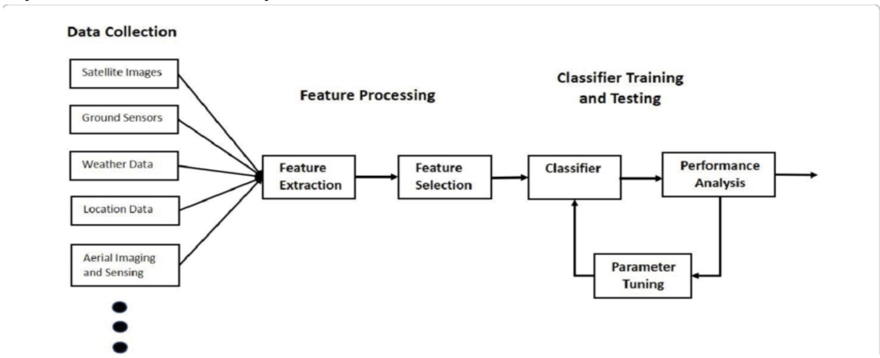

Fig.2: Fire Monitoring Through Surveillance of Temperature, Humidity Information.

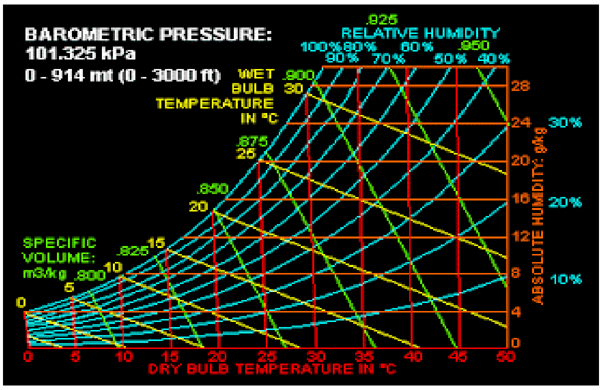

Fig.3: Humidity- Temperature Correlation

Relative Humidity (%)	temperature (°F)															
	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Caution Extreme Caution Danger Extreme Danger

Fig.4: Risk Assessment Heatmap, Displaying on a Grid

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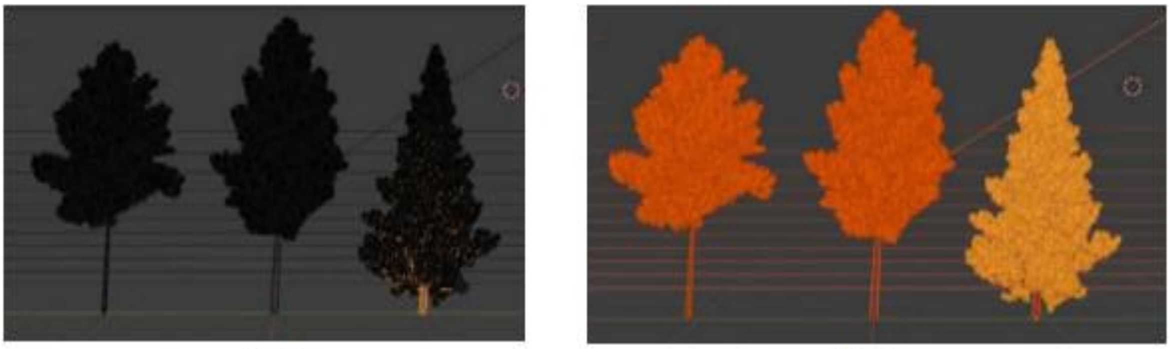

(a) (b)

Fig.5: Surrounding Environment RTH indexing: (a) Minimum RTH, indicating low hazards. (b) Maximum RTH, representing a denoting peak risk level.

Observations

Fire Verification:

After identifying the environmental conditions that favor fire ignition, UAVs are dispatched to confirm the presence of a fire. These UAVs are equipped with CMOS cameras that capture video images at 30 frames per second. They capture both aerial and semi-aerial perspectives of the area being monitored by the node. Fire detection carried out using the RCNN model (Sharma and Khanal 2024), which effectively identifies the presence of fire. The dataset employed for this purpose was developed during the 2018 NASA Space Apps Challenge. aiming to develop a model that could recognize fire images. The dataset contains over 1000 images, categorized into three classes. One of the key advantages of this dataset is its imbalance, as the classes contain varying numbers of images. It includes 755 pictures depicting outdoor fires, some with significant smoke, and 245 pictures of nature scenes that do not show fire.

(a) **(b)** **(c)**

Fig. 6: Three classes of the Dataset: (a) Forest affected by fire, (b) Forest with smoke, and (c) Forest without fire.

To avoid dataset overfitting, several data augmentation methods were employed, such as image flipping and a 300-degree revolution, brightness enhancement at different scales, zooming, and shearing. Various deep learning models are well-suited for tackling challenges in computer vision, including occlusion, noise, clutter, fluctuations in flame smoke, lighting variations, and viewpoint distortions. Initially, the training data was fed into the CNN model for processing. AI has made significant progress, bridging the gap between human and machine capabilities. Researchers and enthusiasts alike are actively contributing to different aspects of AI, striving to achieve remarkable advancements. One key area of focus is machine vision, which aims to enable computers to perceive and interpret the world similarly to humans. This capability is applied in tasks such as image and video recognition, image processing and classification, content generation, recommendation systems, and computational linguistics. (Sathishkumar et al 2023)

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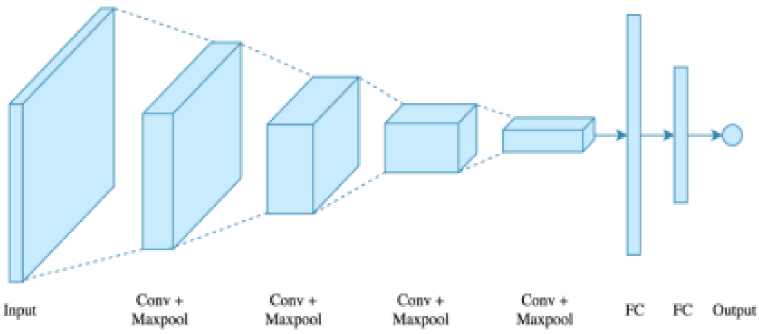

Fig.7: CNN Model

A Convolutional Neural Network (CNN) is a deep learning model designed to process input images by assigning learnable weights and biases to different features or objects, enabling it to distinguish between them. Unlike traditional classification techniques, CNNs require significantly less pre-processing. In conventional methods, filters are manually designed, whereas CNNs can automatically learn and optimize these filters through sufficient training.

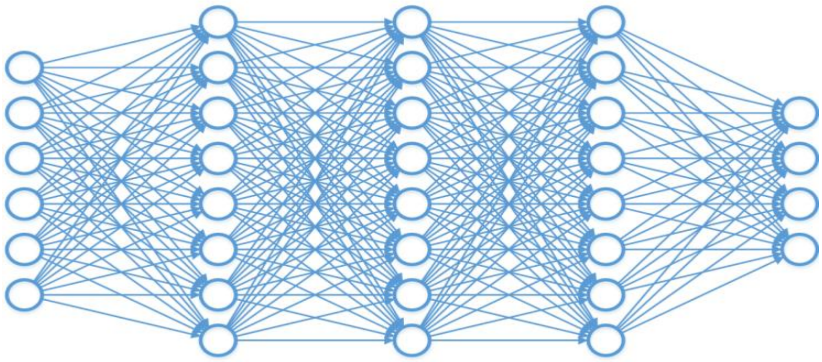

Fig. 8: CNN Networking

Numerous challenges arise in image analysis, including object detection, recognition, classification, and representation, for example, when developing an image classifier, this process continues accordingly., For instance, a picture classifier must be able to perform accurately even with variations like occlusion, lighting changes, and different viewing angles. The traditional image classification pipeline, which relies on feature engineering, is not effective in complex environments. Even experts may struggle to define a set of features that consistently achieve high accuracy under different conditions. To address this, feature learning was introduced, where relevant features are automatically derived. This is why artificial neural networks (ANNs) learn automatically. Through learning algorithms like gradient descent (GD), ANNs learn from images. Raw images are used as an input into the ANN, and the network generates the features that describe it.

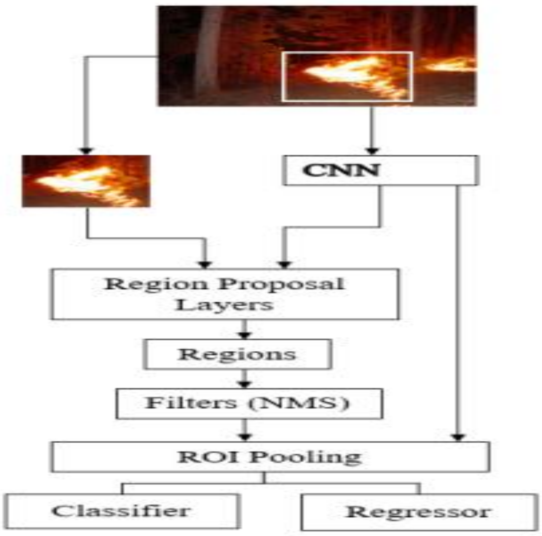

Fig. 9: RCNN Model

Results: The model is binary in classification, successfully distinguishing among images with and without fire, achieving an accuracy of 97.40%. The accuracy of the Bluetooth and RTH sensors is fully dependent on the adjustment of the devices. Moreover, the clarity of the frames depends on the quality of the input images. A 5MP camera is utilized to capture instantaneous footage when threat levels increase.

Table.1: Accuracy Study of CNN

Classifiers	Training Accuracy (in %)
CNN	90.01
Fully Connected CNN Layers	94.70

In conclusion, RCNN offers notably higher accuracy compared to CNN layers.
The paper performs flawlessly with calibrated instruments ensuring enhanced responsiveness to heat and humidity, which enhances the overall results and improves the performance during the prototype's functional evaluation.

Conclusion: This system offers a reliable solution for detecting and confirming fire outbreaks in forested areas. By integrating region proposals into CNN layers, it improves both the accuracy and processing speed. Utilizing the RCNN model, the system can verify the presence of fire with an impressive 97.29% accuracy. This early detection capability is crucial for containing fires and preventing large-scale destruction. Furthermore, the system is designed to operate autonomously, reducing the need for constant human intervention in forest monitoring.

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