Real-Time Detection of Forest Fires Using Firenet-CNN And Explainable AI Techniques

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Abstract- *This study proposes FireNet-CNN, a lightweight and efficient deep learning model for real-time forest fire detection using Convolutional Neural Networks (CNN) and Explainable AI (XAI) techniques. The model was trained and evaluated on augmented datasets containing fire and non-fire images, achieving high performance with 99.05% accuracy, 99.41% precision, and 98.28% recall. Stable Diffusion-based synthetic image generation and traditional augmentation methods were used to improve dataset diversity and reduce class imbalance. To enhance transparency and reliability, Grad-CAM and Saliency Map techniques were integrated to visualize the model's decision-making process by highlighting fire-related regions in images. With a compact model size and fast inference time, FireNet-CNN is suitable for deployment in real-time wildfire monitoring systems, drones, and embedded devices for early forest fire detection and disaster management..*

Keywords: Forest fire detection, FireNet-CNN, Deep learning, Convolutional Neural Network (CNN), Explainable AI (XAI), Grad-CAM, Saliency Map, Stable Diffusion, Data augmentation, Wildfire monitoring, Image classification, Real-time detection.

I. INTRODUCTION

1.1 Background

Forest fires are one of the major environmental disasters that cause severe damage to ecosystems, wildlife, human life, and the global climate. Traditional fire detection methods such as satellite monitoring and ground-based sensors often suffer from delayed response, limited coverage, and low accuracy, making early fire detection difficult. With the rapid growth of Artificial Intelligence and Deep Learning technologies, automated forest fire detection systems have gained significant attention due to their ability to identify fire patterns quickly and accurately from images and video data. Convolutional Neural Networks (CNNs) have shown remarkable performance in image classification tasks, especially in detecting fire and smoke under different environmental conditions. However, existing models still face challenges such as limited datasets, computational complexity, and lack of interpretability. To address these issues, this study introduces FireNet-CNN integrated with Explainable AI techniques and synthetic data augmentation to improve detection accuracy, reliability, and transparency for real-time wildfire monitoring and disaster management.

1.2 Scope of the System

- Real-time forest fire detection
- Fire and smoke identification
- Supports drones and CCTV monitoring
- High accuracy using FireNet-CNN
- Explainable AI integration
- Early wildfire warning system
- Suitable for disaster management Financial institutions

II. PROBLEM STATEMENT

Traditional forest fire detection methods suffer from delayed response, low accuracy, and limited monitoring coverage. Existing systems also face challenges such as insufficient datasets, high computational cost, and lack of transparency in decision-making. Therefore, an efficient real-time forest fire detection system with high accuracy, low complexity, and explainable predictions is required.

III. OBJECTIVES

3.1 Main Objective

To develop an intelligent real-time forest fire detection system using FireNet-CNN and Explainable AI techniques for accurate and reliable wildfire monitoring.

3.2 Specific Objectives

- To classify fire and non-fire images effectively.
- To improve detection accuracy using data augmentation.
- To reduce false alarms in wildfire detection.

- To integrate Explainable AI for prediction transparency.
- To support real-time monitoring using drones and cameras.

IV. LITERATURE SURVEY

Previous studies used CNN, ResNet, YOLO, and MobileNet models for forest fire detection. Many systems achieved good accuracy but suffered from issues such as computational complexity, overfitting, limited datasets, and lack of interpretability. Recent research introduced Explainable AI techniques like Grad-CAM and SHAP to improve transparency. However, there is still a need for lightweight, accurate, and explainable models for real-time wildfire monitoring.

V. PROPOSED SYSTEM

5.1 Overview

The system collects forest images, preprocesses them, applies data augmentation, and classifies them into fire or non-fire categories using FireNet-CNN. Grad-CAM and Saliency Maps are used to visualize important fire regions.The system stores appointment data in a database and allows bank administrators to manage customer schedules effectively.

5.2 Working Principle

1. Input forest image/video frame
2. Image preprocessing and augmentation
3. Feature extraction using CNN layers
4. Fire/non-fire classification
5. Visualization using XAI techniques
6. Display detection result

VI. SYSTEM ARCHITECTURE

6.1 User Layer

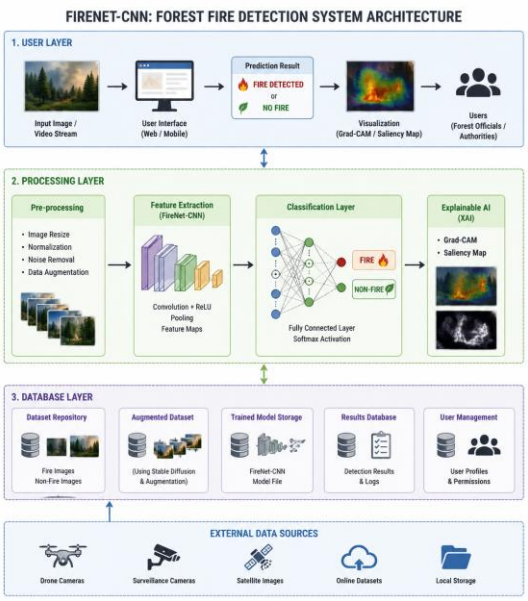
- User uploads image/video
- Displays fire detection results
- Provides monitoring interface

6.2 Processing Layer

- image preprocessing
- CNN-based feature extraction
- Fire classification
- Explainable AI visualization

6.3 Database Layer

- Customer information
- Appointment schedules
- Banking service records



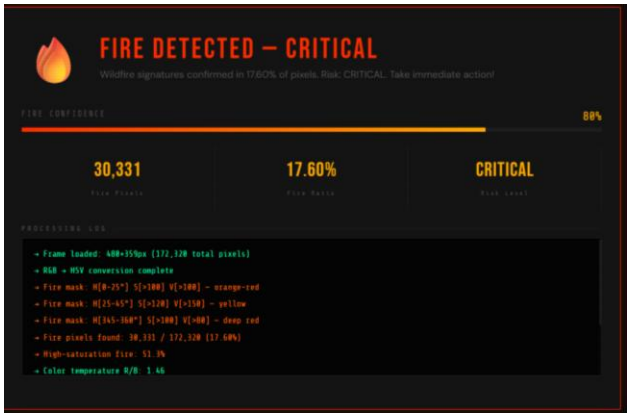
VII. METHODOLOGY

1. Data collection from forest fire datasets
2. Image preprocessing and segmentation
3. Data augmentation using Stable Diffusion
4. Training FireNet-CNN model
5. Testing and validation using 5-fold cross-validation
6. Applying Grad-CAM and Saliency Maps for explainability

VIII. SOFTWARE IMPLEMENTATION

The system is developed using:

- Programming Language: Python
- Framework: TensorFlow, Keras
- Development Platform: Kaggle Notebook
- Libraries: OpenCV, NumPy, Matplotlib
- GPU Support: NVIDIA P100 GPU



IX. RESULTS AND DISCUSSION

The proposed FireNet-CNN achieved high performance with 99.05% accuracy, 99.41% precision, and 98.28% recall. The model outperformed existing CNN models while maintaining low computational complexity. Explainable AI techniques successfully highlighted important fire regions, improving model transparency and reliability.

Observed Results

- FireNet-CNN achieved **99.05% accuracy** in forest fire detection.
- Precision value reached **99.41%** with fewer false alarms.
- Recall rate of **98.28%** showed efficient fire identification.
- Faster inference time of **0.95 seconds/image** enabled real-time monitoring.
- The model outperformed VGG16, VGG19, and InceptionV3 models.
- Stable Diffusion augmentation improved dataset diversity and model generalization.
- Grad-CAM and Saliency Maps successfully highlighted fire regions in images.
- The lightweight model size (**10.58 MB**) supported deployment in drones and embedded systems.
- 5-fold cross-validation confirmed stable and reliable model performance.
- The system effectively detected fire under different environmental and lighting conditions.

X. ADVANTAGES

- High detection accuracy
- Real-time monitoring capability
- Lightweight model architecture
- Reduced false positive rate
- Explainable and transparent predictions
- Suitable for embedded systems and drones

XI. APPLICATIONS

- Forest wildfire monitoring
- Smart surveillance systems
- Disaster management
- Drone-based fire detection
- Environmental protection systems

XII. FUTURE ENHANCEMENTS

Future improvements include:

- Integration with IoT sensors
- Live video stream fire detection
- Mobile application support
- Cloud-based wildfire monitoring
- Multi-hazard detection system

XIII. CONCLUSION

The proposed FireNet-CNN system provides an efficient and reliable solution for real-time forest fire detection. By combining deep learning with Explainable AI techniques, the system achieves high accuracy, fast detection speed, and improved transparency. The model can support early wildfire prevention and disaster management applications effectively.

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