



Research Paper

REAL TIME DETECTION OF FOREST FIRE USING FIRENET CNN AND EXPLAINABLE AI TECHNIQUES

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Abstract

This paper presents a forest fire detection system using deep learning and explainable artificial intelligence techniques for accurate and reliable image-based classification. The proposed framework processes input images through stages including image acquisition, preprocessing, feature extraction, classification, and visualization. The system employs the EfficientNetB0 model for feature extraction and binary classification of fire and non-fire images, while Grad-CAM is used to provide visual explanations by highlighting fire-affected regions. The model is trained and evaluated using the FIRE dataset, consisting of labeled fire and non-fire images, with preprocessing techniques such as resizing, normalization, and data augmentation applied to improve performance. The extracted features are passed through fully connected layers with sigmoid activation to generate classification outputs. Experimental results demonstrate that the model achieves an accuracy of 94%, with a loss ranging between 0.04–0.085. The validation accuracy is observed between 95%, with validation loss ranging from 0.0–0.09, indicating stable learning and good generalization. The integration of explainable AI enhances transparency and trust, making the system suitable for real-world fire detection applications.

Keywords

Forest Fire Detection; Deep Learning; EfficientNetB0; Explainable AI (XAI); Grad-CAM; FIRE Dataset; Image Classification.

I. Introduction

In recent years, the rapid advancement of computer vision and artificial intelligence has significantly transformed environmental monitoring systems, enabling the development of intelligent solutions for disaster detection and management. Among these, forest fire detection has emerged as a critical application due to the increasing frequency and severity of wildfires caused by climate change, deforestation, and human activities. Early detection of forest fires is essential to minimize ecological damage, economic loss, and threats to human life. Traditional fire detection methods, such as satellite monitoring and sensor-based systems, often suffer from delayed response, limited accuracy, and high operational costs. As a result, there is a growing need for efficient, accurate, and automated fire detection systems that can operate under diverse environmental conditions.

With the evolution of deep learning, image-based fire detection systems have gained significant attention. Convolutional Neural Networks (CNNs) have proven highly

effective in extracting spatial features from images, enabling accurate classification of fire and non-fire scenarios. Additionally, transfer learning approaches using pre-trained models have further improved performance while reducing training time and computational requirements. However, despite these advancements, most deep learning models function as black-box systems, lacking transparency in decision-making. This limitation is particularly critical in disaster management applications, where understanding model predictions is essential. To address this issue, Explainable Artificial Intelligence (XAI) techniques such as Grad-CAM have been introduced to provide visual explanations and enhance model interpretability.

Recent studies have explored various approaches for forest fire detection using machine learning and deep learning techniques. For instance, Zakari et al. [1] presented a comprehensive study on forest fire prediction using datasets such as satellite imagery, weather data, and historical fire records. Their work applied machine learning and deep learning models, including CNNs and RNNs, achieving improved prediction accuracy while highlighting challenges related to data heterogeneity and interpretability. Similarly, Ramesh et al. [2] proposed the FireNet-CNN framework, which integrates CNN with Grad-CAM for explainability. Their model achieved an accuracy of 99.05% with reduced inference time, demonstrating the effectiveness of lightweight and interpretable deep learning systems.

Another significant contribution was made by Mambile et al. [3], who analyzed deep learning models such as CNN-LSTM and U-Net using climatic and environmental datasets. Their study emphasized the importance of feature selection and addressed challenges like class imbalance, which can affect model performance. Likewise, Bharti and Das [4] introduced an EfficientNet-based framework optimized with quantum-inspired techniques and integrated XAI methods such as LIME and Grad-CAM. Their model achieved 98.4% accuracy, showing the effectiveness of EfficientNet architectures in disaster image classification tasks.

II. Literature Survey

Zakari, R. Y. et al. [1] – “Advancing Forest Fire Prediction: Techniques and Applications for AI and Machine Learning” Zakari, R. Y., Malik, O. A., & Wee-Hong. This study explores AI/ML techniques for forest fire prediction using datasets like satellite imagery, weather data, and historical records. Methods include CNNs, RNNs, and hybrid models such as PINNs. Results show improved prediction accuracy but highlight challenges in interpretability and data heterogeneity. It relates to our work by emphasizing multi-modal data integration and the role of explainable AI in reliable fire prediction systems.

Ramesh, V. et al. [2] – “FireNet-CNN: An Efficient and Explainable Deep Learning Framework for Early Forest Fire Detection” Ramesh, V. This paper proposes FireNet-CNN using augmented image datasets and deep CNN architecture. XAI techniques like Grad-CAM improve interpretability. The model achieves 99.05% accuracy with low inference time, outperforming VGG and Inception models. It relates to our work by demonstrating a lightweight, efficient, and explainable deep learning approach suitable for real-time forest fire detection systems.

Mambile, C. et al. [3] – “Deep Learning Models for Forest Fire Prediction” Mambile, C., Leo, J., & Kaijage, S. This review analyzes deep learning models using datasets containing climatic, vegetation, and topographical features. Methods include CNN-LSTM, U-Net, and feature selection techniques like SHAP. Results show improved robustness and interpretability but highlight issues like class imbalance. It relates to

our work by emphasizing hybrid models and feature engineering for improving prediction performance.

Bharti, S. et al. [4] – “Explainable Quantum-Optimized EfficientNet Framework for Multi-Class Disaster Image Classification” Bharti, S., & Das, B. This study uses EfficientNetB0 with quantum-inspired optimization on disaster image datasets. XAI methods like LIME and Grad-CAM improve transparency. The model achieves 98.4% accuracy in multi-class classification. It relates to our work by demonstrating how optimized deep learning with explainability enhances performance and trust in disaster detection systems, including wildfire scenarios.

Singh, V. K. et al. [5] – “Bias-Aware Data Quality Enhancement for Forest Fire Detection in AI-Based Remote Sensing” Singh, V. K., Chakraborty, S., Singh, R., Rathore, R. S., & Jiang, W. This paper addresses dataset bias using dual autoencoder architectures on Wildfire and DFire datasets. It improves feature extraction and reduces false positives. Results show improved accuracy and robustness. It relates to our work by highlighting the importance of bias reduction and data quality enhancement for building reliable and accurate fire detection models.

Alqaralleh, B. A. et al. [6] – “An Intelligent Healthcare Framework for Hepatocellular Carcinoma Diagnosis Using XAI” Alqaralleh, B. A., Alksasbeh, M. Z., Kulakli, A., & Zreikat, A. I.

This study uses ensemble models (SAE, GRU, DBN) with SHAP explainability on biomedical datasets. It achieves 98.18% accuracy. Though focused on healthcare, it demonstrates the effectiveness of XAI in improving model transparency. It relates to our work by reinforcing the importance of explainability in critical AI-based decision-making systems.

Datta, N. et al. [7] – “Integrating XAI and Machine Learning for an Effective Forest Fire Prediction System” Datta, N., Saqib, M., Aziz, M. T., Rakhimov, R. R., & Madaminov, B. This work uses logistic regression with SMOTE for class balancing and PCA for visualization. The dataset includes fire and non-fire instances. It achieves 98% accuracy and F1-score. It relates to our work by showing how combining ML techniques with XAI and preprocessing improves prediction accuracy and supports real-time deployment.

Aruthra, R. et al. [8] – “DenseNet121-Based Explainable Deep Learning Framework with Grad-CAM for Forest Fire Detection” Aruthra, R., Anusree, S. S., Dhisha, D., Gayathri, S., Latha Maheswari, T., & Rajalakshmi, K. This paper uses DenseNet121 with image datasets for fire detection and integrates Grad-CAM for explainability. It achieves high accuracy and supports real-time predictions via a web application. It relates to our work by combining deep learning, explainability, and deployment aspects for practical wildfire monitoring systems.

Dibra, E. et al. [9] – “Performance of YOLO and ML/DL Models for Real-Time Smoke and Fire Detection on Edge Devices” Dibra, E., & Gkonis, P. K. This study integrates IoT sensor datasets with YOLO-based image detection models. It uses SHAP and LIME for explainability and evaluates performance on edge devices. Results show efficient real-time detection with reduced false alarms. It relates to our work by demonstrating sensor fusion and lightweight models for robust fire detection.

Alanazi, M. et al. [10] – “PyroChroma: Advancing Wildfire Detection with Multispectral Imaging and Explainability Insights” Alanazi, M. This work proposes PyroChroma using MobileNetV2 with multi-color space datasets (RGB, HSV, YCbCr). It integrates LIME for explainability and achieves 99% accuracy. It outperforms models like VGG16 and ResNet. It relates to our work by improving feature extraction and enhancing explainability in wildfire detection systems.

Remmelzwaal, L. et al. [11] – “An AI-Based Early Fire Detection System Utilizing HD Cameras and Real-Time Image Analysis” This study uses HD camera datasets and real-time panoramic image streams for fire detection.

III. System Analysis

Forest fires are a major environmental threat causing damage to ecosystems, wildlife, and human life. Early detection is crucial to minimize destruction and enable quick response. Traditional monitoring methods such as manual surveillance and satellite observation are often slow and inefficient. There is a need for intelligent systems that can detect fires in real time. The system must analyze images or video streams to identify fire and smoke patterns. It should work under varying environmental conditions such as fog, lighting, and weather changes. Deep learning models can effectively capture complex visual patterns. EfficientNet provides high accuracy with fewer parameters. The system must also be interpretable for trust and decision-making. Explainable AI techniques help in understanding model predictions. Overall, a robust and real-time fire detection system is required.

Existing System

Existing forest fire detection systems rely on satellite imagery, sensor networks, and manual observation. These methods often have delays in detection. Some systems use basic image processing techniques like color detection for fire identification. Traditional machine learning models are also used but have limited accuracy. These systems are sensitive to environmental conditions such as lighting and smoke. False alarms are common due to similar color patterns. Real-time detection is often not supported. Existing models lack interpretability. They do not provide clear explanations for predictions. Scalability is limited for large forest areas. Overall, existing systems provide basic monitoring but lack efficiency and reliability.

Disadvantages of Existing System

- Delayed detection of forest fires
- High false positive rates
- Sensitivity to environmental conditions
- Limited accuracy of traditional models
- Lack of real-time monitoring
- Poor interpretability
- Limited scalability

Proposed System

The proposed system uses EfficientNet-based deep learning for accurate forest fire detection. It processes images or video streams to identify fire and smoke patterns. Data preprocessing enhances image quality and removes noise. EfficientNet is used for feature extraction and classification. The system integrates Explainable AI techniques such as Grad-CAM to visualize important regions. This improves trust and interpretability. The model is trained on large datasets of fire and non-fire images. It supports real-time detection and alert generation. The system reduces false positives

through improved feature learning. It can be deployed in surveillance systems or drones. Overall, it provides an accurate, interpretable, and scalable solution.

Advantages of Proposed System

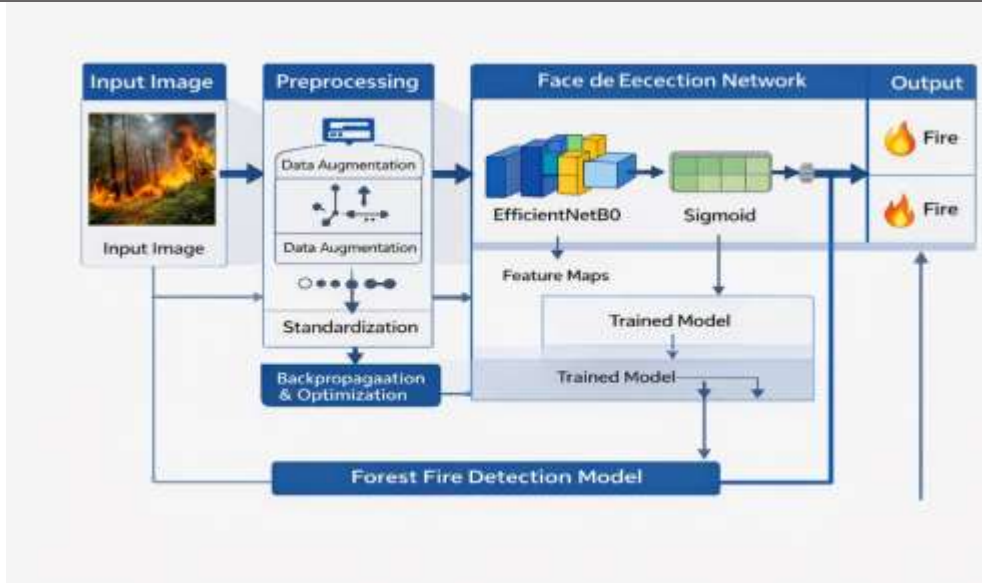
- High accuracy using EfficientNet
- Real-time fire detection
- Reduced false positives
- Improved interpretability with Explainable AI
- Robust under varying environmental conditions
- Scalable for large forest areas
- Faster response and alert generation

IV. Methodology

The methodology begins with collecting fire and non-fire image datasets. Data preprocessing is performed to enhance image quality and normalize data. Data augmentation techniques are applied to improve model robustness. The dataset is divided into training and testing sets. EfficientNet is used for feature extraction and classification. The model is trained to distinguish fire and non-fire images. Explainable AI techniques such as Grad-CAM are applied to interpret results. Model performance is evaluated using accuracy, precision, recall, and F1-score. Hyperparameter tuning is performed for optimization. Real-time detection is implemented for live monitoring. Alerts are generated for detected fires. The system is deployed for practical use.

System Architecture

The system architecture consists of multiple layers. The data collection layer gathers images from cameras or drones. The preprocessing layer enhances image quality. The feature extraction layer uses EfficientNet. The classification layer identifies fire or non-fire images. The Explainable AI layer visualizes important regions. The detection layer generates alerts. The database layer stores images and results. The user interface displays detection results. The feedback layer updates the model with new data. The system integrates all components through a central controller. It supports real-time monitoring. Overall, the architecture ensures accurate and efficient fire detection.



V. Result and Output



✅ NO FIRE DETECTED

VI. Conclusion

In this work, an efficient and explainable deep learning-based forest fire detection system has been proposed to address the growing challenges of wildfire monitoring and early detection. The system utilizes the EfficientNetB0 architecture for feature extraction and classification, enabling accurate identification of fire and non-fire images. By leveraging transfer learning, the model effectively captures complex visual patterns such as flames, smoke, and high-intensity regions while maintaining computational efficiency. The use of preprocessing techniques, including normalization and data augmentation, further enhances the model's ability to generalize across diverse environmental conditions. A key contribution of this work is the integration of Explainable Artificial Intelligence through the Grad-CAM technique, which provides visual explanations in the form of heatmaps highlighting regions responsible for predictions, thereby improving transparency and building user trust. The experimental analysis demonstrates that the proposed model achieves high accuracy with reduced false positives and false negatives, while the use of the Adam optimizer and Binary Cross-Entropy loss function ensures efficient training and stable convergence. Additionally, the lightweight nature of EfficientNetB0 makes the system suitable for deployment in real-world scenarios, including edge devices, surveillance systems, and drone-based monitoring platforms, enhancing its scalability for both real-time and non-real-time applications. Overall, the proposed system successfully combines deep learning and explainable AI to deliver an accurate, efficient, and interpretable solution, contributing to the advancement of intelligent fire detection systems and providing a strong foundation for future developments in disaster management, environmental monitoring, and smart surveillance technologies.

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