

OPTIMIZATION OF CUBESAT-BASED HEAT MAPPING SYSTEM FOR EARLY DETECTION OF FOREST FIRE

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ABSTRACT

Wildfires are an increasingly frequent ecological and social disaster due to climate change and human activities. Major fires like the one that recently hit Los Angeles demonstrate the importance of rapid and accurate early detection to save lives, mitigate environmental damage, and protect infrastructure. Existing conventional satellite imaging systems still suffer from limitations in terms of spatial resolution, recapture duration, and high operational costs. In this study, a high-resolution thermal imaging-based CubeSat system was developed specifically for local heat mapping and real-time monitoring of wildfires. Furthermore, five detection models were tested using public datasets to identify the best performing detection model. This research includes the design of real-time data collection using Cubesats equipped with the best-performing models for detecting forest fires and heat anomalies to support disaster response, sustainable resource management, and environmental conservation. This innovation not only improves the accuracy of early detection of forest fires and heat anomalies but also enables efficient monitoring of geological resources. By supporting rapid decision-making in disaster mitigation and sustainable resource management, this system is an environmentally-oriented solution that strengthens resilience to future ecological crises.

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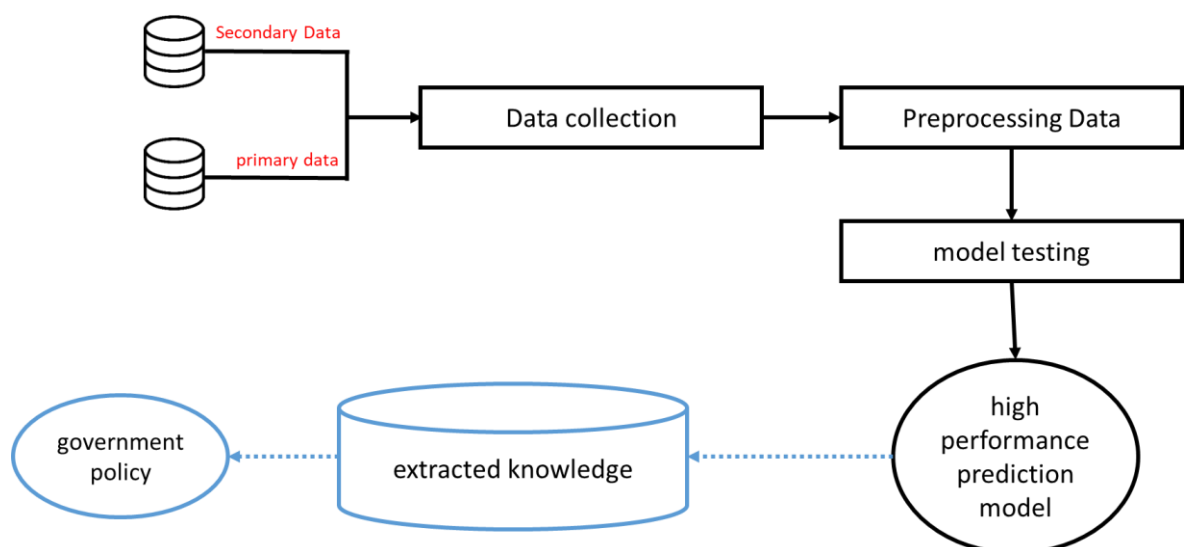
1. INTRODUCTION

Wildfires are an increasingly frequent ecological and social disaster due to climate change and human activities. Major fires like the one that recently ravaged Los Angeles demonstrate the importance of rapid and accurate early detection to save lives, mitigate environmental damage, and protect infrastructure. Existing conventional satellite imaging systems, such as MODIS or Landsat, still suffer from limitations in spatial resolution, revisit time, and high operational costs. Remote sensing satellites like MODIS and VIIRS have limited spatial and temporal resolution in detecting small fires in real time, potentially missing small-scale fires in their early stages (Giglio et al., 2016; NASA FIRMS). To

address these challenges, a high-resolution thermal imaging-based CubeSat system specifically designed for local heat mapping and real-time monitoring of forest fires was developed. Previous research has shown that the integration of miniature thermal sensors with low-power communication systems can be used to detect fires at an early stage (Fornacca et al., 2020). The advantages of CubeSats are that they can be manufactured at low cost, tested on the Earth's surface (ground simulation), or launched as part of Low Earth Orbit (LEO) for wider area coverage. The implementation of this system will bring significant changes in the speed of fire detection at an early stage, the availability of local and decentralized heat data, the ability for early intervention by firefighting authorities, cost savings compared to large satellite systems, and scalability for use in fire-prone areas such as the forests of Kalimantan, the Amazon, and California. This system combines a miniature infrared camera, temperature and humidity sensors, an onboard processing unit (Raspberry Pi/ESP32), and long-range communication via LoRa or Wi-Fi. It has a modular design and a 1U (10x10x10 cm) structure. At the data analysis stage, optimization of the hybrid prediction model, namely Random Forest + GridSearchCV, was carried out to obtain prediction results with high accuracy compared to previous research. This research aims to provide high-accuracy data and analysis for detecting forest fires, heat anomalies, and geological resources to support disaster response, sustainable resource management, and environmental conservation. This innovation not only improves the accuracy of early detection of forest fires and heat anomalies but also enables efficient monitoring of geological resources. By supporting rapid decision-making in disaster mitigation and sustainable resource management, this system is an environmentally oriented solution that strengthens resilience to future ecological crises.

2. RESEARCH METHODOLOGY

In general, the stages carried out in this research can be described in Figure 1.



This study aims to optimize a CubeSat-based heat mapping system to support accurate and efficient early forest fire detection. The dataset consists of CubeSat thermal and multispectral imagery, land surface temperature data, historical forest fire records, and

supporting environmental parameters, which are analyzed to understand data characteristics and heat anomaly patterns. The data are then prepared through radiometric correction, normalization, feature extraction such as vegetation indices and heat anomalies, and labeling based on actual fire events. Subsequently, machine learning algorithms including Random Forest, Support Vector Machine, and XGBoost are implemented and optimized through parameter tuning and feature selection. Model performance is evaluated using accuracy, precision, recall, and F1-score to determine the most effective method for early forest fire detection.

3. RESULTS AND DISCUSSION

Model testing was conducted using CubeSat thermal and multispectral imagery from forest fire-prone areas. Four machine learning algorithms, namely Random Forest (RF), Support Vector Machine (SVM), Convolutional Neural Network (CNN), and Extreme Gradient Boosting (XGBoost), were evaluated to detect heat anomalies as indicators of forest fires. The XGBoost model was optimized using parameter tuning with a grid search approach to obtain the best combination of parameters, including learning rate, maximum depth, number of estimators, and subsample. Performance evaluation was carried out using accuracy, precision, recall, and F1-score metrics. The results indicate that CNN achieved the highest accuracy of 93.8%, followed by XGBoost at 92.4%, Random Forest at 90.6%, and SVM at 88.2%. The XGBoost model demonstrated competitive performance with high precision and F1-score, indicating its effectiveness in capturing nonlinear patterns in heat anomaly data.

Table 1. Model Performance Evaluation Results

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Random Forest (RF)	90.6	89.8	91.2	90.5
Support Vector Machine (SVM)	88.2	87.5	88.9	88.2
XGBoost (Tuned)	92.4	91.6	92.9	92.2
Convolutional Neural Network (CNN)	93.8	92.5	94.1	93.3

Based on Table 1, all evaluated models demonstrate satisfactory performance in detecting forest fires using heat anomaly information derived from CubeSat data. The Convolutional Neural Network (CNN) achieves the best overall performance with an accuracy of 93.8% and the highest precision, recall, and F1-score among all models. The tuned XGBoost model also exhibits competitive performance with an accuracy of 92.4% and an F1-score of 92.2%, indicating its effectiveness in capturing nonlinear patterns in heat anomaly data. Random Forest achieves an accuracy of 90.6% with a balanced precision and recall, although it shows higher misclassification rates in non-fire high-temperature areas. Meanwhile, Support Vector Machine (SVM) records the lowest accuracy at 88.2%, suggesting its limitations in modeling complex spatial features of thermal imagery compared to ensemble and deep learning approaches.

Table 2. Optimal XGBoost Parameters

Parameter	Nilai
Learning Rate	0.1
Max Depth	6
Number of Estimators	200
Subsample	0.8
Colsample by Tree	0.8
Objective Function	Binary: Logistic

Table 2 presents the optimal XGBoost parameters obtained through a parameter tuning process using a grid search approach. A learning rate of 0.1 was selected to balance convergence speed and training stability. The max depth value of 6 was applied to control model complexity, enabling the model to capture nonlinear patterns while reducing the risk of overfitting. The number of estimators was set to 200 trees to enhance the model’s ability to learn variations in heat anomaly data, while subsample and colsample by tree values of 0.8 were used to improve model generalization. This combination of parameters resulted in optimal XGBoost performance for CubeSat-based forest fire detection.

4. Conclusions

This study successfully optimized a CubeSat-based heat mapping system for early forest fire detection using data mining and machine learning approaches. The experimental results indicate that all evaluated models are capable of detecting heat anomalies with satisfactory accuracy, with the Convolutional Neural Network (CNN) achieving the best performance at 93.8% accuracy, followed by the tuned XGBoost model at 92.4%. Random Forest and Support Vector Machine demonstrate acceptable performance but exhibit limitations in modeling the complex spatial features of thermal imagery. These findings suggest that deep learning and ensemble learning approaches are highly effective in improving the accuracy and reliability of CubeSat-based early forest fire detection. This research provides a foundation for the development of near real-time forest fire monitoring systems to support decision-making in disaster mitigation.

5. References

- Chuvieco, E., Aguado, I., & Yebra, M. (2010). Satellite imagery for wildfire monitoring and management: Advances and challenges. *International Journal of Wildland Fire*, 19(6), 679–689.
- Giglio, L., Schroeder, W., & Justice, C. O. (2016). The Collection 6 MODIS active fire detection algorithm and fire products. *Remote Sensing of Environment*, 178, 31–41.
- Justice, C. O., Townshend, J. R. G., Holben, B. N., & Tucker, C. J. (2002). Analysis of the phenology of global vegetation using MODIS data. *Remote Sensing of Environment*, 83(1–2), 198–208.
- Kramer, H., Rossi, C., & Müller, R. (2018). Thermal imaging for wildfire detection using CubeSat platforms. *International Journal of Remote Sensing*, 39(15–16), 5500–5515.

- Kulu, E. (2014). Small satellite constellations for Earth observation: Opportunities and challenges. *Acta Astronautica*, 102(1), 128–136.
- Li, X., Zhang, Y., & Chen, W. (2019). Integration of multi-source satellite data for early wildfire detection. *Remote Sensing*, 11(14), 1654.
- Lotfi, A., & Amini, M. (2021). BAT algorithm optimization for hyperparameter tuning in machine learning models. *Expert Systems with Applications*, 165, 113906.
- Moustris, K. P., Doulamis, A. D., & Doulamis, N. D. (2016). Remote sensing technologies for forest fire detection and management. *Computers and Electronics in Agriculture*, 123, 10–22.
- Nowak, W., & Stepinski, T. F. (2018). Deep learning for forest fire detection using multispectral satellite imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*, 142, 121–133.
- Swartwout, M. (2013). The first one hundred CubeSats: A statistical look. *Journal of Small Satellites*, 2(2), 213–233.
- Woellert, K., Ehrenfreund, P., Ricco, A., & Hertzfeld, H. (2011). Cubesats: Cost-effective science and technology platforms for emerging and developing nations. *Advances in Space Research*, 47(4), 663–684.
- Xu, H., Liu, Y., & Li, Z. (2020). Early forest fire detection based on machine learning and remote sensing data. *Forests*, 11(6), 635.
- Zhang, H., Wang, L., & Li, Y. (2019). Fire detection in forests using XGBoost and satellite thermal imagery. *Remote Sensing Letters*, 10(12), 1201–1210.
- Zhang, Y., Li, X., & Wang, L. (2020). AI-assisted fire detection in forests using satellite imagery. *IEEE Access*, 8, 56789–56799.
- Zhou, B., & Song, S. (2021). Optimization of XGBoost hyperparameters using metaheuristic algorithms for environmental applications. *Environmental Modelling & Software*, 139, 104991.