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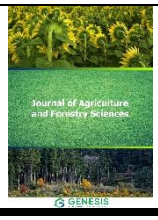

Editorial

Forest fire detection: Advanced technologies for protect global ecosystems

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Abstract

Forests maintain the global ecosystems for millions of years. The increasing frequency of forest fires caused by climate change and human activities. It poses severe threats to biodiversity, human life, and economic stability. Modern technologies offer promising solutions for forest fire detection and management. Satellite systems, such as MODIS, VIIRS, and GOES, provide real-time monitoring by detecting thermal anomalies and tracking fire progression. Integrated systems enhance firefighting resource allocation using dynamic indices. Artificial intelligence (AI), Deep Learning (DL) and the Internet of Things (IoT) bring further precision to forest fire detection through advanced algorithms and analyzing satellite and ground-based data. UAVs (drones) and wireless sensor networks (WSNs) contribute localized and high-resolution data. A multi-technology approach combining these innovations has proven effective in Europe' EFFIS and Brazil's INPE. Continued advancements in satellite resolution, AI optimization, and sensor scalability hold the potential to further mitigate wildfire impacts.

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Forests are the sources of natural oxygen and protectors of earth's ecological balance. Fire is a great invention in human history and a natural phenomenon in the Earth System which shaped the landscape of Earth for millions of years (Shi *et al.*, 2022). Fires burn around 3–5 million km^2 per year which emit 8 billion tonnes of carbon di-oxide to the atmosphere (Chuvieco *et al.*, 2019). Natural fires reduces 10% of carbon stored in vegetation to maintain CO_2 concentrations (Lasslop *et al.*, 2020).

Forest fires become increasingly common due to climate change and human activities in recent years those fires cause devastating impacts on biodiversity, human life, and the environment (Flannigan *et al.*, 2000). The location of forest in remote areas filled with trees and dry wood, makes forest fires unmanageable (Alkhatib, 2014). Centre for Research on the Epidemiology of Disasters (CRED) estimates that wildfire have killed at least 2,500 people, injured 10,500 people and displaced 175,000 people since 1990 globally (Jones *et al.*, 2022). Economic losses due to California wildfires in 2020 were estimated to be 149 billion US$ (Wang *et al.*, 2021). Australian wildfires of 2019-2020 caused around 75 billion US$ economic losses and impacted over 30% of the available habitat of 70 vertebrate species, including 21 endangered species (Jones *et al.*, 2022; Ward *et al.*, 2020). Effective monitoring and detection may mitigate the economic losses. Modern technologies are revolutionizing forest fire detection, offering real-time monitoring and enabling timely interventions.

Satellite systems is an indispensable tools for fire detection and monitoring in modern era. Sensor systems such as Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS), Advanced Very High Resolution Radiometer (AVHRR), Spinning Enhanced Visible and InfraRed Imager (SEVIRI) and Geostationary Operational Environmental Satellites (GOES) have demonstrated their utility in detecting thermal anomalies, identifying and maping fire hotspots and tracking fire progression (Barmpoutis *et al.*, 2020; Alkhatib, 2014). Integrated Satellite System (ISS) combines fire detection algorithms with Fire Danger Dynamic Index (FDDI) to prioritize firefighting efforts. This system collects data from various satellite sensors and delivers actionable information in real time. It enhancing the allocation of firefighting resources by updating indicators such as wind intensity (Mazzeo *et al.*, 2022).

Artificial intelligence (AI) and Internet of things (IoT) have further enhanced forest fire detection (Avazov *et al.*, 2023). Advanced algorithms such as YOLO (You Only Look Once), Faster R-CNN, and EfficientDet have been employed to analyze satellite imagery, thermal data, and visual footage from ground-based systems and drones. These models have significantly improved response times by reducing false positive results (Shi *et al.*, 2023). Studies have shown that Deep Learning based systems achieve 90% accuracy rates (Guede-Fernández *et al.*, 2021). The integration of generative data augmentation and optimized architectures further enhances their performance. However, challenges like high computational requirements and limited training data need to be addressed for widespread adoption. Additionally, issues like dataset imbalance and the potential for biased predictions require careful consideration during model development.

Unmanned aerial vehicles (UAV), known as drones have emerged as versatile tools for forest fire detection and monitoring. UAVs provide detailed views of affected areas and detect heat signatures indicative of fires with high-resolution cameras and infrared sensors.

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However, UAV deployment is constrained by limited flight durations, battery life, and adverse weather conditions. Regulatory restrictions on drone operations in certain regions also limit their widespread application (Sudhakar *et al.*, 2020).

Wireless sensor networks (WSN) are an innovative solution for localized forest fire monitoring. These sensors measure temperature, humidity and gas concentration to identify fire ignition. However, their deployment faces challenges such as environmental susceptibility, communication limitations in dense forests, and the need for regular maintenance. Improving the scalability and resilience of WSNs could greatly enhance their utility in fire detection (Dampage *et al.*, 2022).

Effective forest fire management requires a holistic approach that combines technology with proactive measures. A multi-technology approach that integrates satellites, UAVs, WSNs, and AI algorithms has proven to be the most effective strategy for forest fire detection and management. This synergy minimizes delays in detection, reduces false alarms, and ensures efficient allocation of resources during firefighting efforts. European Forest Fire Information System (EFFIS) and Brazil's Instituto Nacional de Pesquisas Espaciais (INPE) demonstrate the power of integrating diverse data sources for comprehensive monitoring (Oliveira *et al.*, 2023).

The future of detecting forest fires depends on improving these technologies. By enhancing the spatial and temporal resolution of satellite systems, we can spot smaller fires more effectively. Additionally, creating lightweight and energy-efficient AI models will allow for their use on devices with limited resources. Active collaboration among researchers, governments, and industries can significantly reduce the impact of wildfires on ecosystems and communities.

In conclusion, the integration of cutting-edge technologies has revolutionized forest fire detection, providing remarkable capabilities for early warning and effective management. The synergy of satellite systems, AI, UAVs, and WSNs marks a significant shift in how we manage forest fires. Ongoing innovation and collaboration are crucial for creating a future where the destructive effects of wildfires are lessened, protecting both ecosystems and human populations.

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None to declare.

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Not applicable.

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The authors declare no competing interests.

Authors' contribution

Kazi Abdus Sobur: Conceptualization, formal analysis, writing-original draft preparation, review and editing; **Partha Pratim Ghosh**: editing-original draft preparation, validation. The author has read and approved the final version of the published editorial.

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