International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 3, May-Jun-2026, ISSN (Online): 2395-566X

Drone-Based Smart Forest Fire Detection: A Survey of Aerial Sensing, Vision-Based Recognition and Early Warning Systems

Chaskar Siddhi Dattatray[1] Chinchawade Tanvi Santosh[2] Bhore Tanvi Santosh[3]
Prof. P. S. Dumbre[4] Prof. M. S. Nalawade[5] Dr. V. M. Dhede[6]
[1,2,3]Department Of Electronics And Telecommunication Jaihind College Of Engineering Kuran, Pune, Maharashtra, India
Seminar Guide Department Of Electronics And Telecommunication Jaihind College Of Engineering Kuran, Pune, Maharashtra, India;
Seminar Coordinator Department Of Electronics And Telecommunication Jaihind College Of Engineering Kuran, Pune, Maharashtra, India;
Head Of Department Department Of Electronics And Telecommunication Jaihind College Of Engineering Kuran, Pune, Maharashtra, India

Abstract—Forest fires destroy trees, wildlife habitats and natural resources, release large amounts of smoke and threaten nearby communities. Their impact depends strongly on how quickly they are detected, yet traditional methods based on watchtowers and ground patrols require continuous human effort and are slow to cover remote terrain. Satellites observe large areas but revisit a location only a few times a day and cannot see small fires under cloud or canopy. Unmanned aerial vehicles, commonly called drones, fill this gap by carrying cameras and sensors over the forest on demand. This survey reviews forest fire detection methods and focuses on drone-based systems. It discusses the sensing payload, including visible and thermal cameras and gas and temperature sensors, the detection algorithms, from colour-rule methods to convolutional neural networks, and the communication links that deliver alerts with GPS coordinates to forest authorities. Representative studies and datasets are compared. A layered architecture for a smart drone-based fire detection and alert system is then presented, covering sensing, onboard processing, communication, ground-station verification and alert dissemination. Practical challenges such as limited flight time, false alarms, communication range and regulation are discussed along with future directions such as drone swarms and integration with satellite data.

Index Terms—Drone, unmanned aerial vehicle, forest fire detection, thermal imaging, deep learning, sensors, GPS, wireless communication, early warning system.

I. INTRODUCTION

Forests regulate climate, protect soil and water, support biodiversity and provide livelihoods to millions of people. Fire is a natural part of some forest ecosystems, but uncontrolled fires, many of them caused by human activity, can spread rapidly in dry and windy conditions. In India, forest fires are a recurring problem during the dry season, and the Forest Survey of India monitors fire-prone areas as part of its national assessments [1]. The damage caused by a fire grows quickly with time, so the most effective way to limit it is to detect it early, while it is still small enough to be controlled.

Traditional detection relies on lookout towers, ground patrols and reports from local people. These methods depend on human attention, are limited by line of sight and terrain, and may take a long time to notice fires in remote areas. Automatic systems based on ground sensor networks, tower-mounted cameras and satellite imagery have been developed to address these limitations [2], [3]. Each has its own strengths and weaknesses, as discussed in Section II.

Unmanned aerial vehicles (UAVs), or drones, have emerged as a flexible complement to these methods. They can be launched quickly, fly below clouds, carry visible and infrared cameras, and send data in near real time [4], [5]. Combined with image-processing and machine-learning algorithms, a drone can identify smoke and flames automatically and report the location to authorities. This survey reviews such systems. Its contributions are:

- A comparison of forest fire detection platforms, including ground, tower, satellite and drone-based systems.
- A review of the sensing payload, detection algorithms and communication methods used in drone-based fire detection.
- A layered architecture for a smart drone-based fire detection and early warning system.
- A discussion of challenges and future research directions.

Section II reviews detection platforms, Section III covers drone sensing and detection methods, Section IV presents the

© 2026 IJSRET

system architecture, Section V compares approaches, Section VI discusses challenges, and Section VII concludes.

II. FOREST FIRE DETECTION PLATFORMS

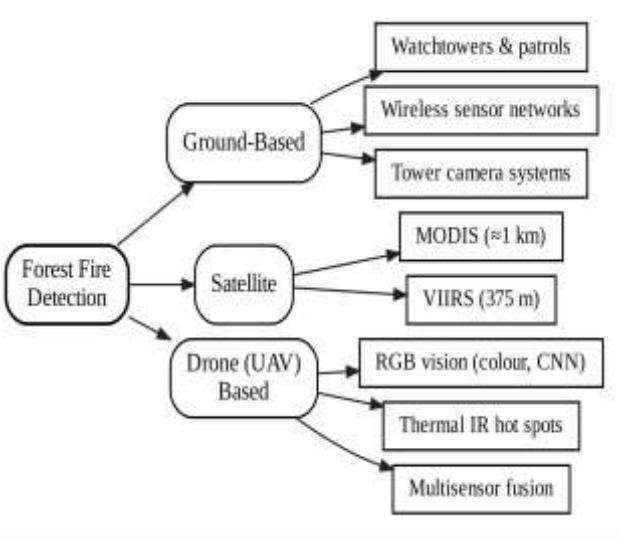


Fig. 1. Classification of forest fire detection approaches.

1 Ground Sensor Networks

Wireless sensor networks place battery-powered nodes with temperature, humidity, smoke or gas sensors throughout a forest. They can detect local changes quickly, but covering a large forest requires many nodes, and maintenance and battery replacement in remote terrain are difficult [2]. Long-range low-power radio technologies such as LoRa have improved the range of such networks [6].

2.Tower-Based Camera Systems

Optical or infrared cameras mounted on towers scan the landscape and use image analysis to detect smoke plumes. Barmpoutis *et al.* reviewed such terrestrial systems together with aerial and satellite approaches and noted that tower cameras give continuous coverage of a fixed area but are blocked by hills and dense vegetation [3].

3. Satellite Remote Sensing

Satellites detect active fires through the strong emission of hot surfaces in the middle-infrared band. The MODIS active fire product provides global detections at about 1 km resolution [7], and the VIIRS 375 m product improved the detection of smaller fires [8]. Satellite systems cover very large areas at low cost to the user, but their revisit time, spatial resolution and sensitivity to cloud limit their usefulness for detecting a fire within minutes of ignition.

4 Drone-Based Systems

Drones operate between the ground and satellite scales. Yuan, Zhang and Liu surveyed UAV-based forest fire monitoring and identified three tasks: detection of new fires, diagnosis of fire behaviour, and support for firefighting [4]. Merino *et al.* developed an unmanned aircraft system that detected fires with infrared and visual cameras, geolocated them and measured fire-front properties in field experiments [9]. Drones can be deployed on demand to suspicious areas or fly scheduled patrols over high-risk zones.

III. DRONE SENSING AND DETECTION METHODS

1 Sensing Payload

The most common sensors are visible-light (RGB) cameras, which detect smoke and flame colour and shape, and thermal infrared cameras, which detect hot spots even through light smoke and at night. Multisensor payloads may add temperature, humidity and gas sensors for carbon monoxide or carbon dioxide, which indicate combustion near the drone. A GPS receiver and inertial measurement unit provide position and attitude so that a detection in the image can be converted into ground coordinates [9].

2 Rule-Based Image Processing

Early vision methods detected fire pixels using colour rules. Çelik and Demirel proposed a generic colour model in the YCbCr colour space that separates luminance from chrominance and improves discrimination between fire and fire-like objects [10]. Such methods are fast and suitable for small processors, but they produce false alarms for sunsets, red objects and reflections, and they detect smoke poorly.

3 Deep Learning Methods

Convolutional neural networks (CNNs) learn features automatically from labelled images. Muhammad *et al.* showed that a fine-tuned CNN detected fire in surveillance video more accurately than handcrafted colour features [11], and later presented an efficient CNN that also localised fire regions and was suitable for resource-constrained devices [12]. Single-stage object detectors such as YOLO predict bounding boxes and classes in one pass and can run in real time [13], which makes them attractive for onboard processing. Shamsoshoara *et al.* published the FLAME dataset of aerial visible and thermal images of prescribed burns collected by drones, enabling training and benchmarking of aerial fire classifiers [14].

4 Communication And Alerting

When a fire is detected, the drone or ground station must send an alert containing the location, time and supporting image.

© 2026 IJSRET

Depending on terrain and infrastructure, links may use a telemetry radio to the ground station, cellular 4G/LTE networks where coverage exists, or long-range low-power radio for small messages [6]. The ground station or a cloud server then forwards the alert to forest officers through SMS, a mobile application or a web dashboard.

5. Autonomous Mission Planning

Coverage of large areas needs efficient flight paths. Afghah *et al.* studied the coordination of multiple autonomous UAVs for wildfire monitoring in remote areas, distributing the area among drones and handling limited communication [15]. Planning must consider battery life, wind and the need to return for recharging.

Table I Summary Of Representative Studies On Fire Detection Relevant To Drone Systems

Ref.	Platform	Method	Contribution	Limitation
[9]	UAV	IR and visual cameras with geolocation	Field-tested fire detection and measurement	Costly sensors; short flights
[10]	Camera (generic)	YCbCr colour rules	Fast fire-pixel detection	False alarms with fire-coloured objects
[11]	Surveillance camera	Fine-tuned CNN	Higher accuracy than handcrafted features	Needs GPU-class hardware
[12]	Surveillance camera	Efficient CNN with localisation	Suitable for constrained devices	Ground-view training data
[14]	UAV	Aerial RGB and thermal dataset with CNN	Benchmark for aerial fire classification	Prescribed burns in one region
[7]	Satellite	MODIS active fire algorithm	Global daily fire product	About 1 km resolution
[15]	Multi-UAV	Coordinated autonomous monitoring	Coverage of remote areas	Simulation-oriented study

IV. PROPOSED SYSTEM ARCHITECTURE

Based on the review, a layered architecture for a smart drone-based forest fire detection system is presented in Fig. 2.

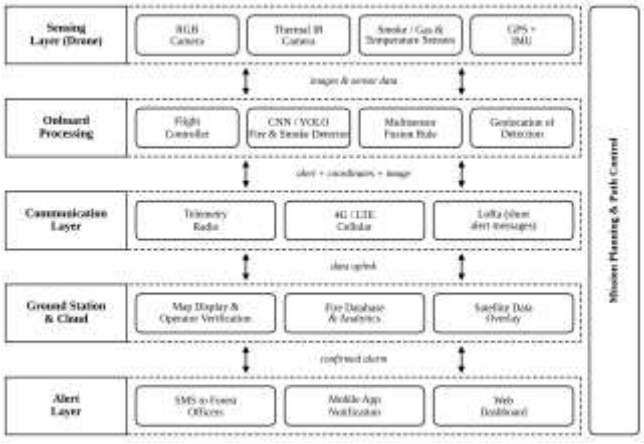


Fig. 2. Layered architecture of the smart drone-based forest fire detection and early warning system.

1. Sensing Layer

The drone carries an RGB camera, a thermal camera, smoke or gas sensors, an ambient temperature sensor and a GPS module. Thermal data detect hot spots, RGB images detect smoke and flames, and gas readings provide supporting evidence.

2. Onboard Processing Layer

A flight controller handles navigation, while a companion computer such as a single-board computer runs a lightweight CNN or YOLO-type detector on incoming frames [12], [13]. A fusion rule combines evidence, for example raising an alarm only when a thermal hot spot coincides with a visual detection or abnormal gas reading, which reduces false alarms. The detected pixel location is converted to ground coordinates using the GPS position, altitude and camera orientation [9].

3. Communication Layer

Alerts, compressed images and telemetry are sent to the ground station over a radio link or a cellular network. Where coverage is weak, a short alert containing coordinates can be sent over long-range low-power radio, while full images are uploaded later [6].

© 2026 IJSRET

4 Ground Station And Cloud Layer

The ground station displays the drone position and detections on a map, allows an operator to confirm the alarm from the image, stores data for later analysis, and plans further flights. Satellite fire products can be overlaid to provide wider context [7].

5. Alert Layer

Once confirmed, the alert is sent to forest authorities and fire-response teams through SMS, a mobile application or a web dashboard, giving the location, time and an image of the fire. This allows a rapid and well-directed response.

6. Comparative Analysis

Table II compares detection platforms on key criteria.

Criterion	Ground Sensor Network	Tower Cameras	Satellite	Drone-Based
Area coverage	Small per node	Medium (line of sight)	Very large	Medium, flexible
Detection delay	Low near nodes	Low in view	Hours (revisit)	Low when deployed
Spatial detail	Point readings	Medium	375 m to 1 km [7], [8]	Centimetres to metres
Night operation	Yes	With IR camera	Yes (thermal)	With thermal camera
Main limitation	Many nodes, maintenance	Terrain blocking	Cloud, coarse resolution	Flight time, regulation
Cost	Medium	Medium to high	Low for user	Low to medium

V. CHALLENGES AND FUTURE DIRECTIONS

Drone-based fire detection faces several practical challenges. Battery-powered multirotor drones fly for only a limited time, which restricts the area covered per flight; fixed-wing or hybrid designs extend endurance but need more space for launch and landing [5]. False alarms caused by sunlight, hot rocks or fire-coloured objects reduce trust in automatic systems, so multisensor fusion and better training data are needed [14]. Communication in hilly forest terrain is unreliable, and data rates for live video may not be available. Smoke, heat and strong winds near a fire are hazardous to small drones. Aviation regulations restrict beyond-visual-line-of-sight operation in many countries, which limits autonomous patrols. Future work is expected to address these through swarms of cooperating drones [15], automatic docking and charging stations, edge AI chips that run accurate models at low power, integration of drone, ground-sensor and satellite data into a single monitoring platform, and prediction of fire spread to guide firefighting.

VI. CONCLUSION

Early detection is the key to limiting forest fire damage. This survey has shown that ground sensors, tower cameras and satellites each cover part of the problem, and that drones add flexible, high-resolution and rapidly deployable observation. Thermal and visual cameras, combined with deep learning detectors and GPS-based geolocation, allow drones to identify smoke and flames and report their locations quickly. The layered architecture presented here integrates sensing, onboard processing, communication, ground-station verification and alerting into a smart early warning system. With continued progress in endurance, onboard intelligence and regulation, drone-based systems can reduce human effort, improve forest safety and help protect wildlife and the environment.

REFERENCES

1. Forest Survey of India, India State of Forest Report 2021. Dehradun, India: Ministry of Environment, Forest and Climate Change, 2021.
2. A. A. A. Alkhatib, "A review on forest fire detection techniques," International Journal of Distributed Sensor Networks, vol. 10, no. 3, Art. no. 597368, 2014.
3. P. Barmpoutis, P. Papaioannou, K. Dimitropoulos, and N. Grammalidis, "A review on early forest fire detection systems using optical remote sensing," Sensors, vol. 20, no. 22, Art. no. 6442, 2020.
4. C. Yuan, Y. Zhang, and Z. Liu, "A survey on technologies for automatic forest fire monitoring, detection, and fighting using unmanned aerial vehicles and remote sensing techniques," Canadian Journal of Forest Research, vol. 45, no. 7, pp. 783–792, 2015.
5. H. Shakhatreh, A. H. Sawalmeh, A. Al-Fuqaha, Z. Dou, E. Almaita, I. Khalil, N. S. Othman, A. Khreishah, and M. Guizani, "Unmanned aerial vehicles (UAVs): A survey on civil applications and key research challenges," IEEE Access, vol. 7, pp. 48572–48634, 2019.
6. M. Centenaro, L. Vangelista, A. Zanella, and M. Zorzi, "Long-range communications in unlicensed bands: The rising stars in the IoT and smart city scenarios," IEEE Wireless Communications, vol. 23, no. 5, pp. 60–67, 2016.
7. L. Giglio, W. Schroeder, and C. O. Justice, "The collection 6 MODIS active fire detection algorithm and

© 2026 IJSRET

fire products," Remote Sensing of Environment, vol. 178, pp. 31–41, 2016.
8. W. Schroeder, P. Oliva, L. Giglio, and I. A. Csiszar, "The New VIIRS 375 m active fire detection data product: Algorithm description and initial assessment," Remote Sensing of Environment, vol. 143, pp. 85–96, 2014.
9. L. Merino, F. Caballero, J. R. Martínez-de-Dios, I. Maza, and A. Ollero, "An unmanned aircraft system for automatic forest fire monitoring and measurement," Journal of Intelligent & Robotic Systems, vol. 65, no. 1–4, pp. 533–548, 2012.
10. T. Çelik and H. Demirel, "Fire detection in video sequences using a generic color model," Fire Safety Journal, vol. 44, no. 2, pp. 147–158, 2009.
11. K. Muhammad, J. Ahmad, I. Mehmood, S. Rho, and S. W. Baik, "Convolutional neural networks based fire detection in surveillance videos," IEEE Access, vol. 6, pp. 18174–18183, 2018.
12. K. Muhammad, J. Ahmad, Z. Lv, P. Bellavista, P. Yang, and S. W. Baik, "Efficient deep CNN-based fire detection and localization in video surveillance applications," IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 49, no. 7, pp. 1419–1434, 2019.
13. J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, "You only look once: Unified, real-time object detection," in Proc. IEEE Conf. Computer Vision and Pattern Recognition (CVPR), 2016, pp. 779–788.
14. A. Shamsoshoara, F. Afghah, A. Razi, L. Zheng, P. Z. Fulé, and E. Blasch, "Aerial imagery pile burn detection using deep learning: The FLAME dataset," Computer Networks, vol. 193, Art. no. 108001, 2021.
15. F. Afghah, A. Razi, J. Chakareski, and J. Ashdown, "Wildfire monitoring in remote areas using autonomous unmanned aerial vehicles," in Proc. IEEE INFOCOM Workshops, 2019, pp. 835–840.

© 2026 IJSRET