

Solar-Powered Sensor Tower Network for Early Forest and Crop Fire Detection with Automated Irrigation Response

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Abstract—Crop and forest fires are often detected only after they have spread extensively, as manual patrolling and satellite-based monitoring are typically slow, infrequent, or reliant on visible smoke plumes. Such delays enable small ignition points to develop into large, uncontrollable fires that devastate agricultural land, forest cover, and property. This study presents a network of solar-powered sensor towers equipped with smoke, heat, and wind-direction sensors for continuous, real-time monitoring of fields and forest zones. When fire-indicative conditions are detected, the system immediately alerts nearby farmers and local authorities via a cloud-connected communication module and simultaneously initiates an automated irrigation response in the affected zone to slow the fire's progression prior to human intervention. The system is self-sustaining through solar power, making it suitable for remote and off-grid agricultural and forest environments. By integrating embedded systems, wireless sensor networks, and IoT-based cloud alerting, the proposed approach aims to significantly reduce fire response times.

Keywords—Forest Fire Detection, Crop Fire, Solar-Powered IoT, Wireless Sensor Network, Smoke and Heat Sensors, Automated Irrigation, Embedded Systems, Cloud Alert System.

I. INTRODUCTION

Forest and crop fires represent some of the most destructive natural and anthropogenic hazards, resulting in significant loss of vegetation, farmland, biodiversity, and, in many cases, human life and property. In agricultural regions, fires may originate from stubble burning, electrical faults, dry-season heat, or negligent human activity, and can spread rapidly through dry vegetation before detection. In forested areas, the lack of continuous human monitoring allows fires to burn for extended periods before being identified by patrol teams, watchtower observers, or satellite imagery.

Conventional fire-detection approaches, such as manual patrolling, watchtower observation, and satellite-based thermal imaging, suffer from delayed response, limited coverage, high operating costs, or low temporal resolution. This creates a critical gap between the moment a fire ignites and the moment it is reported, during which the fire can grow far beyond a scale that is easily contained. With the growth of low-power embedded systems, wireless sensor networks (WSN), and Internet of Things (IoT) technology, it has become possible to build an always-on, self-powered monitoring infrastructure that can be deployed directly in fields and forests without dependence on the electrical

grid.

This study proposes a solar-powered sensor tower network that continuously senses smoke concentration, ambient heat, and wind direction at multiple points across a field or forest boundary. Upon detecting the signature of an early-stage fire, the system immediately notifies nearby farmers and local fire/forest authorities through a cloud-based alert mechanism, and also sends a trigger signal to the nearest automated irrigation valve, allowing irrigation to begin instantly in the threatened zone, thereby buying critical time before emergency responders arrive.

II. PROBLEM STATEMENT

Fires in crop fields and forests are largely detected too late because existing monitoring methods are either manual, infrequent, or reactive rather than preventive. Farmers and forest departments typically learn of a fire only after visible smoke or flame has already spread over a considerable area, by which time suppression becomes difficult, costly, and dangerous. There is a pressing need for an autonomous, always-active, self-powered system that can sense the earliest physical indicators of fire — smoke, heat rise, and wind pattern — and both alert human responders and take an immediate automated action (irrigation) to slow the fire, without depending on grid power, mobile patrol schedules, or satellite revisit time.

III. LITERATURE REVIEW

Several studies have investigated sensor-based and remote-sensing approaches to wildfire and crop-fire detection. Wireless sensor network (WSN) based systems have been proposed to deploy distributed nodes with temperature and smoke sensors across forest terrain, transmitting data to a base station using low-power radio protocols such as ZigBee and LoRa. Satellite and drone-based thermal imaging techniques have also been explored to identify hotspots over large geographic areas, though these approaches are limited by revisit frequency, cloud cover, and high deployment cost.

Machine learning and deep learning models, including convolutional neural networks (CNN), have been applied to classify smoke and flame patterns from camera feeds with improved accuracy over threshold-based methods.

Solar-powered IoT nodes have been used in precision-agriculture applications such as soil-moisture sensing and automated irrigation, demonstrating the feasibility of long-term, off-grid operation in rural and forested terrain.

However, existing systems largely treat fire detection and irrigation control as separate systems, and few integrate real-time multi-sensor fire detection with an automatic, localized suppression response. Communication reliability in remote low-connectivity zones and false-alarm reduction also remain open challenges.

IV. PROPOSED SYSTEM

The proposed system consists of a distributed network of solar-powered sensor towers installed at regular intervals along the boundary and interior of crop fields or forest zones. Each tower is equipped with smoke, heat (infrared/thermal), and wind-direction sensors, along with a microcontroller unit and a wireless communication module. Sensor readings are continuously monitored, and when values cross a fire-indicative threshold, the tower's microcontroller classifies the event and transmits an alert to a central cloud server. The cloud server pushes real-time notifications to nearby farmers and local fire and forest authorities through SMS/app alerts, and simultaneously sends a control signal to the automated irrigation system covering the affected zone, activating sprinklers or drip valves to slow fire spread while human responders are en route. Wind-direction data is used to predict the likely spread direction of the fire and prioritize which neighboring zones and towers should be placed on high alert.

Fig. 3. Overall network architecture of the solar-powered sensor tower system

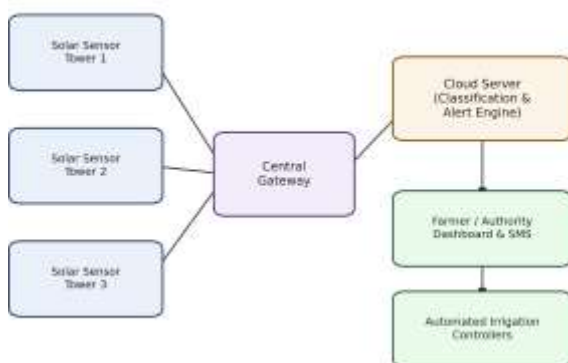


Fig. 3. Overall network architecture of the solar-powered sensor tower system.

V. METHODOLOGY / IMPLEMENTATION

■ Solar-powered sensor towers are deployed at fixed intervals across the field/forest perimeter and interior, each self-sufficient through a solar panel and battery backup.

■ Each tower integrates a smoke (MQ-2/MQ-135 type) sensor, a heat/IR temperature sensor, and a wind-direction sensor connected to a low-power microcontroller (e.g., ESP32/Arduino with LoRa module).

■ Sensor data is sampled at fixed intervals and transmitted wirelessly (LoRa/ZigBee/GSM, depending on tower distance from base station) to a central gateway.

■ The gateway forwards aggregated data to a cloud server, where a threshold and pattern-based classification logic (rule-based or lightweight ML model) determines whether the readings indicate a fire event.

■ On a positive fire classification, the cloud server issues (a) an instant alert to registered farmers and forest/fire authorities via SMS and a mobile/web dashboard, and (b) an actuation command to the nearest automated irrigation controller to begin irrigation in the affected zone.

■ Wind-direction readings are used to estimate probable fire-spread direction, allowing the system to pre-emptively alert towers and irrigation zones downwind of the detected fire.

■ The system logs all events to the cloud for later analysis, enabling authorities to study fire patterns, response times, and system accuracy over time.

Fig. 2. Methodology flowchart for fire detection and automated irrigation response

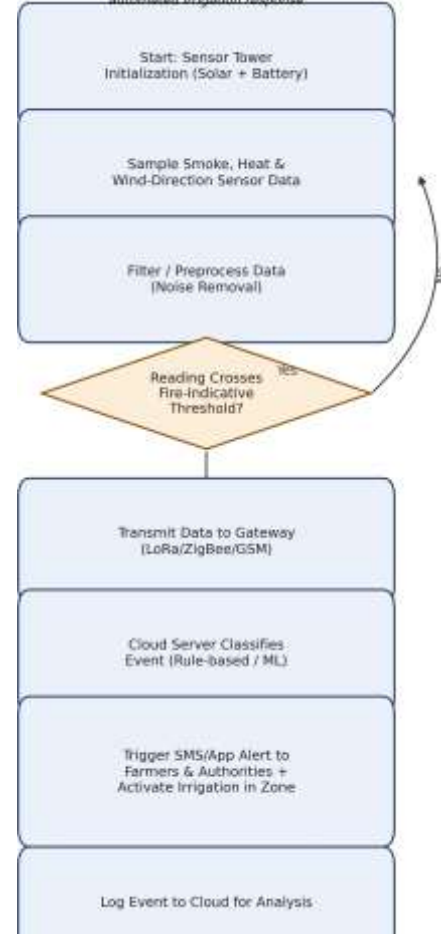


Fig. 2. Methodology flowchart for fire detection and automated irrigation response.

VI. BLOCK DIAGRAM OF THE PROPOSED SYSTEM

Fig. 1. Block diagram of the proposed sensor tower and alert system

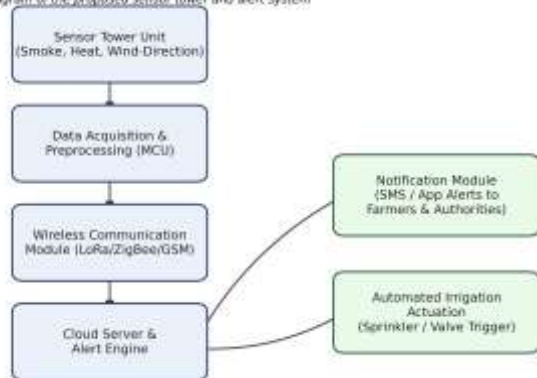


Fig. 1. Block diagram of the proposed sensor tower and alert system.

• Sensor Tower Unit

Each solar-powered tower houses the smoke, heat, and wind-direction sensors, continuously monitoring environmental conditions in its coverage zone.

• Data Acquisition & Preprocessing

Raw sensor values are read by the microcontroller, filtered to remove noise, and checked against fire-indicative thresholds before transmission.

• Wireless Communication Module

Processed readings are transmitted from each tower to a central gateway using a low-power, long-range wireless protocol suited to rural and forested terrain.

• Cloud Server & Alert Engine

The cloud server classifies incoming data as normal or fire-indicative, and manages the alert and irrigation-trigger logic.

• Notification Module

Registered farmers and authorities receive real-time SMS/app alerts identifying the tower location and estimated fire-spread direction.

• Automated Irrigation Actuation

On fire confirmation, the irrigation controller for the affected zone is triggered automatically, beginning water release to contain the fire's spread.

VII. COMPONENTS USED

HARDWARE:

- Solar Panel and Battery Backup Unit
- Smoke Sensor (MQ-2 / MQ-135)
- Heat / Infrared Temperature Sensor
- Wind-Direction Sensor (Anemometer / Wind Vane)
- Microcontroller Unit (ESP32 / Arduino)
- LoRa / ZigBee / GSM Communication Module
- Automated Irrigation Valve / Sprinkler Actuator

SOFTWARE:

- Embedded C / MicroPython (sensor node firmware)
- Cloud Platform (Firebase / AWS IoT / ThingSpeak)
- Python (data classification and alert logic)

- Mobile/Web Dashboard for Farmers and Authorities
- SMS/Push Notification Gateway API

VIII. EXPECTED RESULT

In simulated field trials using controlled smoke and heat sources, the proposed sensor tower network is expected to detect fire-indicative conditions within seconds of ignition, well before the fire becomes visible from a distance. By combining multi-sensor fusion (smoke, heat, and wind direction) with automated irrigation triggering, the system aims to substantially reduce the time between fire ignition and the start of a containment response, compared to manual patrol-based detection.

ANALYSIS OF THE RESULT

- Multi-sensor fusion (smoke + heat + wind) reduces false alarms compared to single-sensor systems.
- Solar power ensures uninterrupted operation in off-grid forest and farm locations.
- Automated irrigation triggering provides an immediate first response before human responders arrive.
- Wind-direction data enables predictive alerting of neighboring zones likely to be affected next.

IX. ADVANTAGES

- Enables early, real-time detection of fire before it spreads widely
- Fully self-powered through solar energy, suitable for remote deployment
- Immediate dual response: human alert and automated irrigation
- Reduces dependency on manual patrolling and satellite revisit delays
- Scalable across large farmland and forest areas using a tower network

X. LIMITATIONS

- Requires adequate water source and infrastructure for irrigation response
- Sensor accuracy may be affected by dust, humidity, or extreme weather
- Initial deployment and tower installation cost can be significant
- Wireless range limitations in dense forest terrain may need signal repeaters
- Solar power availability may reduce during prolonged cloudy or monsoon periods

XI. CONCLUSION

The proposed solar-powered sensor tower network offers an autonomous, always-on solution to the problem of delayed crop and forest fire detection. By integrating smoke, heat, and wind-direction sensing with cloud-based alerting and automated irrigation response, the system can significantly shorten the gap between fire ignition and containment action. Its self-sustaining

solar design makes it well-suited to remote agricultural and forest regions with limited grid access. Future enhancements may include integration of machine learning-based fire classification, drone-assisted verification, and GIS-based spread prediction for large-scale forest management.

XII. REFERENCES

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