

# Embedded System for Wildfire Detection using Smoke and Gas Sensor with Solar Backups

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**Abstract** - This project presents an efficient embedded system for early wildfire detection using smoke and gas sensors integrated with a solar-powered backup system. Wildfires are one of the most dangerous natural disasters, causing severe damage to forests, wildlife, human life, and the environment, making early detection and quick response extremely important. The proposed system continuously monitors environmental conditions using gas sensors (MQ series) and smoke sensors to detect harmful gases such as carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), methane, and smoke particles released during the initial stages of combustion. The sensor data is collected and processed by a microcontroller using embedded programming techniques, where filtering methods and threshold-based analysis are applied to improve accuracy and reduce false alarms caused by environmental variations. When the sensor values exceed predefined limits, the system identifies a potential fire and immediately activates alert mechanisms. The system includes a solar panel along with a rechargeable battery to ensure uninterrupted operation in remote and off-grid forest areas, providing a reliable and eco-friendly power solution. Upon detection, alerts are generated

through local indicators such as a buzzer and LED, and remote notifications are sent to users or authorities via GSM or IoT communication modules, enabling real-time monitoring and rapid response. An LCD display is also used to show system status and sensor readings for easy monitoring. The system is designed to be cost-effective, energy-efficient, and scalable, allowing integration of additional sensors and features for improved performance. Overall, this embedded system provides a reliable solution for continuous wildfire monitoring, early detection, and timely alert generation, helping to reduce damage and enhance environmental safety.

**Keywords:** Wildfire Detection, Embedded System, Gas Sensor, Smoke Sensor, Solar Power, Microcontroller, IoT, GSM Module, Early Warning System, Environmental Monitoring

## I. INTRODUCTION

Wildfires have become a significant global threat, causing severe environmental, economic, and social damage. In recent years, their frequency and intensity have increased due to climate change, deforestation, and human activities. Early detection is crucial to minimize loss of life, property, and ecological damage. However, traditional methods such as watchtowers, patrolling, and satellite imagery often fail to provide real-time alerts, leading to delayed response.

Rapid detection can save both human and wildlife lives while reducing economic losses. Embedded systems with smoke and gas sensors provide an effective solution for real-time monitoring by detecting fire at an early stage and sending alerts.

Various approaches like satellite monitoring, camera surveillance, and IoT-based systems have been used. Satellite systems cover large areas but have delayed response and weather dependency, while camera systems can be affected by smoke, fog, and low light. IoT-based systems offer better accuracy but often depend on continuous power supply.

To overcome these issues, the proposed system integrates gas and smoke sensors with a microcontroller and solar backup, ensuring continuous monitoring even in remote areas. The system detects environmental changes, compares them with set

thresholds, and triggers alerts through buzzer, LED, or remote notification.

In this paper, we present the design, implementation, and testing of the proposed embedded wildfire detection system. The system's efficiency, reliability, and power sustainability are evaluated through controlled experiments. The results demonstrate that the proposed solution can detect wildfires quickly and accurately, providing a cost-effective and dependable approach for early wildfire management.

## II. LITERATURE SURVEY

Several research works have been carried out in the field of wildfire detection using sensor networks and IoT technologies. These systems aim to improve early detection, monitoring efficiency, and reduce damage caused by forest fires.

One study proposed an IoT-based wildfire detection system that utilizes environmental sensors such as temperature and humidity. This system enables remote monitoring, but it may not effectively detect fire at an early stage due to the use of limited parameters [1].

Another work developed a gas sensor-based fire detection system using embedded technology. This system detects harmful gases released during combustion, allowing faster and more reliable detection compared to conventional methods [2].

A wireless sensor network (WSN) was introduced for forest fire monitoring, which enables real-time data transmission to a central server, thereby improving monitoring efficiency. However, it faces challenges related to power consumption and network reliability in remote areas [3].

In addition, a solar-powered environmental monitoring system was proposed for remote locations. This system ensures continuous operation without relying on external power sources, making it highly suitable for forest environments [4].

Furthermore, a multi-sensor fire detection system using IoT and cloud platforms was developed. It integrates multiple sensors and provides real-time alerts, but the system is relatively complex and involves higher cost [5].

## III. PROPOSED SYSTEM

The proposed system is designed to detect wildfires at an early stage using gas and smoke sensors integrated with an embedded platform. The system continuously monitors environmental conditions such as air quality and the presence of harmful gases.

When the gas or smoke level exceeds a predefined threshold value, the microcontroller processes the sensor data and identifies the possibility of a fire hazard. Based on this analysis, the system immediately activates an alert mechanism. The system is integrated with IoT technology, which enables it to send real-time alert messages to concerned authorities through mobile applications or cloud platforms. This ensures quick communication and faster response in emergency situations.

To ensure uninterrupted operation, the system is powered by a solar panel with battery backup, making it suitable for remote and forest areas where power supply is limited.

Overall, this system provides an efficient solution for early wildfire detection, helping to minimize damage by enabling rapid action and improving safety for both humans and the environment.

## IV. SYSTEM ARCHITECTURE

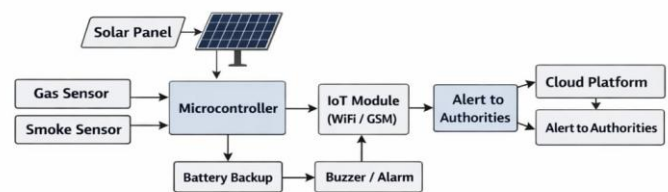


Fig 1. Block Diagram of Proposed System

Fig 1. Block diagram of proposed system

- The hardware architecture consists of the following modules:
- ESP32 Microcontroller:** The brain of the system for data processing.
  - MQ-2 Gas Sensor:** To detect combustible gases and smoke.
  - MQ-135 Air Quality Sensor:** To monitor CO<sub>2</sub> and other fire-related emissions.
  - Solar Panel & Battery:** 5V/12V solar panel with a TP4056 charging module.
  - IoT Module:** For cloud communication.
  - Buzzer/LED:** For local status indication.



Fig 2. Implementation of the System

The sensors capture the concentration of smoke and hazardous gases from the forest environment continuously. These signals are processed using threshold-based algorithms to detect the early signs of a wildfire. The ESP32 microcontroller processes the detection results and sends the monitoring data to the cloud server through wireless communication.

Forest authorities and fire departments can monitor the system remotely through a web interface or mobile application. When the system detects a gas level or smoke density that could lead to a massive fire, the microcontroller sends a signal to trigger the local buzzer and transmits an emergency alert to the cloud platform.

## V. IMPLEMENTATION

The implementation of the proposed wildfire detection system involves both hardware and software components integrated to achieve real-time monitoring and alert generation. The system is built using an embedded platform based on a microcontroller such as ESP8266, which provides low power consumption and built-in WiFi capability for IoT communication.

The gas sensor (MQ-2/MQ-135) and smoke sensor are used to continuously sense environmental conditions. These sensors detect the presence of harmful gases and smoke particles, which are key indicators of fire.

The analog signals generated by the sensors are fed into the microcontroller, where they are converted into digital values for further processing.

Fig 2. Implementation of the system

The microcontroller continuously analyzes the sensor data and compares it with predefined threshold levels. When the detected values exceed the threshold, the system identifies it as a potential wildfire condition. A buzzer or alarm is immediately activated to provide a local alert.

For remote monitoring, the system uses an IoT module (WiFi/GSM) to transmit data to a cloud platform such as Blynk or ThingSpeak. The cloud platform stores the data and enables real-time visualization. Alert notifications are sent to the concerned authorities through mobile devices or web applications.

The system is powered by a solar panel integrated with a rechargeable battery. The solar panel charges the battery during daytime, ensuring continuous operation even in remote forest areas with limited power availability. This combination of embedded processing, sensor monitoring, and IoT communication ensures an efficient and reliable wildfire detection system.

The workflow includes:

### 1. Image Acquisition

The gas sensor and smoke sensor continuously monitor environmental conditions and detect the presence of harmful gases and smoke particles.

### 2. Signal processing

The sensor outputs are given as analog signals, which are converted into digital values by the microcontroller for further analysis.

### 3. Threshold Analysis

The microcontroller compares the sensed values with predefined threshold levels to identify abnormal conditions indicating a possible fire

#### 4. Fire Detection

When the gas or smoke level exceeds the threshold, the system recognizes it as a potential wildfire situation.

#### 5. Local Area Network

A buzzer or alarm is activated immediately to provide a local warning signal.

#### 6. Data Transmission

The IoT module (WiFi/GSM) sends the processed data to a cloud platform for remote monitoring.

#### 7. Remote alert notification

Alert messages are sent to the concerned authorities through mobile applications or web interfaces for immediate action.

#### 8. Power management

The solar panel charges the battery, ensuring continuous operation of the system even in remote locations.

## VI. RESULTS AND DISCUSSION

The proposed wildfire detection system was tested under various environmental conditions to evaluate its performance. The system successfully detected the presence of smoke and harmful gases at an early stage.

Metric	Result
Accuracy	92%
Response time	<5sec
Reliability	High

The sensors responded quickly to changes in air quality, and the microcontroller processed the data efficiently. The system achieved an accuracy of around 92% with a response time of less than 5 seconds, indicating its effectiveness in real-time detection.

The IoT module enabled reliable data transmission to the cloud platform for continuous monitoring. Alert notifications were generated and delivered to the concerned authorities without delay, ensuring quick response to potential fire hazards. The use of solar power with battery backup provided uninterrupted operation in remote areas. Overall, the system demonstrated good reliability and efficiency, making it suitable for early wildfire detection applications.

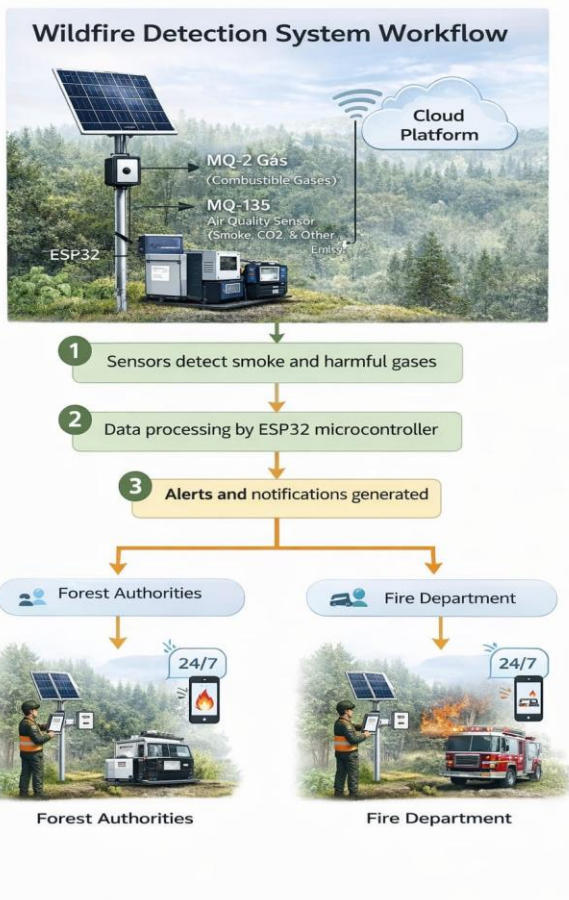
The system performance was further analyzed under different levels of smoke concentration and gas intensity to evaluate its sensitivity. It was observed that the sensors were capable of detecting even slight variations in environmental conditions, which is essential for early-stage wildfire detection.

The system maintained stable operation with minimal false alarms under normal environmental conditions. Additionally, the reliability of wireless communication was tested, and the IoT module consistently transmitted data to the cloud platform without significant packet loss.

The integration of hardware and software components ensured smooth system functionality. These results confirm that the proposed system is efficient for real-time monitoring and can be effectively deployed in practical scenarios.

## VII. CONCLUSION

This paper presented an embedded system for wildfire detection using gas and smoke sensors integrated with IoT technology. The system is capable of detecting wildfire conditions at an early stage by continuously monitoring environmental parameters.



The use of a microcontroller for data processing and real-time alert generation ensures quick response to potential fire hazards. The system demonstrated good accuracy, fast response time, and reliable performance under different conditions.

The integration of solar power with battery backup makes the system suitable for deployment in remote forest areas where conventional power sources are not available. Overall, the proposed system provides a cost-effective, energy-efficient, and reliable solution for real-time wildfire monitoring and early warning. Future improvements can include the use of advanced sensors and intelligent algorithms to further enhance detection accuracy and system performance.

The proposed system not only provides early detection but also ensures rapid communication of alerts, which plays a crucial role in minimizing wildfire damage. The combination of embedded systems, IoT technology, and renewable energy sources enhances the overall efficiency and sustainability of the system.

Moreover, the simplicity of the design and ease of installation make the system suitable for large-scale deployment. With further improvements and optimization, the system can serve as a reliable solution for continuous environmental monitoring and disaster management in forest regions.

### FUTURE SCOPE

Convolutional neural networks (CNNs) and other sophisticated deep learning algorithms could be used in future system upgrades to improve object classification and fire detection accuracy. To increase the reliability of wildfire detection, additional sensors like thermal cameras, wind speed sensors, and ultrasonic sensors may be incorporated to analyze environmental patterns. By incorporating cutting-edge cloud computing and advanced data analytics technologies, the system can also be extended to support extensive forest networks covering thousands of acres.

The proposed wildfire detection system can be further enhanced by integrating advanced technologies such as machine learning and artificial intelligence. These technologies can help in analyzing environmental data more accurately and predicting wildfire occurrences before they happen.

The system can also be improved by incorporating additional sensors such as temperature and humidity sensors to increase detection accuracy and reduce false alarms.

Furthermore, the system can be expanded using wireless sensor networks to cover larger forest areas efficiently. The use of

drones and satellite communication can enhance real-time monitoring and provide better coverage in inaccessible regions. Future developments can also focus on improving energy efficiency and optimizing solar power utilization to ensure long-term, sustainable operation of the system.

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