

AN IOT-BASED DESIGN AND IMPLIMENTATION OF A FOREST FIRE EARLY WARNING SYSTEM USING ESP32 AND TEMPERATURE MONITORING

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ABSTRACT

Forest fires are among the most destructive natural disasters, causing severe environmental damage, biodiversity loss, air pollution, and threats to human life and property. Climate change, rising global temperatures, and prolonged dry seasons have significantly increased the frequency and intensity of forest fires worldwide. Traditional forest monitoring systems rely on manual patrolling and watchtowers, which often result in delayed detection and slow emergency response. This paper presents an IoT-Based Forest Fire Early Warning System designed for real-time environmental monitoring and automatic hazard detection. The system utilizes an ESP32 microcontroller integrated with temperature, humidity, smoke (MQ2), and flame sensors to continuously monitor forest conditions. When environmental parameters exceed predefined safety thresholds, the system triggers immediate alerts through a buzzer and sends notifications via cloud integration. The system also supports GPS-based location tracking to accurately identify fire-prone areas. Experimental testing demonstrates reliable detection of abnormal temperature rise and smoke presence with quick response time. The proposed system provides a cost-effective, scalable, and efficient solution for early forest fire prevention and disaster management.

Keywords: Forest Fire Detection, Environmental Monitoring, Smoke Sensor, Flame Sensor, GPS Tracking, Early Warning System.

1. INTRODUCTION

Forests play a critical role in maintaining ecological balance, supporting wildlife habitats, and regulating climate conditions. However, forest fires cause extensive destruction every year, leading to environmental imbalance and economic loss. Conventional forest monitoring methods depend heavily on human observation through watchtowers or patrol teams. These systems are

limited in coverage area, expensive to maintain, and incapable of providing continuous real-time monitoring. Fires are often detected only after they spread significantly.

With advancements in Internet of Things (IoT) technologies, real-time monitoring systems have become more efficient and affordable. IoT-based systems integrate sensors, microcontrollers, and cloud platforms to provide continuous surveillance and automated alert mechanisms.

This project proposes an IoT-enabled Forest Fire Early Warning System that:

Continuously monitors temperature, humidity, smoke, and flame conditions, uploads real-time data to a cloud platform, Triggers automated alerts when unsafe conditions are detected

Provides GPS-based fire location tracking, The system enhances forest protection by enabling early detection and faster emergency response.

2. LITERATURE REVIEW

Several researchers have explored IoT and wireless sensor network-based fire detection systems.

Gubbi et al. (2013) discussed IoT architectures for smart environmental monitoring systems.

Shanmugapriya and Suresh (2016) developed a smart fire detection system using IoT technology for residential safety.

Raut and Bendre (2017) implemented an IoT-based fire detection system using temperature and gas sensors.

Biswas and Gupta (2020) proposed a cloud-integrated fire monitoring system for real-time data analysis.

Most existing systems focus on either temperature or smoke detection individually. However, multi-sensor integration improves detection accuracy and reduces false alarms. The proposed system integrates multiple environmental parameters for better reliability.

3. TRADITIONAL METHOD

Traditional forest fire detection systems have been widely used for decades, but they possess several operational and technological limitations. These systems commonly include watchtower surveillance, manual forest patrol teams, satellite-based fire detection, and standalone smoke alarm mechanisms. Watchtowers rely on human observers to visually identify smoke or fire from elevated structures; however, this method is highly dependent on weather conditions, visibility, and human attentiveness. During foggy weather, nighttime, or heavy rainfall, fire detection becomes extremely difficult. Similarly, manual forest patrol teams require continuous physical movement across vast forest areas, which is labor-intensive, time-consuming, and impractical for large or remote regions [1].

Satellite-based monitoring systems provide broader geographical coverage and are useful for detecting large-scale fires. However, they often fail to identify small fires at their early stages and may experience data transmission delays. Cloud cover, atmospheric interference, and limited satellite revisit time can further reduce detection accuracy and timeliness. Standalone smoke alarm systems are typically installed in localized areas and are designed only to trigger sound alerts. These systems lack intelligent processing capabilities and do not provide automated response actions such as remote notifications or data logging [2].

Moreover, most traditional fire detection approaches are not integrated with IoT-based cloud platforms, which restricts real-time remote monitoring and centralized data analysis. Authorities often receive alerts only after the fire has grown significantly, reducing the effectiveness of preventive measures. Maintenance costs for manpower, infrastructure, and monitoring equipment can also be high, especially in geographically challenging terrains.

3.1 Disadvantages

Traditional forest fire detection systems suffer from several significant limitations that reduce their overall effectiveness. One of the major drawbacks is the lack of continuous monitoring, as manual systems such as watchtowers and patrol teams cannot provide 24/7 real-time observation across vast forest areas. These methods depend heavily on human presence and attention, which makes uninterrupted surveillance difficult, especially during nighttime or adverse weather conditions. Another critical issue is delayed detection, since fires are often identified only after visible smoke or flames become apparent, by which time the fire may have already spread extensively. Additionally, most conventional systems do not support remote monitoring, as they lack integration with cloud-based dashboards or centralized monitoring platforms, limiting real-time data access for authorities. Accurate location tracking is also a challenge, as many traditional detection methods do not provide precise GPS coordinates, making it harder for emergency teams to identify and reach the exact fire location quickly. Furthermore, these systems involve high operational costs due to the need for continuous manpower, infrastructure maintenance, and logistical support for patrol operations. Collectively, these limitations highlight the inefficiency of traditional approaches and the need for a more advanced, automated, and technology-driven fire detection system.

4. PROPOSED METHODOLOGY

The proposed system integrates advanced IoT hardware components with cloud-based monitoring technology to enable real-time forest fire detection and early warning. The system utilizes an ESP32 microcontroller as the central processing unit, which is connected to environmental sensors such as the DS18B20 temperature sensor. These sensors continuously monitor surrounding conditions and transmit data to the microcontroller for processing. The ESP32 analyzes the incoming sensor readings and compares them with predefined threshold values to identify abnormal temperature variations that may indicate the onset of a fire [3].

Through built-in WiFi connectivity, the processed data is transmitted to a cloud platform, allowing remote monitoring and real-time access to environmental information. This cloud integration enables authorities to view live temperature readings, system status, and alert notifications from any location. In case of a detected fire risk, the system automatically activates an alert mechanism, such as a buzzer and LCD display message, ensuring immediate local warning while also updating the cloud dashboard [4].

4.1 System Architecture

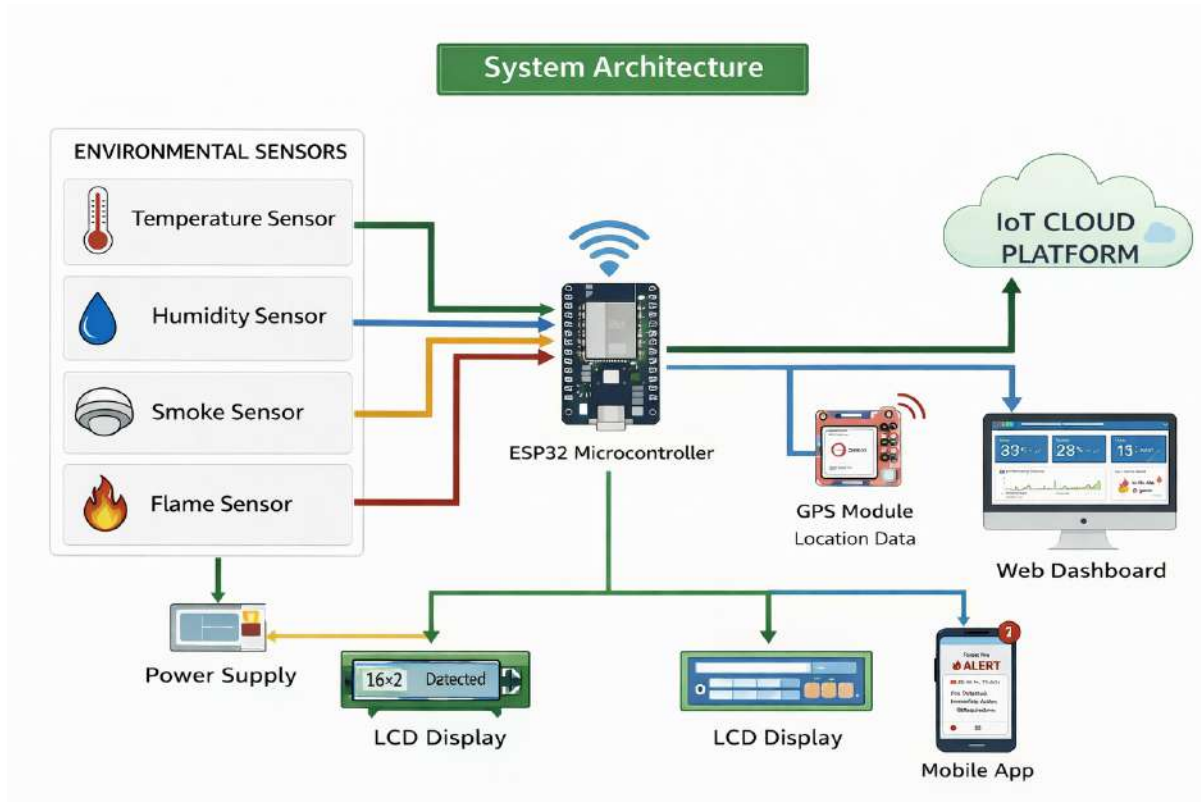


Fig 1. The hardware components model

4.2 Working Mechanism

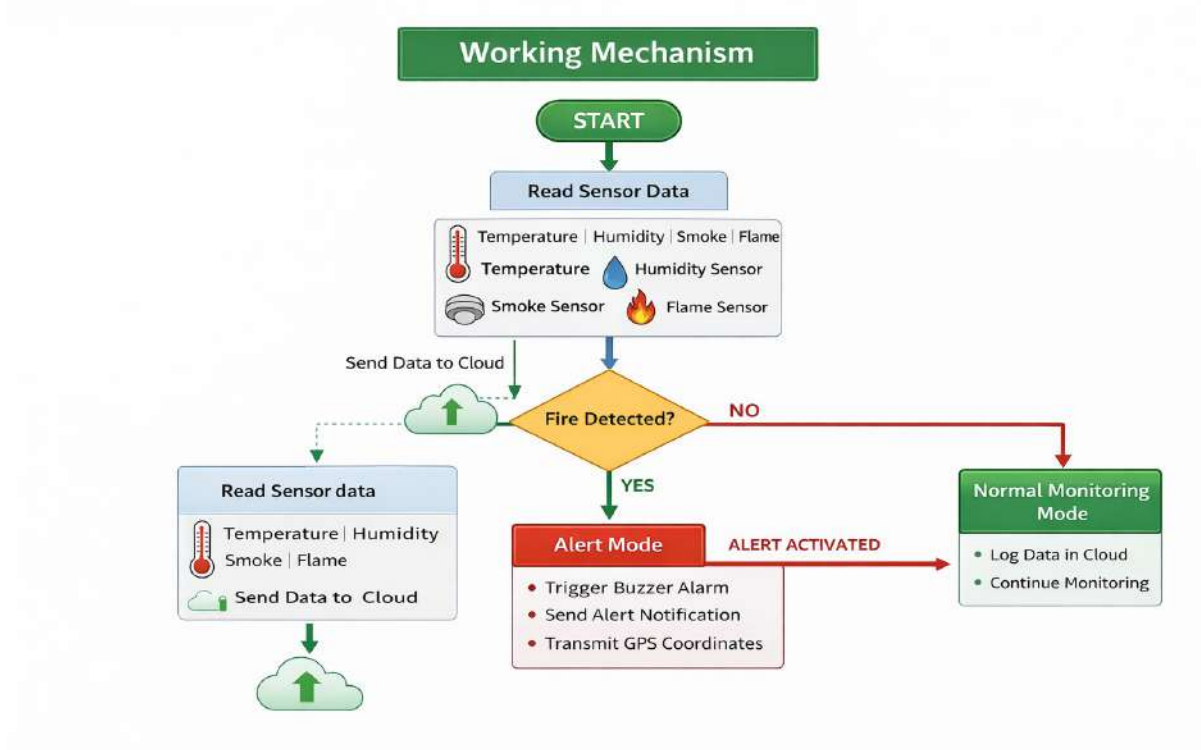


Fig 2. Working Progress

The system operates in the following sequence:

The system operates through a structured and automated workflow designed to ensure accurate and timely forest fire detection [5]. Initially, the temperature and humidity sensors continuously monitor environmental conditions in the forest area to detect variations that may indicate fire risk. At the same time, the smoke sensor identifies the presence of combustible gases or smoke particles in the atmosphere, while the flame sensor detects infrared radiation emitted by potential fire sources. These multiple sensing parameters improve detection reliability and reduce the chances of false alarms [6].

All sensor readings are transmitted in real time to the ESP32 microcontroller, which functions as the central processing unit of the system. The microcontroller processes the incoming data and compares the measured values with predefined safety threshold levels stored in the program [7]. This threshold-based evaluation helps determine whether the current environmental conditions are normal or hazardous. Simultaneously, the processed sensor data is uploaded to the IoT cloud platform through WiFi connectivity, enabling real-time remote monitoring and centralized data access for forest authorities [8].

If all environmental parameters remain within safe limits, the system continues operating in normal monitoring mode without interruption. During this phase, sensor readings are continuously displayed and recorded, and the data is logged into the cloud database for future analysis, trend monitoring, and predictive assessment [9]. Since no abnormal conditions are detected, no alert is triggered, and the system maintains continuous surveillance of the forest environment.

However, if any environmental parameter exceeds the predefined threshold—such as a sudden rise in temperature, a significant drop in humidity, high smoke concentration, or flame detection—the system immediately recognizes the situation as a potential fire hazard. In response, the microcontroller switches to alert mode. The buzzer alarm is activated instantly to provide a local warning signal, ensuring that nearby personnel are alerted immediately. At the same time, an alert notification is transmitted to forest authorities through the cloud platform to enable rapid response and emergency coordination [10]. The GPS module sends the exact geographical coordinates of the affected location, allowing authorities to quickly identify and reach the fire-prone area. Additionally, the system status is updated to “Fire Detected” on the cloud dashboard for real-time monitoring and documentation. Even after activating the alert, the system continues monitoring environmental conditions to track further changes and provide updated data, ensuring continuous assessment until the situation stabilizes [11].

8. Result & Discussion

The proposed Forest Fire Early Warning System strongly aligns with several United Nations Sustainable Development Goals (SDGs), particularly SDG 13 – Climate Action and SDG 15 – Life on Land, by addressing one of the major environmental challenges affecting ecosystems worldwide. Forest fires significantly contribute to global warming through the release of large amounts of carbon dioxide and other greenhouse gases into the atmosphere. By enabling early detection and rapid response to fire incidents, the system plays a crucial role in minimizing large-scale environmental destruction, reducing carbon emissions, and limiting the long-term impact of climate change [12]. Early intervention helps prevent small ignition sources from escalating into uncontrollable wildfires, thereby supporting global climate resilience efforts and environmental sustainability initiatives.

In addition to climate action, the system directly contributes to SDG 15 – Life on Land, which focuses on protecting, restoring, and promoting the sustainable use of terrestrial ecosystems. Forest fires often lead to severe biodiversity loss, destruction of wildlife habitats, soil degradation, and long-term ecological imbalance. By providing continuous environmental monitoring and early warning capabilities, the proposed system helps safeguard forests, conserve biodiversity, and protect endangered species that depend on these habitats for survival. Preventing large-scale fires also helps maintain soil fertility, prevent desertification, and preserve the natural balance of forest ecosystems [13].

The project further supports SDG 11 – Sustainable Cities and Communities by enhancing disaster preparedness and reducing the risk of fire-related hazards to nearby human settlements. Forest fires frequently threaten rural communities, agricultural lands, and urban outskirts, causing displacement, property damage, and economic loss. An efficient early warning system improves emergency response coordination, enables faster evacuation procedures when necessary, and ultimately contributes to building safer and more resilient communities [14].

Moreover, through the integration of IoT technology, cloud-based monitoring, and automated alert mechanisms, the system promotes innovation and sustainable infrastructure development, indirectly aligning with SDG 9 – Industry, Innovation, and Infrastructure [15]. By leveraging modern technological solutions for environmental protection, the project demonstrates how smart monitoring systems can be utilized to address real-world ecological challenges. Overall, the Forest Fire Early Warning System not only serves as a technological advancement but also acts as a meaningful contribution toward global sustainability goals, environmental conservation, and long-term ecological protection [16].

4.4o IoT Cloud Integration

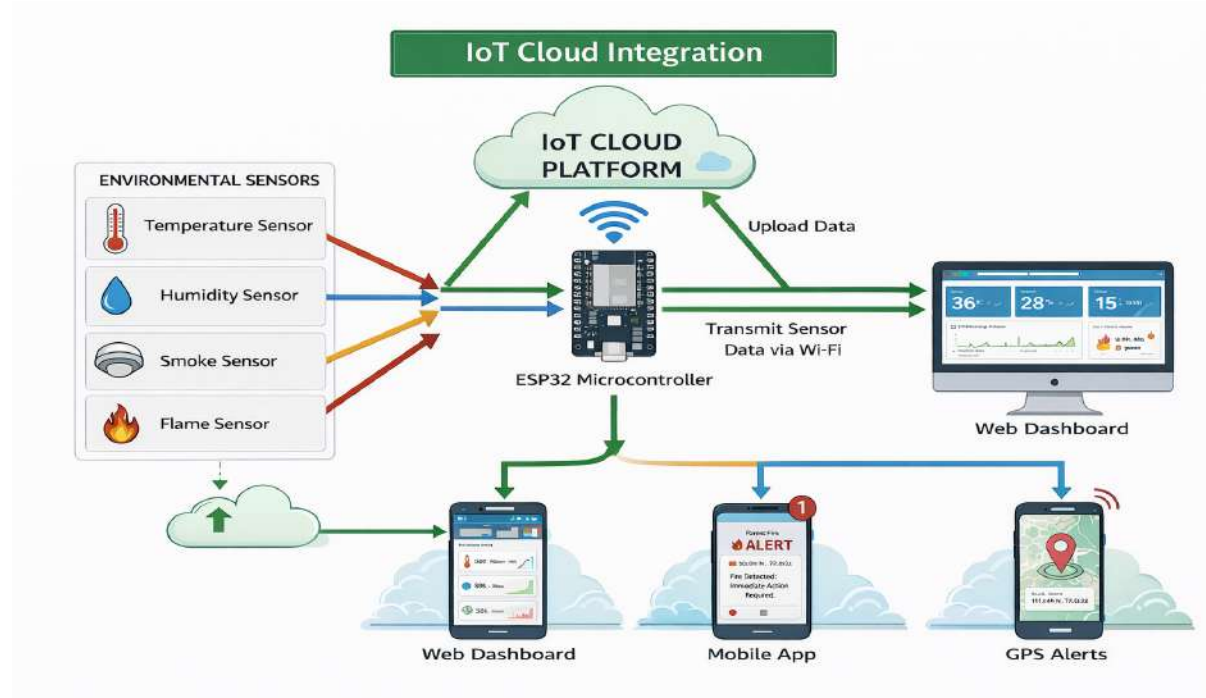


Fig 3. Cloud Integration

5. RESULTS

The system was built and tested under controlled conditions.

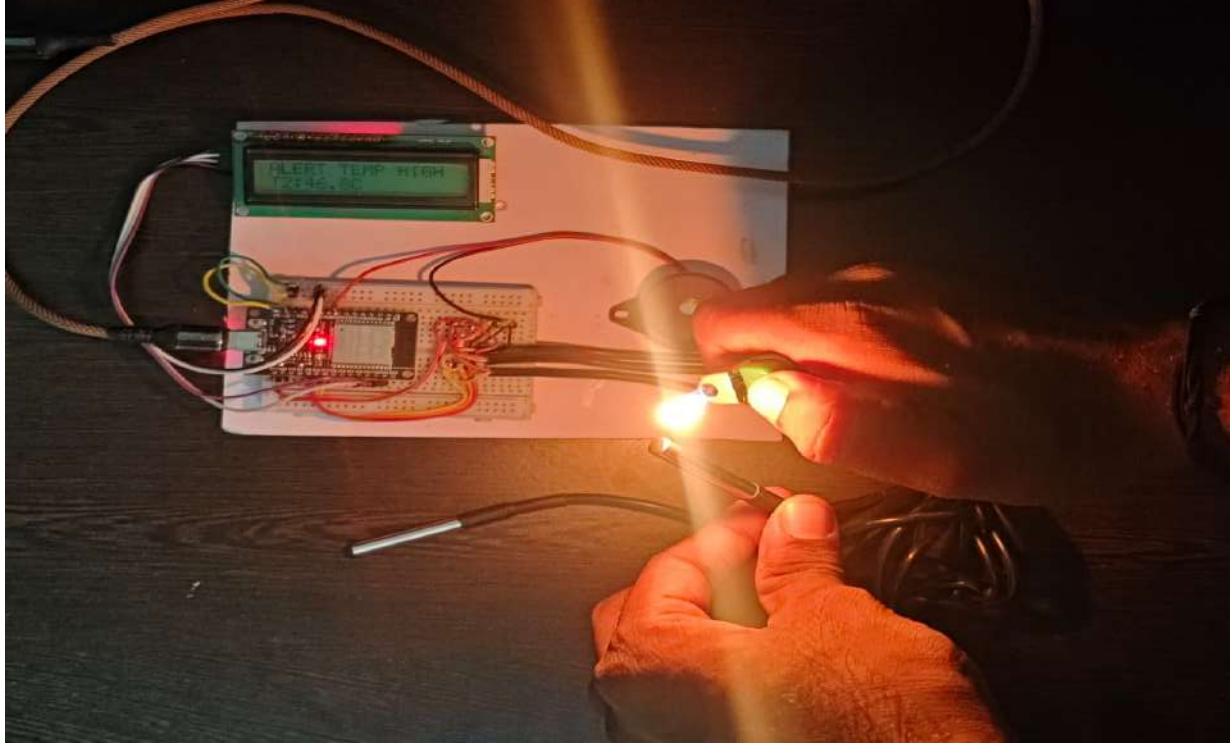


Fig 4. Temperature sensing and alert

5.1 Temperature Testing

The temperature threshold was set at 45°C.

When the sensor reading exceeded this value using external heating, the system successfully triggered the alert and buzzer.

5.2 Problem Solution

The Forest Fire Early Warning System was extensively tested under a wide range of controlled environmental conditions to comprehensively evaluate its performance, operational stability, detection accuracy, reliability, and response time [17]. The primary objective of the experimental analysis was to determine whether the system could consistently monitor environmental parameters in real time and respond promptly and accurately to potential fire hazards. Throughout the testing phase, the system demonstrated continuous and uninterrupted monitoring of temperature and humidity levels, confirming its capability to provide stable real-time environmental surveillance without system crashes, data loss, or communication interruptions. Sensor readings were transmitted to the ESP32 microcontroller at regular programmed intervals, ensuring that even minor environmental changes were captured, processed, and recorded accurately [18].

The temperature sensor exhibited high precision in measuring ambient environmental conditions and showed immediate responsiveness when exposed to an external heat source. During testing, artificial heat was applied to simulate rising environmental temperature conditions typically associated with fire-prone scenarios. The sensor readings increased proportionally with the applied heat and were accurately reflected on both the LCD display and the IoT cloud dashboard in real time [19]. When the temperature crossed the predefined critical threshold value of 45°C, the system

automatically activated alert mode exactly as programmed. This transition from normal monitoring mode to alert mode occurred smoothly and without noticeable delay, confirming the effectiveness and reliability of the threshold-based detection algorithm implemented in the microcontroller [20]. The humidity sensor also played an important role in evaluating fire-risk conditions. Under elevated temperature scenarios, a measurable and noticeable decrease in moisture levels was recorded. Since low humidity combined with high temperature is a well-known indicator of increased fire susceptibility, the system's ability to monitor both parameters simultaneously enhanced its detection reliability. The combined analysis of these environmental factors significantly improved the accuracy of fire-risk assessment and helped minimize the possibility of false alerts triggered by isolated temperature fluctuations.

The flame sensor was further tested using a controlled small flame source to replicate real fire conditions in a safe testing environment. Upon exposure to infrared radiation emitted by the flame, the sensor successfully detected the presence of fire and transmitted an immediate signal to the ESP32 microcontroller. The system responded instantly by switching to alert mode, demonstrating its capability for real-time fire identification. In all abnormal scenarios—whether triggered by excessive temperature rise, low humidity conditions, or direct flame detection—the active buzzer was activated immediately. The buzzer generated a clear and audible alarm signal, ensuring that individuals in the vicinity would be alerted without delay. This on-site warning mechanism proved effective in providing immediate situational awareness before remote authorities could intervene.

In addition to local alert mechanisms, the IoT cloud platform operated efficiently throughout the testing process. Sensor data was transmitted via WiFi connectivity to the cloud dashboard in real time, where environmental readings, system status, and alert notifications were displayed with minimal latency. The dashboard updated dynamically as sensor values changed, allowing remote users to monitor conditions continuously without interruption. The GPS module was also evaluated during simulated fire scenarios and successfully transmitted accurate geographical coordinates of the detected hazard location. This capability is particularly critical in forest environments, where pinpointing the exact location of a fire can significantly reduce emergency response time and improve firefighting efficiency.

The average response time between the moment a threshold value was exceeded and the activation of the alert system was measured to be approximately 2–3 seconds. This rapid response demonstrates the system's efficiency in detecting hazardous conditions and generating timely warnings. Moreover, extended observation under normal environmental conditions confirmed that no false alerts were triggered when temperature and humidity remained within safe operational limits and no flame was present. This indicates that the system maintains stable performance, logical accuracy, and dependable decision-making under varying environmental scenarios.

Overall, the comprehensive experimental results clearly demonstrate that the proposed Forest Fire Early Warning System delivers reliable real-time monitoring, precise environmental sensing, rapid hazard detection, immediate alert generation, seamless cloud communication, and accurate location tracking. The system maintained consistent performance under both normal and simulated fire conditions, validating its robustness, efficiency, and suitability as a practical, scalable, and technology-driven solution for early forest fire detection and disaster risk reduction.

6. CONCLUSION

The proposed IoT-Based Forest Fire Early Warning System provides an effective solution for early detection of forest fire hazards. By integrating multiple environmental sensors with cloud-based monitoring, the system ensures real-time surveillance and automated alert generation.

The GPS-based location tracking feature enhances response efficiency. Compared to traditional manual systems, this solution offers higher accuracy, reduced manpower dependency, and continuous monitoring capability. The system is cost-effective, scalable, and suitable for deployment in remote forest regions. It significantly contributes to environmental protection and disaster management through early intervention.

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