# Real-time forest fire detection, monitoring, and alert system using Arduino

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**ABSTRACT**

Early fire detection is critical to protecting forests from wildfires and enabling rapid responses to minimize fire spread. Existing forest fire detection methods cannot quickly detect forest fires and evaluate the fire risk of these sensitive areas. Hence, this research aims to develop a real-time forest fire detection, monitoring, and alert system. The development of the system started with assembling temperature and humidity sensors, a smoke sensor, an Arduino microcontroller, and a wireless fidelity module. Then, a fire monitoring and alert system was developed using Blynk. From the sensitivity flame sensor analysis with the fire, the flame sensor detected the presence of fire up to 60 cm. The sensor also indicated high temperature (45 °C) and low humidity (53.4%) at noon. Low temperature (29 °C) and high humidity (88.4%) were identified in the morning. Moreover, the highest carbon dioxide ($CO_2$) concentration of 1,800 ppm was recorded when the smoke from the fire was detected. The global positioning system module shows the accurate real-time location of the system displayed in the Blynk application. In conclusion, this system can detect and monitor early forest fires in real-time and can alert the authorities to protect forests from wildfires.



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## 1. INTRODUCTION

Every year, the world witnesses new, devastating wildfires. These forest fires present significant hazards to human lives, wildlife, and global vegetation [1]. Forest fires can be categorized into two primary types: surface and crown fires. A surface fire propagates across the forest floor, while a crown fire consumes the upper canopies of trees and shrubs. Crown fires are typically initiated by surface fires, often resulting from accidental human activities such as unattended campfires or open burning. Furthermore, natural phenomena like high atmospheric temperatures and lightning strikes contribute to forest fires [2]. Forest fires can be initiated by natural or anthropogenic sources often associated with land clearing and deforestation activities in tropical, temperate, and boreal forests. These fires, in turn, contribute to the greenhouse effect and climate change by elevating atmospheric carbon dioxide levels [3], [4]. Prior to the advent of technology, forest fire monitoring heavily relied on manual human observation methods. Fire lookout towers were constructed and strategically placed in elevated positions across various forest landscapes for monitoring purposes [5], [6]. However, this conventional approach demanded extensive human and material resources and could not provide real-time monitoring data.

Contemporary forest fire monitoring systems primarily involve satellite imagery, although such monitoring is not done in real-time and requires manual analysis by authorities. This approach has several inherent disadvantages, notably its inability to rapidly detect forest fires and assess the fire risk in these vulnerable regions [7], [8]. Satellite-based monitoring is further compromised by adverse weather conditions, rendering it relatively inaccurate and unreliable due to its dependence on weather patterns. Additionally, high spatial resolution satellite images are expensive. Furthermore, overcast conditions significantly hinder the generation of precise forest images. In the modern era, technology has made significant advancements, enabling the development of highly effective fire monitoring systems [9], [10]. Various research approaches have been employed to create these systems, including image processing [11]–[13], airborne technologies [14]–[16], and fuzzy logic-based approaches [17], [18].

Mohammed *et al.* [19] conducted a comparative study of machine learning algorithms for early forest fire detection using geodata. It proposed a spatial prediction model for real-time identification of fire risk zones, alerting authorities and presenting geographical treatments for enhanced efficacy. However, the study was conducted in the northeastern region of Portugal, and the results may not be directly applicable to other regions with different environmental and climatic conditions. Meanwhile, Grari *et al.* [20], the research presented a machine learning-based approach for early wildfire detection using internet of things (IoT) devices equipped with sensors. The proposed approach has the potential to significantly improve the efficiency of detecting active forest fires and mitigate the harmful impact of wildfires on public health, biodiversity, and the economy. However, the effectiveness of the approach may depend on the quality and accuracy of the data collected by the IoT sensors, as well as the availability and reliability of the communication networks used to transmit the data to the machine learning model.

An innovative alternative for fire detection within areas is the utilization of wireless sensor networks (WSNs) based on fourth-generation long-term evolution technology [21]. A WSN comprises numerous small nodes connected wirelessly to facilitate interactions between humans or computers and the surrounding environment [22]. Alkhatib [23], for instance, implemented a WSN system for forest fire detection utilizing a sub-network coverage technique. This network was assembled using waspmotes communicating through XBee 802.15.4. The proposed solution involved dividing the network into three subnetworks, resulting in a remarkable 2.7% extension of the network’s lifespan. Herutomo *et al.* [24] conducted a reliability assessment on a machine-to-machine forest WSN detection system. The system was equipped with various components, including a gas sensor (MQ7), a temperature sensor (LM35), a humidity sensor (DHT11), a global positioning system (GPS) shield, and an XBee adapter. These components were integrated with Arduino UNO nodes to facilitate Zigbee communication. The nodes exhibited a maximum operational range of 341 meters and a transmission time of 1,250 milliseconds.

Alagarsamy *et al.* [25] introduced a WSN framework for forest fire detection, utilizing a degree-supervised snitch approach with gossip routing to optimize communication and energy consumption. The proposed methodology employed node-to-cluster header communication to enhance efficiency demonstrated through simulations. It emphasized the framework's potential for accurate and timely forest fire detection, contributing to improved environmental monitoring and fire management. However, the research needs to highlight real-world testing and optimization to address potential limitations in different environmental settings. Furthermore, building on the research of Vega-Rodriguez *et al.* [26], a cost-effective forest fire detection system was developed utilizing long-range (LoRa) technology. This system featured a LoRa node and sensors designed to monitor variables such as temperature, relative humidity, wind speed, and carbon dioxide ($CO_2$) levels. A similar setup was implemented in [27], incorporating $CO_2$, temperature, humidity, and wind speed sensors linked to an Arduino platform and the Dragino LoRa shield for comprehensive environmental monitoring. The system underwent rigorous testing in a natural environment, with assessments covering the received signal strength indicator, signal-to-noise ratio, and the functionality of the sensor modules.

A critical issue with existing forest fire detection systems employing WSNs is their limited focus on sensor data analysis, often lacking direct connections to user monitoring and alert mechanisms. Equally significant is the precise localization of the fire’s point of origin, a critical factor for firefighters and first responders. Delays in alerting them to fires can substantially increase the risks they face, potentially resulting in dangerous situations and more casualties. Without a real-time alert system, firefighting resources may be deployed reactively rather than proactively, leading to inefficiencies and reduced effectiveness in fire containment. Hence, the primary objective of this project is to implement a real-time forest fire detection, monitoring, and alert system utilizing a WSN. Several specific objectives must be accomplished to achieve this overarching goal. First and foremost, it is imperative to design a fire detection system integrating Arduino, temperature and humidity sensors, a smoke sensor, and general packet radio service (GPRS) technology. Subsequently, a software application for real-time fire detection, monitoring, and alert must be developed. Finally, an in-depth analysis of the monitoring system’s performance, encompassing parameters such as temperature, humidity, and $CO_2$ concentration, is a crucial component of this project.

The rest of this work is organized as follows: Section 2 discusses the process of developing a real-time forest fire detection, monitoring and alert system. Meanwhile, section 3 presents the results collected from the experiments. All collected results are displayed and analyzed. Lastly, section 4 concludes the present work.

## 2. DEVELOPMENT OF A REAL-TIME FOREST FIRE DETECTION, MONITORING, AND ALERT SYSTEM

The methodology started with the design of the prototype of the forest fire detection device using Arduino, a temperature and humidity sensor, a smoke sensor, and a GPRS. The next step is to develop a software application for real-time fire detection, monitoring, and alert systems. Lastly, the monitoring system’s performance in terms of temperature, humidity sensor, and $CO_2$ concentration was tested and analyzed. Figure 1 shows the prototype of the forest fire detection device. Figure 1(a) shows the schematic diagram of the prototype. Temperature and humidity sensors (DHT11), a smoke sensor (MQ135), a flame sensor, and a GPS module were connected to the Arduino microcontroller [28]. Figure 1(b) shows a device connection diagram. Figure 1(c) depicts the device box. This box was placed in the remote forest area to monitor fire detection. The box contains a microcontroller Arduino, a Zigbee Arduino shield, and a 12 V power supply. The top of the lid consists of three sensors: a flame sensor, a smoke sensor, and a temperature and humidity sensor.

Figure 2 shows the prototype of the forest fire gateway. Figures 2(a) and 2(b) depict a schematic diagram and a device connection diagram of the gateway, respectively. The receiver box contains a microcontroller Arduino, WiFi shield Arduino, and Zigbee. The gateway was placed outside the jungle where the Arduino controller could receive GPRS/WiFi signals.


(a) (b) (c)

Figure 1. Prototype of the forest fire detection device; (a) a schematic diagram, (b) a device connection diagram, and (c) the front view of the device box

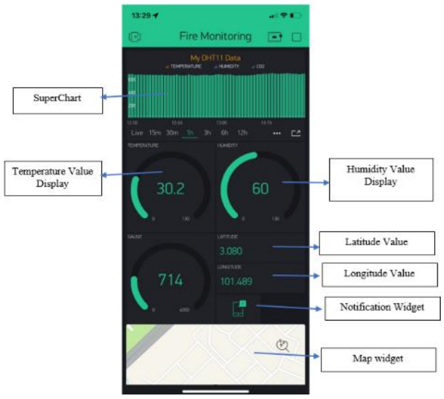

(a) (b)

Figure 2. Prototype of the forest fire detection gateway (a) a schematic diagram and (b) a device connection diagram

Figure 3 shows a real-time forest fire detection, monitoring, and alert system. All configurations and graphical user interfaces have been created for smartphones using Blynk 2.0. Based on Figure 3(a), the widget used in this system was a super chart, gauge, value display, notification, and map widget. The super charts were used to collect all the temperature, humidity, and $CO_2$ readings from the sensor and visualize live and historical data. This system implemented a three-gauge widget and value display in the software application. The incoming data from sensors (temperature, humidity, and $CO_2$ level) were displayed by the gauge.

Figure 3(b) shows code snippets to display and record all the data from the sensor. Figure 3(c) shows the code snippets for alert notification in Blynk. If the flame is equal to zero, the Blynk will send a notification "Fire! Fire!" indicating that the fire is nearby. The value display widget displayed the latitude and longitude of the device box. The notification widget was also implemented to generate a notification when the flame sensor detected a flame or fire. Lastly, the map widget was used to track and determine the exact location of the transmitter box consisting of all the sensors. The monitoring and alert system started by collecting and receiving data from the sensor. The data were then transferred through the GPRS network. Next, data were converted into digital signals and sent to Zigbee for transmission and reception. Lastly, an alarm signal was sent when the fire was detected.

The forest fire detection device and gateway were tested in the forest community Shah Alam demographic comprising 4,596 hectares. The placements of the forest fire detection device and gateway are shown in Figure 4. Figure 4(a) shows the placement of the forest fire detection device within the area without internet coverage; Figure 4(b) shows the placement of the gateway within the internet coverage area. The distance between the device and the gateway was 10 m. The system started by collecting and receiving the data from the sensor, and the data were then transferred through the GPRS/WiFi network. Next, data were converted into digital signals and sent to Zigbee for transmission and reception. Lastly, an alarm signal was sent when the fire was detected.




(a)

```
Blynk.virtualWrite(V1, data[1]);
Blynk.virtualWrite(V2, data[2]);
Blynk.virtualWrite(V6, data[1]);
Blynk.virtualWrite(V7, data[2]);
Blynk.virtualWrite(V8, data[3]);
Blynk.virtualWrite(V9, Lat);
Blynk.virtualWrite(V10, Long);
```

(b)

```
if(Flame == 0)
{
  Blynk.notify("Fire! Fire!");
}
```

(c)

Figure 3. Real-time forest fire detection, monitoring, and alert system; (a) graphical user interfaces, (b) code snippets for data display, and (c) code snippets for alert notification in Blynk

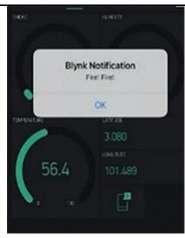
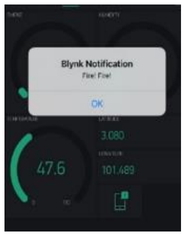
(a) (b)

Figure 4. The placement of (a) a fire detection device and (b) a gateway in the forest community Shah Alam

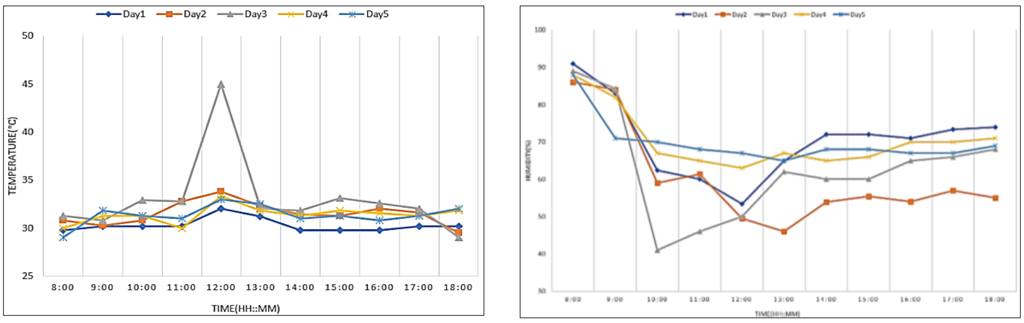
## 3. RESULTS AND DISCUSSION

Table 1 shows the results of the flame sensor range from the fire. The experiment was conducted in a flat and open area to avoid an actual fire hazard. Three ranges of flame sensors were tested: 30 cm, 60 cm, and 90 cm. The results were observed via the Blynk app. If the Blynk app sends the notification “Fire! Fire!” it means the flame sensor can sense the presence of a flame or fire, and the sensor’s temperature increases. According to Table 1, the flame sensor detected the presence of a fire within the 30 cm and 60 cm range at 56.4 °C and 47.6 °C; the flame sensor could not detect a fire within 90 cm.

Table 1. Results of flame sensors located different distances from a fire

| Distance between the flame sensor and fire | Experimental figure | Temperature, humidity, and $CO_2$ concentration | Results from the monitoring system |
|---|---|---|---|
| 30 cm |  | Temperature = 56.4 °C<br>Humidity = 52%<br>$CO_2$ = 100 ppm |  |
| 60 cm |  | Temperature = 47.6 °C<br>Humidity = 62%<br>$CO_2$ = 1,748 ppm |  |
| 90 cm |  | Temperature = 34.7 °C<br>Humidity = 45%<br>$CO_2$ = 1,060 ppm |  |

Figures 5 to 8 depict the results obtained from the experimental test in forest community Shah Alam. Figure 5 shows the reading from the DHT11 sensor from day 1 until day 5. Figure 5(a) shows that the highest temperatures from day 1 until day 5 were recorded at 12:00 p.m. and 1:00 p.m. According to the graph, the highest temperature (45 °C) was recorded on day 3 at 12:00 p.m. This is because the experiment was conducted near the fire at that time. The temperature slowly dropped starting at 4:00 p.m. Figure 5(b) shows the humidity trend from day 1 until day 5. Because of the dew and air condensation in the early morning, the average humidity for the seven days was high between 8:00 a.m. and 9:00 a.m. The humidity was around 88.4% on average. At 12:00 p.m., the humidity became low because the temperature was high at that time. Figure 6 shows the trend of $CO_2$ concentration from MQ135 from day 1 until day 5. According to the graph, the highest $CO_2$ concentration of 1,800 ppm was recorded on day 3 at 1:00 p.m. The sensor detected the presence of the gas emitted by the fire.




(a) (b)

Figure 5. Readings from the experimental test in forest community Shah Alam for (a) temperature and (b) humidity

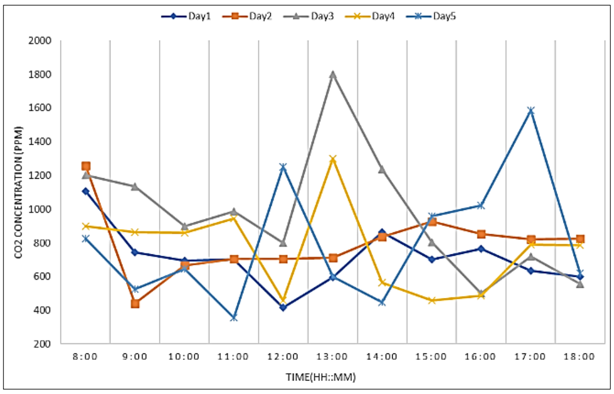
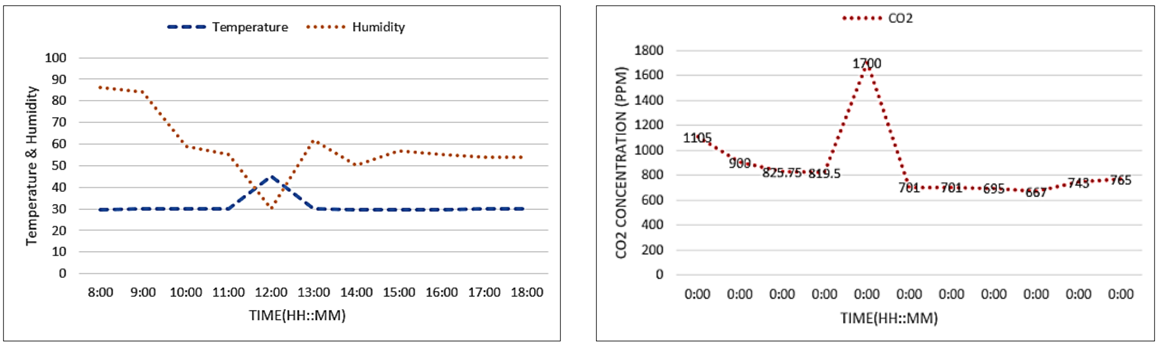



Figure 6. Readings from the experimental test in forest community Shah Alam for $CO_2$ concentration

Figure 7 shows the readings from the flame sensor range experiment. Figure 7(a) depicts the temperature and humidity readings, and Figure 7(b) shows the $CO_2$ concentration readings. At 12:00 p.m., when the sensor was placed near the flame, the temperature was 45.2 °C, the humidity was 30%, and the $CO_2$ concentration was 1,700 rpm. The temperature sensor's reading rapidly increased when the sensor was near the flame, and the humidity decreased due to the flame's high temperature. $CO_2$ concentration also rapidly increased because the fire heavily contaminated the air quality.

Figure 8 shows the location of the forest fire detection device on the monitoring system. The black indicator shows the location of the GPS sensor. Meanwhile, the blue indicator shows the location of the phone or users. The location of the forest fire detection device shown on the monitoring system gave an accurate location. This is because the transmitter module shows the exact location of the experiment place, which is at forest community Shah Alam. It is important for the user to know the fire's exact location in the forest to prevent it from spreading.

The ramifications of the findings presented in the research are significant and have the potential to influence future developments in forest fire prevention and management. The developed real-time forest fire detection system addresses a critical need for early detection and rapid response to forest fires. Its immediate impact lies in its ability to provide timely alerts to authorities and relevant stakeholders, enabling them to take proactive measures to contain and extinguish fires before they escalate. This can lead to reduced damage to forests, wildlife, and human lives, as well as minimized economic and environmental consequences. In addition, the technology and methodology employed in this research can serve as a foundation for future advancements in forest fire detection and monitoring systems. The integration of Arduino microcontrollers, wireless communication modules, and various sensors sets a precedent for the development of more sophisticated and robust systems. Future iterations of such systems could incorporate machine learning techniques for enhanced predictive capabilities and the integration of satellite data for broader coverage and more accurate fire mapping.




(a) (b)

Figure 7. Readings from the flame sensor range experiment for (a) temperature and humidity and (b) $CO_2$ concentration

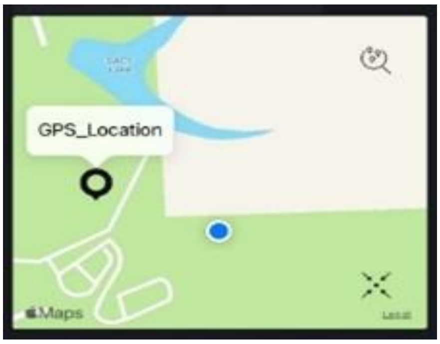



Figure 8. Location of the fire detection device

The data collected and analyzed by the real-time forest fire detection system can be utilized by authorities and policymakers to make informed decisions regarding forest management, fire prevention strategies, and resource allocation for firefighting efforts. The insights derived from the system's performance can contribute to the development of evidence-based policies aimed at reducing the occurrence and impact of forest fires. Therefore, the findings from this research not only address an immediate need for effective forest fire detection and monitoring but also lay the groundwork for future advancements in this field. The technology and insights generated by this research can contribute to improved forest fire prevention and management practices, with far-reaching implications for environmental conservation, public safety, and policy development.

## 4. CONCLUSION

A prototype of a real-time forest fire detection, monitoring, and alert system was developed. The monitoring network based on this technology has many advantages, such as a simple circuit, low cost, and, most importantly, the ability to detect fires in real-time. The system can read the temperature, humidity, and $CO_2$ level accurately and detect the presence of a flame in real-time. Moreover, the data from the sensor can help users, especially the authorities, analyze the trend of the forest environment to reduce the possibility of forest fires. Based on the results, the sensor achieved the objectives, which were to design a fire detection system using Arduino, a temperature and humidity sensor, a smoke sensor, and GPRS; develop a software application for a real-time fire detection, monitoring, and alert system; and analyze the monitoring system's performance in terms of temperature, humidity, and $CO_2$ concentration. The results can be used by authorities to analyze forest conditions. This research can help to reduce forest fires. The authorities can consider this research to prepare early if a forest fire happens.

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