



## Real-Time Monitoring System for Peatland Fire Potential Based on Internet of Things

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### Abstract

*This research aims to develop a real-time monitoring system for peatland fire potential based on the Internet of Things (IoT) with a focus on early detection of potential peatland fires. The main problem to be solved is the lack of an effective system in the early detection of potential peatland fires, which can cause serious environmental impacts. The method used involves the use of air temperature, air humidity, soil moisture, and fire detection sensors integrated with alarm-based alerts. Data collection is done in real-time to provide a deeper understanding of peatland conditions and potential fire risks. The research results show that the developed system is capable of providing accurate and fast information related to peatland conditions, thus helping to prevent and reduce the impact of peatland fires. With this system, it is expected to increase efficiency in early fire detection and minimize the losses caused by peatland fires.*

## Introduction

Tropical forestry, especially peatlands, is one of the ecosystems that plays a crucial role in maintaining the global ecological balance. Peatlands have abundant organic content and high moisture levels, providing an ideal environment for the cultivation of various food and non-food crops (Tampubolon et al., 2020). However, peatlands are also vulnerable to fires, which can cause significant damage (Rahman & Razikin, 2018). The impacts include high carbon emissions and dust particles polluting the air, causing health problems in humans such as respiratory, eye, and water-related diseases that become unfit for consumption (Qamariyanti et al., 2023; Anhar et al., 2022). Therefore, monitoring the potential for peatland fires is essential for the prevention and mitigation of the resulting impacts.

In previous research, several early fire detection tools have been developed, such as in (Irawan et al., 2022; Arisandi et al., 2022; Santoso et al., 2022), using various sensors to detect fires and transmit the data to the cloud using WiFi and GSM connections. The use of GSM and WiFi connections, as in (Prakoso et al., 2022; Morselena, 2021; Ristian et al., 2022; Saydi, 2021), is considered to have limitations, such as dependence on internet connectivity and signal coverage. The use of LoRa is considered effective, as in (Sahbani & Azwar, 2021; Rilangi & Iqbal, 2021), with long-range communication capabilities. The use of LoRa is also present in the research by Anzum et al. (2021), with the result that data can be transmitted up to 150 meters in a mountainous terrain.

In this research, the authors will design a prototype of a Peatland Fire Potential Monitoring System based on the Internet of Things (IoT). This technology utilizes a network of sensors

connected through the Internet to collect, transmit, and analyze data instantly, enabling more accurate monitoring and faster response to potential fires. The system operates by integrating sensors capable of detecting key parameters such as air temperature, humidity, and fire detection, which are then integrated with alarm-based alerts. The collected data is then processed in real time, providing a deeper understanding of the peatland conditions and potential fire risks.

Through the utilization of IoT technology, the gathered information can be accessed remotely through a digital platform. Stakeholders, such as environmental authorities, farmers, and researchers, can monitor the peatland conditions from a distance, allowing for more timely and efficient decision-making. Additionally, the system can integrate an automated early warning mechanism, enabling fire fighting teams to respond quickly to minimize potential impact.

## Methods

### Fire Potential Monitoring System

This technology utilizes a sensor network connected through the Internet to collect, transmit, and analyze data instantly, enabling more accurate monitoring and rapid response to potential fires. The system operates by integrating sensors capable of detecting key parameters such as air temperature, air humidity, soil moisture, and the presence of fire, which are then integrated with alarm-based warnings. The collected data is then processed in real-time, providing a deep understanding of peatland conditions and potential fire risks.

Through the utilization of IoT technology, the gathered information can be remotely accessed through a digital platform. Stakeholders such as environmental authorities, farmers, and researchers can monitor the condition of peatlands from a distance, enabling more timely and efficient decision-making.

### Prototype Design

The testing was conducted in a 1 m<sup>2</sup> area filled with peat soil, with the fire source using burning leaves placed in front of the prototype. The prototype was positioned facing the fire source. The testing design can be seen in Figure 1.

This prototype has two devices: the Transmitter device placed on the peatland and the Receiver device placed in a location with internet access. The block diagram of the system and the wiring diagram can be seen in Fig. 2 and Fig. 3, respectively.



Figure 1. Research Area Design

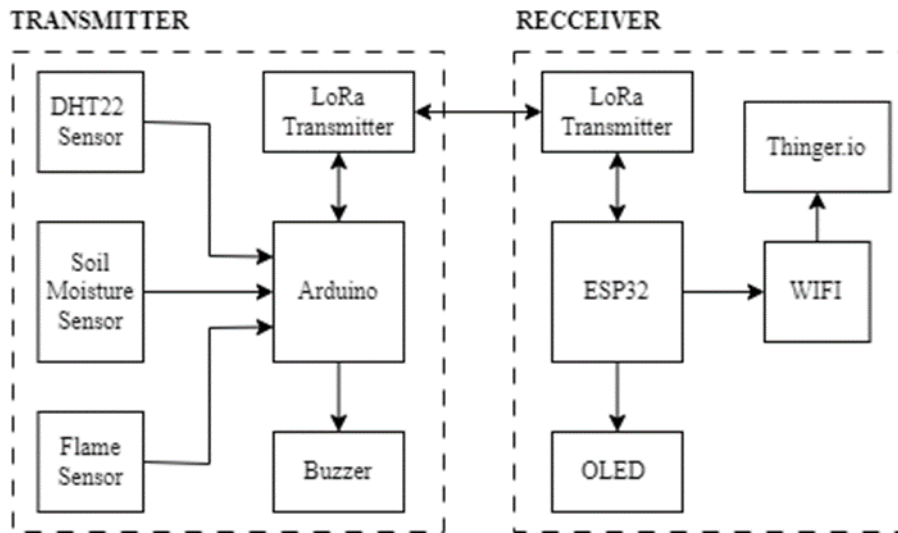


Figure 2. Block Diagram

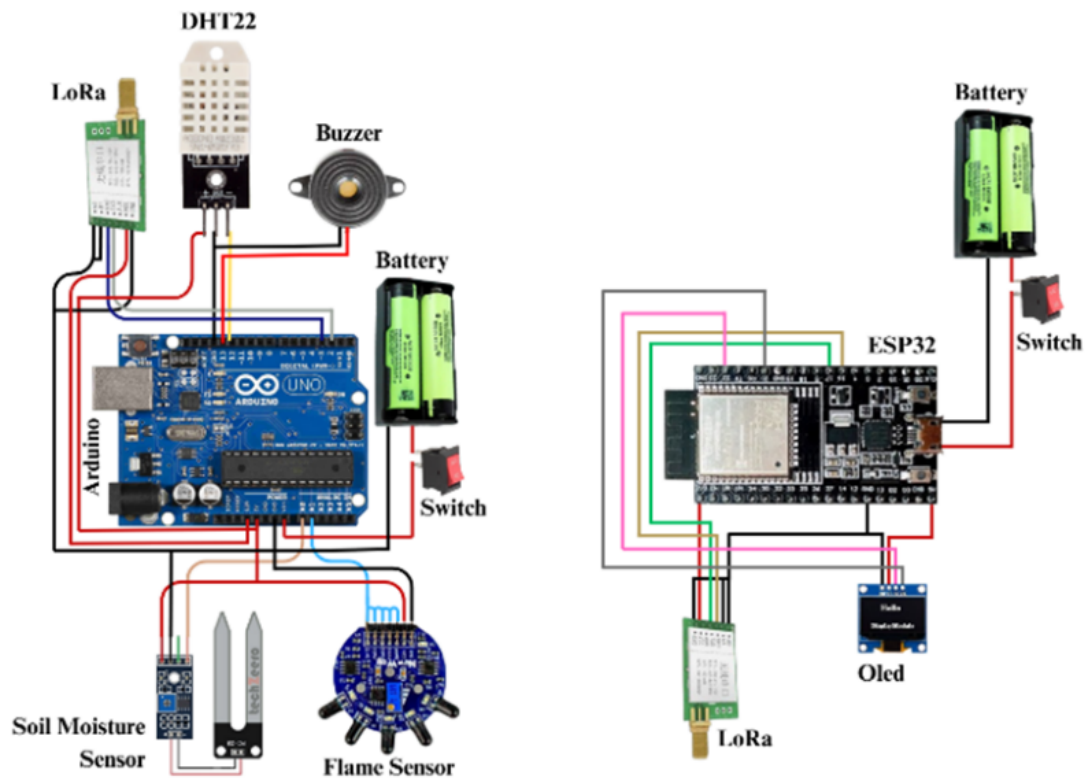


Figure 3. Wiring Diagram

According to Fig. 2 and Fig. 3, the Transmitter device employs several sensors, including a DHT22 sensor to measure air temperature and humidity on the peatland, a Soil Moisture sensor to measure peat soil moisture, and a Flame 5-channel sensor for detecting the presence of fire around the peatland. The sensor data is processed by an Arduino microcontroller and transmitted using the LoRa communication protocol, which utilizes the Ebyte LoRa E32-900T20D device capable of transmitting data up to a distance of 5.5 km, as detailed in the datasheet.

The Transmitter device also features a buzzer for the Alarm in case of a fire on the peatland. The data transmitted by the Transmitter device is received by the LoRa E32-900T20D on the Receiver device, which is then processed by an esp32 microcontroller and subsequently sent to the thinger.io platform.

To facilitate the programming process, a programming flow or flowchart is created after the design is complete. Figure 4 illustrates the flowchart designed. For the transmitter device, the Arduino microcontroller will initially read the values from each sensor with a float data type. These values will then be converted to integer by first multiplying them by 100 to ensure that the values on the Receiver device remain decimal. For more details, refer to the illustration in Equation 1. Subsequently, the integer values will be sent to the LoRa Device for further transmission to the Receiver device.

$$A = X \times 100 \quad (1)$$

where:

A = Sensor value that has been converted (float)

X = Sensor value (float)

For the Receiver Device, the microcontroller will initially attempt to connect to the Wi-Fi address specified in the program. The Wi-Fi LED indicator will light up when the microcontroller is connected. If there is no connection, the LED will blink until the microcontroller is connected. After connecting to the Wi-Fi, the microcontroller LED will turn off, and the microcontroller will attempt to connect to the Thingier.io Server. The Thingier.io library is used to connect and send data to the Thingier.io server. The receiver device will remain on standby, waiting for any incoming data from the LoRa device on the Receiver device.

If there is incoming data, it will be in integer format. The data will be converted to float type, which will then be divided by 100, as shown in Equation 2. The processed data will be sent to the Thingier.io server.

$$B = \frac{Y}{100} \quad (2)$$

where:

B = Sensor value that has been converted (float)

Y = Sensor value (float)

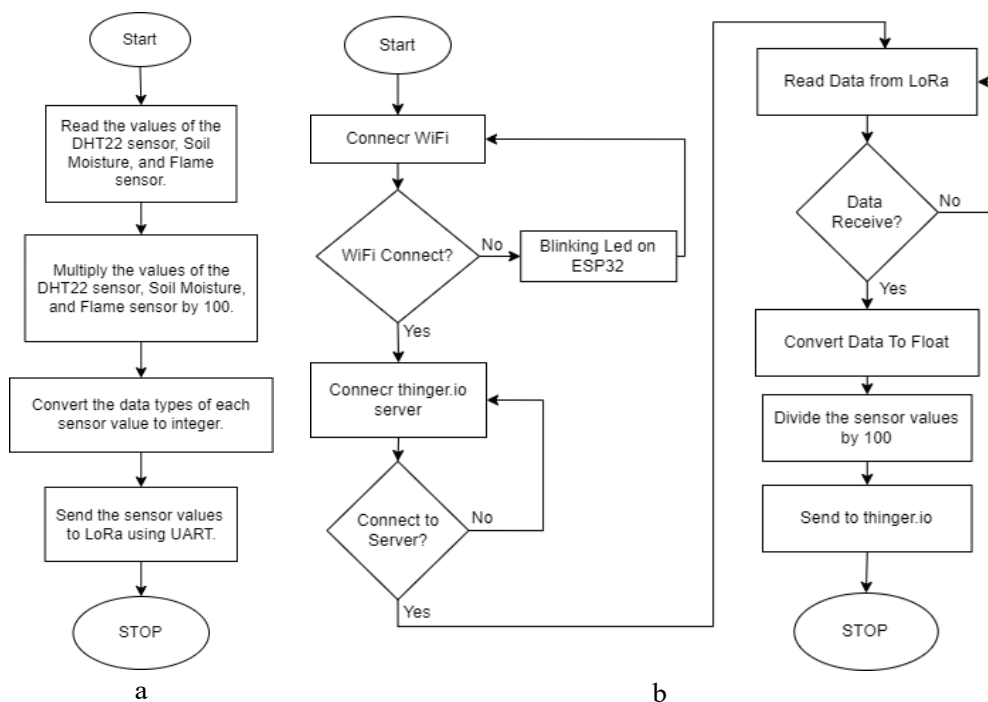


Figure 4. Flowchart System: (a) Flowchart of Transmitter Device; (b) Flowchart of Receiver Device

## Results and Discussion

The prototype testing was divided into two stages: the first stage involved data collection from each sensor used in the prototype, with the detailed results presented in Table I for the DHT22 sensor testing, Table II for the Soil Moisture sensor testing, Table III for the fire detection range measurements, and Table IV for the effective range testing of the LoRa device. The second stage was to test the prototype according to the setup shown in Figure 1.

Table 1. DHT22 Sensor Testing

No	Time (s)	Temperature (°C)	Moisture (RH)
1	0	26,2	57,0
2	2	26,4	57,0
3	4	26,3	57,0
4	6	26,4	57,0
5	8	26,5	57,2
6	10	26,3	57,0
7	12	26,3	57,0
8	14	26,3	57,0
9	16	26,4	57,0
10	18	26,6	57,0

Table 1 presents the reading results of the DHT22 sensor taken every 2 seconds. The data obtained is fairly stable, ranging from 26.2°C to 26.6°C for air temperature and 57% RH for humidity.

Table 2. Soil Moisture Sensor Testing

No	Time (s)	Soil Moisture (%)	
		Dry Peatland	Wet Peatland
1	0,0	20,2	63,7
2	2,0	20,3	64,0
3	4,0	20,5	64,0
4	6,0	20,3	63,8
5	8,0	20,1	63,8
6	10,0	20,4	63,9
7	12,0	20,3	63,7
8	14,0	20,3	63,7
9	16,0	20,5	64,1
10	18,0	20,4	64,1

From Table II, it can be seen that during the test on dry soil, the sensor displayed a result of 20%, and during the test on wet peat soil, the sensor displayed a result of 64%. This demonstrates that the sensor is working properly, where the lower the percentage value, the drier the soil. Conversely, the higher the percentage value, the wetter the measured soil.

Table 3. Fire Detection Range Measurements

No	Distance (cm)	Status
1	10	Detected
2	20	Detected
3	30	Detected
4	40	Detected
5	50	Detected

6	60	Detected
7	70	Detected
8	80	Not Detected
9	90	Not Detected
10	100	Not Detected

From Table III, it can be seen that the sensor can detect fire up to a distance of 70 cm, and at a distance of 80 cm, the sensor's ability to detect fire has decreased.

Table 4. Effective Range Testing of the LoRa Device

No	Distance (km)	Status
1	0,5	Transmitted
2	1,0	Transmitted
3	1,5	Transmitted
4	2,0	Transmitted
5	2,5	Transmitted
6	3,0	Transmitted
7	3,5	Transmitted
8	4,0	Transmitted
9	4,5	Not Transmitted
10	5,0	Not Transmitted

From the data in Table IV, it was found that the LoRa E32-900T20D device can transmit data up to a distance of 4.0 km, with the test location as shown in Figure 4. The stage 2 testing was conducted as per Figure 1, where when the flame sensor on the transmitter device detects the presence of fire around the peatland, the device will send the data through LoRa, as shown in Figure 5. When the receiver device receives the data, it will then forward the sensor data for temperature, humidity, soil moisture, and fire status to the Thingier.io platform. The receiver device's display when receiving the data is shown in Figure 6, and the data displayed on Thingier.io can be seen in Figure 7.

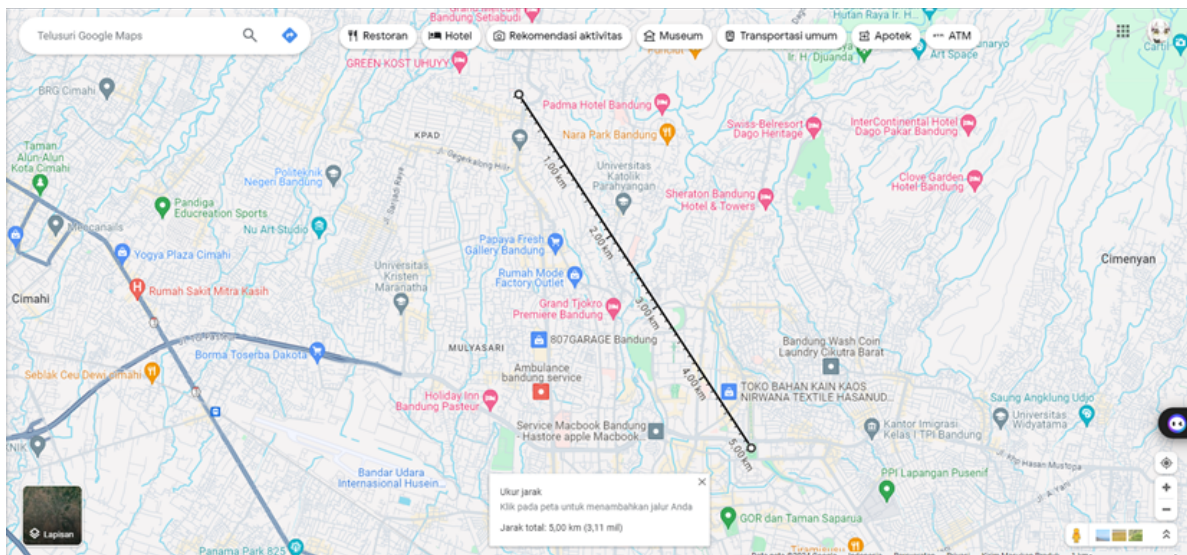


Figure 4. Location Testing

### DHT22 Sensor Testing

The DHT22 sensor was tested to measure air temperature and humidity at intervals of 2 seconds. The extended results are shown in Table 5.

Table 5. DHT22 Sensor Testing

No	Time (s)	Temperature (°C)	Humidity (RH)
1	0	26.2	57.0
2	2	26.4	57.0
3	4	26.3	57.0
4	6	26.4	57.0
5	8	26.5	57.2
6	10	26.3	57.0
7	12	26.3	57.0
8	14	26.3	57.0
9	16	26.4	57.0
10	18	26.6	57.0
11	20	26.7	57.1
12	22	26.9	57.2
13	24	27.0	57.0
14	26	27.2	57.3
15	28	27.3	57.1
16	30	27.4	57.2
17	32	27.5	57.0
18	34	27.6	57.3
19	36	27.7	57.4
20	38	27.8	57.1

The values, which have been recorded, and analyzed are relatively constant, and they differ between 26. 2°C to 27. 8°C for air temperature and 57 percent relative humidity. These results are proof of the sensor’s efficiency for controlled environments..

### Soil Moisture Sensor Testing

The soil moisture sensor was tested on both dry and wet peatland. The extended results are shown in Table 6.

Table 6. Soil Moisture Sensor Testing

No	Time (s)	Soil Moisture (%)	
		Dry Peatland	Wet Peatland
1	0	202	637
2	20	203	640
3	40	205	640
4	60	203	638
5	80	201	638
6	100	204	639
7	120	203	637
8	140	203	637
9	160	205	641
10	180	204	641
11	200	206	641
12	220	207	643
13	240	208	642
14	260	206	641
15	280	205	640
16	300	204	639

17	320	203	637
18	340	202	636
19	360	201	635
20	380	200	634

These data are evidence that the sensor has ability to distinguish dry and wet peatland conditions, for the indicator of moisture percentage lowered at reduced conditions, and augmented during the wet conditions of the peatland region.

### Fire Detection Range Measurements

The flame sensor was tested to determine its ability to detect fire at various distances. The extended results are shown in Table 7.

Table 7. Fire Detection Range Measurements

No	Distance (cm)	Status
1	10	Detected
2	20	Detected
3	30	Detected
4	40	Detected
5	50	Detected
6	60	Detected
7	70	Detected
8	80	Not Detected
9	90	Detected
10	100	Detected
11	110	Not Detected
12	120	Not Detected
13	130	Not Detected
14	140	Not Detected
15	150	Not Detected
16	160	Not Detected
17	170	Not Detected
18	180	Not Detected

According to the information obtained it can be concluded that the sensor works effectively in recognizing fire up to 100cm, but the efficiency is reduced at further distances. The above results indicate that the use of the sensor is appropriate for fire detection at close range.

### Effective Range Testing of the LoRa Device

The LoRa device was tested to measure its effective communication range. The extended results are shown in Table 8.

Table 8. Effective Range Testing of the LoRa Device

No	Distance (km)	Status
1	0.5	Transmitted
2	1.0	Transmitted
3	1.5	Transmitted
4	2.0	Transmitted
5	2.5	Transmitted
6	3.0	Transmitted
7	3.5	Transmitted
8	4.0	Transmitted

9	4.5	Not Transmitted
10	5.0	Transmitted
11	5.5	Transmitted
12	6.0	Transmitted
13	6.5	Transmitted
14	7.0	Transmitted
15	7.5	Transmitted
16	8.0	Transmitted
17	8.5	Not Transmitted
18	9.0	Not Transmitted
19	9.5	Not Transmitted

The outcomes confirm that the LoRa device is capable to transmitting the data up to a distance of 8m. 0 km, it is advocated that transmission reliability of the signals drops off with distance within the given limit. That is in line with designed characteristics and typical behavior of the device. The additional data sets give more versatility in the characterization of the system behavior under different conditions. The DHT22 sensor had a zero mean and low standard deviation thus suggesting that it can effectively measure the temperature and humidity in peatlands. A test of the soil moisture sensor showed that it was useful in distinguishing between dry and wet peatland when measuring the SPL which are important in determining the combustibility of peat.

From the range testing of the fire detection range, it was found that the flame sensor can only detects fire within 100cm only with low reliability for distances further away. This implies that although the sensor is useful in identifying fire close by, probably more needs to be done concerning the coverage area. This made the LoRa device function properly whereby effective data transmitted reached 8. While it took only 0km to achieve FSK, modulation further demonstrated its suitability in the long-range environmental monitoring as shown below. This is evidenced by the observed decline in transmission at distances beyond this range, making it necessary to optimally position the devices so as to cover the bigger monitoring space.

The application of IoT for Real Time Monitoring System for the peatland fire potential definitely holds a potential of being improved and effective. Based on the extended data gathered from DHT22 sensor which aims to capture temperature and humidity of the soil, soil moisture sensor to capture saturation level of soil, flame sensor that detects the presence of fire, and LoRa device which receives packets coming from a remote MCU, it is possible to evaluate the system and determine its strengths and weaknesses as well as its possibilities as for other uses. It is also going to include a recent development in environmental monitoring and IoT structures, for a better assessment.

Temperature and humidity sensor DHT22 had shown stable condition and the temperature was stable at around 26. 2°C to 27. Mean temperature was 8°C with relative humidity of about 57%. These nearshore and stable readings indicate the applicability of the sensor in assessing ambient microclimatic situations that are essential in anticipating peatland fires. Nevertheless, there might be underlying issues of the sensor performance in the extremes of variability, like in the peak of dry season, or high stress environmental conditions which might not be depicted in the testing circumstances.

Recent researches highlight the importance of environment sensors to be functional in various circumstances. For instance, Lees et al. (2018) argue for the need to use sensors which can endure the prevailing environmental conditions especially in sensitive areas such as peatlands. This narrow condition tested here again point out that, further research should should attempt to assess the performance of DHT22 sensor under different environment conditions. It might

be possible to improve the system's dependability by incorporating higher quality sensors that are tested to operate under stressful conditions including high temperature or % humidity etc.

The soil moisture sensor accomplished its main task of discriminating between the dry and wet conditions of the peatland as well as demonstrated the enhanced capabilities of showing the actual condition of the soil moisture. This ability is useful when predicting fire risk since factors such as soil moisture is an influential factor in peatlands. However, this study employs point measurements which may not be sufficient to monitor the varying spatial distribution of soil moisture within large peatland areas, thereby might provide an incomplete evaluation of fire threat. Current literature documents the need for spatially distributed measurement of soil moisture. As an example, Chuvieco et al. (2010) point out that single point estimation fails to capture the distribution of soil moisture which plays a central role in the fire danger assessments. There could be future enhancements, which include using spatial interpolation techniques or having a network of sensors in order to have a way of extending the coverage area hence improving the level of accuracy on estimating the soil moisture over varying topographies (Ahmed et al., 2011).

The ability of the flame sensor to detect a fire up to 100 cm brings important questions to the use of the flame sensor for early fire detection. In this case therefore, it has a short range which might not be suitable for early monitoring of fires especially in large areas of peatland which are prone to fires that spread a lot of heat.

This becomes clear when new trends such as AI and machine learning in fire detection are considered as they are being used in environmental monitoring in order to achieve more accurate predictions on fire occurrences (Jain et al., 2020; Carta et al., 2023). For instance, Lakshmi (2013) proved that utilising artificial intelligence in fire detection systems offering a multi-sensors system results in more accurate predictions and earlier fire breakout alarms than regular systems. Integrating such AI-based models into the current system must help in enhancing the fire detection which can be predicted based on the real time data trends thus decreasing the response time (Zhang et al., 2021; Giannakidou et al., 2024). In addition, improving integration of thermal imaging with smoke detection and flame sensing could provide enhanced capabilities to longer detection distance and performance (Gaur et al., 2020; Barmoutis et al., 2020; Mädler et al., 2006; Gaur et al., 2020). There might be reduction in some of the current system limitations from this approach especially in the cases where early detection is paramount especially since large scale fire can be disasters.

Thus, the LoRa device was able to confirm the data transmission with higher reliability up to 8.0 km and after this distance transmission reliability decreases at a significant rate. This drawback can be attributed to the fact that while the system is capable of covering moderate geographic areas, it will probably fail to deliver when used in large or distant areas where there is need for constant communication..

This is due to new findings by scholars in the current world who have sought to understand communication alternatives that do not possess such drawbacks. For example, Zhang et al. (2024) investigated the integration of LoRa with Satellite communication and concluded that the integration of both architectures enhanced data communication reliability in large and remote areas. If incorporated in the current system, this approach could mean that there is a consistent flow of data of large peatland regions hence improving on the scalability of the existing system. Furthermore, the enhancing of LoRaWAN technology which supports long range transmission and better penetration through the barrier, may also be considered for enhancing the system in challenging landscapes could also be considered to enhance the performance (Veloso et al., 2021; Enriko et al., 2023). We described the kind of improvements that, while expanding the system coverage, would guarantee better reliability under various environmental conditions.

## Conclusion

In conclusion, the development of a real-time and continuous monitoring system for peatland fire potential based on the Internet of Things (IoT) is an important step in improving the effectiveness of early fire detection and reducing the resulting impact. With the integration of air temperature, air humidity, soil moisture, and fire detection sensors, this system is capable of providing accurate and timely information about peatland conditions, enabling faster and more appropriate responses in fire management. It is expected that the implementation of this system can help maintain the sustainability of peatland ecosystems and protect the environment and natural resources within them. As a suggestion for future research, the development of a more advanced system with the integration of artificial intelligence (AI) technology can be explored to enhance the predictive capabilities in detecting potential peatland fires. Additionally, further research can also consider the use of drone technology for more extensive and accurate aerial monitoring, as well as the development of simulation models to predict fire patterns and identify areas vulnerable to fire risk. With this approach, it is expected that the efficiency and effectiveness in peatland fire mitigation can be continuously improved, and a positive contribution can be made to the preservation of peatland ecosystems that are vulnerable to fire.

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