Design and Implementation of LoRa-Based Forest Fire Monitoring System

Yosi Apriani [1*], Wiwin A. Oktaviani [2], Ian Mochamad Sofian [3]
[1, 2] Department of Electrical Engineering, Universitas Muhammadiyah Palembang, Palembang, Indonesia
[3] Department of Nautical Technology, Politeknik SDP Palembang, Banyuasin, Indonesia
Email: [1] yosi_apriani@um-palembang.ac.id, [2] wiwin_oktaviani@um-palembang.ac.id, [3] ian.msof@gmail.com
*Corresponding Author

***Abstract*—One of the great disasters on earth is forest fires. Attempts to detect disaster events have been made with the help of monitoring technology. However, the problem is that the sensor is less responsive to detecting the presence of fire. Furthermore, sending information about fire incidents throughout the forest cannot use the existing communication platform. Therefore, we designed a forest fire monitoring system using LoRa. This technology is based on wireless which can transmit data across the forest. To detect the presence of fire, Arduino Uno is used as a microcontroller that regulates input from the AMG8833 sensor and GPS Ubox 6M. The experiment shows that the AMG8833 sensor is more sensitive in detecting the presence of fire as the catch range changes between 3 to 10 meters. In that distance range, hotspots were detected 19.25 ºC to 122.5 ºC when testing the sensor node is done. The monitoring system developed in this study demonstrated that sensor nodes and gateways could communicate up to 500 meters apart with a signal quality of -134 dBm. The best LoRa configuration mode for this communication capability is a Bandwidth of 250, a Code Rate of 4/5, and a Spread Factor of 10.**

Keywords—Fire Detection; AMG8833; LoRa; Arduino

I. INTRODUCTION

Fire is a disaster that always causes many unwanted things and can result in many losses, material losses, and threats to human life safety. One of the disasters is forest fires. Forests have many functions for human life, including forests as a source of oxygen and medicine, forests prevent flooding, resisting winds, providing jobs, and many other forest functions [1][2]. These functions will be lost when the forest burns.

Efforts to minimize the occurrence of fire disasters in forests have been carried out both technologically through environmental monitoring systems [3][4]. In this system, monitoring is carried out by observing the variables of changes in environmental temperature [5]-[7]. If the change increases drastically, the potential for forest fires is quite high. The use of several tools, such as a temperature sensor, gas sensor, and fire sensor (UV Flame) as a fire detector, indicates the use of existing environmental monitoring system technology. However, this effort is still not optimal in terms of the detection sensitivity of the sensor [8]-[10]. Another issue is the data transmission from sensor readings to monitoring systems that still rely on the internet network. In general, connecting to the internet network in forest areas is extremely difficult [11]-[13]. Therefore, it is necessary to create a monitoring system that is more optimal in terms of sensor sensitivity and long-range data transmission without relying on internet network connectivity in forest areas.

The potential problem-solving in this paper is through a forest digitization approach. The term forest digitization applies the latest technology for monitoring, data acquisition, and data transmission [14]. Data acquisition is obtained from sensors that have good precision in detecting the presence of fire and a large monitoring area, namely AMG8833 [15]. This fire detection sensor is based on a thermal camera to recognize even small fire points. A data communication networks that can inform forest fires in real-time can use a long-distance wireless communication-based tools [16], namely LoRa [17]-[21].

There have been several previous studies regarding thermal camera sensors and LoRa. Thermal camera sensors are used for tracking and facial recognition because there is abuse in facial manipulation by using excessive makeup and using masks that are not following the rules [22][23]. In addition, a thermal camera sensor is used to find out the whereabouts of a person somewhere [24]. This sensor is even capable of measuring a person's body temperature. During the COVID-19 pandemic, tracking human activity is very important to know the scope of the distribution area marked by an increase in body temperature, especially in a closed room [25]. The thermal camera sensor can be used because there is a correlation between increased body temperature (fever) and identifying someone positive for Covid-19 [26]. In education, thermal camera sensors monitor a teacher to prevent learning focus from dropping in darling learning activities [27]. In terms of data transmission, the use of LoRa as an early warning monitoring forest fires in Riau Province can send data from sensors to a gateway as far as 30 miles [28].

Therefore, this research focuses on developing a monitoring system that can detect the presence of fires and monitor forest fires in real time. This study proposes using AMG8833 to improve the detection technology than the existing sensors [29][30]. This thermal camera sensor has never been used in a fire monitoring system, so this research is a novelty in the field of forest digitization. In addition, the use of data communication technology for forest fire monitoring systems is also installed with low-power wireless devices in the form of LoRa-IoT. It is hoped that this work can contribute to efforts to anticipate forest and land fires, especially in South Sumatra.

II. System Architecture

A. Sensor Node

In this research, we use Arduino Uno for sensor nodes. The microcontroller is attached to the AMG8833 sensor and the Ublox 6M GPS module on the input pin. While on the output pin, there is LoRa-Tx (module RA-01) which is called the transmitter. The AMG8833 sensor is a thermal camera type sensor with a reading capability of 0ºC-80ºC (+-2.5ºC accuracy) [31]. This thermal camera sensor will detect the presence of hotspots. AMG8833 reading results will be transformed into an image with a resolution of 8x8 (array) via I2C communication. The GPS module will initiate the coordinates of the fire. At the same time, Lora-Tx will publish data obtained from thermal camera sensors and GPS. Fig. 1 is the configuration of the sensor node.

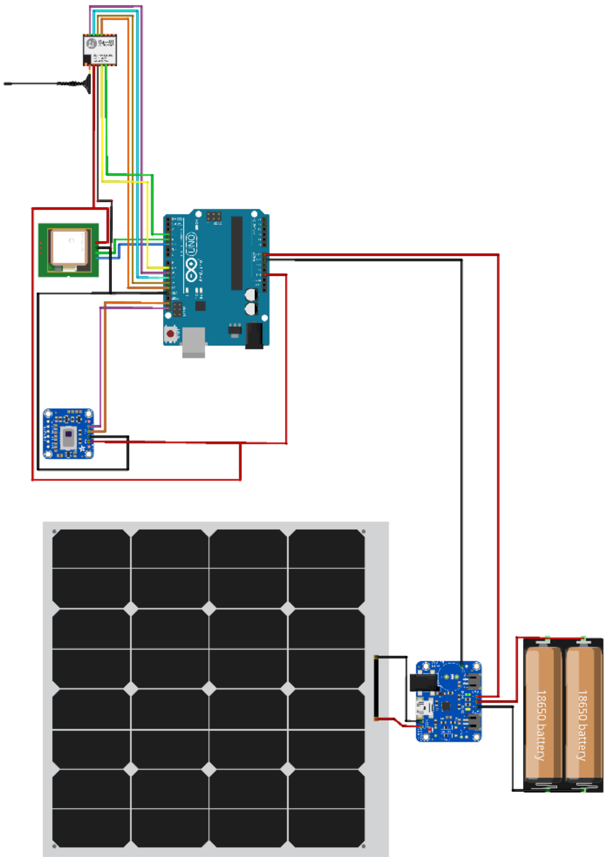


Fig. 1. Sensor node

B. Gateway

This section used Arduino Nano and installed LoRa-Rx (RA-01), which is called a receiver, and ESP8266. This microcontroller will process data from LoRa-Rx via the LoRa-Tx pin as a data traffic controller. The collected data is then continued to ESP8266 on the Wifi pin. Users can access it after ESP8266 publishes data to Blynk App (cloud). Fig. 2 is the configuration of the gateway.

III. System Design

A. General System Design

In general, the design of a forest fire monitoring system consists of two main parts. In the first part, there are sensor nodes placed in the forest. Forest areas usually do not have internet access services, so LoRa-Tx must send data to the gateway. While the second part, there is a gateway (LoRa-Rx) that receives data from LoRa-Tx. Then the gateway will continue the sensor data to the cloud service, which can then be processed and monitored by the user. The delivery pattern can be seen in Fig. 3. For the experimental scenario in this study, two stages were carried out, namely the stage of testing the responsiveness of the sensor node and the gateway connectivity when receiving data from the sensor node. The second stage of this experiment is to measure the data transmission signal strength (RSSI) between the sensor node and the gateway. Especially for the second stage of the experiment, was carried out by placing sensor nodes at five different points (locations), where each point was 100 meters away.

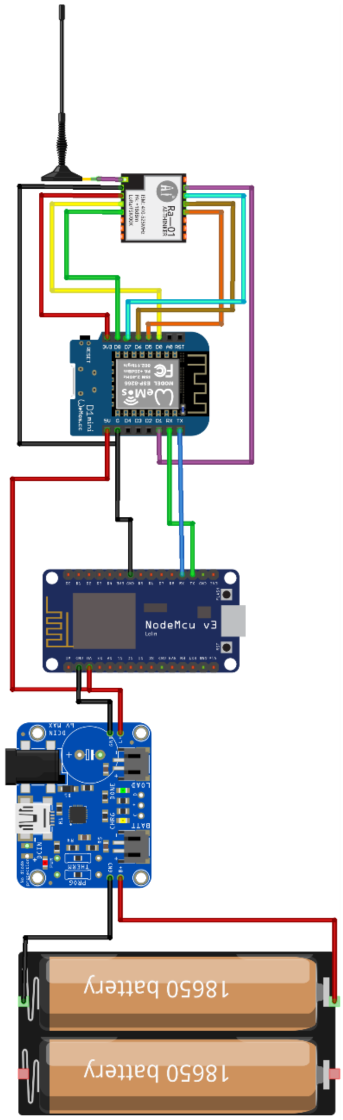


Fig. 2. Gateway

To get the RSSI value is given by [32]

$$RSSI = EIRP + MAPL \qquad (1)$$

Where RSSI is ReceivedSignal Strength Indicator (dBm), EIRP is Equivalent Isotopically Radiated Power (24 dBm) and MAPL is Maximum Allowed Path Loss (dBm).

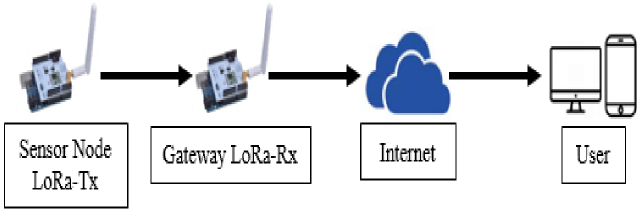


Fig. 3. Design of a forest fite detection sytem

B. *Software Design*

The software design transmits information from the AMG8833 sensor readings and GPS (sensor node). In addition, software design is made to trace data at the gateway (base station) to the cloud. The software design in question can be seen in Fig. 4.

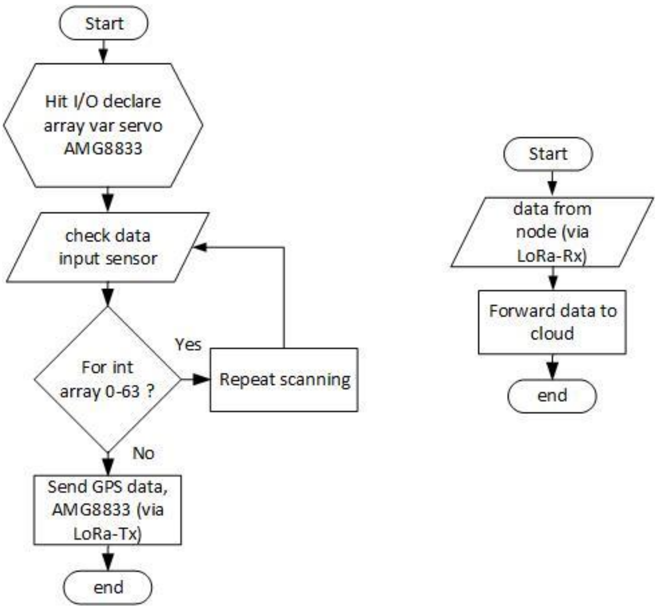


Fig. 4. Flowchart of software design; node (left); gateway (right)

The AMG8833 sensor carries out fire detection in the sensor node. Arduino's temperature data acquisition comes from digital and analog (I/O) pins. The sensor node sends data over a LoRa-Tx connection. The data sent by Lora-Tx will reach the cloud via a LoRa-Rx link (gateway). The user can monitor the processed data to ensure that a forest fire is detected at a certain point. The AMG8833 sensor is set up on the microcontroller to respond to a temperature of 60oC. The threshold value is set as the basis for detecting forest fires. The detected temperature value will be recorded and represented in an image in 64 pixels (array) of AMG8833. Of the 64 pixels, only one value with the highest temperature will be taken. In addition, GPS on sensor nodes is used to determine the location of forest fires.

IV. Experiment And Results

A. *Tool Assembly Results*

Fig. 5 and Fig.6 depict the tool created according to the architecture of the forest fire monitoring system. Fig. 5 is the sensor node system architecture, where the AMG8833 sensor is connected to the I2C pin with a power of 5 Vcc. LoRa-Tx is connected to the SPI pin (SCK, MISO, MOSI, SS) and is supplied with 3.3 Vcc of power through the Arduino Uno's internal regulator. GPS is cross-connected to the Arduino Uno serial pin, namely, pin 3 and pin 4. The gateway system architecture is shown in Fig. 6. The data received by LoRa-Rx will be sent to the Arduino Nano on the Rx pin as a data traffic controller. The data collected on the Arduino Nano will be sent to the ESP8266's TXD0 and RXD0 pins via the SPI pin. Furthermore, the ESP8266 transfers data to the cloud.

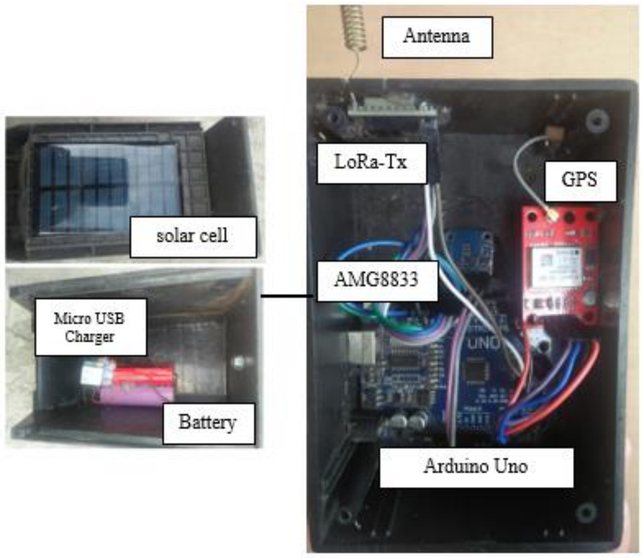


Fig. 5. Sensor node

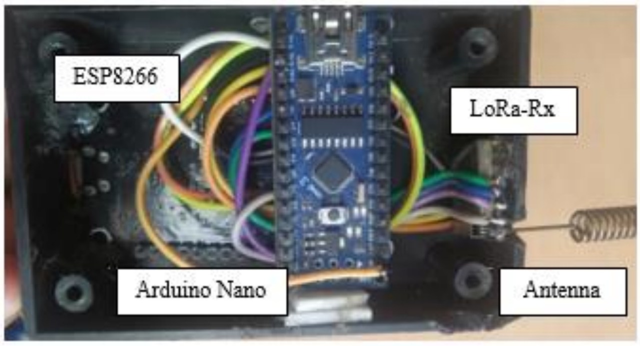


Fig. 6. Gateway

B. *Devices and LoRa Connectivity Results*

Tests on the AMG8833 sensor show success in detecting the presence of a fire source which is processed into an 8x8 image (array). In Fig. 7, the sensor is able to detect a fire source at a distance of 10 meters and the highest temperature pattern (red color) is seen at pixels [$x_{1,1}$ … $x_{1,5}$], [$x_{2,1}$ … $x_{2,5}$]. While the low-temperature pattern (light blue) is at pixels [$x_{8,4}$ … $x_{8,7}$]. The temperature value for each pixel at a distance of 10 meters is shown in Fig. 8.

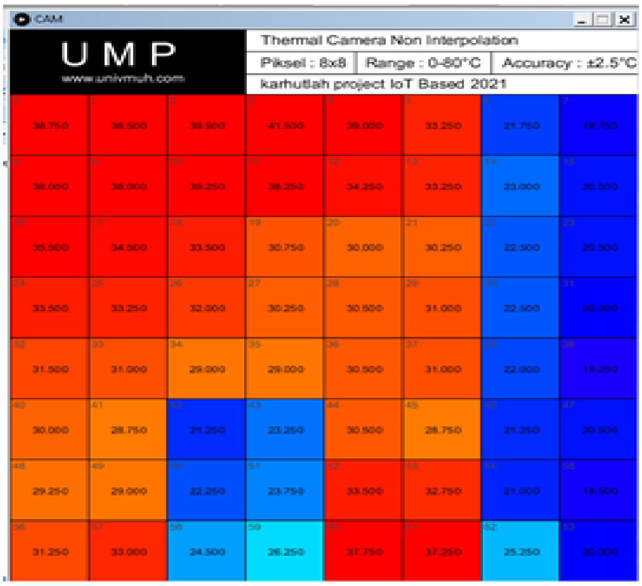


Fig. 7. Image captured by the 8x8 AMG8833 sensor for the presence of a fire source. The distance between the sensor and the fire source is 10 meters

38.75	38.75	38.75	41.50	39.00	33.25	21.75	19.75
38.75	38.75	39.00	38.25	34.25	33.25	23.00	20.50
35.50	34.50	33.50	30.75	30.00	30.25	22.25	20.25
33.50	33.25	32.00	30.25	30.50	31.00	22.50	20.00
31.50	31.00	29.00	29.00	30.50	31.00	22.00	19.25
30.00	29.75	21.25	23.25	30.50	28.75	21.25	20.50
29.25	29.00	22.25	23.75	33.50	32.75	21.00	19.50
31.25	33.00	24.50	26.25	37.75	37.25	25.25	20.00

Fig. 8. Temperature value in each pixel at a distance of 10 meters.

In Fig. 9, the sensor can detect a fire source at a distance of 7 meters, and a nearly homogeneous temperature pattern can be seen in each pixel. The temperature value for each pixel at a distance of 7 meters is shown in Fig. 10.

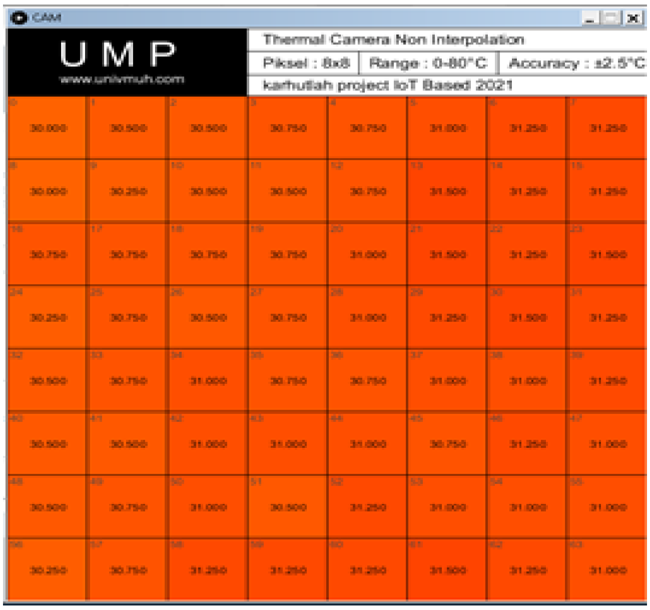


Fig. 9. Image captured by the 8x8 AMG8833 sensor for the presence of a fire source. The distance between the sensor and the fire source is 7 meters.

30.00	30.50	30.50	30.75	30.75	31.00	31.25	31.25
30.00	30.25	30.50	30.50	30.75	31.50	31.25	31.25
30.75	30.75	30.75	30.75	31.00	31.50	31.25	31.50
30.25	30.75	30.50	30.75	31.00	31.25	31.50	31.25
30.50	30.75	31.00	30.75	30.75	31.00	31.00	31.25
30.50	30.50	31.00	31.00	31.00	30.75	31.25	31.00
30.50	30.75	31.00	30.50	31.25	31.00	31.00	31.00
30.25	30.75	31.25	31.25	31.25	31.50	31.25	31.00

Fig. 10. Temperature value in each pixel at a distance of 7 meters.

In Fig. 11, the sensor can detect the source of the fire at a distance of 5 meters. The temperature value for each pixel at a distance of 5 meters is shown in Fig. 12.

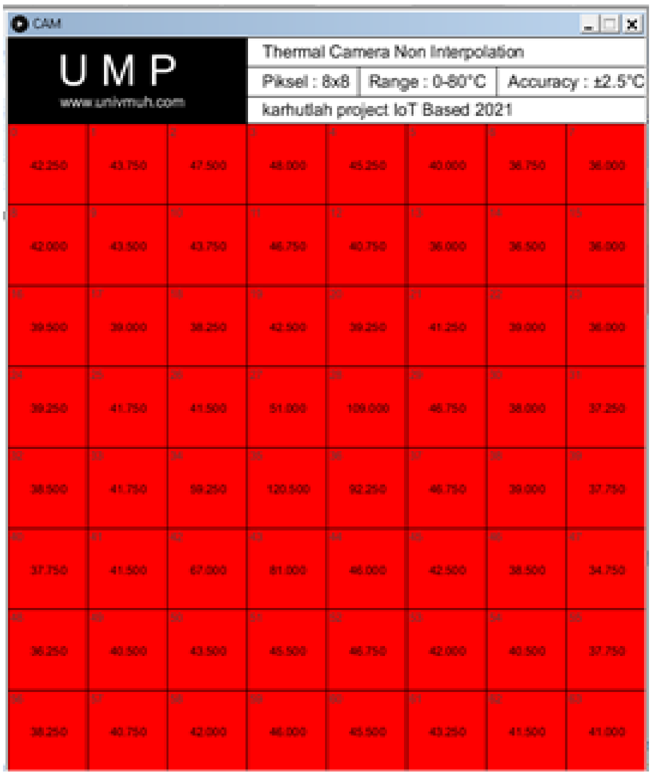


Fig. 11. Image captured by the 8x8 AMG8833 sensor for the presence of a fire source. The distance between the sensor and the fire source is 5 meters

42.25	43.75	47.50	48.00	45.25	40.00	36.75	36.00
42.00	43.50	43.75	46.75	40.75	36.00	36.50	36.00
39.50	39.00	38.25	42.50	39.25	41.25	36.00	36.00
39.25	41.75	41.50	51.00	109.0	46.75	36.00	37.25
38.50	41.75	59.25	120.5	92.25	46.75	39.00	37.75
37.75	41.50	67.00	81.00	46.00	42.50	38.50	34.75
36.25	40.50	43.50	45.50	46.75	42.00	42.50	37.75
38.25	40.75	42.00	46.00	45.00	43.25	41.50	41.00

Fig. 12. Temperature value in each pixel at a distance of 5 meters.

In Fig. 13, the image results show a high-temperature pattern that is almost homogeneous in each pixel. At this distance the maximum temperature detected is 122.5 ºC (Fig. 14).

The image capture in the array produces a correlation between the color gradation (change in temperature) and the detection distance. The closer the fire source is to the sensor, the more intense the red colour displayed on the pixels.

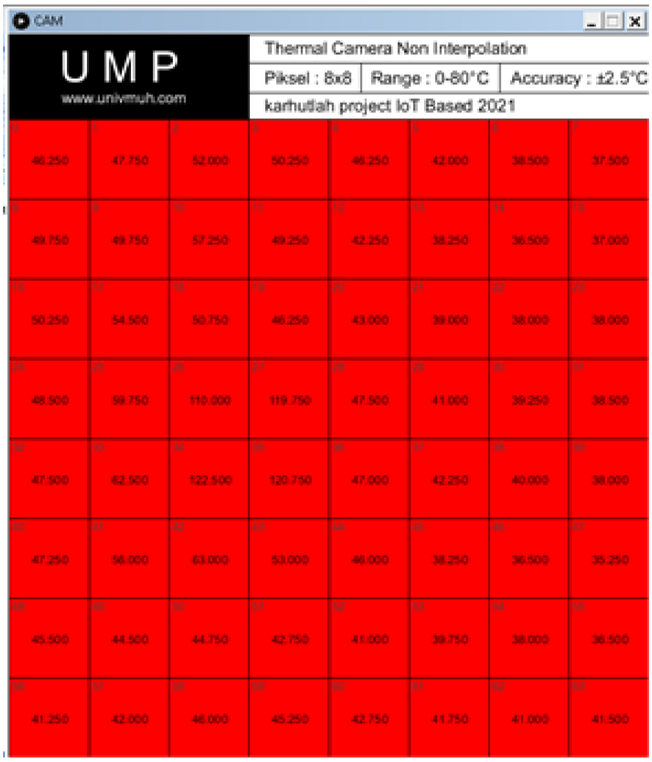


Fig. 13. Image captured by the 8x8 AMG8833 sensor for the presence of a fire source. The distance between the sensor and the fire source is 3 meters.

46.25	47.75	52.00	50.25	46.25	42.00	38.50	37.50
49.75	49.75	57.25	49.25	42.25	38.25	36.50	37.00
50.25	54.50	50.75	46.25	43.00	39.00	38.00	38.00
48.50	59.75	110.0	119.7	47.50	41.00	39.25	38.50
47.50	62.50	122.5	120.7	47.00	42.25	40.00	38.00
47.25	56.00	63.00	53.00	48.00	38.25	36.50	36.25
45.50	44.50	44.75	42.75	41.00	39.75	36.00	36.50
41.25	42.00	46.00	46.25	42.75	41.75	41.00	41.50

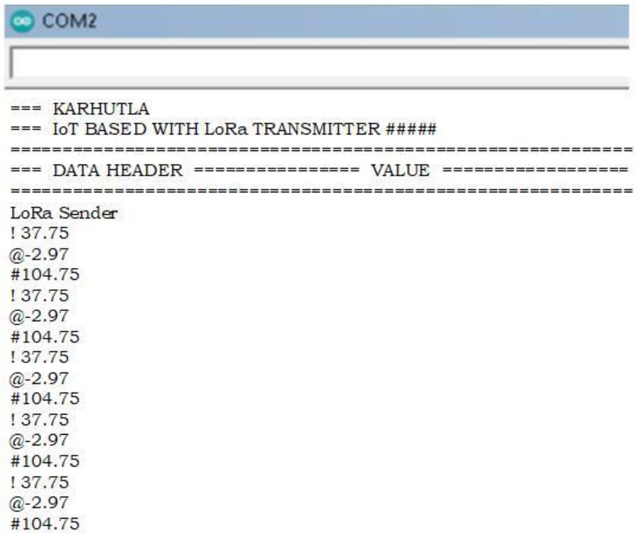
Fig. 14. Temperature value in each pixel at a distance of 3 meters.

The monitoring system will be active if the sensor node detects the presence of a fire with a temperature above 63 ºC which is taken from one of the AMG883 pixels which have the highest value (Tabel I).

TABLE I. SENSOR NODE TEST RESULTS

Distance (meters)	Temperature (ºC)	Description
10	41.50	Passive
7	31.50	Passive
5	120.5	Active
3	122.5	Active

The test results on the connectivity at the sensor node, LoRa-Tx successfully sent data to the gateway. Fig. 15 shows the data transmitted by LoRa-Tx in Header, temperature value (37.75 ºC), and coordinate value (latitude=-2.97 and longitude=104.75).



```
COM2

=== KARHUTLA
=== IoT BASED WITH LoRa TRANSMITTER #####
============================================================
=== DATA HEADER =============== VALUE =================
============================================================
LoRa Sender
! 37.75
@-2.97
#104.75
! 37.75
@-2.97
#104.75
! 37.75
@-2.97
#104.75
! 37.75
@-2.97
#104.75
! 37.75
@-2.97
#104.75
```

Fig. 15. Test results of sensor nodes and LoRa-Tx

Meanwhile, the gateway connectivity test shows the success of LoRa-Rx to receive data from LoRa-Tx. Fig. 16 shows the data that LoRa-Rx successfully received in Header, temperature value (38.50 ºC), coordinate value (latitude=-2.97 and longitude=104.75), and RSSI=-55 dBm.

```
COM4

Received packet '
!38.50
@-2.97
#104.75
' with RSSI
-55
Received packet '
!38.50
@-2.97
#104.75
' with RSSI
-55
Received packet '
!38.50
@-2.97
#104.75
' with RSSI
-55
```

Fig. 16. Gateway test results

The cloud connection test results show the success of data transfer from ESP8266 to the cloud. Fig. 17 shows the data transferred to the cloud in the form of; temperature (37.75 ºC) and coordinate values (lat=-2.967612 and lon=104.746635). The monitoring application (Blynk) will display these data later.

Fig. 17. Test results of data transfer from ESP8266 to cloud

C. *Application Test Results*

The data transferred from ESP8266 to the cloud for processing can be accessed by the user in an android application display (Blynk). Blynk is what then acts like a forest fire monitoring system. Fig. 18 shows where the sensor node detected the fire source with a black pointer. The location in question has coordinates (-2.97 S, 104.74 E). At the same time, the temperature value that was detected was 64.75ºC. The temperature and coordinates data were obtained from the tool testing and LoRa connectivity testing results.

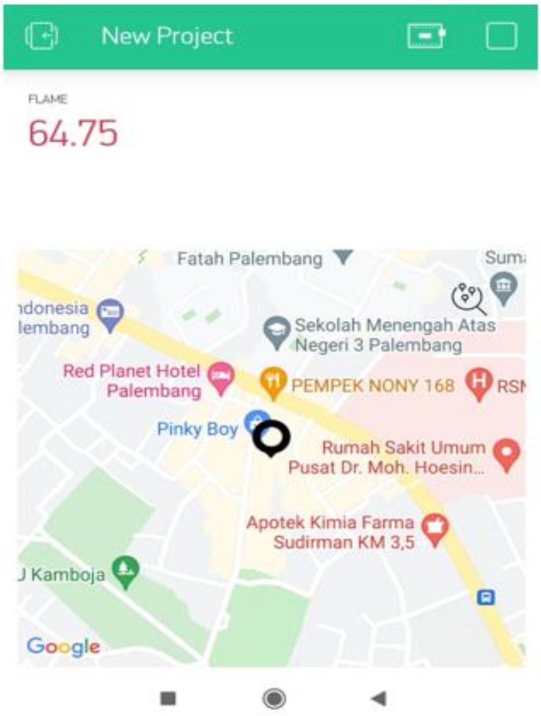


Fig. 18. Display of the forest fire monitoring system on the Blynk application

D. *System Design Implementation*

In this section, the system design implementation is carried out through an approach in the form of a system performance test, where the tool will be placed in the actual location, namely the forest. Parameters of tool performance test results are in RSSI (Receive Signal Strength Indicator). It was previously known that the created forest fire monitoring system consisted of two main tools, one sensor node, and one gateway. The LoRa-Tx on the sensor node is configured in such a way as to find out which setting mode is effectively used at the experimental location. For Tx power used is 20 dBm, using a 2.5 dBi antenna that works at a frequency of 473 Hz.

Fig. 19 shows the experimental location where data collection was carried out, located in the Punti Kayu Nature Park, Palembang City. This forest is divided into two areas, namely the utilization area and the conservation area (Fig. 20).

Fig. 19. Experimental location (Source: Google maps)

Table II is the result of RSSI measurements based on changes in distance. The RSSI is obtained by sending data in the form of 3 data with 1 byte each Header, 11 digits of latitude, 12 digits of longitude, 4 bytes of temperature. So the total data transmission is 30 bytes for a single send. In this experiment, data packets were successfully sent from the sensor node to the gateway, where the distance between the two devices was 100 meters, 200 meters, 300 meters, 400 meters, and 500 meters.

TABLE II. RESULTS OF RSSI MEASUREMENTS ON DISTANCE

LoRa SF	RSSI (dBm)				
	100 m	*200 m*	*300 m*	*400 m*	*500 m*
12	-92	-109	-126	-136	-139
10	-90	-106	-125	-132	-134
9	-90	-110	-127	-	-

Fig. 20. Experimental situation of conservation forest (top) and utilization forest (bottom).

Fig. 21 until Fig. 23 shows that the farther the sensor node is from the gateway, the weaker the signal strength (RSSI). The best LoRa configuration from the experiment is the Spread Factor (SF) of 10. This configuration can send data well up to a distance of 500 meters with an RSSI of -134 dBm. Information from RSSI results can be considered in the placement and addition of sensor nodes so that the signal coverage can cover the forest area. This information is important to confirm whether the data is received or not by the gateway. The higher the RSSI quality, the better the data traffic between sensor nodes and the gateway.

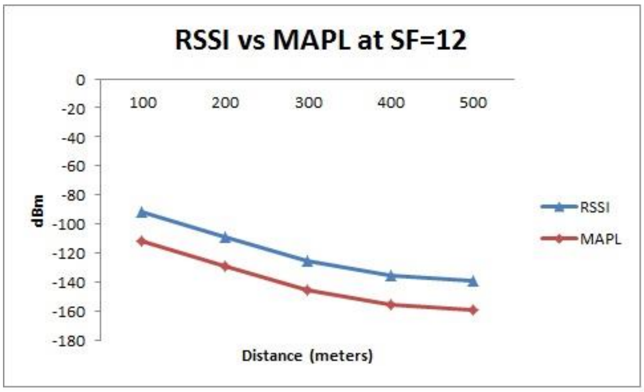


Fig. 21. Results of RSSI vs MAPL (SF=12) measurements on changes in distance.

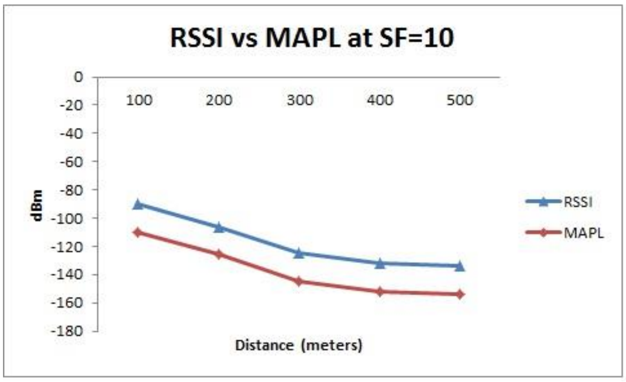


Fig. 22. Results of RSSI vs MAPL (SF=10) measurements on changes in distance.

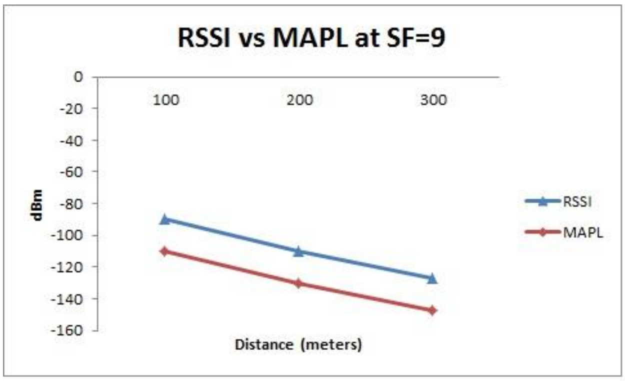


Fig. 23. Results of RSSI vs MAPL (SF=9) measurements on changes in distance.

V. CONCLUSION

The conclusions we can draw are, first, that the design of the forest fire monitoring system that has been built is quite realistic. The AMG8833 sensor is very responsive in detecting the presence of fire. Changes in the detection distance to the gradation of color changes in the sensor array provide a significant value. Second, the test results of the sensor and gateway nodes show the success of the two tools in sending and receiving data with a size of about 30 bytes for one send. Third, the implementation of LoRa in the forest provides performance in the form of communication capabilities as far as 500 m. RSSI at this distance is -134. The gateway will receive data better if the RSSI is greater than its performance. Meanwhile, the signal will be lost if the RSSI is smaller than its performance value. Finally, the best LoRa mode is in the configuration of Bandwidth (BW) = 250, Code Rate (CR) = 4/5, and Spread Factor (SF) = 10 with Tx power used is 20 dBm.

ACKNOWLEDGMENT

This research was supported by the RisetMU Project grant from the Diktilitbang Muhammadiyah Central Leadership through the Research Directorate of Universitas Muhammadiyah Palembang for the 2021 fiscal year, given to A/P Yosi Apriani, ST, MT.

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