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Innovative Forest Fire Detection Using LoRa Wireless Network for Long-Range and Real-Time Monitoring

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ABSTRACT

Purpose of the study: This research aims to design and create a forest fire detection tool based on wireless technology that can send information in real-time without an internet network. This system helps related parties detect and respond to fires more quickly and efficiently.

Methodology: This study employs an experimental research method, using tools such as Arduino, LoRa, DHT11, MQ2 sensors, and ESP32 Wi-Fi modules. Data collection methods include observation, interviews, and literature review. Software used includes Arduino IDE, Sublime, and Windows 10. Prototyping is applied for system design, with unit, system, and integrity testing for system validation. Data analysis is qualitative, with a focus on real-time monitoring.

Main Findings: The LoRa forest fire detection system works well, sending temperature, humidity, and smoke data to the website. Tests show that the device can work at a distance of up to 1 km. The fire status only appears if the temperature is above 40°C, humidity is above 10%, and smoke is above 2670 ppm. At close range, the device successfully detects fires, while at further distances, the safe status is displayed.

Novelty/Originality of this study: This study introduces a forest fire detection system using LoRa wireless communication, combining real-time monitoring of temperature, humidity, and smoke. The integration of Arduino-based sensors with LoRa for long-range data transmission offers an innovative approach. This research advances existing fire detection technologies by improving coverage and real-time data transmission, enhancing the accuracy and reliability of wildfire monitoring systems.

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1. INTRODUCTION

Forests are natural resources that occupy a very strategic position in the life of the nation and state. Approximately two-thirds of Indonesia's 191 million hectares of land are forest areas with diverse ecosystems, ranging from lowland tropical forests, highland tropical forests, to peat swamp forests, freshwater swamp forests, and mangrove forests [1], [2]. The importance of these resources is increasing because forests are a source of livelihood for many people [3]-[5]. And forests are also areas that have lots of dense vegetation containing, among others, trees, shrubs, ferns, grass, mushrooms and so on and occupy a fairly large area [6]-[8]. Forests function as carbon dioxide sinks, animal habitats, hydrological current modulators, and soil conservationists and are one of the most important aspects of the earth's biosphere.

Forest and land fires are a problem that is increasingly occurring in Indonesia. These forest and land fires cause various negative impacts on forest and land functions which then increase losses from various aspects, such as ecological, economic, and social aspects [9]-[11]. The impacts that arise include disruption of the health of the surrounding community, decreased biodiversity, declining economic value of the forest, and changes in the microclimate to the global [12]-[14]. One of the main causes of forest fires cannot be handled quickly because of human actions, both intentional and unintentional, such as throwing cigarette butts carelessly, and forgetting to put out fires at campsites, and forest fires that have often occurred recently are caused by residents' actions to clear wider land.

Other causes of forest fires are influenced by natural factors such as the dry season, lightning strikes, and climate change, this condition is exacerbated by the absence of a communication network, especially an internet network in the forest, this causes forestry service officers to be late in receiving information that a fire has occurred. If information about the fire is known too late, the fire will be difficult to handle because the fire spreads faster [15]-[17]. Islam as a religion that not only regulates the relationship between humans and their God, but Islam also regulates the relationship between humans and other creatures (including their environment) actually has a normative basis, both implicitly and explicitly, regarding the management of this environment. Explicitly, the Qur'an states that all types of damage that occur on the surface of the earth are the result of human actions in interacting with their environment [18], [19]. Along with the development of technology in the fields of education, communication and industry and the increasing power of human thought in utilizing technology [20]-[22]. Emerging various innovations in new technologies that will help humans in carrying out their work [23]-[25]. One of the technologies that continues to develop today is wireless technology [26]-[28]. With wireless technology that can send information without the need for cables, accompanied by tools where the delivery process is quite far and does not use the internet network, but uses tools such as Arduino, DHT11 Sensor, Mq2 Sensor and LoRa (Long Range). Where the information conveyed by the tool will be displayed on the web which can check forest conditions in real-time.

Several previous studies have developed a forest fire detection system using wireless sensor networks (WSN) and long-distance communication technologies such as LoRa. For example, research by Herring et al. [29] assessing the feasibility of LoRaWAN sensor nodes embedded underground to monitor temperature in detecting bushfires. Another study by Skouteri et al. [30] proposed an IoT system for forest fire detection and prediction in India, leveraging LoRa communication and an edge computing-based gateway to improve short-term fire risk estimation and early detection. Although these approaches have shown effectiveness in early detection of forest fires, several limitations still exist, such as dependence on network infrastructure that may not be available in remote forest areas, high implementation costs, and challenges in power management of sensor devices.

The current study aims to address these gaps by designing and implementing a forest fire detection system using DHT11 and MQ2 sensors connected via LoRa communication without the need for an internet network. The system is designed to provide real-time information on temperature, humidity, and gas concentrations in the forest area, which is displayed through a web interface that can be accessed by forest officers [31]-[33]. With this approach, it is expected that forest fire detection can be carried out faster and more efficiently, even in areas that are difficult to reach and have minimal communication infrastructure.

The uniqueness of this study lies in the development of an Internet of Things (IoT)-based forest fire detection system that integrates DHT11 and MQ2 sensors with LoRa communication technology, without relying on a commercial internet network. This approach distinguishes this research from previous studies that still rely on network infrastructure that is often not available in remote forest areas. The designed system is independent, energy efficient, and able to send environmental condition data in real time via a web interface, allowing direct monitoring by officers in the field [34]-[36]. The implications of this research are very significant, because it not only increases efficiency in early detection of forest fires, but also makes a real contribution to disaster mitigation and ecosystem preservation efforts.

The web will later display information from tools and sensors, such as providing information about temperature, information about gas conditions in areas where sensors have been installed, and information on where the sensors are installed. All of this information will also be seen directly by the operator on duty at that time, and based on the information displayed on the web will determine the next action to be taken by the relevant parties. The purpose of this research is to design and create a tool that can detect forest fires so that such events are quickly responded to and handled by the relevant parties.

2. RESEARCH METHOD

This research was conducted using an experimental method. Experimental research is a study that attempts to find the effect of certain variables on other variables under strictly controlled conditions [37], [38]. Based on the description above, it can be concluded that the type of research used by the researcher is experimental research, by conducting experiments in the form of smoke levels, temperature values and humidity values as input and the distance between the fire source and the tool as a variable (with a distance of 0.25, 0.5, 0.75 and 1km) with the output being the results of reading smoke sensors, temperature sensors, humidity sensors, forest condition status and monitoring time in real time. The location of the research is the Rammang-Rammang Protected Forest in the Maros Region.

This research uses a scientific research approach, namely an approach based on science and technology, and quantitative research, namely research that requires a lot of use of numbers, starting from data collection, interpretation of the data, and the appearance of the results. Likewise, at the conclusion stage of the research it would be better if accompanied by pictures, tables, graphs, or other displays. In this study, the output is in the form of numbers displayed in the table [39], [40].

The data source in this study is using Library Research which is a way of collecting data from several books, journals, theses, theses or other literature that can be used as a reference for discussion in this problem. In addition, data sources are also obtained from online data or the internet. The data collection method in this study consists of three main methods. First, the observation method is carried out by conducting research and direct review of the problems and related research objects. Second, the interview method is applied through direct interaction between researchers and respondents to explore relevant information. In this case, the researcher interviews an officer or party responsible at the research location. Third, literature studies are used as a method for collecting data by reading books, journals, theses, theses, and other literature related to the research topic. In addition, data from online sources or the internet are also used to enrich the information obtained. The research instruments used in this study consist of two types, namely hardware and software. Hardware includes several main components such as an Asus Intel Core i3 laptop with 4 GB RAM, Arduino, LoRa (Long Range), DHT11 sensor, MQ2 sensor, and ESP32 Wi-Fi module. These components function as tools to detect temperature, humidity, and smoke, and send data via the LoRa network. Meanwhile, the software used includes Arduino IDE for microcontroller programming, Sublime as a code editor, and the Windows 10 Enterprise 64-bit operating system as a working platform. The combination of these instruments allows for optimal development, testing, and data analysis in forest fire detection research using LoRa communication.

Data processing and analysis techniques in this study were carried out through several stages. At the data processing stage, researchers reduced data by filtering and sorting relevant data according to the research topic. Furthermore, data coding was carried out to provide a specific code for each data obtained, both from field research and literature studies, in order to facilitate the analysis process.

At the data analysis stage, researchers used a qualitative data analysis method which aims to describe and solve problems based on the data that has been collected. This process includes collecting, sorting, recording, and coding data so that information sources can be easily traced. With this approach, researchers can present research results in descriptive form that provides an in-depth picture of the research findings. The tool design method in this study uses the prototyping method [41]-[43]. This method involves creating a prototype as an initial example to show needs and designs to users. This process allows for an initial version of the system that can be tested and evaluated before developing the system as a whole.

In this approach, a prototype is created to represent the main functions of a forest fire detection tool using LoRa communication. After the prototype is tested, feedback from users or test results will be used to improve the design and functionality of the tool. With this method, tool development becomes more focused and in accordance with needs, until finally producing an optimal system for detecting temperature, humidity, and smoke in real-time. The system testing technique in this study was carried out through three main stages, namely unit testing, system testing, and integrity testing [44], [45]. At the unit testing stage, each component or hardware, such as temperature, humidity, and smoke sensors, as well as the LoRa communication module, is tested separately to ensure that its function is running properly and providing accurate data. Furthermore, system testing is carried out by integrating all components to ensure that the overall system functions according to design. This testing also includes verifying that data from the sensor can be transmitted in real-time via the ESP32 Wi-Fi module to the website. Finally, integrity testing is carried out to ensure that all system elements are well connected and able to communicate efficiently. Through these three stages, the reliability of the system in detecting and monitoring potential forest fires can be ensured.

3. RESULTS AND DISCUSSION

3.1. Block Diagram Design

The block diagram is used to explain the design of the tool carried out in order to realize the research of forest fire detectors using LoRa (Long Range) wireless network communication with output in the form of fire locations and the results of sensor readings used. The block diagram display can be seen in Figure IV.1 as follows:

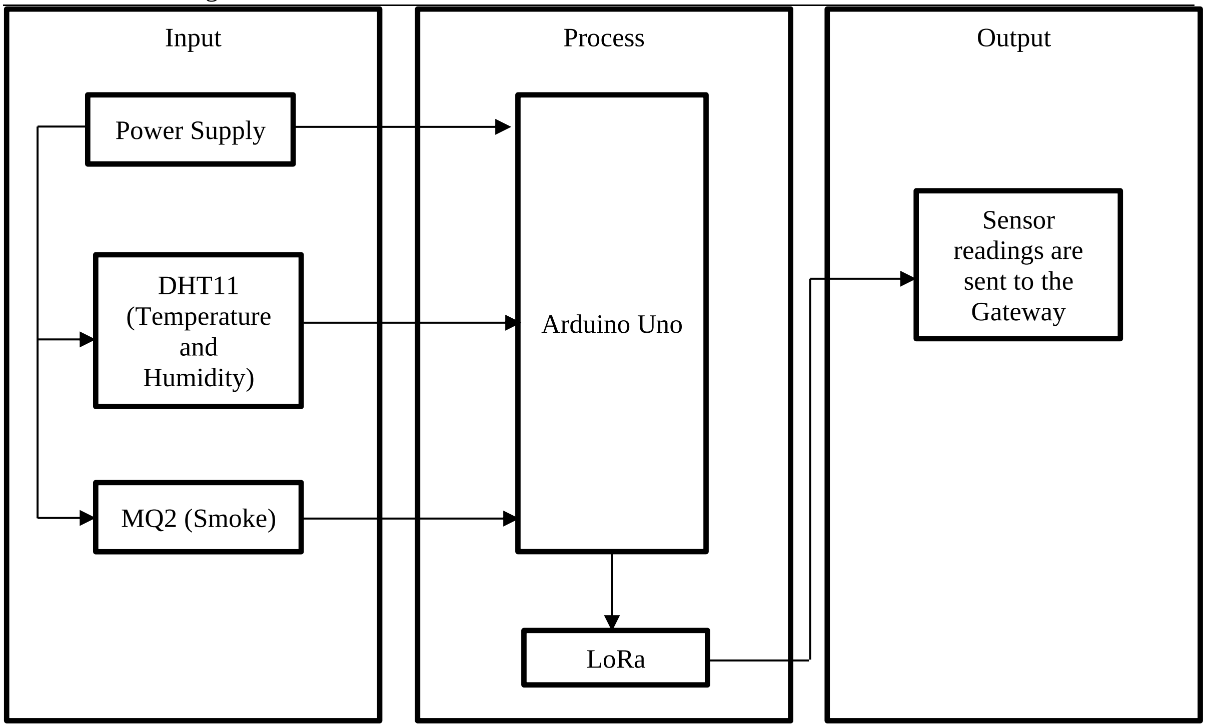


Figure 1. Node diagram design

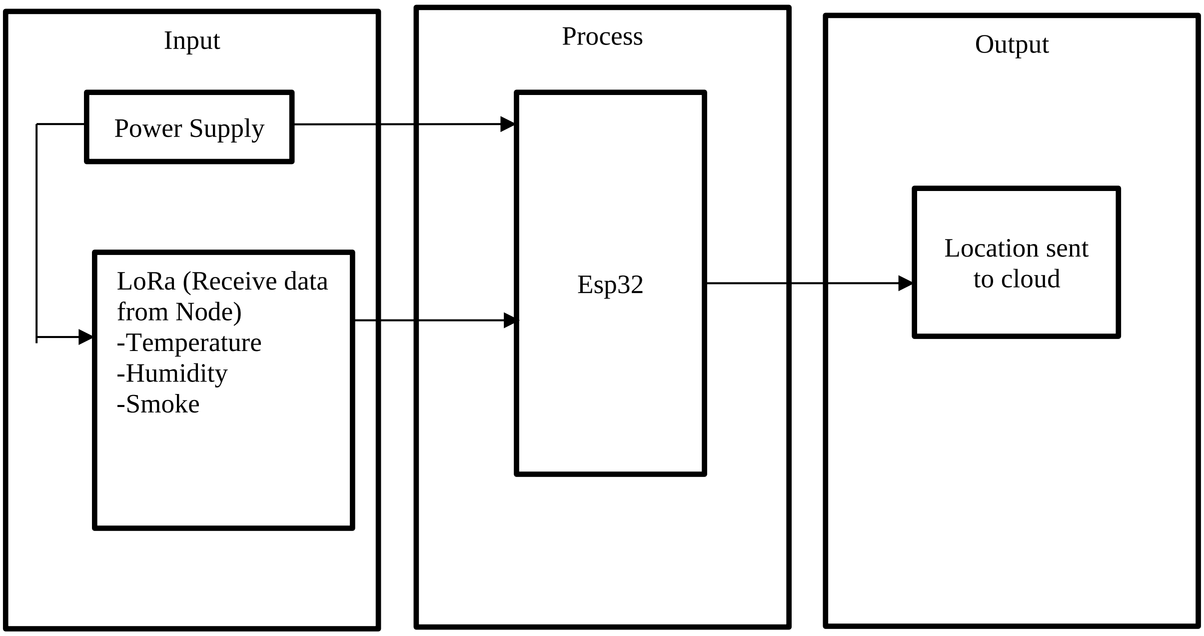


Figure 2. Gateway Block Diagram Design

In this study, the Arduino Uno microcontroller is used as the central processing unit that manages data received from environmental sensors—specifically the DHT11 for temperature and humidity detection, and the MQ2 for smoke detection. After collecting the sensor data, the Arduino Uno processes the values and prepares them for transmission. As shown in Figure 1, the sensor readings are first processed at the node level, where the DHT11 and MQ2 sensors send their data to the Arduino Uno. Then, as depicted in Figure 2, the data is transmitted via a LoRa module to a gateway system. At the gateway, the ESP32 microcontroller forwards the processed information to a web platform for real-time monitoring, including sensor readings and fire location. This design allows for an integrated system of multiple inputs and outputs with reliable data transmission to the cloud. The effectiveness of this configuration is supported by Zafar et al. [46], who demonstrated that combining Arduino Uno with DHT11 sensors and wireless communication modules such as the ESP8266 enables efficient real-time environmental monitoring systems based on IoT, with seamless data collection and transmission to cloud services for further analysis.

3.2. Hardware Design

The following is an overall design of a series of Forest Fire Detection Tools Using LoRa (Long Range) Wireless Network Communications:

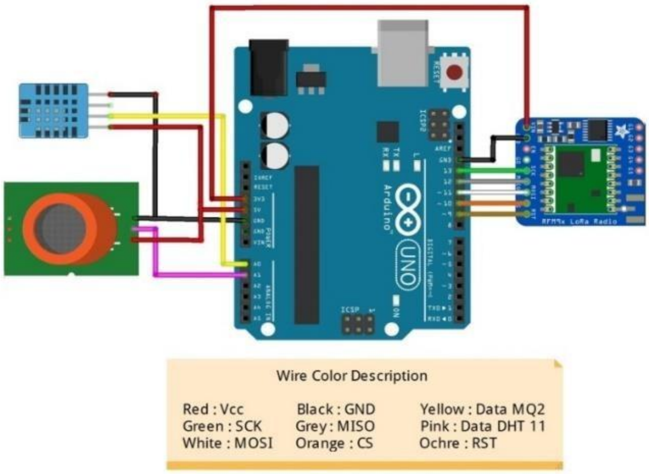


Figure 3. Node

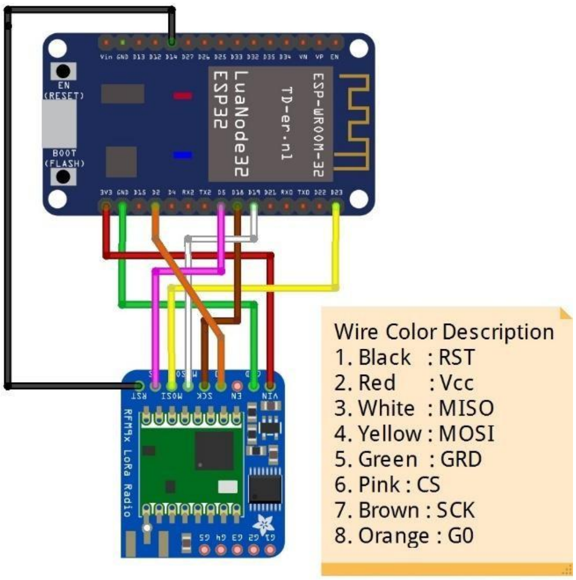


Figure 4. Gateway

The components in Figure IV.3 include Arduino Uno, DHT11, MQ2, Dragino LoRa Shield 915Mhz, while the components in Figure 4 include esp32 and LoRa Hat.

3.2. Software Design

Flowchart or flow chart is a chart that shows the flow in a program or system procedure logically. Flowcharts are used as percentage tools or communication materials and as documentation files. This flowchart explains the software design on the system being developed, The node software is designed to send information or data obtained from the MQ2 and DHT11 sensors to the LoRa Gateway, the design can be seen from the flowchart in Figure 5.

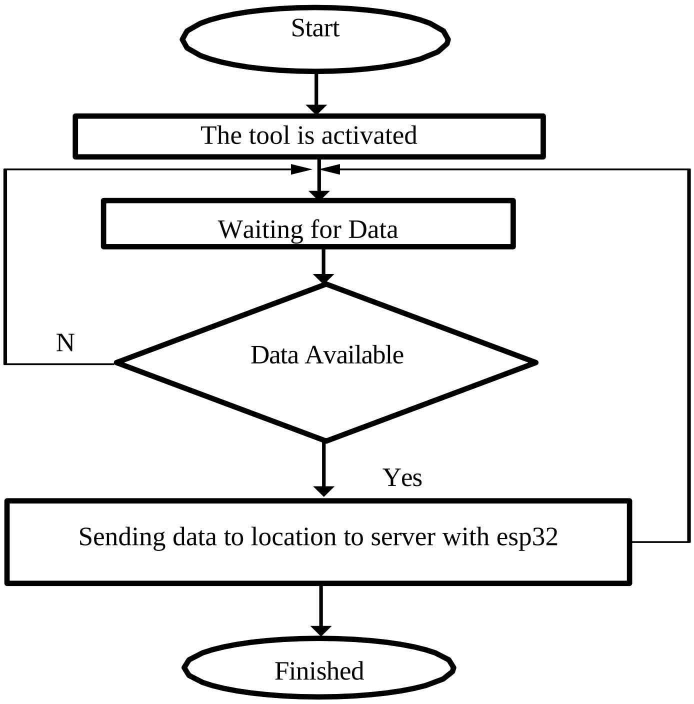


Figure 5. Flowchart

From the flowchart above, it can be explained that when the device is activated, the system will be connected after that the DHT11 sensor will detect the temperature at the location where the device is placed and the MQ2 sensor will detect smoke at the location, if the DHT11 sensor and MQ2 sensor get a value, the value is sent to the microcontroller to be processed and sent to the LoRa-Gateway with LoRa transmission media. If both sensors do not detect anything, the sensor will loop to get real-time results. The LoRa-Gateway software is designed to forward information from LoRa to the web, the design can be seen from the flowchart in Figure 6.

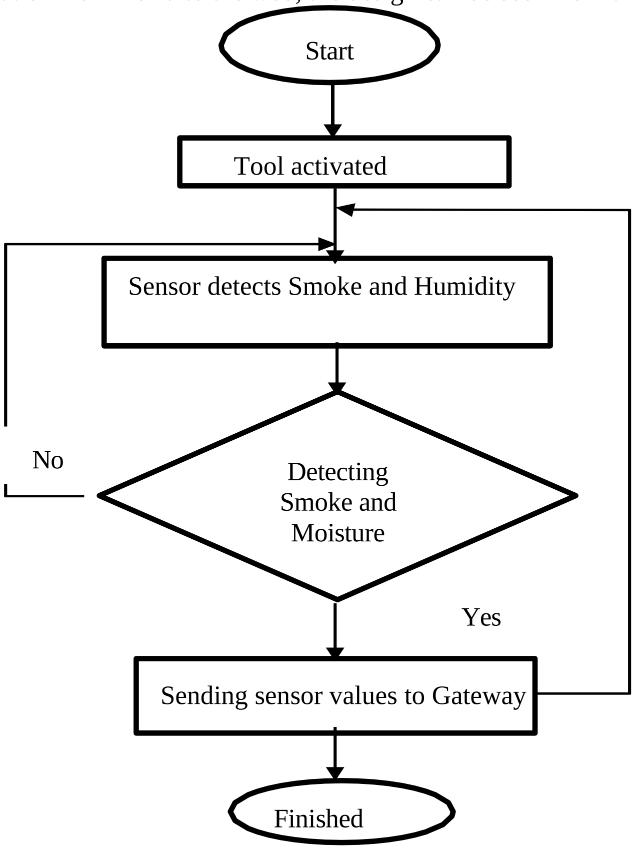


Figure 6. Gateway Flowchart

In the gateway flowchart, it can be seen that when the detector is activated, the device will wait for data to be sent by the LoRa node and when the data is available it will be received by the LoRa gateway, then the data is forwarded and processed with the time output, sensor reading results, and sensor reading status using the Arduino uno microcontroller. After that, the data is sent to the server using esp32.

The display of fire monitoring data is the reading results from the smoke, temperature and humidity sensors, status and time of fire monitoring:

FIRE MONITORING DATA DISPLAY

No.	Temperature (°C)	Humidity (%)	Smoke (PPM)	Status	Time
1	29	10	1143	Safe	2024/10/13
2	29	10	1143	Safe	2024/10/13
3	29	10	1163	Safe	2024/10/13
4	29	10	1143	Safe	2024/10/13
5	30	10	1115	Safe	2024/10/13
6	30	10	1125	Safe	2024/10/13
7	30	10	1124	Safe	2024/10/13
8	30	10	1124	Safe	2024/10/13
9	29	10	1134	Safe	2024/10/13
10	29	10	1134	Safe	2024/10/13
11	29	10	1134	Safe	2024/10/13
12	29	10	1134	Safe	2024/10/13
13	29	10	1134	Safe	2024/10/13
14	29	10	1134	Safe	2024/10/13
15	29	10	1134	Safe	2024/10/13
16	29	10	1143	Safe	2024/10/13
17	29	10	171	Safe	2024/10/13
18	34	7	71	Safe	2024/10/13
19	34	9	71	Safe	2024/10/13
20	34	9	71	Safe	2024/10/13
21	34	9	71	Safe	2024/10/13
22	34	9	71	Safe	2024/10/13
23	34	9	71	Safe	2024/10/13
24	34	9	22	Safe	2024/10/13
25	34	9	22	Safe	2024/10/13

Figure 7. Fire Monitoring Data Display

3.2. Implementation

This display displays information on the results of reading smoke sensors, smoke and humidity sensors, time, and status of the results of reading both sensors which are carried out in real time.

FIRE MONITORING DATA DISPLAY

No.	Temperature ('c	Humidity (%)	Smoke	Status	Time
1	29	10	1143	Safe	2024/10/13
2	29	10	1143	Safe	2024/10/13
3	29	10	1153	Safe	2024/10/13
4	29	10	1143	Safe	2024/10/13
5	30	10	1125	Safe	2024/10/13
6	30	10	1125	Safe	2024/10/13
7	30	10	1124	Safe	2024/10/13
8	29	10	1124	Safe	2024/10/13
9	29	10	1124	Safe	2024/10/13
10	29	10	1134	Safe	2024/10/13
11	29	10	1134	Safe	2024/10/13
12	29	10	1134	Safe	2024/10/13
13	29	10	1134	Safe	2024/10/13
14	29	10	1143	Safe	2024/10/13
15	29	10	1172	Safe	2024/10/13
16	29	10	1115	Safe	2024/10/13
20	34	9	71	Safe	2024/10/13
21	34	9	71	Safe	2024/10/13
22	34	9	71	Safe	2024/10/13
22	34	71	71	Safe	2024/10/13

Figure 8 Fire Monitoring in Safe Status

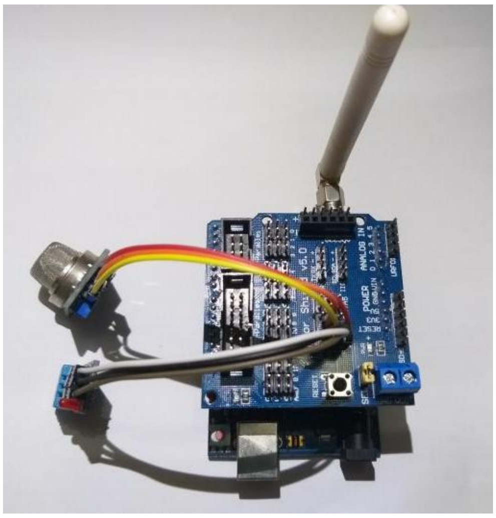
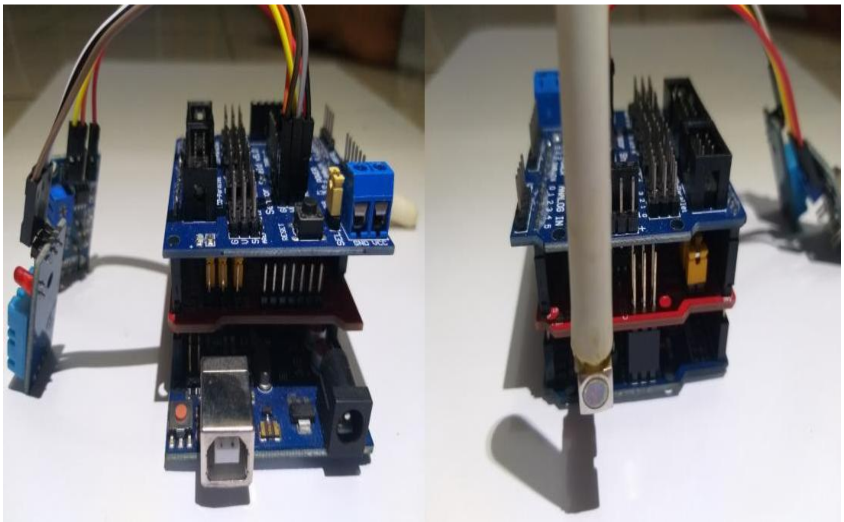
Tabel Fire Monitoring Data Display

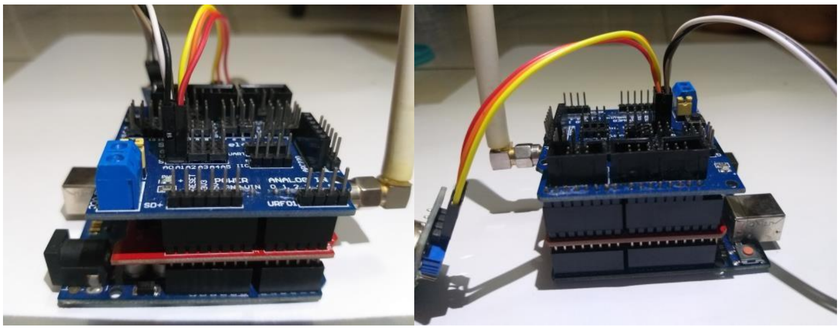
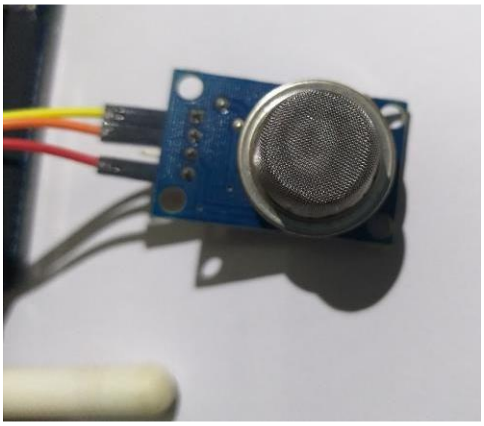
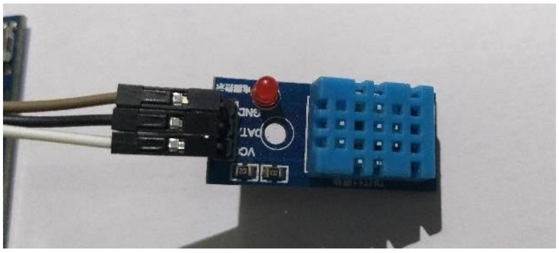
No.	Temperature (°C)	Humidity (%)	Smoke (PPM)	Status	Time
15	32	74	1494	Fire	2024/11/04-09:20:22
16	32	80	1485	Fire	2024/11/04-09:20:15
17	32	80	1485	Fire	2024/11/04-09:20:12
18	32	80	1532	Fire	2024/11/04-09:20:06
19	32	77	1523	Fire	2024/11/04-09:20:00
20	31	77	1523	Fire	2024/11/04-09:19:57
21	31	77	1504	Fire	2024/11/04-09:19:54
22	32	80	1513	Fire	2024/11/04-09:19:48
23	32	82	1513	Fire	2024/11/04-09:19:45

Figure 9. Fire Monitoring During Fire Status

In fire conditions, there is a standard with a temperature sensor reading of more than 40 degrees Celsius, a humidity sensor value of more than 10% and a smoke sensor value of more than 2670 ppm and must meet these three conditions, if these three conditions are not met, the safe status will be read. However, in Figure 8 the author lowers the fire standard to a temperature sensor of more than 30 degrees Celsius, humidity of more than 50% and a smoke sensor of more than 1000 pmm, to facilitate the simulation of the tool. The components contained in the node circuit are Arduini Uno, DHT11, MQ2, and Dragino LoRa Shield 915Mhz and Power Supply as a resource.

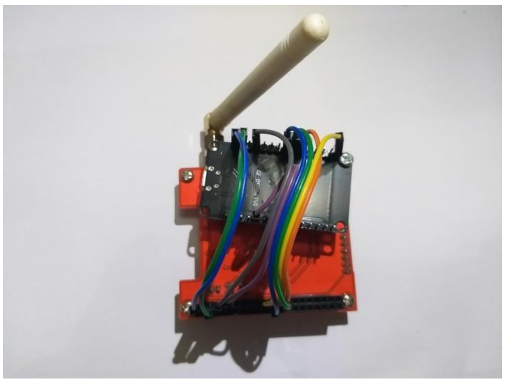
Table 1. Components found in the node circuit, namely Arduino Uno, DHT11, MQ2, and Dragino LoRa Shield 915Mhz and Power Supply as a power source.

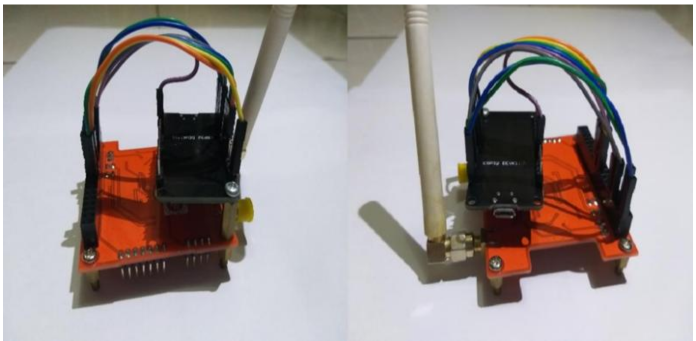
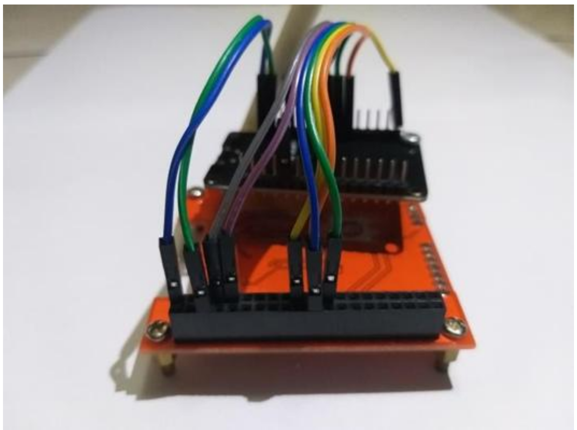
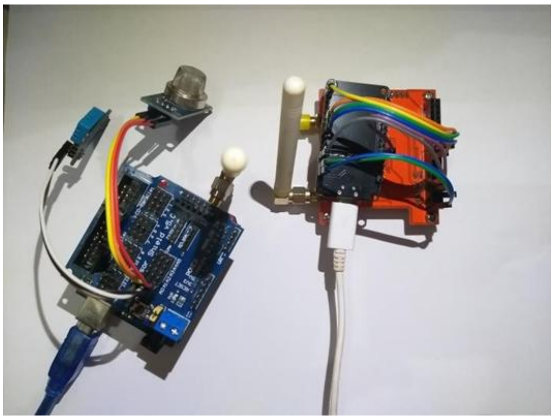
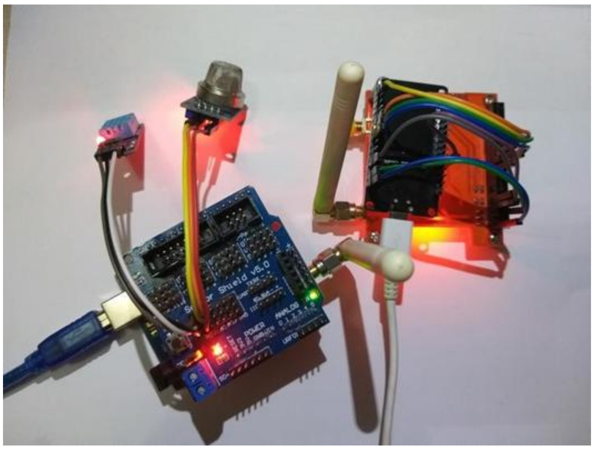
Image Caption	Picture
Top View of Node Circuit	
Front and Back View of Node Circuit	

Side View of Node Circuit	
DHT11 Sensor in Node Circuit	
MQ2 Sensor in Node Circuit	

The components in the gateway series are esp32 and LoRa Hat and this gateway series is connected to the website:

Table 2. Components found in the gateway circuit, namely esp32 and LoRa Hat and this gateway circuit is connected to the website.

Image Caption	Picture
Top View of Gateway Circuit	

Front and Back View of Gateway Circuit	
Side View of Gateway Circuit	
Tool in Off Condition	
it can be seen that the tool is inactive, meaning that the tool cannot operate, namely the tool cannot detect temperature, humidity and smoke in the area, and cannot send and forward information displayed on the website.	

There is a safe and unsafe status from the sensor reading results. If the temperature is 40 degrees Celsius, humidity 50% and smoke 2670 ppm, then these conditions indicate that a fire is occurring in the area, and vice versa if the temperature is below 40 degrees Celsius, humidity below 10% and smoke less than 2670 ppm, this indicates that the conditions around the area where the device is installed are fine.

The results of this study are in line with several literatures that have discussed early fire detection systems using environmental sensors and wireless communication technology. In the study reviewed by Li et al. [47], explained that the early warning system for fires based on gas and temperature sensors has an important role in reducing the impact of fire disasters by providing warnings before the fire spreads widely. This is in accordance with the approach in this study which uses the MQ2 sensor to detect smoke and DHT11 to measure temperature and humidity as early indicators of a fire.

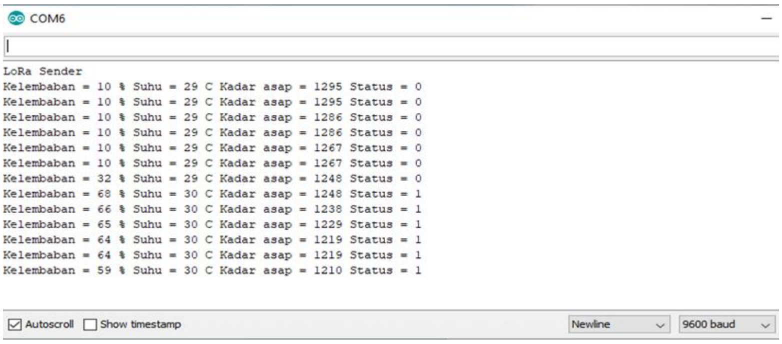
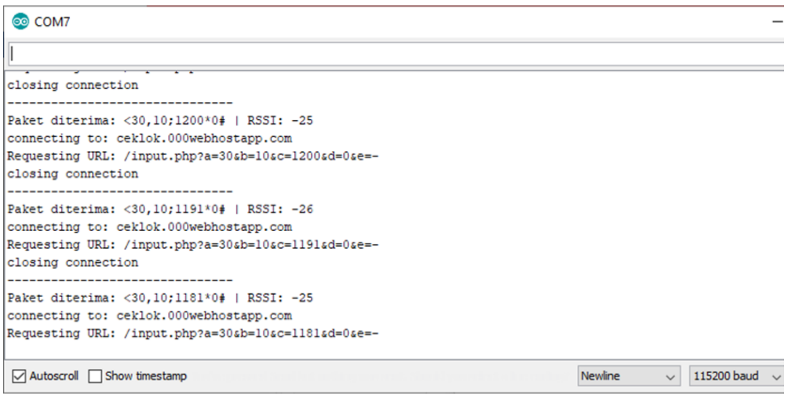
3.3. System Testing

Testing is the process of executing or testing the entire tool to determine whether the tool is in accordance with what the researcher wants. Testing is done by conducting experiments to see the possibility of errors that occur in the tool. The testing method used is black box.

Black Box testing is testing the device in terms of functional specifications without testing the design and program code. Testing is intended to determine whether the functions and outputs are running as desired. In conducting testing, what we need to do is test several functions that will later become a single function.

The stages that need to be carried out in this testing are testing input devices such as testing each sensor on the node system, gateway system and website testing.

Table 3. Input device testing stages

Testing	Picture
Node System Testing (In node system testing, this is done by testing whether the temperature and humidity sensors and smoke sensors and LoRa will work as they should, and the distance that this tool can reach is 1km. Then the data obtained from the node system will be forwarded to the gateway system)	
Gateway System Testing (Gateway system testing is done by sending data from the node to the Gateway and forwarding it to the website. This method is done to ensure that the gateway function is running as it should. The function intended in the gateway design is to be able to receive data from the node and be able to forward the data to the website.)	

Website Testing

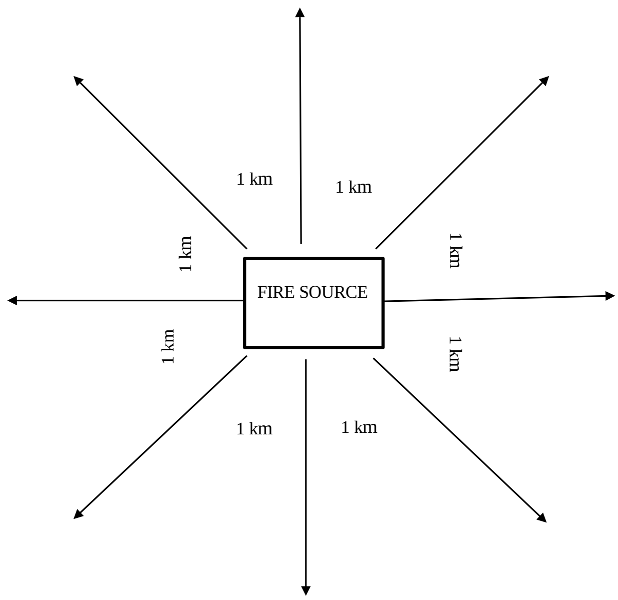
(website testing is done by whether the website receives information from the gateway system. The information displayed is the value of the smoke, temperature and humidity sensor readings, the current time when monitoring the fire, and the status conditions of the sensor reading results, namely safe and fire. The safe category if the temperature sensor value is less than or equal to 40 degrees Celsius, the humidity value is less than or equal to 10%, and the smoke sensor value is less than or equal to 2670 ppm, while the fire category is the opposite of the above conditions)

FIRE MONITORING DATA

No.	Temperature (°C)	Humidity (%)	Smoke (PPM)	Status	Time
1	30	10	1172	Safe	2024/10/29-23:20:01
2	30	10	1172	Safe	2024/10/29-23:19:57
3	30	10	1172	Safe	2024/10/29-23:19:54
4	30	10	1172	Safe	2024/10/29-23:19:51
5	30	10	1172	Safe	2024/10/29-23:19:48
6	30	10	1172	Safe	2024/10/29-23:19:45
7	30	10	1172	Safe	2024/10/29-23:19:42
8	30	10	1172	Safe	2024/10/29-23:19:39
9	30	10	1172	Safe	2024/10/29-23:19:36
10	30	10	1172	Safe	2024/10/29-23:19:33

Overall testing

The device is stored on a tree with a range of 1km, at a distance of 1km the device still functions and continues to provide information related to the reading results of the two sensors but does not display the fire status if it does not meet the three conditions, namely the temperature sensor is greater than 40 degrees Celsius, the humidity sensor value is greater than 10% and the smoke sensor value is greater than 2670 ppm at a distance of 0.75m the three conditions have not been met, this is also caused by the wind direction at that time if the wind direction is opposite to the location of the device, the smoke content automatically does not meet the fire status conditions. While at a distance of 0.25m and 0.5 the three conditions will be met because the closer the fire source is to the installed device so that later the status that appears is fire.



The results of this study are in line with previous studies showing that the combination of temperature and gas sensors, such as DHT11 and MQ2, with LoRa communication technology is effective for early detection of forest fires. The implementation of such a system allows for real-time monitoring of environmental conditions and rapid response to potential fires, which is very important for risk mitigation and environmental protection.

Research by Anand et al.[48] developed a forest fire detection system using LoRa network and Internet of Things (IoT) technology. This system utilizes temperature and gas sensors to monitor environmental conditions in real time. The collected data is sent via LoRa network to a monitoring center, enabling early detection and rapid response to potential forest fires. Although this study used MQ6 and DS18B20 sensors, this approach is in line with the use of DHT11 and MQ2 sensors in your study, which also aims to detect changes in temperature and the presence of gases that indicate fires.

Then the study by Apriani et al.[49] design and implement a forest fire monitoring system using LoRa technology. This system consists of sensor nodes equipped with AMG8833 and GPS sensors, as well as a gateway to send data to the server. Tests show that this system is able to detect hotspots at a distance of 3 to 10 meters and send data up to a distance of 500 meters with good signal quality. Although the sensors used are different, the basic principle of this system is similar to your research, namely using sensors to detect fire indications and sending data via the LoRa network for monitoring and rapid response.

Furthermore, Saryendy and Unik's research [50] developed an IoT-based forest fire detection system that uses solar energy as a power source. This system is equipped with DHT11, MQ2, and flame sensors, as well as a LoRa SX276 module for data transmission. Tests have shown that this system successfully detects fires with a high level of reliability and is able to send data efficiently over the LoRa network. This research supports your approach in using DHT11 and MQ2 sensors to detect forest fires, and shows that the system can operate independently with renewable resources.

This research presents a novelty in the integration of DHT11 and MQ2 sensors with a LoRa communication module for an IoT-based forest fire detection system that is able to display data in real time via the web, with safe and dangerous detection limits that can be adjusted for simulation needs or real conditions. The implications of this research indicate that the developed system is able to increase the effectiveness of fire monitoring in remote areas at low cost and wide coverage, so that it can support disaster mitigation efforts more quickly and efficiently. However, this system still has several limitations, such as sensor sensitivity to environmental conditions such as wind direction and limited detection distance accuracy, as well as dependence on connectivity and electrical power, which can affect the performance of the tool in extreme conditions in the field.

4. CONCLUSION

The conclusion of this study shows that the fire monitoring system developed using LoRa Shield, LoRa Hat, and Arduino Uno as the main components successfully functions in real-time in monitoring temperature, humidity, and smoke levels at the location. This system is also connected to the website via the ESP32 module, allowing easy and efficient monitoring of environmental conditions. Although the system has been able to work well, there are several aspects that can still be improved, such as adding a container to improve the neatness of the device, improving the quality of the tool for wider coverage, and improving the distance between the node system and the gateway to increase monitoring effectiveness. With further development, this system has the potential to be integrated with additional features, such as direct notification to firefighters to improve response to potential fires.

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