Analysis of Data Communication and Soil Moisture and pH Sensors in Soil Monitoring System using LoRa Technology: Performance Evaluation and Distance Measurement

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Abstract. Monitoring soil moisture and pH levels is crucial for tracking the health of plants. Therefore, it is necessary to develop a device for measuring soil moisture and pH with the aim of plant monitoring. This device utilizes Long Range technology and consists of two nodes that monitor two different soil parameters: soil moisture and pH levels. Test results indicate that this device is capable of measuring soil moisture with the smallest error rate of 0.0254% and pH levels with the smallest error rate of 0.29%. Monitoring data is transmitted via LoRa technology with a range of up to 400 meters, and the testing results successfully detected RSSI and SNR values. For Node A, the average RSSI value was -113.6 dBm, and the average SNR value was -2.55 dB. Meanwhile, for Node B, the average RSSI value was -116.6 dBm, and the average SNR value was 2.35 dB. Data can be accessed through a website using Firebase services.

Keywords. Humidity, Acidity Level (pH), LoRa, Firebase sevices

1. Introduction

Soil plays a crucial role in supporting the growth and development of plants. In many cases, mismanagement of soil can hinder plant growth, especially the root system, ultimately leading to crop failure. One key factor that affects plant growth is soil moisture. Soil moisture is a vital aspect of both agriculture and natural ecosystems as it serves as a crucial water source for plants and vegetation. Soil moisture also plays a role in regulating energy transfer, such as heat exchange between the soil surface and the atmosphere, influencing the balance of water and energy through processes like evaporation and soil temperature [1]. Another factor influencing plant growth is soil acidity, or pH. Soil pH refers to the level of acidity or alkalinity in the soil, which can significantly impact plant growth. pH values provide information about the concentration of H+ ions in a solution, meaning lower pH values indicate higher concentrations of H+ ions and more acidic soil [2]. Each type of plant requires a specific pH level for optimal growth. In Indonesia, the ideal soil pH for various food crops, plantations, and horticulture typically falls within the range of 6-7. Deviations from this range can hinder plant growth and lead to losses for farmers [2].

Several research studies have explored the complexity of the impact of temperature and soil moisture on soil pH in various plant species. A study found the

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complexity of the influence of soil temperature and humidity on soil pH levels in crystal guava (Psidium guajava L.) plantations in Bumiaji, Batu City. This research involves measuring soil temperature and soil pH in the guava plant growth area. [3]. These studies have integrated various measurement tools, including temperature sensors like DS18B20, soil moisture sensors like YL-69, electrodes, and Arduino Uno microcontrollers, resulting in error rates of 0.22% for temperature, 1.58% for soil moisture, and 2.68% for soil pH [4]. Furthermore, a study based on IoT and LoRa technology for monitoring soil moisture levels indicated error rates of 8.8% for humus soil and 10.7% for agricultural soil [5]. Soil testing due to gold processing waste involved measurements of soil temperature, moisture, and pH, and the results were mapped [6]. Additionally, IoT technology was applied to monitor soil quality, such as a study on water quality monitoring in fishponds [7]. Another study investigated soil moisture control using YL-69 soil moisture sensors in agarwood tree cultivation, with sensors detecting moisture levels exceeding 80% [8]. Further research focused on soil pH levels in chili plants using IoT technology, revealing pH variations at different times [9]. Studies also explored automated systems for measuring soil moisture, temperature, and pH based on Android and Arduino ESP32 in spinach cultivation, resulting in a soil pH of around 7 and a temperature of 7 degrees Celsius [10]. The importance of monitoring extends to the use of IoT in ornamental plant cultivation, such as snake plants. Research investigated the monitoring of soil moisture, temperature, pH levels, as well as automated irrigation and stacking in snake plant cultivation, yielding various pH and moisture readings for different plants [11]. There is also research on the design and construction of soil quality measurement devices based on Arduino Uno, with varying error rates for normal soil, soil mixed with vinegar, and soil mixed with dolomite limestone [12]. An ESP32 microcontroller-based monitoring device measures nutrient levels, pH, soil moisture, temperature, and air humidity. The device sends this processed data to Firebase via the internet and displays it on an LCD16x2. The device is accurate, with NPK, pH, soil moisture, and DHT11 temperature sensor providing an accuracy of about 98% [13]. A monitoring system using LoRa technology has been designed for a starfruit plantation. pH and soil moisture sensors are employed to monitor the soil quality within the plantation. Our experiments reveal that the system has an RSSI value of -120 dBm and a PDR below 50%. The end-user interface is accessible through desktop. Furthermore, the average response time for the proposed monitoring system is approximately 0.408 for all menus [14]. A system involves the use of nitrogen, phosphorus, and potassium fertilizers alongside soil moisture sensors equipped with an automatic compaction system to control real-time measurements. Additionally, the Antares LR-ESP201 board was employed to transmit data to the cloud, and a Low-Power Wide Area Network LoRa was implemented at a frequency of 920-923 MHz. Measurement data is displayed on an Android smartphone through the Internet of Things [15].

When plant growth is hindered, one of the potential causes may be inadequate soil moisture and pH levels. This can have serious consequences such as crop failures and significant losses of time, resources, and efforts for farmers. To address this issue, a system is required to accurately measure soil moisture and pH, and these measurement results can be seamlessly integrated through a smartphone application using Long Range (LoRa) technology.

As technology advances and our understanding of the importance of monitoring environmental conditions for plant growth continues to grow, these studies have provided valuable insights. Through the use of technologies like IoT and microcontrollers, we can measure and understand these critical parameters more accurately and efficiently, ultimately helping to improve agricultural yields and plant cultivation practices.

The significance of adding at least two additional nodes to an environmental monitoring system, such as soil moisture and pH levels, cannot be overstated. Firstly, having redundancy ensures a more reliable system; if one node experiences issues, others remain operational to produce essential data. Furthermore, using multiple nodes allows for data validation by comparing consistent and accurate results. By placing nodes in different locations within a larger area, variations in the environment can be observed, which is valuable when factors like soil moisture or pH fluctuate. Improved temporal monitoring allows for understanding trends and changes over time, as well as addressing experiment complexity with various variables and parameters. Moreover, using multiple nodes helps test hypotheses and concepts in environmental monitoring. The required number of nodes will be adjusted based on monitoring objectives and the complexity of the environment faced, thus flexibility in the number of nodes can enhance more detailed and reliable monitoring.

2. Problem Statement

1. How can LoRa technology be applied to enhance the monitoring of soil moisture and pH, leading to more efficient agriculture practices and improved yields?
2. What are the primary challenges faced in measuring and controlling the variability of soil pH and soil moisture across various types of crops and environmental conditions?
3. How can the use of IoT technology and microcontroller devices like Arduino be employed to enhance the monitoring and control of soil quality parameters, and how can this information be applied in the cultivation of diverse crops to support optimal growth?

3. Method

3.1 Block Diagram Design

The design and implementation of the system are conducted in two parts, namely Hardware and Software. The hardware section encompasses the tools used to monitor soil pH and humidity levels. In the node section, tools or components are used as depicted in the block diagram shown in Figure 1.

The LoRa module operating at a frequency of 915 MHz is used to transmit sensor data as illustrated by the block diagram in the node section of Figure 1. The devices employed in this section consist of the pH electrode probe sensor and the soil moisture sensor YL-69. Additionally, the Arduino UNO microcontroller is utilized here, and the measurement results are displayed on a 16x2 LCD.

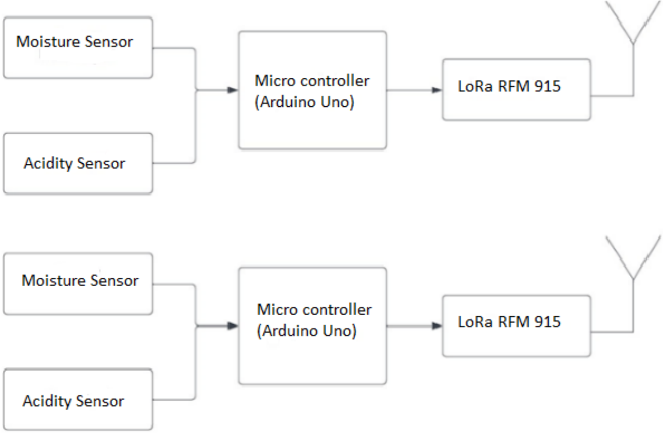


Fig.1. Block Diagram in the Node Section

Picture 2 shows the block diagram in the gateway or receiver section. It utilizes an LoRa module operating at a frequency of 915 MHz to receive data from the node section. The type of microcontroller employed in the gateway section is the ESP32 module.

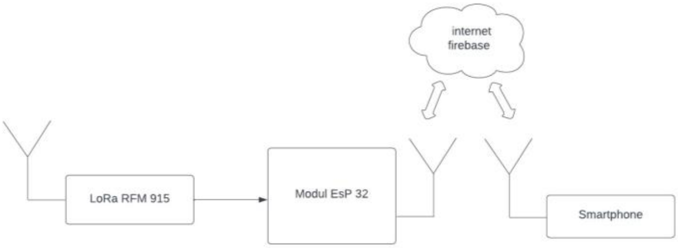


Fig.2. Block Diagram in the Gateway Section

3.2 Flowchart Design

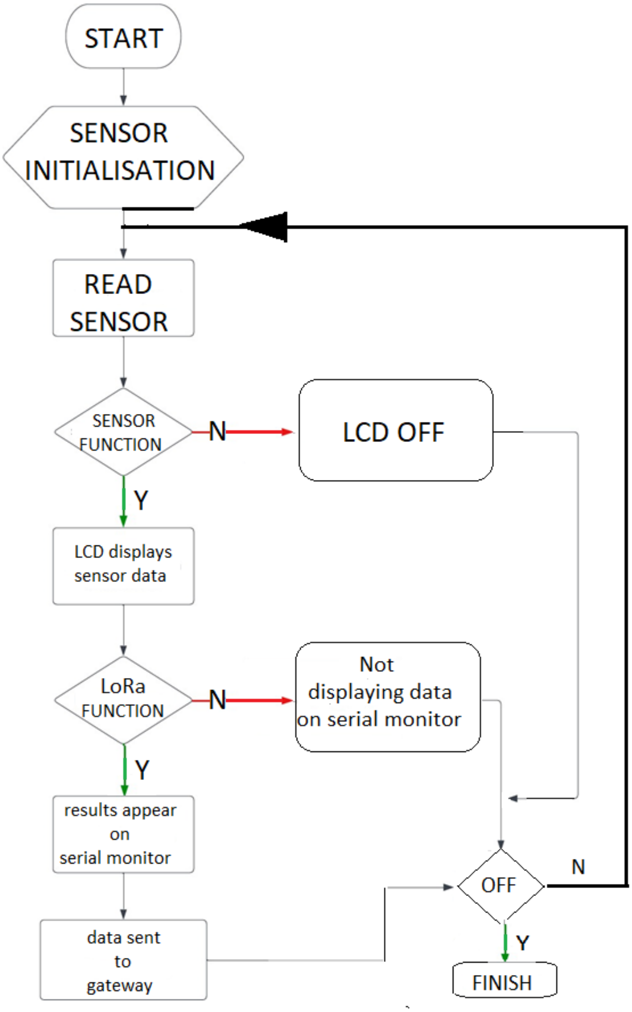


Fig. 3. Flowchart in the Node Section

Conducting testing in a phased manner according to the flowchart depicted in Figure 3 (Node section) and Figure 4 (Gateway section) is a good approach in project management. This approach helps ensure that all testing stages are carried out correctly.

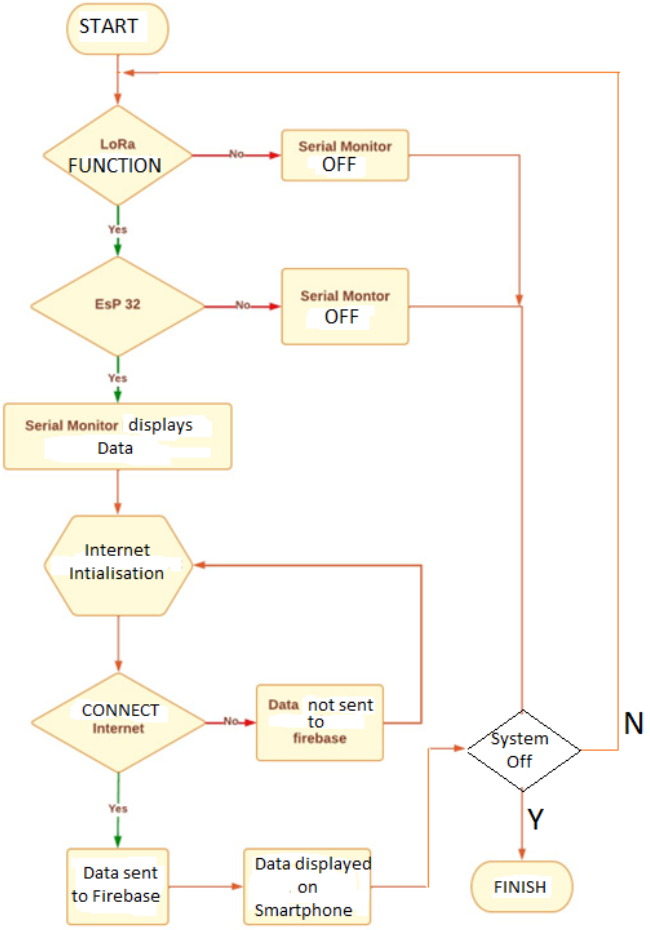


Fig. 4. Flowchart in the Gateway Section

3.3 Soil Test Situation

Fig. 5. Measurement of Humidity, pH, and Effectiveness

The software was implemented using the Arduino IDE application. Measurement data from both the Humidity and pH sensors were presented on an I2C LCD. The YL-69 sensor was connected to Arduino's A2 pin, while the pH sensor was linked to Arduino's A0 pin. The LCD employed for visualizing the results of these sensors had a 16x2 size and utilized the I2C communication protocol with the address set to 0x27. Figur 5 shows the sensor testing conducted on two different types of soil. The testing was performed to determine the differences in measurement results obtained through comparative testing.

4. RESULT AND DISCUSSION

4.1 Sensor Test

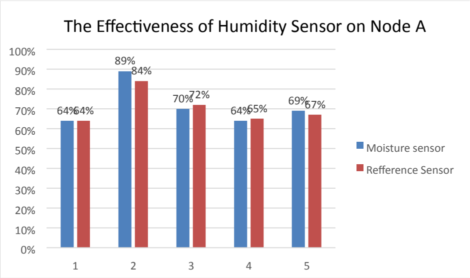


Fig. 6. The Effectiveness of Humidity Sensor on Node A

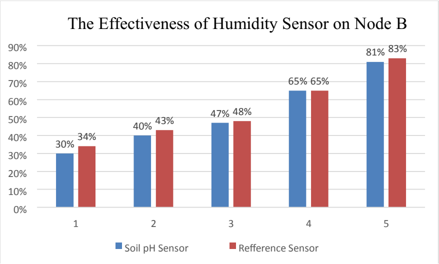


Fig. 7. The Effectiveness of Humidity Sensor on Node B

The effectiveness of humidity and pH sensors is shown in figures 6, 7, 8, and 9. Effectiveness testing was carried out to assess the accuracy of both the humidity and pH sensors compared to a reference sensor. The testing of the YL-69 humidity sensor and pH sensor in the soil monitoring system using LoRa technology has shown highly promising results. The humidity sensor accurately detected soil moisture levels, which are displayed in percentages. Meanwhile, the pH sensor required prior calibration using an Arduino program to produce accurate pH values.

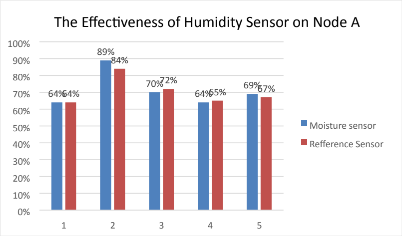


Fig. 8. The Effectiveness of pH Sensor on Node A

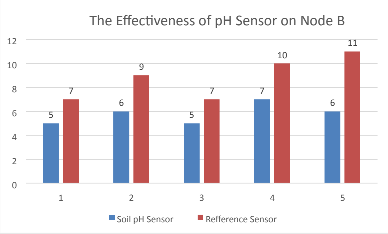


Fig. 9. The Effectiveness of pH Sensor on Node B

The evaluation of the effectiveness of the YL-69 humidity sensor and pH sensor when compared to reference sensors provided informative error data. The lowest error values were recorded for the YL-69 humidity sensor, with 0% error on Node A and the highest error reaching only 0.05. On the other hand, for the soil pH sensor, the smallest error was 3%, while the largest error reached 36%. Node B demonstrated some humidity sensors matching the reference, but pH values remained relatively high. Calibration of the pH sensor is crucial for accurate results.

Table 1 and 2 shown The testing was conducted with two nodes, each equipped with a YL-69 humidity sensor and a pH sensor. Soil humidity levels approaching 0% indicated dry soil conditions, while values nearing 100% indicated moist soil. The testing of the humidity sensor revealed relatively accurate and stable values. In contrast, pH values, which have a range of 0-6 (acidic), 6.5-7.8 (neutral), and 8-14 (alkaline), required more precise calibration to match the reference sensors.

Table 1. Measurement of Humidity and pH Sensors on Node A

Moisture Sensor		**pH Sensor**	
74%	Moist Soil	5,74	Acidic Soil
74%	Moist Soil	5,60	Acidic Soil
74%	Moist Soil	5,71	Acidic Soil
74%	Moist Soil	5,68	Acidic Soil
74%	Moist Soil	5,75	Acidic Soil
74%	Moist Soil	5,60	Acidic Soil
74%	Moist Soil	5,55	Acidic Soil

Table 2. Measurement of Humidity and pH Sensors on Node B

Moisture Sensor		**pH Sensor**	
20%	Moist Soil	8	Acidic Soil
20%	Moist Soil	7	Acidic Soil
20%	Moist Soil	8	Acidic Soil
20%	Moist Soil	9	Acidic Soil
20%	Moist Soil	8	Acidic Soil
20%	Moist Soil	7	Acidic Soil
20%	Moist Soil	6	Acidic Soil

The data communication process between nodes and the gateway proceeded smoothly. The use of Arduino Uno microcontrollers on the nodes enabled successful transmission of sensor measurement data via LoRa. Communication testing at distances of 10, 50, 100, 200, 300, 400, and 500 meters indicated that the gateway could accurately receive data, even at the maximum distance of 500 meters. During testing with two nodes, both nodes were able to reach a distance of 400 meters. However, Node 1 experienced packet loss at this distance due to noise interference during data transmission. In contrast, Node B did not encounter similar issues, with all packets successfully received by the gateway.

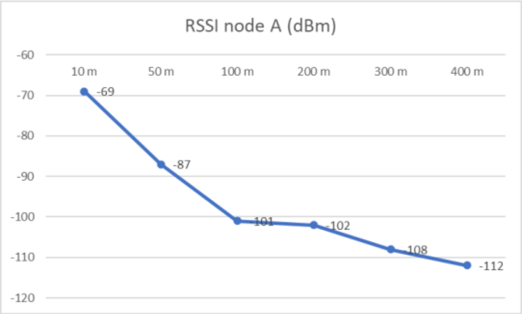


Fig.10. The RSSI on Node A

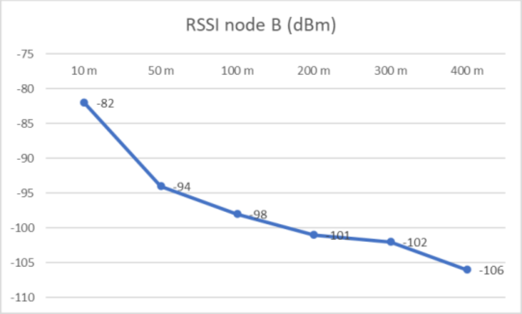


Fig.11. The RSSI on Node B

Testing was conducted to assess the impact of changing distances between nodes and the gateway on RSSI values at the gateway, shown in figure 10 and 11. The results showed that as the distance between nodes and the gateway increased, RSSI values decreased. This is expected since greater distances result in weaker signal strength. For Node A, RSSI values ranged from -69 dBm at the closest distance (10 meters) to -112 dBm at the farthest distance (400 meters). Meanwhile, for Node B, RSSI values ranged from -82 dBm at the closest distance to -106 dBm at the farthest distance.

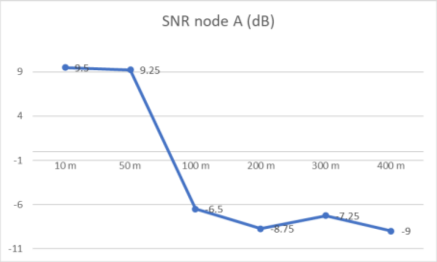


Fig.12. The SNR on Node A

In addition to RSSI, distance also influenced the Signal-to-Noise Ratio (SNR) values at the gateway. Figure 12 and 13 shown as the distance between nodes and the gateway increased, SNR values decreased. The LoRa SNR specification ranges from -20 dB to 10 dB, and the test results fell within this range. For Node A, the highest SNR value was 9.50 dB at a distance of 10 meters, while the lowest was -9 dB at a distance of 400 meters. For Node B, the highest SNR value was 6 dB at a distance of 10 meters, and the lowest was -9.50 dB at a distance of 300 meters.

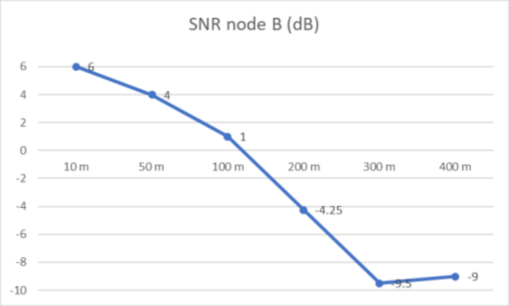


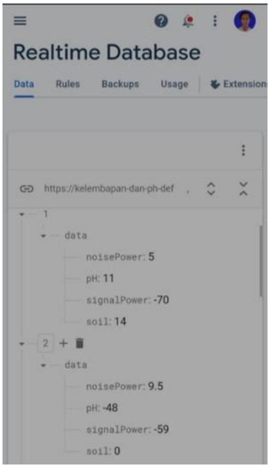
Fig.13. The SNR on Node B

Table 3. "Testing data communication between node A and the gateway"

Distance (meter)	Packet Data Sent (packet)	Packet Data Received (packet)	Error
10	5	5	0%
50	5	5	0%
100	5	5	0%
200	5	5	0%
300	5	5	0%
400	5	4	20%
500	5	0	100%

Table 3 shown in the testing using dual nodes, both nodes were able to reach a distance of 400 meters. The testing was conducted under conditions with minimal obstacles that could impede the communication process between the node and the gateway. However, at a distance of 400 meters, Node 1 experienced packet loss, where the gateway received only 4 out of 5 packets sent by the node. This was attributed to noise interference during data transmission, making it challenging for the gateway to receive the data. On the other hand, Node B did not encounter such issues, and at a distance of 400 meters, the gateway successfully received all 5 packets sent by the node.

Figure 14 shown when testing is conducted to determine whether the values from the soil moisture and pH sensors are accurate, both at the node (1 is node A, 2 is node B) gateway, and Firebase levels. The test involves using two different sensors in each node. Table 4 shown the function of all part. (Node, Gateway, and Firebase)



```
https://kelembapan-dan-ph-def
1
  data
    noisePower: 5
    pH: 11
    signalPower: -70
    soil: 14
2
  data
    noisePower: 9.5
    pH: -48
    signalPower: -59
    soil: 0
```

Fig.14. Data Display on a Smartphone

Table 4. "Testing data communication between node and the gateway and firebase"

NODE		GATEWAY		FIREBASE		Description
Moisture	pH	Moisture	pH	Moisture	pH	
20%	7	20%	7	20%	7	acording to
29%	7	29%	7	29%	7	acording to
34%	7	34%	7	34%	7	acording to
39%	9	39%	9	39%	9	acording to
40%	8	40%	8	40%	8	acording to
45%	8	45%	8	45%	8	acording to
54%	9	54%	9	54%	9	acording to
59%	8	59%	8	59%	8	acording to
75%	8	75%	8	75%	8	acording to
86%	9	86%	9	86%	9	acording to

According to this research, this concept can be extended for monitoring not only soil but also other aspects that require surveillance from multiple points, such as monitoring multiple agricultural conditions simultaneously or observing multiple water content points in areas without internet access.

5. Conclusion

Based on the conducted design, testing, and analysis, the following key findings are evident:

1. The soil moisture and pH sensors demonstrated robust performance with minimal error rates. The average error rates for soil moisture were 0.0244% for Node A and 0.0254% for Node B. Meanwhile, the soil pH sensors exhibited average error rates of 0.324% for Node A and 0.29% for Node B.
2. The Node and Gateway components effectively operated at a frequency of 915MHz, achieving reliable communication within a Line of Sight (LOS) range of up to 400 meters.

3. Alterations in the distance between the Node and Gateway significantly impacted the detected RSSI and SNR values. Node A reached a maximum RSSI of -112 dBm and a peak SNR of -9 dB, whereas Node B attained a maximum RSSI of -106 dBm and a peak SNR of -9.50 dB.
4. The Firebase website seamlessly received real-time sensor data, granting users immediate access to crucial information such as soil moisture levels, soil pH values, RSSI data, and SNR measurements.

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