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Monitoring system for water level and soil moisture for rice fields with LoRa communication on a wireless sensor network

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ABSTRACT

The monitoring system for water level and soil moisture of wetland rice is an important issue for farmers to pay attention to if more than one field is being monitored. The problem is that farmers are still monitoring manually and without proper tools. These problems underlie this research to implement a monitoring system with the application of the concept of wireless sensor networks with LoRa communication. The implementation of LoRa communication because it has low power consumption so it is suitable for applications in open spaces and long communication range. The application of LoRa communication at sensor and gateway nodes so that it can send sensing data. The data will be forwarded to the data center and can be monitored via a web application. Because there are several fields being monitored, this study uses the concept of a wireless sensor network so that it reaches far away distances of monitored rice fields. The results of the first system evaluation are that the system can measure the water level and soil moisture well. Second, it can send sensor data from the sensor node to the client. Finally, the communication performance of LoRa is the successful rate found in packet delivery, which is a total average of 92.72% or good category. Packet loss with an average total of 7.28% or good category. RSSI signal (Received Signal Strength Indicator) with a total average of -95.95 dBm. The system has good packet delivery success, small delivery failures, and good delivery signal strength.

Keywords: LoRa, monitoring systems, wireless sensor networks, rice fields

INTRODUCTION

One of the important factors of rice plant growth is the availability of sufficient water while seeding to rice harvesting (Rosada et al., 2019). Providing water and maintaining sufficient water content is essential because, besides being able to meet the water needs of rice plants, it can also prevent the growth of weeds that will kill rice seeds. In addition, one of the factors that affect agricultural land is soil moisture, water availability that can be affected by rain or irrigation, and weather, which can cause water evaporation on rice fields (Munir et al., 2018). Soil moisture in rice fields in each season has the optimal humidity for rice plant growth, namely wet category humidity for the beginning of the season, slightly wet for the middle of the season, and dry for the end of the season (Munir et al., 2018).

Generally, farmers in monitoring and knowing the water conditions on their agricultural land need to check directly and periodically on environmental conditions and crops according to the experience of the farmers themselves over the years, and farmers also do not have measuring tools to monitor water conditions in the lowland rice system right (Bakhri and Sudaryono, 2016). Apart from environmental factors, the main problem indirectly checking the condition of the plants is the distance between the rice fields that need to be checked and monitored from one another. The spacing of fields that need to be checked and monitored makes it impossible for farmers to check all crop conditions directly. From these problems, we need a tool that can monitor water conditions on agricultural land, especially the water level and soil moisture periodically, so that the time to provide water for lowland rice plants is not too late. The monitoring tool needed is a rice field monitoring system that can monitor and operate automatically, one of which is to use wireless sensor network technology.

Wireless sensor nodes are also known as WSN. The Internet of Things is also a development of the WSN network concept that connects the WSN network to the data center through internet data communication. Energy consumption is essential for several systems with the WSN concept so that it can use battery power for WSN systems that have relatively small energy consumption. To support relatively small energy consumption, a technology that also has a low energy consumption is needed, such as the LoRa (Long Range) technology that includes the LPWAN network, which requires low power energy consumption and has high efficiency in terms of transmitting radio frequencies. Compared with Z-Wave, Bluetooth, and WiFi, which have high energy consumption. Meanwhile, when compared to Zigbee, LoRa communication has advantages in range (Ali et al., 2019). Some LoRa systems have a communication range of more than 2 km, subject to adjustments in terms of environment and configuration. However, LoRa itself has a maximum payload size limit of 243 bytes, so it is suitable for use for WSN networks that send text messages because of its relatively small size (Mekki et al., 2018). Even so, LoRa requires a gateway device that can connect the WSN network with the server as a data center. The WSN network interface with the server can use the websocket protocol, which has advantages over HTTP because it is enough to do a one-time handshake and send messages immediately. The websocket protocol can send and receive packets at the same time (Zhang and Shen, 2013). The websocket protocol compared to other protocols such as HTTP has advantages, namely the lack of header usage, CPU usage, memory consumption, and response time (Chika and Esther, 2019).

Monitoring of paddy fields with parameters of water level and soil moisture is indicated as needed. In addition, with the distance of rice fields that need to be monitored, it is crucial to create a monitoring system that can monitor agricultural land so that it is expected to help ease farmers in monitoring the condition of their agricultural land. This research will use the LoRa communication module, which has a far enough range with low energy consumption equipped with ultrasonic sensors and soil moisture to facilitate data acquisition with a long coverage and the number of nodes more than one. The system also requires a websocket protocol to connect the WSN network with the server as a data center

MATERIALS AND METHODS

The first research on irrigation systems in terraced rice fields was using a wireless sensor network that implements a data acquisition system from rice fields using a water level sensor, namely, the HCSR04 ultrasonic sensor. The system is only limited to a microcontroller circuit device, the results of which are displayed on an android device that is connected wirelessly to the NRF24L01 for communication between nodes and uses Bluetooth to communicate on the android then also moves the servo to open the sluice latch. The system testing used is the result of monitoring conducted by ultrasonic sensors and displayed on a microcontroller to detect water levels, servo testing, and processing time to show the length of time it takes to detect altitude to process data transmission (Rosada et al., 2019).

The second research is the development of a monitoring system used to monitor the physical condition of fish pond water, which uses the LoRa communication protocol. The method used to develop a gateway that can connect with one other sensor node by using the LoRa communication module to one gateway node with the LoRa communication module and then sent to the data center using the HTTP communication protocol on the Wireless Sensor Network. The results of the tests conducted by this study were the successful rate testing of struct data packets sent from the sensor node to the gateway node with a distance of 50, 100, 200, and 400 meters (Adin et al., 2019).

The next research is to analyze the parameters of the LoRa communication used to determine the RSSI results and packet loss obtained. This research analyzes the transmission of LoRa communication data so that RSSI and packet loss values can be determined based on the testing distance. The test in this study resulted in an RSSI that increased with the farther the distance traveled by the transmitted data packet, whereas packet loss has excellent results at distances of 10 meters to 500 meters and poor results at distances of more than 500 meters to 2 km. It can be seen that data are lost in the package sent (Yanziah et al., 2020).

Rice farming land

In agricultural land, several important factors affect the growth rate of rice plants. One of the important factors of rice plant growth is the availability of sufficient water while seeding to rice harvesting. Providing water and maintaining sufficient water content is essential because, besides being able to meet the water needs of rice plants, it can also prevent the growth of weeds that will kill rice seeds. In addition, one of the other factors that affect agricultural land is soil moisture, water availability that can be affected by rain or irrigation, and weather that can cause water evaporation on rice fields (Munir et al., 2018). Soil moisture in rice fields in each season has the optimal humidity for rice plant growth, namely wet category humidity for the beginning of the season, slightly wet for the middle of the season, and dry for the end of the season (Arif et al., 2014).

Initially, paddy farming was conducted by a dryland cropping system with a field system. This technique has proven to be unsuitable for crop yields due to the limited availability of water on agricultural land. Therefore, the technique of stagnating water in paddy fields began to develop because, actually, the rice plant is a semi-aquatic plant that requires a lot of water. Especially during the reproductive period, the reproductive phase itself starts from tillers to filling the rice seeds. Water stagnation on rice fields, apart from fulfilling the water needs of rice plants, can also be used to suppress weed growth (Bintariadi et al., 2010).

Wireless sensor networks

The wireless sensor node or wireless sensor network is an infrastructure consisting of measurement, computing, and data communication parts so that it can be used to monitor certain environments or events (Sohraby et al., 2007). The wireless sensor network is part of the wireless sensor network, known as WSN. The Internet of Things is also developing the WSN network concept that connects several sensor nodes on the WSN network to the data center through internet data communication. A node is equipped with sensor equipment that is used to determine changes in the surrounding environment with a communication module that is used to communicate between sensor nodes and to other nodes (Dargie and Poellabauer, 2010). Wireless sensor network architecture consists of several sensor nodes (source nodes) that are connected to each other and sink nodes that are connected to the Internet for later access by users. There are two forms of wireless sensor networks, namely, those that use multi-hop and single-hop. If using multi-hop, it will use more than 1 hop between the sensor node and the gateway node. Meanwhile, if using single-hop, it only uses 1 hop between the sensor node and the gateway node. Single-hop itself can use just point to point using one sensor node and one gateway node, while multipoint to point has more than one sensor node (Dargie and Poellabauer, 2010). The way wireless sensor networks work is that the sensor data obtained from several sensor nodes are collected into a sink node. The role of sink nodes in wireless sensor networks is to collect sensor data and have Internet accessibility. Internet of Things (IoT) is a network that connects a system consisting of various physical devices so that they can communicate with each other via the Internet (Patel and Patel, 2016). The application of hardware into IoT can turn the hardware device into a smart device that can communicate with other hardware devices. This hardware device can see, hear, think and make its own decisions according to the algorithms applied to the hardware. IoT itself is a form of M2M (machine to machine) communication, which is often called an intelligent system.

LoRa

LoRa is a wireless technology that has long-distance services, low power consumption requirements, and security in transmitting data for IoT applications with low transmission rates (Lavric and Popa, 2017). LoRa technology has different frequencies of use in each country. The frequencies used for the United States, the European region, and the Asian region are 915 MHz, 433/868 MHz and 433 MHz, respectively.

Websocke

Websocket is a communication protocol between client and server, which is developed to support full-duplex function (Zhang and Shen, 2013). The websocket communication protocol can support two-way communication between the client and server, which can be used to send and receive data.

Websocket itself is similar to TCP, except that it cannot be used as an alternative to TCP. This is because of how many websocket and TCP are in two different network layers with websocket using the TCP transport layer. The following is Figure 2.3 describes how the work or communication flow of the websocket protocol.

General description of the system

A general description of the system will describe in general how the arrangement of this system includes the architecture that is in it. The following is the system architecture in Figure 1.

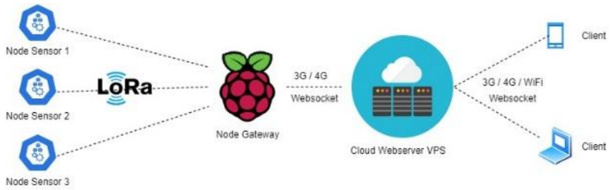

Figure 1. System architecture.

In making hardware design, 3 sensor nodes are needed, with Sensor Node 1 being in the Rice Field 1, Sensor Node 2 being in the Rice Field 2, Sensor Node 3 being in the Rice Field 3. The sensor node consists of a series of microcontrollers in the form of an Arduino Uno equipped with an ultrasonic sensor, which functions to detect water levels in rice fields, a pressure sensor equipped with a tensiometer that detects soil moisture in rice fields, and the LoRa module. In addition, there is also a Raspberry Pi, which is used as a middleware/gateway node that is equipped with a LoRa communication module and a 3G/4G modem with the LoRa communication protocol. All nodes will be connected and communicate with the LoRa communication module so that they can exchange data in the form of data structs between the sensor and the gateway nodes.

Design of water level sensor nodes

A design is needed to connect the pins between the ultrasonic sensors and the pins on the sensor node microcontroller in the form of an Arduino Uno. Here is picture 2, which describes the sensor pins with the Arduino microcontroller pins.

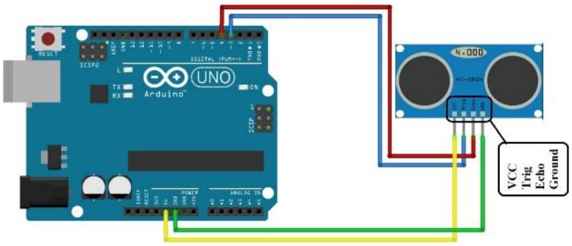

Figure 2. Water level sensor node design.

Soil moisture sensor node design

In addition, a design is also needed to connect the pins between the MPX5700DP pressure sensor and the pins on the sensor node microcontroller in the form of an Arduino Uno. Here is picture 3, which explains the sensor pins with the Arduino microcontroller pins.

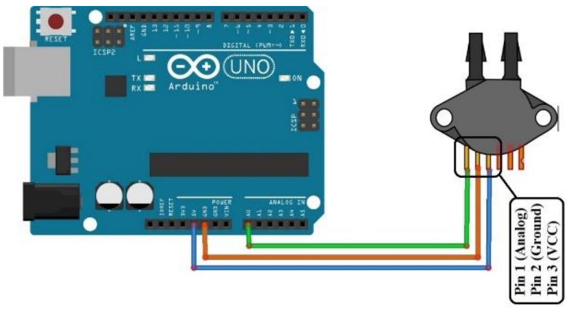

Figure 3. Soil moisture sensor node design.

Sensor node communication design

A design is needed to connect the pins between the LoRa module and the pins on the sensor node microcontroller in the form of an Arduino Uno to be used as a communication module on the sensor node. Here is picture 4, which explains LoRa pins with Arduino microcontroller pins.

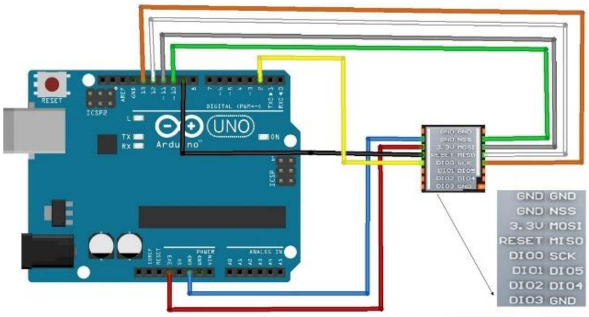

Figure 4. Sensor node communication design.

Communication design node gateway

A design is needed to connect the pins between the LoRa module and the pins on the gateway node microcontroller in the form of the raspberry pi to be used as a communication module at the gateway node. The following is picture 5, which explains LoRa pins with raspberry pi microcontroller pins.

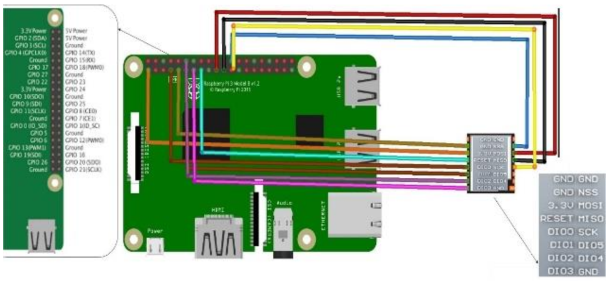

Figure 5. Gateway node communication design.

Server design

The design of a cloud server in this system will be in the form of a web-based application, namely, a web server and client. The cloud server will use Xampp as a server consisting of Apache2 as the webserver plus MySQL as the database. The web server is accompanied by a program with the Python programming language with additional libraries as a server with the websocket communication protocol.

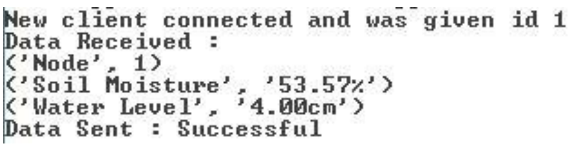

Figure 6. Server design.

Sensor node implementation

The sensor nodes in this study consisted of an Arduino Uno as a microcontroller, with two types of sensor modules, namely the HC-SR04 ultrasonic sensor, which is used to detect water levels in paddy fields, and the MPX5700DP air pressure sensor module using a tensiometer used to detect soil moisture based on the recorded air pressure in the tensiometer tube. In addition, there will also be a LoRa SX1278 module which is used for sending sensor data to the gateway node. The implementation of this sensor node is conducted using the Arduino IDE application. The following figure 7 about the sensor node.

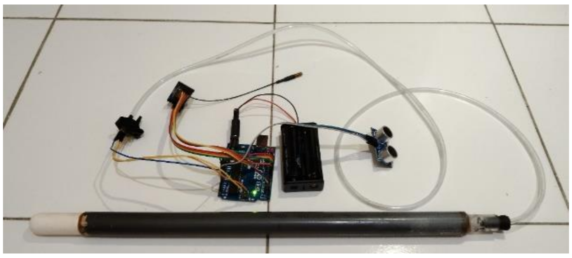

Figure 7. Sensor node implementation.

Gateway node implementation

The gateway node in this study consists of raspberry pi as a microcontroller, with the addition of a modem communication module which is used to get internet accessibility. In addition, there will also be a LoRa SX1278 module which is used to receive sensor data from sensor nodes. The implementation of the gateway node is done using the Python program. The following figure 8 about the sensor node.

Figure 8. Gateway node implementation.

Server implementation

The server implementation is used so that the gateway node can send sensor results to the webserver. The following is a figure 9 implementation of a server using the websocket communication protocol.

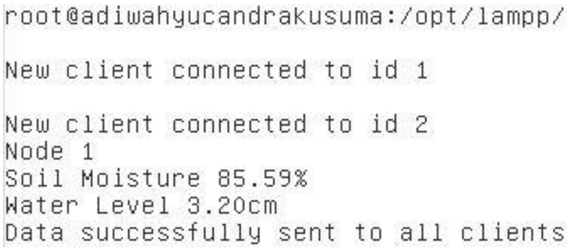

Figure 9. Server implementation.

RESULTS AND DISCUSSION

Water level testing results

Through this test, it was found that the sensor nodes can acquire water level data from the HC-SR04 ultrasonic module. The following is a table of ultrasonic sensor accuracy.

Table 1. Results of water level testing

Testing		Average Error
Sensor Node 1	Test 1	1, 33%
	Test 2	0, 67%
	Test 3	0, 67%
Sensor Node 2	Test 1	1,33%
	Test 2	0, 67%
	Test 3	0, 67%
Sensor Node 3	Test 1	0, 67%
	Test 2	0, 67%
	Test 3	0%
Average		0, 74%

The water level data acquisition test for the sensor node is going well, with the testing treatment according to predetermined stages showing that the ultrasonic sensor module can detect the water level value according to the value in reality, which has a fairly high-value accuracy. The water level value obtained is a number in "cm" units. The values recorded in each sensor node can be the same or not the same; this is because the rice fields are sensed differently. Sensor nodes can acquire groundwater level data through the ultrasonic sensor module; the ultrasonic module itself can also provide good data accuracy with an average total error of 0.74% in detecting water level values that match the reality.

Soil moisture testing results

Through this test, the results show that the sensor node can acquire soil moisture data from the MPX5700DP pressure sensor module, which has been connected to a tensiometer. The following are the results of the accuracy of the MPX5700DP pressure sensor module.

Table 2. Results of soil moisture testing

Testing		Average Error
Sensor Node 1	Test 1	0%
	Test 2	0%
	Test 3	0%
Sensor Node 2	Test 1	0%
	Test 2	0%
	Test 3	0%
Sensor Node 3	Test 1	0%
	Test 2	0%
	Test 3	0%
Average		0%

Through testing the soil moisture above, it can be concluded that sensor node 1, sensor node 2, sensor node 3 can acquire data well. The results of each sensor node can be different because the sensor nodes are placed on different rice fields. The water level value obtained is a number in "percent (%)" units that have been calculated and converted from the kPa value obtained by the sensor node. The final results can also provide good data accuracy with an average total error of 0% in detecting soil moisture values that match the reality.

Communication testing results

Through this test, the results show that the gateway node has also succeeded in receiving water level and soil moisture data which have been combined in structured data sent by each of the three sensor nodes via LoRa communication. Here is a picture of 10 terminals on the gateway node.

Figure 10. Receiving LoRa data on the gateway.

Testing of each sensor node can send water level and soil moisture data in the form of data structs to the gateway node via LoRa communication and prove that the gateway node can receive water level and soil moisture data in the form of struct data sent by each sensor node via LoRa communication. Three data are sent, the first is the node name data, the second is the soil moisture data, and the last is the water level data.

Websocket data communication testing results

Through this test, the results show that the vps cloud server can receive water level and soil moisture data which have been combined in JSON-form data sent by the gateway node to the websocket server in the idcloudhost vps cloud via the websocket protocol. The following is a picture of 11 terminals on a vps cloud server.

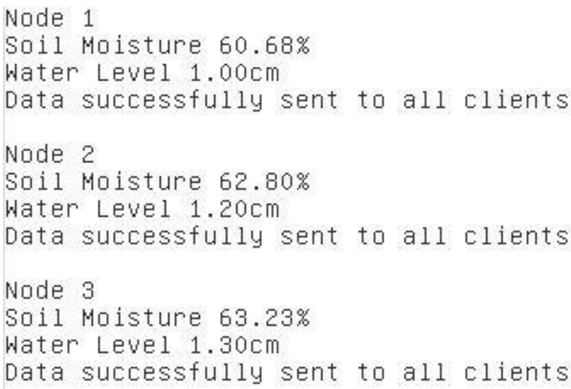

Figure 11. Receiving websocket data on the server.

Through this test, the results show that the client can receive water level and soil moisture data which have been combined in JSON-form data sent by the vps cloud server to the client via the websocket protocol. Here is a picture of 12 browsers display on the client.

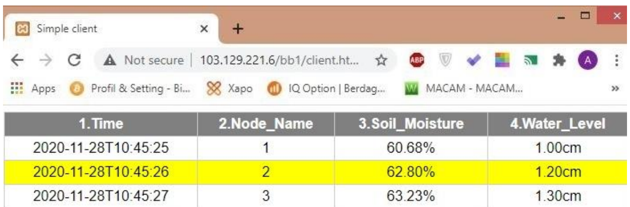

Figure 12. Browser display on a client.

Testing the gateway node can send data packets and prove that the idcloudhost vps cloud server can receive water level and soil moisture data packets in the form of struct data sent by each sensor node via LoRa communication to be sent back to the websocket server in the idcloudhost vps cloud via the websocket protocol. Three data are sent, the first is the node name data, the second is the soil moisture data, and the last is the water level data. The data have also been entered into the cloud server database.

In addition, it also proves that the idcloudhost vps cloud server can send water level and soil moisture data packets in the form of JSON data that are sent to the client via the websocket protocol so that it can be displayed in table form on the web client application.

The sending of JSON data will go through the server IP number, which is 103.129.221.6 with port 9002. The use of port 9002 is one of the ports for the TCP or UDP transport layer. This conforms to the use of the websocket protocol, which also runs at the TCP transport layer.

Successful rate testing

The successful rate through this test, the success rate is in accordance with the tests conducted by the journal (Adin et al., 2019); it can be seen that the success of the packet can be sent safely and successfully influenced by the size and a small distance used, which greatly affects the occurrence of the success rate. The following graph shows the average success rate based on distance.

Table 3. The quality category of the successful rate

Category	Successful Rate	Index
Excellent	100 - 98%	4
Good	97 - 86%	3
Medium	85 - 76%	2
Poor	<75%	1

According to the category table, figure 13 above illustrates that sensor node 1, sensor node 2, and sensor node 3 have an average total success of sending consecutive packages with each test for 30 min at 100 meters is 99.72% or in category excellent, at 200 meters it is 95.56% or in the good category, at 300 meters is 93.24% or in the good category, at 400 meters is 89.54% or in the good category, at 500 meters is 85.55% or with the medium category. Judging from the results of the graph above that package delivery is high. Meanwhile, having a total average decreases with increasing distance used. Based on the overall distance range, the total success rate of package delivery is 92.72% or in a good category.

Figure 13. Successful rate graph.

Furthermore, Table 3 shows the successful rate categorization.

Packet loss testing

The next test, namely packet loss, through this test, the packet loss is in accordance with the tests conducted by the journal (Yanziah et al., 2020) can be seen that the unsuccessfulness of the packet influenced by the size and small distance used which greatly affects the occurrence of packet loss. The following graph shows the average packet loss based on distance.

Table 4. The quality category of the packet loss

Category	Packet Loss	Index
Excellent	0 - 2%	4
Good	3 - 14%	3
Medium	15 - 24%	2
Poor	>25%	1

According to the category table, figure 14 above illustrates that the sensor node 1, sensor node 2, and sensor node 3 have an average total unsuccessful packet delivery successively with each test for 30 min is at 100 meters is 0.28% or by category excellent, at 200 meters it is 4.44% or in the good category, at 300 meters it is 6.76% or in the good category, at 400 meters is 10.46% or in the good category, at 500 meters is 14.45% or with the medium category. Judging from the results of the graph above that packet delivery has a low packet loss or failure. Meanwhile, it has a total average that gets higher with the increasing distance used. Based on the overall distance range, it has an average total packet loss or unsuccessful delivery of packages, namely, 7.28% or in a good category.

RSSI signal testing

The next test, namely, the RSSI signal, can be seen that the signal strength of the packet can be transmitted safely and is successfully influenced by the distance used. The following graph shows the average RSSI signal based on distance.

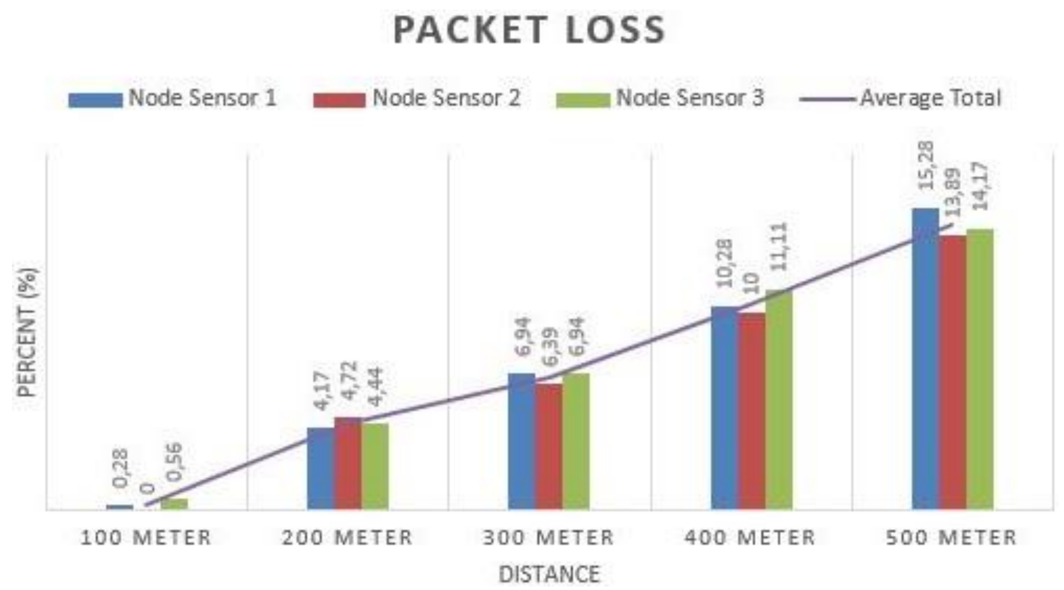

Figure 14. Packet loss graph.

Furthermore, Table 4 shows the packet loss categorization based on the TIPHON standard (Telcommunications and Internet Protocol Harmonization Over Network) (ETSI, 1999).

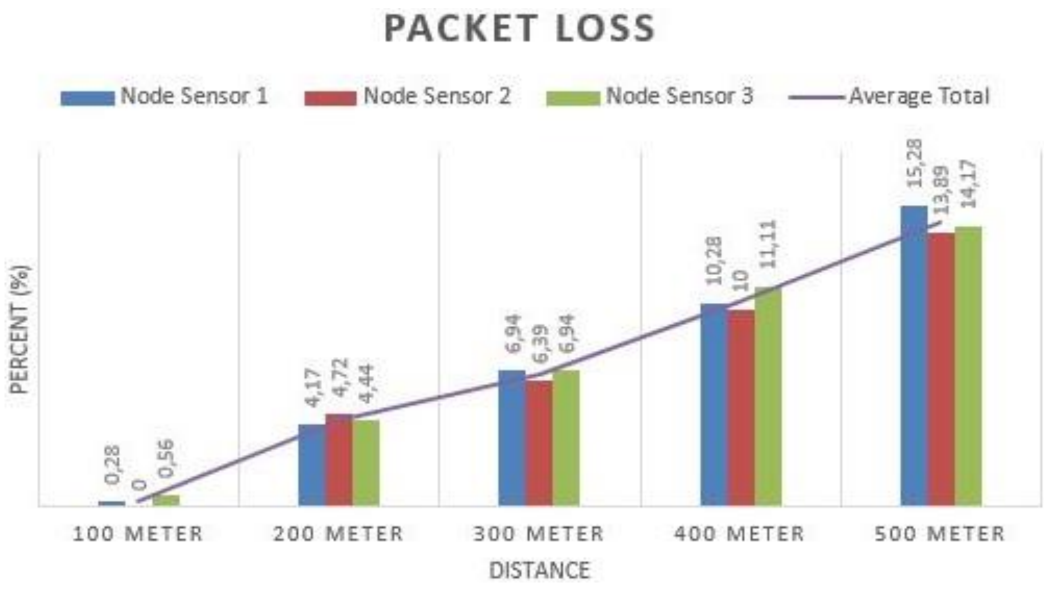

Figure 15. RSSI signal graph.

Furthermore, Table 4 shows the packet loss categorization based on the TIPHON standard (Telcommunications and Internet Protocol Harmonization Over Network) (ETSI, 1999).

Figure 15 above illustrates that the sensor node 1, sensor node 2, and sensor node 3 have an average total RSSI packet delivery signal in a row with each test for 30 min at 100 meters is -84.9 dBm, at 200 meters it is -95.15 dBm, at 300 meters it is -97.23 dBm, at 400 meters it is -99.96 dBm, at 500 meters it is -102.5 dBm. Judging from the results of the graph above that packet delivery has a good RSSI packet delivery signal. Meanwhile, it has a lower total average with the increasing distance used. Based on the overall distance range, the total RSSI signal for packet delivery is -95.95 dBm.

CONCLUSIONS

The reading of the sensor nodes equipped with the HC_SC04 ultrasonic sensor module and the MPX5700DP air pressure sensor which is equipped with a tensiometer, has succeeded in reading data. This is because the two sensors from each sensor node can acquire data well. The ultrasonic module itself can also provide good data accuracy with an average total error of 0.74% in detecting water level values that match the reality. The MPX5700DP pressure sensor module and Tensiometer can also provide good data accuracy with an average total error of 0% in detecting soil moisture values that match the reality.

LoRa data communication testing can also be said to be successful by sending struct data packets from the three sensor nodes to the gateway. Another test is sending through the websocket from the gateway node to the cloud server so that data can be received and entered into the database server. In addition, the server can also send data to the client to be displayed on the client browser monitor.

LoRa communication performance is the successful rate found in packet delivery, which is a total average of 92.72% or in a good category. Packet loss with a total average of 7.28% or in a good category. RSSI signal (Received Signal Strength Indicator) with a total average of -95.95 dBm.

The advantage of this system is that monitoring the water condition of rice fields, especially with water level and soil moisture parameters, can be directly monitored online. So that farmers do not need to come directly to the farm to conduct monitoring.

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