Communication Performance Test of LoRa-Based Vibration Monitoring System

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Abstract. The rapid development of technology and changes in the industrial era 4.0 is an innovation in monitoring and control over long distances. One example is the Internet of Things. The advantages of IoT are the particular interest to its users, easy installation, and the fact that it can be controlled remotely, which are considerations for users in using IoT. LoRa-based monitoring systems are often associated with building safety, which is essential in today's modern era. With aging infrastructure and increasing development, unfit building structures can cause fatal accidents and huge losses. Building maintenance is necessary to prevent structural damage due to vibration and displacement. Conventional vibration monitoring is costly, and the installation process is complicated. In this case, technology is needed that can be a solution to the traditional monitoring process, where the system does not require significant installation costs and a complicated installation process. LoRa has performed well as a communication tool. In urban areas, LoRa can transmit data from 0 to 500 meters with an average delay of 217m/s. Because of this problem, an innovative monitoring system is needed with low installation costs, and the installation process can be done quickly and perform real-time monitoring. The research will be carried out in several stages. The literature study is the first stage in this research. It will identify the problems that must be solved in this research, then determine the research objectives, design the system, and implement and test it. The research ends by writing a discussion and analyzing the data. This research is expected to overcome the limitations of conventional Lora-based vibration monitoring systems.

Keywords: LoRa, Monitoring, Vibration.

1 Introduction

Along with the rapid development of technology, the need for remote monitoring systems is increasing, especially for industries that require intense real-time monitoring of the condition of a machine or a building structure. One of the essential parameters for monitoring is vibration because a change in vibration intensity can indicate mechanical problems, such as worn components, imbalances, and potential structural failures. Previous research states that the vibration that occurs due to vehicles passing over a structure is one factor that affects the road structure, depending on the weight and speed

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when passing [1]. Monitoring can recognize damage and quality degradation early before more significant damage occurs and requires greater costs [2].

Technology in the field of wireless communication has developed and is widely used to support remote monitoring systems [3-6]. One of the latest technologies is LoRa (Long Range). LoRa is a solution to a problem that requires two-way remote communication. LoRa can transmit long distances with low power and bit rate. From the research, it was found that LoRa performs well as a communication tool. In urban areas, LoRa can transmit data from 0 to 500 meters with an average delay of 217m/s [7].

The LoRa-based vibration monitoring system allows continuous data collection without a complex communication system. The data obtained can be collected and analyzed to determine a condition that can provide an early warning of potential problems [8]. However, although LoRa has many advantages, LoRa's performance is also greatly influenced by several things, such as environmental conditions, distance, and signal interference around the area. Therefore, testing the LoRa-based vibration monitoring system's communication performance is vital to ensure that it can function optimally in various conditions. This research aims to fint out how well this system can operate properly, specifically regarding range distance, data accuracy, and transmission reliability in different environmental scenarios.

This research is expected to contribute to developing LoRa-based remote monitoring technology and provide practical solutions for industries that need efficient and effective monitoring systems.

2 Material and Methods

2.1 Tools and Materials

The tools and materials needed in this research are attached in Table 1 below.

Table 1. Tools and Materials

Research Tools and Materials		
Item	**Amount**	**Function**
Sensor SEN0386	1 piece	The sensor measures vibrations
NodeMCU ESP32	1 piece	Microcontroller Transmitter
NodeMCU ESP8266	1 piece	Microcontroller Receiver
LoRa RFM95W	2 pieces	Communication tool
Antena External 915MHz	2 pieces	Transmitter & Receiver
Kabel Male dan Female	1 Set	Component Connector
Battery	2 pieces	Resource

2.2 Schematic Design

The following is a detailed explanation of the research design applied (Fig. 1 and Fig. 2).

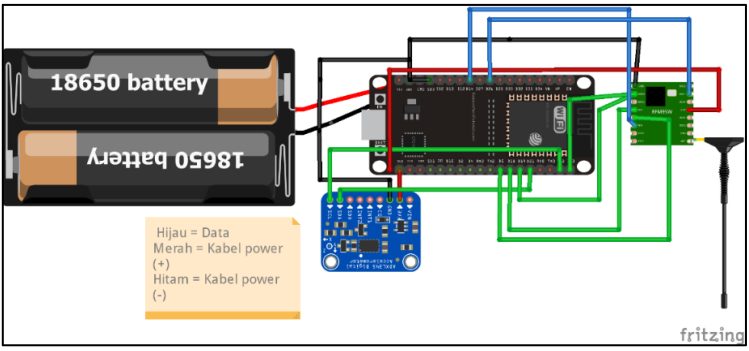

Fig. 1. Transmitter Schematic

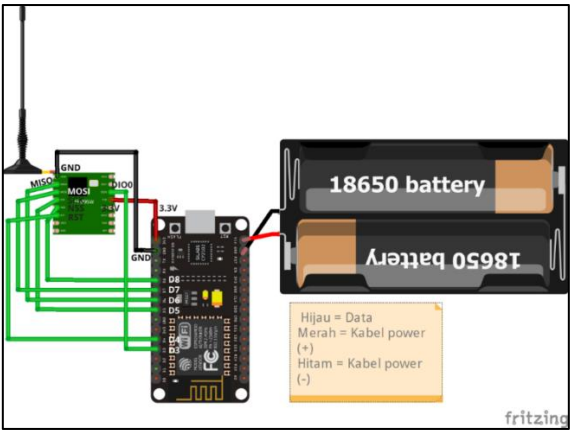

Fig. 2. Receiver Schematic

Table 2. Transmitter Circuit Path

ADXL345 PIN	NodeMCU ESP32 PINS
VCC	3.3V
GND	GND
SCL	D22
Natural Resources	D21
LoRa RFM95W PIN	NodeMCU ESP32 PINS
VCC	3.3V
GND	GND
SCK	D18
MISO	D19
MOTION	D23
NSS	D5
RST	D14
DIO0	D26

Table 3. Receiver Circuit Path

LoRa RFM95W PIN	NodeMCU ESP8266 PINS
VCC	3.3V
GND	GND
SCK	D5
MISO	D6
MOTION	D7
NSS	D8
RST	D4
DIO0	D3

2.3 Sensor Placement Scenario

The accelerometer device will be placed on a table considered a building structure. The accelerometer device is placed close to the center of vibration to maximize the vibration value to be measured. Vibration will be given manually to measure the vibration that occurs.

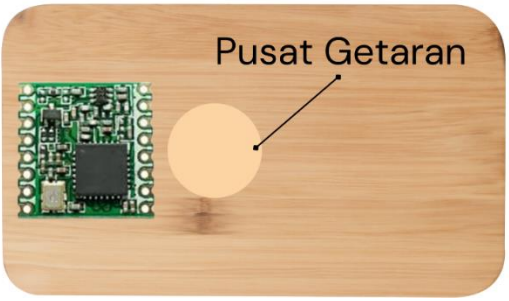

Fig. 3. Top View of the Testing Site

2.4 Test Scenario

In conducting the performance test of the vibration monitoring system communication using the ADXL-345 accelerometer sensor, the testing stage was carried out with the following stages:

- Place the SEN0386 accelerometer sensor on the table, which is considered the building structure, together with the transmitter device.
- The SEN0386 sensor measures vibration values using the x, y, and z axes.
- Give vibrations manually to measure the vibration value the accelerometer sensor will read.
- Manage data received from the transmitter device, which will then be sent to the receiver device, and then the data will be displayed via the serial monitor.

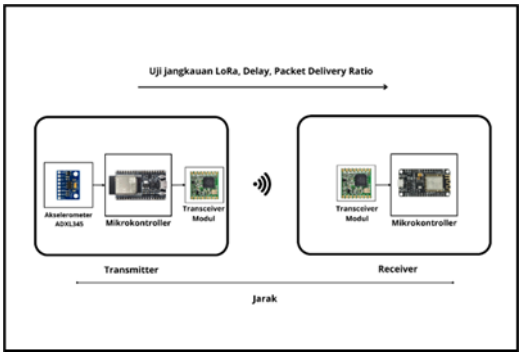

Fig. 4. Test Scenario

3 Results

3.1 Design Results

The LoRa-based consists of transmitter and receiver devices that vibrate the monitoring system of performance test tool communication, where the transmitter device is data-sending, and the receiver device is data-receiving with the transmitter device consisting of a NodeMCU ESP32 microcontroller, SEN0386 DF-Robot Accelerator Sensor, LoRa RFM95W, Jumper cable. The receiver device consists of LoRa RFM95W, and the microcontroller used is NodeMCU ESP8266.

Fig. 5. Transmitter Device

Fig. 6. Receiver Device

3.2 Research Location

The research was conducted at Ex-Airport Temindung, Samarinda. With a data collection interval of every 50 meters, starting at a distance of 50 meters to 500 meters.

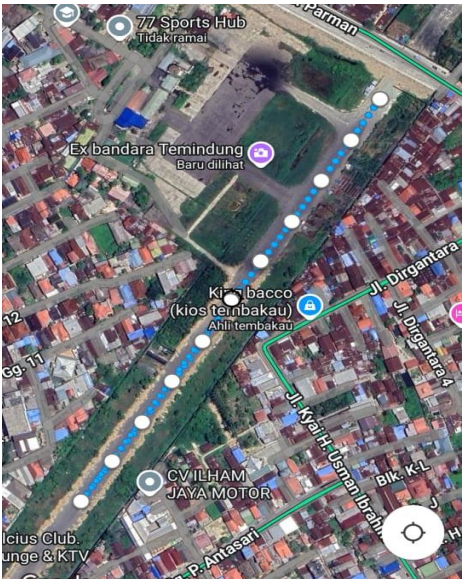

Fig. 7. Research Site Map

3.3 LoRa RFM95W Test Results

The test results of LoRa RFM9W obtained data in Table 4, where at 50 meters, the average time obtained from the transmitter data was 19.51.16, while for the average value of the delivery time where the data time was received from the transmitter to the receiver was 19.51.56, with a delay of 40 seconds, the average value was obtained from

10 experimental results conducted. At 100 meters, the average value of the required delivery time was 19.54.55, with a received time of 19.55.35 and a delay value of 39.9. At 150 meters, the average value for the delivery time was 19.59.39, with a received time of 20.00.00 and a delay value of 40 seconds. At 200 meters, the average delivery time required was 20.03.14, with a delivery time of 20.03.45 and a delay of 40 seconds. At 250 meters, the average delivery value is 20.07.26, with an average received time value of 20.03.45 and a delay value of 59.6 seconds. At 300 meters, the delivery time value is 20.21.01 with an average received time value of 20.21.54 with a delay value of 60 seconds. At 350 meters, the average delivery time value is 20.21.03, while the average received time value is 20.21.04, with a delay value of 61 seconds. At 400 meters, the average delivery time value is 20.25.30, while the average received time value is 20.26.20, with a delay value of 61 seconds. At distances of 450 and 500, no packets were successfully received by the receiver.

Value. The 5th data obtained a value of 313.41 for the acc x value, 313.42 for the acc y value, and 9.76 for the acc z value. The mode of the acc z value is 9.78, and the data appears in the 6th to 9th data set.

Table 4. LoRa RFM95W Test Results Table

Distance	***Average Delivery Time***	***Average Received Time***	***Average Delay(s)***
50 Meter	19:51:16	19:51:56	40
100 Meter	19:54:55	19:55:35	39.9
150 Meter	19:59:39	20:00:00	40
200 Meter	20:03:14	20:03:45	40
250 Meter	20:07:26	20:07:49	59.6
300 Meter	20:21:01	20:21:54	60
350 Meter	20:21:03	20:21:04	61
400 Meter	20:25:30	20:26:20	61.33
450 Meter	Packet Loss	Packet Loss	Packet Loss
500 Meter	Packet Loss	Packet Loss	Packet Loss

3.4 Accelerometer Sensor Test Results

The results of the accelerometer test carried out at 50 meters have been obtained the results in the Table 5, wherein the first data value obtained was 313.48 for the acc x value or x-axis of the accelerometer used, while for acc y, the value obtained was 313.39, in acc z the value obtained was 9.78. In the second data set, the acc x value obtained was 313.49, and the acc y value was 313.36 with an acc z value of 9.78. In the third data, the acc x value obtained was 313.47, the acc y was 313.36, and the acc z value obtained was 9.78. In the 4th data set, the data obtained was 313.47 for the acc x value; for acc y, it was 313.36, and the acc z value was 9.78. In the 5th data, the acc x value obtained is 313.47, the acc y value obtained is 313.37, and the acc z value obtained is 9.76. In the 6th data, the acc x value obtained is 313.47, the acc y value is 313.37, and the acc z value is 9.75. In the 7th data, the values obtained are 313.46, 313.37 and 9.79 for each acc x, y, and z value. In the 8th data, the values obtained for acc x are 313.46, acc y is 313.36, and acc z is 9.78. In the 9th data, the values obtained

are 313.45 for acc x, 313.38 for acc y, and 9.78 for acc z. Meanwhile, in the latest data, the values obtained were 313.46 for the acc x value, 313.37 for the acc y value, and the acc z value was 9.79.

Table 5. 50 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
50 Meter	313.48	313.39	9.78	Shiver
50 Meter	313.49	313.36	9.78	No Vibration
50 Meter	313.47	313.36	9.78	Shiver
50 Meter	313.47	313.36	9.79	No Vibration
50 Meter	313.47	313.37	9.76	Shiver
50 Meter	313.47	313.37	9.75	No Vibration
50 Meter	313.46	313.37	9.79	Shiver
50 Meter	313.46	313.36	9.78	No Vibration
50 Meter	313.45	313.38	9.78	Shiver
50 Meter	313.46	313.37	9.79	No Vibration

The results of accelerometer testing at 100 meters obtained the data listed in the Table 6, wherein the 1st data, the acc x value, was obtained as 313.30, 313.21 for the acc y value, and 8.95 for the acc z value. For the 2nd data, the data was obtained as 313.38 for the acc x value, 313.47 for the acc y value, and 9.84 for the acc z value. In the 3rd data, the results were 313.41 for the acc x value, 313.43 for the acc y value, and 9.80 for the acc z value. In the 4th data, the values were obtained as 313.42, which were the acc x value, 313.43 for the acc y value, and 9.79 for the acc z value. The 5th data obtained a value of 313.41 for the acc x value, 313.42 for the acc y value, and 9.76 for the acc z value. The mode of the acc z value is 9.78, and the data appears in the 6th to 9th data set.

Table 6. 100 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
100 Meter	313.30	313.21	8.95	No Vibration
100 Meter	313.38	313.47	9.84	Shiver
100 Meter	313.41	313.43	9.80	No Vibration
100 Meter	313.42	313.43	9.79	Shiver
100 Meter	313.41	313.42	9.76	No Vibration
100 Meter	313.41	313.44	9.78	Shiver
100 Meter	313.41	313.43	9.78	No Vibration
100 Meter	313.42	313.43	9.78	Shiver
100 Meter	313.42	313.42	9.78	No Vibration
100 Meter	313.43	313.45	9.75	Shiver

The accelerometer test results with a distance of 150 meters produced the data in Table 7. The data obtained are pretty diverse. The data values on the acc x-axis range between 313.46, 313.48, and 313.49. 313.50, while on the acc y-axis, the values obtained range between 313.45, 313.43, 313.41, 313.40, 313.39, and 313.38. on the acc z-axis, the values obtained are only 2, namely 9.78 or 9.79.

Table 7. 150 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
150 Meter	313.46	313.45	9.79	Shiver
150 Meter	313.46	313.43	9.78	No Vibration
150 Meter	313.48	313.41	9.79	Shiver
150 Meter	313.48	313.41	9.78	No Vibration
150 Meter	313.49	313.40	9.79	Shiver
150 Meter	313.49	313.40	9.79	No Vibration
150 Meter	313.49	313.39	9.78	Shiver
150 Meter	313.49	313.39	9.78	No Vibration
150 Meter	313.50	313.38	9.78	Shiver
150 Meter	313.50	313.19	9.78	No Vibration

In the accelerometer sensor test results with a distance of 200 meters, the results were obtained that there were four packet losses where the receiver did not receive the packets given by the transmitter. Hence, the number of packets received was only six out of 10 sent by the transmitter. The acc x values are as follows: 313.51, 313.50, 313.52, 313.52. 313.56. The acc y values are 313.18, 313.39, 313.35, 313.35, and 313.27. The acc z values obtained are 5.00, 9.78, 9.77, 9.40.

Table 8. 200 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
200 Meter	313.08	0.90	9.68	No Vibration
200 Meter	Packet Loss	Packet Loss	Packet Loss	-
200 Meter	313.51	313.38	5.00	No Vibration
200 Meter	313.50	313.39	9.78	Shiver
200 Meter	Packet Loss	Packet Loss	Packet Loss	-
200 Meter	Packet Loss	Packet Loss	Packet Loss	-
200 Meter	313.52	313.35	9.77	No Vibration
200 Meter	313.52	313.35	9.78	Shiver
200 Meter	313.56	313.27	9.40	No Vibration
200 Meter	Packet Loss	Packet Loss	Packet Loss	-

The results of the accelerometer test with a distance of 250 meters are obtained in the Table 9. The receiver did not receive five packet losses successfully, so the incoming vibration data is 5. Where the data is data 1, 2, 6, 7, and 8 while the other data is categorized as packet loss because the data did not reach the receiver.

Table 9. 250 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
250 Meter	313.11	313.21	9.60	No Vibration
250 Meter	313.11	313.26	9.74	Shiver
250 Meter	Packet Loss	Packet Loss	Packet Loss	-
250 Meter	Packet Loss	Packet Loss	Packet Loss	-
250 Meter	Packet Loss	Packet Loss	Packet Loss	-

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
250 Meter	313.11	313.25	9.78	Shiver
250 Meter	313.51	312.63	9.35	No Vibration
250 Meter	313.55	313.33	9.78	Shiver
250 Meter	Packet Loss	Packet Loss	Packet Loss	-
250 Meter	Packet Loss	Packet Loss	Packet Loss	-

The results of the accelerometer sensor test, which is as far as 300 meters, are obtained as shown in the Table 10. Several packet losses occur at a distance of 300 meters, and as many as five packets are not received by the receiver. The receiver gets five packets with 313.43, 313.11 and 313.12 for the acc x value, while the acc y value is 313.04, 313.29, 313.28. For the acc z values of 9.80, 8.79, 9.77, and 9.78.

Table 10. 300 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
300 Meter	313.43	313.04	9.80	Shiver
300 Meter	313.11	313.29	9.79	No Vibration
300 Meter	313.11	313.28	9.77	Shiver
300 Meter	Packet Loss	Packet Loss	Packet Loss	-
300 Meter	Packet Loss	Packet Loss	Packet Loss	-
300 Meter	Packet Loss	Packet Loss	Packet Loss	-
300 Meter	313.11	313.29	9.78	Shiver
300 Meter	Packet Loss	Packet Loss	Packet Loss	-
300 Meter	Packet Loss	Packet Loss	Packet Loss	-
300 Meter	313.12	313.29	9.78	No Vibration

The accelerometer test results with 350 are attached to Table 11. There are five packet losses and five packets received by the transmitter. The acc x value is 313.18 313.16, the acc y value is 313.29, 313.30, 313.28, and the acc z value is 9.00, 9.78, 9.77.

Table 11. 350 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
350 Meter	313.18	313.29	9.00	No Vibration
350 Meter	313.16	313.30	9.78	Shiver
350 Meter	313.16	313.28	9.77	No Vibration
350 Meter	Packet Loss	Packet Loss	Packet Loss	-
350 Meter	313.16	313.28	9.77	No Vibration
350 Meter	313.16	313.29	9.77	Shiver
350 Meter	Packet Loss	Packet Loss	Packet Loss	-
350 Meter	Packet Loss	Packet Loss	Packet Loss	-
350 Meter	Packet Loss	Packet Loss	Packet Loss	-
350 Meter	Packet Loss	Packet Loss	Packet Loss	-

The results of accelerometer testing with a distance of 400 meters are attached in the table 12. With packet loss of 7 packets, and successfully received packets of 3 packets,

with acc x values of 313.58, 313.50, and acc y values of 313.21 and 313.24, and acc z values of 9.77 and 9.79.

Table 12. 400 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
400 Meter	313.58	313.21	9.77	No Vibration
400 Meter	313.50	313.24	9.79	Shiver
400 Meter	Packet Loss	Packet Loss	Packet Loss	-
400 Meter	313.50	313.24	9.79	Shiver
400 Meter	Packet Loss	Packet Loss	Packet Loss	-
400 Meter	Packet Loss	Packet Loss	Packet Loss	-
400 Meter	Packet Loss	Packet Loss	Packet Loss	-
400 Meter	Packet Loss	Packet Loss	Packet Loss	-
400 Meter	Packet Loss	Packet Loss	Packet Loss	-
400 Meter	Packet Loss	Packet Loss	Packet Loss	-

In the test results with a distance of 450 meters, no packets were received by the receiver, meaning no vibration data entered the receiver.

Table 13. 450 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-
450 Meter	Packet Loss	Packet Loss	Packet Loss	-

In the test results with a distance of 500 meters, no packets were received by the receiver, meaning no vibration data entered the receiver.

Table 14. 500 Meter Accelerometer Test Results Table

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-
500 Meter	Packet Loss	Packet Loss	Packet Loss	-

Distance	Acc Value X	Acc Value Y	Acc Z Value	Environmental Conditions
500 Meter	Packet Loss	Packet Loss	Packet Loss	-

3.5 The Results of Received Signal Strength Indicator Test

The RSSI values are obtained from the results of the tests that have been carried out, as attached in table 15. With values of -81, -85, -82, -87, -82. -86. -85, -87, -87, and -88.

Table 15. 50 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
50 Meter	1	-81
50 Meter	2	-85
50 Meter	3	-82
50 Meter	4	-87
50 Meter	5	-82
50 Meter	6	-86
50 Meter	7	-85
50 Meter	8	-87
50 Meter	9	-87
50 Meter	10	-88

From the test results that have been carried out, the RSSI values are obtained, as attached in the table above. With 100 meters, the RSSI results are -91, -93, -94 -90, -96, -87, -95, -94. -95, and -94.

Table 16. 100 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
100 Meter	1	-91
100 Meter	2	-93
100 Meter	3	-94
100 Meter	4	-90
100 Meter	5	-96
100 Meter	6	-87
100 Meter	7	-95
100 Meter	8	-94
100 Meter	9	-95
100 Meter	10	-94

From the test results that have been carried out, the RSSI value is obtained, as attached in the table 17. With 150 meters, the RSSI results are -103, -99, -98, -100, -98, -99, -98, -101, -95, and -99. At 150 meters, the RSSI value reaches -103, where the higher the RSSI value, the lower the transmit power, which will result in packet loss.

Table 17. 150 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
150 Meter	1	-103
150 Meter	2	-99
150 Meter	3	-98
150 Meter	4	-100

Distance	Data to-	RSSI Value
150 Meter	5	-98
150 Meter	6	-99
150 Meter	7	-98
150 Meter	8	-101
150 Meter	9	-95
150 Meter	10	-99

From the test results that have been carried out, the RSSI value is obtained, as attached in the table 18. With 200 meters, the RSSI results were -101 and -100. At 200 meters, the receiver did not receive four packet losses.

Table 18. 200 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
200 Meter	1	-101
200 Meter	2	Packet Loss
200 Meter	3	-101
200 Meter	4	-100
200 Meter	5	Packet Loss
200 Meter	6	Packet Loss
200 Meter	7	-101
200 Meter	8	-101
200 Meter	9	-100
200 Meter	10	Packet Loss

From the test results that have been carried out, the RSSI value is obtained, as attached in the table 19. With 250 meters, the RSSI results are -99 to -102. At 250 meters, the receiver does not receive five packet losses.

Table 19. 250 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
250 Meter	1	-99
250 Meter	2	-101
250 Meter	3	Packet Loss
250 Meter	4	Packet Loss
250 Meter	5	Packet Loss
250 Meter	6	-101
250 Meter	7	-101
250 Meter	8	-102
250 Meter	9	Packet Loss
250 Meter	10	Packet Loss

From the test results that have been carried out, the RSSI value is obtained, as attached in the table 20. With 300 meters, the RSSI results are -98 to -102. At 300 meters, the receiver does not receive five packet losses.

Table 20. 300 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
300 Meter	1	-98

Distance	Data to-	RSSI Value
300 Meter	2	-99
300 Meter	3	-101
300 Meter	4	Packet Loss
300 Meter	5	Packet Loss
300 Meter	6	Packet Loss
300 Meter	7	-101
300 Meter	8	Packet Loss
300 Meter	9	Packet Loss
300 Meter	10	-102

From the test results that have been carried out, the RSSI value is obtained, as attached in the table 21. With 350 meters, the RSSI results are -101 to -103. At 350 meters, the receiver does not receive five packet losses.

Table 21. 350 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
350 Meter	1	-103
350 Meter	2	-101
350 Meter	3	-103
350 Meter	4	Packet Loss
350 Meter	5	-102
350 Meter	6	-103
350 Meter	7	Packet Loss
350 Meter	8	Packet Loss
350 Meter	9	Packet Loss
350 Meter	10	Packet Loss

From the test results that have been carried out, the RSSI value is obtained, as attached in the table 22. With 400 meters, the RSSI results are -105 to -106. At 400 meters, the receiver does not receive seven packet losses.

Table 22. 400 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
400 Meter	1	-105
400 Meter	2	-105
400 Meter	3	Packet Loss
400 Meter	4	-106
400 Meter	5	Packet Loss
400 Meter	6	Packet Loss
400 Meter	7	Packet Loss
400 Meter	8	Packet Loss
400 Meter	9	Packet Loss
400 Meter	10	Packet Loss

In the test results with 450 meters, the receiver did not receive all the data, so the RSSI value at a distance of 450 meters is unknown.

Table 23. 450 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
450 Meter	1	Packet Loss
450 Meter	2	Packet Loss
450 Meter	3	Packet Loss
450 Meter	4	Packet Loss
450 Meter	5	Packet Loss
450 Meter	6	Packet Loss
450 Meter	7	Packet Loss
450 Meter	8	Packet Loss
450 Meter	9	Packet Loss
450 Meter	10	Packet Loss

At 500 meters, all packets cannot be received by the receiver, so the RSSI value at a distance of 500 meters cannot be known.

Table 24. 500 Meter RSSI Test Results Table

Distance	Data to-	RSSI Value
500 Meter	1	Packet Loss
500 Meter	2	Packet Loss
500 Meter	3	Packet Loss
500 Meter	4	Packet Loss
500 Meter	5	Packet Loss
500 Meter	6	Packet Loss
500 Meter	7	Packet Loss
500 Meter	8	Packet Loss
500 Meter	9	Packet Loss
500 Meter	10	Packet Loss

3.6 Packet Delivery Ratio (PDR) Test Results

There is a formula that can be used to calculate the Packet Delivery Ratio, which is attached in the following formula:

$$\text{Packet Delivery Ratio 50 Meters} = 10/10 \times 100\% = 100\% \quad (1)$$

$$\text{Packet Delivery Ratio 100 Meters} = 10/10 \times 100\% = 100\% \quad (2)$$

$$\text{Packet Delivery Ratio 150 Meters} = 10/10 \times 100\% = 100\% \quad (3)$$

At 50 to 150 meters, all packets sent by the transmitter can be received well by the receiver so that 10 packets are received intact. This condition causes the PDR at 50 - 150 meters to be worth 100% because there is no packet loss.

$$\text{Packet Delivery Ratio 200 Meters} = 6/10 \times 100\% = 60\% \quad (4)$$

At 200 meters, four packet losses occur, which causes the PDR value to decrease according to the number of packets received. From 10 packets sent, only six packets can be received by the receiver, so four packets are categorized as packet loss. This results in a decrease in the PDR value at 200 meters.

$$\text{Packet Delivery Ratio 250 Meters} = 5/10 \times 100\% = 50\% \quad (5)$$

$$\text{Packet Delivery Ratio 300 Meters} = 5/10 \times 100\% = 50\% \quad (6)$$

$$\text{Packet Delivery Ratio 350 Meters} = 5/10 \times 100\% = 50\% \quad (7)$$

At 250 to 350, the number of packets received is half the packets sent by the transmitter. The receiver gets five packets, 10 of which are sent, so the other five packets can be categorized as packet loss.

$$\text{Packet Delivery Ratio400 Meters} = 3/10 \times 100\% = 30\% \quad (8)$$

At 400 meters, packet loss increases, whereas at 250-350, packets are lost only 5. At 400 meters, 70% of packets experience packet loss, so the PDR value decreases due to the lack of packets that the receiver can receive.

$$\text{Packet Delivery Ratio450 Meters} = 0/10 \times 100\% = 0\% \quad (9)$$

$$\text{Packet Delivery Ratio500 Meters} = 0/10 \times 100\% = 0\% \quad (10)$$

At 450 - 500, the receiver cannot receive packets that the receiver has sent, so all packets are categorized as packet loss, and the PDR value is 0% because there are no successful packets that can be received at 450 - 500.

Table 25. PDR Test Results Table

No	Distance (m)	*Package Delivered*	*Packet Received*	*Packet Loss*	*PDR (%)*
1.	50	10	10	0	100%
2.	100	10	10	0	100%
3.	150	10	10	0	100%
4.	200	10	6	4	60%
5.	250	10	5	5	50%
6.	300	10	5	5	50%
7.	350	10	5	5	50%
8.	400	10	3	7	30%
9.	450	10	0	10	0%
10.	500	10	0	10	0%

4 Conclusions

Based on the study, this research successfully achieved the objectives that had been set, namely designing and building a prototype of a LoRa-based vibration monitoring system and conducting a system communication performance test. The test results showed that the system could function well at up to 350 meters, with a consistent delay of around 40 to 61 seconds. However, packet loss began to occur at 200 meters. It increased significantly at 400 to 500 meters, indicating limitations in the LoRa communication range that need to be considered.

The LoRa-based vibration monitoring system performed well at up to 350 meters, where data could still be received well. However, at 400 meters and beyond, there was a significant decrease in communication capability, indicated by many packet loss entries. This result shows that the effective range for this system is below 400 meters. The average measured delay varied between 40 and 61 seconds at the tested distances. This delay remained consistent at 50 to 300 meters but started to increase to 350 meters and beyond. The consistent delay indicates the system can handle data transmission well within this range. The RSSI value shows that the signal quality decreases with increasing distance. At 50 meters, the RSSI value is around -81 dBm, but at 400 meters, it drops to -106 dBm. This decrease contributes to increased packet loss and indicates that the signal becomes unstable at longer distances. Many packet loss entries at distances of 200 meters and above indicate that the packet delivery ratio decreases significantly at longer distances. This result is a significant concern, as a low Packet Delivery Ratio can affect the reliability of the monitoring system.

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