Implementation of Wireless Sensor Network on Smart Trash Bins Using LoRa With AES128 Algorithm (Case Study: Mentari Waste Bank Panceng Gresik)

Nur Hanafi[1], Ahmad Wilda Yulianto [2], Amalia Eka Rakhmania[3]

[1,2] Digital Telecommunication Network Study Program,
Electrical Engineering Departement, State Polytechnic of Malang, 65141, Indonesia
[3] Telecommunication Engineering Study Program,
Electrical Engineering Departement, State Polytechnic of Malang, 65141, Indonesia

[1]nurhanafi.han@gmail.com, [2]ahmadwildan@polinema.ac.id, [3]amaliaeka.rakhmania@polinema.ac.id

***Abstract* - Waste bank systems such as Bank Sampah Mentari (BSM), located in Prupuh, Panceng, Gresik Regency, were created as a method of reducing waste. In its operation, the BSM management still has several difficulties such as the need to check the resident's shelters, to administrative problems that are still done manually. Based on these problems, the implementation of a wireless sensor network on a smart trash bin using LoRa with the AES128 algorithm was made. The way it works is that the node device sends sensor reading data to the gateway every hour. The gateway will describe the incoming data, then upload it to MySQL and firebase before being accessed in the application. The test shows that the system can run well according to the plan where the farthest distance of LoRa is 300 meters. The average RSSI generated by node 1 is -95.78 dBm, node 2 is -112.57 dBm, and node 3 is -117 dBm. HC-SR04 ultrasonic sensor testing has an error of 0.795% (accuracy of 99.205%), while the MAX17048 sensor has an error of 0.3% with accuracy of 99.7%.**

***Keywords*— AES128, Android Application, Firebase, LoRa, MySQL, Waste Bank, WSN**

I. INTRODUCTION

Indonesia is the second largest waste contributor in the world after China, with national solid waste production reaching 151,921 tons per day, which means that each Indonesian resident throws away an average of 0.85 kg of solid waste per day [1]. To minimize the amount of waste, various ways can be done such as 3R (Reduce, Reuse, Recycle) independently to create a waste bank system [2]. One of the existing waste banks is Bank Sampah Mentari (BSM) which is located in Prupuh Village, Panceng District, Gresik Regency. In its operations, BSM still faces problems such as waste bins that are often full before the pick-up schedule, the process of manually checking the contents of the bins, and the recording of financial data by the neighborhoods leader which is done by handwriting. This manual process is less effective and inefficient, because it takes a lot of time and there are often data mismatches. especially if the notebook is lost, then all parties will be harmed.

There are several previous studies that have similarities and can be used as references in conducting this research. In research [3] has discussed the benefits of waste banks in reducing the amount of existing waste, but there are still shortcomings in the entire process in the waste bank still using conventional methods, starting from collecting waste, inputting weighing data, to recording history which is still in the form of an ordinary savings book (conventional). In research [4], the waste bank system has used mobile applications for transactions and customer savings, but there are still shortcomings, namely the absence of weighing data features, price information for each type of waste, let alone waste pickup features. Research [5] discusses the use of ultrasonic sensors to detect the volume of use in trash bins, but is only limited to 1 location point (single node).

Meanwhile, research [6] [7] discusses the use of WSN and LoRa in monitoring several remote devices (multinode). WSN is a distributed system consisting of nodes with the ability to obtain information about environmental conditions and transmit it wirelessly to a base station for further processing. Meanwhile, both researches also use Long Range (LoRa) technology as a wireless communication system for the Internet of Things (IoT) [8]. LoRa is used for its ability to transmit data with a long range. it also does not require an internet connection to transmit data, because LoRa uses radio frequencies to communicate between nodes [9]. While research [6] also uses the AES Algorithm on LoRa Communication Media to minimize data that is read by other irresponsible parties. The use of AES as encryption is also based on research [10], which proves that AES has speeds that are 48% superior to other encryptors such as Blowfish, DES, and IDEA.

Based on the research above, this study combines several existing parameters to create a system titled "Implementation of Wireless Sensor Network on Smart Trash Bins Using LoRa with AES128 Algorithm (Case Study: Mentari Waste Bank Panceng Gresik)" to address current issues at Mentari Waste Bank. WSN with LoRa is used in this research considering the location of each trash bin is separated from each other in a relatively long distance, the location of the device is placed outdoors, to very low power consumption. AES128 [11][12] is also used as a preventive measure to ensure the data is secured so as not to be misused by irresponsible parties [13]. The use of this encryption also ensures that the gateway [14] unit only processes valid data sent by the node [15].

II. METHOD

A. *Research Stages*

In conducting this research, there are several stages of research that have been planned. The first stage is to conduct a literature study on the implementation of wireless sensor networks, then determine the object and parameters of the problem and find out the specifications of the tools and materials that will be used for the realization of this research. The second stage is system design by modeling the monitoring system at the garbage shelter using LoRa transmission and application needs. Overall, this system consists of 3 parts, namely the sensor node, Gateway, and cloud. Sensor Node consists of ultrasonic sensor (HC-SR04), microcontroller, LoRa module, and 3.7V battery. While the gateway device used is Mappi32.

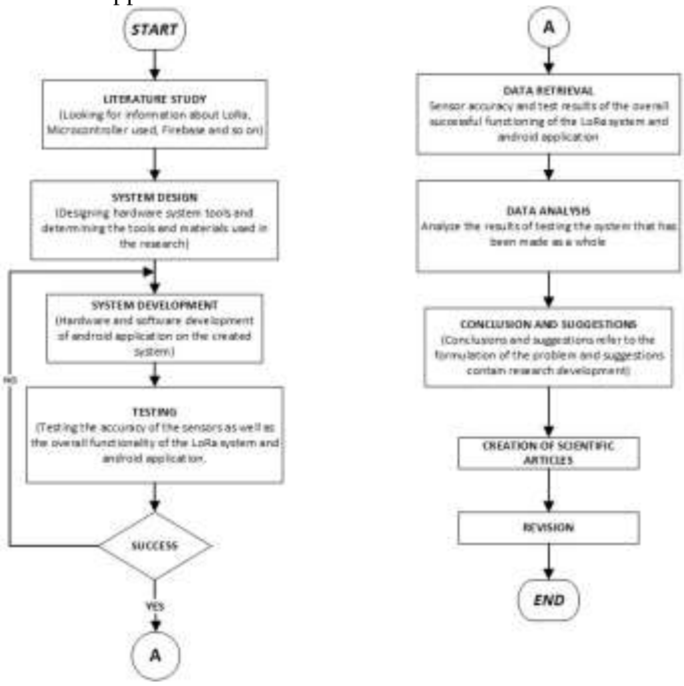

Figure 1. Flowchart of Research Stages

The third stage is to make the system, and implement the system in accordance with the system design that has been made. The fourth stage is to test the system according to the parameters to be tested. The fifth stage is to collect sensor accuracy data and test results on the success of the overall function of the LoRa system and android application. The sixth stage is to analyze the results of testing the tool to get the percentage of error of each sensor and analyze the results of testing the entire LoRa system. The seventh stage is to make conclusions and suggestions based on the analysis data obtained. The eighth stage is to make a report as proof that research has been carried out. The last stage is revision, which is the improvement of the report that has been made. The flowchart of the reserach stages is shown in Figure 1.

B. *Block Diagram of Mentari Waste Bank System*

1) *Block Diagram of Mentari Waste Bank Current System*

The block diagram of the Bank Sampah Mentari system is shown in Figure 2 and Figure 3. After collecting and sorting waste, customers must wait for a waste pickup schedule from the Bank Sampah Mentari (BSM) management. After the officer arrives, the customer will submit a passbook to input the weighing data in the customer's passbook and the officer's notes by the officer before the customer's passbook is returned.

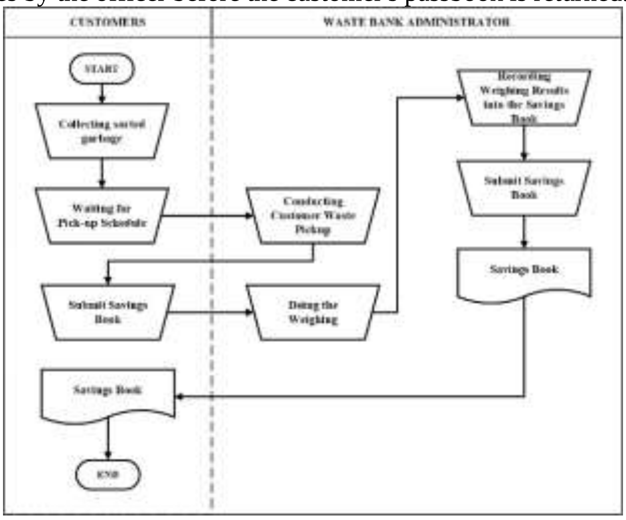

Figure 2. Bank Sampah Mentari's Current System

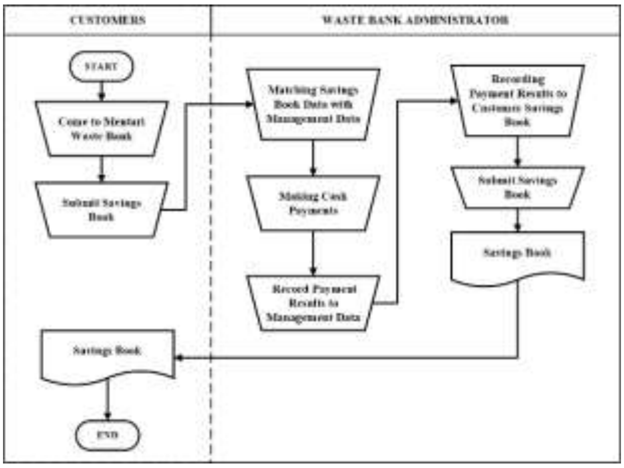

Figure 3. Current BSM Customer Fund Disbursement System

2) *Block Diagram of Mentari Waste Bank System Using Smart Trash Bin and Android Application*

After collecting and sorting waste, customers do not need to wait for a pick-up schedule, because the application will automatically send a notification to the officer if the trash bin is full. After the officer comes and does the weighing, the officer can input the weighing result data into the application. Thus, the waste collection history data will automatically be updated in the customer and officer applications. Figure 4 and Figure 5 shows BSM working system using smart bins and apps.

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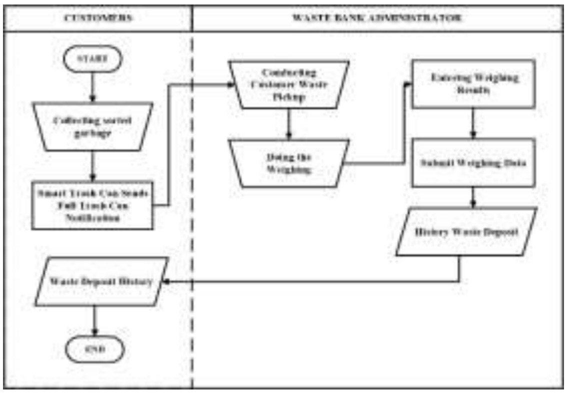

Figure 4. BSM Working System Using Smart Bins and Apps

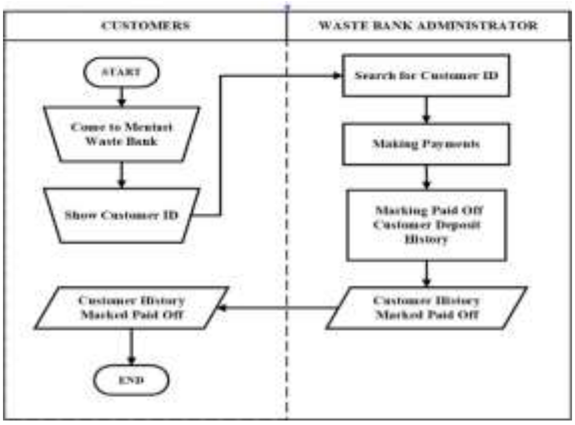

Figure 5. Customer Fund Disbursement System Using Application

C. Block Diagram of Smart Trash Bins System

Figure 6 is a block diagram of the smart trash bins system. Mappi32 as a system gateway that receives and sends sensor reading data; ESP32 as the main controller microcontroller of the sensor reader node; Ultrasonic Sensor to measure the height of the waste; GPS module to determine the coordinates of the garbage; RFM95 module for data transmission between the node and the gateway; Battery Sensor to read battery capacity; Battery as the main power source on the node; Firebase as a cloud database and mobile application server; Android smartphone as an admin device to receive notifications and pick-up locations; and XAMPP as a local web server to host data from the gateway.

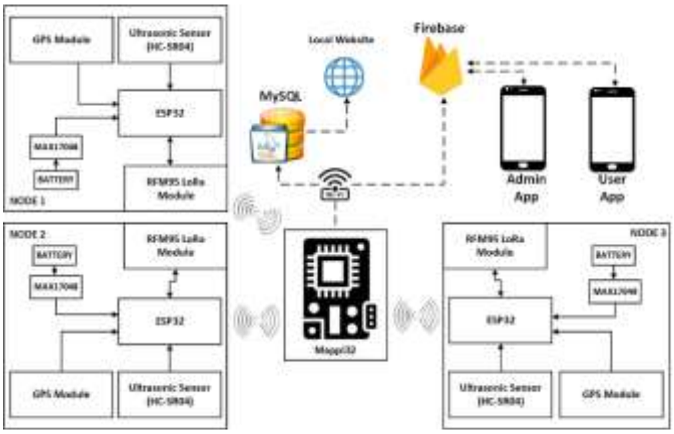

Figure 6. Block diagram of System

D. Hardware Design

Figure 7 shows the hardware design of device node rear view.


Figure 7. Device Node Rear View

Figure 8 shows the content of device node. The tools consist of GPS, ESP32, RFM95, Lora Antena,

Figure 8. Contents of The Node Device Box

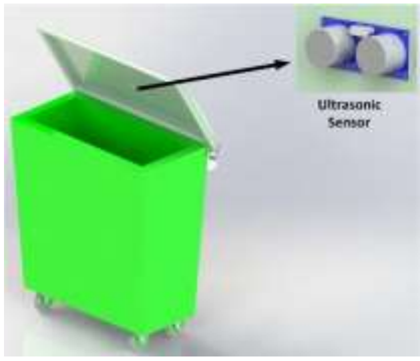

Figure 9. Inner Front Node Device

E. Hardware Schematic of Nodes 1, 2, and 3

Figure 10 and Figure 11 show the schematic circuit of the smart trash bin.

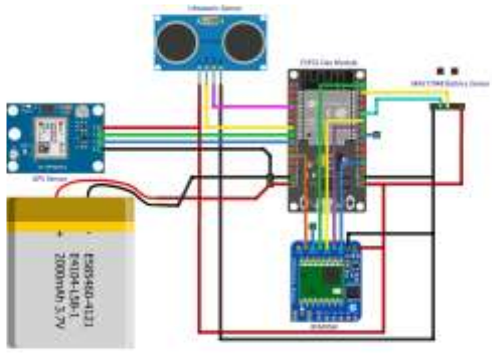
Figure 10. Wiring Components of Nodes 1,2, and 3

F. Overall circuit

Figure 12 show the overall schematic circuit of the smart trash bin, includes gateway device.

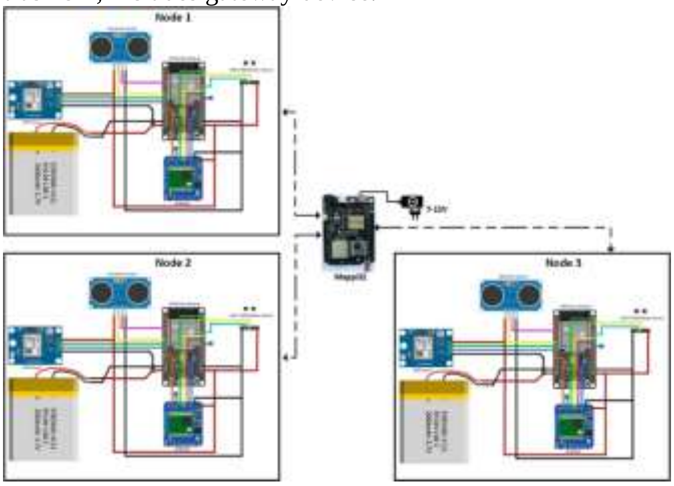

Figure 12. Overall Circuit

G. System Flowchart

1) Node Device Flowchart

The workings of the device node system are shown in Figures 13 and 14, with the following explanation: The device node reads the bin capacity, battery, and GPS location, then sends the data to the gateway in the form of a payload. The payload is created based on the distance between the bin and the sensor, which indicates whether the bin is full or not. The payload from nodes 1 and 2 is encrypted using the AES128 algorithm, while the payload from node 3 is sent without encryption. After sending the payload, the system returns to standby mode.

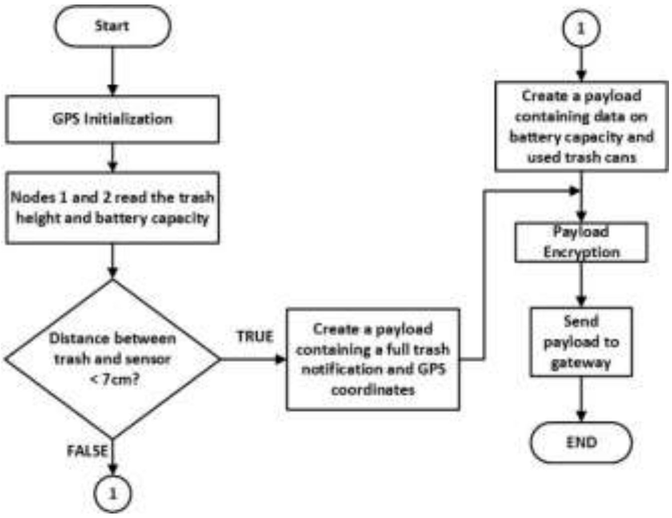

Figure 13. Flowchart Nodes 1 and 2

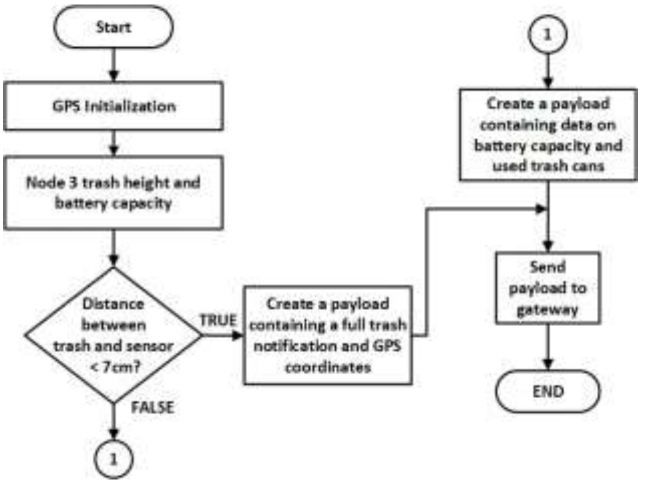

Figure 14. Flowchart Node 3

2) Overall System Flowchart

Figure 15 shows how the system works as a whole, with the following explanation: The system starts the process with the nodes sending sensor readings to the gateway. The gateway then describes the data received, except from node 3 which does not require a description. The gateway also performs condition selection to determine whether the trash bin is full or not. The condition selection data is then sent to firebase which can be accessed by the android application.

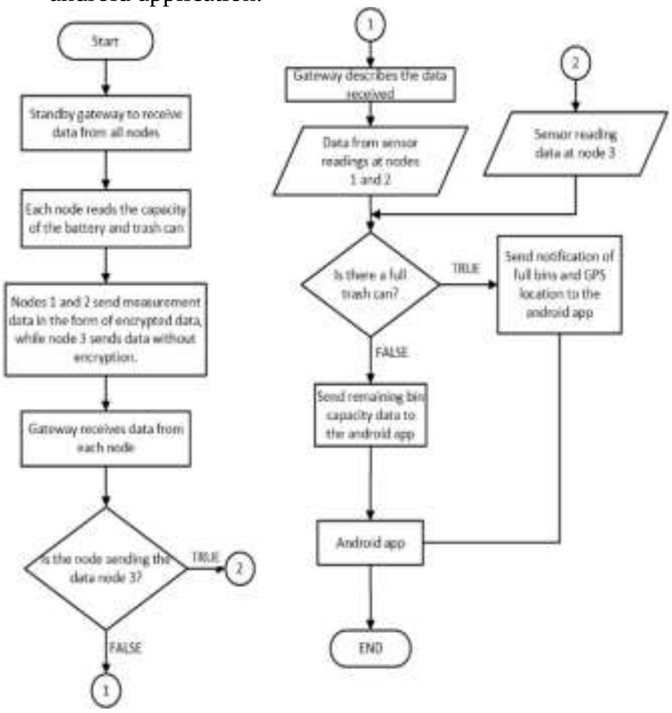

Figure 15. Overall System Flowchart

3) Admin Application Flowchart

Figure 16 shows how the admin application works, with the following explanation: The application opens with a login page, where the admin must fill in a valid username and password. After login, the admin can see the used node capacity on the main page. The admin can also access the profile page to display and change personal data, the waste pickup page to find out the location of the trash bin and get GPS assistance, and the data input page to enter garbage weighing data and save it. Then the admin can log out of the application page

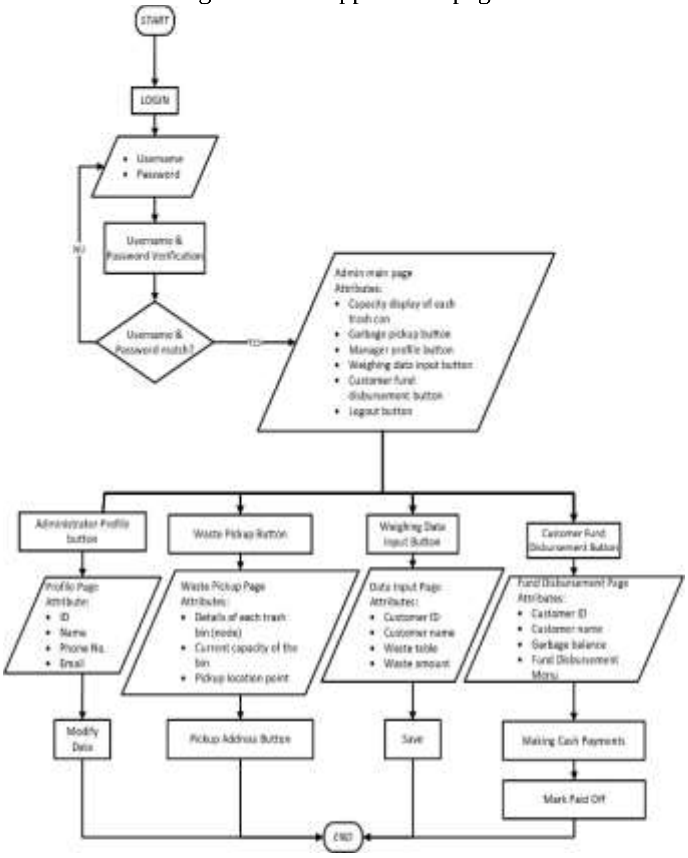

Figure 16. Admin Application Flowchart

4) *Customer Application Flowchart*

The workings of the BSM customer application can be seen in Figure 17, with the following explanation: The application starts with the login page, where customers must enter the correct username and password. If you do not have an account, you can register first in the application. After logging in, customers can view customer ID and balance information on the main page. Customers can also access the profile page to view and change their personal data, the history page to view garbage collection history, and the information page to view information about garbage. Customers can exit the application at any time. Then the customer can exit the application page

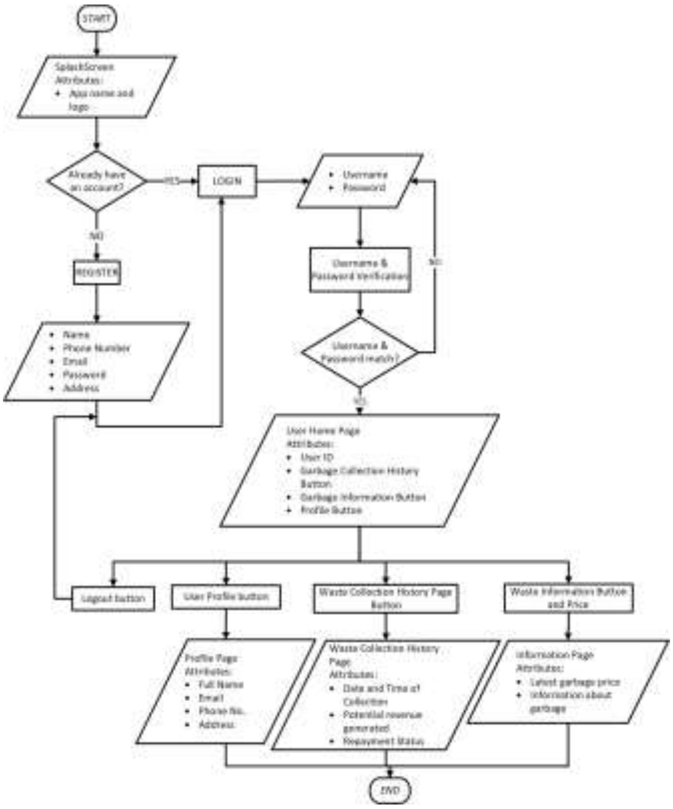

Figure 17. Customer Application Flowchart

III. RESULTS AND DISCUSSION

A. *Implementation Hardware*

1) Device Node

The hardware implementation results of the node device are shown in Figure 18 to Figure 21 below.

Figure 18. Device Node Front View

Figure 19. Device Node Rear View

Figure 20. Front View of the Inside of the Node Device

Figure 21. Node Device Box

2) Gateway Device

The hardware implementation results of the gateway device are shown in Figure 22 to Figure 23 below.

Figure 22. Gaetway Device Front View

Figure 23. Rear View of Gateway Device

B. Overall System Testing

In this sub chapter, overall testing of the system that has been made is carried out, starting from sensor accuracy, the resulting RSSI value, the suitability of the data read between the application and the database, and battery life of each node.

1) Accuracy Level of the Sensor

In this sub chapter, the calibration test of the sensor used is carried out, with the aim of ensuring that the sensor works properly and can provide accurate measurement results.

• Ultrasonic Sensor (HC-SR04)

Calibration of the ultrasonic sensor (HCSR-04) was carried out by comparing the measurement results on a factory-made distance measuring instrument (Ruler) for 6 trials, which are shown in Table I.

TABLE I
ULTRASONIC SENSOR (HCSR-04) CALIBRATION RESULTS

Experiment	Ruler Distance (cm)	Measured Distance (cm)	Difference (cm)	Error Rate (%)
1	30	30,05	0,05	0,16
2	25	24,91	0,09	0,36
3	20	20,05	0,05	0,25
4	15	14,91	0,09	0,6
5	10	9,90	0,1	1
6	5	4,88	0,12	2,4

Based on the data in table 4.3 in the HC-SR04 ultrasonic sensor test which is carried out by comparing the measurement results on the ruler, the test percentage can be obtained as follows:

$$Error\ rate\ (\%) = \frac{\sum(Error\ Percentage)}{Total\ experiments} \times 100\% \quad (1)$$

$$= \frac{0.16 + 0.36 + 0.25 + 0.6 + 1 + 2.4}{6} \times 100\% = 0.795\%$$

The average error generated from ultrasonic sensor testing shows that the HC-SR04 ultrasonic sensor is quite accurate with an average error of 0.795% and an accuracy rate of 99.205%. Table 4.3 also shows that the smallest error difference is in the 30cm distance test with a difference of 0.05 cm, while the largest error is in the 5 cm distance test with a difference of 0.12 cm.

• Battery Sensor (MAX17048)

Calibration of the battery sensor (MAX17048) is done by comparing the measurement results on a factory-made measuring instrument (multimeter). Table II is a table of calibration results from each battery sensor.

TABLE II
BATTERY SENSOR (MAX17048) TESTING RESULTS

Battery	Avometer Voltage (V)	Measured Voltage (V)	Battery Percentage (%)	Voltage Difference (V)	Error Rate (%)
1	4,071	4,06	84,62	0,011	0,27
2	4,067	4,054	84,01	0,013	0,32
3	3,629	3,618	3,45	0,011	0,30

Table 4.6 which shows the data of the battery sensor calibration results (MAX17048) by comparing the measurement results on the multimeter also has a fairly high reading accuracy of 99.7% with an average error of 0.3%. The average percentage value of this error is obtained from the total percentage error divided by the number of sample tests to produce an average percentage value of 0.3%.

The calculation formula used to obtain the percentage value of sensor calibration is as follows:

$$Error\ (\%) = \frac{Voltage\ \ sensor - Voltage\ on\ Avometer}{Voltage\ on\ Avometer}\ x\ 100\%$$

$$Error\ Rate\ (\%) = \frac{Total\ error}{Total\ Experiments} \quad (2)$$

• GPS Sensor (Neo-6MV2)

In this sub chapter, the accuracy of the coordinate points on the GPS module used by the node device, Garmin Etrex H GPS, and Smartphone GPS (Poco X3 Pro) is tested. Tables III is a table of coordinate data obtained from each device.

The GPS test results shown in table 3 show that the Garmin Etrex H has the lowest accuracy compared to other testing devices. This is because the number of coordinate numbers on the Garmin Etrex H is only 5 digits behind the comma, so the point shown is less accurate with a distance difference exceeding 50 meters compared to other GPS devices.

TABLE III
GPS COORDINATES TESTING RESULTS

No.	Testing Location		Neo-6MV2 GPS	Garmin Etrex H	Smartphone's GPS
1	Gazebo of AI building	Latt	-7.94535300	-7.94575	-7.946124
		Long	112.61507750	112.61434	112.615061
2	Polyclinic gazebo	Latt	-7.94608400	-7.94640	-7.946552
		Long	112.61514033	112.61431	112.615520
3	Graha theater	Latt	-7.9468650	-7.94686	-7.946559
		Long	112.61559483	112.61476	112.615519
4	Mini soccer	Latt	-7.94769167	-7.94802	-7.947691
		Long	112.61630600	112.61557	112.616288
5	AH building parking lots	Latt	-7.94733333	-7.94765	-7.947346
		Long	112.61526067	112.61456	112.615283

2) Average RSSI Value at Each Node

In this sub chapter, testing is carried out on each node to measure the average RSSI value generated. The following is the RSSI measurement data from each node when data is received by the gateway every hour via LoRa:

• Node 1

TABLE IV
RSSI VALUE AT NODE 1

No.	Time	RSSI (dBm)	No.	Time	RSSI (dBm)
1	21/07/2023 15:45	-61	15	21/07/2023 02:38	-96
2	21/07/2023 15:41	-60	16	21/07/2023 01:38	-97
3	21/07/2023 15:41	-62	17	21/07/2023 00:38	-96
4	21/07/2023 15:22	-62	18	20/07/2023 23:38	-97
5	21/07/2023 15:19	-61	19	20/07/2023 22:38	-97
6	21/07/2023 11:38	-94	20	20/07/2023 21:38	-96
7	21/07/2023 10:38	-95	21	20/07/2023 20:38	-97
8	21/07/2023 09:38	-96	22	20/07/2023 19:38	-97
9	21/07/2023 08:38	-94	23	20/07/2023 18:38	-93
10	21/07/2023 07:38	-93	24	20/07/2023 16:38	-97
11	21/07/2023 06:38	-97	25	20/07/2023 15:38	-97
12	21/07/2023 05:38	-95	26	20/07/2023 14:38	-95
13	21/07/2023 04:38	-95	27	20/07/2023 13:24	-98
14	21/07/2023 03:38	-94	28	20/07/2023 13:22	-97

From Table IV which shows the test results of node 1, there are 28 data received by the gateway and the RSSI value of node 1 varies, ranging from -60 dBm to -98 dBm. However, the data that can be analyzed is data from July 20 at 13:22 to July 21 at 11:38 WIB as much as 23 data. The average RSSI generated is as follows:

$$Average\ RSSI = \frac{\Sigma\ RSSI\ Value}{data\ count} \tag{3}$$

$$= \frac{\begin{array}{c}(-94)+(-95)+(-96)+(-94)+(-93)+(-97)+(-95)+(-95)\\ +(-94)+(-96)+(-97)+(-96)+(-97)+(-97)+(-96)\\ +(-97)+(-97)+(-93)+(-97)+(-97)+(-95)+(-98)+(-97)\end{array}}{23}$$

$$Average\ RSSI = \text{-95,78 dBm}$$

• Node 2

TABLE V
RSSI VALUE AT NODE 2

No.	Time	RSSI (dBm)	No.	Time	RSSI (dBm)
1	22/07/2023 02:04	-115	20	21/07/2023 07:35	-118
2	22/07/2023 01:35	-113	21	21/07/2023 06:35	-115
3	22/07/2023 00:35	-116	22	21/07/2023 05:35	-113
4	21/07/2023 23:35	-119	23	21/07/2023 04:35	-114
5	21/07/2023 22:35	-114	24	21/07/2023 03:35	-114
6	21/07/2023 21:35	-115	25	21/07/2023 02:35	-115
7	21/07/2023 20:35	-120	26	21/07/2023 01:35	-117
8	21/07/2023 19:35	-120	27	21/07/2023 00:35	-117
9	21/07/2023 18:35	-113	28	20/07/2023 23:35	-117
10	21/07/2023 17:35	-116	29	20/07/2023 22:35	-119
11	21/07/2023 16:35	-114	30	20/07/2023 21:35	-118
12	21/07/2023 15:35	-115	31	20/07/2023 20:35	-117
13	21/07/2023 14:35	-115	32	20/07/2023 19:35	-114
14	21/07/2023 13:35	-116	33	20/07/2023 18:35	-111
15	21/07/2023 12:35	-117	34	20/07/2023 16:35	-114
16	21/07/2023 11:35	-112	35	20/07/2023 15:35	-113
17	21/07/2023 10:35	-114	36	20/07/2023 14:35	-117
18	21/07/2023 09:35	-114	37	20/07/2023 13:35	-119
19	21/07/2023 08:35	-114	38	20/07/2023 13:21	-110

From Table V which show the tests result of node 2 since July 20 at 13:21:15 to July 22 at 02:04:19 WIB, there are 38 data received by the gateway with RSSI values varying from -110 dBm to -119 dBm. The resulting average RSSI is as follows:

$$Average\ RSSI = \frac{\Sigma\ RSSI\ Value}{data\ count} \tag{4}$$

$$\frac{\begin{array}{c}(-115)+(-113)+(-116)+(-119)+(-114)+(-115)+(-120)+(-120)\\ +(-113)+(-116)+(-114)+(-115)+(-115)+(-116)+(-117)+(-112)\\ +(-114)+(-114)+(-114)+(-118)+(-115)+(-113)+(-114)+(-114)\\ (-115)+(-117)+(-117)+(-117)+(-119)+(-118)+(-117)+(-114)\\ +(-111)+(-114)+(-113)+(-117)+(-119)+(110)\end{array}}{38}$$

$$Average\ RSSI = \text{-112,37 dBm}$$

• Node 3

TABLE VI
RSSI VALUE AT NODE 3

No.	Time	RSSI (dBm)	No.	Time	RSSI (dBm)
1	22/07/2023 02:31	-118	17	21/07/2023 04:37	-118
2	22/07/2023 01:37	-117	18	21/07/2023 03:37	-118
3	22/07/2023 00:37	-118	19	21/07/2023 02:37	-119
4	21/07/2023 23:37	-117	20	21/07/2023 01:37	-117
5	21/07/2023 22:37	-118	21	21/07/2023 00:37	-118
6	21/07/2023 21:37	-119	22	20/07/2023 23:37	-118
7	21/07/2023 20:37	-118	23	20/07/2023 22:37	-118
8	21/07/2023 19:37	-117	24	20/07/2023 21:37	-119
9	21/07/2023 18:37	-118	25	20/07/2023 20:37	-119
10	21/07/2023 17:37	-118	26	20/07/2023 19:37	-118
11	21/07/2023 16:37	-119	27	20/07/2023 18:37	-119
12	21/07/2023 15:37	-120	28	20/07/2023 16:37	-120
13	21/07/2023 13:37	-120	29	20/07/2023 15:37	-119
14	21/07/2023 12:37	-119	30	20/07/2023 14:37	-120

No.	Time	RSSI (dBm)	No.	Time	RSSI (dBm)
15	21/07/2023 06:37	-117	31	20/07/2023 13:21	-120
16	21/07/2023 05:37	-118	32	20/07/2023 13:18	-120

From Table VI which show the tests result of node 3 since July 20 at 13:18:32 to July 22 at 02:31:14 WIB, there are 32 data received by the gateway with node 3 RSSI values ranging from -117 dBm to -120 dBm. The resulting average RSSI is as follows:

$$Average\ RSSI = \frac{\Sigma\ RSSI\ Value}{data\ count} \quad (5)$$

$$\frac{\begin{matrix}(-118)+(-117)+(-118)+(-117)+(-118)+(-119)+(-118)+(-117)\\+(-118)+(-118)+(-119)+(-120)+(-120)+(-119)+(-117)+(-118)\\+(-118)+(-118)+(-119)+(-117)+(-118)+(-118)+(-118)+(-119)\\+(-119)+(-118)+(-119)+(-120)+(-119)+(-120)+(120)+(-120)\end{matrix}}{32}$$

$Average\ RSSI =$ -117,72 dBm

3) Data Compatibility Between Apps, Local Database, and Firebase

In this sub chapter, testing the filling of waste in each node is carried out to ensure that the system data is integrated between the local web, firebase, and the android application. The following table display the result from firebase, local database, and android application in the test conducted, as shown in the Table VII.

TABLE VII
SCENARIO OF FILLING GARBAGE AT EACH NODE

Node	Trash Bin Filling	Battery (%)	Capacity Used on Local Database (%)	Readout Data on Firebase (cm)	Used Capacity on Application (%)
1	Empty	78.79	0	55.62	1
2	Half	85.48	55.51	30.02	55
3	Full	79.93	100	9.74	100

- Trash Bin Condition
  Figure 24 to 26 show the real condition of each trash bin node.


Figure 24. Empty Trash Bin


Figure 25. The Trash Bin is 50% Filled


Figure 26. Full Trash Bin

- Local Database View
  Figure 27 shows local web view of all data received by gateway device.

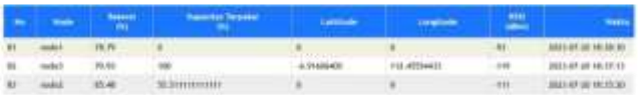
Figure 27. Local Web View

In the local database, it can be seen that there is a slight difference in the time of sending data from the nodes, which is caused by the time difference when the device turns on. In the used capacity column, the data displayed is the data that has been calculated in advance by the server after the data is received.

In determining the capacity used, there are several parameters used, namely; the maximum depth of the trash bin (55 cm), the reading distance, and the closest reading limit (10cm). Thus, the capacity of the trash bin can be accurately determined according to the sensor readings and displayed in the **Used Capacity** column.

- Firebase Display
  Figure 28 shows the display of Firebase Realtime DB.

Figure 28. Firebase Realtime DB View

In the firebase realtime database, the data uploaded is raw data from the gateway reception (not yet calculated), so the data displayed on firebase and the local database will certainly experience differences. The data in this realtime database will later be read and used by the android application, and processed in it.

- Android App Display

There are basically 3 (three) activity pages connected to the Firebase Realtime Database in displaying the sensor readings of each node in the android application, which are shown in figure 29 to 31 below. In the android application, the used capacity data displayed is data that has been calculated previously, with the aim of being easier for users to understand.


Figure 29. Admin App Dashboard View


Figure 30. Garbage Pickup View


Figure 31. Customer Application Dashboard View

4) Battery Life of Nodes 1, 2, and 3

In this subsection, tests are carried out on each node to measure the battery life installed. The following is the battery measurement data from each node measured every hour and sent via the LoRa network to the gateway and then sent to the local database:

- Node 1 (with Encryption)

The Table VIII shows the battery life data of Node 1.

TABLE VIII
BATTERY LIFE AT NODE 1 (WITH ENCRYPTION)

No.	Time	Battery (%)	No.	Time	Battery (%)
1	21/07/2023 15:45	4.98	15	21/07/2023 02:38	53.46
2	21/07/2023 15:41	6.24	16	21/07/2023 01:38	58.21
3	21/07/2023 15:41	8.01	17	21/07/2023 00:38	61.66
4	21/07/2023 15:22	66.43	18	20/07/2023 23:38	64.27
5	21/07/2023 15:19	62.53	19	20/07/2023 22:38	66.72
6	21/07/2023 11:38	5.15	20	20/07/2023 21:38	69.62
7	21/07/2023 10:38	7.23	21	20/07/2023 20:38	72.58
8	21/07/2023 09:38	11.29	22	20/07/2023 19:38	75.69
9	21/07/2023 08:38	15.43	23	20/07/2023 18:38	78.79
10	21/07/2023 07:38	20.95	24	20/07/2023 16:38	84.91
11	21/07/2023 06:38	27.82	25	20/07/2023 15:38	87.78
12	21/07/2023 05:38	34.27	26	20/07/2023 14:38	91.33
13	21/07/2023 04:38	41.19	27	20/07/2023 13:24	99.13
14	21/07/2023 03:38	47.71	28	20/07/2023 13:22	99.40

From the tests that have been carried out, table 8 shows that the battery on node 1 lasts for ± 26 hours 22 minutes before the device is inactive. When compared to other nodes, the battery life on node 1 tends to be more wasteful because there is a suspicion that the battery has dropped so that it becomes more wasteful. This can be proven in the results of data recap numbers 3 to 7 which show a spike in battery value in just a few minutes. It can be seen that the battery value changed significantly from 60% to 8% within 20 minutes and dropped back to 6% within one second. Thus, it can be said that the battery on node 1 was faulty during the test.

- Node 2 (with Encryption)

The Table IX shows the battery life data of Node 2.

TABLE IX
BATTERY LIFE AT NODE 2 (WITH ENCRYPTION)

No.	Time	Battery (%)	No.	Time	Battery (%)
1	22/07/2023 02:04	4.97	20	21/07/2023 07:35	67.01
2	22/07/2023 01:35	7.02	21	21/07/2023 06:35	68.17
3	22/07/2023 00:35	12.01	22	21/07/2023 05:35	69.46
4	21/07/2023 23:35	17.24	23	21/07/2023 04:35	70.77
5	21/07/2023 22:35	21.56	24	21/07/2023 03:35	72.41
6	21/07/2023 21:35	26.34	25	21/07/2023 02:35	73.89
7	21/07/2023 20:35	32.12	26	21/07/2023 01:35	75.20
8	21/07/2023 19:35	36.50	27	21/07/2023 00:35	76.02
9	21/07/2023 18:35	40.82	28	20/07/2023 23:35	76.83
10	21/07/2023 17:35	46.50	29	20/07/2023 22:35	77.65
11	21/07/2023 16:35	47.26	30	20/07/2023 21:35	78.95
12	21/07/2023 15:35	49.39	31	20/07/2023 20:35	80.59
13	21/07/2023 14:35	53.08	32	20/07/2023 19:35	82.87
14	21/07/2023 13:35	54.93	33	20/07/2023 18:35	85.48
15	21/07/2023 12:35	57.64	34	20/07/2023 16:35	93.23
16	21/07/2023 11:35	60.43	35	20/07/2023 15:35	98.29
17	21/07/2023 10:35	62.24	36	20/07/2023 14:35	100
18	21/07/2023 09:35	63.98	37	20/07/2023 13:35	100
19	21/07/2023 08:35	65.57	38	20/07/2023 13:21	100

From the tests that have been carried out, table 9 shows that the battery on node 2 lasts for ± 36 hours 43 minutes before the device turns off. This means that the battery in node 2 has a much better resistance than the node 1 battery with a difference of 10 hours 21 minutes longer. This means that the battery in node 2 has a fairly good and feasible condition.

- Node 3 (without Encryption)

The table X shows the battery life data of Node 3 that had not used encryption during its operation.

TABLE X
BATTERY LIFE AT NODE 3 (WITHOUT ENCRYPTION)

No.	Time	Battery (%)	No.	Time	Battery (%)
1	22/07/2023 02:31	4.99	17	21/07/2023 04:37	68.80
2	22/07/2023 01:37	8.35	18	21/07/2023 03:37	70.12
3	22/07/2023 00:37	13.04	19	21/07/2023 02:37	71.59
4	21/07/2023 23:37	18.73	20	21/07/2023 01:37	73.23
5	21/07/2023 22:37	22.80	21	21/07/2023 00:37	74.55
6	21/07/2023 21:37	28.43	22	20/07/2023 23:37	75.53
7	21/07/2023 20:37	34.27	23	20/07/2023 22:37	76.18
8	21/07/2023 19:37	38.66	24	20/07/2023 21:37	76.67
9	21/07/2023 18:37	43.23	25	20/07/2023 20:37	77.48
10	21/07/2023 17:37	45.87	26	20/07/2023 19:37	78.46
11	21/07/2023 16:37	47.71	27	20/07/2023 18:37	79.93
12	21/07/2023 15:37	50.01	28	20/07/2023 16:37	84.17
13	21/07/2023 13:37	51.81	29	20/07/2023 15:37	86.78
14	21/07/2023 12:37	55.05	30	20/07/2023 14:37	90.07
15	21/07/2023 06:37	66.14	31	20/07/2023 13:21	99.45
16	21/07/2023 05:37	67.59	32	20/07/2023 13:18	99.65

From the tests that have been carried out, table 10 shows that the battery on node 3 lasts for ±37 hours 12 minutes before the device is deactivated. Of all the nodes tested, node 3 has the best battery life because it lasts ±29 minutes longer than node 2. This is because the node 3 device is not accompanied by encryption so that the size of the data sent on the LoRa network is smaller than the encrypted data as in node 1 and node 2.

IV. CONCLUSION

From the research results of the Implementation of Wireless Sensor Networks in Smart Trash Bins Using Lora with AES128 Algorithm, it can be concluded that the wireless sensor network system in smart trash bins using LoRa has been successfully made well. The results showed that the HC-SR04 ultrasonic sensor had an accuracy of 99.205%, the MAX17048 battery sensor had an accuracy of 99.7%, and the Neo-6M GPS had a location difference of 0.063710 km with smartphone GPS. Moreover, the system consisting of Mappi32 and ESP32 could transmit data up to a distance of 300 meters with the lowest RSSI value of -117.72 dBm at node 3. The data processing system involving MySQL, firebase realtime database, and android application also worked well and integrated. The study also found that node devices without encryption had longer battery life than node devices with encryption because of the smaller data packet size. However, unencrypted packets have the opportunity to be read by other parties using the same frequency.

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