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Real Time Smart Trash Bin Monitoring System Using Fuzzy Logic Method in Kuripan Village

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Abstract

The rise of electronic technology has transformed people's lifestyles, and they now want convenience, automation, and flexibility, including when it comes to keeping the environment clean by disposing of rubbish where it belongs. However, despite the importance of this issue, awareness of the need to dispose of waste in its proper place remains low. Additionally, garbage bin supervision in Kuripan Village is still manual, exacerbating the problem of waste accumulation caused by the increasing population. To address this issue, we developed an IoT-based system that utilizes the Fuzzy Logic method. This mathematical approach enables the modeling of uncertainty in data processing. The system allows for real-time monitoring of the garbage load level, notifying staff when action is required. The Fuzzy Logic method is then used to determine the appropriate action based on the garbage load level and the last cleaning time. This research involves developing a prototype that uses NodeMCU ESP8266, HC-SR04 ultrasonic sensor, and LCD for data monitoring. The sensor testing demonstrated an accuracy of approximately 96.7%. The system includes an application interface with a login page, main dashboard, volume dashboard, and time dashboard.

Keywords: Fuzzy Logic, IoT, Smart Trash Bin

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I. INTRODUCTION

Technological development and electronic modernization have brought about significant changes in human life. The need for comfort and convenience has become increasingly important, including the maintenance of environmental hygiene [1]. However, there is still uneven awareness of the importance of proper waste disposal, resulting in the accumulation of waste in various inappropriate locations. Waste, the leftover material from different types of goods, not only pollutes the environment but can also be a breeding ground for diseases and harmful bacteria [2]. Every day, households and industries produce various types of waste. Improper waste management can interfere with human health and pollute the air [3]. Despite the presence of waste officers responsible for cleaning trash bins, manual supervision poses obstacles. This approach not only reduces efficiency but also results in high operational costs [4].

In this context, waste accumulation is a problem due to an ineffective monitoring system. This is particularly evident in Kuripan Village, where the population continues to grow, making the need for a more effective and efficient solution increasingly urgent. Therefore, the development of an android-based information system that utilizes the Fuzzy Logic method using IoT technology is the focus of this research. Fuzzy logic is a logical system that models uncertainty or vagueness by using membership values between

0 and 1. It is widely used in automatic control systems, decision-making processes, and other artificial intelligence applications where uncertainty or vagueness is encountered [5]. The Internet of Things (IoT) is a concept in which physical objects or everyday devices are connected to the Internet and communicate with each other, collecting and sharing data. The main goal of IoT is to create a network that enables these devices to interact automatically without human intervention [6]. This method enables real-time monitoring of garbage load levels, providing timely information to garbage officers about the status of specific bins. As a result, officers can take necessary actions more efficiently and effectively, without the need for manual checks that consume time and resources. In order to facilitate waste management in the village of Kuripan, an IoT-based real-time bin monitoring system using the fuzzy logic method is required. The purpose of this system is to effectively address the challenges of waste management in Kuripan Village, ensuring a clean and healthy environment for all residents.

II. RESEARCH METHODS

This research was conducted with an experimental method where direct experiments were carried out and then analyzed the results of the experiments that had been carried out[7]. The study was conducted in the Kuripan Village Housing Environment, Kesugihan District, Cilacap Regency, Central Java. The research preparation will be completed within 6 months. The research process involves several stages, including literature review, design, manufacture, testing, data analysis, and conclusion.

A. System Block Diagram

The system block diagram in this study is shown in Fig. 1.

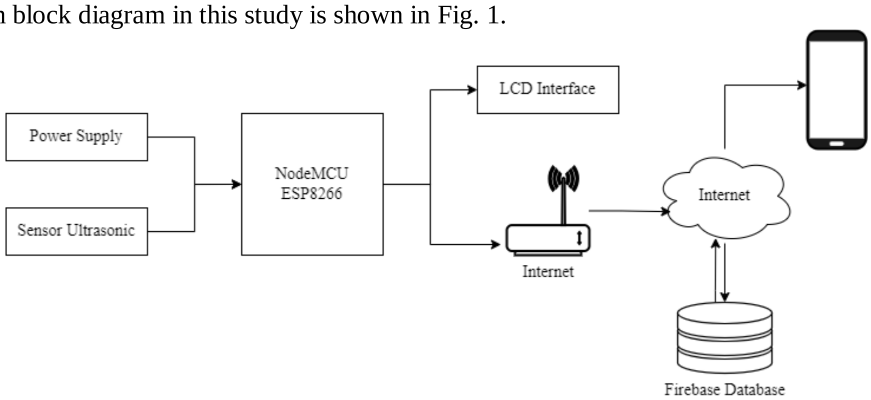

Fig. 1. System Block Diagram

The block diagram in Fig. 1 consists of three parts: input, process, and output [8]. The input section includes a power supply as the source of electricity in the system device and an HCSR-04 ultrasonic sensor that detects the volume of garbage in each trash can based on the height of the garbage. The process section consists of a NodeMCU ESP8266 for processing input and output data. The output section comprises fuzzy logic, which serves as a reference for determining action criteria based on input in the form of garbage volume and the last collection time (LCD), and IoT, which enables data to be accessed anytime and anywhere. To enhance the clarity of the system block diagram, an overview of the system implementation that will be carried out can be provided [9]. Fig. 2 shows the description of the system implementation that will be carried out.

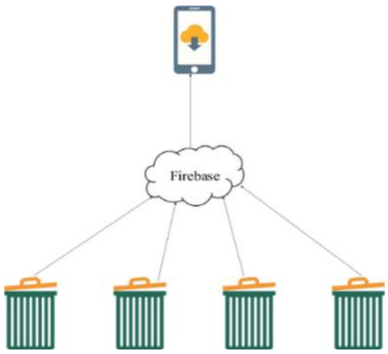

Fig. 2. Block Diagram of System Implementation on Trash bins

B. *Fuzzy Logic Implementation*

The study utilizes two input variables: waste volume and last collection time, and one output variable is criteria. Fig. 3 below illustrates the stages of fuzzy logic implementation in the system.

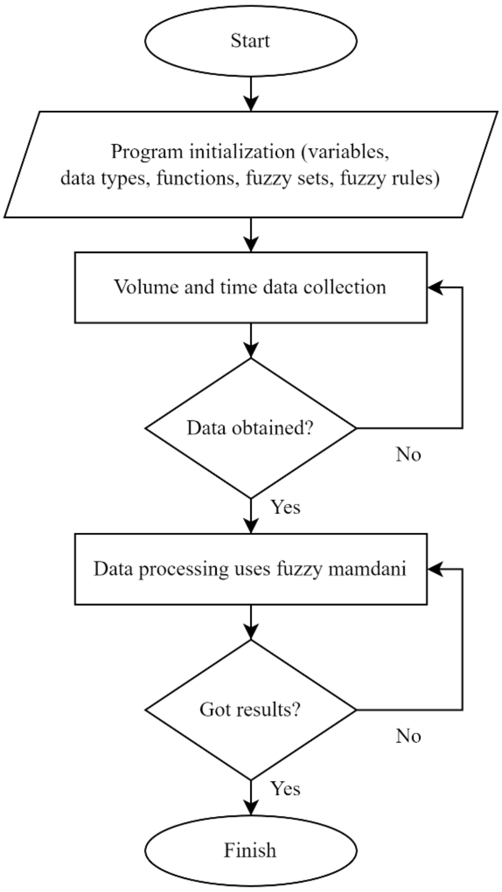

Fig. 3. Stages of Fuzzy Logic System Implementation

C. *Use Case Diagram*

Fig. 4 shows the use case diagram for the real-time smart trash bin monitoring system using the fuzzy logic method, as a case study in Kuripan village.

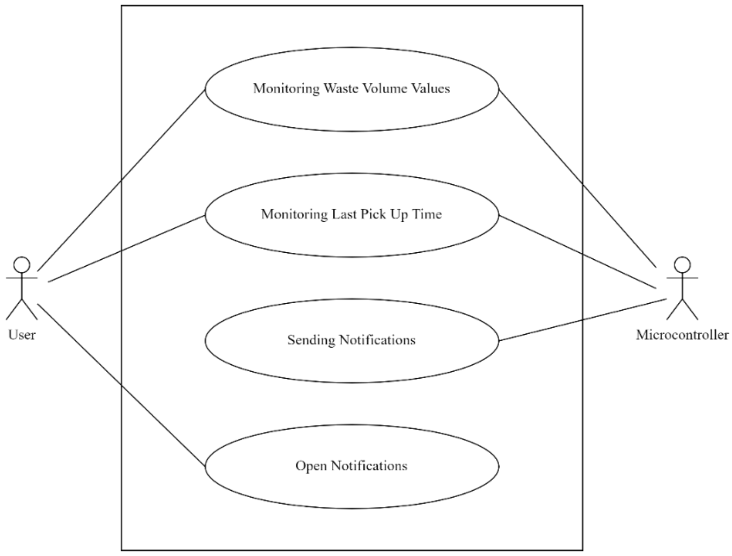

Fig. 4. Use Case Diagram of the real-time smart trash bin monitoring system

III. RESULTS AND DISCUSSION

A. Prototype Results

This study presents a prototype of a real-time smart trash bin monitoring system using the fuzzy logic method. The manufacturing process involves several components, including NodeMCU ESP8266, HC-SR04 ultrasonic sensor, 20x4 LCD Interface, and power supply. The prototype operates by inputting a voltage of 5-7VDC to supply the voltage needs of electronic devices in the control system. The prototype requires wifi connectivity to connect to the Firebase database. For data retrieval, a 20x4 LCD interface is used to monitor sensor readings. The results of this research prototype are displayed in Fig. 5.

Fig. 5. System Prototype Results

B. HC-SR04 Ultrasonic Sensor Testing

The HC-SR04 ultrasonic sensor functions to detect the volume of the garbage can by detecting the depth of the garbage can against the sensor[10]. To test the sensor in detecting volume, HC-SR04 ultrasonic sensor testing is carried out to determine the accuracy of the sensor. Testing is done by placing the ultrasonic sensor facing a certain object to detect the distance of the object. Ultrasonic sensor testing is done by testing as many as 10 iterations for each sensor measurement at object distances of 2cm, 4cm, 6cm, 8cm, 10cm, 12cm, 14cm, 16cm, 18cm, 20cm. The sensor reading results are compared with the length measuring instrument so that it can be seen how much error is obtained from the ultrasonic sensor reading results with the following formula.

$$\%error = \frac{Sensor\ measurement\ results - instrument\ measurement\ results}{Instrument\ measurement\ results} \times 100 \quad (1)$$

The test results of the ultrasonic sensor are shown in Table I.

TABLE I. ULTRASONIC SENSOR TEST RESULTS

Measurement Result of Measuring Device (cm)	Sensor Measurement Result (cm)	Error (%)
2	2.1	5.00
4	4.1	2.50
6	6.2	3.33
8	8.4	5.00
10	10.4	4.00
12	12.3	2.50
14	14.3	2.14
16	16.4	2.50
18	18.5	2.78
20	20.7	3.50
Average		3.33

Based on the readings from 10 measurement iterations, the ultrasonic sensor used in this study has an accuracy level of 96.7%. The average error was found to be 3.33%. The sensor is suitable for use, despite the potential impact of several factors on its performance, such as the age of the sensor, the quality of the sensor (if it is not original), and voltage fluctuations affecting readings.

C. Data Collection

Data collection is a crucial step in the acquisition of the information necessary for research. Measurements were taken of the trash bin's volume and the time of its last collection. Observing is done using a mobile application that has been developed. Finally, the research results are collected. Table II displays the collected data results.

TABLE II. DATA COLLECTION RESULTS

BIN	Volume (%)	Last Retrieval Time (WIB)	Retrieval Criteria
1	33	17	DO NOT TAKE
2	55	13	PLEASE TAKE
3	18	6	DO NOT TAKE
4	80	6	PLEASE TAKE

D. *Fuzzy Logic Calculation Results*

This research employs fuzzy logic calculations, which involve three stages: fuzzy set formation, membership function application, and implication function application. The following sections will explain each stage.

1. *Fuzzy Set Formation*

Data processing involves determining the universe of speech data variables and forming a fuzzy set. The model comprises three fuzzy variables: volume, which consists of three fuzzy sets (EMPTY, MEDIUM, and FULL), and last pickup time, which also consists of three fuzzy sets. MORNING, AFTERNOON, and EVENING. The Retrieval criteria variable consists of three fuzzy sets: DO NOT TAKE, FREE, and PLEASE TAKE.

From the existing data, the universe of speech is determined by starting with the minimum value and ending with the maximum value, the universe of speech is shown in Table III. This universe of speech is used as a reference for the implementation of fuzzy logic in the system that has been created. Also, see the Fuzzy results for Fuzzy set on volume variable in Fig 6. For Fuzzy set on last retrieval time variable in Fig. 7 and Fig 8 for Fuzzy Sets on Criteria Variables.

TABLE III. TALKING UNIVERSE

Function	Variables	Fuzzy set	Talking Universe	Domain
Input	Volume	Empty	0-100	[0-40]
		Medium		[30-70]
		Full		[60-100]
	Last Retrieval Time	Morning	0-24	[0-10]
		Afternoon		[7-17]
		Afternoon		[14-24]
Output	Criteria	Blank	0-100	[0-40]
		Medium		[30-70]
		Full		[60-100]

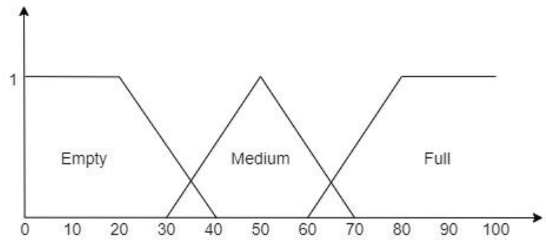

Fig. 6. Fuzzy set on volume variable

$$\mu\ emptyVolume = \begin{cases} 1 & ; x \le 20 \\ \frac{(40-x)}{(20)} & ; 20 \le x \le 40 \\ 0 & ; x \ge 40 \end{cases}$$

$$\mu\ mediumVolume = \begin{cases} 0 & ; x \le 30 \ atau \ x \ge 70 \\ \frac{(x-30)}{(20)} & ; 30 \le x \le 50 \\ \frac{(70-x)}{(20)} & ; 50 \le x \le 70 \end{cases}$$

$$\mu\ fullVolume = \begin{cases} 0 & ; x \le 60 \\ \frac{(x-60)}{(20)} & ; 60 \le x \le 80 \\ 1 & ; x \ge 80 \end{cases}$$

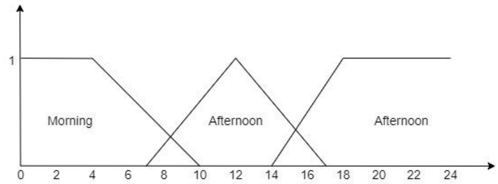

Fig. 7. Fuzzy set on last retrieval time variable

$$\mu\ Morning = \begin{cases} 1 & ; x \le 5 \\ \frac{(10-x)}{(5)} & ; 5 \le x \le 10 \\ 0 & ; x \ge 10 \end{cases}$$

$$\mu\ Afternoon = \begin{cases} 0 & ; x \le 7 \ atau\ x \ge 17 \\ \frac{(x-7)}{(5)} & ; 7 \le x \le 12 \\ \frac{(17-x)}{(5)} & ; 12 \le x \le 17 \end{cases}$$

$$\mu\ Evening = \begin{cases} 0 & ; x \le 14 \\ \frac{(x-14)}{(5)} & ; 14 \le x \le 19 \\ 1 & ; x \ge 19 \end{cases}$$

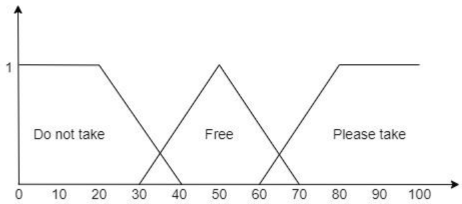

Fig. 8. Fuzzy Sets on Criteria Variables

$$\mu\ donottake = \begin{cases} 1 & ; x \le 20 \\ \frac{(40-x)}{(20)} & ; 20 \le x \le 40 \\ 0 & ; x \ge 40 \end{cases}$$

$$\mu\ free = \begin{cases} 0 & ; x \le 20 \ atau\ x \ge 70 \\ \frac{(x-30)}{(20)} & ; 30 \le x \le 50 \\ \frac{(70-x)}{(20)} & ; 50 \le x \le 70 \end{cases}$$

$$\mu\ pleasetakeit = \begin{cases} 0 & ; x \le 60 \\ \frac{(x-60)}{(20)} & ; 60 \le x \le 80 \\ 1 & ; x \ge 80 \end{cases}$$

2. *Implication Function Application*

After determining the variable membership function, fuzzy logic rules are formed. Based on the existing data, the following rules can be formed:

[R1] If (volume is EMPTY) and (time is MORNING) then (criterion is DO NOT TAKE)
[R2] If (volume is EMPTY) and (time is SORE) then (criterion is DO NOT TAKE)
[R3] If (volume is EMPTY) and (time is SORE) then (criterion is DO NOT TAKE)
[If (volume is MEDIUM) and (time is MORNING) then (criteria is PLEASE PICK UP)
[R5] If (volume is MEDIUM) and (time is SIANG) then (criterion is PLEASE PICK UP)
[R6] If (volume is MEDIUM) and (time is SORE) then (criterion is DO NOT TAKE)
[If (volume is FULL) and (time is MORNING) then (criteria is PLEASE PICK UP)
[R8] If (volume is FULL) and (time is MORNING) then (criterion is PLEASE PICK UP)
[R9] If (volume is FULL) and (time is SORE) then (criterion is FREE)

In the Mamdani method, the implication function used is *Min* (minimum). To determine the retrieval criteria for each trash can, the following calculation is done. For example, from the data, the volume in barrel 1 is 33%, so the membership value can be determined based on the membership function of the volume variable, namely:

$$\mu_{emptyVolume}=\frac{40-x}{20}=\frac{40-33}{20}=0{,}35$$
$$\mu_{mediumVolume}=\frac{x-30}{20}=\frac{33-30}{20}=0{,}15$$
$$\mu_{fullVolume}=0$$

And it is known that the last pickup time in barrel 1 is 17 o'clock, so the membership value can be determined based on the membership function of the time variable, namely:

$$\mu_{Morning}=0$$
$$\mu_{Afternoon}=0$$
$$\mu_{Evening}=\frac{x-14}{5}=0{,}6$$

Now we will find $\alpha - predikat$ for each rule:

[R1] If (volume is EMPTY) and (time is MORNING) then (criterion is DO NOT TAKE)

$$\begin{aligned}\alpha - predikat_1 &= \mu_{emptyVolume(33)} \cap \mu_{Morning(17)}\\ &= \min(\mu_{emptyVolume(33)} \cap \mu_{Morning(17)})\\ &= \min(0{,}35; 0)\\ &= 0\end{aligned}$$

[R2] If (volume is EMPTY) and (time is SORE) then (criterion is DO NOT TAKE)

$$\begin{aligned}\alpha - predikat_2 &= \mu_{emptyVolume(33)} \cap \mu_{Afternoon(17)}\\ &= \min(\mu_{emptyVolume(33)} \cap \mu_{Afternoon(17)})\\ &= \min(0{,}35; 0)\\ &= 0\end{aligned}$$

[R3] If (volume is EMPTY) and (time is SORE) then (criterion is DO NOT TAKE)

$$\begin{aligned}\alpha - predikat_3 &= \mu_{emptyVolume(33)} \cap \mu_{Evening(17)}\\ &= \min(\mu_{emptyVolume(33)} \cap \mu_{Evening(17)})\\ &= \min(0{,}35; 0{,}6)\\ &= 0{,}35\end{aligned}$$

[If (volume is MEDIUM) and (time is MORNING) then (criteria is PLEASE PICK UP)

$$\begin{aligned}\alpha - predikat_4 &= \mu_{mediumVolume(33)} \cap \mu_{Morning(17)}\\ &= \min(\mu_{mediumVolume(33)} \cap \mu_{Morning(17)})\\ &= \min(0{,}15; 0)\\ &= 0\end{aligned}$$

[R5] If (volume is MEDIUM) and (time is SIANG) then (criterion is PLEASE PICK UP)

$$\begin{aligned}\alpha - predikat_5 &= \mu_{mediumVolume(33)} \cap \mu_{Afternoon(17)}\\ &= \min(\mu_{mediumVolume(33)} \cap \mu_{Afternoon(17)})\\ &= \min(0{,}15; 0)\\ &= 0\end{aligned}$$

[R6] If (volume is MEDIUM) and (time is SORE) then (criterion is DO NOT TAKE)

$$\begin{aligned}\alpha - predikat_6 &= \mu_{mediumVolume(33)} \cap \mu_{Evening(17)}\\ &= \min(\mu_{mediumVolume(33)} \cap \mu_{Evening(17)})\\ &= \min(0{,}15; 0{,}6)\\ &= 0{,}15\end{aligned}$$

[If (volume is FULL) and (time is MORNING) then (criteria is PLEASE PICK UP)

$$\begin{aligned}\alpha - predikat_7 &= \mu_{fullVolume(33)} \cap \mu_{Morning(17)}\\ &= \min(\mu_{fullVolume(33)} \cap \mu_{Morning(17)})\\ &= \min(0; 0)\\ &= 0\end{aligned}$$

[R8] If (volume is FULL) and (time is MORNING) then (criterion is PLEASE PICK UP)

$$\begin{aligned}\alpha - predikat_8 &= \mu_{fullVolume(33)} \cap \mu_{Afternoon(17)}\\ &= \min(\mu_{fullVolume(33)} \cap \mu_{Afternoon(17)})\\ &= \min(0; 0)\\ &= 0\end{aligned}$$

[R9] If (volume is FULL) and (time is SORE) then (criterion is FREE)

$$\begin{aligned} \alpha - predikat_9 &= \mu_{fullVolume(33)} \cap \mu_{Evening(17)} \\ &= \min\left(\mu_{fullVolume(33)} \cap \mu_{Evening(17)}\right) \\ &= \min(0; 0{,}6) \\ &= 0 \end{aligned}$$

3. *Rule Composition*

From the results of the application of the implication function of each rule, the Max (Maximum) method is used to perform the composition between all rules, the rule used is the rule that produces the maximum α-predicate.[11]. With volume data is 33% and time is 17, the maximum predicate value is obtained, namely: [R3] If (volume *is EMPTY*) *and* (time *is* SORE) *then* (criterion *is* DO NOT TAKE)

[R3] If (volume *is EMPTY*) *and* (time *is* SORE) *then* (criterion *is* DO NOT TAKE)

$$\begin{aligned} \alpha - predikat_3 &= \mu_{emptyVolume(33)} \cap \mu_{Evening(17)} \\ &= \min\left(\mu_{emptyVolume(33)} \cap \mu_{Evening(17)}\right) \\ &= \min(0{,}35; 0{,}6) \\ &= 0{,}35 \end{aligned}$$

Then,

$$Z_{donottake}: \frac{40 - z}{20} = 0{,}5$$

$$= 40 - (20)(0{,}5)$$

$$= 30$$

4. *Defuzzification*

The input of the defuzzification process is a fuzzy set obtained from the composition of fuzzy rules, while the resulting output is a firm number in the domain of the fuzzy set. To determine the crisp z value, it is done by dividing the area into 2 parts with their respective areas. The affirmation method used is the centroid method[11]. The center point can be obtained from the following equation:

$$\begin{aligned} z^* &= \sum \frac{a - predikat_i \times Z_i}{a - predikat_i} \\ &= \frac{0{,}35 \times 30}{0{,}35} \\ &= 30 \end{aligned}$$

By using the Mamdani method, the optimal criterion is 30, which is included in the category of DO NOT TAKE criteria.

E. *Monitoring System*

There are four themes in total: Login, Main Dashboard, Volume Dashboard and Time Dashboard. The login page serves as the initial point of entry for users to access the application. See in Fig 9.

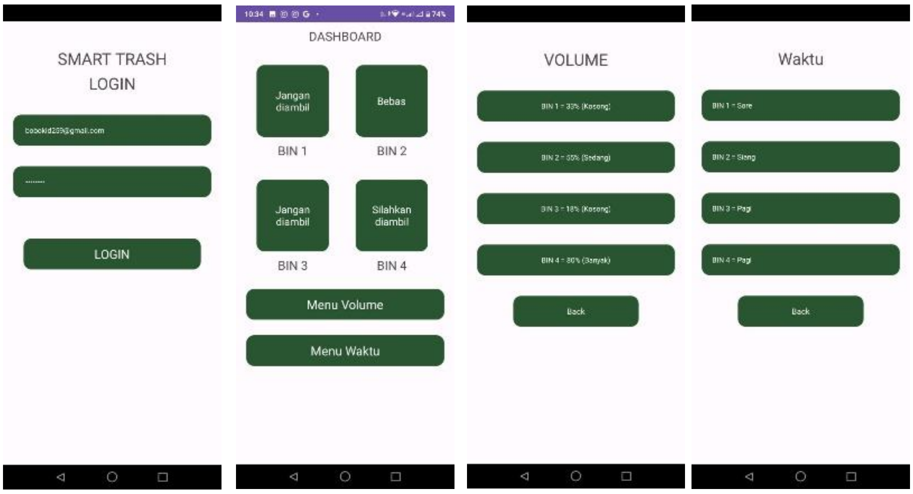

Fig. 9. Monitoring System Design

Once logged in, users will be directed to the Main Dashboard, which contains a summary of important information about the status of the bin or links to other parts of the application. The Volume Dashboard is the part of the application that provides information about the volume of waste in each bin. The Time Dashboard is the part of the application that provides information about the time of the waste collection. Fig. 9 illustrates the design of each dashboard.

F. Discussion

This research presents a prototype of a smart trash bin monitoring system that utilizes the fuzzy logic method. The manufacturing process involves the use of technological components such as NodeMCU ESP8266, HC-SR04 ultrasonic sensor, and 20x4 LCD Interface, which are integrated with a power supply that meets the voltage requirements of electronic devices. The prototype is capable of connecting to a Wi-Fi network to transmit data to the Firebase Database. Additionally, the researchers conducted thorough testing of the HC-SR04 ultrasonic sensor to assess its accuracy. The results of the tests indicated that the sensor has an accuracy rate of approximately 96.7%. As part of a comprehensive data collection method, the researchers took a series of measurements of the garbage volume and the time of the last pickup. The garbage pickup criteria were determined based on the variables of volume, last pickup time, and pickup criteria, using the results of the fuzzy logic calculations. In addition, the prototype has an intuitive interface design that includes a login page, main dashboard, volume dashboard, and time dashboard. This design provides useful and detailed information about the condition and management of the trash bins in real-time. Thus, this research provides a foundation for developing an efficient and adaptive bin monitoring system in waste management.

This research is in line with previous research [12], where using IoT technology can increase human work effectiveness and efficiency. The improvement in this study is the incorporation of fuzzy logic, which enhances the accuracy of decision-making regarding trash can criteria. Additionally, the ultrasonic sensor used as a volume measurement tool has a high accuracy rate of 96.7%.

IV. CONCLUSION

This research proposes using the Fuzzy Logic method to develop a real-time bin monitoring system. The method allows the modeling of uncertainty in data processing by monitoring the level of waste in real time and determining actions based on the level of waste and the last cleaning time. The HC-SR04 ultrasonic sensor was tested as a trash volume meter and achieved an accuracy rate of approximately 96.7%. The system prototype efficiently measured trash volume and last pickup time. The proposed monitoring system includes NodeMCU ESP8266 for data processing, an HCSR-04 ultrasonic sensor to detect waste volume, and an LCD to monitor the data. The implementation of fuzzy logic involves forming fuzzy sets, defining membership functions, applying implication functions, composing rules, and affirming (defuzzifying) to determine the optimal criteria for garbage collection. The system also includes an application interface with a login page, main dashboard, volume dashboard, and time dashboard, providing information on the volume and time of garbage collection.

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