Journal of Applied Informatics and Computing (JAIC)
Vol.9, No.6, December 2025, pp. 3831~3839
e-ISSN: 2548-6861

Smart Waste Management Monitoring and Control Analysis Based on Objects Based on Smart Systems and Internet of Things

Sarmila [1]*, Andani Achmad [2], Abdul Latief Arda [3]***
*Department of Computer Systems, Handayani University Makassar, Makassar
** Department of Computer and Network Engineering, Hasanauddin University
milaaaaa615@gmail.com[1],andani@unhas.ac.id [2],abdullatief@handayani.ac.id[3]

Article Info

Article history:

Received 2025-09-20
Revised 2025-11-27
Accepted 2025-12-10

Keyword:

Smart Waste Management,
Internet of Things,
Fuzzy Logic,
Smart Trash Bin.

ABSTRACT

Garbage is a problem that often becomes a trending topic in almost every country.throughout developing countries. The current condition of waste in our environment is still in a mixed condition, because the garbage has not been sorted. The minimum waste management information technology by officers also causes Waste management is slow, so that waste often piles up.The aim of this research is to develop a smart trash can that can sort metal, dry and wet waste automatically via Internet function of Things (IoT). The methodology used is Research and Development which can provide information when the trash can is full. This research was successful designing and implementing a prototype of a smart trash can based onInternet of Things (IoT) with the ability to sort waste into three categories The main components are metal, wet, and dry. The system utilizes proximity sensors inductive, soil sensor, and ultrasonic sensor HC-SR04 integrated with Blynk application for real-time monitoring of waste capacity. Algorithm Fuzzy logic is used so that the system is able to make adaptive decisions according to with the sensor condition. from the performance in the research Where the Accuracy of the system is 97.10%. The calculation is based on the number of correct predictions on the diagonal. main data divided by total data: true = 189 (Dry) + 187 (Wet) + 194 (Metal) = 570 out of a total of 587 samples, so 570/587 = 0.9710 (97.10%), with 17 error (error rate 2.90%). These values describe how much the accuracy and completeness of the model in recognizing each category of waste, with results consistently high (average 0.97).

I. INTRODUCTION

Waste management is one of the challenges the largest in sustainable development, especially in areas with high growth rate Rapid population growth In Indonesia, the volume trash Continue to improve together with economic growth and lifestyle changes public especially in the area of Balleangin. If NOTmanaged properly, waste can cause various environmental, health and environmental problems social. like many other areas facing problems complex waste management, especially in sorting waste that can be processed (organic and recyclable) repeat) repeat) and those that cannot be processed (residue). Traditional management system based on collection and disposal to final disposal sites (TPA) often inefficient and not environmentally friendly. Therefore it req,uires innovative solutions and is able to support waste management in a certain way that is more effective and efficient.

Technological advances, especially in the field of*nternet of Things* (IoT) and smart systems, offering opportunities to develop waste management systems more modern. IoT allows data collection *real* time monitoring of tool shows and stunning data-based tool for waste sorting system decisions This smart supported can help separate wet, dry, and metal waste in a certain way automatically, thus simplifying the process processing and recycling repeat.

Previous learning deficiencies related to waste sorting namely limited ability in sorting types trash, with a large part of learning only being able to distinguish one or two categories, such as etals and non- metals or organic and inorganic [1]. In addition, that The existing system cannot sort more than two categories of waste in a certain way automatically From Besides notifications, there are still many studies that are still being carried out takes place using SMS or alarm based methods simple, which is less efficient especially in large scale an,d no real time monitoring system yet based on applications that can provide a quick response to waste site conditions. Implementation of *Internet of Things* technology *Things* (IoT) is also still limited, just a cover monitoring of trash bin capacity without more data processing continues, and NO IoT System which is able to manage waste sorting data or provide analysis of waste patterns in a certain way automatic. Apart from that, there is, no research that.

The novelty of this research lies in the development of a place smart and capable trash sorting three types of trashin a certain way automatically (metal, dry, and wet) using a combination of inductive proximity sensors and ultrasonic, which increases efficiency in the recycling process repeat repeat . In addition , this research integrates Blynk IoT platform To provide time notifications real to the janitor when the trash can is full, allowing remote monitoring and increased operational efficiency. This system also collects and analyze waste disposal pattern data by means of certain *real time ,* which can be used for Determining the optimal waste transportation time reduces the frequency of unnecessary transportation. By approaching *Research and Development (R&D),* learn This Conduct repeated evaluations and testing ensure system reliability and scalability before implemented in a certain way broadly. Its contribution towards *Smart City* program and environmental sustainability reflected through automation of sorting and management waste and increasing public awareness of the past easy to use interactive technology.Research references previously in the journal it has been explained with sufficient and relevant to support the background behind the research. This can be seen from the explanation that previous research is generally still limited to the ability to sort only one or two types of waste, and has not integrated the monitoring system real-time based on the Internet of Things. In addition, some the existing system still uses the notification method simple things like alarms or SMS, so that management and monitoring of trash bin capacity has not been implemented optimal. From this explanation, the author shows there are gaps or deficiencies that have not yet been resolved in previous research, so that it becomes a strong basis the need for this research to be conducted. The research discussed in this journal then offers new things in the form of smart trash bin design that can sort three waste categories (metal, dry, and wet) automatically, while providing a capacity monitoring system based on IoT applications. Thus, the references that used not only relevantly, but also successfully directing the reader to the urgency and contribution research conducted.

Based on the problems above, it was made Analysis". Waste Monitoring and Management System Smart Based on Object Based on Smart System and *Internet **of Things** ".* this system will be very helpful users, in evaluating the effectiveness of the sorting tool automatic trash in separating trash that can be processed and waste that cannot be processed can be processed.The results of this study are expected to be a model that can be replicated or make a real contribution to efforts more waste management Good.

II. METHOD

A. Study Design This

Study is an experimental study designed in a systematic manner.quantitative To develop systems and sorting waste based on objects based on smart design systems and internet of things (IoT) learning

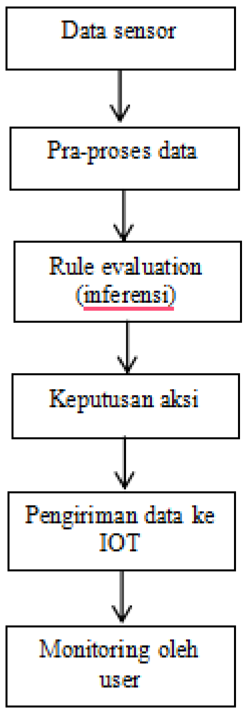

Figure 1 Research Design

This is illustrated in the following figure:

1. Sensor Data

On stage Here multi-, data collected from various modal sensors such as ;

a. Soil Sensor (detects wet waste and dry waste)
b. Inductive proximity sensor (metal trash detector)
c. Ultrasonic sensor (measuring the height of the waste in in the trash)

The data collected at this stage remains in depth raw data form, which may contain noise.

2. Data pre-processing

The purpose of this initial processing stage is to prepare the data so that it is suitable and ready for further processing. This stage includes calibration, which adjusts sensor readings to match actual standards; filtering, which removes noise from the sensor data; and normalization, which converts the data into a uniform scale, such as 0–1. Through these steps, the resulting data becomes cleaner and more stable, making it ready for use in the Fuzzy processing stage.

3. Blurring

This stage involves converting numerical sensor values into fuzzy values. For the ultrasonic sensor, the height readings are categorized to determine the level of waste inside the trash bin, starting from the empty condition when the height is less than 15 cm, the medium condition when the height is around the middle or approximately half of the container's volume, and the full condition when the height exceeds 85 cm. For the inductive proximity sensor, metal is considered fully detected when the distance is less than 5 cm, but after exceeding 15 cm, the metal is considered undetectable. If the distance is greater than 35 cm, the metal is confirmed to be absent, while at distances between 25–35 cm, a transitional or fuzzy value occurs. For the soil moisture sensor, dry conditions are indicated when the moisture level is below 20%, with the membership value decreasing to zero at 40%. Conversely, wet conditions are detected when the moisture level exceeds 80%, with the membership value increasing from 60% until it reaches full membership at 80%. Through this conversion process, each sensor value can be represented more flexibly in the form of fuzzy values.

4. Evaluation of Rules (Disorders)

This stage is the process of making decisions based on fuzzy rules. The system determines the output by evaluating several conditions, such as: if the inductive proximity sensor detects metal, then the output is classified as Metal Waste; if the soil moisture is in the Wet category and the ultrasonic sensor indicates that the container is Empty, then the output is Wet; and if the soil moisture is Dry while the ultrasonic sensor also shows Empty, then the output is Dry. At this stage, the system combines all fuzzy input values and applies the rule base to produce the appropriate fuzzy output.

5. Defuzzification

The defuzzification process is carried out using the centroid method, producing an output value of 14.35 on a scale of 0–100. This value is obtained by dividing the total moment of 285.71 by the total area of 19.915. In addition to the centroid method, several other common defuzzification techniques can also be used, such as the center of gravity method, the bisector method, and the Mean of Maximum (MoM) method.

6. Decision/Action

Based on the results of defuzzification, the system generates an output that can be used to support the waste management and sorting process. First, the system provides information to the user regarding the type of waste detected, allowing for more accurate sorting based on the identified object, such as metal, wet waste, or dry waste. Second, the system also utilizes the automatic height measurement obtained from the ultrasonic sensor. This allows the trash bin to be detected when its volume is approaching full capacity, enabling timely notifications or further actions. This process makes waste management more efficient, accurate, and responsive, especially in environments that require automatic monitoring.

7. Data Delivery to IoT

Decision data, real-time sensor readings, and status of trash objects and trash heights in in the trash sent to the IoT Platform for remote monitoring and control This research method uses an approach Research and Development (R&D). First stage is the identification of needs, namely collecting information related to waste management problems, the need for automatic sorting, and specifications the required system through literature studies and environmental observation. The second stage is system design, which includes preparation system block diagram, microcontroller selection (ESP32), sensors (inductive, soil moisture, and ultrasonic), actuators (servos), and designfuzzy logic algorithm for classification process.The third stage is implementation, where the device hardware is assembled and software is in the form of programs microcontroller and IoT platform integration (Blynk) realized. The fourth stage is testing system, is done to ensure the sensor is working according to reading range, fuzzy logic produce the right decisions, and IoT systems display data in real-time. The final stageis evaluation, namely analyzing system performance using accuracy calculations, error rates, and reliability of the classification process based on test data that have been collected. The evaluation results are used as a basis for system improvement and refinement.

B. Block Diagram

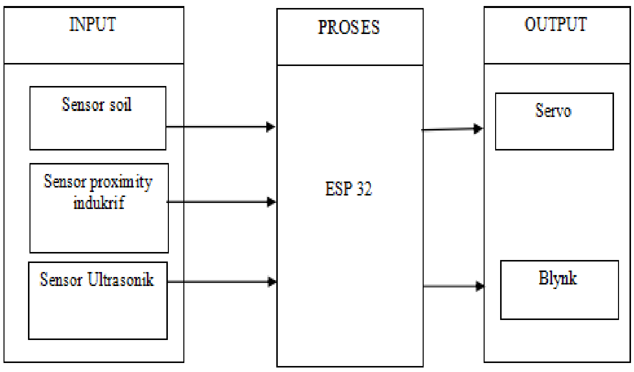

Figure 2 Block Diagram

A block diagram is a type of system diagram in which unctions are represented by blocks connected by lines, depicting the relationships and flow between the blocks.field of engineering e,lectronic hardware design developm ent soft and threaded devices Work ,system ,block diagrams are used in a wide variety of ways .This system diagram blog consists of three main parts, namely, input, process, and output. In the input section, three types of sensors are used: inductive sensors for detect the presence of metal waste, soil sensors for distinguish between wet and dry waste, ultrasonic and sensorsfor measuring distance or height that represents trash bin capacity. All data from the sensors are thenprocessed by the ESP32, a microcontroller that functions as a control center. ESP32 manages the system logic. based on input received from sensors and determine the action to be taken to complete In the output there,are two main mechanisms namely servo which moving the components of the body likes to open or close the trash can according to the detection results and The Blynk app displays data in real-time, including capacity status of the trash can and provide otification When a full condition is detected .

C. Schematic Diagram

IoT Electronic Design or schematic diagram is electronic serial number indicating the connections in between components like actuator microcontrollers sensors, and the reso, urces used forbuilding and connecting IoT systems so that it can function as needed.

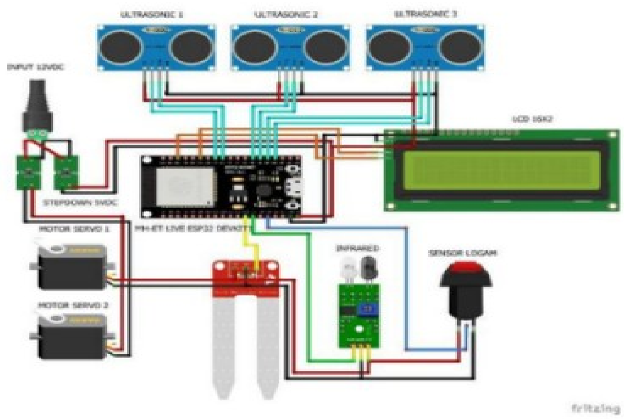

Figure 3. electronic disegn

The image above shows a schematic diagram of the System. IoT based ESP32 microcontroller. This circuit consists of from several interacting sensors and actuators connected to each other. Ultrasonic sensors are used For measuring the distance or capacity of the trash can, a soil sensor to detect wet and dry trash, a metal sensor to detect the presence of metal trash, and an infrared sensor for additional object detection. The ESP32 microcontroller functions as a middleman control the process all sensor data. Processing results are displayed via 16x2 LCD as visual information, while the two servo motors used to move physical mechanisms (eg. open or close the trash can). In addition, the 5VDC stepdown, module is used for lower 12V input voltage to match requires series.

D. Blurring

Each sensor reading is converted into appropriate linguistic devices, In a fuzzy logic–based measurement system, several variables are used to determine environmental conditions more flexibly. For the ultrasonic sensor, there are three main categories used to describe height. The *Empty* category uses a trapezoidal membership function with full membership values between 0 and 15 cm, decreasing to zero at 30 cm. This indicates that heights below 15 cm are considered completely empty. The next category, *Currently*, uses a triangular membership function with a peak membership value at 50 cm, decreasing to zero at 25 cm and 75 cm. This represents a medium or intermediate height condition. The *The Height* category represents a high or full condition, using a trapezoidal function that reaches full membership at 85–100 cm and begins increasing from 70 cm. Thus, heights above 85 cm are interpreted as full. For the metal distance sensor, the system distinguishes between *Metal Detected (Near)* and *No Metal (Far)* conditions. In the metal-detected condition, the trapezoidal membership function indicates that distances of 0–5 cm are considered full detection, then decrease to zero at 15 cm. This means that the farther the metal is from 5 cm, the lower the detection level becomes, and beyond 15 cm the metal is considered undetected. Meanwhile, the *No Metal (Far)* condition also uses a trapezoidal function, where full membership values occur at 35–50 cm and begin increasing from 25 cm. The range of 25–35 cm forms a transition zone that represents a gradual shift from the possibility of metal still being present to the condition where no metal is present.For the soil moisture variable, two categories are used to distinguish soil conditions: *Dry* and *Wet*. The *Dry* category uses a trapezoidal function with full membership at 0–20% moisture, decreasing to zero at 40%, meaning soil with less than 20% moisture is considered completely dry. Meanwhile, the *Wet* category also uses a trapezoidal function with full membership at 80–100% and begins increasing from 60%. In the intermediate range, a fuzzy value occurs, representing a gradual transition between not-wet and fully-wet soil conditions. Thus, the fuzzy system across these three sensors allows for smoother, non-rigid measurements, enabling a more accurate representation of real-world conditions.

E. . Membership Function

1. Ultrasonic sensor membership function

The following is the fuzzy diagram of the ultrasonic sensor:

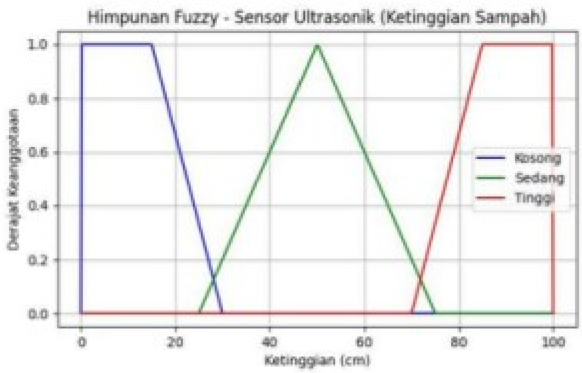

figure 4. fuzzy set of ultrasonic sensors

The fuzzy set chart of ultrasonic sensor illustrates distribution of waste height in three categories linguistics, namely Empty, edium, and High. The Empty category is represented by a trapezoidal function. in the range of 0–30 cm, full under 15 cm. Current Category uses the triangle function with peak at 50 cm and limit 25–75 cm as the area transition. Meanwhile, the High category trapezoidal shape with full membership above85 cm to 100 cm. With this distribution system, 60% is an unclear transition area, whereCan interpret the condition of waste capacity based on the height detected by the sensor is flexible andeasy to approach male logic

2. Membership function of inductive proximity sensor.

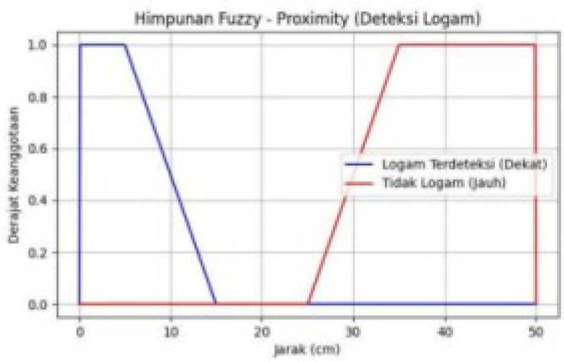

Figure 5. fuzzy inductive proximity sesnor

Fuzzy set chart for inductive proximity sensor divide metal detection into two categories linguistics, namely Metal Detected (Near) and NotMetal (Far). At a distance of 0–5 cm, metal considered fully detected (ÿ=1), whereas in above 15 cm is no longer detected metal more than 35 cm, system Sure metal NO exist (ÿ=1), with a transition in the range of 25–35 cm. Area between these two categories into a gray zoneindicating uncertainty or rejecting the Levelsensor trust. With the fuzzy approach, the system Can make more flexible decisions compared to just binary logic.

3. Soil sensor membership function

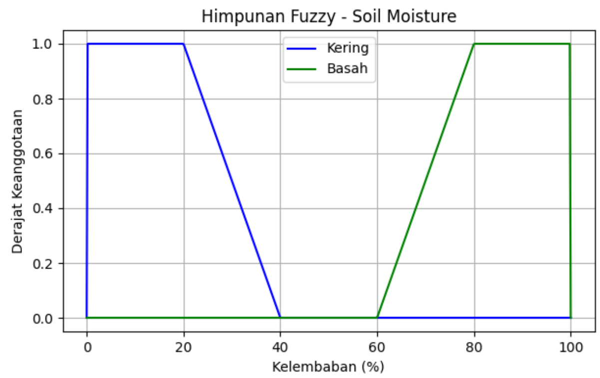

Figure 6. fuzzy logic soil mousture set

Fuzzy set chart for division soil moisture waste oisture into twolinguistic categories, namely Dry and Wet Conditions dry is represented by a trapezoidal function in the range 0–40%, with full membership below 20%. In On the othe,r hand, wet conditions are valid in the range of 60–100%, with full membership above 80%. The range is 40–60% is an unclear transition area, where the status of the trash is difficult to determine in a certain way Of course. With fuzzy logic, the system can evaluate the moisture content of the waste gain flexibly compared to approaching binary .

Identifier	If condition	Then (Actuator)
R1	Proximity= metal	Metal
R2	Land= Wet and ultrasonik empty	Wet
R3	Land = Dry ultrasonik empty	Dry
R4	Ultrasonic = medium	

III. Result And Discussion

Testing is done in the laboratory withcontrolled environmental conditions (temperature 27–30°C, humidity 60–75%, medium lighting). The waste tested consisted of from metal, wet, and dry with a total of 587 samplesExperiment. Variation of waste conditions and distance to the sensor also tested to ensure the system can work stably and accurate.

1. System implimentation summary

Learning This has a generating system selection of waste objects and height of waste based on intelligent systems and the internet of things (IoT) The system consists of:

a. Ultrasonic inductive, soil mousture, distance sensor.

b. ESP 32 microcontroller

c. Blynk platfrom for real-time monitoring

d. Fuzzy logic algotihm for classiying

For the selecion of waste objects and height size rubbish.

Figure 7. system testing

Figure 7 depicts the waste sorting system.works automatically using a combination of sensors and motors Servo. Inductive sensors function to recognize garbage. metal, soil sensors differentiate between wet and dry waste, while ultrasonic sensors are used to detect height of waste and container capacity. Servo motor first set track entering trash, while the second servo motor moves the waste sorting mechanism directed to the appropriate container. If the container is full, the sensor ultrasonic will give a warning signal to act immediately emptied. This system works automatically with Power source from the power supply so it is capable independent waste sorting at a time monitoring container capacity without much manual intervention.System response time is measured from the time the waste is entered. and detected by the sensor until the status data is sent to Blynk app. Average time required for sensor to recognize the type of waste is about 0.4–0.8 seconds, depending on the stability of the humidity sensor reading and inductive. Then, the process of sending data through WiFi connection (ESP32–Blynk) takes approx1.2–1.6 seconds. Thus, the total system response time is in the range of 1.6–2.4 seconds from the detection process to status is displayed on the Blynk dashboard in real-time This time is still considered fast and responsive for operational monitoring needs in the field.

2. Software testing

The system is installed t the waste location 5 sensor points:

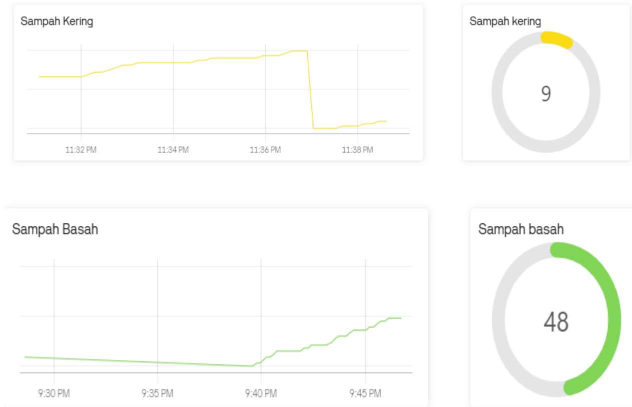

Figure 8. software testimg

Figure 8 shows the monitoring dashboard on the application. Blynk is monitoring the metal, dry, and wet waste sorting system in real-time via IoT devices.Sensor data is displayed in a line chart.For the tendency of the time meter and the meter for latest mark on a scale of 0–100. Measurement results shows the value of the metal waste sensor 48, wet waste 45, and dry waste 39, so the metal detecSted mostclear visualization of waste distribution and makes it easier to analyze conditions by means of certain directly, by supporting fuzzy logic in classify the height and type of waste based on input from five sensors.

Figure 9. device testing on mobile

IoT-based waste sorting system is successfudisplay data in real-time via the Blynk application. The results show that the amount of metal waste reached 10, dry waste **6** and we, t waste 15. Graph on Blynk shows a trend of increasing amounts of waste gradually based on category, with wet waste dominates the largest number. The measuring dashboard makes it easier to monitor the capacity of each container, so that officers can know the latest conditions.Overall, this system is capable of sorting and monitoring

3. Descriptive Data

Descriptive statistics are used for general information. about the characteristics collected during the experiment. Explanation for each part of the following table is:

TABLE 2.
DESCRIPTIVE DATA

Type volume	Mean it	Maxi mall	Berat	Develope r bro standard	Term uan
Logam	0%	54%	24.9%	25.24%	54%
Dryg	3%	81%	42.0%	39.27%	54%

The table above shows the following information:

1. Metal waste has the lowest average (24.9%) with large fluctuations (Std Dev 25.24).
2. Dry waste shows the highest average (42%) and also the largest variation (Std Dev 34.02), which shows frequent drastic increases
3. Wet waste is quite stable in moderate amounts (average 39%) with moderate variation (Std Dev 22.39)

The sensor provides a fairly clear variation for detec ritical conditions that require system action.Sensor values support fuzzy logic activation under conditions certain (inductive proximity sensor and soil sensor). Conditions the average is still within reasonable limits, but the variability I height provides space for decision makingn dynamic by the system.

4. unclear Decisions

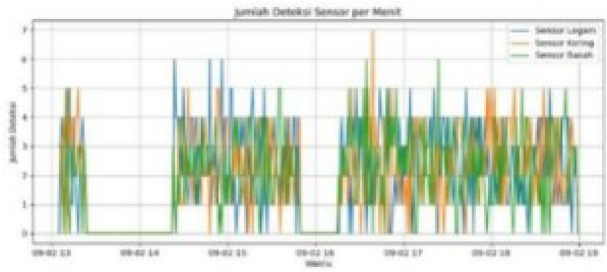

Figure 10. number of sensor detections per minute

The chart shows the results of metal, dry, and wet sensor detections per minute within the management system. smart IoT-based waste. At first, the observation (13.00–14.00) detection has low to zero time then increases intensively with meeting fluctuations at 14.00–18.00, indicating Garbage disposal dynamic . Metal and wet sensors achieve six-hour detectiontimes w, hen the dry sensor has time to reach seven After 18.00 the initial activity reduces al though There is still detection. This pattern shows the system's capability in distinguishing waste types in real-time, providing information on accumulation speed andallows automatic alerts the moment the container is filled by supporting smart algorithms, data can be usedFor volume prediction, fleet schedule route optimization transportation and regulation, where during rush hour monitored at 14.00–18.00.

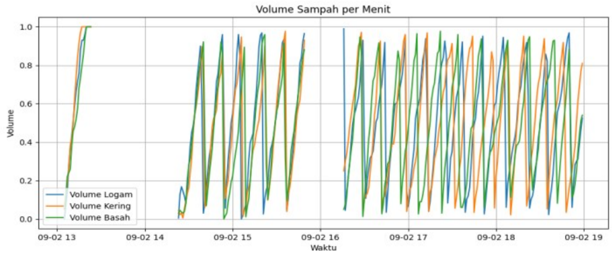

Figure 11. Volume of waste per minute

The graph above shows the volume of waste per minute in in the waste management monitoring and control system Smart IoT is system-based and intelligent, which includes three categories namely metal waste (blue), dry (orange), and wet (green). The X-axis represents the observation time at September 2nd at 13.00–19.00, while the axisY indicates the relative capacity of the container with a scale of 0 up to 1, where a value of 1 means full. around 13.00 the volume of waste from the three ategories increase sharply to full, then start the beat pattern 14.00–18.00 the chart shows fluctuations thatshows the rise and fall of the system NOT only detects adding volume but also doe Automatic sedimentation When capacity is full. Peak activity occurs at 17.00–18.00 with morefluctuations in the meeting, while approaching Activity at 19.00 over volume detection stable condition Thisshows that the system is capable of carrying out monitoring real time, container capacity control throughautomatic deposit mechanism and ,supports efficiency ,operational by providing notifications during peak hours For transportation schedule arrangements. In addition, the pattern the data can be integrated with intelligent algorithms such as fuzzy logic or machine learning for volume prediction full, transportation route optimization, and collection This proves that the monitoring system is not only detect but also control the volume of waste in a certain way intelligent and balanced on all three category.

B. Discussion

The learning outcomes section shows that the system intelligent and highly measurable waste monitoring and control waste based on smart technology uccess system and internet of things is implemented using sensors multi-modal (inductive proximity, ground, and ultrasonic) connected to the ESP32 and monitored via the app Blynk . This system is able to detect the type of metal, wet and dry waste at,a time monitoring the capacity container in a certain way automatically. Hardware results including LCD, PCB control driver modul,e, up to servo actuator whil,e soft device Showing real-time sensor data. Data acquisition showssignificant variation in waste volume between types, where dry waste tends to have an average highest. Fuzzy analysis divides the sensor conditions into linguistic categories (empty, medium, full) and generate sorting decisions based on rules Mamdani. Evaluation of the performance showed that there was incompatibility on some sensors, but in a way certain the entire system is able to achieve Accuracy 97.1% with high precision, recall, and F1 score on all three categories of waste. These results prove that The system can work effectively as a sorting solution. automatic sensor waste and fuzzy logic atic sensor waste and fuzzy logic.

Selection of fuzzy logic method in this researchbased on the characteristics of sensor data which areuncertain and has transition values between wet, dry, and metallic states. Thus, fuzzy logic is assessed more suitable than the binary decision method because able to accommodate threshold values and changes gradual changes that occur in sensor readings. ApproachThis strengthens the scientific reasoning in the system, because the system can imitate the way humans make decisions based on membership level, not just conditionor not. Based on this, the use of fuzzy logic provides greater flexibility and accuracy in automatic sorting of waste objects

IV. CONCLUSION

Learn to succeTehids and designing and implementing a smart trash can prototypeInternet of Things (IoT) based sorting systemwaste is divided into three main categories, namely metal, waste wet and ,dry waste. This system integrates inductive proximity sensor To detect metal, soil sensor to distinguish wet and dry waste, ultrasonic HC-SR04 to monitor the height of waste. Resultsresearch shows that the prototype is capable of working sorting in a certain way automatically and providesreal-time notifications via the Blynk app When waste capacity is almost full or full. Implementation fuzzy logic algorithms help the system in make more adaptive decisions according to conditions sensor. Therefore, this research supportsmore efficient, modern, and efficient waste management in harmony with the concept of Smart City and sustainability environment.

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