

DESIGN AND CONSTRUCTION OF A FULLNESS MONITORING SYSTEM INTERNET OF THINGS BASED TRASH CAN USING FUZZY LOGIC

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Abstract

Keywords:

ESP32,
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Internet of Things,
MQTT,
Waste Bin Monitoring.

This study aims to design an Internet of Things (IoT)-based waste bin fullness monitoring system using the Fuzzy Tsukamoto logic method. The system integrates an ESP32 microcontroller, an HC-SR04 ultrasonic sensor, an RTC DS3231 module, and an SD Card module installed on waste bins within the Universitas Wiraraja environment. Waste volume data and the duration since the last waste collection are processed using the Fuzzy Tsukamoto method with 15 rules to determine the priority status for waste collection. The system implements a layered architecture using MQTT communication, a Node.js backend, Firebase Realtime Database, and a Vue.js dashboard. The test results show that the sensor achieves an accuracy with an average error tolerance of less than ± 0.5 cm. MQTT transmission operates stably, with all messages successfully delivered in less than 1 second. Testing of the consistency of the fuzzy output shows that the Z^* values remain stable under the same input conditions. The conclusion of this study is that the system successfully visualizes waste bin fullness data in real time, integrates a multi-status waste collection workflow, and provides adaptive priority information to support more efficient waste collection decisions.

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INTRODUCTION

Wiraraja Madura University is one of the universities in Sumenep Regency that has academic and non-academic activities that produce waste every day. Less than optimal waste management often causes accumulation in garbage bins scattered in the campus area, such as faculty areas, canteens, and libraries. This condition causes negative impacts in the form of bad odors, bacterial growth, and reduced comfort of the campus environment.

The current process of monitoring the fullness of the bins is still carried out manually by the janitors who go around checking each trash can periodically. This method has several drawbacks: there is no real-time data on the level of fullness, unstructured transport priorities, and late handling responses. Research [1] develops an IoT-based smart bin monitoring system using ESP32 and ultrasonic sensors. Research [2] applies fuzzy algorithms for the detection of physiological conditions in IoT-based e-learning users. Research [3] develops WebGIS for mapping urban facilities.

Based on these problems, this study proposes the construction of an Internet of Things (IoT)-based garbage bin monitoring system using the Fuzzy Tsukamoto logic method. The system is designed using a layered architecture that includes hardware (ESP32, HC-SR04 ultrasonic sensor, DS3231 RTC module), MQTT communication, Node.js backend, Firebase Realtime Database, and Vue.js dashboard. Tsukamoto's Fuzzy logic is used to classify the priority status of transportation based on the parameters of waste volume and the duration of time since the last transport.

LITERATURE REVIEW

A lot of research has been done on IoT-based bin monitoring systems. Priyansah et al. [1] developed an IoT-based Smart Trash Box using ESP32 and ultrasonic sensors to monitor the full level of the bin in real-time. The system sends data to the server over a Wi-Fi connection and displays the information on a web dashboard.

Pradana et al. [2] applied Fuzzy Tsukamoto to detect physiological conditions in IoT-based e-learning users. The study proved that Fuzzy Tsukamoto's method is able to generate adaptive decisions with firm outputs through a weighted average mechanism. This approach is relevant to be applied to multi-parameter-based decision-making systems such as waste monitoring.

Addas et al. [7] developed an IoT-based smart waste management 2.0 system for smart cities that integrates sensors, cloud computing, and data analytics. Maturi et al. [8] designed smart dustbins with real-time monitoring and waste management optimization using IoT devices. Tundo et al. [9] implemented fuzzy algorithms with ESP32 for watering monitoring. Austin et al. [10] implemented IoT with ESP32 for temperature monitoring using the MQTT protocol.

Based on the above literature review, this study fills the gap in the form of integrating the Fuzzy Tsukamoto method with layered IoT architecture (ESP32, MQTT, backend, Firebase, Vue.js) for monitoring the fullness of the bin with adaptive transportation priority status classification based on two parameters (volume and time), equipped with a local backup storage mechanism and automatic notifications.

RESEARCH METHODS

Research Design

This research was carried out through several stages: problem identification, literature study, needs analysis, system design, system development, testing, and analysis and conclusions. Problem identification was carried out through direct observation within Wiraraja Madura University and interviews with cleaning officers.

The research instruments consisted of hardware (ESP32, HC-SR04 ultrasonic sensor, DS3231 RTC module, SD Card module, 5V adapter, UPS, 18650 lithium-ion battery) and software (Arduino IDE, Visual Studio Code, Node.js, Firebase, Vue.js). The dataset was obtained

from sensor readings on five bin units at 60-second intervals. Table I presents the structure of the dataset.

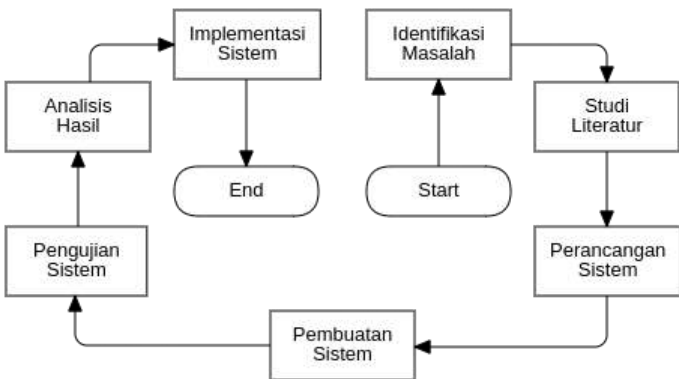


Figure 1.
Research Flow Diagram

Table I.
Dataset Structure

Yes	Parameter	Data Type	Remarks
1	Volume of Waste	Float	Percentage of waste capacity
2	Time	Timestamp	Duration since transport
3	Status	String	Fuzzy results (5 levels)

System Planning

This IoT-based bin fullness monitoring system is designed using a layered architecture consisting of five main layers, namely the hardware layer, MQTT Broker layer, backend layer, database layer, and dashboard layer. Figure 2 shows the system-layered architecture.

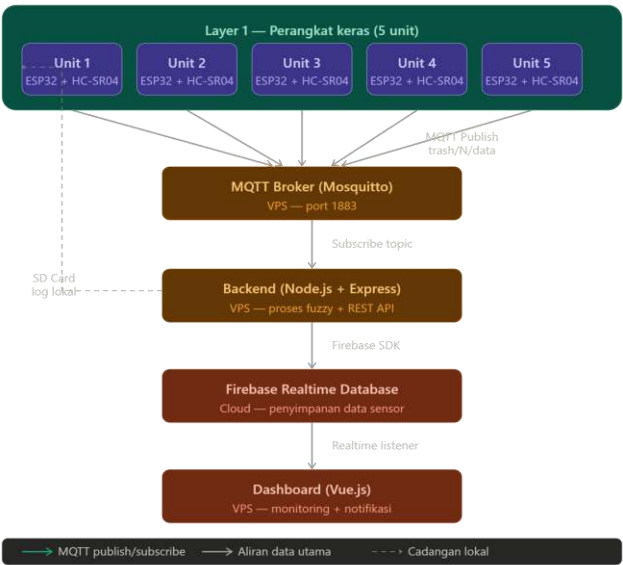


Figure 2.
System-Layered Architecture

The hardware layer consists of five trash can units, each equipped with an ESP32, an HC-SR04 sensor, an SD Card module, and a lithium-ion battery. Data from each ESP32 is sent to MQTT Broker Mosquitto. The backend Node.js subscribe to the entire topic, validate the data, and pass it to the Firebase Realtime Database. The dashboard Vue.js display the data in real-time.

The system's workflow starts with an ultrasonic sensor reading that measures the trash surface distance. The ESP32 converts the distance to a percentage of fullness, then reads the time from the RTC. Volume and time data are processed using Tsukamoto's fuzzy logic. The results are saved to the SD Card as a backup, then sent to the MQTT Broker. Figure 3 and Figure 4 present the system workflow and the system flowchart, respectively.

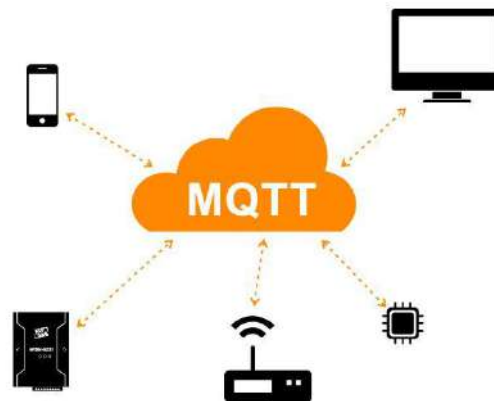


Figure 3.
System Workflow

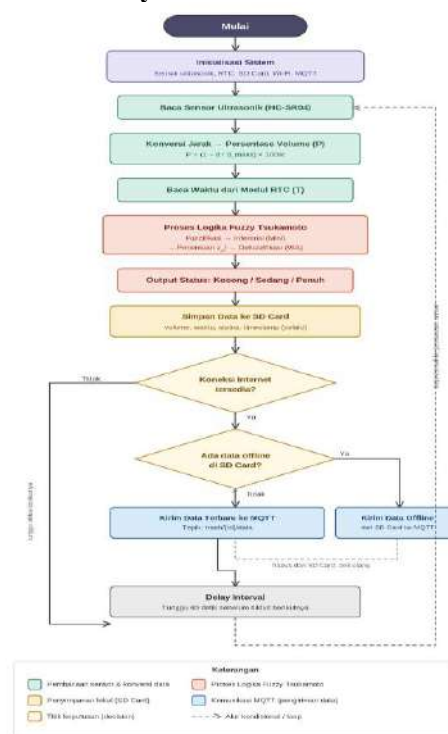


Figure 4.
Flowchart System

Fuzzy Tsukamoto's Planning

Tsukamoto's fuzzy logic method is used to determine the priority status of waste transport based on two input parameters: percentage of fullness (P) and duration of time since the last transport (T). Table II presents the linguistic variables of the fuzzy system.

Table II.

Fuzzy System Linguistic Variables				
Components	Variabel	Symbols	Universe	Fuzzy Set
Input 1	Percentage of Fullness	P	[0, 100]%	Empty, Low, Medium, Almost Full, Full
Input 2	Time	T	[0, 18] hours	A Moment, a Long Time, a Very Long Time
Output	Status	Z	[0, 100]	No Need to Transport, Low Priority, Medium Priority, High Priority, Immediately Transported

The system uses 15 fuzzy rules designed based on domain knowledge. Table III presents a summary of the rule base.

Table III.
Basis Aturan Fuzzy

Yes	IF (Volume)	AND (Waktu)	THEN (Status)
R1	Empty	Short / Long	NoNeed to Be Transported
R2	Low / Medium	Short / Long	PriorityLow/Medium
R3	Almost Full	Short / Long	High Priority
R4	Almost Full	Very Long	Immediately Transported
R5	Full	All	Immediately Transported

Testing Techniques

The test was carried out on three aspects. First, testing the accuracy of the sensor reading by comparing the readable distance of the HC-SR04 sensor to the actual value. Second, the stability test of the MQTT transmission by monitoring the success of message delivery. Third, the fuzzy output consistency test by observing the stability of the Z* value at the input condition that did not change.

RESULTS AND DISCUSSION

The hardware implementation consists of an ESP32 microcontroller as the control center, an HC-SR04 ultrasonic sensor mounted on the trash can lid, an RTC DS3231 module for time recording, an SD Card module for local storage, and a power supply using a combination of a 5V adapter and an 18650 lithium-ion battery with a UPS module. Figure 5 shows the hardware design of the system.



Figure 5.
System Hardware Design

Sensor accuracy testing showed that the HC-SR04 sensor was able to provide consistent readings with an average error tolerance of below ± 0.5 cm. MQTT transmission stability testing showed that all messages were successfully sent and received by the server in less than 1 second. Fuzzy output consistency testing showed that at 70.8% fixed volume conditions with a deposition time of more than 16 hours, the system consistently generated $Z^* = 90.06$ with an Immediately Transported classification. Table IV presents a sample of the test results.

Table IV.
Fuzzy Output Consistency Test Results

Timestamp	Volume (%)	Time (hours)	Z^* Value	Status
2026-05-24 20:53:24	70,8	16,33	90,06	Immediately Transported
2026-05-24 21:23:24	70,8	16,83	90,06	Immediately Transported

System advantages include: real-time monitoring with fullness data visualization, adaptive priority status classification using fuzzy logic, local backup storage mechanism via SD Card, automatic notifications, and a power management system with UPS for continuity of operation.

System disadvantages: smartphone interface responsiveness is not optimal, reliance on an internet connection, is not yet integrated with the financial system, and there are no mobile push notifications.

CONCLUSION

Based on the results of design, implementation, and testing, it was concluded that the Internet of Things-based garbage can fullness monitoring system using Tsukamoto's Fuzzy Logic method was successfully designed and implemented. The system integrates an ESP32 microcontroller, an HC-SR04 ultrasonic sensor, an RTC DS3231 module, and an SD Card module.

The implementation of Tsukamoto's Fuzzy Logic method with two input variables (fullness volume and time duration) successfully resulted in an adaptive state classification into five levels. The test results showed that the sensor had accuracy with an average fault tolerance of below ± 0.5 cm, the MQTT transmission ran stably with a latency of less than 1 second, and the fuzzy output was consistent under the same input conditions.

Further development suggestions include increasing smartphone interface responsiveness, adding offline modes, integration with financial systems, adding push notifications, and implementing automatic data backups.

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