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# Utilization of IoT for Waste Transportation Optimization Through a Web-Based Monitoring System

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**Abstract**

Ineffective waste management can lead to waste of resources, accumulation of waste, and inefficient mobility of cleaning staff. The current waste transportation system is still carried out routinely without considering the fullness of the bins, causing a waste of fuel and labor. This research aims to develop an Internet of Things (IoT)-based trash bin monitoring system and Web application to improve the efficiency of waste management. The system uses ultrasonic sensors to detect the fullness level of bins and sends real-time data to a Web-based monitoring platform. The system is also equipped with an automatic notification function to notify the janitor when the bin is full. This research uses the Research and Development (R&D) method for IoT system development and the Extreme Programming (XP) method for Web application development. The eXPected result is a system that can reduce the number of unnecessary trips, reduce operational costs, and improve overall environmental cleanliness. With this system, waste management is eXPected to be more efficient, sustainable, and environmentally friendly.

***Keywords**: Waste management, Internet of Things (IoT), ultrasonic sensor, operational efficiency.*

## 1. Introduction

Waste management is one of the serious challenges faced by urban areas, including Waingapu City, East Sumba Regency. According to data from the National Waste Management Information System (SIPSN), waste accumulation in East Sumba Regency reaches 59.71 tons per day. Currently, waste collection is conducted regularly using six trucks with fixed routes and a fuel allocation of 40 liters per month per unit. However, monitoring of Temporary Waste Storage Sites (TPS) is still done manually. Sanitation workers must inspect each TPS individually without accurate occupancy data, leading to transportation to TPS that are not yet full or delays in handling when TPS are already overflowing. This results in fuel waste, time loss, and increased environmental pollution risks.

These issues highlight the need for a system capable of providing real-time information on the condition of TPS, enabling more efficient decision-making and waste transportation. One solution that can be implemented is an Internet of Things (IoT)-based monitoring system, which allows physical devices such as ultrasonic sensors to measure the fill level of waste bins and automatically transmit data via the internet. According to Atzori et al. (2010), IoT enables the automation of accurate and responsive environmental data collection. The collected data can be displayed through a web-based system, allowing flexible access to information from various devices (Murugesan, 2007). To support the mapping of waste collection point locations, a digital mapping approach is used to visualize spatial data, thereby facilitating the determination of optimal routes (Goodchild, 2007).

This study aims to design and develop an IoT-based waste bin monitoring system, digital mapping, and a web application. This system is designed to provide automatic notifications to sanitation workers, visualize TPS locations, and display real-time fill status. It is hoped that this system will reduce resource waste, improve the effectiveness of waste transportation, and support smarter, more efficient, and sustainable environmental management.

**Table 1:** Previous Research

| No | Author | Research Title | Main Results |
|---|---|---|---|
| 1 | Hidayat & Safitri (2024) | Designing Smart Household Waste Bins Based on IoT | Smart trash cans can open lids automatically and send Android notifications |
| 2 | Suarti & Islamy (2023) | Waste Volume Monitoring and Sensor Segregation | The sensor detects smoke and types of waste, with notifications sent via Telegram. |
| 3 | Hanafie et al. (2021) | IoT-based Smart Waste Bin | ESP32 and Blynk are used, capable of automatic waste sorting |
| 4 | Putra et al. (2022) | IoT Waste Bin Monitoring System | NodeMCU + ultrasonic sensor, but accuracy and connection issues |
| 5 | Harya et al. (2023) | IoT-Based Scales for Monitoring and | Effective monitoring of waste via IoT, but hampered by |

| | | |
|---|---|---|
| | Managing Organic Waste in Smart Waste Management in Manyingsal Village | accuracy and connectivity issues. |

Table 1 summarizes five studies related to IoT-based smart waste bin systems. Most studies use ultrasonic sensors and microcontrollers such as Arduino or NodeMCU to monitor waste volume in real time. Some systems are also equipped with automatic sorting based on waste type and notification delivery via applications such as Android, Telegram, and Blynk. In general, the results of the study show the effectiveness of the system in improving waste management efficiency.

However, challenges remain, such as limitations in sensor accuracy and reliance on internet connectivity. This research aims to address these challenges by integrating IoT sensors, digital mapping, and web-based systems to create a more efficient, accurate, and real-time accessible solution for sanitation workers.

## 2. Research Method

The methods used in system development are Research and Development (R&D) and Extreme Programming (XP). The R&D method is used to design and test IoT-based hardware systems, while XP is used for the development of web-based monitoring systems.

1. Hardware Design
   The hardware is designed using one ESP32 microcontroller and four HC-SR04 ultrasonic sensors placed at four points on the top of the TPS to detect the height of waste from various sides. Distance data is sent via Wi-Fi to the Firebase Realtime Database, then processed and sent to the monitoring system.
2. Software Design
   The web-based monitoring system is built using HTML, JavaScript, and Tailwind CSS. The backend is directly connected to Firebase using the official SDK. The web system displays the TPS status in real-time and provides automatic notifications when the trash bin is full.

## 3. Results and Discussion

This research resulted in an Internet of Things (IoT)-based waste bin monitoring system and web system, capable of detecting when temporary storage sites (TPS) are full in real time and sending automatic notifications when waste bins are full. The development process included system design, hardware and software implementation, and functional and integrative system testing.
All paragraphs must be justified alignment. With justified alignment, both sides of the paragraph are straight.

### 3.1. Design and Implementation of an IoT-Based TPS Monitoring System


**Figure 1:** IoT-Based Waste Monitoring System Diagram

Figure 1 shows the general flow of the system, illustrating how data is sent from the HC-SR04 ultrasonic sensor to the ESP32 microcontroller. This sensor measures the height of the trash, and the collected data is then sent to the Firebase Realtime Database. The data is then processed and displayed through a web system, where staff can view the status of the waste collection point (WCP) in real-time. If the WCP is full, the system will automatically send a notification via Firebase Cloud Messaging (FCM) to inform the staff.

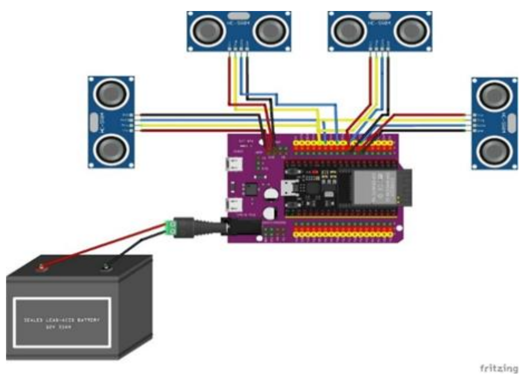


**Figure 2:** Sensor and ESP32 Circuit Diagram

In Figure 2, the circuit diagram shows four HC-SR04 ultrasonic sensors directly connected to the ESP32 microcontroller. These sensors are mounted on the four sides of the TPS to provide broader detection of trash height at each corner of the trash bin. This figure explains how the sensors work to measure distance and send data to the microcontroller, which then processes the data.

**Table 1.** TPS Status Based on Sensor Readings

| HC-SR04 Sensor Condition (4 Points) | TPS Status | Notification |
|---|---|---|
| All sensors > 17 cm | Empty | No |
| 1–3 sensors < 17 cm | Almost Full | No |
| All sensors < 17 cm | Full | Yes |

Table 1 illustrates the logic used to determine the fullness status of the TPS based on ultrasonic sensor readings. If all sensors indicate a distance of more than 17 cm, the TPS is considered empty. If some sensors indicate a distance of less than 17 cm, the TPS is considered nearly full. If all sensors read a distance of less than 17 cm, the TPS is considered full and a notification is sent. The 17 cm threshold is set as half the height of the prototype waste container used in this study.

**Figure 3:** Physical Implementation of the IoT TPS Prototype

Figure 3 shows the physical implementation of the tested system prototype. In this figure, the TPS simulation container is filled with paper as a representation of waste, and four ultrasonic sensors are installed on top to detect the volume of waste. The ESP32 microcontroller is connected to a laptop used as a power source and for programming. The system successfully detected changes in waste volume with a quick response, indicating that the prototype is functioning as expected.

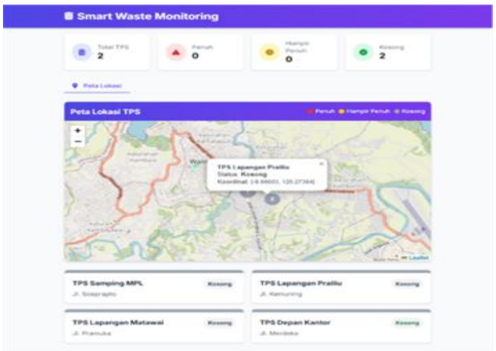


**Figure 4:** Dashboard Display

Figure 4 shows the system dashboard interface when all polling stations are empty. On the dashboard, the status of each polling station is displayed in the form of data cards linked to an interactive map. Blue is used to indicate that a polling station is empty, making it easier for officers to see the overall status of the polling stations.

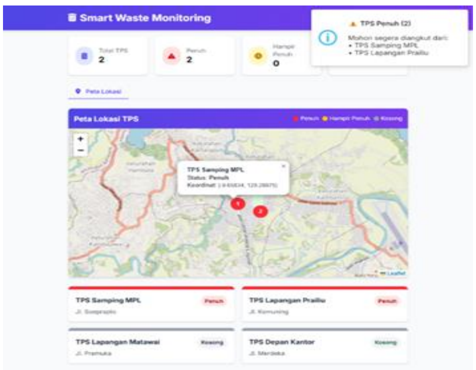


**Figure 5:** Dashboard Display When TPS Is Full

Figure 5 shows the dashboard display when two TPS, namely TPS Samping MPL and TPS Lapangan Prailiu, are full. The color indicator on the full TPS changes to red, and the system displays a pop-up notification to inform the officer that the TPS needs to be emptied immediately. This real-time visualization helps officers monitor the condition of the TPS more efficiently.

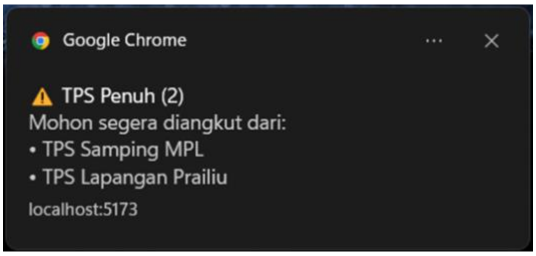


**Figure 6:** Automatic Notification in the Background When the TPS is Full

Figure 6 shows the automatic notification that appears in the background when the TPS is full. This notification is sent via a browser using Firebase Cloud Messaging (FCM). The notification message contains a list of TPS that require transportation, providing immediate information to officers to immediately handle the TPS that is already full.


**Fig. 7:** Firebase Realtime Database Data Structure

Figure 7 shows the data structure in the Firebase Realtime Database used to store information about each TPS. The data stored includes the TPS name, fullness status, and timestamp (last update time). This information enables historical tracking and auditing of the time of action taken by cleaning staff.

## 3.2. Testing

System testing was conducted to ensure that all hardware and software components of the IoT-based trash monitoring system were functioning properly. This testing was divided into two main categories: hardware testing and software testing. The following are the results of the testing conducted on both components.

### 3.2.1. Hardware Test Results

**Table 2:** Software Testing Results

| No | Software Components | Test Functions | Test Results |
|---|---|---|---|
| 1 | HC-SR04 Ultrasonic Sensor | Measures distance and trash bin fullness | Successful |
| 2 | ESP32 Microcontroller | Sends data from the sensor to Firebase and processes it | Successful |
| 3 | Wi-Fi Connection | Connects the ESP32 to the Wi-Fi network | Successful |
| 4 | Power Source (Laptop and Power Bank) | Provides power for the ESP32 and hardware testing | Successful |

### 3.2.2. Software Testing Results

**Table 3:** Software Testing Results

| No | Software Components | Test Functions | Test Results |
|---|---|---|---|
| 1 | Web System (Dashboard) | Displays TPS status in real-time | Successful |
| 2 | Firebase Integration with Web | Saves and displays data from Firebase to the dashboard | Successful |
| 3 | Automatic Notifications (FCM) | Sends notifications when TPS is full | Successful |
| 4 | Web System (User Interface) | Ensures responsiveness and ease of use | Successful |

# 4. Conclusion

This study successfully developed an Internet of Things (IoT)-based waste bin monitoring system that can detect waste bin fullness in real-time and send automatic notifications to sanitation workers. Testing of the hardware and software showed that the system functions well and is reliable for improving waste management efficiency. Further testing on a larger scale is needed to ensure the scalability of this system. Additionally, improving sensor accuracy and utilizing alternative connections besides Wi-Fi can enhance system performance in diverse environmental conditions.

## 5. Conclusion

This study successfully developed a web-based trash monitoring system using Internet of Things (IoT) technology to detect the fullness of waste bins in real-time and send automatic notifications to sanitation personnel. The novelty lies in the integration of ultrasonic sensors with Firebase and a real-time web dashboard that enables efficient, responsive, and accessible monitoring. The system has proven effective in reducing unnecessary waste pickups and operational costs while improving environmental cleanliness. Future improvements should address sensor accuracy and explore alternative connections beyond Wi-Fi to enhance system reliability in diverse conditions.

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