

Design and Implementation of a Smart Waste System Using Internet of Things

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ABSTRACT

In this paper, the development of a smart waste system using internet of things technology to enhance urban waste management was developed. The system integrates an ESP32 microcontroller with ultrasonic sensors to monitor garbage levels in real-time, addressing the inefficiencies in waste collection. The introduction highlights the challenges faced by urban waste management systems due to population growth and outdated infrastructure, emphasizing the need for effective monitoring solutions to reduce pollution and health hazards. The system is designed to provide real-time waste level detection and automated notifications, thereby improving collection efficiency and reducing operational costs. The literature review covers existing smart garbage systems, their components, functionalities, and challenges such as sensor reliability and scalability. The methodology outlines the use of the ESP32 board and ultrasonic sensors, detailing the design, programming, and testing processes to ensure system effectiveness. Results indicate that the ultrasonic sensor provides accurate measurements of waste levels, and the system's notification mechanism functions reliably for critical fill thresholds. The system demonstrated good power efficiency and effective data transmission through the Blynk app, though limitations including sensor interference and network dependency were observed. The paper concludes with a discussion on the successes of Internet of Things (IoT) integration and recommendations for future improvements, signaling notable advancements in urban waste management and the potential for smarter, cleaner cities.

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INTRODUCTION

Garbage management involves a range of activities from collection to disposal, including the gathering, transportation, regulation, treatment, monitoring, and clearance of waste. Collection methods differ depending on the environment; local authorities commonly manage waste collection through curbside pickups. However, in many developing cities, weak waste collection services and poorly managed landfills increase challenges due to fragile institutional frameworks and rapid urbanization [1]. The increasing integration of everyday systems and

tasks with the Internet of Things (IoT) aims to create more efficient workflows and faster task completion. IoT enables the seamless integration of various systems, providing valuable data that can be leveraged by the public. However, designing a common framework for IoT is complex due to the diversity of devices, technologies, and services involved.

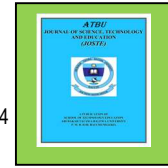
One significant environmental concern related to waste management is its impact on public health and the environment. Traditional methods of manually monitoring waste levels in garbage bins require substantial human effort,

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time, and resources. This can be mitigated through the use of technology for monitoring purposes. An IoT-based garbage monitoring system offers an innovative solution for maintaining environmental hygiene by automating the process of monitoring waste levels in bins. This concept of interconnected devices, widely adopted across the globe, continues to expand even amidst challenges like the COVID-19 pandemic, which started in 2019. It is anticipated that by 2025, nearly 30 billion devices will be connected through IoT. The foundational technologies enabling IoT include cloud computing, open-source server software, and web development tools.

The Internet of Things is set to play a critical role in developing smart city applications, particularly through real-time monitoring and management of urban processes. Among the various challenges facing smart cities, waste management significantly affects public health and environmental sustainability. Some studies have proposed smart bin monitoring systems using wide-area network technology. For household waste, a Wi-Fi-based solution could be practical since many homes already have wireless internet, reducing the need for additional infrastructure. However, this approach is less suitable for monitoring public garbage bins, which might require LoRa-based surveillance technology for better coverage, though it comes with additional costs [2].

The proposed paper aims to address these issues by providing real-time data on waste levels through internet connectivity. Given the rapid population growth and increasing waste production, there is a pressing need for an efficient waste management system to prevent disease spread by effectively managing and monitoring waste bins. This utilizes several city trash cans connected to smart devices, such as an Arduino Uno microcontroller equipped with ultrasonic sensors, GPS, and Wi-Fi modules. An ultrasonic sensor measures the waste level in the bin, transmitting the data to the Arduino system, which then communicates the information via Wi-Fi to a mobile application. This setup allows users to

receive notifications and alerts, prompting timely action to empty the bins [3].

In today's world, the merging of tasks and systems with IoT capabilities leads to more efficient workflows and faster completion of tasks. IoT aims to facilitate the seamless integration of diverse systems while providing data that can be widely utilized. Developing a general IoT architecture is a complex endeavor due to the wide range of devices, link-layer technologies, and services that may be part of such systems.

The rest of the paper is structured as follows; section II presents the literature review, while methodology is discussed in section III, section IV gives the results and section V highlights the discussion & future work. Finally, the conclusion is given in section VI.

LITERATURE REVIEW

Garbage encompasses all materials discarded after their initial use, deemed to have no further value. It includes several categories of waste: municipal solid waste, consisting of everyday items discarded by the public; industrial waste generated from manufacturing and industrial activities; hazardous waste that poses potential risks to human health and the environment; electronic waste (e-waste) comprising discarded electronic devices; and organic waste, which is biodegradable and originates from plant or animal sources. Effective garbage management is crucial for environmental protection, resource conservation, and public health, involving the processes of collection, transportation, treatment, and disposal of waste materials [4].

Traditional garbage bins, often referred to as waste bins or trash cans, are containers for temporarily storing waste. These bins vary in size and design to suit different needs, including small bins for household use, public litter bins for pedestrian areas, larger commercial bins for businesses, and industrial bins for substantial amounts of industrial waste. Conventional bins require manual monitoring and emptying, which can result in overflow problems if not managed properly [5].

The advent of the Internet of Things (IoT) has introduced new possibilities in garbage management. IoT is a network of physical objects embedded with sensors, software, and other technologies that enable these objects to connect and exchange data over the internet. Key components of IoT in garbage management include sensors for monitoring fill levels, connectivity modules for communication with management systems, data processing capabilities for analyzing collected information, and automation features that reduce the need for human intervention [6].

Smart garbage bins represent a specific application of IoT in waste management. These bins are equipped with sensors to monitor fill levels, communication modules to transmit data, and power management systems such as batteries or solar panels to ensure uninterrupted operation. The integration of IoT technology in garbage bins enables real-time monitoring, optimized collection routes, and overall improved efficiency in waste management. This not only helps prevent overflow but also reduces operational costs and environmental impact by

minimizing unnecessary collection trips. By employing smart garbage bins, cities can enhance their waste management strategies, making them more efficient and sustainable. These innovations contribute to cleaner urban environments and support public health by reducing waste overflow and optimizing resource use. As technology continues to advance, the role of IoT in garbage management is likely to expand, offering even more sophisticated solutions to waste-related challenges [7].

METHODOLOGY

The development of the IoT-based garbage management system involved a methodical combination of hardware and software components aimed at effectively monitoring and managing waste levels. The system's hardware design incorporated various key components that played specific roles in the collection and management of garbage, while the software aspect focused on user-friendly interfaces for data communication and monitoring via the Blynk application. The system architecture is shown in figure 1 below.

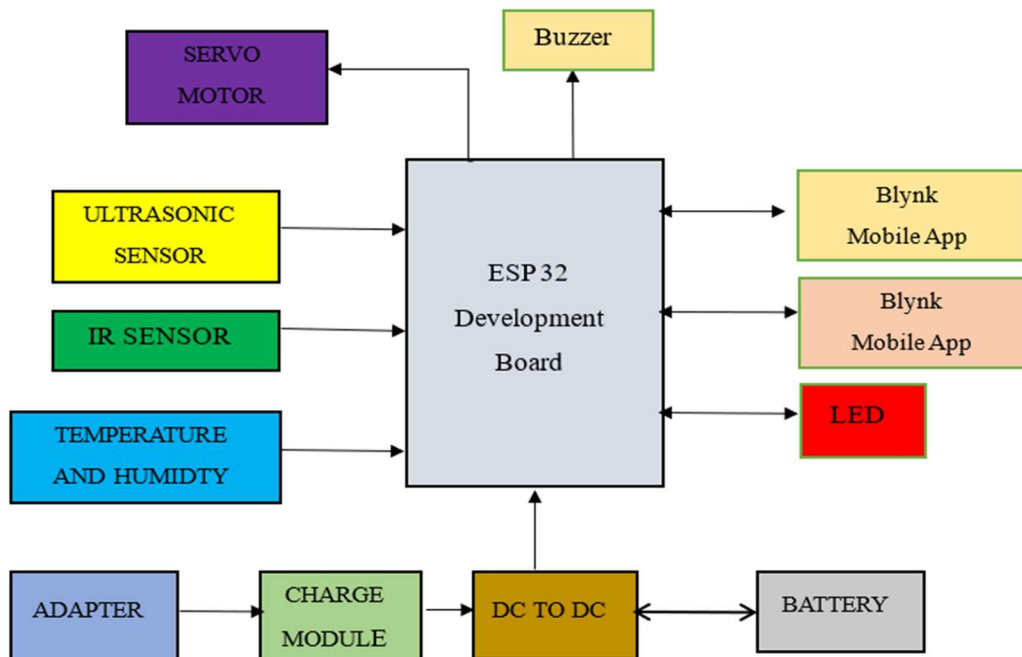


Fig. 1: System Architecture

The central element of the system's hardware was the ESP32 development board, which functioned as the control hub, processing sensor data and managing communication with the cloud and mobile applications. The ESP32's built-in Wi-Fi capabilities facilitated real-time data transmission, making it essential for the system's operation. Figure 2 depicts the ESP32 development board, illustrating its connectivity and processing role within the system.

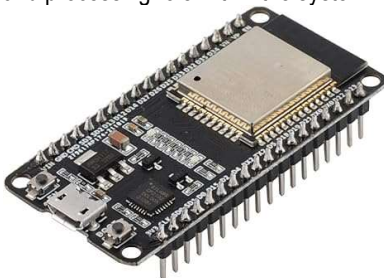


Fig. 2: ESP 32 Development Board [4]

To detect waste levels, ultrasonic sensors were utilized, sending signals to the ESP32 based on the proximity of waste to the sensor. The precise mathematical relation between time and distance was used to determine the waste level, which was then communicated to the system for further action is given by:
Distance (d) = Speed (v) x Time (t)

$$t = 2/340 = 0.0058s = 5.8ms$$

Figure 3 shows the ultrasonic sensor setup used in the system.



Fig. 3: Ultrasonic Sensor [5]

The system also integrated a servo motor for controlling the waste bin lid, opening and closing it in response to sensor data. This motor operated on pulse-width modulation signals from the ESP32, ensuring the lid functioned smoothly in response to waste levels. Figure 4 provides a visual representation of the servo motor and its placement within the system.



Figure 4: Servo Motor [6]

Temperature and humidity sensors, such as the DHT11 or DHT22, were used to monitor the internal conditions of the waste bin, providing data relevant to waste decomposition and potential odor issues. The design and functionality of these sensors are illustrated in Figure 5.



Figure 5: Temperature & Humidity Sensor [7]

Power management was addressed through the incorporation of a TP18650 charging module and a DC to DC step-up converter, ensuring consistent power supply even in off-grid scenarios. The charging module supported the system's autonomy, while the step-up converter enhanced power efficiency. Figures 6 and 7

respectively depict DC to DC step-up converter and charging module.



Fig. 6: DC to DC converter [8]



Fig. 7: Charging Module [9]

The system also featured an infrared (IR) sensor for detecting user proximity, automatically opening the bin lid when someone approached, as shown in Figure 8.



Fig. 8: Infrared IR sensor [10]

A lithium polymer battery, capable of powering the system during interruptions, was used to maintain continuous operation. This battery, shown in Figure 9, ensured the system's reliability by providing backup power for up to a full day when fully charged.

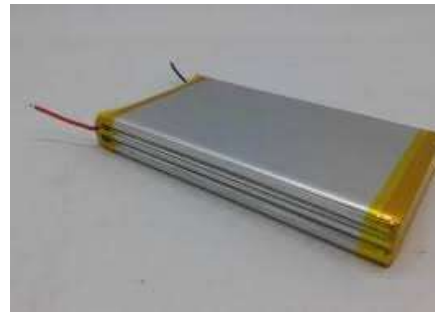


Fig. 9: Lithium Polymer Battery [11]

Additional components, such as a switch and a buzzer, were integrated to enhance user control and feedback. The switch allowed for power control, mode selection, and system reset, while the buzzer provided audible alerts for critical system statuses like garbage fill levels. The buzzer's detailed specifications and functionality are shown in Figure 10.



Fig. 10: Buzzer

The hardware components were connected as shown in the Figure 11, with the ESP32 board, sensors, and power management components working in unison to facilitate system operation. The software development for the system was carried out using the Arduino IDE, where C++ was used to write the code for configuring the ESP32 development board. The system was tested and evaluated through a series of tests that ensured each component's functionality, including component testing, integration testing, and environmental testing.

These tests verified the system's reliability, power consumption, and overall performance in real-world scenarios.

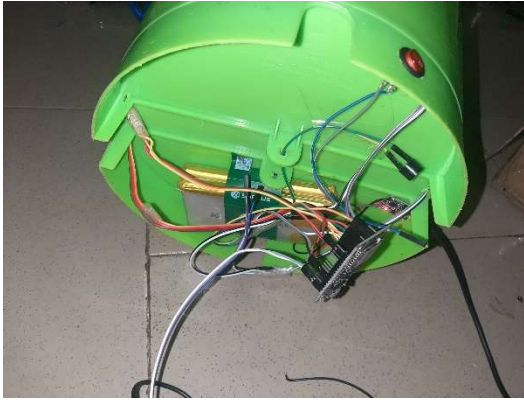


Fig. 11: Connection of Hardware Components

RESULT AND DISCUSSION

The results and discussion of the smart garbage monitoring system highlight the performance of various sensors and components integrated into the system. The ultrasonic sensor accurately measured the fill level of the garbage bin, with an empty bin recording a distance of 25 cm and a filled bin measuring 8 cm. Figure 12 illustrates both the empty and partially filled bin scenarios.

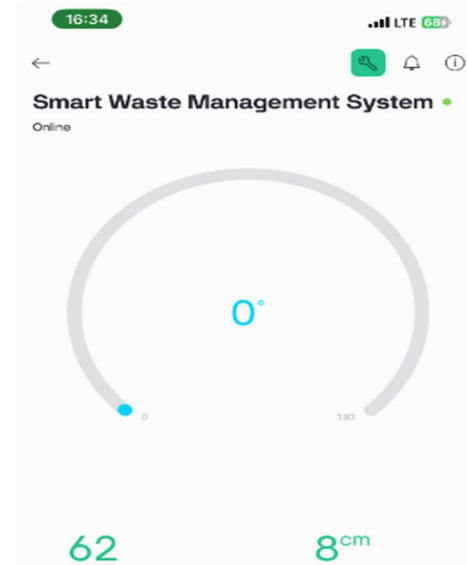
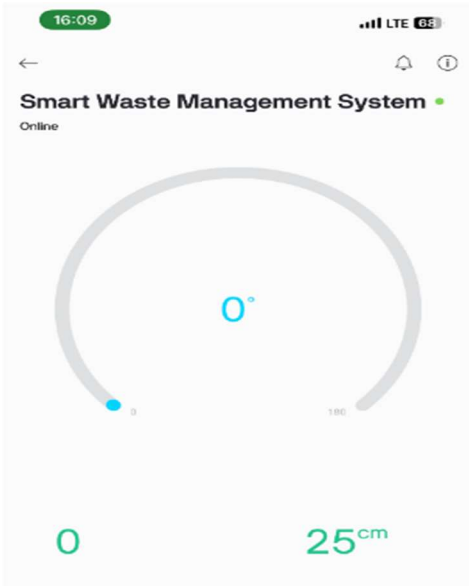


Fig. 12: Results of Empty Bin and Partially Filled Bin

The DHT22 temperature and humidity sensor monitored environmental conditions inside the garbage bin. Over a 3-day period, temperature data illustrated in Table 1 below showed average values of 24.03°C on Monday, 27.53°C on Tuesday, and 24.7°C on Wednesday, while humidity data showed in Table 2 below indicated average relative humidity levels of 81% on Monday, 70% on Tuesday, and 41% on Wednesday. Key observations from this data revealed that temperature peaks during midday hours correlated with outdoor temperatures, and humidity levels increased sharply after rainfall events, particularly affecting the decomposition rate of organic waste. This information provides valuable insights into predicting odor development, optimizing collection schedules, and ensuring proper functioning of electronic components under varying conditions.

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Table 1: Temperature Data Collected Over a 3-day Period

Days	Temperature (°C)	Temperature (°C)	Temperature (°C)	Average (°C)
Monday	24.5	19.5	28.1	24.03
Tuesday	25.0	32.1	25.5	27.53
Wednesday	18.2	23.8	32.1	24.7

Table 2: Humidity Data Collected Over a 3-day Period

Days	Relative humidity (%)	Relative humidity (%)	Relative humidity (%)	Average RH (%)
Monday	100	45	100	81
Tuesday	75	45	95	70
Wednesday	75	20	30	41

Additionally, the system incorporated an IR sensor, as shown in Figure 13, and a buzzer for audible alerts. Testing of the buzzer functionality revealed a short beep sequence at a 70% fill level and a prolonged alarm sound at a 90% fill level. The sound intensity, measured at 75 dB from 1 meter away, was sufficient for nearby awareness without causing noise pollution, and the buzzer had a 100% activation rate when thresholds were reached. The buzzer provided effective in complementing the mobile app notifications by providing immediate local alerts, especially in scenarios requiring urgent attention. Future improvements may include adjustable volume settings and customizable alert patterns to suit different types of bins or locations.



Fig. 13: IR Sensor on the Bin

The battery module of the system demonstrated good power efficiency, with the system operating continuously for 20 hours on a single 120-minute charge. Data collected on the empty and filled garbage bins indicated that, when the bin was empty, a space of 28 cm corresponded to a 0% garbage level, while a filled bin recorded a space of 8 cm, corresponding to a 62% garbage level. Table 3 and Table 4 respectively presents the data from both empty and filled garbage bins.

Table 3: Empty Garbage Bin

Space (cm)	Garbage level (%)
28	0
26	0
25	0

Table 4: Filled Garbage Bin

Space (cm)	Garbage level (%)
10	52
9	57
8	62

The Blynk mobile app successfully displayed real-time fill level percentages, a graph of fill levels over time, and alerts at critical levels of 90% and 100%. Figure 14 provides a visual representation of the garbage bin at 100% fill.

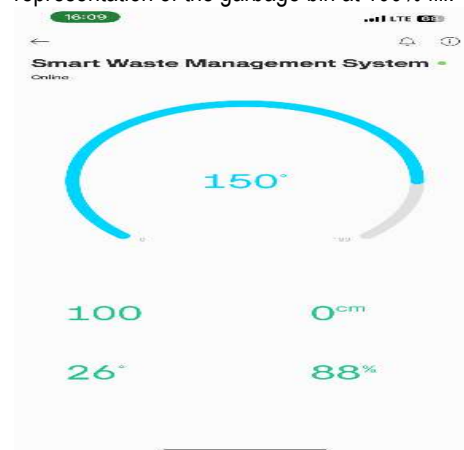


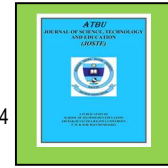
Fig. 14: Garbage Bin at 100% Filled

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Over a 1-week testing period, the system showed 99.5% uptime, consistent data transmission, and no false alerts, confirming the system's reliability. The smart garbage monitoring system demonstrated high accuracy in measuring fill levels and reliable data transmission. The mobile app interface provided clear, actionable information to users, while the system's battery life exceeded expectations, though longer-term testing is recommended. Key advantages observed include real-time monitoring, proactive alerts, and the potential for optimizing waste collection routes.

CONCLUSION

This paper titled Development of a Smart Garbage Monitoring System Utilizing Internet of Things (IoT) Technology successfully achieved its primary objective. The system was designed to integrate an ESP32 microcontroller, ultrasonic sensors, and a mobile application to enable real-time monitoring of garbage levels in waste bins. This innovation aimed to enhance waste management practices by providing timely and actionable data to garbage collection authorities, allowing them to optimize collection routes and schedules. The hardware components, including the integration of sensors and efficient power management, were successfully designed and implemented. Simultaneously, software was developed to handle the collection, processing, and transmission of data seamlessly.

The mobile application, designed with a user-friendly interface, allows for the easy tracking of garbage levels in real-time. Extensive testing of the system confirmed its accuracy and reliability, proving the viability of IoT technology in improving urban waste management processes. Key findings from the study highlighted that the ultrasonic sensor provided consistent accuracy across different types of waste, while real-time data transmission via IoT technology greatly enhanced the responsiveness of garbage management systems. Additionally, the mobile application played a crucial role in fostering user engagement, which has the potential to promote better waste disposal practices. The system demonstrated notable cost savings and

environmental benefits by optimizing garbage collection routes and schedules, solidifying its potential as an effective solution to the growing challenges in modern waste management.

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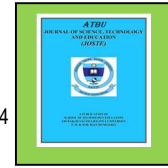
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