Smart Waste Management: Enhancing Recycling through Automated Metal Detection and IoT Integration

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Abstract. Inefficient waste collection and contamination of recycling streams hinder efforts towards environmental sustainability. This paper presents the development of a Smart Bin that integrates metal detection and sorting functionalities that segregates metal from domestic waste. The system is designed to enhance recycling efficiency and support environmental sustainability. The system employs an ultrasonic sensor to monitor the fill level of the bin, while a load cell is utilized to measure the bin's weight, ensuring accurate tracking of waste accumulation. By integrating the system with the Internet of Things (IoT) platform Blynk, real-time monitoring and warning capabilities are made possible. This integration allows the Smart Bin to send instant updates on its fill level and weight, ensuring timely waste collection and preventing overflow. Thus, metal waste is automatically identified, separated, and reported, facilitating safe and efficient metal recycling. This paper details the design and development of the Smart Bin system, exploring its potential to contribute to a more sustainable waste management approach. The study highlights the potential of Smart Bin technology to support green initiatives and contribute to more sustainable urban environments.

Keywords: Smart Bin, metal detection, IoT, Blynk Platform, sustainable waste management.

INTRODUCTION

The urgent need for sustainable waste management solutions has driven significant advancements in green technology. One such advancement is the development of a Smart Bin system designed to enhance recycling efficiency through the automated detection and sorting of metal from domestic waste. By leveraging advanced sensing technology, the Smart Bin can accurately identify and segregate metallic items, facilitating their appropriate recycling and reducing contamination in waste streams (1).

Sustainable waste management has increasingly become a focal point in urban planning and environmental policy, driven by the imperative to mitigate environmental impacts and conserve resources (2). Traditional waste management practices often struggle with efficiency and environmental sustainability, prompting the exploration of innovative technologies such as Smart Bins for improved waste segregation and recycling (3) (4).

Automated waste sorting systems have emerged as a promising solution to enhance recycling rates and reduce contamination in waste streams. (5) highlight advancements in automated sorting technologies, emphasizing their ability to accurately segregate different types of waste materials, including metals, thereby optimizing recycling processes. This capability is particularly crucial for metal recycling, which is essential for resource conservation and reducing reliance on primary metal extraction (6).

The integration of Internet of Things (IoT) platforms, such as Blynk, into waste management systems has revolutionized real-time monitoring and management capabilities (7). Blynk facilitates remote monitoring of Smart Bins, providing instant updates on fill levels and operational status. This integration not only improves operational efficiency by optimizing waste collection schedules but also enhances environmental sustainability by minimizing waste overflow and ensuring timely collection (8).

Smart waste management technologies have been implemented in various urban settings worldwide, demonstrating their scalability and effectiveness in enhancing waste segregation and recycling rates (9). These technologies contribute to creating more sustainable and resilient urban environments by promoting resource conservation and reducing greenhouse gas emissions associated with landfill disposal (10).

This paper aims to address both the technical and practical challenges associated with automated waste segregation. The Smart Bin system represents a scalable, efficient, and sustainable approach to urban waste management. By promoting effective recycling and resource conservation, this technology supports broader environmental sustainability goals. Through comprehensive analysis, this paper illustrates the potential of Smart Bin technology to support green initiatives and drive progress towards more sustainable urban living environments.

METHODOLOGY

System Design and Integration

The Smart Bin system was designed to detect and sort metal from domestic waste using advanced sensing technology. Figure 1 below shows the block diagram of the Smart Bin design.

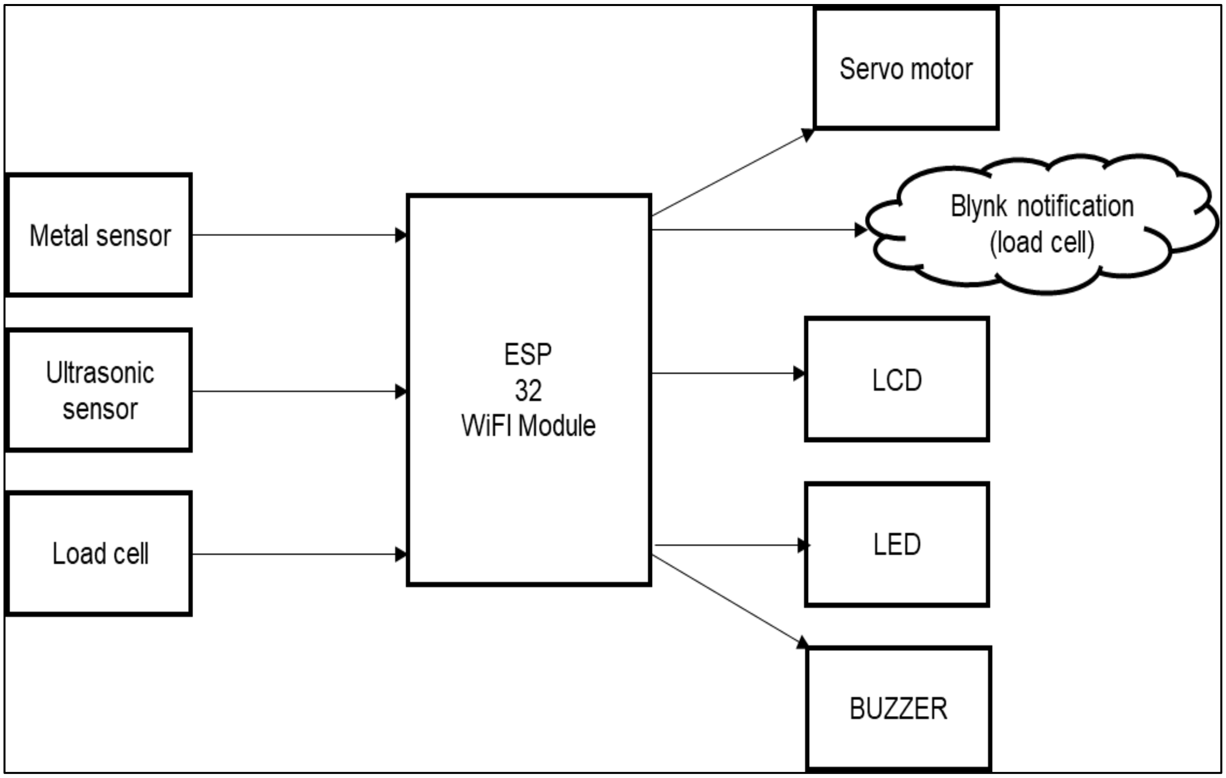

FIGURE 1: Block Diagram of the Smart Bin project

The block diagram in Figure 1 shows a detailed design phase which included the selection of appropriate sensors which is metal sensor capable of identifying metallic objects within the waste stream. It also included the ultrasonic sensor (HC-SR04) that can detect the level of the waste inside the bin and a load cell for determining the weight of the bin. These sensors were integrated into the bin's structure to ensure accurate detection and segregation. The system is driven by an ESP32 microcontroller, which acts as the central processing unit. For the output section, servo motor's function is to separate between metal and domestic waste. A platform called Blynk enables the developments of smartphone apps for monitoring Internet of Things (IoT) devices. The ESP32 will send signal to the Blynk server and notifies the mobile phone application when it hits certain indicator level and weight. Its output will emit light from LEDs, display LCD and a buzzer sound when the metal is detected each time the metal sensor detects metal. Upon metal detection, its output will illuminate via LEDs, show the results on an LCD, and sound an audible buzzer. The detailed design of this Smart Bin is shown in Figure 2 below.

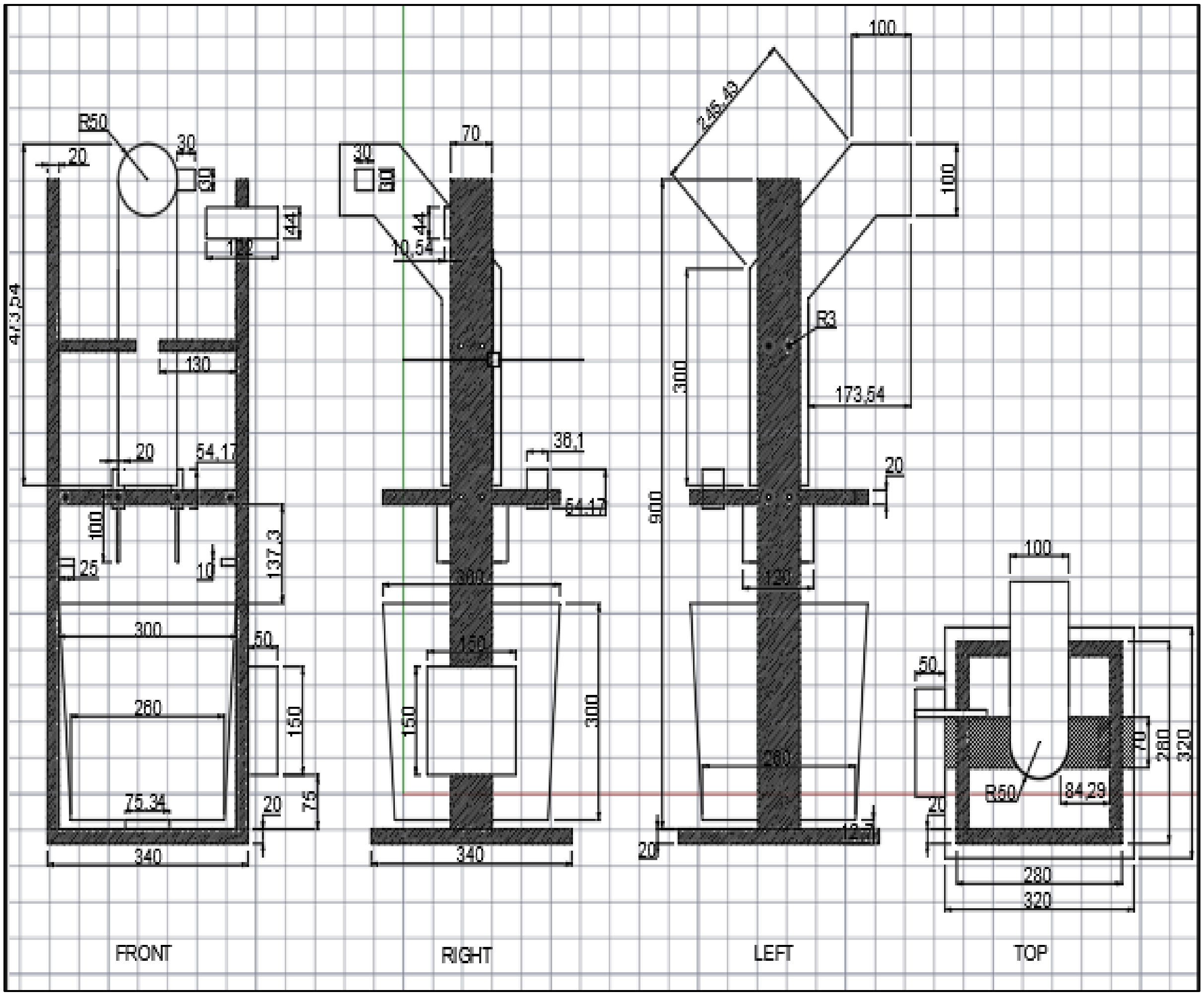

FIGURE 1: Project Design of Smart Bin System

Based on the project design in Figure 2, the bin is divided into two compartments, one for metal waste and one for general domestic waste. Then, a sensor is placed near the bin's opening to detect metal objects as they are thrown away. When metal is detected, a mechanism, like a trapdoor or conveyor belt, separates the metal object and directs it to the metal compartment. A microcontroller governs the entire process, receiving signals from the sensor and triggering the sorting mechanism. The system also includes ultrasonic sensor installed at the top of the bin to measure the distance to the waste surface, enabling fill level detection, that indicates the level when the bin is full and needs to be emptied.

The bin also is integrated with IoT as it connects to a network via Wi-Fi or Bluetooth, allowing users to monitor fill levels or receive alerts when the bin needs to be emptied. The design of this Smart Bin can be reformed depending on factors like size, capacity, and desired functionalities. The operation of the Smart Bin is explained in the following flowchart in Figure 3.

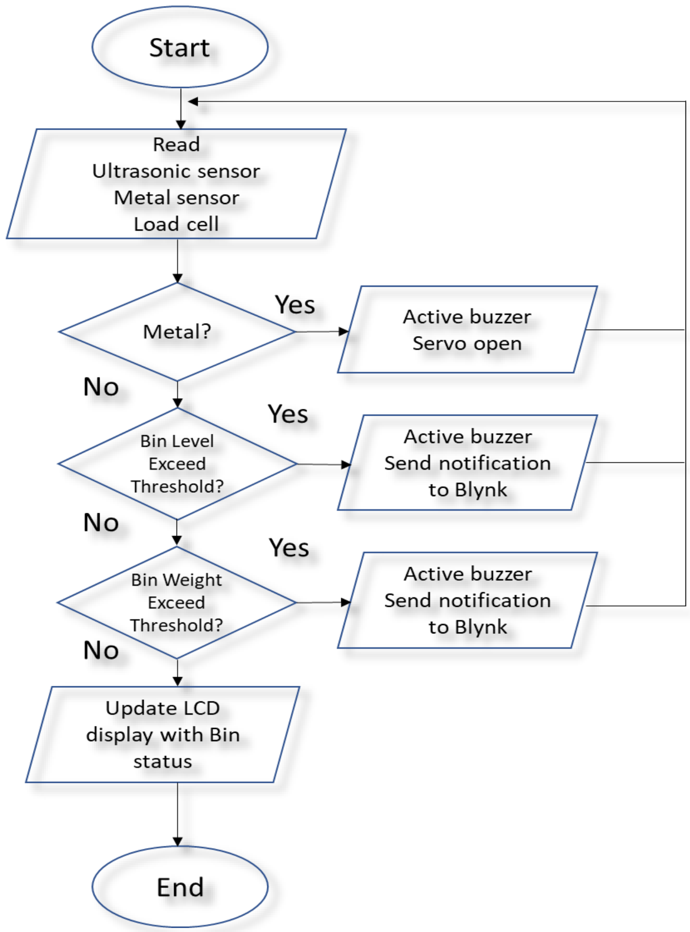

FIGURE 2: Flowchart of Smart Bin Operation

The flowchart in Figure 3 illustrates the operation of a waste management system designed for efficient waste disposal and monitoring. It begins with system initialization and enters a loop for continuous operation. The ultrasonic and metal sensors, along with a load cell, gather data about the waste bin's status. If metal is detected, a buzzer activates, and servo motors separate the metal waste. The system checks if the bin level exceeds predefined thresholds and alerts via a Blynk application if necessary. An LCD display is updated with the bin's current status. The system repeats this process indefinitely, ensuring continuous monitoring and management of waste disposal.

The integration of the Smart Bin with the Blynk IoT platform facilitated real-time monitoring and notification capabilities. This involved setting up communication protocols between the sensors embedded in the Smart Bin and the Blynk cloud server. The platform was configured to send notifications to designated users when the bin reached its capacity, ensuring timely waste collection and preventing overflow.

Testing and Validation

The developed Smart Bin system underwent rigorous testing to validate its functionality and performance. The functional testing includes controlled experiments to assess the accuracy of data collection and processing such as metal detection and sorting capabilities under varying conditions of waste composition and environmental factors. The functional testing also simulates various waste scenarios to verify the correct operation of fill level detection, weight measurement, and metal segregation.

Meanwhile, performance evaluations were also done to evaluate the system's performance in real-time conditions. Experiments were done to assess the accuracy of sensor readings, the reliability of IoT notifications, and the effectiveness of metal detection and segregation. Ethical considerations related to data privacy and environmental impact were carefully addressed throughout the research process. Measures were implemented to ensure that the deployment and operation of the Smart Bin system complied with relevant regulations and standards concerning waste management and IoT technologies.

RESULT AND DISCUSSION

The smart bin system was tested extensively to evaluate its functionality and performance in real-world conditions. The following key results were obtained.

TABLE 1. Functionality Test on Metal Detection

Metal Size	Metal Detection
Small (1mm – 10mm)	75%
Medium (11mm – 50mm)	100%
Large (51mm – 100mm)	100%

By referring to Table 1, the metal detection sensor was able to detect any metallic material if the size of the metal is greater than 11mm, with maximum size is 100mm according to the size of bin with a rate of 100%. However, the metal sensor was not able to detect metal in several circumstances when the size of metal is within 1mm to 10 mm in size. The metal detection sensor may have difficulty detecting very small or deeply embedded metallic items (11). Then, the fill level detection testing was performed to test for the ultrasonic sensor.

TABLE 2. Functionality Test on Fill Level Detection (Ultrasonic sensor)

Fill Level	Level Detection
Low (1mm – 10mm)	100%
Medium (11mm – 50mm)	100%
High (51mm – 100mm)	100%

Based on Table 2, the ultrasonic sensor was able to detect the distance of waste as low as 1mm to maximum of 100mm according to the size of bin with a rate of 100%. However, the ultrasonic sensor's accuracy can be affected by the shape and distribution of waste within the bin. Then, the testing procedure was further done on IoT notification.

TABLE 3. Smart Bin Functionality Test on IoT Notification

Functionality	Tolerance/ accuracy	IoT Notification
Metal Detection	95% accuracy of metallic	Any metal detected
Fill Level Detection (Ultrasonic sensor)	±2 cm	75% full
Weight Measurement (Load Cell)	±100 grams tolerance	Any weight

By referring to Table 3, the IoT notification was observed for three parameters which are metal detection, fill level and weight measurement. The system was able to send notification in Blynk Platform upon any metal detection. The notification was also sent if the fill level reached 75% full. The accuracy of the ultrasonic sensor and load cell ensures reliable data on the bin's fill level and weight, which is crucial for timely waste management interventions. The high accuracy of the metal detection sensor is particularly noteworthy, as it ensures that metallic waste is consistently identified and segregated, facilitating efficient recycling processes. The IoT integration via the Blynk platform adds significant value by enabling remote monitoring and notifications. This feature not only enhances convenience but also allows for proactive waste management, reducing the likelihood of overflow and associated environmental hazards. However, connectivity issues could potentially disrupt real-time data transmission and notifications, highlighting the need for robust network infrastructure (12).

CONCLUSION

This paper presents a Smart Bin system that enhances waste segregation and recycling through advanced sensors and IoT integration. The system accurately detects and segregates metallic waste, monitors fill levels, and measures waste weight, providing real-time data via the Blynk platform. This real-time monitoring prevents overflow and supports proactive waste management, contributing to environmental sustainability. The results indicate that the Smart Bin system performs effectively in detecting, segregating, and monitoring waste. While effective, the system faces challenges such as sensor accuracy affected by waste shape and difficulty detecting small metals. Future improvements will address these issues through enhanced algorithms and advanced detection technologies. In a nutshell, the Smart Bin system significantly advances sustainable waste management by leveraging IoT technology for efficient and accurate waste processing. Future enhancements will further improve the system's accuracy and reliability, solidifying its role as a valuable tool in sustainable waste management practices.

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