Enhancing Waste Management with IoT Technology: A smart Waste Collection System for Campus Operations

N Mohammed Ashraf
Computing Technologies
SRM Institution of Science and Technology, Kattankulathur
Chennai, India

Vaishnav P Nambiar
Computing Technologies
SRM Institution of Science and Technology, Kattankulathur
Chennai, India

Dr. R. Jebakumar,
Computing Technologies
SRM Institution of Science and Technology, Kattankulathur
Chennai, India

***Abstract*—With the rapid urbanization and population growth in modern cities, efficient waste management has become a critical challenge. Traditional waste management systems often suffer from inefficiency, resource overuse, and environmental hazards. This Smart Waste Collection System (SWCS) explores the integration of Internet of Things (IoT) technology to revolutionize waste management practices by enhancing operational efficiency, sustainability, and automation. Through real-time data collection and analysis, IoT-enabled smart bins can monitor waste levels, optimize collection routes, and improve resource allocation. The SWCS solution aims to reduce fuel consumption, lower carbon emissions, and minimize human intervention. Moreover, the system promotes eco-friendly waste disposal practices by providing data-driven insights that can aid in better decision-making for urban planning. The results demonstrate significant improvements in reducing costs and environmental impact, paving the way for smarter and cleaner cities.**

Keywords— IoT (Internet of Things), Smart waste collection system (SWCS), Real-time monitoring, Optimized collection routes, Sustainability

I. INTRODUCTION

Campuses, much like urban areas, are increasingly burdened with the challenges of effective waste management due to rising waste production. Overflowing bins, littered walkways, and inefficient waste disposal methods not only degrade the campus environment but also pose serious health and environmental risks. Traditional waste management systems, which operate on fixed schedules and rely heavily on large fleets of collection vehicles, are often plagued by inefficiencies such as unnecessary collection trips, missed pickups, and escalated operational costs.[1] These outdated methods fail to respond dynamically to the varying levels of waste generation across different areas of a campus, leading to resource wastage and diminished environmental quality.

To address these pressing issues, it is essential to adopt a modern, data-driven approach to waste management within campus operations. By integrating Internet of Things (IoT) technology into waste management systems, campuses can leverage real-time data to monitor waste bin fill levels and optimize collection routes. This smart waste management approach involves the deployment of sensors in waste bins that continuously track fill levels and communicate with a centralized system. When bins reach a specified capacity, the system can automatically notify waste management teams, enabling timely and efficient waste collection. This not only prevents the overflow of waste bins and reduces litter but also optimizes resource allocation, reduces fuel consumption, and minimizes the environmental impact of waste collection activities.

The goal is to develop an IoT-based system that ensures proper waste collection, disposal, and transportation with minimal resources. A scalable, cost-effective, and technologically advanced approach to waste management, which is particularly crucial for regions where waste management has been neglected.

IoT-based smart waste collection system that uses real-time data from sensors to monitor waste bin levels, optimize collection routes, and reduce operational costs.

II. A MOTIVATION

The inspiration for this project was sparked by a video presented by my principal, showcasing impeccably clean streets and well-maintained communities observed during his visit to the USA. This impactful footage underscored the critical role of efficient waste management in fostering a cleaner and healthier environment. Driven by this realization, we embarked on developing an IoT-based smart waste collection system aimed at replicating such levels of cleanliness and efficiency in our urban environments. By harnessing modern technology, this project aspires to revolutionize waste management practices, mitigate pollution, and significantly enhance the quality of urban life.

II. B INNOVATION IDEA OF THE PROJECT

The SWCS utilizes IoT sensors placed within waste bins to continuously monitor fill levels, ensuring timely waste collection. When bins reach a specified threshold, automatic alerts are generated to prompt immediate action, thereby optimising the collection process. This approach reduces operational costs by saving fuel and labor, as waste is collected only when necessary. The system also provides insightful analytics, allowing for data-driven decisions regarding bin placement and frequency of collection in specific areas. By preventing overflow and maintaining cleaner streets, the system significantly enhances public health and hygiene. Additionally, an educational component is included to raise public awareness about the benefits of smart waste management, fostering a more sustainable and informed community.

III. COMPONENT FOR SMART WASTE MANAGEMENT

A. *Ultrasonic sensor*

Ultrasonic sensors are utilized in the waste management system to accurately measure the fill levels of waste bins by detecting the distance between the sensor and the waste. When the waste reaches a predetermined threshold, the sensor triggers an alert, indicating that the bin requires emptying.[2] These sensors are particularly well-suited for waste management due to their high accuracy and reliability in real-time monitoring. They perform effectively in a variety of environmental conditions, delivering precise measurements that are essential for preventing overflow and optimizing waste collection schedules, thereby enhancing the overall efficiency of the waste management process.[3]

B. *ESP8266 NodeMCU*

The ESP8266 NodeMCU serves as the Wi-Fi module in the waste management system, facilitating internet connectivity for real-time data transmission from sensors to a centralized monitoring platform. This module is particularly advantageous for waste management due to its cost-effectiveness, energy efficiency, and robust wireless communication capabilities.[4] These features make the ESP8266 an ideal choice for linking multiple waste bins within an IoT network, ensuring that timely alerts are generated and critical data is available to optimize waste collection routes and schedules. This connectivity ultimately enhances the efficiency and responsiveness of the waste management system.

C. *Arduino Board*

The Arduino board acts as the central microcontroller in the waste management system, processing data collected from sensors, managing the system's logic, and interfacing with other components such as the ESP8266 and the GSM module.[5] Its versatility, ease of programming, and compatibility with a broad range of sensors and modules make the Arduino an ideal choice for developing customizable and scalable waste management solutions.[6] These characteristics enable the system to be tailored to meet specific operational needs, ensuring that it can effectively address various waste management challenges while remaining adaptable to future requirements.

D. *SIM800L GSM Module*

The SIM800L GSM module is integrated into the waste management system to enable SMS notifications and data transmissions over cellular networks, particularly in situations where Wi-Fi connectivity is unavailable. This functionality is essential for maintaining communication in remote or less-connected areas. The GSM module offers a reliable backup communication method, ensuring that waste management operations can continue seamlessly even in regions with poor or no Wi-Fi coverage. This redundancy is critical for ensuring consistent and efficient waste management across diverse locations, contributing to the overall reliability of the system.[7]

A. *Circuit Diagram*

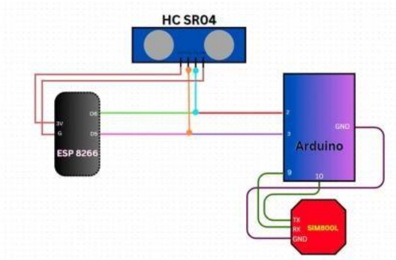

Fig . 1

IV. PURPOSE OF THE PROJECT

The SWCS is designed to prevent waste bins from overflowing by ensuring they are emptied promptly, thereby maintaining cleaner streets and reducing litter. By optimizing waste collection routes and schedules, the system significantly lowers fuel consumption and operational costs, making the process more efficient.[8,11] This approach not only promotes a cleaner and more hygienic urban environment, thereby reducing health risks, but also enhances resource allocation through data-driven insights, enabling the strategic placement of additional bins and the efficient deployment of collection teams. Moreover, the system fosters sustainability by minimizing unnecessary collection trips and emissions, ultimately reducing the environmental impact of waste management operations.[9]

V. SWCS METHODOLOGY

The IoT-based smart waste collection system is designed to provide real-time monitoring of bin fill levels, sending notifications via the Blynk IoT platform and SMS alerts using the SIM800L GSM module. The methodology involves several key components working together to ensure efficient and automated waste collection.

1. Ultrasonic Sensor Working:

The system begins with the ultrasonic sensor, which is mounted at the top of the bin, oriented towards the waste. It operates by emitting high-frequency ultrasonic pulses and measuring the time taken for the sound wave to bounce back after hitting the surface of the waste. The sensor calculates the distance from the sensor to the waste surface using the formula

$$d_x = \frac{\Sigma(v \cdot t_x)}{2}$$

Where,

- d_x is the measured distance to the waste surface.
- is the speed of sound in air (approximately 343 m/s).
- t_x is the time taken for the sound wave to travel to the waste surface and back.[13]

where the speed of sound is approximately 343 meters per second (0.0343 cm/µs), and the time is the duration between the emission and reception of the sound wave. The measured distance is used to determine how full the bin is. For instance, if the bin is 100 cm deep and the sensor detects a distance of 10 cm to the waste surface, the bin is 90% full

2. Arduino Processing and Calculation:

1. **Distance Measurement**: The **ultrasonic sensor** measures the distance to the waste surface, providing data to the **Arduino**.

2. **Calculation of Remaining Space**: The remaining space in the bin is calculated using the following formula:

$$\Delta S\ (\%) = \left(\frac{\Sigma(H_{\max} - H_x)}{H_{\max}}\right) \times 100$$

Where,

- ΔS represents the remaining space as a percentage.
- $H_{\max}$ is the maximum height (bin depth).
- H_x is the measured height from the sensor to the waste.[18]

3. ESP8266 NodeMCU – Wi-Fi Connection and Blynk Integration:

The ESP8266 NodeMCU is used to transmit the processed data wirelessly from the Arduino to the Blynk IoT platform via a Wi-Fi network. After the Arduino calculates the bin fill level, it sends this information to the ESP8266, which connects to the local Wi-Fi and transmits the data to the Blynk cloud server. The connection is established using the Blynk library, which is integrated into the Arduino code.

Once the data reaches the Blynk platform, it is displayed on a custom dashboard, where users can monitor the bin fill levels in real time on their smartphones or laptops.[10] The Blynk app interface provides visualizations (e.g., graphs, percentage indicators) that show the bin status. If the fill level exceeds a critical threshold (e.g., 90%), the system triggers a notification via the Blynk app, informing users of the need for waste collection.

4. SIM800L GSM Module – SMS Alert System:

In addition to real-time monitoring through Blynk, the SIM800L GSM module is integrated into the system to provide SMS alerts. When the bin fill level exceeds the predefined threshold, the Arduino sends a command to the SIM800L module, which connects to a mobile network using a SIM card. The SIM800L then sends an SMS alert to designated phone numbers, notifying the waste management team that the bin is nearly full and requires attention.[14]

The SMS functionality ensures that alerts are sent even in the absence of Wi-Fi connectivity, making the system reliable for remote areas. The module is programmed to send alerts when the bin reaches a fill level above 90%, ensuring timely action.

B. Architecture diagram

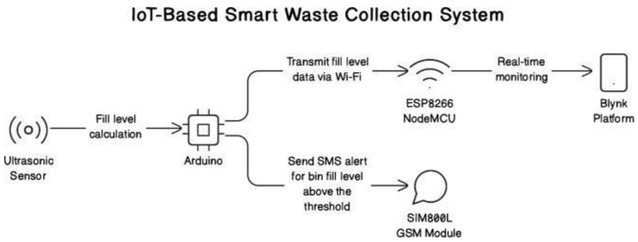

Fig . 2[9]

5. Continuous Data Monitoring and Alerts:

The system operates continuously to ensure efficient waste monitoring and management. At its core, the ultrasonic sensor consistently measures the fill level of the waste bin, providing real-time updates. This data is processed by the Arduino, which immediately transmits the information to the Blynk platform through the ESP8266 NodeMCU module.[16] This setup allows for seamless, real-time monitoring via the Blynk app. Simultaneously, the SIM800L GSM module remains in standby mode, ready to send SMS alerts to designated personnel whenever the bin fill level surpasses a predefined threshold. This two-tiered notification system—combining both app-based alerts through Blynk and SMS notifications—ensures that the waste management team remains informed at all times, facilitating timely interventions and maintaining cleanliness efficiently.

TABLE I. Hardware Essentials for IoT-Based Smart Waste Collection System[12]

Essential Of the Waste Collection System	Hardware
Sensor	HC - SR04 Ultrasonic Sensor, IR Sensor
User Interface Device	Smartphone, Laptop, Computer
Type of networking	Wireless- Bluetooth,Wifi
Centralised Control	NODE MCU,Arduino IDE
Sending SMS	SIM800L

D . Flow Chart

The IoT-based smart waste collection system leverages an ultrasonic sensor to monitor the fill level of waste bins. This data is processed by an Arduino controller, which then sends the information to two communication modules. The ESP8266 NodeMCU transmits the fill-level data via Wi-Fi to the Blynk platform, where users can monitor bin status in real time through a mobile app or web interface.[20]

In parallel, the SIM800L GSM module sends SMS alerts when the bin is 90% full, ensuring timely waste collection. This system automates the waste management process, reducing manual monitoring efforts and enabling efficient operations in smart city environments.

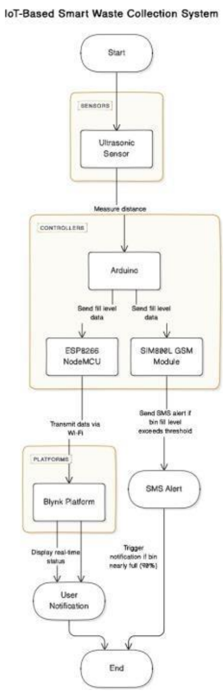

Fig . 3[18]

6. System Workflow:

Step 1- Ultrasonic Sensor measures the distance to the waste surface.

Step 2- Arduino processes the sensor data and calculates the bin fill level using the formula for fill percentage.

Step 3- ESP8266 NodeMCU transmits the fill level data to the Blynk IoT platform, where it is displayed in real time.

Step 4- When the fill level crosses the threshold (e.g., 90%), the SIM800L GSM module sends an SMS alert to the designated phone numbers.

Step 5- The waste management team receives real-time alerts via both the Blynk app and SMS, ensuring timely waste collection and preventing overflows.

7. Performance Analysis: Waste Fill Level Monitoring Over Time

In this section, we present the results of the waste bin's fill level monitoring over time, demonstrating the effectiveness of the system in ensuring timely waste collection. The graph below visualizes the **Bin Fill Level** as it increases with time, indicating when alerts are triggered as the bin approaches critical capacity.

Graph Description:

- **X-axis**: Time (hours/days), representing the duration over which the bin is monitored.
- **Y-axis**: Bin Fill Level (%), indicating how full the bin is at any given time.

As shown in **Fig . 5**, the bin's fill level steadily increases as waste is added. The system continuously measures the fill level using the ultrasonic sensor and computes the percentage of space left. The critical threshold is set at 90%, represented by the red dashed line. Once the bin fill level reaches or exceeds this threshold, the system triggers an alert, prompting the waste management team to take action.

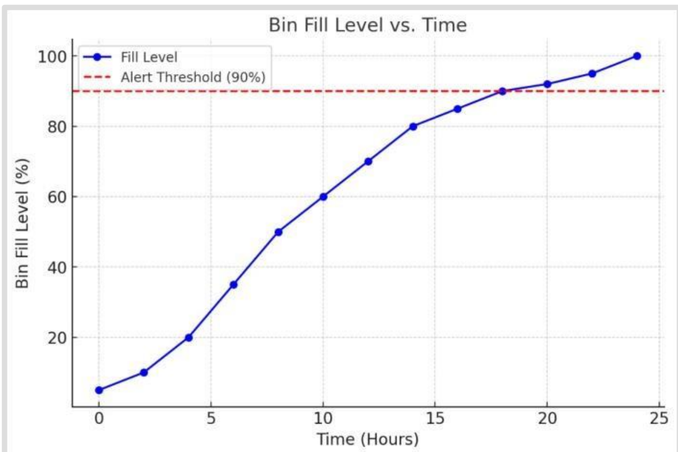

Fig . 4[13]

This graph provides clear evidence of how the system ensures real-time waste monitoring, minimizing the risk of overflow and improving overall efficiency.[17]

8. Project Analysis Bar Graph: Waste Bin Fill Levels Over Time

Variables to Include:

1. **Weeks**: Different time intervals (e.g., Week 1, Week 2, Week 3, Week 4 , Week 5)
2. **Target Fill Level**: The expected fill level percentage for each week.
3. **Actual Fill Level**: The measured fill level percentage for each week.
4. **Observation**: Highlight any discrepancies or insights (could be shown with color coding or annotations).

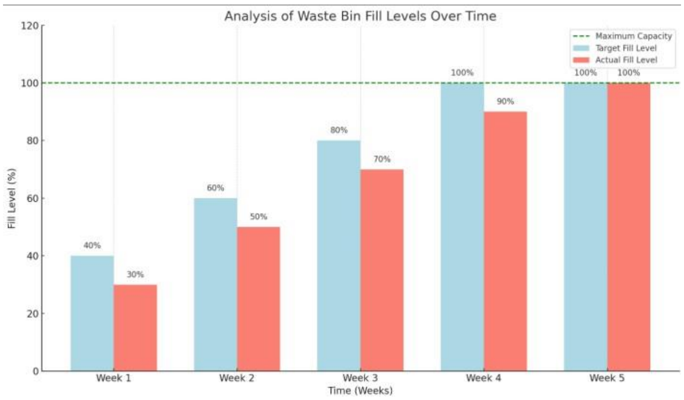

Fig . 5[19]

Key Features of the Graph:

Comparison: The graph shows how the actual fill levels align with the target levels, providing insight into the efficiency of the waste collection process.
Maximum Capacity: A dashed green line indicates the maximum capacity (100%), which helps visualize how close the actual levels come to full capacity.
Data Labels: Each bar includes data labels for easy reference.

VI. CONCLUSION

The IoT-based smart waste collection system provides an innovative approach to managing waste efficiently by using real-time data collection and automation. The integration of an ultrasonic sensor allows accurate measurement of bin fill levels, while the Arduino microcontroller processes this data. Through the use of the ESP8266 NodeMCU module, the system sends real-time updates to the Blynk IoT platform, enabling users to monitor bin statuses remotely on their smartphones or laptops. The addition of the SIM800L GSM module ensures that SMS alerts are sent when bins are almost full, providing a backup notification method when internet access is unavailable.

This system offers significant advantages in terms of reducing overflow risks, optimizing collection schedules, and minimizing manual intervention. The continuous monitoring of bin levels ensures that the waste management team is alerted promptly when action is needed, allowing them to respond efficiently and avoid unnecessary collections when bins are not yet full. The ability to track multiple bins in real-time through a centralized platform like Blynk enhances overall operational effectiveness and improves resource management.

With its cost-effective and scalable design, the system can be deployed in various environments, such as smart cities, campuses, or industrial areas. By promoting timely waste collection and reducing the chances of overflow, this system contributes to cleaner public spaces and better environmental sustainability. Overall, the smart waste collection system aligns with modern efforts toward smart city development and offers a practical solution for managing waste more effectively.

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