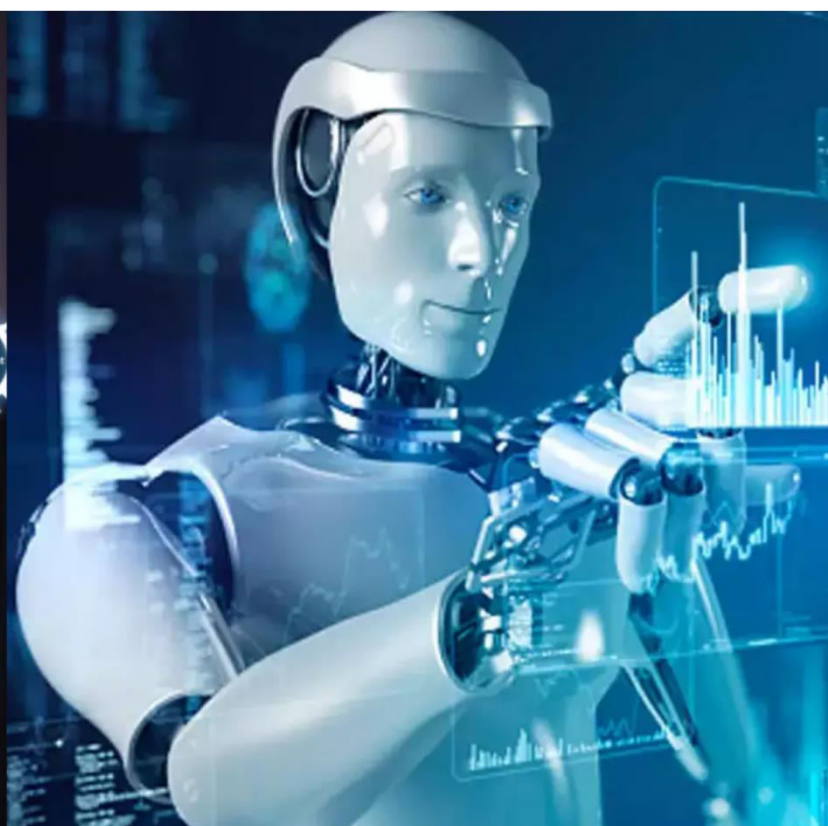




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Smart Bin: A Smart Dustbin Solution for Smart Cities

Neha Rai¹, Moksha Mandape², Sonshree Piwalatkar³, Aayushi Patil⁴, Anand Mahamuni⁵

Assistant Professor, Department of Computer Engineering, AISSMS College of Engineering, Savitribai Phule Pune University, Pune, India¹

Department of Computer Engineering, AISSMS College of Engineering, Savitribai Phule Pune University, Pune, India²⁻⁵

ABSTRACT: As urban populations continue to grow, cities are facing increasing pressure to manage waste more efficiently. This paper introduces Smart Bin, an IoT-powered waste monitoring system designed to improve how waste is collected and handled in smart city environments. The system uses ultrasonic sensors paired with an ESP32 microcontroller to measure how full a bin is, sending real-time updates to the cloud using either Wi-Fi or GSM (SIM800) modules. A lightweight, responsive web interface built with Svelte/SvelteKit displays bin data such as fill level, location, and status, while Mapbox and Leaflet.js are used for map integration and route visualization. Alerts are automatically generated when bins reach certain thresholds, and data is synced through service like Ngrok and PocketBase. Although the current system focuses on real-time monitoring and efficient routing, it is designed to be scalable and ready for future upgrades, including automated route optimization. By combining affordability, modularity, and environmental focus, Smart Bin offers a practical step toward smarter, cleaner, and more sustainable cities.

KEYWORDS: Waste management, Smart waste management, Internet of Things (IoT), Waste classification, Real-time waste tracking, Routing optimization, Scalability, System integration, Technological advancements, Economy of scale, Waste collection optimization, Waste disposal processes.

I. INTRODUCTION

The speed of urbanization and population expansion has immensely augmented the amount of municipal solid waste, becoming a great challenge to sustainable urban growth. Conventional waste management mechanisms usually suffer from inefficiencies like overfilled bins, irregular collection times, and poor monitoring of waste distribution. Against these challenges, recent innovations in Internet of Things (IoT) and wireless communications technologies have made it possible to create intelligent waste management systems that enable cleaner, smarter cities.

Smart waste management applies IoT-capable sensors and data analytics to measure waste levels, optimize collection routes, and facilitate timely waste disposal. The problems of solid waste have increased due to urbanization, rising population, and the consumption of packaging products, among other factors [1]. Ultrasonic sensors and GPS technology are utilized to receive real-time data from dustbins, which is computed using cloud-based platforms or edge devices. Various research efforts have been undertaken to integrate IoT; for example, hybrid deep learning schemes have been employed to forecast waste generation trends and improve decision-making. The system aims to collect waste by transforming normal waste bins into an intelligent system with the help of the Internet of Things [3]. Comparative analysis also emphasizes the superiority of long-range communication, rendering it ideal for real-time monitoring and data exchange in smart cities.

This paper introduces a smart waste management system that leverages IoT sensors to enable accurate tracking of waste levels and optimize collection logistics. Navigation and tracking capabilities, analysis of waste processing, and optimization of relevant information would ultimately improve waste management efficiency. Through the integration of low-cost microcontrollers and scalable network infrastructures, the proposed system can minimize maintenance expenses, enhance route efficiency, and support environmental sustainability objectives aligned with Smart and Green City initiatives.

II. BACKGROUND

The convergence of Artificial Intelligence (AI) and Machine Learning (ML) in healthcare has transformed the analysis, interpretation, and application of medical data to patient care. In recent years, the exponential increase in healthcare data—from electronic health records to biomedical imaging—has presented challenges and opportunities for healthcare systems worldwide. AI and ML, being subfields of computer science that aim at developing systems able to learn and decide, provide promising means to take control of and derive meaning from this enormous and intricate data.

Healthcare has discovered applications of AI across several areas including diagnostics, tailored treatment, drug discovery, and predictive analytics. Machine learning algorithms have the capability to identify patterns within clinical data that may go unnoticed by human experts, thus allowing for earlier diagnoses and more efficient interventions. For instance, supervised learning techniques are becoming more commonly used to identify diseases like diabetes and cancer from imaging or lab data, whereas unsupervised algorithms assist in clustering populations of patients for specialized treatments.

Despite the promise, the application of AI and ML in healthcare is not without its challenges. Data privacy, algorithmic bias, and requirements for large, high-quality datasets remain constraints on large-scale implementation. However, with continued innovation and cross-disciplinary collaboration, AI-based technologies are about to become indispensable parts of contemporary healthcare infrastructure.

III. LITERATURE REVIEW

The inefficiencies of traditional waste management systems—like tardy collection, bin overflows, and minimal data-informed decision-making—have inspired studies on smart and automated systems with the aid of emerging technologies like IoT, machine learning (ML), and optimization methods.

Alsabt et al. (2024) highlight the revolutionary potential of artificial intelligence and machine learning to enhance the economic and environmental effectiveness of waste management systems.

Their research uses predictive analytics and optimization techniques such as support vector machines (SVM), random forests, and linear programming to examine trends in waste generation and resource optimization. The study, using the World Bank's extensive dataset, demonstrates the potential for ML to boost operational efficiency up to 15% and illustrates the benefits of combining socio-economic data for enhanced forecasting and strategic planning.

Ahmed et al. (2023) introduce an IoT-enabled Intelligent Waste Management System (IWMS) that also tackles energy consumption and incompleteness of data problems often encountered by smart bin networks.

Their approach uses low-energy adaptive clustering and the Artificial Hummingbird Algorithm (AHA) to fill in missing data and maximize the life of smart bins. They also implement optimized truck routing algorithms that lower fuel consumption and collection time, further enhancing the potential of combining IoT and intelligent optimization for effective urban waste management.

Khan et al. (2021) also describe a hardware implementation that incorporates an Arduino microcontroller, moisture and ultrasonic sensors, and image processing for bin-level monitoring and waste classification.

Their framework shows how accurate detection of bin status is possible with sensor-based systems and the delivery of optimized collection routes to drivers via a mobile app. The real-time monitoring minimizes overflow problems and makes municipal waste services more sustainable, especially in urban areas of high density.

Arthur et al. (2024) present an extensive overview of smart dustbin systems and categorize different technological methods based on deep learning, IoT, and computer vision. Their research highlights the shortcomings of existing systems, such as improved automatic waste sorting, real-time data fusion, and route optimization. Smart bins with sensors (ultrasonic, gas, and load) and AI models are promising to enhance hygiene, lower operational expenses, and enable city-scale scalability.

Laha et al. (2023) propose a LoRa-based Smart Waste Management System for green city projects.

Their system surpasses the limitations of GSM and Wi-Fi using LoRa's long-range, low-power communication and uses the Floyd-Warshall algorithm to determine the shortest route for garbage collection vehicles. This model provides timely updates regarding bin status and location, which greatly improves the responsiveness and cost-effectiveness of waste collection in big cities.

Together, these studies show that the combination of IoT, machine learning, and smart routing in waste management systems provides a scalable, sustainable solution to conventional methods. Although each method has its advantages—ranging from energy efficiency and predictive analytics to hardware-based automation—issues persist regarding data accuracy, real-time integration, and system scalability. Future studies need to continue filling these gaps to fully harness the potential of smart waste systems in urban sustainability and public health.

IV. METHODOLOGIES

The Smart Dustbin System was designed to make urban waste collection and management easier by integrating machine learning-optimized optimization with Internet of Things-based real-time sensing. It utilizes sensor technologies to sense waste levels and applies data analytics to predict fill levels and optimize routes for waste collection vehicles.

For this project, we've used a modular approach with IoT sensors, a website for monitoring, and a GSM module for alert notifications. This system automates waste collection, providing timely updates and ensuring efficient waste management.

Key Components:

- IoT Sensor Layer: This layer quantifies the amount of garbage in bins via ultrasonic sensors. Communication modules (e.g., ESP32 or GSM) periodically collect and send these values to the central server.
- Microcontroller Unit: Acts as a gateway between cloud services and sensors. It processes sensor signals and formats data for network transmission.
- Cloud databases like Firebase store all incoming sensor data in real-time. The database is a central hub for visualization and analysis.
- Web/Mobile Interface: Provides collection workers and municipal officials with real-time bin status updates, alerts, and optimized collection routes

Using the Google Maps API for Route Optimization:

Waste collection routes can be dynamically optimized by integrating the Google Maps API. The routing algorithm takes into account:

1. Bin fill levels in real time
2. Closeness to the location
3. Traffic information

This lowers fuel consumption and greenhouse gas emissions, in addition to the number of necessary trips.

Advantages:

Real-Time Monitoring: Immediate feedback from bins enables quick response.

Predictive Collection: Reduces missed pickups and overflows.

Optimized Routes: Minimizes fuel consumption and operational costs.

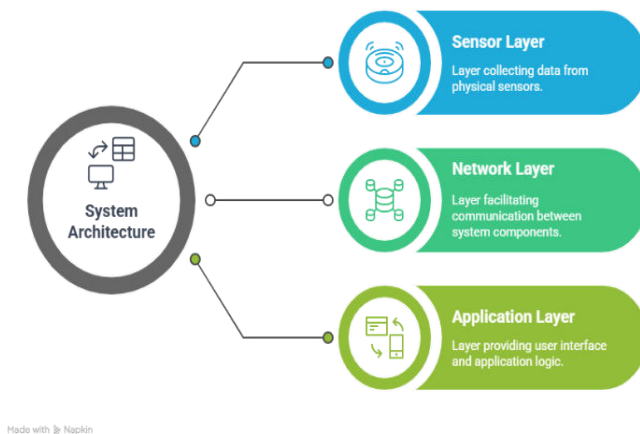


Fig. 1 System Architecture Layers

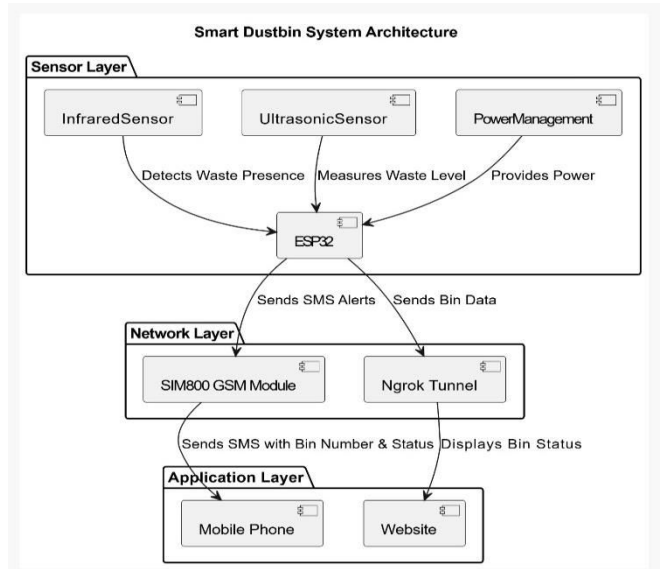


Fig. 2 System Architecture Diagram

Website design

1. Frontend Framework: Svelte/SvelteKit :

- Svelte is a JavaScript frontend framework. As described on its website: "Svelte is a UI library that compiles to let you write stunningly short components that perform a bare minimum of work in the browser, with languages you're already familiar with — HTML, CSS, and JavaScript."
- The reason why Svelte was picked was to take advantage of a hassle-free framework, which doesn't mess with developing a project with components just beyond the UI, and provides a responsive, fast, and snappy user experience.
- Svelte is also combined with SvelteKit, its meta-framework, which addresses two of the most significant issues in building the website: dynamic file routing and Server-Side Rendering (SSR). It also offers excellent and fast initial load performance, as well as SEO optimizations.
- SSR also ensures that the dynamic aspect of the project can run smoothly on low-end devices.

2. Map Integration:

- Map integration being an integral part of the development, a light library such as Leaflet.js was required. As per its website, Leaflet.js "is designed with simplicity, performance, and usability in mind."
- Leaflet, being readily cross-compatible on all platforms and having a well-documented UI, offered the necessary features such as markers, polylines, etc., required for the project.
- Consistent, visually appealing, and well-themed map tiles were utilized from Mapbox for enhanced visibility.
- The Mapbox Directions API was also employed to determine and retrieve routing data to be used on the map interface. The API allows a method for transferring the route that is needed by using Polyline Encoding, a lossy compression algorithm by which you can encode a series of coordinates as one string.]

3. Backend / Data Layer:

- "PocketBase is an open-source backend that includes an embedded database (SQLite) with real-time subscriptions, built-in authentication management, easy-to-use dashboard UI, and a trivial REST-ish API. Can be utilized both as a Go framework and as a stand-alone app."
- PocketBase was chosen specifically due to its simplicity and its capacity to deal with real-time data using a properly documented API.

V. IMPLEMENTATION

System Architecture :

The smart dustbin is designed using embedded systems and IoT-based monitoring, aimed at improving waste management through automation. The system consists of sensors, a microcontroller, and a communication module to detect garbage levels and transmit status updates to a centralized monitoring unit.

Components Required:

Component	Specification
Microcontroller	ESP32
Ultrasonic Sensor	HC-SR04
Wi-Fi Module	ESP32
GSM Module	SIM800 or similar
Power Supply	5V – 9V battery or USB
Jumper Wires	Male-to-male and male-to-female
Breadboard / PCB	For circuit assembly
Dustbin	Plastic bin (10L–30L capacity)

Ultrasonic Sensor Functioning :

The HC-SR04 ultrasonic sensor measures the distance between the sensor and the garbage level. It emits ultrasonic waves and calculates the time taken for the echo to return.

Formula for distance:

$$\text{Distance} = \text{Time}() \times 0.0343 / 2$$

- 0.0343 cm/ μ s is the speed of sound in air.
- Divide by 2 because the wave travels to the object and back.

Example: If the time between sending and receiving the signal is 1200 μ s:

$$\text{Distance} = 1200 \times 0.0343 / 2 = 20.58 \text{ cm}$$

By comparing this to the height of the dustbin, we calculate the **fill level**:

$$\text{Garbage Level (\%)} = (1 - \text{Bin Height} / \text{Distance}) \times 100$$

Communication Protocol :

- The **ESP32 Wi-Fi module** sends data to a remote database or dashboard using HTTP POST/GET.
- It can also interface with for real-time monitoring.
- Operating voltage: 2.2V to 3.6V
- Recommended voltage: 3.3V

Real-time Monitoring Dashboard :

- Created a **web interface** by using the Svelte framework .
- Display:
 - Bin ID
 - Garbage Fill Level %
 - Status (Empty, Half, Full)
 - Timestamp
 - Location (via GPS or manual entry)

Testing and Calibration :

- **Calibration** is done by testing the bin at different fill levels (0%, 25%, 50%, 75%, 100%) and mapping distances accordingly.
- Multiple trials are taken to ensure accuracy.
- Error margin: ± 1.5 cm (acceptable for practical deployment).

Power Supply Options :

- USB Power Bank (5V) for portability.
- 9V Battery with Voltage Regulator.
- Solar-powered supply for outdoor bins.

Hardware / IoT Layer:**1. ESP32 Development Board:**

The ESP32 is a powerful microcontroller, perfect for IoT and smart applications like smart waste management. With built-in Wi-Fi and Bluetooth, a dual-core processor, and support for sensor interfaces like I2C, SPI, and UART, it's designed for seamless integration. Its low power consumption and large memory are great for over-the-air (OTA) updates, and it's compatible with the Arduino IDE, making it easy to work with. The ESP32's strong connectivity and extensive library support make it ideal for real-time monitoring and remote control.

- Acts as the primary microcontroller with integrated Wi-Fi and Bluetooth.
- Processes sensor data and communicates with the server through Ngrok.

2. SIM800 GSM Module:

- Utilized to send SMS notifications when the dustbin is at certain fill levels (0%, 50%, and 100%).
- Allows for remote notifications in regions with poor internet connectivity.

3. Ultrasonic Sensor (HC-SR04):

Ultrasonic sensors are affordable, precise, and reliable devices used to measure distances, making them ideal for detecting fill levels in waste bins. These sensors work by sending out ultrasonic waves and measuring the time it takes for the echo to return. Since they don't rely on lighting conditions or the type of waste, they're highly versatile. Easily integrated with microcontrollers like Arduino or Raspberry Pi, they can trigger a GSM modem to send alerts when the bin reaches its capacity.

- Records the distance from the sensor to the waste surface.
- Aids in determining the fill level of the bin (empty, half-empty, or full).

4. Infrared (IR) Sensor:

IR sensors are a cost-effective solution for detecting waste levels by measuring the proximity of objects using reflected infrared light. While they work well for basic applications, they might not be as reliable as ultrasonic sensors due to their sensitivity to lighting changes and obstructions. This makes them ideal for controlled environments or as backup sensors when needed.

- Senses object proximity around the bin lid for automated tracking of use or activation of lid mechanisms (if used).
- Also utilized for more accurate detection in close-range situations.

5. Power Supply (Battery or Adapter):

- Powers the ESP32 board and peripheral devices with regulated power.

6. Ngrok (for Web Hosting Integration):

- Enables real-time bin status information to be forwarded to a remote server or dashboard, allowing remote monitoring.

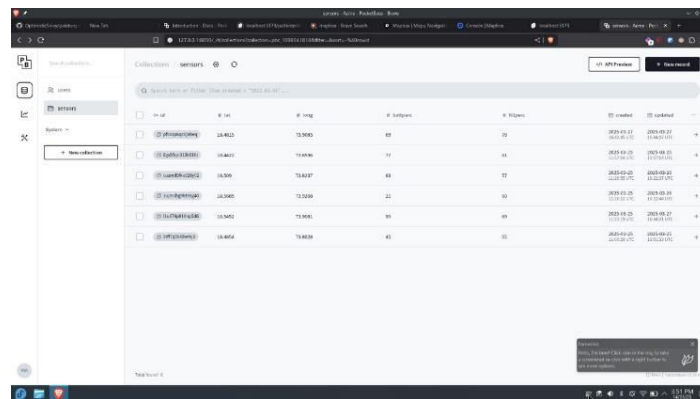
Integration / Structure:**The Map Interface:**

- The page displays all the sensors on one page with the functionality to interact with them.
- Each sensor has an indicator with metadata such as its battery level, fill level, coordinates, and sensor number.
- The map is dynamically responsive to changes in real time through the refresh button at the top right, thus the whole page doesn't need to reload to reflect minor updates. The updates are retrieved smoothly from the database server.
- Full bins are indicated in red, and bins below the specified threshold (75%) are indicated in green.

Route Optimization:

1.Data Acquisition:

The smart dustbin is equipped with an ultrasonic sensor that checks how full the bin is. This information is sent to the Arduino Uno, which then triggers a message through the SIM800 GSM module. Depending on how full the bin is—empty, half-full, or full—the system automatically sends updates to both a live website (via Ngrok) and as SMS alerts. This eliminates the need for anyone to manually check the bins.



Bin ID	Bin Name	Bin Type	Bin Status	Bin Location	Bin Fullness	Bin Last Updated	Bin Next Update	Bin Action	Bin Notes
1	Bin 1	1	0	1	0	2025-05-22 10:00:00	2025-05-22 11:00:00	1	
2	Bin 2	1	0	2	0	2025-05-22 10:00:00	2025-05-22 11:00:00	1	
3	Bin 3	1	0	3	0	2025-05-22 10:00:00	2025-05-22 11:00:00	1	
4	Bin 4	1	0	4	0	2025-05-22 10:00:00	2025-05-22 11:00:00	1	
5	Bin 5	1	0	5	0	2025-05-22 10:00:00	2025-05-22 11:00:00	1	

Fig. 3 Database Interface

2.Parameter Analysis:

To help manage waste collection better, the system looks at key details such as:

- How full each bin is
- The physical location of each bin
- Manual inputs that could later include traffic or timing info While some of this is currently handled manually, the system is ready for future upgrades like real-time traffic or GPS-based analysis.

3.Optimized Route Calculation:

Using the data collected, the system supports smart planning by:

- Focusing on bins that are nearly full
 - Helping decide the most efficient order for pickups
 - Reducing unnecessary travel and saving fuel
- In future versions, the route planning could be fully automated and include live traffic data.

4.Real-Time Optimization:

As soon as a bin hits a set level, the system instantly updates the website and sends an SMS alert. This helps the waste collection team respond right away, instead of waiting for a scheduled check or manual report.

5.Operational Advantages:

This smart system brings several practical benefits:

- Bins are emptied on time, reducing overflow issues
- Less fuel is used, which lowers costs and pollution
- Vehicles last longer due to more efficient travel
- Staff save time by avoiding unnecessary trips

The Routing Interface:

- A live website shows the current status and location of each smart bin
- A refresh button lets users update the data instantly without reloading the whole page
- Though routing is currently handled manually, color-coded paths and auto-routing using tools like Mapbox can be added in the future to make navigation even easier

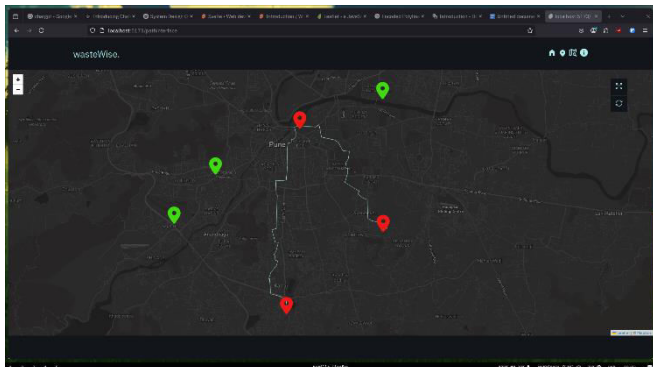


Fig. 4 Map Interface

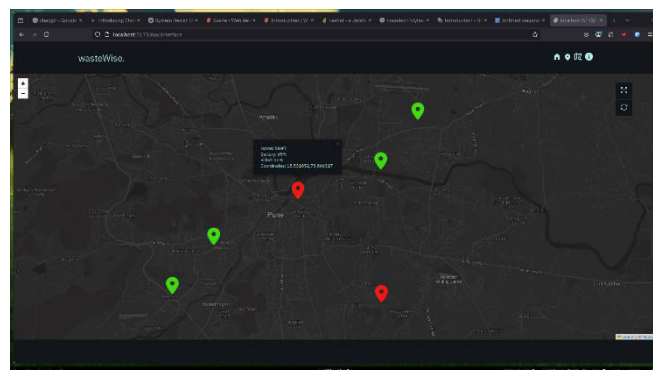


Fig. 5 Routing interface

VI. RESULTS

The Smart Dustbin system has successfully automated waste level monitoring and enhanced collection efficiency. Using the ESP32 microcontroller and an ultrasonic sensor, the system accurately measures the bin's fill level and sends real-time data to a web interface via Ngrok. Adding an IR sensor further improved measurement accuracy by detecting obstructions and confirming bin occupancy.

The SIM800 GSM module played a key role in sending SMS alerts when the bin reached 0%, 50%, or 100% capacity, allowing for timely action without needing manual checks. During testing, the system consistently delivered accurate sensor readings and quick alerts. While environmental factors caused slight fluctuations, the system remained reliable, and the web interface offered an easy and intuitive monitoring experience.

VII. DISCUSSION

The Smart Dustbin project showcases the power of integrating ESP32 with IoT components like ultrasonic sensors, IR sensors, and the SIM800 GSM module to enable real-time waste monitoring. The ultrasonic sensor accurately tracked the fill level of the bin, while the IR sensor ensured reliability by detecting obstructions. Together, they delivered consistent performance even in changing conditions.

The ESP32 acted as the brain of the system, processing data from the sensors and managing communication with both the web dashboard and SMS alerts. The modular design made it easy to integrate new components and scale the system in the future. With real-time updates via Ngrok and SMS notifications at critical fill levels (0%, 50%, 100%), the system streamlined waste collection and minimized manual intervention.

The project offered several advantages, including precise monitoring, cost efficiency, scalability, a reduced environmental impact, and better public hygiene. However, some limitations were noticed, such as fluctuations in ultrasonic readings due to environmental factors and GSM alert delivery depending on mobile network availability.

Despite these challenges, the project effectively demonstrates how affordable IoT technology can automate waste collection, setting the stage for future upgrades like machine learning for predictive analysis and route optimization.

VIII. CONCLUSION

In conclusion, the Smart Dustbin project, powered by ESP32, represents an innovative and effective solution for automating waste monitoring and improving waste management efficiency. By utilizing IoT components like the ultrasonic sensor, infrared sensor, and SIM800 GSM modem, the system provided real-time data on waste levels and sent timely alerts to users, reducing the need for manual monitoring.

Though there are some limitations, such as sensor accuracy influenced by environmental factors and the reliance on

mobile network connectivity, the system demonstrated significant potential for streamlining waste management. With the addition of more sensors, energy-efficient technologies, and a feedback system, the system could be further optimized for use in smart cities, contributing to more sustainable and effective urban waste management solutions.

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