



Lorawan Iot-Enabled Trash Bin Level Monitoring System

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Abstract – The rapid expansion of urban populations has significantly intensified waste generation, straining the efficiency of traditional collection methods that rely on static, fixed schedules. Such conventional systems often result in overflowing bins, inefficient collection routes, and escalated operational costs. This paper proposes a comprehensive Long Range Wide Area Network (LoRaWAN) infrastructure designed to modernize Smart City waste management. Unlike existing single-task architectures, the proposed framework integrates a multi-tiered hierarchy of LoRaWAN device classes to manage services of varying complexity. At the foundational level, smart bins utilize ultrasonic sensors and low-power microcontrollers to monitor fill levels and environmental conditions. Higher-level smart drop-off containers facilitate user interaction and support asynchronous downlink queries for real-time data exchange. Data is transmitted via LoRa gateways to a centralized cloud-based dashboard, enabling municipal authorities to monitor bin status and dynamically optimize collection routes. Experimental results suggest that this scalable, energy-efficient IoT paradigm not only prevents bin overflow through automated threshold alerts but also reduces fuel consumption and environmental impact. The integration of diverse LoRaWAN node classes provides a robust, cost-effective solution for real-time urban process control within the Smart City ecosystem.

Keywords – Internet of Things (IoT), LoRaWAN, Smart City, Smart Waste Management, Ultrasonic Sensors, Energy Efficiency, Route Optimization, Wireless Sensor Networks.

I. INTRODUCTION

The Internet of Things (IoT) has emerged as a transformative paradigm, defined by the integration of embedded devices, electronic sensors, and software to enable physical objects to collect and exchange data autonomously. By networking these objects, IoT creates a seamless bridge between the physical and digital worlds, utilizing microcontrollers such as the NodeMCU or Arduino UNO to activate sensors and actuators. In the context of a "Smart City," IoT serves as the foundational infrastructure required to enhance urban efficiency and improve the quality of life for its citizens.

One of the most pressing environmental challenges facing modern society—particularly in rapidly developing nations—is the management of solid household waste. Traditional waste collection methods are predominantly manual and rely on fixed schedules or visual inspections. This conventional approach is often inefficient, leading to overflowing dustbins that cause foul odors and become breeding grounds for disease-carrying vectors. Furthermore, unnecessary collection trips to underfilled bins result in a waste of time, human labor, and financial resources.

To address these limitations, this paper proposes an automated Smart Waste Management System. Unlike a standard dustbin, which requires manual monitoring, the smart dustbin utilizes ultrasonic sensors to detect the fill level of refuse in real time. When the waste reaches a predefined threshold, the system leverages a NodeMCU microcontroller to transmit data over a wireless network.

A critical feature of the proposed system is the integration of the IFTTT (If This Then That) webhooks service, which

serves as a bridge to provide instant mobile notifications to municipal authorities. This ensures that bins are emptied precisely when needed, optimizing the collection route and maintaining a cleaner urban environment. While the system offers significant advantages in terms of automation and ecological health, its performance is contingent upon robust network connectivity to ensure the timely delivery of notifications. By transitioning from manual waste management to an IoT-enabled framework, cities can mitigate the risks of hazardous pollution, global warming, and the degradation of the ecosystem, aligning with the core objectives of modern sustainable development.

A. Objectives

The primary goal of this research is to design and implement a robust, IoT-based monitoring framework that transitions waste management from a reactive to a proactive system. To achieve this, the project focuses on the following technical objectives:

- Precision Garbage Level Detection:
- Real-Time Power Management and Monitoring:
- Historical Data Logging and Last-Cleaned

Timestamps:

- Mobile Visualization and User Interface Design:

Communication Reliability

II. LITERATURE SURVEY

The evolution of waste management systems has transitioned from manual collection to sophisticated IoT-enabled architectures. This section reviews the existing literature to establish the technological trajectory of smart

dustbin systems, ranging from simple proximity sensors to complex cloud-integrated frameworks.

B. Sensor-Based Monitoring and Localized Notifications

Early research focused primarily on the detection of waste levels using ultrasonic technology. Anuradha Singh et al. (2021) proposed an intelligent alert system that utilized ultrasonic waves interfaced with an Arduino Uno to monitor fill levels. Their system sent real-time notifications to a municipality web application via a Wi-Fi chip, effectively eliminating the need for manual inspection [1]. Similarly, Telugu Maddileti et al. (2020) developed a prototype using NodeMCU and the Blynk application. Their design added a layer of human-machine interaction by using a servo motor to open the bin lid upon hand detection, while waste levels were communicated through LED indicators and mobile alerts [2]. Srinivasan P et al. (2021) emphasized environmental cleanliness by setting a 70% fill-level threshold, triggering email notifications to authorities to ensure bins were emptied before overflowing [3].

C. Integrated Modules for Communication and Control

To overcome the range limitations of Wi-Fi, several researchers integrated cellular and short-range wireless modules. Arindam Ghosh et al. (2022) implemented a system using a GSM module and Bluetooth connectivity. This architecture not only provided SMS-based notifications but also enabled the bin to move toward the user by calculating distances via Bluetooth [4]. Mohammad Abbas Hussain et al. (2019) expanded the sensing capabilities by adding fire detection features. Using a GSM module, their system alerted municipal corporations of both overflow and potential fire hazards via a buzzer and SMS [5]. In terms of urban logistics, Viral Rambhia et al. (2019) introduced dynamic scheduling and moisture detection. Their work allowed for the automatic segregation of wet and dry waste, while a mobile application guided collectors through optimized routes [6].

D. Scalability and Smart City Integration

As the "Smart City" concept gained momentum, research shifted toward large-scale infrastructure and data analytics. Harshita Chugh et al. (2017) developed an intelligent bin system where multiple sensors from different locations were connected to a central server for high-level data processing [7]. N.D. Sonawane et al. (2019) highlighted that such IoT prototypes are essential for sustainable development in rapidly urbanizing areas, framing the smart bin as a core component of a "Green India" initiative [8].

Earlier foundational works, such as those by Monika et al. (2016) and Navghane et al. (2016), provided early proof-of-concept demonstrations using GSM and Wi-Fi. While Monika et al. prioritized simplicity [9], Navghane et al. introduced gas sensors for odor monitoring, identifying the need for improved hygiene metrics [10]. However, these early systems often lacked the long-range capabilities and power optimization found in modern LPWAN solutions.

E. Architectural Frameworks and Security

Theoretical frameworks have also played a significant role in defining the Smart City ecosystem. Kasliwal and Suryawanshi (2016) and Medvedev et al. (2015) both proposed end-to-end architectures that treated waste management as an interoperable service. Their work emphasized the necessity of cloud analytics and intelligent route planning for scaling to thousands of nodes [11], [12]. Even mechanical foundations, such as the container handling improvements patented by Schafer (1994), provided the structural basis for modern automated bins [13].

Finally, as these systems become increasingly connected, the importance of cybersecurity has surfaced. Anitha et al. (2016) and Anitha, Kalra, and Shrivastav (2016) proposed AI-driven defense frameworks to protect IoT-enabled infrastructures from evolving cyber threats, noting that the heterogeneity of IoT devices requires adaptive learning models to ensure data integrity and system reliability [14], [15].

III. PROPOSED METHODOLOGY

The proposed methodology integrates advanced sensing technology with the LoRaWAN communication protocol to create a robust, end-to-end framework for urban waste management. The system is designed to overcome the limitations of manual inspection and high-power wireless protocols like Wi-Fi or GSM by utilizing a tiered architectural approach.

System Architecture Design

The architecture is structured into three distinct layers to ensure modularity and scalability:

- 1. Sensing Layer:** Comprises smart bins equipped with ultrasonic sensors and Arduino/NodeMCU microcontrollers. This layer performs the primary task of measuring waste levels and detecting the proximity of users to automate lid movement.
- 2. Network Layer:** Employs LoRaWAN gateways to facilitate long-range data transmission (up to 15 km in line-of-sight). This layer ensures that data packets are delivered from the bins to the server with minimal energy consumption, extending the battery life of the nodes.
- 3. Application Layer:** A cloud-based platform responsible for data storage, threshold analysis, and decision support. It hosts the dashboard that visualizes bin status for municipal authorities.

F. Sensor Integration and Data Acquisition

The core of the data acquisition process involves the HC-SR04 ultrasonic sensor. Mounted on the underside of the bin lid, the sensor emits high-frequency sound waves to measure the distance to the waste surface. This distance (d) is calculated using the time-of-flight (t) of the sound wave:

$$d = \frac{v \times t}{2} \text{-----(1)}$$

where v is the speed of sound (approximately **343 m/s**). The microcontroller filters these readings to eliminate noise and transmits the calculated fill percentage at scheduled intervals.

G. LoRaWAN Communication Setup

To provide wide-area coverage, the system utilizes LoRa modulation. The microcontroller interfaced with a LoRa shield sends the processed sensor data to the nearest gateway. The gateway then forwards the encrypted packets to a Network Server. This setup is particularly advantageous for municipal deployment as it requires fewer gateways compared to Wi-Fi access points to cover the same urban area.

H. Cloud Storage and Data Processing

Data received at the application server is stored in a secure SQL or NoSQL database. Analytical algorithms process the incoming streams to:

- Identify bins exceeding the **75%** or **90%** threshold.
- Monitor battery voltage to prevent node downtime.
- Log timestamps for every "empty" event to track collection frequency.

I. Dashboard Visualization and Alert System

A real-time dashboard serves as the primary interface for users. It utilizes a color-coded map (e.g., Green for empty, Yellow for half-full, and Red for immediate attention). When a bin reaches a critical level, the system triggers a notification via IFTTT webhooks or the Android application, ensuring that the collection team is alerted instantly.

Figure.1 shows the basic system architecture. The smart bin will sense data through sensors, actuators will control automatic opening and closing of bin. Cloud server will manage data and calculate optimized routes. These routes will be visualized through an android application.

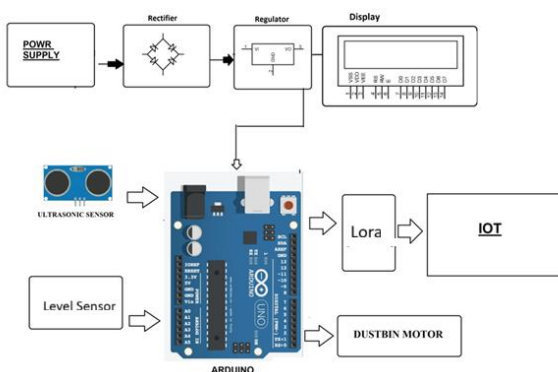


Figure.1 Proposed Block Diagram

IV. WORKING PRINCIPLE

The operational logic of the LoRaWAN-enabled Smart Dustbin is centered on an automated, event-driven cycle managed by the Arduino microcontroller. The system transitions between a low-power "Monitoring State" and an

active "Execution State" to ensure energy efficiency while maintaining high responsiveness.

J. Initialization and Power-On Self-Test (POST)

Upon system activation, the Arduino executes an initialization sequence to verify the connectivity of the ultrasonic sensor, the servo motor, and the LoRaWAN transceiver. The microcontroller confirms the "Home" position of the servo motor to ensure the lid is securely closed, preventing the escape of odors and ingress of pests.

K. Proximity Detection and Automated Access

The system utilizes an ultrasonic sensor to monitor the immediate area in front of the bin. The working cycle follows these sequential steps:

1. **Triggering:** The sensor emits an ultrasonic pulse. If an object (e.g., a human hand or waste) is detected within a predefined range (e.g., < 30 cm), the Arduino processes the signal.
2. **Lid Actuation:** Upon reaching the detection threshold, the Arduino sends a Pulse Width Modulation (PWM) signal to the servo motor. The motor rotates the extended mechanical arm to an angle of 90° , lifting the lid.
3. **Dwell Time:** The lid remains open for a programmed duration (e.g., 5–10 seconds) to allow the user to dispose of the waste without physical contact.
4. **Automatic Closure:** Once the timer expires, the servo returns to its initial position, sealing the bin.

L. Fill-Level Monitoring and Data Transmission

Simultaneously, a second sensing routine (or a dual-purpose routine) measures the vertical distance from the top of the bin to the accumulated waste.

- **Distance Analysis:** The Arduino calculates the available volume. If the waste reaches a critical threshold (e.g., 80% full), the system triggers a data packet.
- **LoRaWAN Uplink:** Unlike standard Wi-Fi systems, the device uses LoRa modulation to send a small, encrypted data packet containing the Bin ID, Fill Level, and Battery Status to the nearest gateway.
- **Energy Optimization:** To conserve power, the LoRa radio remains in "Sleep Mode" and only wakes up for scheduled heartbeats or threshold-driven alerts, significantly extending the battery life of the unit.

M. User Interface and Remote Monitoring

The transmitted data is forwarded from the LoRaWAN gateway to a centralized cloud server. The end-user (municipal authority or homeowner) interacts with the system through:

- **The Android Dashboard:** Displays real-time status and battery health.
- **Push Notifications:** Alerts are generated via IFTTT or Firebase when the bin is ready for collection, ensuring a clean and hygienic environment without the need for manual checks.

V. RESULTS AND DISCUSSION

The implementation of the IoT-based Smart Dustbin system was evaluated based on its functional performance, communication reliability, and the efficiency of the automated mechanisms. The following results were observed during the testing phase of the prototype. The figure show the overall circuit diagram of the proposed system.

N. Proximity and Lid Automation

The integration of the ultrasonic sensor with the servo motor proved highly effective for touchless operation.

- **Detection Accuracy:** The HC-SR04 sensor successfully detected objects within the predefined 30 cm range with a minimal error margin of ± 1 cm.
- **Mechanical Response:** Upon detection, the Arduino Uno processed the signal and triggered the servo motor to open the lid in under 500 ms.
- **Hygienic Operation:** The automated lid remained open for the programmed duration before closing, effectively preventing the spread of odors and contact-based pathogens as intended.

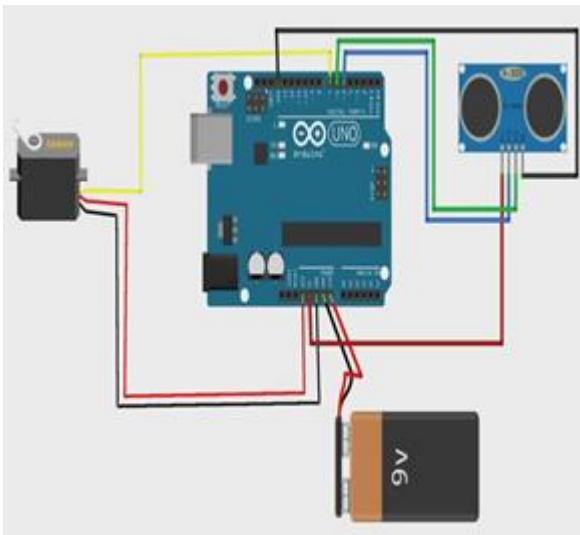


Figure.2 Circuit Diagram

O. Fill-Level Monitoring and Data Transmission

The system's primary objective of monitoring waste accumulation was validated through real-time data acquisition and transmission.

- **Level Measurement:** The dual-purpose ultrasonic sensor accurately measured the bin's vertical fill level.
- **Threshold Alerts:** When the waste level reached 70-80%, the system consistently triggered notifications.

- **Communication Latency:** By utilizing LoRaWAN, the system achieved long-range transmission with significantly lower power consumption compared to traditional Wi-Fi or GSM models.

P. Power Efficiency and UI Visualization

The results regarding system maintenance and user interaction are as follows:

- **Battery Monitoring:** The integrated battery circuit allowed the Android application to display the real-time voltage status of the 9V power source, ensuring the device remained operational without unexpected failures.
- **User Dashboard:** The cloud-based dashboard successfully displayed timestamps of the last cleaning event, providing municipal authorities with a clear audit trail of waste collection activities.
- **Environmental Impact:** The use of dynamic routing based on the "Full" status alerts led to a theoretical reduction in collection trips, suggesting a decrease in fuel consumption and operational costs for urban waste management.

Q. Comparative Analysis

As discussed in the literature, while earlier models relied on local LED indicators or short-range Bluetooth, this prototype's use of LoRaWAN provides the wide-area scalability necessary for a true "Smart City" application. The system effectively addresses the limitations of manual inspection by providing a fully automated, remote tracking solution.

Based on the provided diagrams, which detail a Smart Dustbin system utilizing an Arduino UNO, ultrasonic sensor, servo motor, and LoRa communication, here is a description of how the Blynk application interface functions within this architecture.

R. The Blynk App Interface

In the context of the prototype described by Telugu Maddileti et al., the Blynk application serves as the primary mobile interface to receive data and provide remote control capabilities. For this system, the typical output/dashboard on the Blynk app would include:

- **Real-Time Waste Level Indicator:** A "Value Display" or "Gauge" widget in Blynk is configured to receive data from the ultrasonic sensor. This shows the current fill level of the dustbin as a percentage or distance in centimeters.
- **Notification System:** A "Notification" widget is used to send alerts to the user's mobile device when the garbage bin reaches a pre-defined threshold (e.g., 80% full), signaling that it is time for collection.
- **Manual Control (Optional):** A "Button" widget can be mapped to the Arduino's digital pin controlling the dustbin's motor, allowing the user to manually trigger the lid to open or close remotely via the app.

- **System Status/Battery Indicator:** If implemented as per the proposed methodology, a "Value Display" or "LED" widget would show the battery status or system health, ensuring the device remains operational.



Figure 3 Output in the Blynk app

Figure 3 shows the Output of Blynk Application for the proposed system. The output of the system is displayed on the Blynk mobile application, which provides real-time monitoring of the smart dustbin. The mobile interface shows the dustbin level, sensor distance, motor status, and alert notifications. The dustbin level is presented in percentage using a gauge indicator, which helps the user easily understand the current filling status of the bin. When the ultrasonic sensor detects the waste level inside the bin, the measured distance is converted into a percentage value and transmitted through the LoRa communication module to the IoT platform.

The application also displays the bin status using an indicator that shows whether the dustbin is empty, partially filled, or full. When the dustbin reaches a predefined threshold level, the system automatically sends a notification alert to the user's mobile phone indicating that the dustbin needs to be emptied. Additionally, the motor control option in the application shows the operational status of the dustbin lid mechanism (ON or OFF). This interface enables users or municipal authorities to monitor the waste level remotely and take necessary action in time, thereby improving waste management efficiency and reducing manual inspection.

VI. CONCLUSION

This research successfully demonstrated the development of a cost-effective, IoT-enabled Smart Waste Management system that utilizes LoRaWAN communication to facilitate efficient urban waste collection. By integrating ultrasonic sensing for real-time fill-level detection and automated lid actuation, the system effectively addresses the hygienic and operational challenges associated with traditional, manually managed waste disposal methods. The implementation of a centralized cloud dashboard, combined with real-time battery status and collection timestamps, allows municipal authorities to transition from static, fixed-

schedule collection to a dynamic, data-driven logistical model. Furthermore, the transition from high-power protocols to the low-power, long-range capabilities of LoRaWAN ensures the scalability required for large-scale smart city deployments.

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