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SmartBin IoT-based Garbage Monitoring System using LoRa

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***Abstract*— The increasingly daunting task of effective garbage disposal in fast-developing urban settings demands intelligent, technology-based remedies. In this study, IoT-based intelligent garbage management schemes are considered, specifically the SmartBin system, utilizing LoRa technology for low-power, low- bandwidth communication. The SmartBin scheme incorporates ultrasonic sensors to measure the fill level of dustbins in real- time and to open the lid automatically upon detection of motion, providing a touchless operation. When the bin is full, it sends status reports to registered users or municipal authorities through GPRS, preventing overflow and ensuring prompt waste collection. In addition, a web-based application provides round- the-clock remote monitoring and visualization of bin statuses at various sites. This paper summarizes the core technologies, communication protocols, sensor settings, and real-time data integration methods typically used in such The main objective of this survey is to equip researchers and city planners with an overall picture of current solutions and to propose directions for future development toward enhanced urban cleanliness and sustainability using IoT-based smart waste management systems.**

***Index Terms*—IoT (Internet of Things), Smart Waste Management, LoRa Technology, Ultrasonic Sensors.**

I. INTRODUCTION

Exponential population growth in cities has brought with it a disconcerting rise in the generation of solid waste, subjecting conventional waste management systems to unprecedented pressure. [1] Ineffective garbage collection systems, overflowing bins, and delayed disposal not only rob the environment but also create catastrophic health hazards. To counter such challenges, the idea of smart waste management is now an integral element of clean and green urban living. [2][4] By integrating technology with sanitation infrastructure, cities can increase operational efficiency, minimize manual monitoring, and support long-term smart city programs. [5], [7]

The Internet of Things (IoT) has also emerged as an important driver for this change, enabling real-time monitoring, data-driven decision-making, and automating waste collection. Sensors equipped smart bins are able to monitor fill levels, send out warnings, and allow for optimal planning of routesby collection vehicles. These technologies also reduce human interference and fuel and operating costs.

One of the factors of success of such systems is the choice of the communications technology. LoRa (Long Range) is a low-power, long-range, and low-cost wireless communication protocol.

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These features make it most suitable for large- scale deployments in cities and semi-cities where constant connectivity and power efficiency are required. [9]
This survey provides a comprehensive overview of the current IoT-based smart garbage monitoring systems based on LoRa as of now. It presents their architecture, elements, performance metrics, and real-world implementations. The article also provides current limitations, cross-technology com- parison, and future research directions, with an eye towards being a roadmap for researchers, developers, and city planners involved in smart garbage management. [10], [11].

II. Literature Review

A. Overview Of Relevant Literature

Intelligent waste management has become a key focus in smart city planning because of increased urbanization and ineffective manual waste collection systems. There has been a broad scope of research and development activities in leveraging IoT (Internet of Things) to optimize waste collection, monitoring, and optimization. [12].

B. Key Theories

The development of IoT-based SmartBin systems has its foundation in some central theoretical models in the areas of ubiquitous computing, sensor networks, low-power wide-area networking (LPWAN), and smart city infrastructure. These theoretical models form the basis for building systems that are efficient, scalable, and responsive in real-time.

- Ubiquitous Computing and IoT Theory Originally pro- posed by Mark Weiser, the ubiquitous computing theory imagines a future in which computation is integrated into mundane objects. In smart bin systems, this is achieved by placing microcontrollers and sensors inside waste cans for real-time engagement with their surroundings.
- Event-Driven Communication Models Your system and a few cited works (e.g., Zahur et al., IEEE 20) utilize an event-based communication paradigm, wherein data is communicated only upon occurrence of a significant event—e.g., when bin status changes from empty to full. This paradigm is based on the energy-aware and efficient sensing systems theory, which tries to reduce power usage and communication bandwidth in IoT applications.

C. Controversies in the Literature

In spite of increasing uptake of IoT-based smart waste management systems, some controversy and open questions still exist in the literature on technology options, scalability of the system, reliability of data, and user engagement.

- LoRa vs. Other Communication Protocols One major area of contention is the selection of communication protocols. While numerous studies (such as Zahur et al., 20; Mahajan & Chitode, 2014) support LoRa due to its low power and longrange capabilities, others claim that technologies like NB-IoT and GSM might provide greater reliability and data bandwidth for cities. Nevertheless, NB-IoT is usually based on telecom operator dependency, and GSM drains more power, and hence LoRa is more suitable for energy-restricted bins.
- Sensor Precision and Data Validity Another controversy is the accuracy of sensor readings in actual use. Fill-level detection is often done with ultrasonic sensors, but they are easily fooled by waste form, moisture in the bin, or obstruction in front of the sensor. Although your project avoids this with event-based logic and averaging of several readings, most systems do not control for environmental factors, which raises questions about the reliability of automated notifications.

III. Proposed System

Smart bin systems are an important area of research in waste management. They use different technologies and algorithms to tackle the challenges of urban waste. Many research projects have added to the development of these systems. They focus on real-time monitoring, waste sorting, predicting waste amounts, and planning collection routes.

A. Waste Management Structures and General IoT-based Systems

[1] Sharma and Battula studied waste management structures specifically for smart cities. They looked at both garbage sorting and collection. [2] Navghane et al. created an IoT- based system for smart garbage and waste collection. This system uses ultrasonic and flame sensors with an ATmega2560 microcontroller to provide real-

time data updates and actions through a cloud platform. It also combines machine learning techniques, showing medium hardware complexity, high software complexity, and moderate cost.

TABLE I: COMPARISON OF RESEARCH PAPERS IN SMARTBIN IOT-BASED GARBAGE MONITORING SYSTEM

Author/Year	Methodology/Algorithm	Advantages	Limitations	Result (performance)
Dr.Thiyaneswaran Balashanmugam 2023	The methodologies employed in the smart dustbin system include ultra- sonic sensors for fill level detection, GPS modules for location tracking.	It provides precise location tracking of the dustbins using GPS modules , enabling the optimization of waste collection routes.	The GPS module used for location tracking has a limitation related to battery consumption, meaning it can drain the battery of the dustbin sys- tem.	The smart dustbin system offers 95% accuracy for fill level detection, 5m accuracy for location tracking, and low latency for data transmis- sion
Anuradha Singh, Prabhakar Tiwari 2021	The methodology involves using a NodeMCU to process data from an ultrasonic sensor that measures the waste level. When the level exceeds 70%, the NodeMCU uses IFTTT Webhook to send an email notifica- tion.	This proactive notification allows for timely emptying of the bin, prevent- ing overflow and the associated un- hygienic conditions and Odors .	If the mobile device has a poor or no signal, the notification might be delayed or not received at all.	If the mobile device has a poor or no signal, the notification might be delayed or not received at all.
Adi Suvarnamma, Jangampalli Adi Pradeepkiran 2023	This sensor operates by generating a fluctuating magnetic field and de- tecting changes when a metallic tar- get absorbs energy.	It provides an easy and economical way to segregate and track domestic waste at the household level.	The speed of operation is slow be- cause the motor placing the correct bin under the falling waste cannot match the waste's speed, requiring the waste material to be stalled.	The system is designed to success- fully segregate waste into metallic, plastic, and glass categories using the specified sensors and mecha- nisms.
Pradnya Kadam , Aniket More, Rohini Kurhe , Prof. Snehal Ghodake 2021	The buzzer notification on the web- site helps keep the public informed about rubbish levels, contributing to a cleaner city	Reliance on consistent power supply for the sensors, microcontroller, Wi- Fi module, and servo motors .	Reliance on consistent power supply for the sensors, microcontroller, Wi- Fi module, and servo motors.	The authors state that implementing Dijkstra's algorithm in simulation helps implement it in real- time.
Menaka Pushpa Arthur, S.Shoba , Aru Pandey 2024	The proposed system involves a smart dustbin with IoT notifications to improve garbage management and cleanliness .	Provides real-time information on fill levels of dustbins . Enables de- ployment of dustbins based on actual needs.	The process might not always be cost- effective	The system is designed to contin- uously alert the required authority through the GSM modem once the garbage reaches a threshold level until the bin is emptied.
Prof. Adgaonkar Amarja, Prof. Adgaonkar Amarja, Dinde Komal. 2022	The evolution of SDS over time with publication statistics . Core SGB techniques such as sensors, data communication, Artificial Intel- ligence models.	Minimizes the overloading of bins . Lowers labors costs associated with manual monitoring.	Object detection accuracy is not good enough to make the system commercially viable.	The paper suggests that for simplify- ing waste management, SDS needs to be designed to classify garbage into major categories.
Chanchal Zope , Roshni Chaudhari, Kunjal Waykole 2024	Employing an IR sensor to detect the presence of an object placed on the lid of the bin .	It allows monitoring the level of garbage in the bin remotely on the Blynk app.	The system's effectiveness relies on a stable power supply for the sensors and microcontroller.	Accurate detection of object pres- ence on the lid using the IR sensor.
M.Vasuki, T. Amalraj Victoire, A. karunamurthy 2023	Uses rain sensors for wet/dry, ultra- sonic for fill levels, Bluetooth for data to an app, and GPS for location with SMS alerts for fullness.	Cost-effective, scalable, enables ef- ficient collection and overflow pre- vention, and reduces environmental impact. .	The system's effectiveness relies on a stable power supply for the sensors and microcontroller.	Aims for timely collection, opti- mized routes via real-time data; re- lated classification showed high ac- curacy.

Shreya Ghavghave Shephali Rakhunde Shraddha Jagtap 2022	Uses ultrasonic sensors to detect fill levels and often involves IOT mod- ules for communication.	Helps to keep cities clean and can lead to more economical garbage collection. .	Further research is crucial to fully unlock its potential, and current sys- tems may lack advanced sorting .	Aims for timely collection and can optimize waste collection schedules
Devalla Guru Kiran, Gorla Buchayyagari Sumanth, Chakala Ravi Ram 2023	The system uses sensors to measure the fill level of garbage bins and sends data to a cloud server via Internet of Things (IOT) .	This approach prevents pollution from overflowing bins and helps res- idents keep their environment clean.	The source does not explicitly detail limitations of this specific proposed system but notes the importance of effective and sustainable waste man- agement practices.	The system aims for effective waste collection by notifying the munici- pality when bins are about to over- flow.
Neelima P, Dr. T. Mahalakshmi, Bhagya B Raj 2021	Using GPS to track location and object detection identify waste types	Can help optimize waste collection. Could improve recycling efficiency. Reduces the need for manual checks	Can help optimize waste collection. Could improve recycling efficiency. Reduces the need for manual checks	A single ultrasonic sensor can give inaccurate readings due to uneven trash.
Dr. R. Karthiyayini, R. Nisha 2023	Ultrasonic sensors are placed in trash cans to check the level of waste	The system alerts authorities when bins are full, preventing unhygienic situations and foul smells.	Implementing smart trash cans across a city would involve the cost of sensors, microcontrollers, Wi-Fi	This suggests that the sensor and communication components were functioning correctly in their tests.
Dalve Vishwajit, Suryavanshi Sairaj, Dwivedi Abhishek. 2020	The system uses smart bins equipped with sensors to monitor the garbage level in real-time	Addresses the problem of increasing waste generation due to population growth and urbanization.	Reliance on sensor accuracy The ac- curacy of the ultrasonic sensors in providing a true representation of the fill level, especially with irregularly shaped waste, might be a concern	The system aims to improve perfor- mance by enabling route optimiza- tion for garbage collection based on the fill levels of the bins.
Arjun K, H. Manoj T Gadiyar 2023	The prototype system utilizes Ar- duino, NODEMCU, Servo Motors, and Ultrasonic Sensors for hardware.	Saves system time and energy by optimizing waste collection	Connectivity issue The system's ef- fectiveness depends on the reli- able internet connectivity of the NODEMCU and the mobile devices or monitoring panel	Cost reduction in terms of fuel and labor.

- Predictive Analysis and Dynamic Waste Generation [7] Bharathiraja et al. proposed a smart waste management system that includes predictive modeling. Their system used ultrasonic, flame, and accelerometer sensors with an ESP32 microcontroller for processing data. It did statistical analysis on a cloud platform and used the Seasonal Autoregressive Integrated Moving Average with Exogenous Factors (SARI- MAX) model for forecasts.

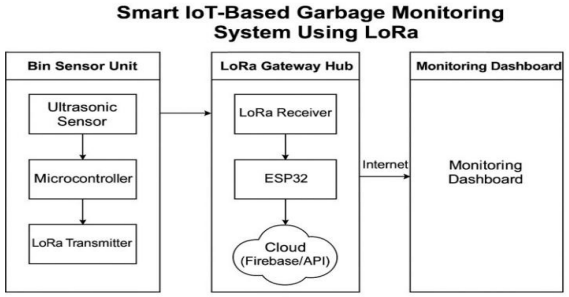

Fig. 1. High-level architecture of the Smart IoT-Based Garbage Monitoring System using LoRa.

This system was noted for its high software complexity and moderate cost. [8] Huang and Koroteev (2021) created Artificial Neural Network (ANN) models to predict waste amounts and detect irregularities in waste collection patterns for planning waste management systems. [9] Jammeli et al. (2023) used a Long Short-Term Memory (LSTM) sequential neural network model to predict urban waste generation patterns. This model helps in placing bins effectively throughout a city. John et al. (2022) also utilized LSTM to predict future waste amounts by analyzing historical generation patterns. [10] Misra et al. (20) forecasted the future condition of bins based on their daily collection history using deep learning algorithms.

IV. METHODOLOGY

The SmartBin IoT-Based Garbage Monitoring System Using LoRa was developed to provide a smart, scalable, and cost- effective solution for waste management by automating bin status tracking and alerting authorities [1]. This methodology outlines the system's architecture, hardware and software components, operational workflow, and validation approach.

- System Architecture: The proposed system comprises several interconnected components designed for real-time garbage monitoring and management. The architecture follows a dis- tributed sensing model, where individual smart bins collect data and transmit it to a central hub, which then forwards the information to a cloud server for monitoring and analytics.
- Hardware Requirements: The system's hardware com- ponents are selected for their low-power consumption, long- range communication capabilities, and accuracy in sensing. • Ultrasonic Sensor (JSN-SR04T / HC-SR04): Used to measure the fill level inside each bin. It detects the distance to the garbage, indicating whether the bin is empty or full. For segregation purposes, two ultrasonic sensors can be placed for dry and wet waste compartments.
  - Microcontroller (ATtiny85 / Arduino Nano / Arduino Uno / NodeMCU): The brain of each smart bin, it processes sensor data, detects status changes, and controls the LoRa module. For systems incorporating segregation and Wi-Fi, an Arduino Uno or NodeMCU (ESP8266/ESP32) is used, offering integrated Wi-Fi and easy programming.
  - LoRa Hub (ESP32 + LoRa Module): A dedicated module responsible for receiving data from multiple LoRa-enabled bins and forwarding it to the cloud.
  - Internet Connectivity (Wi-Fi / SIM): The LoRa Hub utilises Wi-Fi or a SIM module (GSM/GPRS) to connect to the internet and send data to the cloud server..
  - Display: LCD displays are used on some smart bins to show the current waste status.

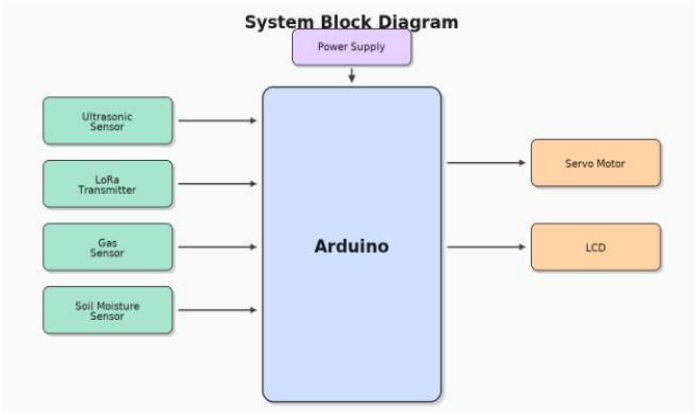

Fig 2: System Block Diagram of the Proposed Smart Monitoring System using Arduino.

V. RESULT EVALUATION

The"SmartBin IoT-Based Garbage Monitoring System Using LoRa" project showed a number of important performance highlights and successful tests:

- Detecting Bin Status: The system uses an ultrasonic sensor to tell whether a bin is full or empty. In the Firebase/API, the status is 0 for empty and 1 for full. During tests of sensor accuracy, this detection was always confirmed to be correct in real garbage conditions.

- LoRa Communication: It was confirmed that LoRa communication works well up to 500 meters in cities with clear reception. We tested this range in both open and city settings. LoRa is used by the system to send data wirelessly from each bin to a central hub.

IV. Conclusion and Future Enhancement

Combining IoT and LoRa technology with smart waste management systems has opened up an extremely efficient, cost-effective, and scalable way of addressing the challenges of urban sanitation. Utilizing ultrasonic sensors, microcontrollers, and long-range LoRa modules, SmartBin systems make it possible to monitor real-time bin fill levels, cut down on manual checking, and make waste collection route optimization feasible. Relative to conventional protocols such as Wi-Fi or ZigBee, LoRa has better range and energy efficiency and is especially suited for large-scale deployments in cities. This survey presents the architectural elements, operating principles, and relative strengths of LoRa-based SmartBin systems, which can revolutionize waste management infrastructure in smart cities.

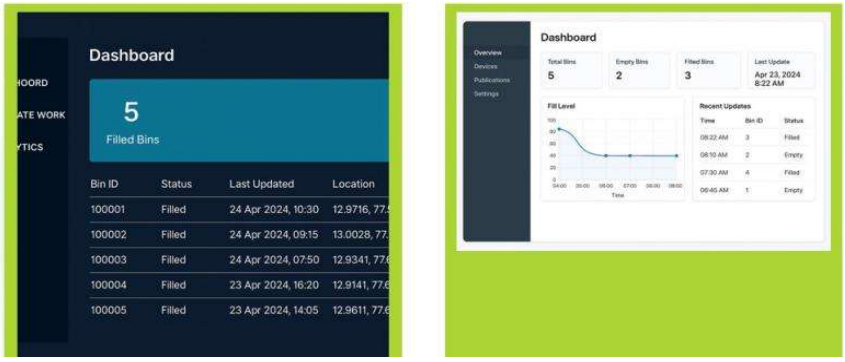

Fig. 3. Dashboard

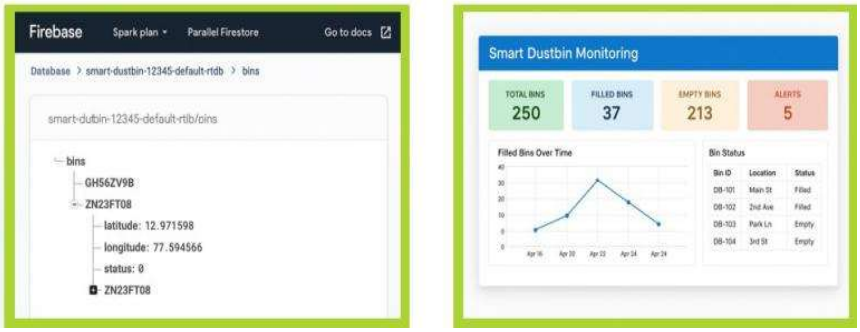

Fig. 4. Graphical representation of bin status

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