Smart Garbage System for Efficient Waste Management

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Abstract— ***In this rapid growing population and urbanization condition, the production or generation of waste after domestic or commercial use is also increasing. Thereby a proper Waste Disposal method is necessary for the reduction of waste causing pollution and negative impact to the sustainable environment. This paper proposes an idea of disposing the waste effectively using a smart dustbin. The dustbin mainly consists of sensors which detects the level of waste collected when it reaches a specific threshold (80%-90%) and gives a notification the concerned cleaning authorities. Also, the proposed project includes a waste segregation method that separates and divides the waste into degradable and non-degradable which helps the authorities for the proper disposal of waste. The bin consists of sensors for sensing the level of waste collected, GPS for get to know about the location of the dustbin, microcontrollers for segregating the waste. This project helps the authorities for the proper disposal of waste, efficient use of resources and fuels required and avoiding regular checking of the threshold limit of the waste.***

I. INTRODUCTION

The idea of a smart city has grown from different technological developments that focus on making urban services more user-friendly, responsive, and capable of operating automatically with minimal human intervention. At its core, the smart city concept seeks to improve public welfare and overall quality of life through better governance, efficient service delivery, and intelligent system management. This vision is largely made possible by Information and Communication Technology (ICT), which supports a wide range of urban applications such as health and building monitoring, waste management, air quality and noise monitoring, energy consumption tracking, smart lighting, public building automation, traffic optimization, parking management, agricultural support, and road incident detection. In addition, smart geospatial technologies help city authorities manage and analyze spatial data more effectively, enabling informed decision-making at different administrative levels.

Among these applications, waste management has become a pressing concern, particularly in developing countries striving for higher standards of living. In Malaysia, for example, effective waste management is viewed as an essential step toward achieving developed nation status. Reports from 2015 indicated that the country generated approximately 15–18 kilotons of waste per day, totaling nearly 7.77 million tons annually. However, only about 76%–80% of this waste was successfully collected, despite significant government spending. A major reason for this inefficiency lies in the traditional fixed weekly collection schedules and static routing plans, which do not account for the actual fill levels of waste bins. As a result, trucks often collect half-empty bins while other areas may be overlooked, leading to poor resource utilization.

To address these shortcomings, researchers have proposed various smart Garbage Management Systems (GMS). Some studies focus on system architecture, where bins are equipped with sensors to monitor waste levels and send alerts via communication technologies such as Wi-Fi or GSM when they reach a certain threshold. In some cases, two-way communication is enabled between bins, trucks, and control centers to improve coordination. Other studies emphasize route optimization strategies by modeling waste collection as a Capacitated Vehicle Routing Problem (CVRP), applying mathematical, heuristic, or meta-heuristic methods to minimize total travel distance.

Although these optimization techniques effectively reduce overall distance traveled, they often overlook fairness in workload distribution among collection trucks. This can result in significant differences in travel distances and working hours for drivers. Since drivers are typically paid based on time rather than performance, such imbalances can create dissatisfaction and operational challenges. To address this issue, this paper introduces a fairness-based optimum solution (FBOS), which treats fairness as a measure of distance variation among trucks and incorporates it into the routing strategy. By balancing total travel distance with distance equality, the proposed method provides a more practical and equitable solution. The approach also highlights the trade-off between minimizing total distance and ensuring fairness, offering a two-factor metric that allows decision-makers to adjust priorities according to their preferences. Implemented and tested within an Internet of Things (IoT) framework using LoRa communication and mobility considerations, the FBOS demonstrates performance comparable to traditional CVRP methods while significantly improving fairness in route allocation.

A. Problem Statement

The rapid growth of population, urbanization, and industrial activities has significantly increased the quantity of solid waste generated in cities and public areas. Conventional waste management systems mainly depend on fixed collection schedules and manual inspection of garbage bins. These traditional methods are inefficient because waste collection vehicles often collect bins that are only partially filled, while some bins overflow before the scheduled collection time. This results in unnecessary fuel consumption, increased operational costs, traffic congestion, and poor utilization of resources.

Overflowing garbage bins create unhygienic surroundings, unpleasant odors, and environmental pollution, which may lead to serious public health issues and the spread of diseases. In addition, improper segregation of waste at the source makes recycling difficult and increases the amount of waste sent to landfills, causing environmental degradation.

Many existing research works propose solutions such as IoT-based monitoring systems or automated waste segregation techniques. However, most of these systems address only a single aspect of waste management, such as bin-level monitoring, notification systems, or route optimization. Very few systems provide a combined solution that integrates waste segregation, real-time monitoring, intelligent decision-making, and communication with authorities.

Therefore, there is a need for an efficient smart garbage monitoring system that can automatically detect waste levels, segregate different types of waste, provide real-time alerts to cleaning authorities, and support optimized waste collection. Such a system can improve operational efficiency, reduce environmental impact, minimize human intervention, and contribute to the development of smart and sustainable cities.

Proposed System Description

The proposed Smart Garbage Monitoring System is designed to improve waste management efficiency by integrating IoT technology, automated waste segregation, and real-time monitoring. Existing systems mainly focus either on garbage level monitoring [1], [3], [4] or on waste segregation [2], [5], which highlights the need for an integrated solution.

The system uses multiple sensors such as ultrasonic sensors, infrared (IR) sensors, inductive sensors, and capacitive sensors to detect waste presence, identify material type, and monitor bin fill levels continuously. Similar sensor-based monitoring approaches have been implemented in earlier smart dustbin systems [1], [3].

When waste is deposited, the IR sensor detects the object and initiates the segregation process. The inductive sensor identifies metal waste, while the capacitive sensor detects plastic waste, similar to automated segregation techniques discussed in [2] and [5]. Waste that does not fall under metal or plastic categories is directed into the organic waste compartment.

The ultrasonic sensor monitors the fill level of each bin in real time. When the garbage reaches approximately 80% of the bin capacity, the system sends notifications to the concerned authorities through IoT communication modules such as ESP32 and WiFi, following alert mechanisms proposed in [1] and [3].

The collected data is transmitted to a cloud platform for monitoring and decision-making, supporting optimized waste collection strategies similar to the smart city approach discussed in [6]. This integration of segregation, monitoring, and communication helps reduce overflow, improve recycling efficiency, and optimize waste collection routes.

Thus, the proposed system overcomes the limitations of existing systems by combining automated segregation, real-time monitoring, IoT communication, and intelligent notification into a single framework.

METHODOLOGY

The methodology of the proposed Smart Garbage Monitoring System is based on automation, waste segregation, real-time monitoring, and IoT communication to achieve efficient waste management. When a user disposes of waste into the smart dustbin, an infrared (IR) sensor detects the presence of the object and activates the system automatically. The waste is then guided through a segregation unit where different sensors identify the material type. An inductive proximity sensor detects metallic waste and directs it into the metal bin, while a capacitive proximity sensor identifies plastic waste and diverts it into a separate compartment. Waste that is not recognized as metal or plastic is categorized as organic waste and collected in another bin, ensuring proper segregation at the source.

Each bin is continuously monitored using ultrasonic sensors that measure the garbage level by calculating the distance between the waste surface and the sensor. When the fill level reaches approximately 80% of the bin capacity, the system triggers alerts through LEDs, display messages, and IoT notifications. An Arduino microcontroller acts as the central control unit, processing sensor inputs, controlling segregation mechanisms, and managing system operations. The ESP32 WiFi module transmits real-time data to a cloud platform, allowing authorities to monitor bin status remotely. The system also provides bin location information, enabling optimized waste collection routes and reducing unnecessary trips. By combining sensing, automation, and communication technologies, the methodology minimizes manual inspection, prevents bin overflow, improves recycling efficiency, and supports sustainable smart city waste management.

II. LITERATURE SURVEY

[1] G. N. Keshava Murthy et al., (2023) – Automated Smart Dustbin Using ESP32

G. N. Keshava Murthy, Akhilesh S., Arpita K. N., Yashaswini R., and Janhavi T. S. (2023) proposed an automated smart dustbin using ESP32 and IoT technology. The system monitors garbage levels using sensors and enables wireless communication for real-time waste monitoring. The proposed solution improves collection efficiency but provides limited waste segregation features.

[2] Pragun Jaswal et al., (2023) – Intelligent Waste Segregation Using Smart IoT-based Dustbin

Pragun Jaswal, Zubair Ahmad Sofi, Akshay Kanwar, and Vicky Kumar (2023) developed an IoT-based smart dustbin capable of intelligent waste segregation. The system automatically detects waste types and transfers data to cloud servers for monitoring and control. This approach enhances recycling efficiency but increases system complexity.

[3] Palomi Gawali et al., (2023) – Smart IoT Based Dustbin and Waste Monitoring System

Palomi Gawali, Swarup Shinde, Janhavi Tambolkar, Gauri Shinde, and Sujal Sawant (2023) proposed a smart waste monitoring system using ultrasonic sensors, NodeMCU, and IoT platforms. The system detects bin fill levels and sends alerts when the garbage reaches a predefined threshold. It enables remote monitoring but lacks automatic waste segregation.

[4] Priyanka Thirumugam et al., (2023) – Smart Dustbin and Garbage Monitoring System Using Internet of Things

Priyanka Thirumugam, Daminda Herath, and Shehan Amarasooriya (2023) introduced a smart garbage monitoring system using GSM modules and wireless sensing technologies. The system sends notifications to authorities when waste levels exceed limits and supports wet and dry waste monitoring. However, the automation level remains basic.

[5] Kailash Sharma et al., (2023) – IoT Based Smart Dustbin with Waste Segregation

Kailash Sharma, Mahaveer Singh Naruka, Rahul Singh, Ginni Nijhawan, Rakesh Chandrashekhar, and

B. Santhosh Kumar (2023) proposed an IoT-based smart dustbin capable of segregating waste into recyclable, biodegradable, and non-recyclable categories. The system promotes sustainable waste management but requires accurate sensing mechanisms.

[6] Md. Arafatur Rahman et al., (2024) – IoT-Enabled Intelligent Garbage Management System for Smart City

Md. Arafatur Rahman, Sze Wei Tan, A. Taufiq Asyhari, Ibnu Febry Kurniawan, Mohammed J. F. Alenazi, and Mueen Uddin (2024) presented an IoT-enabled garbage management system focusing on smart city applications. The study introduces fairness-based route optimization for waste collection, reducing fuel consumption and improving operational efficiency.

III. COMPARITIVE ANALYSIS OF LITERATURE SURVEY

[I] G. N. Keshava Murthy et al. (2023)

G. N. Keshava Murthy et al. (2023) developed an automated smart dustbin using ESP32 for monitoring garbage levels through IoT connectivity. The system enables real-time communication and efficient waste monitoring; however, it mainly focuses on monitoring rather than waste segregation.

[II] Pragun Jaswal et al. (2023)

Pragun Jaswal et al. (2023) proposed an intelligent IoT-based dustbin capable of automatic waste segregation using sensors and cloud integration. The system enhances recycling efficiency but increases system complexity due to advanced sensing and processing requirements.

[III] Palomi Gawali et al. (2023)

Palomi Gawali et al. (2023) introduced a smart IoT-based waste monitoring system using ultrasonic sensors and NodeMCU. The system provides threshold-based alerts and online monitoring but lacks intelligent classification of waste materials.

[IV] Priyanka Thirumugam et al. (2023)

Priyanka Thirumugam et al. (2023) proposed a smart garbage monitoring system using GSM and wireless sensing technology. The system sends notifications when bins are full and supports wet and dry waste monitoring, but automation and smart decision-making capabilities are limited.

[V] Kailash Sharma et al. (2023)

Kailash Sharma et al. (2023) developed an IoT-based smart dustbin with automatic waste segregation into recyclable, biodegradable, and non-recyclable categories. The system promotes sustainable waste management, though accurate sensor calibration is necessary for reliable performance.

[VI] Md. Arafatur Rahman et al. (2024)

Md. Arafatur Rahman et al. (2024) proposed an IoT-enabled intelligent garbage management system for smart cities focusing on optimized waste collection routes using fairness-based algorithms. The system improves logistics efficiency but concentrates more on collection management rather than bin-level automation.

Research Gap Identified

1. Existing smart waste management systems mainly focus on either garbage level monitoring or waste segregation individually, rather than providing a fully integrated solution.
2. Many proposed systems rely on fixed monitoring or simple alert mechanisms without intelligent automation for efficient waste classification
3. Several studies lack real-time IoT-based communication that enables continuous monitoring and instant notification to cleaning authorities.
4. Most existing models do not include proper waste segregation at the source, which reduces recycling efficiency and increases landfill waste.
5. Current systems often do not provide location-based information for optimized waste collection and route planning.
6. Limited integration of multiple sensors results in reduced accuracy and reliability in detecting different waste types.

7. Few systems combine monitoring, segregation, cloud data management, and smart decision-making into a single unified framework.

IV. CONCLUSION

The Smart Garbage Monitoring System presented in this work offers an effective and intelligent approach to improving waste management processes using IoT and automation technologies. The system successfully integrates automated waste segregation, real-time bin level monitoring, and wireless communication to address the limitations of traditional waste collection methods. By using sensors to identify waste types and monitor bin capacity continuously, the system ensures proper segregation at the source and prevents garbage overflow in public areas.

The implementation of IoT communication enables instant notifications to cleaning authorities when bins reach a predefined threshold level, allowing timely waste collection and optimized route planning. This reduces unnecessary collection trips, saves fuel, minimizes labor effort, and lowers operational costs. Additionally, automated segregation improves recycling efficiency and reduces the amount of waste sent to landfills, thereby supporting environmental sustainability.

Overall, the proposed system enhances cleanliness, improves public hygiene, and promotes efficient resource utilization. The integration of sensing technologies, microcontrollers, and cloud-based monitoring makes the system suitable for smart city applications and future waste management solutions. Hence, the developed system provides a reliable, scalable, and cost-effective solution for modern waste management challenges.

V. FUTURE SCOPE

The proposed Smart Garbage Monitoring System can be further enhanced by incorporating advanced technologies to improve efficiency and scalability. Artificial Intelligence and machine learning techniques can be integrated to achieve more accurate waste identification and to predict garbage generation patterns, helping authorities plan collection schedules effectively. The system can be upgraded with solar power support to reduce electricity consumption and enable sustainable operation in outdoor environments.

In the future, the system can be connected to smart city infrastructure for centralized monitoring of multiple dustbins across different locations. GPS-based route optimization can be implemented to automatically suggest efficient waste collection paths, reducing fuel usage and operational costs. Mobile applications can also be developed for real-time monitoring and user interaction, encouraging public participation in proper waste disposal. Additionally, cloud-based data analytics can be used to analyze waste trends and support data-driven decision-making for improved urban waste management.

This research focuses on smart city waste management using IoT and optimization algorithms. It introduces fairness-based route planning so garbage trucks travel balanced distances, improving efficiency, reducing fuel consumption, and enabling data-driven waste collection strategies.

REFERENCES

[1] G N Keshava Murthy, Akhilesh S, Arpitha K N, Yashaswini R, Janhavi T S, "Automated Smart Dustbin Using ESP32", 2023 International Conference on Recent Advances in Science and Engineering Technology (ICRASET), DOI: 10.1109/ICRASET59632.2023, 23-24 Nov. 2023

[2] Pragun Jaswal, Zubair Ahmad Sofi, Akshay Kanwar, Vicky Kumar, "Intelligent Waste Segregation Using Smart IoT-based Dustbin", 2023 3rd International Conference on Advancement in Electronics & Communication Engineering (AECE), DOI: 10.1109/AECE59614.2023, 23-24 Nov. 2023

[3] Palomi Gawali, Swarup Shinde, Janhvi Tambolkar, Gauri Shinde, Sujal Sawant, "Smart IOT Based Dustbin and Waste Monitoring System", 2023 International Conference on Advances in Computation, Communication and Information Technology (ICAICCIT), DOI: 10.1109/ICAICCIT60255.2023, 23-24 Nov. 2023

[4] Priyanka Thirumugam, Daminda Herath, Shehan Amarasooriya, "Smart Dustbin and Garbage

Monitoring System Using Internet of Things", 2023 5th International Conference on Advancements in Computing (ICAC), Colombo, 7-8 Dec. 2023

[5] Kailash Sharma; Mahaveer Singh Naruka; Rahul Singh; Ginni Nijhawan; Rakesh Chandrashekar; B Santhosh Kumar, "loT Based Smart Dustbin with Waste Segregation", 2023 International Conference on Power Energy, Environment & Intelligent Control (PEEIC), DOI: 10.1109/PEEIC59336.2023, 19-23 Dec. 2023

[6] Md. Arafatur Rahman; Sze Wei Tan; A. Taufiq Asyhari; Ibnu Febry Kurniawan; Mohammed J. F. Alenazi; Mueen Uddin, "IoT-Enabled Intelligent Garbage Management System for Smart City: A Fairness Perspective", IEEE Access, vol. 12, pp. 82693-82705, 2024, doi: 10.1109/ACCESS.2024.3412098, 2024