Mamta , 2026, 14:4
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Smart Waste Segregation Monitoring System for Urban Local Bodies

Mamta, Roshan Kumar, Bhavishya, Peassa Prithvi

Abstract- Rapid urbanization has made the amount of municipal solid waste much larger, which makes it much harder to sort and manage. Traditional methods heavily depend on manual processes, which are slow and often make mistakes. This paper describes a Smart Waste Segregation Monitoring System that uses the Internet of Things (IoT) to automatically sort waste into dry and wet categories while keeping an eye on the fill level of bins in real time. The system combines sensors, microcontrollers and a cloud-based dashboard to make it possible to automatically sort items and keep an eye on them from a web interface. The system performance is analyzed in terms of sensor limitations, communication reliability, and scalability, highlighting challenges in handling composite waste. The proposed system helps with urban city projects and makes urban waste management more efficient by improving the waste in sorted order and how it is picked up.

Keywords: IoT, Waste Segregation, Smart Dustbin.

I. INTRODUCTION

The increasing amount of solid waste produced in cities is a big problem for logistics and the environment. Traditional waste management methods depend heavily on manual labour for collection and sorting which makes it harder to segregate the waste. This is a slow, inefficient process that puts workers in dirty conditions and at risk of health problems. Many cities tell people to separate their trash into dry and wet bins, but this isn't always enough for recycling and resource recovery to work well. Technology, especially the Internet of Things (IoT), has a lot of potential to change this field for environmental improvement.

We can make smart trash cans that not only automate the sorting process but also let us know what's going on in real time by adding sensors, microcontrollers, and communication modules. This paper suggests a smart waste sorting system that will automatically sort trash into different groups(Dry, Wet). A NodeMCU ESP8266 is the main part of the system. It works with different sensors to tell what kind of trash it is. It also has features like automatic lid opening for the user's convenience, fill-level monitoring and improve route optimization efficiency to keep things clean. The goal is to make waste management more efficient, clean, and long-lasting, which will help with projects like "Clean India" and the "Viksit Bharat 2047".

Unlike existing IoT-based waste management systems that focus primarily on monitoring or classification independently, the proposed system integrates waste segregation, real-time monitoring, odor detection, and route optimization within a unified low-cost architecture. This combination represents the key novelty of the proposed work.
Therefore, this study aimed to develop a low-cost IoT-based smart waste segregation and monitoring system capable of automatic waste classification, real-time cloud monitoring, and efficient collection support for urban local bodies.

II. LITERATURE REVIEW

Rapid urbanization has significantly increased municipal solid waste, making efficient waste management a major challenge. Several researchers have explored the use of the Internet of Things (IoT) to improve waste collection and monitoring systems. Bharadwaj et al. proposed an IoT-based smart waste management system that uses sensors to monitor bin levels and optimize collection routes, thereby reducing operational costs and preventing bin overflow [6].

Similarly, Popa and Carutasu developed a smart city platform that integrates automated waste collection with real-time monitoring to improve operational efficiency in urban environments [2]. Wijaya et al. designed a smart waste bin capable of detecting fill levels and sending alerts to authorities; however, the proposed system primarily focused on monitoring rather than automatic waste segregation [7].

Several researchers have also investigated machine learning and image processing techniques for waste classification, but these approaches generally require high computational resources and expensive hardware, making them unsuitable for low-cost deployment.

Overall, existing studies mainly focus on bin monitoring, route optimization, or waste classification as separate tasks, while limited work has integrated waste segregation, real-time monitoring, and route optimization into a single low-cost system. This research gap motivated the development of the proposed IoT-based Smart Waste Segregation Monitoring System.

III. PROBLEM STATEMENT

There are few problems with which we currently handle waste. First, separating mixed waste by hand is a long and dangerous work that puts sanitation workers at risk of getting sick. Second, the lack of real-time information about the status of bins often leads to collection schedules that don't work well. For example, bins overflow while collection vehicles make unnecessary trips to bins that are only half-full.

Fig-1: Garbage Overflow

Third, not being able to correctly separate recyclable materials at the dump yards like plastics end up in landfills, which pollutes the environment and wastes economic potential.

An automated, intelligent system that can accurately sort waste, keep an eye on the status of bins, and make collection quick and easy that is clearly needed to solve these problems.

Fig-2: Improper treatment of garbage in dump yards.

IV. PROPOSED SYSTEM

The Smart Waste Segregation Monitoring System is an IoT-based solution that is meant to automate waste sorting and let urban local bodies keep an eye on it in real time. There are three layers to the system architecture: sensing, communication, and application.

The sensing layer of the proposed smart dustbin consists of multiple sensors. A moisture sensor picks up on dry or wet waste, and an ultrasonic sensor confirms that waste is there. Each bin's fill level is constantly checked by ultrasonic sensors. A servo motor mechanism sends trash to the right compartment, whether it is dry or wet based on the sensor readings.

The communication layer uses an Arduino Uno to gather data from all the sensors and send it to ESP8266 NodeMCU microcontroller which further sends it to Firebase cloud dashboard over Wi-Fi. This makes it possible to sync data in real time and access it from anywhere.

The application layer has a web dashboard that lets city officials see fill percentages, waste detection history, and bin status from anywhere. Alert systems notify officials when bins are full and require emptying. The system also has the ability to optimize routes by looking at fill level data from multiple bins and making priority lists and suggestions for the best collection routes.

The current system uses a heuristic-based priority scheduling approach, where bins with higher fill levels are prioritized for collection. However, this method is not formally optimized. Future work will implement standard algorithms such as Dijkstra's algorithm and Vehicle Routing Problem (VRP) models for optimal route planning and performance evaluation.

Fig-3: Route optimization for waste collection

V.METHODOLOGY

Tools Used

The project uses a collection of sensors to find and sort trash correctly. Each sensor has a unique job that helps the system run automatically and reliably. The Arduino Uno is used as the main control unit of the system, responsible for processing input data from sensors and controlling outputs. It enables communication between different components and ensures the system operates automatically and efficiently.

Fig-4: Arduino Uno used as a Primary Micro Controller

The Raindrop Sensor job is to find wet trash, like food scraps or organic matter. It works by checking how much moisture is in the trash. If the moisture level is too high, the waste is considered wet.

Fig-5: Raindrop Sensor

Ultrasonic Sensors are put in each compartment to keep an eye on the bin's capacity. These sensors check how far apart the top of the bin and the waste level are. The system uses this distance to figure out how full the bin is and sends alerts when it gets too full.

Fig-7: Ultrasonic sensor

A servo motor is used to mechanically direct trash to the right bin. It turns a flap based on sensor inputs to direct trash into dry or wet compartments.

Fig-8: Servo Motor

Technology Used

A combination of hardware and software technologies was used to develop an efficient and connected smart waste management system. The ESP8266 NodeMCU is the main controller at the center. It connects the system to the internet using built-in Wi-Fi and processes data from sensors.

The project uses Google Firebase as a cloud platform for the software. It keeps track of real-time data like how full the bins are and what kind of waste they are. This makes it easy to get information and check on things from a distance.

Fig-9: NodeMCU

HTML, CSS, and JavaScript are used to make a web dashboard that shows the data in a way that is easy to read and understand. It shows the status of bins, alerts, and activity at the system.

Wi-Fi lets the hardware talk to the cloud, which makes the system a part of the Internet of Things (IoT). These tools and technologies work together to make the system efficient, scalable, and good for managing trash in smart cities.

Sensor calibration was performed using multiple waste samples under controlled conditions. Threshold values for moisture detection were tuned experimentally to distinguish between wet and dry waste. Despite calibration, variations in mixed or composite waste affect classification accuracy.

VII. RESULT AND DISCUSSION

The proposed Smart Waste Segregation Monitoring System was evaluated under controlled experimental conditions using multiple samples of dry and wet waste materials. Each category was tested repeatedly to ensure consistency and reliability of results. The system was tested using 40 dry waste samples and 40 wet waste samples. Out of 80 samples the proposed system correctly classified 71 samples resulting in an average accuracy of 88.75%. This indicated effective performance in identifying and classifying waste types using the combination of moisture sensors.

The ultrasonic sensors used for fill-level detection provided stable and consistent measurements, enabling accurate monitoring of bin capacity. The system successfully generated alerts when predefined thresholds were reached, ensuring timely waste collection. Real-time communication between the ESP8266 microcontroller and the Firebase cloud platform was observed to be reliable under stable Wi-Fi conditions, with minimal latency.
However, occasional delays were noticed during network fluctuations, which may impact real-time responsiveness in practical deployments.

Despite the overall effectiveness, certain limitations were identified during testing. The sensor-based classification approach showed reduced accuracy when handling mixed or composite waste materials, as the sensors are designed to detect specific physical properties and may not perform well when multiple materials are combined. Additionally, the system performance is influenced by sensor calibration and environmental factors such as moisture variation. Compared with existing low cost IoT systems the proposed model integrates segregation monitoring odour detection and route optimization in a single architecture while maintaining low hardware cost.

In terms of operational efficiency, the implemented route optimization strategy, based on a heuristic priority approach using bin fill levels, helped reduce unnecessary collection trips. However, this approach lacks formal algorithmic validation and does not guarantee optimal routing. Future improvements will focus on integrating advanced optimization techniques such as Vehicle Routing Problem (VRP) models for better performance.

Overall, the system provides a practical and low-cost solution for smart waste management by integrating segregation, monitoring, and basic optimization. While the results are promising, further large-scale testing and advanced techniques are required to improve accuracy and robustness in real-world scenarios.

FLOWCHART

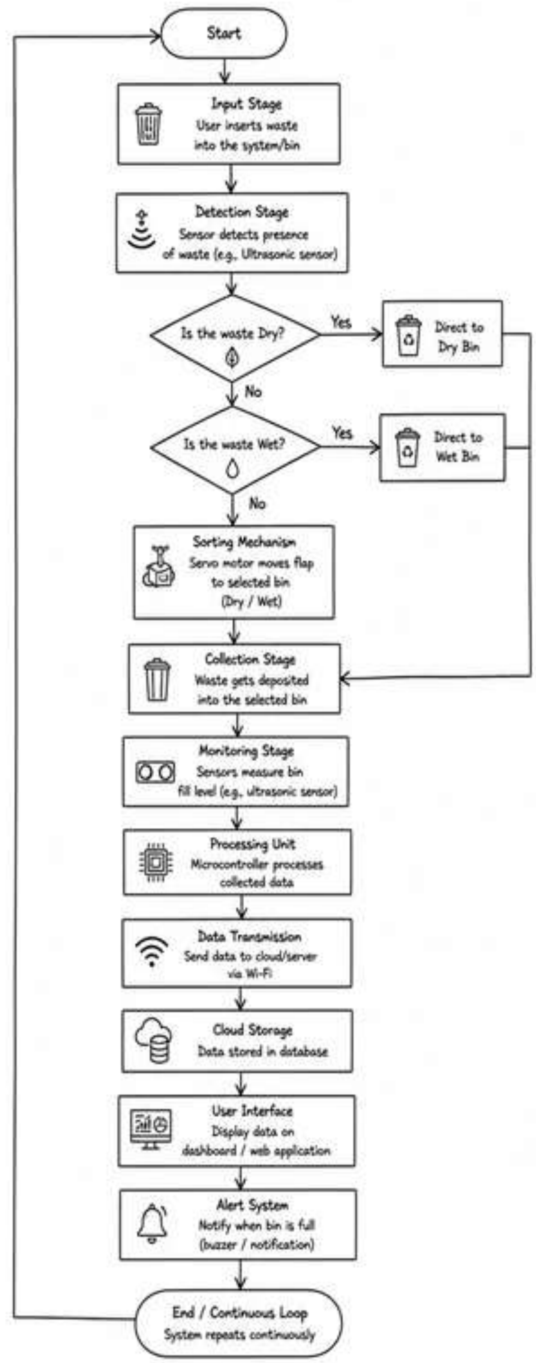

Fig-10: Workflow of the Project

VII. CONCLUSION

The Smart Waste Segregation Monitoring System is a useful way to deal with common problems with trash collection in cities. It reduces the need of workers to handle trash directly by automating the sorting process and giving city officials real-time information about collection schedules.

The system can accurately sort trash into dry and wet categories while keeping track of fill levels thanks to the ESP8266 microcontroller and the combination of raindrop sensors, and ultrasonic sensors. Municipal officials can easily see the status of all the bins in their city by sending data to the cloud and showing it on a web dashboard. This makes it easier to plan efficient collection routes. While the system performs effectively under controlled conditions, further improvements are required for handling composite waste and validating large-scale deployment. This project shows how IoT technology can make traditional waste management more efficient by using data.

VIII. FUTURE SCOPE

The current system meets its main goals, but there are a few ways it could be improved:

Fig-11: Future Enhancement of the Project

The proposed Smart Waste Segregation Monitoring System can be further enhanced by integrating camera-based recognition with artificial intelligence to automatically identify different types of waste, such as paper, glass, plastic, and electronic waste, thereby improving segregation accuracy and efficiency. The inclusion of GPS modules in collection vehicles and waste bins would enable real-time tracking, allowing authorities to monitor collection activities, verify completed services, and respond promptly to missed collections. The use of solar panels with battery backup could make the system energy-efficient and suitable for deployment in areas with limited or unreliable electricity supply. Predictive analytics based on historical fill-level data could be incorporated to estimate when bins are likely to become full, enabling proactive collection scheduling instead of relying solely on threshold-based alerts.

A mobile application could also be developed to help users locate nearby waste bins, check their availability, and encourage proper waste disposal practices. Furthermore, future research will focus on integrating AI-based image classification, advanced route optimization algorithms, and comprehensive communication performance evaluation to improve the overall efficiency, scalability, and reliability of the proposed smart waste management system.

REFERENCES

1. K. Pokalekar, A. Salunkhe, P. Kachare, and N. C. Yadav, "IoT-Based Garbage Monitoring System," International Research Journal of Engineering and Technology (IRJET), vol. 5, no. 3, pp. 3060-3061, 2018.
2. C. L. Popa and G. Carutasu, "Smart City Platform Development for an Automated Waste Collection System," Sustainability, vol. 9, no. 11, Art. no. 2064, 2017, doi: 10.3390/su9112064.
3. S. Mdukaza, B. Isong, N. Dladlu, and A. Abu-Mahfouz, "Analysis of IoT-Enabled Solutions in Smart Waste Management," in Proc. 44th Annual Conf. IEEE Industrial Electronics Society (IECON), Washington, DC, USA, 2018, pp. 4639-4644, doi: 10.1109/IECON.2018.8591236.
4. Nkolika, O., Nafiu, I. and Olanrewaju, K. (2019) 'Development of a smart, automated waste management system', European Journal of Engineering and Technology, 7(2), pp. 56–75.
5. B. Bharadwaj, M. Kumudha, N. G. Chandra, and G. Chaithra, "Automation of Smart Waste Management Using IoT to Support Swachh Bharat Abhiyan: A Practical Approach," in Proc.

2nd Int. Conf. Computing and Communication Technology, 2017.
6. A. S. Bharadwaj, R. Rego, and A. Chowdhury, "IoT Based Solid Waste Management System: A Conceptual Approach with an Architectural Solution as a Smart City Application," in Proc. IEEE Annual India Conf. (INDICON), Bengaluru, India, 2016, pp. 1-6, doi: 10.1109/INDICON.2016.7839147.
7. A. S. Wijaya, Z. Zainuddin, and M. Niswar, "Design a Smart Waste Bin for Smart Waste Management," in Proc. 5th Int. Conf. Instrumentation, Control, and Automation (ICA), Yogyakarta, Indonesia, 2017, pp. 62-66.
8. S. C. Patil and M. R. Gidde, "An IoT-Based Waste Management Approach for Environmental Sustainability," Journal of Integrated Science and Technology, vol. 12, no. 3, p. 769, 2024.