Smart Garbage Segregation and Level Monitoring System

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Abstract
With the rapid urbanization and growing population, effective solid waste management has become an increasingly critical challenge. Improper segregation of waste at the source results in inefficient recycling and disposal processes, leading to increased environmental and health hazards. This paper proposes a cost-effective and scalable system for automatic waste segregation and bin-level monitoring using microcontroller-based IoT technology. The system segregates waste into three categories: dry, wet, and metal, using IR, moisture, and metal sensors. A NodeMCU ESP8266 microcontroller processes sensor data and activates servo motors to direct waste into the appropriate bin. Additionally, ultrasonic sensors monitor bin levels, and status updates are wirelessly displayed via a local Wi-Fi webpage. The results demonstrate reliable classification, timely alerts, and significant reductions in manual effort, enhancing hygiene and contributing to sustainable urban waste management.

Keywords—Waste segregation, NodeMCU, moisture sensor, metal detection, IR sensor, ultrasonic, IoT, smart bin.

I. Introduction

Waste disposal remains a persistent challenge globally, particularly in developing nations. Traditional methods often involve uncontrolled dumping, which leads to groundwater contamination, health issues, and environmental degradation. In India, manual segregation is common, yet it is inefficient, hazardous, and largely unregulated. Source-level segregation is a key strategy to enhance waste recycling and minimize landfill load.

This paper introduces a Smart Garbage Segregation and Level Monitoring System that automates waste classification using embedded systems. It aims to address the inefficiencies of manual sorting and support initiatives like Swachh Bharat Abhiyan and Smart Cities.

II. Literature Review

Effective waste management, particularly at the source level, is a growing challenge in urban environments. Numerous research efforts have been directed toward the development of automatic waste segregation systems, IoT-based smart bins, and intelligent monitoring techniques. This section presents an in-depth review of previous work relevant to our proposed "Smart Garbage Segregation and Level Monitoring System."

K.S. Raju and A. Ramesh [1] proposed a comprehensive model integrating IoT and machine learning to handle waste categorization in real-time. Their approach was primarily focused on using cloud platforms for decision-making, but the system incurred high latency and required extensive training data.

S. Patel et al. [2] developed a waste segregation system using Arduino coupled with machine learning algorithms to classify dry and wet waste. While promising, the cost and computational resources needed limited its practical deployment in low-income regions.

A. Mishra and P. Kumar [3] implemented a simpler version using a combination of IR and moisture sensors for automatic segregation. Although the solution was low-cost and efficient, it lacked advanced monitoring features such as waste level alerts or remote status tracking.

Md. A. Rakib [4] designed a smart dustbin for smart cities with GSM-based notification features. His system focused more on the alerting mechanism rather than waste type classification, leaving room for integration with segregation features.

A. Verma and R. Khandelwal [5] worked on a smart waste bin that monitored garbage levels using ultrasonic sensors. They implemented Wi-Fi-based dashboards for real-time alerts but did not include categorization features for recyclable and non-recyclable waste.

A. Sharma et al. [6] expanded on the idea by combining ultrasonic sensors and NodeMCU to monitor bin status. Their prototype featured a user-friendly web interface; however, they did not automate the physical segregation of waste.

D. Gaurav and B. Yadav [7] designed a smart bin utilizing IR and ultrasonic sensors with IoT connectivity. The bin alerted users when full, but the project lacked the integration of moisture and metal detection capabilities.

J. Bhatt et al. [8] emphasized the importance of integrating smart waste bins in smart city ecosystems. Their research focused on large-scale implementation models rather than detailed hardware execution for real-time sorting.

T. Kumar et al. [9] introduced an Arduino-based waste segregation system capable of sorting wet and dry waste. The simplicity of their design demonstrated the feasibility of implementing such systems at the household level, but lacked scalability and cloud connectivity.

M. Chandra and R. P. Singh [10] developed a classification model for solid waste using IoT, highlighting the potential of edge computing. Their work supported segregating data locally, yet hardware interaction and bin control mechanisms were not addressed.

According to the World Bank [11], global solid waste generation is expected to rise to 3.4 billion tons by 2050, up from 2.01 billion tons in 2016. This alarming statistic underscores the need for source-level segregation and real-time monitoring.

The Ministry of Urban Development's 2021 Swachh Bharat Mission report [12] revealed that despite massive awareness efforts, only 38% of households in India properly segregate waste, indicating the necessity for user-friendly automatic segregation systems.

A. Mehta and S. Mahajan [13] presented a wireless garbage monitoring system using GSM modules. Although effective for remote monitoring, the lack of waste-type classification made it unsuitable for comprehensive segregation.

R. Aggarwal and M. Singh [14] proposed an IoT-based to track bin status but did not implement real-time monitoring system for urban solid waste collection. Their system used cloud dashboards automated waste sorting mechanisms.

M. Gupta [15] developed a low-cost embedded system that physically separated dry, wet, and metal waste. Their servo-based rotating mechanism was similar in design to our proposed system, but their implementation lacked wireless communication for bin status updates.

Recent advancements include AI integration for image-based waste classification. Lam *et al.* [16] proposed an AI-powered smart trash bin with mobile integration. Li and Grammenos [17] designed a low-power, edge-based smart recycling bin achieving high classification accuracy. Ghahramani *et al.* [18] introduced an IoT-enabled route recommendation system for optimized waste collection. Nafiz *et al.* [19] built *ConvoWaste*, a deep learning-based waste segregation machine with GSM alerts.

III. System Design

The hardware components of the proposed Smart Garbage Segregation and Level Monitoring cost System are carefully selected to ensure -effectiveness, efficiency, and real-time functionality. At the core of the system is the Node MCU ESP8266, a Wi-Fi-enabled microcontroller that acts as the central controller, responsible for processing sensor inputs and managing communication. To detect the presence of waste and initiate the segregation process, Infrared (IR) sensors are used. Once detected, the Moisture Sensor plays a key role in distinguishing between dry and wet waste based on their dielectric properties. For identifying metallic waste, a Metal Sensor is integrated into the system. The fill levels of each waste bin are continuously monitored using Ultrasonic Sensors, which ensure timely alerts when bins are full, thereby preventing overflow and maintaining hygiene. The physical movement required for sorting the waste is managed by Servo Motors, which control both the rotating base that positions the correct bin and the flap mechanism that opens and closes during disposal. Together, these components create a fully automated and responsive waste management system suitable for household or institutional deployment.

Working Principle

Upon waste detection via IR sensor, the system classifies it using the moisture and metal sensors. Servo motors rotate a base plate to align the correct bin beneath the disposal point. Bin fill status is monitored through ultrasonic sensors, and updates are shown on a local web page hosted by Node MCU.

IV. Results and Discussion

Tests were conducted using sample waste items .The system accurately identified and segregated the waste into the appropriate bin. Bin full conditions triggered alerts via the webpage interface. Response times were within acceptable limits, and the segregation accuracy exceeded 90%

Table 1 Smart Bin Simulator Status

Bin	Level	Capacity	% Full	Alert
Dry	106.0	100.0	106.0	YES
Wet	92.3	100.0	92.3	YES
Metal	33.6	100.0	33.6	NO

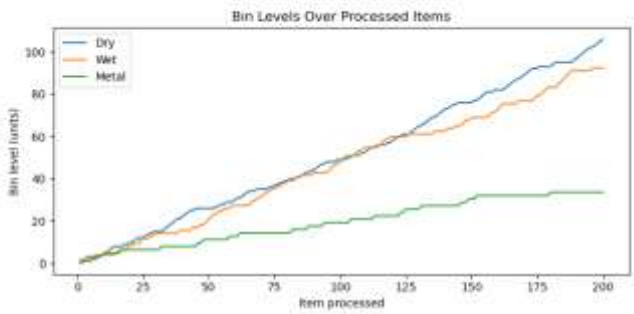

Fig 1 graph of bin levels

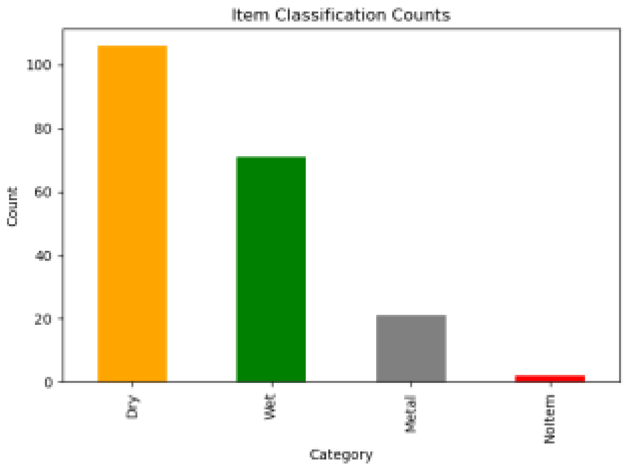

Fig 2 graph of item classification counts

V. Conclusion

The proposed Smart Garbage Segregation and Level Monitoring System provide an efficient, low-cost solution for primary-level waste segregation. By reducing manual labor, enhancing hygiene, and facilitating recycling, it supports sustainable urban living. Future enhancements can extend its applications to industrial and municipal levels.

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