Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/BA08.20250463
Published: December 20, 2025

Smart Waste Segregation System Using Multi-Sensor Classification

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Abstract

Effective segregation is now a critical component of urban environmental management, particularly in emerging regions, due to the sharp rise in municipal solid waste. This study presents a low-cost, sensor-driven intelligent waste sorting system that uses an infrared sensor, rain-drop moisture sensor, and inductive proximity sensor connected to an Arduino-based control unit to automatically classify household waste into metallic, wet, and dry non-metal categories. 30 waste samples were used in the system's experimental evaluation, which produced a total classification accuracy of 76.67%, 80% accuracy for metal and dry trash, and an improvement in wet waste accuracy from 60% to 70% after sensor recalibration. At a total cost of 4320 BDT, the prototype operated with perfect hardware reliability, demonstrating its suitability for environments with low resources, such as households, universities, and small businesses. By reducing the need for manual sorting and minimizing direct human contact with mixed garbage, the proposed method increases worker safety, improves the quality of recyclable material recovery, and encourages more sustainable solid waste management practices.

Keywords

Smart waste segregation, Sensor-based waste classification, Automatic waste sorting.

1. Introduction

The exponential rise in municipal solid waste (MSW), projected to reach 3.40 billion tonnes annually by 2050, imposes severe environmental and economic burdens, particularly in developing nations reliant on open dumping(S., Y. L., B.-T. P., & W. F. V. Kaza, 2018). Although advanced AI-driven classification systems offer high purity, their significant computational demands and operational costs render them unsuitable for decentralized, resource-limited environments, highlighting a critical gap between inefficient manual sorting and inaccessible high-tech solutions. Addressing this limitation, this study presents the design and experimental validation of a cost-effective, multi-sensor smart bin that autonomously segregates waste into metallic, wet, and dry categories using inductive, moisture, and infrared sensing modalities. This research contributes to reliable, economically viable architecture for source-level waste management, serving as a scalable foundation for smart city applications in low- and middle-income contexts.

1.1 Objectives

- To develop a low-cost automated waste segregation system

2. Literature Review

Rapid urbanization has greatly increased municipal solid waste (MSW), disturbing the conventional collection and disposal process and causing environmental pollution, health risks and economic burden(Kabilan M et al., 2024). As a result, automatic waste-segregation devices have come out to reduce manual handling, improve recycling and enable data-driven collection that aligns with the objectives of smart city(Okomba et al., 2024). These solutions promise benefits like reduced landfill overflow, lower contamination of recycled products and a decrease in exposure of sanitation workers to hazardous materials. It also provides operational efficiencies using real-time monitoring(Ranade, 2025).

IoT-based waste management for smart cities was introduced (Rao et al., 2020). A low-cost cloud-based smart recycling bin for in-house classification was introduced (Baras et al., 2020). The system utilizes artificial intelligence and neural networks to classify waste, achieving 93.4% accuracy automatically. Bin data is collected and managed by a centralized information system. SAF-Sutra: A Prototype of Remote Smart waste segregation and Garbage Level Monitoring System, which offers portability and user interaction through a web application(Shetty & Salvi, 2020). A Smart Waste Bin was proposed by Shetty & Salvi which uses sensors to measure weight and how much is filled using Bluetooth. It is a more efficient alternative because traditional systems rely on manual clearance(Shetty & Salvi, 2020). A waste management system using Arduino Uno was introduced, which monitors bin levels and an alert is sent to the city server when the bin is full(Rao et al., 2020). A waste management system was introduced by Issac & Akshai based on a microcontroller with an IR remote and a central framework system where real-time status is shown. Spot Garbage uses convolutional neural networks to detect garbage, and the location is found through smartphone GPS(Issac & Akshai, 2013).

However, despite the recent research that illustrates considerable advancement in terms of AI-based classification, remote bins, and sensor-driven monitoring, most of the existing solutions are restricted when evaluated in terms of low-resource settings. Expensive AI models demand a lot of computing power, whereas most IoT-enabled prototypes rely on a stable network and are almost never tested in non-controlled laboratory environments. Moreover, there are other sensor-based systems available that can only detect a single-parameter, and this makes the sensors less reliable when the waste characteristics differ in terms of moisture content, material structure, or surface characteristics. Such gaps imply that a simple, inexpensive, and multi-sensor segregation mechanism is required that can be run with a high degree of reliability without involving a complicated hardware, or cloud computing.

In an attempt to fill this void, the current project suggests a cost-effective Arduino-based system that incorporates metal, moisture, and infrared sensors to enhance the accuracy of category-specific detection and still make it feasible enough in homes, campuses, and other small institutions. This strategy is a direct response to the fact that the literature is short of scalable, experimentally investigated, and resource economy waste segregation strategies (Table 1).

3. System Design and Architecture

3.1 Hardware Components

Table 1. List of Components

Serial No	Component	Quantity(nos.)	Purpose
1	Arduino Uno	1	Central microcontroller for system control
2	Servo Motor	1	Actuates sorting mechanism for lightweight items
3	Stepper Motor	1	Drives conveyor or rotary sorting platform
4	Stepper Motor Driver	1	Controls stepper motor operation
5	Rain Drop Moisture Sensor	1	Detects moisture content in waste
6	IR Sensor	1	Identifies object presence and type
7	Proximity/Metal Sensor	1	Detects distance and triggers sorting
8	USB Cable	1	Powers and programs of Arduino
9	Jumper Wire	40	Electrical connections
10	Battery (3.7V)	3	Portable power supply

11	Battery Holder	1	Holds and connects batteries
12	Big Buzzer	1	Audio alert for system notifications
13	Male jack	1	Power interface

3.2 Software Components

- **Arduino IDE:** Open-Source software to run the Microcontroller

3.3 System Flow Diagram

The system flow diagram shown in Figure1 demonstrates the complete operational sequence of the suggested automated waste sorting system. The procedure starts with a waste item being placed in the input section, where it undergoes an initial assessment by an inductive proximity sensor to identify if it is metallic. When metallic content is identified, the microcontroller triggers the relevant mechanism to redirect the item to the metal waste bin. If no metal is found, the item moves to the following stage, where a moisture sensor assesses its dampness to categorize it as wet non-metal waste. Consequently, items that do not meet the moisture threshold are automatically classified as dry non-metallic waste and directed to the designated container. During this process, the microcontroller oversees the gathering of sensor data and control commands, ensuring every waste object is categorized based on these sequential decision rules.

4. Methods

An effective and simple method was employed to categorize waste by utilizing various inexpensive sensors and to automatically separate it into metal, wet, and dry non-metal categories. Special attention was focused on choosing and integrating suitable sensing components, ensuring the dependability of the Arduino control and actuation system, as well as optimizing system expenses, structural compactness, and ease of operation (Figure 1).

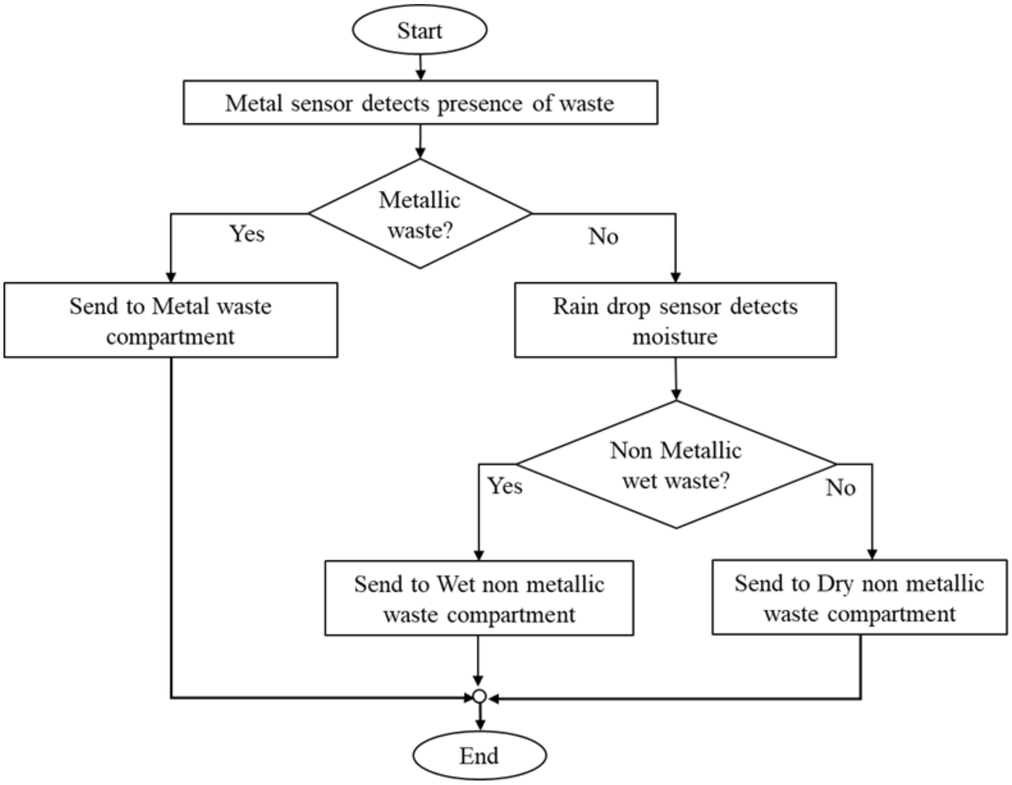

Figure 1. System flow diagram

4.1 Circuit Design:

The sensor and actuator circuit are designed around an Arduino microcontroller, which receives digital signals from the inductive proximity, rain drop, and IR sensors and based on the classification logic, drives the servo motor and buzzer through appropriate control lines and a shared DC power supply (Figure 2).

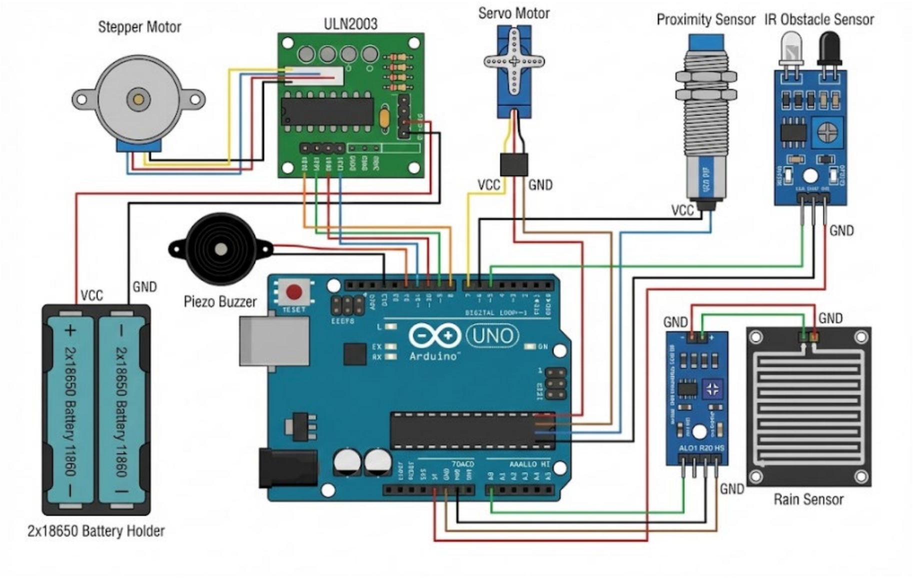

Figure 2. Circuit Design

5. Testing and Results

5.1 Testing Methodology

The system experienced thorough evaluations in two stages to assess the detection precision of the multi-sensor waste separation system. Initial testing (Phase-1) involved 30 samples to verify and ensure system performance across various waste categories. Another test (Phase-2) was conducted.

5.1.1 Prototype Preparation

The samples tasted were tasted via our physical prototype, which is demonstrated in Figure 3. Figure 3 represents the physical prototype.

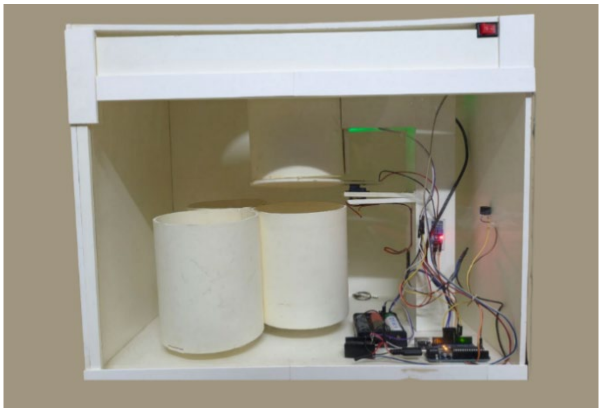

Figure 3. Waste Segregation Prototype

5.1.2 Test Sample Preparation

For the comprehensive 30 sample validation test, waste items were systematically selected and distributed equally across three target waste categories:

1. Metal waste items: 10 samples (aluminum cans, tin containers, iron scraps, wire, metal foil)
2. Dry non-metallic waste: 10 samples (plastic bottles, cardboard, dry paper, fabric, wood pieces)
3. Wet non-metallic waste: 10 samples (food residues, wet paper, vegetable scraps, wet leaves, damp cloth)

5.1.3 Testing Environment & Conditions

Temperature: 25°C ± 2°C
Relative Humidity: 45-50%
Lighting: Standard artificial light (500 lux)
Power Supply: 11.1V DC from three 3.7V lithium-ion batteries in series
Test Duration: 3.5 hours total

5.2 Testing Result Summary

Table 2 presents the data from tests while Figure 4 displays a summary of the experimental findings, with the blue bars denoting the first phase of testing and the red bars indicating the second phase of testing. The results showed that, the system performed well in metallic and dry non metallic waste detection while, inefficiency was observed in wet non-metallic waste detection mechanism.

Table 2. Result of the testing

Waste Category	Samples Tested	Phase 1 Correct	Phase 1 Accuracy	Phase 2 Correct	Phase 2 Accuracy	Improvement
Metal	10	8	80%	8	80%	—
Dry Non-Metallic	10	8	80%	8	80%	—
Wet Non-Metallic	10	6	60%	7	70%	+10%
TOTAL	30	22	73.33%	23	76.67%	+3.34%

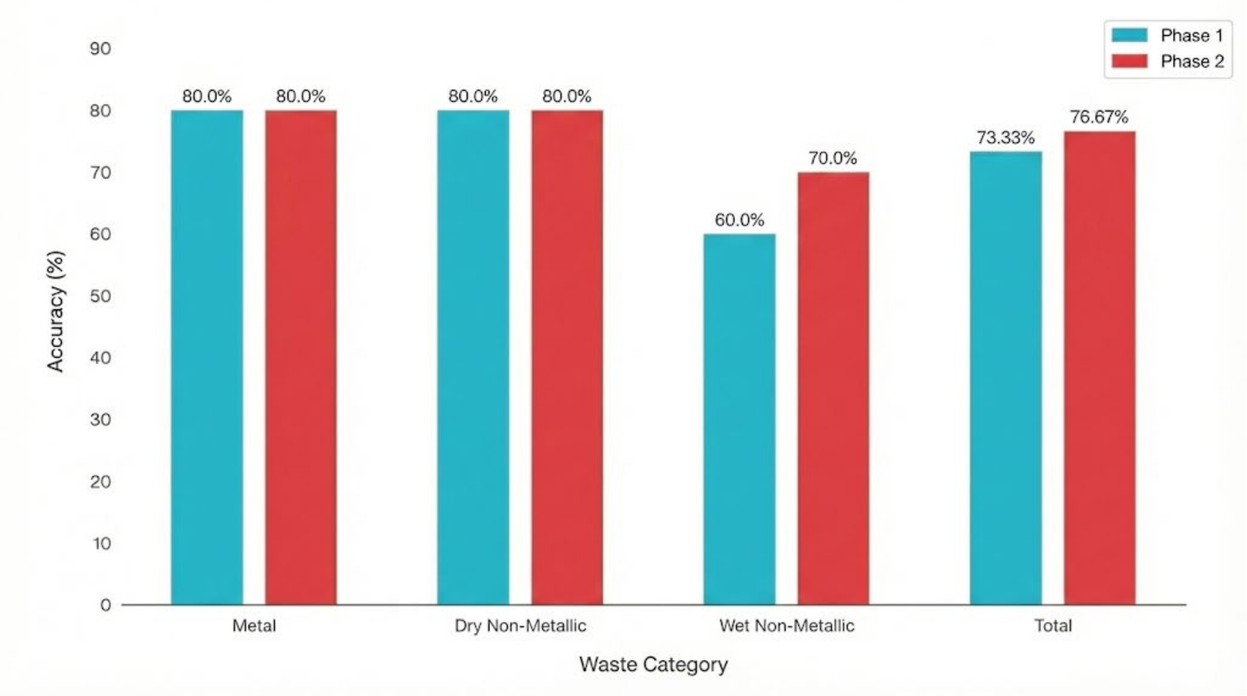

Figure 4. Result Summary of two-phase testing

The project was developed with an objective to develop a low-cost automated waste segregation system and to accomplish that, the components purchased is listed below along with its respective cost. The entire information regarding the costing is tabulated in Table 3.

Table 3. Price for Components

Serial No	**Component Name**	**Unit Price (Taka)**	**Quantity (Nos.)**	**Total Price (Taka)**
1	Arduino Uno	600	1	600
2	Servo Motor	200	1	200
3	Stepper Motor	200	1	200
4	Stepper Motor Driver	100	1	100
5	Rain Drop Moisture Sensor	150	1	150
6	IR Sensor	50	1	50
7	Proximity Sensor	300	1	300
8	USB Cable	100	1	100
9	Jumper Wire	2	40	80
10	Battery (3.7V)	120	3	360
11	Battery Holder	100	1	100
12	Big Buzzer	70	1	70
13	Male Jack	10	1	10
14	Bin Box	1000	1	1000
15	Assembly Cost of Bin Box		-	1000
Total cost				**4320**

6. Conclusion

The rapid growth of municipal solid waste poses significant challenges to urban health, environmental quality, and resource efficiency, particularly in developing countries. This study presented a low-cost, sensor-based smart waste segregation system that classifies waste into metal, wet, and dry non-metallic categories using an inductive proximity sensor, rain-drop moisture sensor, and IR sensor integrated with an Arduino microcontroller. Experimental evaluation on 30 samples achieved an overall accuracy of 76.67%, with 80% accuracy for metal and dry waste and an improvement in wet waste accuracy from 60% to 70% after sensor recalibration, demonstrating the technical feasibility of the proposed multi-sensor architecture as a proof-of-concept for automated source-level segregation. The prototype further exhibited 100% hardware reliability and low implementation cost (4320 BDT), indicating suitability for resource-constrained contexts such as households, campuses, and small institutions. While the performance is currently below that of advanced AI- and vision-based systems, the simplicity, affordability, and ease of replication make it a practical baseline for scalable waste segregation. Future work will address larger-scale testing, robust calibration under varying environmental conditions, integration of additional sensing modalities, and IoT-based monitoring to advance the system towards a field-ready solution that supports cleaner urban environments and improved recovery of recyclable and organic fractions.

7. Future Work

The suggested system operates efficiently as an affordable proof-of-concept for sensor-driven waste sorting, yet numerous improvements can be made. Future efforts could concentrate on merging more sophisticated and durable sensors with flexible calibration to boost classification precision in different environmental scenarios, alongside implementing smart classification techniques (such as machine learning on superior microcontrollers) to advance decision-making. Enhancements in mechanics and actuation could boost efficiency and dependability, while IoT connectivity would facilitate real-time tracking and integration with smart city systems. Ultimately, extensive field deployment and testing in varied environments are essential to confirm long-term performance, user acceptance, and economic feasibility.

References

Baras, N., Ziouzios, D., Dasygenis, M., & Tsanaktsidis, C. , A cloud based smart recycling bin for in-house waste classification. *2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, 1–4.2020. https://doi.org/10.1109/ICECCE49384.2020.9179349

Issac, R., & Akshai, M, SVASTHA: An effective solid waste management system for Thiruvalla Municipality in Android OS. *2013 IEEE Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS)*, 254–259. 2013. https://doi.org/10.1109/GHTC-SAS.2013.6629926

Kabilan M, Lokesh B., & Kishore R. , Dry and Wet Waste Segregation: A Comprehensive Overview of an Advanced Automatic Waste Segregation System. *Asian Journal of Applied Science and Technology*, *08*(01), 85–91. 2024. https://doi.org/10.38177/ajast.2024.8107

Okomba, N. S., Abidemi, A. A., Chikezie, A. S., Nwobodo, L. O., & Nduanya, U. I., Development of home applied waste segregation and management system. *Dutse Journal of Pure and Applied Sciences*, *10*(2c), 75–84. 2024/ https://doi.org/10.4314/dujopas.v10i2c.8

Ranade, G. A, Research on Automatic Waste Segregation. *International Journal for Research in Applied Science and Engineering Technology*, *13*(4), 2184–2189. 2025. https://doi.org/10.22214/ijraset.2025.68707

Rao, P. V., Azeez, P. M. A., Peri, S. S., Kumar, V., Devi, R. S., Rengarajan, A., Thenmozhi, K., & Praveenkumar., P. , IoT based Waste Management for Smart Cities. *2020 International Conference on Computer Communication and Informatics (ICCCI)*, 1–5. 2020. https://doi.org/10.1109/ICCCI48352.2020.9104069

Shetty, S., & Salvi, S., SAF-Sutra: A Prototype of Remote Smart Waste Segregation and Garbage Level Monitoring System. *2020 International Conference on Communication and Signal Processing (ICCSP)*, 0363–0367. 2020. https://doi.org/10.1109/ICCSP48568.2020.9182408

Kaza, S. , Y. L. , B.-T. P. , & W. F. V., *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. 2018.

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