Minimax Theory and its Applications
Volume 11 (2026), No. 5s, 17 to 25

Minimax-Based Performance Evaluation of a Nonlinear Automated Waste Segregation System

Dr. Jyoti Rangole[1], Dr. Sanket B. Kasturiwala[2], Dr. Pankaj Gadge[3], Dr. Rushikesh Bankar[4], Prof. Harsha Tembhekar[5], Prof. Nitin Chakole[6]

[1] Department of Electronics and Telecommunication Engineering, Vidya Pratishthan Kamalnayan Bajaj Institute of Engineering and Technology, Baramati.
[2] Department of Electronics & Telecommunication Engineering, G H Raisoni College of Engineering and Management, Nagpur, Maharashtra, India. Email: sanket.kasturiwala@gmail.com
[3] Department of Electronics & Telecommunication Engineering, Sipna College of Engineering and Technology, Amravati.
[4] Department of Electronics & Telecommunication Engineering, G H Raisoni College of Engineering and Management, Nagpur, Maharashtra, India.
[5] Department of Computer Technology, YCCE, Nagpur, Maharashtra, India.
[6] Department of Electronics & Communication Engineering, Ramdeobaba University (formerly Shri Ramdeobaba College of Engineering & Management), Nagpur – 440013.

Abstract
In the 21st century, waste management has emerged as a growing global challenge. Rapid population growth and urbanization are key factors contributing to increased waste generation. Effective waste management is crucial for public health, environmental protection, and economic development, and is a foundational requirement for building hygienic and smart cities. One promising solution is the use of automated waste segregation systems that categorize waste into wet, dry, and metallic types. In this work, we have developed an automatic waste segregation system that utilizes microcontrollers, electronic sensors including moisture sensors, inductive proximity sensors for metals, and infrared sensors for object detection, and a mechanical sorting assembly. The automated system simplifies the waste segregation process, minimizes the need for manual labour, and promotes sustainable waste management practices. By streamlining waste handling and reducing environmental impact, such systems play a vital role in achieving eco-friendly and sustainable urban development. During performance testing on 200 waste samples, the system achieved segregation accuracies of 93% for dry waste, 98% for metallic waste, and 84% for wet waste. The average processing times for segregating metal, wet, and dry waste were 2.3 seconds, 3.4 seconds, and 5.7 seconds, respectively. This paper contributes to the advancement of environmentally responsible technologies by demonstrating the feasibility and effectiveness of automated waste segregation supporting broader goals of sustainable development and environmental conservation.

Keywords:Automatic Waste Segregator, Dry, Inductive Proximity Sensors, Metallic Waste Material, Wet.

Introduction

Rapid population growth in urban areas is leading to inadequate waste disposal and management, which in turn can cause a range of health hazards and infrastructure risks. For example, cities often face increased disease outbreaks and diminished access to vital services due to the buildup of waste. In India, a country with a population of approximately 1.35 billion, about 60 million tons of trash are generated annually, and metropolitan regions alone produce around 10 million tons of garbage. On average, each person generates roughly 0.45 kg of waste per day, although estimates vary between 0.12 and 5.1 kg per person per day (Henam S.D. et al. and Bandela D.R. et al., 2020).

Waste generation encompasses all discarded materials that are either recycled or disposed of in landfills. It is generally categorized into four major types: municipal solid waste (which includes household, school, college, restaurant, and office waste), industrial waste, agricultural waste, and hazardous waste. Municipal solid waste further divides into biodegradable (such as fruit and vegetable remnants) and non-biodegradable components (including plastics, metals, and construction debris), along with minor hazardous items like light bulbs, batteries, and auto parts (V.P. et al., 2020).

One promising solution to these challenges is to segregate waste at the point of disposal. Accordingly, we have developed an economical "Automatic Waste Segregator and Monitoring System" designed for effective waste management. This automated system sorts trash into three categories—wet, dry, and metallic—using a combination of sensors and microcontroller-based control. Specifically, moisture sensors distinguish between wet and dry waste, while proximity sensors identify metallic items. The system integrates ultrasound sensors for enhanced differentiation and employs GSM-based alerts to monitor garbage levels for regulatory bodies (Manjula S. et al. and Bhagya L. et al., 2023).

For user convenience, the system incorporates a voluntary waste segregation mechanism (SWS) that serves as a cost-effective, user-friendly solution for households and businesses alike (Navale A. et al. and Babrah J. et al., 2020). The system's microcontroller—using a PIC16F886-I/SP, an 8-bit CMOS device from the PIC18 family—manages sensor inputs and controls servo motors responsible for deflecting waste into appropriate bins. An LCD displays real-time output, and the entire process is programmed in Embedded C. By sorting waste directly at the source, this approach streamlines the recycling process and eliminates the need for secondary sorting at recycling facilities.

Table 1: Critical Gap Analysis and Our Contributions

Existing Approach	Identified Gaps	Our Contributions
IoT-based Smart Bins	Lack waste-type segregation; used mainly for monitoring fill levels	Our system integrates real-time monitoring with in-situ segregation
AI-based Waste Sorting	High cost, complex implementation, requires training datasets	We use cost-effective, sensor-driven logic suitable for household/urban deployment
Basic Embedded Segregators	No real-time monitoring, limited waste type coverage	We incorporate GSM-based alerts, LCD output, and multiple sensors for accuracy
Manual Sorting Systems	Labor-intensive, unhygienic, inefficient	Fully automated, contactless sorting mechanism with minimal human intervention

Table 1 shows the critical gap analysis among IoT Based Smart Bins, AI based waste sorting, Basic embedded segregation tools and manual sorting system. Existing solutions like IoT bins and AI-based systems either lack segregation capabilities or are costly. This paper presents a low-cost Automatic Waste Segregator and Monitoring System using sensors and a microcontroller to categorize waste into wet, dry, and metallic types.

This automated system not only simplifies waste segregation but also supports sustainable practices by ensuring that recyclables are efficiently directed to processing centres. Through reducing manual labour and improving waste handling efficiency, the system's performance validates its utility in promoting the 3Rs (Reduce, Reuse, Recycle) and supports broader goals of smart city development and environmental sustainability.

Material and Methods

The proposed system has been implemented after studying and learning about various existing technologies related to waste segregation and management. Some of the existing work has been highlighted and noted. The findings are listed in the results section after these systems are contrasted with the suggested system. The smart bin (Hiremath S. *et al* 2018) is a waste management system that has several features, with the main one being the ability to separate different types of garbage. It has four compartments for different types of waste, including plastic, wet, dry, and wastewater from its automatic cleaning feature. The bin also has ultrasound sensors that allow it to open when someone approaches it to throw away garbage, making it more hygienic and convenient to use. In addition, the smart bin has an analysis feature that provides information on the amount and type of garbage disposed of by the user, with data available in daily, weekly, and monthly graphs. The app connected to the bin sends reminders to users when it is time to dispose of their garbage. The sensible bin encourages garbage separation for reprocessing and aids in improving collection and disposal. In order to solve the issue of ineffective garbage segregation, the proposal (Rejeth P.S. *et al*, Badsha T.S., *et al* 2018) suggests an unmanned waste segregation unit by addressing the issue of waste segregation, Smart Bin aims to contribute to the creation of a more sustainable society while maintaining high standards of health and hygiene. A revolutionary trash handling strategy called the Intelligent Waste Separator (IWS) (Sangaiah A. *et al*, 2018) sorts and separates trash intelligently using multimedia image processing using image recognition algorithms, machine learning and multimedia integrated CPU. It has a communal garbage can and extra outlets and makes use of interactive multimedia. This prototype can potentially replace traditional waste management methods. The automatic garbage segregation device detects garbage employing Infrared Sensors which divides waste into several groups by using convolution neural networks.

The goal of this system is to enhance the reuse and recycling procedures, which will result in more effective management of waste. It builds a system that can successfully separate garbage using artificially intelligent neural networks, picture analyzing, and particularly visual detection algorithms. Using an induction method, the Adaptive and Interactive Modeling System (AIMS) (Tarbell, K.A., *et.al.* 2014) analyzes big quantities of information to produce an effective specification of object properties that will guide substance sorting tactics. Mechanism for Segregating Waste (Peer G. *et al*, Prabha L.G. *et al*, (2021) Organic garbage, commonly referred to as wet waste, consists of things like remnants and vegetable skins. Garbage disposal has become a major global concern, as waste that is disposed of in harmful ways to the environment has increased significantly. Industrial and domestic waste are major sources of this problem (Rahman M M. *et al*, Abbas F.I. *et al* 2021). One issue is that people are not properly segregating waste into its basic streams, particularly in the case of industrial waste that is very hazardous to environment. The effort focuses on solving this issue by employing a direct processing, low-cost segregation method through a smart trash can that may be employed in medium-sized as well as minor businesses or enterprises.

The system that has been proposed resolves the issue of waste segregation. This system replaces the manual or traditional methods of waste collection and separation. The waste can be separated automatically as wet, dry and metallic waste and reaches the assigned bin.

The user doesn't need to monitor the system whenever the waste is being segregated and collected in the bins. Once the system is provided with the power supply, the system detects the waste as metallic, wet and dry and then the waste is moved forward to their assigned bins. This leads to successful segregation of waste without any manual interference. Automatic waste segregation helps in proper waste management. Adapting this method will result in proper disposal of waste and thus reduce the harmful effects. The proposed system is cost effective and user friendly.
Following table 2 gives the concise details about the reasons, specifications and their purpose the proposed system. These sensors were selected for their affordability, low power consumption, easy integration with microcontrollers, and suitability for real-time, contactless waste detection in varied environmental conditions.

Table 2 : Selection of Sensors and their specifications

Sensor	Purpose	Specifications	Reason for Selection
Moisture Sensor(e.g., YL-69 /FC-28)	Detect moisture to classify wet waste	- Operating Voltage: 3.3–5V- Analog/Digital output- Corrosion-resistant probes	- Cost-effective- Simple integration with microcontroller- Accurately detects organic wet waste
Inductive Proximity Sensor(e.g., LJ12A3-4-Z/BY)	Detect metallic waste	- Voltage: 6–36V DC-Sensing Distance: ~4 mm- Detects ferrous/non-ferrous metals	- Contactless operation-Durable in waste environments- Highly reliable for metal detection
Ultrasonic Sensor(e.g., HC-SR04)	Object detection & fill-level monitoring	- Range: 2 cm to 400 cm-Accuracy: ±3 mm-Operating Voltage: 5V	- Non-contact measurement-Ideal for garbage level detection- Low cost and widely supported
Infrared (IR) Sensor (e.g.,IR Obstacle Sensor)	Presence detection and reflectivity-based sorting	- Range: up to 30 cm-Digital output- Operating Voltage: 3.3–5V	- Compact and responsive-Good for object classification support- Easy to interface with controller

System Operation
In the block diagram i.e. Figure 1. The Moisture Sensor and Metal detector are connected to the Microcontroller and microcontroller output pins are connected to Display and driver and motors. Liquid Crystal Display is used to display moisture and metallic content. LCD works on the principle of blocking light rather than emitting light whatever the electric signals it is receiving it will represent it in digital form

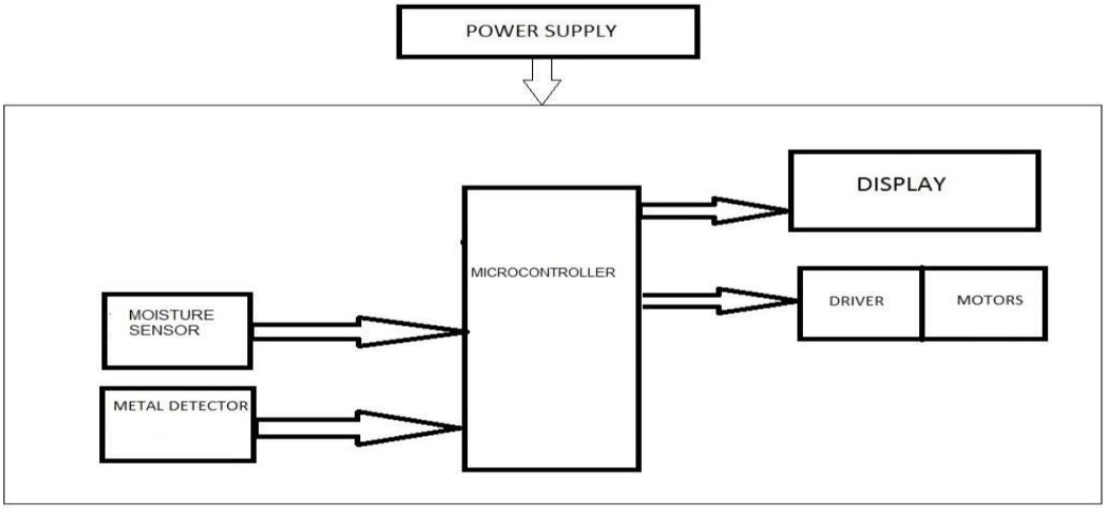


Figure 1: Automatic Waste Segregator (Block Diagram)

Moisture Sensor detects or measures the moisture levels and content in the particular trash. The moisture content is measured using the electrical resistance which is proportional to its moisture content. The sensor has two exposed probes that have to

make direct contact with the waste material. An electrical current is sent from one probe to another, allowing the sensor to measure resistance and accordingly we get the value for moisture levels in the waste.
Metal Detector is the Inductive proximity sensor which is used for the detection of the presence of metallic material. It uses electromagnetic energy to attract metals without having any direct contact. They can only detect the presence of metal and cannot detect non-metallic substances such as glass, wood, paper, etc. It detects the presence of a material like metallic waste when the metal value is greater than 30, PR > 30. The input of these sensors is given to the microcontroller. The computed metallic and moisture contents of the waste material are then displayed on the 16 x 8 LCD display to the user. After detection of metallic waste, a delay of 500ms and after the detection of moisture containing waste a delay of 3000ms are given so that the conveyor belt stops moving and the flaps of the servo motor throws the waste in their assigned bins.
The flow of our proposed system goes as shown in (Fig. 2) and the prototype of "Automatic Waste Segregator and Monitoring System"

a) For the detection of wet waste, when we release a used wet tissue on the conveyor belt the wires connected withthe moisture sensor will immediately detect the moisture present in the particular waste material and will display the moisture value M = 12 on the LCD screen Then after a delay of 3000ms the conveyor belt will stop and the servo motor's flap will push the waste into the assigned bin.

b) For the detection of metallic waste when we release a used DC motor on the conveyor belt the proximity sensor will detect any metallic value which is greater than 30. Here the metallic value displayed on the LCD screen is PR = 70. Further after a delay of 500ms the conveyor belt will stop moving and the servo motor situated near the proximity sensor will push the waste in the assigned bin using the flap.

c) After releasing any dry waste such as a used chocolate wrapper it will pass through the whole conveyor belt withan LCD screen displaying moisture sensor and proximity sensor values M = 0 and PR = 0 respectively. The waste will fall into the last assigned bin situated at the end of the conveyor belt.

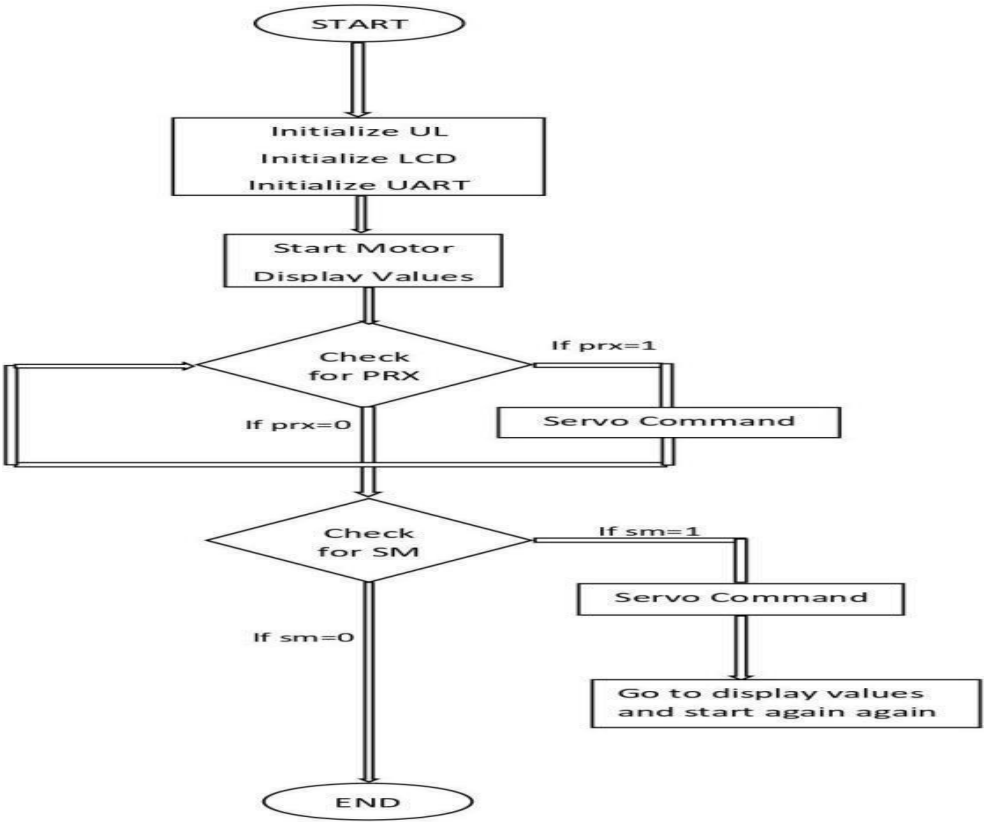


Figure 2: Automatic Waste Segregator Microcontroller Algorithm Flowchart

Figure 3 illustrates the working process of an Automatic Waste Segregator and Monitoring System. Waste is first introduced through the Bin Inlet and carried forward on a Conveyor Belt, which ensures a steady and controlled flow of materials for inspection. As the waste moves along, it first encounters a Proximity Sensor, which detects the presence of any metallic objects. If metal is identified, a Servo Motor is activated to divert the metallic item into the Metallic Waste bin. Non-metallic waste continues further to a Moisture Sensor, which measures the moisture content to determine whether the waste is wet or dry. If the waste is wet (e.g., food scraps), a second Servo Motor diverts it into the Wet Waste bin. Otherwise, the waste is classified as dry and is directed toward the Dry Waste bin with the aid of a Blower, which ensures the lightweight dry materials are efficiently moved. This flowchart highlights a sensor-driven, automated waste segregation process that classifies waste into three categories—metallic, wet, and dry—enabling effective and eco-friendly waste management.

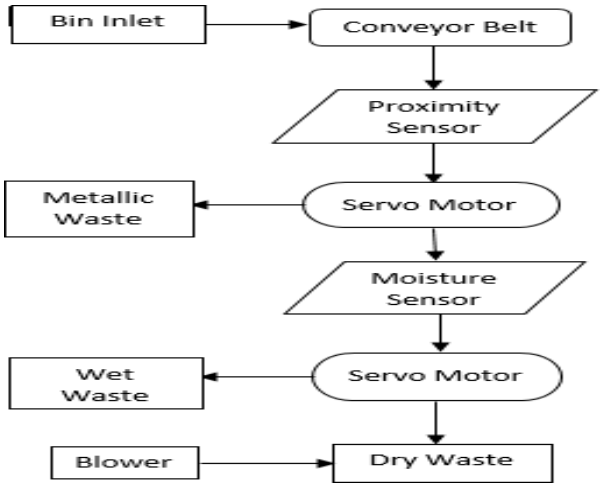


Figure 3: Automatic Waste Segregator Flow Chart

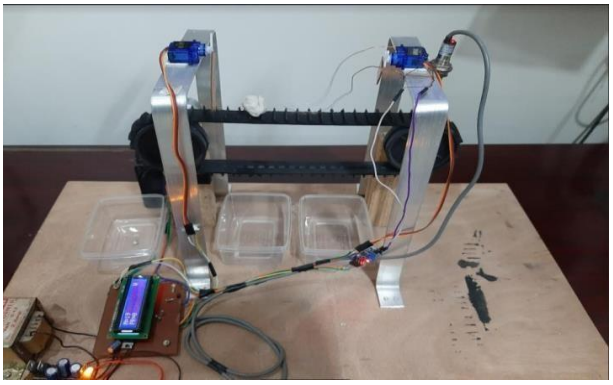


Figure 4: Moisture Sensor Detecting Wet Waste

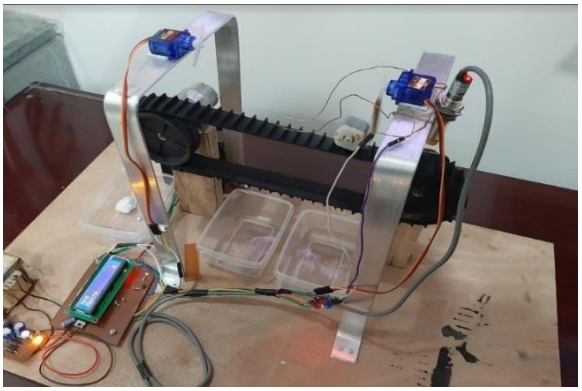


Figure 5: Proximity Sensor Detecting Metallic Waste

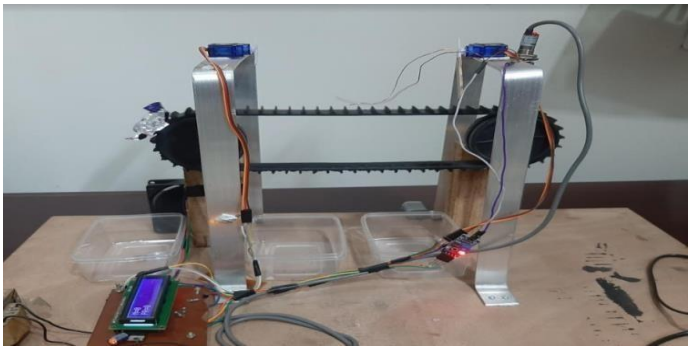


Figure 6: Dry Waste

Figure 4 represents a prototype of Moisture Sensor Detecting Wet Waste, figure 5 represents a prototype of Proximity Sensor

Detecting Metallic Waste and figure 6 represents a prototype of Dry Waste.

Result

Robustness of designed and developed auto waste segregator system shows better performance to achieve the proper segregation of dry, wet and metallic waste at certain conditions. Highly efficient and less costly experimental hardware setup such as servo motors, Microcontroller-PIC16F886,Inductive Proximity Sensor, Moisture Sensor, Blower and Liquid Crystal Display provides flexibility for user operation and performance. Various experiments were performed on the proposed system to check reliability. The proposed system monitors and separates out the dry, wet and metallic waste efficiently. As the waste is detected and sensed, the category of dry, wet, or metallic waste is displayed on the LCD of the system. LCD also gives the exact number of garbage counts. The experiments were conducted with different types of waste material of different kinds to check the accuracy of the system and ensure proper functioning.

Table 3. Result – Analysis of Testing of Types of Waste Material

Sr. No.	Type of Waste Material	Material used	LCD display Sensor Value
1	Dry	Chocolate Wrapper	0
2	Wet	Banana Peel	16
3	Wet	Used Wet Tissue	12
4	Metallic	Old used Battery	71
5	Metallic	DC Motor	70
6	Metallic	Safety Pin	69

From Table 3. we can observe that there are three types of waste materials that were tested i.e Dry, Wet and Metallic that includes Chocolate Wrapper, Banana Peel, Used Wet tissue, Old used Battery, DC Motor and Safety Pin.
We observed that in our proposed system

i. Metallic value lies between 60-75.
ii. Wet waste value lies between 10-20.
iii. Dry waste value will always display 0.

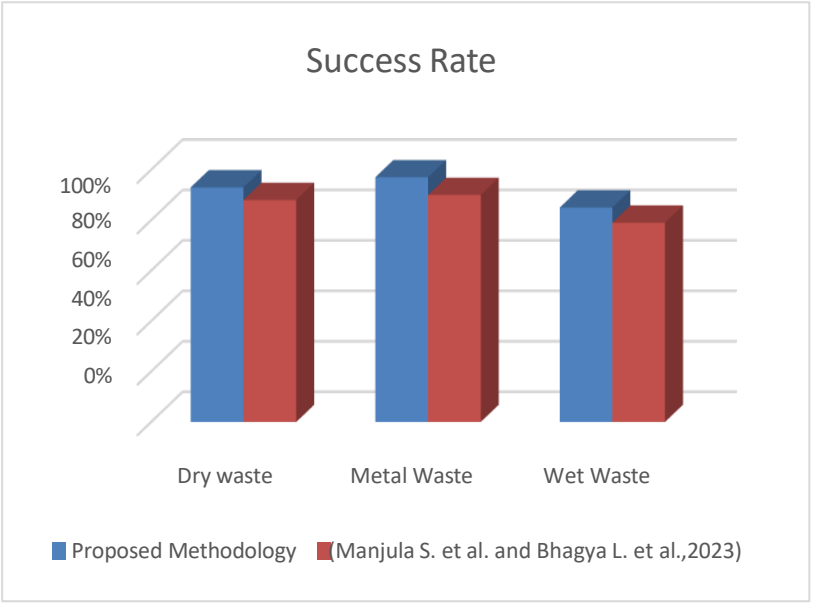


Figure 7: Success Rate for Detection

We have compared result with (Manjula S. e*t al.* and Bhagya L. *et al*.,2023). The overall successful detection rate is found as shown in Fig.7. During the performance testing of the system, the accuracy of the system was for Dry waste 93%, Metal waste 98% and Wet waste 84% for 200 samples and also the time taken by the system to separate metal waste, wet waste, and dry waste respectively was 2.3, 3.4, and 5.7 seconds.
Table 4 shows the test results of the waste after being subjected to the proposed auto waste segregator system.

Table 4: Results – Identification of Types of Wast

Type of waste	Waste Name	Identified or Not
Dry waste	Paper	Yes
	Wood Chips	Yes
	Plastic	Yes
	Cardboard pieces	Yes
Wet Waste	Vegetable peels	Yes
	Fruit pieces	Yes
	Lemons	Yes
	Banana	Yes
Metal Waste	Safety pins	Directly enter metal waste bin
	Small metal pieces	
	Aluminium sheet pieces	
	Tin sheet pieces	

Following table 5 illustrates a comparative analysis of the proposed system against benchmark systems and existing literature, based on referenced works. The proposed system achieves a balance of accuracy, cost-efficiency, and deployability for small-to-medium-scale waste management needs. Compared to vision-based or app-driven systems, it offers faster classification, energy-efficient operation, and potential security applications.

Table 5 Comparative Analysis of Proposed Waste Segregation System vs. Benchmark Models

Feature	Proposed System	Smart Bin (Hiremath et al., 2018)	IWS (Sangaiah et al., 2018)	SWS (Navale et al., 2020)	AIMS (Tarbell et al., 2014)
Waste Categories Detected	Dry, Wet, Metal	Plastic, Wet, Dry, Wastewater	Mixed waste via image recognition	Dry, Wet	Material properties via large data
Sensor Technology	Moisture sensor, Inductive proximity sensor	Ultrasonic, Moisture sensors	Image processing, ML	Moisture, Ultrasound	Data-driven object property analysis
Microcontroller Used	PIC16F886	Not specified	Multimedia integrated CPU	Arduino/ Embedded	High-performance ML processors
Automation Level	Fully automated with real-time display	Semi-automated	Intelligent image-based separation	Semi-automated	High, based on inductive modelling
Accuracy (Reported)	Dry: 93%, Metal: 98% Wet: 84% (200 samples)	Not disclosed	Not disclosed	Not disclosed	High precision expected
Time to Sort Waste	Metal: 2.3s, Wet: 3.4s, Dry: 5.7s	Not reported	Not reported	Not reported	Near real-time
Unique Contributions	Real-time LCD display, sensor fusion, expandable AI-IoT backend	User app integration and auto-cleaning	Vision-based classification with ML	GSM-based monitoring and alerts	Learning-based adaptive classification

Cost-Effectiveness	High (uses low-cost sensors and MCU)	Medium	High (computationally intensive)	Low	Medium to High
Scalability	Household and institutional level	Domestic level	Urban-level smart bins	Homes and small offices	Industrial and public sector
Limitations	Sensor calibration drift, bin overflow.	Limited waste types	High processing requirements	Basic waste categorization	Complex hardware/software integration

Discussions

Improper waste management continues to pose significant risks to both public health and the environment. The proposed AI-IoT-based waste segregation model was tested under real environmental conditions and demonstrated successful classification of waste into three primary categories: dry waste, wet waste, and metal waste. The system effectively collected and segregated solid waste with minimal manual intervention.

Table 3 presents LCD-based sensor outputs for each waste category, enabling real-time monitoring of waste volumes. This data can inform strategies to curb excessive waste generation by identifying predominant waste types. Table 4 details the classification of test samples, including dry waste (paper, wood chips, plastic, cardboard), wet waste (vegetable peels, citrus fruits, banana), and metal waste (safety pins, aluminium sheets, tin pieces). While dry and wet waste were reliably sorted, metal items were directly identified and diverted into a separate bin using embedded inductive metal sensors.

A notable strength of the system is its ability to detect and isolate metallic waste, including potential hazardous components. This functionality has extended use cases in security-sensitive environments, offering utility for defence or intelligence agencies to detect dangerous metallic substances.

However, several limitations were observed:

- **Sensor Calibration Drift**: In prolonged usage, moisture and temperature fluctuations led to drift in sensor calibration, particularly affecting organic/wet waste detection. Periodic recalibration is required to maintain classification accuracy.
- **Bin Overflow and Saturation**: In high-load scenarios, bins filled up faster than anticipated, causing material spillover and incorrect classification. Integrating bin-level weight sensors or fill-level indicators could mitigate this.
- **Ambiguous Waste Materials**: Composite materials (e.g., aluminium foil with food residue, plastic-coated paper) posed challenges for the model, occasionally leading to misclassification.
- **Environmental Interference**: Outdoor trials under heavy humidity or dusty conditions degraded sensor responsiveness, especially in optical and gas sensors used for moisture detection.
- **Mechanical Jamming**: Large or irregularly shaped items sometimes caused jamming in the grinder unit, requiring manual intervention to restore operation.

Despite these constraints, the system performed reliably in controlled environments and moderate outdoor conditions. It remains user-friendly and accessible across different age groups, making it viable for deployment in community-level settings such as schools, offices, and residential complexes.

By minimizing human dependency and automating waste segregation at the source, the proposed model contributes meaningfully toward sustainable waste practices and green urban infrastructure. Future iterations should focus on enhancing sensor robustness, adding predictive maintenance algorithms, and ensuring seamless operation under diverse environmental conditions.

Conclusion and Future Scope

The proposed smart waste segregation system demonstrates a technically robust and scalable solution for modern waste management challenges. By integrating AI-IoT technologies with mechanical innovations—such as automated grinding, compression, and real-time waste tracking—the system achieves efficient, contactless segregation with minimal energy consumption. This not only enhances recycling efficiency and reduces landfill load but also introduces economic value through resource recovery and cost-effective logistics. A key differentiator is the system's adaptability across both domestic and municipal environments, aligning seamlessly with smart city infrastructure. Its modular design allows for flexible deployment, real-time analytics, and autonomous operation—setting it apart from conventional static waste management approaches.

Future Scope includes:

- Advanced AI integration for predictive waste generation analytics and automated route optimization for collection vehicles.
- Blockchain-enabled traceability for tracking waste from source to recycling units, enhancing transparency.
- Edge computing capabilities to reduce cloud dependency and enable faster decision-making at local nodes.
- Integration with carbon footprint monitoring systems to quantify environmental benefits in real time.

- Development of a circular economy model by linking waste producers directly with recyclers or composting units through digital platforms.

With further R&D, the proposed system has the potential to become a cornerstone of sustainable urban infrastructure, supporting zero-waste goals and contributing to global climate action targets.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

[1]Agarwal, C., Yevale, B., & Jagadish, C. (2020). Automatic waste segregation and management. *International Journal of Engineering Research & Technology (IJERT)*, *9*(6). https://www.ijert.org

[2]Anke, F., Mathar, R., & Reyer, M. (2008). Rate and power allocation for multiuser OFDM: An effective heuristic verified by branch-and-bound. *IEEE Transactions on Wireless Communications*, *7*(1), 60–64. https://doi.org/10.1109/TWC.2008.060284

[3]Balagugan, R. S., Maheswaran, T., & Savitha, S. (n.d.). Implementation of automated waste segregator at household level. *International Journal of Innovative Research in Science, Engineering and Technology*. https://doi.org/10.15680/IJIRSET

[4]Balakrishnan, K., Swathy, T. B., Rosmi, & T. D., S. (2016). Automatic waste segregator and monitoring system. *Journal of Microcontroller Engineering and Applications*.

[5]Gupta, N. S., Deepthi, V., Kunnath, M., Rejeth, P. S., & Badsha, T. S. (2018). Automatic waste segregation. In *2018 Second International Conference on Intelligent Computing and Control Systems (ICICCS)* (pp. 1688–1692). https://doi.org/10.1109/ICCONS.2018.8663082

[6]Haque, M. M., Rahman, M. S., & Kim, K. D. (2013). Performance analysis of MIMO-OFDM for 4G wireless systems under Rayleigh fading channel. *International Journal of Multimedia and Ubiquitous Engineering*, *8*(1), 29–40.

[7]Henam, S. D., & Bandela, D. R. (2020). Segregate, segregate, segregate: How to make it work for solid waste management. *Centre for Science and Environment*.

[8]Jayson, M., & Hiremath, S. (2018). Smart bin—Automatic waste segregation and collection. In *2018 Second International Conference on Advances in Electronics, Computers and Communications (ICAECC)*(pp.1–4). https://doi.org/10.1109/ICAECC.2018.8479475

[9]Mapari, R., Narkhede, S., Navale, A., & Babrah, J. (2020). Automatic waste segregator and monitoring system. *International Journal of Advanced Computer Research*, *10*(49). https://doi.org/10.19101/IJACR

[10] Mohamed, L. A.-F. A., & Sangaiah, A. (2018). Metaheuristic algorithms: A comprehensive review. In *Computational Intelligence for Multimedia Big Data on the Cloud with Engineering Applications* (pp. 185–231). https://doi.org/10.1016/B978-0-12-813314-9.00008-2

[11] Mubashira Banu, M., Manjula, S., & Bhagya, L. (2023). Automatic waste segregation. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, *11*(5). https://doi.org/10.22214/ijraset.2023.50232

[12] Nath, S., Supratim, A., Pandey, S., Singh, R., Singh, A. K., Banerjee, S., Ghosh, D., & Sanhita, S. (2017). Waste management using Internet of Things (IoT). In *IEEE*.

[13] Pereira, W., Parulekar, S., Phaltankar, S., & Kamble, V. (2019). Smart bin (waste segregation and optimisation). In *Amity International Conference on Artificial Intelligence (AICAI)* (pp. 274–279). https://doi.org/10.1109/AICAI.2019.8701350

[14] Rakib, A., Abdullah, M., Rana, M. S., Rahman, M. M., & Abbas, F. I. (2021). Dry and wet waste segregation and management system. *European Journal of Engineering and Technology Research*, *6*(5), 129–133.

[15] Raut, S. N., & Jalnekar, R. M. (2021). Taylor-based least square estimation in MIMO-OFDM systems for multimedia applications. *Wireless Personal Communications*, *120*(1), 609–631. https://doi.org/10.1007/s11277-021-08500-2

[16] Sejera, M., Ibarra, J. B. J., Canare, A. S., Lyra, E., & Phillip, S. (2016). Standalone frequency based automated trash bin and segregator of plastic bottles and tin cans. In *IEEE*.

[17] Sharanabasappa, A., Jayalakshmi, B. K., Fathima, I., Peer, G., & Prabha, L. G. (2021). Automated waste segregator. *International Research Journal of Engineering and Technology (IRJET)*, *8*(4).

[18] Tarbell, K. A., et al. (2014). Applying machine learning to the sorting of recyclable containers. *National-Waste-Processing Conference*.

[19] V. P., et al. (2020). Automatic waste segregation and management. In *International Conference on Computer Communication and Informatics (ICCCI)* (pp. 1–5). https://doi.org/10.1109/ICCCI.2020.9104011

[20] Xiaohu, G., Xi, H., Wang, Y., Li, Q., Tao, H., & Cheng, X. W. (2014). Energy-efficiency optimization for MIMO-OFDM mobile multimedia communication systems with QoS constraints. *IEEE Transactions on Vehicular Technology*, *63*(5), 2127–2138.

[21] Xinhua. (2017, October 13). Philippines grapples with 35,000 tons of garbage daily: ADB expert. *Special Report*.