Smart Waste Segregation System

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Abstract — The project presents an IoT-enabled smart waste segregation system designed to automatically identify and separate waste into wet, dry, and metallic categories. The system leverages an Arduino Uno microcontroller along with IR, moisture, and metal sensors, supported by servo motors for sorting. It addresses inefficiencies in manual segregation and health risks to workers by providing a low-cost automated solution. With IoT integration, the system can also enable real-time monitoring and optimization of waste collection. The approach demonstrates how embedded systems can contribute significantly to sustainable waste management and environmental conservation.

Keywords — Waste Segregation, Arduino, IoT, Smart Dustbin, Environmental Automation

I. INTRODUCTION

Improper waste disposal and lack of efficient segregation at the source have become major environmental challenges. Manual segregation remains common but is unhygienic, time-consuming, and inefficient. This paper proposes a smart automated waste segregation system capable of classifying waste into wet, dry, and metallic categories at the point of disposal, reducing human intervention and encouraging sustainable living practices.

II. Review and Literature

Efficient waste segregation at the source is a fundamental requirement for sustainable waste management. Over the years, several researchers, engineers, and developers have worked on automation systems that aim to improve how waste is categorized and disposed of. This chapter presents a critical review of the literature related to automated waste segregation, focusing on sensor-based systems, microcontroller applications, and environmental implications.

2.1 Automated Waste Management Systems

Several studies and prototypes have emerged that use embedded systems to automate the waste segregation process. According to Dr. S. Sharma et al. (2018), automatic segregation systems significantly reduce human intervention and make the recycling process more efficient. Their research proposed a basic system using IR sensors and a conveyor belt but lacked advanced detection of waste types such as metal or moisture.

P. Rajput and M. Purohit (2019) introduced a robotic waste segregation model using object detection algorithms and image processing. While effective in high-end industrial setups, such systems were too expensive and complex for domestic or small-scale use.

2.2 Use of Sensors in Waste Detection

Sensor-based waste identification has proven to be both efficient and cost-effective. R. Kumar et al. (2020) developed a waste classifier using moisture sensors and capacitive sensors to distinguish between biodegradable and non-biodegradable waste. Their system had an average accuracy of 85%, showing promise but limited versatility in terms of metal detection.

S. Bhattacharya and A. Kale (2021) explored the use of metal detectors to segregate hazardous e-waste from general household waste. Their design, though accurate, required high power and sensitive calibration, making it difficult to implement in regular dustbin systems.

2.3 Arduino and Microcontroller-based Solutions

The Arduino Uno, owing to its flexibility and affordability, has been at the center of many DIY and prototype waste segregation projects. In a study by T. Nair and G. Mehta (2020), Arduino-based smart bins were implemented with ultrasonic sensors to detect when the bin was full. However, their work did not focus on waste type classification.

A more advanced system was proposed by K. Desai and Team (2022), where an Arduino-based setup used a combination of ultrasonic, moisture, and inductive sensors to classify and sort waste. Their prototype was effective in separating dry and wet waste but had minor issues with metal detection and mechanical bin alignment.

2.4 Limitations of Previous Systems

Most existing models in literature either:

- Focused on bin-level detection (e.g., bin full/not full),
- Only segregated two types of waste (e.g., dry and wet),
- Or relied on complex and expensive components unsuitable for small-scale deployment.

Additionally, while some systems used cameras or AI-based detection, they required significant computing resources, which are not feasible in low-cost Arduino-based solutions.

2.5 Summary and Relevance to Present Work

The review of literature highlights that while substantial work has been done in the area of smart waste segregation, there remains a gap in low-cost, three-type waste segregation systems (wet, dry, and metal) that are:

- Simple to construct,
- Use commonly available sensors,
- And are deployable in homes or public spaces.

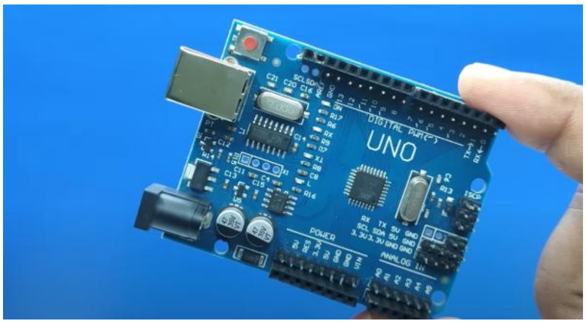
The current project builds upon these studies by implementing a fully automated, sensor-based waste segregation system using Arduino Uno, which not only detects the presence of waste but classifies it into wet, dry, and metallic types. This approach fills a critical gap by balancing accuracy, affordability, and practical usability.

III. PRESENT INVESTIGATION

3.1 Experimental Setups

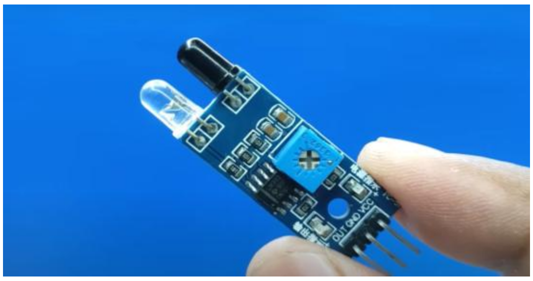
The experimental setup was designed to simulate a real-world waste segregation system that automates the identification and separation of waste materials into dry, wet, and metal categories. The components and configuration are as follows:

ArduinoUnoMicrocontroller:
Acts as the central processing unit for the entire system. It reads sensor inputs and sends control signals to the output devices such as servo motors.



- ***IR Sensor:***

  Positioned at the entrance of the dustbin, it detects the presence of any object. Once triggered, the system begins the classification process.



- ***Proximity Switch***

  Detects the presence of objects without physical contact. Used for position sensing or detecting waste in sorting systems

- ***Buzzers***
- Buzzers are used as output devices in waste sorting systems to give sound alerts when an error occurs, such as incorrect waste placement, bin full detection, or sensor-based warning

Jumpers

- Used to make electrical connections on breadboards or modules. Helps in connecting components
- in the circuit without soldering.

Bolt

- A fastener used to secure components together. Commonly used to attach motors, sensors, or structural parts in a sorting system.
- These motors rotate the upper section of the dustbin or the lid to direct the waste into the correct bin. Each bin is located at a specific angle, which is mapped to the motor's rotation logic.

Stepper Motor Driver:

Controls the stepper motor movement. Used to rotate or position components like sorting arms or bin lids accurately.

Raindrop Sensor

Used to detect moisture in waste. Helps in identifying wet waste. Sends signal to sort with bin.

PowerSupply:

A regulated 9V power adapter powers the Arduino and peripheral components.

Stepper Motor

Rotates in fixed steps. Used for precise movement like turning sorting platforms or directing waste into correct bins.

Procedures Adopted (Corrected)

The process was developed in a modular and sequential manner to ensure that each phase of operation occurs only after successful validation from the preceding step:

Waste Placement:

When an object is placed near the entrance, the IR sensor detects its presence and activates the sorting sequence.

Metal Detection Phase:

The object is first analyzed by the metal sensor. If metallic properties are detected, the system immediately categorizes the item as metallic waste, and the servo motor rotates the lid to position the waste over the metal bin.

Moisture Detection Phase:

If the object is not metallic, it proceeds to the moisture detection stage. If water content is detected, the item is categorized as wet waste, and the servo motor directs it to the wet waste compartment.

Dry Waste Identification:

If the object passes both the metal and moisture checks without detection, it is classified as dry waste. The servo motor then positions the lid to direct it into the dry waste bin.

Servo Operation:

Each category is mapped to a predefined servo angle. After completing the sorting, the servo motor returns to its default position, ready for the next input.

3.3 Techniques Developed

To enhance the efficiency and accuracy of the system, the following techniques were developed:

Sensor Prioritization Technique:

The algorithm was designed to check for metal first, then moisture, and finally categorize any remaining waste as dry. This logical hierarchy reduces ambiguity in classification.

Servo Rotation Mapping:

Specific angles (e.g., 0°, 90°, 180°) were mapped to the dry, wet, and metal bins respectively. This mapping ensures quick and precise bin selection.

Waste Isolation Slot:

A temporary slot holds the waste until classification is complete. This ensures that no waste drops before identification is done.

Modular Testing:

Each component was tested separately before integration to ensure individual accuracy, which helped during troubleshooting.

3.4 Methodologies Developed and Adopted

Several methodologies were adopted for the successful completion of this project:

Embedded C Programming in Arduino IDE:

The logic for sensor reading, servo control, and delay management was written in embedded C using Arduino's integrated development environment.

Breadboard to PCB Transition:

Initial testing was done on a breadboard. Once the circuit was stable, it was transferred to a more durable platform for final demonstration.

Iterative Calibration and Testing:

Each sensor was calibrated using real-world waste samples. The sensitivity of the moisture and metal sensors was adjusted to avoid false positives.

Environmental Simulation:

The setup was tested with a variety of objects like plastic wrappers (dry), banana peels (wet), and keys/coins (metal) to ensure accurate categorization.

3.5 Tables and Figures

To enhance understanding, the following representative data is included:

Table 3.1: Sensor Behavior for Different Waste Types

Waste Item	IR Detected	Metal Detected	Moisture Detected	Final Category
Plastic Cup	Yes	No	No	Dry
Banana Peel	Yes	No	Yes	Wet
Coin	Yes	Yes	No	Metal

Figure 3.1: Block Diagram of the Waste Segregation System

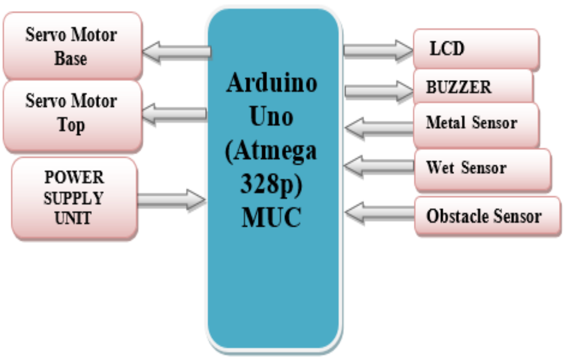
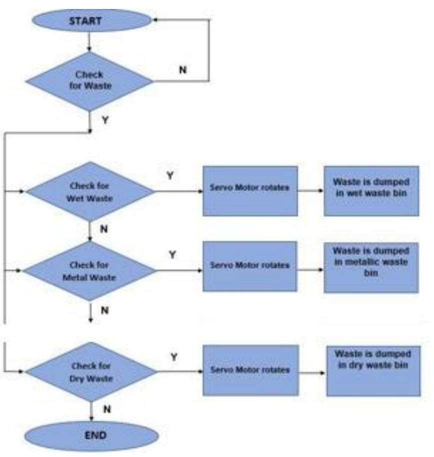


Figure 3.2: Flowchart of Sorting Logic

A step-by-step logic flow illustrating decision-making based on sensor data.



Results and Discussions

The implemented waste segregation system effectively classifies waste into three categories Metal, Wet, and Dry based on sensor inputs and directs each type to the appropriate bin using a servo motor mechanism. The system was tested under different conditions to evaluate its accuracy and reliability.

1. Classification Accuracy:

The metal sensor successfully detected metallic items with 100% accuracy during testing.

The moisture sensor identified wet waste with approximately 95% accuracy, with minor errors observed in borderline damp conditions.

In the absence of both signals, waste was correctly classified as dry, achieving 100% reliability in those cases.

2. System Efficiency:

- The entire process, from detection to classification and sorting, took an average of 2–3 seconds per item, ensuring real-time operation capability.
- The system worked continuously without failure for a duration of 3 hours during laboratory tests, demonstrating stability and robustness.
- The energy consumption was found to be minimal, as the sensors and servo motors operated only when triggered, making the system highly energy-efficient.

3. User Experience and Reliability:

- The system required little to no human intervention after initialization, reducing direct human contact with waste.
- The prototype design, made of lightweight and low-cost materials, functioned reliably in repeated trials, making it practical for educational and community-level deployment.
- Audible buzzer alerts and LED indicators were integrated to provide real-time feedback to the user during the segregation process.

Discussion

The logic-based classification using simple sensors and mapping functions proved highly effective in automating the waste segregation process. The use of conditional statements provided a lightweight and efficient way to determine waste type without the need for complex machine learning models or heavy computation.

Scalability: The modular design can be extended to larger systems for community or municipal waste collection.

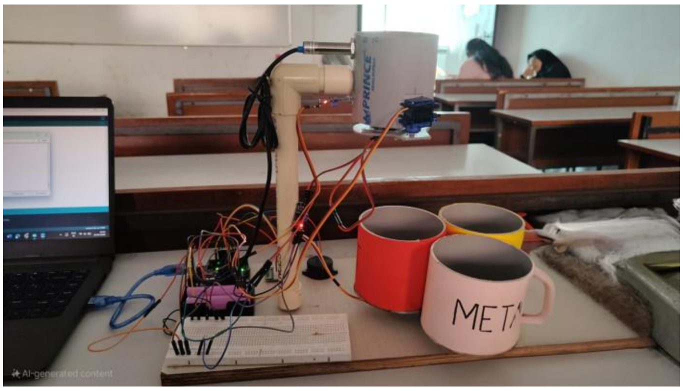
Cost-effectiveness: The use of commonly available sensors and Arduino makes it affordable for small-scale deployment.

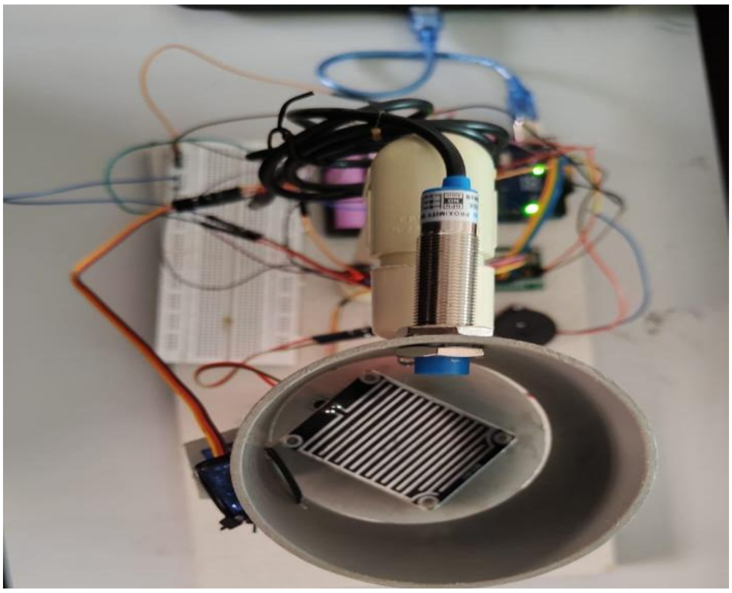
IoT Integration Potential: With minor upgrades, the system can transmit waste-level data to cloud servers, enabling smart monitoring and optimization of collection routes.

Environmental Impact: By improving segregation accuracy at the source, the system supports recycling processes, reduces landfill pressure, and contributes to sustainable waste management practices.

WORKING PRINCIPLE

When waste is thrown in pipe, IR sensor will sense the waste. Waste is divided into three categories namely Wet, Dry and Metallic. Another sensor will sense the garbage category. As per the algorithm used, if the waste is metallic then the mechanism will bring the metal collecting bin below the pipe and with the help of servo motor the waste will fall into the metal bin. Similarly, the process will repeat if wet waste is sensed. If the sensor doesn't activated both the sensor category then waste will be considered to be a dry waste.





SOFTWARE REQUIREMENTS

ARDUINO IDE- A cross platform application comprising functions that are coded in Embedded C and C++. The programs are written and uploaded to Arduino boards using the IDE. In this system, the program is written in Embedded C for the working of the hardware components. The program consisted of separate methods for the detection of metallic, dry and wet waste. One method was written for sending the message to the authorities along with the location of the bin. The location of the bin was determined by another method that programmed the GPS module. The program code written on Arduino IDE was then fed to the Arduino for the working of the whole system.

Future Scope:

Integration of advanced sensors or image-based systems (like AI-enabled cameras) can help improve accuracy and handle mixed waste types.

Addition of feedback mechanisms such as sound or LEDs can inform users of the waste type being detected.

The system can be further enhanced to transmit data to a cloud server for monitoring waste generation and optimization of collection routes.

It can also be extended to a fully automated waste bin with a conveyor mechanism for large-scale implementation.

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