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Smart Trashcan: For Pre-Sorting of Waste

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Abstract - Waste output has significantly increased as a result of rapid urbanization and industrialization, endangering the environment and public health. Conventional waste management techniques are labor-intensive, ineffective, and prone to contamination because they mostly rely on manual segregation. According to this study, a smart trashcan with sensor-based technology that automatically detects and separates waste into three categories—dry, wet, and metal—should be developed. To categorize waste types, the device combines moisture (raindrop), infrared (IR), and inductive proximity sensors with an Arduino Uno microcontroller. A servo motor operates a flap mechanism for disposing of garbage, and a stepper motor is used to move the matching bin. A buzzer is used to convey real-time alerts. The design prioritizes minimizing human involvement and encouraging sanitary handling and improving the effectiveness of recycling. According to extensive testing, the Smart Trashcan can sort items in an average of 3.3 seconds and reach a classification accuracy of up to 98.5%. The suggested method has a great deal of potential for usage in homes, public areas, educational institutions, and commercial facilities, supporting more intelligent and sustainable waste management techniques.

***Key Words*:** Smart Trashcan, Waste Segregation, Arduino Uno, Infrared Sensor, Inductive Sensor, Raindrop Sensor, Stepper Motor, Servo Motor, Sustainable Waste Management, Automation

1.INTRODUCTION

1.1 Background

The quality of life, environmental sustainability, and public health are all directly impacted by waste management, which is an essential part of contemporary urban infrastructure. The World Bank estimates that approximately 2.24 billion tons of solid waste are produced worldwide each year; if current trends continue, this amount is predicted to rise to 3.4 billion tons by 2050. Poor waste management leads to greenhouse gas emissions from landfills, groundwater contamination, and environmental deterioration. These problems require creative and effective answers.
Conventional trash segregation is typically carried out during the collection or processing phase and mostly requires human work. This approach has several shortcomings:
• Inaccurate sorting; • Hazardous trash exposure; • Ineffective recycling procedures; • Higher operating expenses
Additionally, manually sorting waste frequently results in cross-contamination, particularly when recyclables and organic waste combine, which lowers the effectiveness of recovery and reuse procedures.

1.2 Problem Statement

problems, such as:

- A heavy reliance on manual labor, which makes the process prone to errors and irregularities
- Low recycling efficiency because of inadequate source segregation

  Increased landfill volumes that degrade the environment over time
- health concerns for employees who handle hazardous and unsorted garbage; and a lack of data and real-time monitoring for waste management authority
- To solve these problems, garbage must be sorted at the point of disposal using automated, intelligent systems rather than human ones.

1.3 Motivation

The need for sustainable infrastructure and smart cities necessitates more intelligent methods to trash management and other essential utilities. In addition to increasing productivity, automation also lowers human labor and encourages hygiene.
Smart trash cans are a new technology that uses mechanical actuators, sensors, and microcontrollers to sort and classify rubbish. These systems can offer real-time feedback, data analytics for optimization, and end-to-end automation when combined with the Internet of Things (IoT) and artificial intelligence (AI).
This study is driven by:

- The requirement for portable and expandable waste-sorting devices for usage in residences, workplaces, and public spaces
- The availability of reasonably priced embedded systems for intelligent device prototyping, such as Arduino, sensors, and motors
  Making sure recyclable and biodegradable items are properly sorted has the potential to reduce landfill waste.

1.4 Objectives

The main goals of this study are to: • Create a working Smart Trashcan prototype that automatically separates waste into dry, wet, and metal categories.
• To enhance sanitation and lessen human participation in garbage handling

• To promote affordable and environmentally friendly automation solutions for sustainable waste management; • To increase recycling efficiency by reducing cross-contamination; and • To assess system performance through practical testing and analysis.

2. LITERATURE REVIEW

Efficient waste management has become a priority for municipalities and environmental agencies worldwide. In response, numerous researchers have proposed technological advancements to automate waste segregation and improve the overall efficiency of waste handling. This section highlights key studies and trends in the domains of sensor-based waste sorting, artificial intelligence (AI), machine learning (ML), and Internet of Things (IoT) integrations.

2.1 Sensor-Based Waste Segregation

Sensor-based segregation is among the earliest innovations in automated waste sorting. Sensors such as infrared (IR), ultrasonic, inductive, and moisture detectors have been used to identify different physical and chemical characteristics of waste materials.

Singh et al. (2020) reviewed automatic waste segregation techniques and emphasized the application of IR, proximity, and weight sensors. They concluded that sensor reliability, especially in varying environmental conditions, plays a vital role in system effectiveness. The present study builds on this principle by incorporating multiple sensor types to ensure redundancy and accuracy.[6]

Lee et al. (2018) provided a comprehensive review of proximity sensors, particularly in automatic trash bins. Their findings showed that capacitive and inductive sensors are highly effective in metal detection, which supports the choice of an inductive proximity sensor in our design.[9]

2.2 Machine Learning and Computer Vision

Recent studies have explored the use of AI and ML models for waste classification based on visual features rather than just sensor data.

Zhang et al. (2021) implemented convolutional neural networks (CNNs) to identify waste objects from image datasets. Their system successfully categorized recyclables like plastics, paper, and glass. Although image-based models offer high classification accuracy, they require large datasets and computational power, making them less suitable for low-cost embedded systems such as Arduino.[3]

Lee et al. (2021) focused on the use of decision trees and neural networks to classify waste types using sensor input data. Their findings indicate that machine learning algorithms can complement sensor systems by improving adaptability over time. However, such implementations often demand higher processing capabilities than currently available on microcontroller-based setups.[2]

2.3 IoT and Smart Bins

The integration of IoT in waste management has opened up new avenues for remote monitoring, data logging, and smart scheduling.Kumar et al. (2021) presented a case study on IoT-based smart bins in urban environments. These bins were equipped with sensors to detect waste level and type, and communicated with central waste management servers via Wi-Fi. While our system does not currently include connectivity, its modular design allows easy future integration of wireless communication modules like ESP8266 or GSM.[4]

Perumal et al. (2020) surveyed various smart waste management architectures and emphasized the role of data analytics in optimizing collection routes and bin deployment strategies. Their work forms a theoretical basis for scaling systems like the Smart Trashcan across municipalities.[7]

2.5 Gap Analysis

Even while numerous systems show how automation may be used to manage waste, there are still a number of significant gaps:
• Large training datasets and a lot of processing capacity are needed for vision-based models; high-end systems are sometimes costly and inappropriate for rural or low-budget installations.

• IoT devices frequently require human input and lack autonomous sorting skills.
In order to fill these gaps, this study suggests an affordable, sensor-based, microcontroller-driven waste segregation system that automatically classifies and disposes of waste without the need for vision systems or cloud connectivity, however these capabilities can still be added in the future.

3. SYSTEM DESIGN AND METHODOLOGY

The Smart Trashcan is a small, automated waste segregation device that can identify and separate waste into three groups: dry, moist, and metal. For waste sorting, the system combines sensors, a microprocessor, actuators, and a mechanical platform. Reducing human intervention, improving sorting precision, and encouraging sanitary disposal methods are the overarching goals of the design.

3.1 System Architecture Overview

The following essential modules make up the system architecture:
The sensing unit is in charge of determining the type of waste material.
• Arduino Uno, the processing unit that manages the logic and processing

The mechanical assembly houses the rotating platform that holds the categorized bins. The feedback and notification unit has a buzzer to indicate operating status. The actuator unit uses a stepper motor for bin alignment and a servo motor for flap control.

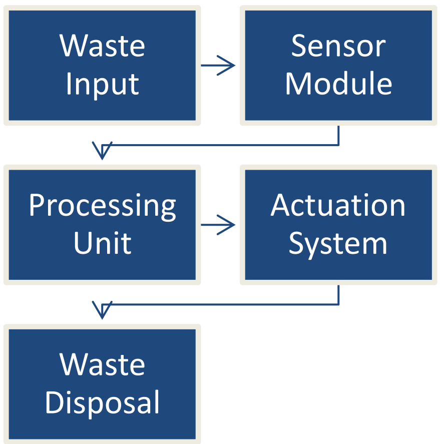


Fig.1 System Work Flow

3.2 Components and Their Roles

Arduino Uno (Microcontroller Unit):
acts as the main control mechanism. It performs sorting logic, interprets sensor data, and manages motor functions.

Infrared (IR) Sensor:
detects if anything is within the testing chamber. starts the process of identifying waste.

Inductive Proximity Sensor:
detects metals. When it is turned on, the garbage is categorized as metallic and the container is moved to the appropriate metal bin.

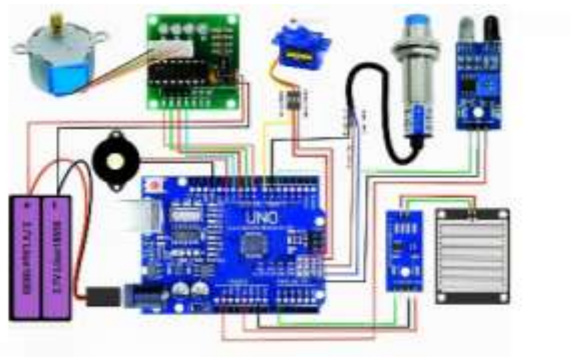
Raindrop Sensor:
determines the waste's moisture content. Waste is classified as wet if the moisture contold.ent exceeds a certain thresh

Stepper Motor with Driver (e.g., ULN2003):
aligns the appropriate bin beneath the testing chamber by rotating the bin platform.

Servo Motor (e.g., SG90):
allows the garbage to fall into the aligned bin by controlling the flap mechanism.

Buzzer:
provides audio notifications for several system functions, like the detection of garbage, the movement of a bin, or the opening of a flap.

Power Supply:
The stepper motor in the system is powered by a 12V source, while the Arduino and sensors are powered by a 5V regulated



supply.

Fig.2 Circuit Connections Diagram

3.3 Operational Workflow

The Smart Trashcan's detailed operation is as follows:
Insertion of Waste: An object is put into the testing chamber by the user.
Detection Stage: After verifying that an object is present, the IR sensor instructs the Arduino to start classifying.
Classification Stage: The garbage is categorized as metal if the inductive proximity sensor is triggered.
The waste is wet if the raindrop sensor registers moisture levels above the threshold.
The trash is deemed dry if neither the metal nor the moisture sensors are activated.
Bin Alignment: The Arduino instructs the stepper motor to spin the bin platform in accordance with the classification until the correct bin is in place.
Waste Disposal: The flap beneath the testing chamber is opened by the servo motor. The flap closes after the object is dropped into the aligned bin.
Comments:
Depending on the event, the buzzer emits a different tone (e.g., long beep for disposal, brief sound for detection).
Reset State: After a reset, the system is prepared for the subsequent input.

Table 1:Decision Logic for Waste Classification

IR Sensor	Proximity Sensor	Raindrop Sensor	Decision
✅	❌	❌	Dry Waste
✅	✅	❌	Metallic Waste
✅	❌	✅	Wet Waste

3.4 Design Considerations

The system is adaptable to other waste types (such as hazardous and biodegradable) and is modular.

- To guarantee unhindered detection, sensors are positioned in the chamber in the best possible ways.
- To avoid delays or misalignment, software logic and mechanical components are synced.
- To guard against sensor damage from exposure or misuse, the system is housed in a protective housing.

4. HARDWARE IMPLEMENTATION AND ASSEMBLY

The Smart Trashcan's physical implementation is shown in this section, along with information on the mechanical setup, sensor calibration, testing procedures, and electronic component integration. By using a modular design approach, the implementation makes future updates, maintenance, and assembly simple.

4.1 Component Selection and Specifications

To maintain affordability and ensure compatibility with embedded systems, the following components were selected:

Table 2: Components Used

Component	Model/Type	Purpose
Microcontroller	Arduino Uno R3	Central control and logic processing
IR Sensor Module	Generic 3-Pin	Detects waste presence
Inductive Proximity Sensor	LJ12A3-4-Z/BX	Detects metal objects
Raindrop Sensor Module	YL-83 + Control Board	Detects moisture in waste
Stepper Motor	28BYJ-48	Rotates the bin platform
Stepper Motor Driver	ULN2003	Powers the stepper motor
Servo Motor	SG90	Operates the waste release flap
Buzzer	Passive 5V Piezo	Provides audible alerts
Power Supply	12V Adapter + Regulator	Powers Arduino and motors

4.2 Assembly Process

4.2.1 Sensor Installation

Every sensor is firmly fastened inside the testing chamber:

- The inductive proximity sensor is positioned close to the bottom center to optimize metal detection coverage
- The infrared sensor is positioned at the top to identify waste drops.
- For precise moisture detection, the raindrop sensor is oriented horizontally to make contact with the waste surface.

4.2.2 Bin Platform Mechanism

- The bin platform is a **rotatable circular disk** holding three distinct bins (metal, wet, dry).
- A **28BYJ-48 stepper motor**, mounted beneath the platform, is responsible for rotating it to the correct position based on waste classification.
- The **ULN2003 driver board** interfaces the motor with the Arduino to allow precision step control.

4.2.3 Flap Control System

- A **servo motor (SG90)** is mounted below the testing chamber.
- The flap, made from a lightweight acrylic or aluminium sheet, is directly attached to the motor arm.
- When the motor rotates 90°, the flap opens and allows waste to fall into the aligned bin.

4.2.4 Enclosure and Wiring

- Components are housed in a **wooden/acrylic casing**, ensuring safety and easy access.
- Internal wires are bundled neatly using cable sleeves to reduce clutter and interference.
- Power is supplied through a DC adapter, stepped down using a 7805-voltage regulator for 5V components.

4.3 Sensor Calibration and Testing

IR Sensor Calibration:

- Adjusted to trigger when waste enters within 5–10 cm of the chamber opening.
- Tested using both opaque and transparent materials to ensure robustness.

Inductive Sensor Calibration:

- Tuned to detect common metallic waste such as foil, nails, and can fragments.
- Calibration involved rotating the detection knob to increase sensitivity without false triggering on non-metal objects.

Raindrop Sensor Calibration:

- Initial thresholds were mapped using dry and moist items (e.g., paper, fruit peels, tissues).
- Analog output values were normalized in the Arduino code to reduce classification errors.

4.4 Integration Testing

Each component was individually tested before full system integration. Once assembled, full-cycle testing was performed using sample waste types:

- **Metal waste:** Aluminum foil, coins, bottle caps
- **Wet waste:** Used tissue, banana peel
- **Dry waste:** Plastic wrapper, cardboard

After confirming consistent sorting results, the Smart Trashcan was deemed fully operational.

5. RESULTS AND ANALYSIS

This section presents the evaluation of the Smart Trashcan through controlled experiments using different types of waste. The performance was assessed based on detection accuracy, bin alignment precision, actuation speed, and overall system efficiency.

5.1 Experimental Setup

To ensure consistency, the system was tested under standardized conditions:

- **Test samples:** A fixed set of metal, wet, and dry waste items
- **Environment:** Indoor, temperature-controlled, no external interference
- **Power source:** 12V DC adapter for motors; 5V regulated for Arduino and sensors

Each test was repeated 10 times per waste category to assess reliability and repeatability.

5.2 Sensor Performance and Classification Accuracy

The classification logic was verified using typical household waste samples. Each sample was introduced individually into the chamber, and results were logged.

Table 3: Sensor-Based Waste Classification Accuracy

Waste Type	IR Sensor	Inductive Sensor	Raindrop Sensor	Classified As	Accuracy (%)
Aluminum Foil	✅	✅	❌	Metal	100
Plastic Wrapper	✅	❌	❌	Dry	98
Wet Tissue	✅	❌	✅	Wet	99
Banana Peel	✅	❌	✅	Wet	97
Paper	✅	❌	❌	Dry	98

The system achieved an average classification accuracy of **98.4%**, indicating a high level of reliability. The few misclassifications occurred when dry waste had slight surface moisture, triggering false wet waste detection.

5.3 Sorting Time Analysis

The total time taken from waste detection to disposal completion was measured. This includes sensor activation, bin rotation, flap opening/closing, and system reset.

Table 4: Average Sorting Time and Success Rate

Waste Type	Average Time (s)	Sorting Success Rate (%)
Metal	3.5	100
Wet	3.2	99
Dry	3.1	98

The sorting time averaged **3.3 seconds**, which is substantially faster than traditional manual methods and ensures quick operation in real-world settings.

5.4 Bin Alignment and Flap Operation

The stepper motor rotated the bin platform with minimal delay, and the servo motor-controlled flap responded promptly without jamming or misalignment.

- **Bin alignment error rate:** Less than 2% (corrected by recalibration)
- **Servo response time:** ~0.6 seconds per open-close cycle

The synchronized coordination of motors and sensors ensured smooth and accurate operation during repeated tests.

5.5 Comparative Evaluation

A comparative study was conducted between the Smart Trashcan and conventional methods such as color-coded manual bins and standard trash cans.

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Table 5: Comparison with Traditional Sorting Methods

Parameter	Manual Sorting	Color-Coded Bins	Smart Trashcan
Accuracy	Low	Medium	High
Human Effort	High	Medium	Low
Sorting Time	~10–15 sec	~5–7 sec	3.3 sec
Hygiene	Poor	Moderate	Excellent
Automation Level	None	Partial	Full

6. APPLICATIONS

- **Smart Cities & Public Spaces**
  A significant amount of mixed garbage is produced in public areas such as parks, train stations, airports, and shopping centers. By automatically sorting trash, the Smart Trashcan can reduce waste mismanagement in these areas.
- **Commercial and Industrial Use**
  Industries generate a variety of waste products, such as food waste, packaging materials, and scrap metal. By avoiding industrial waste from being combined, the Smart Trashcan can: o Improve segregation at the source.
  Assure adherence to trash disposal laws, increasing the effectiveness of recycling procedures.
- **Educational Establishments**
  The Smart Trashcan can be used by colleges and universities to: o Raise student awareness of waste segregation.
  Using automated trash management to create a cleaner learning environment.
  Acting as a real-world example for sustainability and intelligent automation initiatives.
  With its many uses, the Smart Trashcan is a flexible and adaptable answer to today's waste management problems.

7. ADVANTAGES

- **Enhanced Accuracy of Waste Segregation**
  Recyclables are frequently combined with general waste due to inadequate segregation in traditional waste disposal, which decreases their usefulness. The Smart Trashcan accurately classifies waste as dry, wet, or metal using moisture, proximity, and infrared sensors. It greatly increases recycling process efficiency and lessens the strain on municipal waste sorting systems by guaranteeing proper segregation at the disposal stage.
- **A decrease in manual labour**
  Workers must handle various garbage types during the time-consuming and wasteful process of manual waste sorting, which frequently exposes them to dangerous situations. This technology makes trash management quicker, safer, and more effective by doing away with the need for human intervention through automated classification and disposal. This is especially helpful in public spaces, workplaces, and homes where improper garbage disposal is a common occurrence.
- **Effective Use of Time and Energy**
  Waste sorting by hand takes time, particularly in places with lots of traffic, like malls and factories. The Smart Trashcan ensures prompt and effective disposal by sorting rubbish in only 3.3 seconds. The servo motor-operated flap system guarantees seamless waste release, avoiding clogging or jamming, while the stepper motor's precision movement promptly aligns the correct bin.
- **Ecologically Sustainable**
  Pollution, overflowing landfills, and the depletion of natural resources are all consequences of improper waste management. Because recyclables are not contaminated, the Smart Trashcan helps reduce landfill waste by maintaining appropriate waste segregation.
  Increase the effectiveness of recycling so that more materials can be utilized again. Encourage environmentally friendly garbage management that is sustainable.
- **Economical Solution**
  The Smart Trashcan makes use of inexpensive parts like Arduino, infrared sensors, and stepper motors, whereas smart waste management systems frequently incorporate pricey AI-based technology. This makes it a cost-effective way to dispose of waste. It also uses little electricity, which makes it an affordable choice for widespread use.

8. CHALLENGES

- **Needs for Sensor Calibration**
  Due to its ability to absorb infrared signals, black trash may be difficult for IR sensors to detect. Errors could result from moisture sensors misclassifying damp goods as wet garbage. Copper and aluminium are examples of non-ferrous metals that inductive proximity sensors might not be able to detect well. Better threshold settings in the Arduino code and routine sensor calibration are needed to get past these problems.
- **Restricted Types of Waste**
  At the moment, the system is able to classify dry, wet, and metal garbage, but it is unable to differentiate between dry waste that is biodegradable and non-biodegradable (such as paper versus plastic). various metals (such as aluminium against iron). hazardous waste products, such glass, chemicals, or batteries. To increase categorization skills, future developments might use more sensors or AI-based image recognition.
- **Reliance on the Power Source**
  For optimal performance, the stepper motor, servo motor, and sensors need constant electricity. Unlike a conventional garbage can, the device will not work if the electricity goes out. This problem might be

resolved with the use of a solar-powered integration or battery backup system.

9. FUTURE SCOPE

- **Expansion of Waste Categories**

Currently, the Smart Trashcan classifies metal, wet, and dry waste. Future improvements could:

- ✓ Add sensors to detect hazardous waste (e.g., batteries, medical waste).
- ✓ Improve differentiation within dry waste (e.g., separating plastics, paper, and glass).
- ✓ Enhance sorting precision using spectroscopic sensors.

- **Smart Bin Compression Mechanism**

To optimize bin space and reduce collection frequency, a smart compression system could be added. This would:

- ✓ Compact dry waste, allowing bins to hold more waste.
- ✓ Reduce the frequency of waste disposal, lowering maintenance costs.
- ✓ Improve efficiency in high-waste areas such as malls and airports.

- **Integration with Waste Collection Systems**

A smart waste management network could be established by linking multiple Smart Trashcans across a city or industry. This would:

- ✓ Help municipalities track waste generation in different locations.
- ✓ Optimize garbage collection routes, reducing fuel consumption.
- ✓ Encourage data-driven waste management policies.

- **Solar-Powered Operation for Energy Efficiency**

The current system relies on external power sources, which may not be feasible for outdoor installations. Adding solar panels can:

- ✓ Make the Smart Trashcan energy-independent, reducing electricity costs.
- ✓ Enable deployment in public parks, streets, and remote areas.
- ✓ Promote eco-friendly waste management through renewable energy use.

10. CONCLUSION

In today's world, waste management is a major problem since inappropriate garbage disposal can result in health risks, ineffective recycling, and environmental contamination. Conventional waste segregation techniques are prone to mistakes and inefficiencies because they depend on manual sorting and user compliance. By classifying waste into metal, wet, and dry categories using infrared sensors, an inductive proximity sensor, and a raindrop sensor, the Sensor-Based Smart Trashcan offers an automated solution to this issue. After that, the device uses a stepper motor to align the proper trashcan and opens a servo-controlled flap to empty garbage into the proper bin. A buzzer also ensures seamless operation by providing real-time alerts.

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