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Design And Development of an Automatic Waste Segregation Machine using a Rotating Plate Mechanism

Dr.Siva K*, Dr.Nithyanandam C Suresh Krishna A, Riyaz Ahamed, Sundareshan D, Vishnu Pravin K,**

*Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, Coimbatore, Taminadu
Email: hodmech@hicet.ac.in
** Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, Coimbatore, Taminadu.
Email: nithyanandam.mech@hicet.ac.in

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Abstract:
Effective segregation of solid waste is a basic requirement for efficient waste management and recycling in modern urban settings. Conventional manual segregation techniques are time-consuming, laborious, and prone to errors, as well as unsafe and inefficient. While there are highly advanced automated segregation systems available, they often require expensive infrastructure and sophisticated technology, thereby limiting their use in small-scale and decentralized waste management practices. This paper presents the design and development of a compact automatic waste segregation machine using a rotating plate mechanism that is capable of segregating waste into dry, wet, and metallic fractions. The device uses inductive proximity sensors and moisture sensors along with a microcontroller-based rotary actuation system to enable precise object identification and gravity-fed discharge into separate bins. The experimental results on the developed prototype showed an average segregation efficiency of 94.7%, a processing time of 2.1 seconds per object, and a low power consumption of about 18 W. The suggested arrangement provides a mechanically simple, rugged, and economical solution for decentralized waste management in residential areas, educational institutions, hospitals, and public utility areas, thus promoting environmental sustainability and recycling efficiency.

Keywords — Automatic Waste Segregation, Rotating Plate Mechanism, Solid Waste Management, Sensor-Based Sorting, Recycling Automation**.**

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I. INTRODUCTION

Rapid urbanization, industrial growth, and increasing population density have resulted in a substantial rise in municipal solid waste (MSW) generation worldwide. Current estimates indicate that global MSW production exceeds 2.2 billion tons annually and is expected to grow steadily over the coming decades. Improper handling and lack of segregation at the source significantly reduce recycling efficiency, increase landfill dependency, and contribute to environmental pollution, greenhouse gas emissions, and serious public health concerns. Effective waste segregation at the initial stage is therefore essential or achieving sustainable solid waste management and resource recovery.

In the existing system, waste segregation is predominantly carried out manually at collection centres or disposal sites. This approach is labour-intensive, time-consuming, and exposes workers to hazardous materials, sharp objects, and biologically contaminated waste. Furthermore, manual segregation lacks consistency and scalability, making it unsuitable for handling increasing waste volumes. Although advanced automated systems using machine vision, artificial intelligence, and robotic manipulators have been developed, they require complex infrastructure, high capital investment, skilled maintenance, and significant power consumption. These limitations restrict their deployment primarily to large-scale industrial recycling facilities, leaving decentralized locations without efficient automated solutions.

To overcome these challenges, this work proposes a compact and cost-effective automatic waste segregation system based on a rotating plate mechanism. The proposed system separates waste into dry, wet, and metallic

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categories using low-cost moisture and inductive proximity sensors integrated with a microcontroller-controlled rotary actuation unit. The waste is discharged into designated bins through gravity-assisted motion, ensuring fast operation and mechanical simplicity. The design emphasizes low energy consumption, ease of fabrication, minimal maintenance, and operational robustness, making it suitable for deployment in residential complexes, educational institutions, hospitals, and public utility areas. This system offers a practical and scalable solution for decentralized waste management and enhanced recycling efficiency.

II. RELATED WORK

Several studies have explored automation in waste segregation using a wide range of sensing and mechanical technologies. Sensor-based systems using infrared (IR), ultrasonic, moisture, capacitive, and inductive proximity sensors have been frequently reported in the literature for segregating waste into biodegradable, recyclable, and metallic streams [1]–[4]. Although these systems are capable of achieving moderate to high classification accuracy, their practical feasibility is often hampered by overlapping material characteristics, surface contamination, variable moisture content, and sensor calibration errors, which lead to misclassification under real-world conditions [5], [6].

Machine vision and deep learning-based waste classification has received considerable attention due to its high recognition accuracy and ability to handle complex and mixed waste streams [7]–[10]. Convolutional neural networks (CNNs), transfer learning approaches, and multispectral imaging techniques have been successfully employed for waste material identification and robotic sorting. However, these systems require large labeled datasets, high computational power, consistent illumination, and high-quality camera modules, which are often impractical for deployment in decentralized and resource-constrained environments such as residential complexes and small institutions [11]–[13].

Mechanical waste segregation systems such as conveyor-based diverters, pneumatic air-jet systems, vibrating screens, eddy current separators, and robotic pick-and-place manipulators have also been widely reported [14]–[18]. Although these advanced systems offer high throughput and industrial-grade reliability, they involve complex kinematic architectures, high capital investment, frequent maintenance, and significant energy consumption, making them unsuitable for small-scale decentralized installations [19], [20]. In contrast, rotary indexing-based systems exhibit simpler kinematic structures with fewer moving parts, resulting in improved reliability, reduced manufacturing cost, and easier maintenance [21], [22].

The proposed system distinguishes itself by incorporating a rotating plate mechanism integrated with low-cost moisture and inductive sensors, enabling effective waste segregation without reliance on computationally intensive image processing, conveyor transport systems, or complex robotic manipulation.

III. SYSTEM ARCHITECTURE

A. Overall Configuration

The machine for sorting the waste consists of a few key parts:

- An input chute for waste
- A rotating plate that sorts as it turns
- Dry waste, wet waste, metallic waste: three bins
- A sensor unit
- An Actuation and Control System
- A strong supporting frame.

If garbage is inserted into the input chute, it will fall into the rotating plate. The plate will rotate to the appropriate position based on its sense of classification. Finally, gravity will take effect, causing the garbage discharged into the appropriate bin.

B. Mechanical Layout

The design of the proposed automatic waste segregation system is made to be simple, reliable, and easy to manufacture, while still being efficient in material segregation. The major components of the system include the waste input chute, the rotating plate assembly, the collection bins, the motor drive unit, the shaft and bearing assembly, and the supporting frame, as shown in Fig. 3.1.

The waste is introduced into the system through a vertical chute and falls on the center of a horizontally positioned rotating plate. The plate is fixed on a vertical shaft that is supported on ball bearings to minimize friction and facilitate easy rotation. The shaft is driven by a DC geared motor or a servo motor through a flexible coupling, which provides indexed rotation in line with each type of waste. The plate has a discharge hole that is systematically aligned with three bins positioned at 120-degree intervals around the plate, which are specifically labeled for dry, wet, and metallic waste.

The entire assembly is mounted on a robust mild steel frame that supports the system during its operation and maintains its stability. The bins are removable, making it easy to empty and maintain the system.

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Fig. 1 Automatic Waste Segregation System

C. Block Diagram of Operation

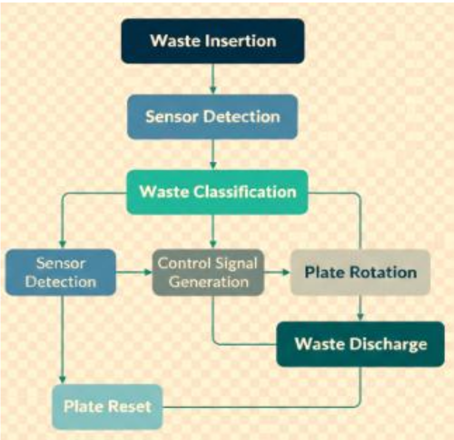

Fig. 2 Flow Diagram of Segregation Process

IV SYSTEM ARCHITECTURE

The operation of the automatic sorter of waste products involves the use of a combination of identity detection through the use of sensors, a simple rotary motion, and the use of gravity to sort the items. Every piece of rubbish will be fed into the sorter individually, and it will rest upon a sensing stage above a rotating plate. When the rubbish enters the detection area, the inductive proximity sensor will, first and foremost, sense metals and instantly rotate the plate to match the position of the metal bin.

If the item is not metallic, it then moves on to the next component, which is the moisture sensor, to determine whether it is dry or wet waste. Based on the reading obtained from the sensor, the microcontroller calculates the angle through which the plate should turn, ensuring the outlet is properly aligned to the target bin, either dry or wet waste. The motor then rotates the plate to the exact angle calculated.

Once alignment is achieved, gravity takes over and the waste ends up in the bin of our choice. Once this is done, the plate goes back to its rest position and awaits the next piece of garbage. The cycle of data sensing, decision-making, and execution ensures accurate performance without requiring mechanical complexity. The device operates using little power and avoids the necessity of image processing, conveyor belts, and robotic assistance.

V MECHANICAL DESIGN AND ANALYSIS

A. Rotating Plate Design

Given:

Maximum waste weight: W = 1 kg, Plate radius: R = 0.2 m, Plate material: Aluminium alloy (Yield strength $\sigma y = 150$ MPa), Plate thickness: t = 5 mm = 0.005 m, Gravity: g = 9.81 m/s^2

B. Torque Calculation

The torque required by the motor:

$T = F * R = W * g * R$

$T = 1 * 9.81 * 0.2 = 1.962$ Nm

Considering a safety factor of 1.5:

$T_{required} = 1.962 * 1.5 = 2.943$ Nm

Motor Selection:

DC gear motor with rated torque ≥ 3 Nm.

C. Bending Stress on Plate

For a circular plate with central support under point load:

$\sigma = (3 * W * R^2) / (2 * t^2)$

$\sigma = (3 * 9.81 * 0.2^2) / (2 * 0.005^2) = 23.53$ MPa

$\sigma < \sigma y = 150$ MPa → Safe

A. Motor and Kinematics

Angular rotation to bins: - Metal bin: 0° - Dry waste bin: 120° - Wet waste bin: 240°

Angular velocity: $\Delta\theta = 120° = 2.094$ rad, desired rotation time t = 2 s

$\omega = \Delta\theta / \Delta t = 2.094 / 2 = 1.047$ rad/s

Power requirement: $P = T * \omega$

$= 2.943 * 1.047 \approx 3.08$ W

TABLE I MOTOR SPECIFICATIONS

Parameter	Value
Type	DC Gear Motor / Stepper Motor
Rated Torque	≥ 3.8 Nm
Rated Speed	10–15 RPM (after gearbox)
Power	≥ 5.7 W
Voltage	12–24 V DC
Control	PWM (DC motor) / Step pulses (Stepper)

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B. Supporting Frame

The supporting frame is fabricated from mild steel square tubing and designed to withstand static loads from bins and waste accumulation. The frame was analysed under vertical loading using standard beam bending equations to ensure adequate factor of safety.

VI ELECTRICAL AND CONTROL SYSTEM

A. Sensors

The following sensors were used:

TABLE II TYPES OF SENSORS USED

Sensor Type	Function
Moisture Sensor	Detection of wet/biodegradable waste
Inductive Proximity Sensor	Detection of metallic waste
IR Obstacle Sensor	Object presence detection

The Automatic Waste Sorter requires electrical power distribution, sensor interfaces, actuator control, and a microcontroller-based decision system to operate efficiently.

B. Selection of Microcontroller

The microcontroller acts as the central control unit of the automated waste sorting system and is responsible for processing sensor inputs and controlling the sorting mechanism. The selected controller must support at least two digital input pins for sensor interfacing, provide PWM output for DC motor control or step pulse generation for stepper motor operation, and maintain low power consumption for efficient continuous operation. Commonly used controllers suitable for this application include the Arduino UNO, ESP32, and STM32 series. The microcontroller performs several key functions such as reading signals from sensors to detect the type of waste, determining the appropriate sorting category (metal, dry, or wet waste), calculating the required rotation angle of the sorting plate, sending command signals to the motor driver to rotate the mechanism to the correct bin, and finally monitoring the completion of the operation before returning the plate to its initial rest position to prepare for the next sorting cycle.

VII SOFTWARE ALGORITHM

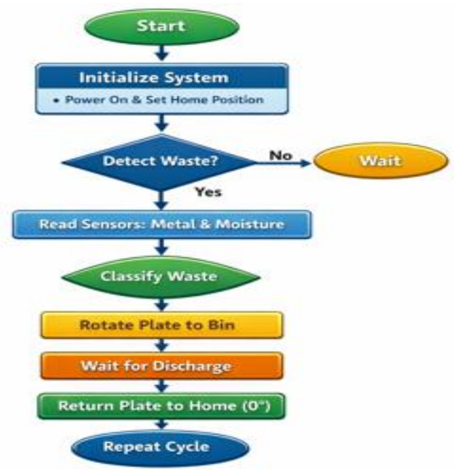

Fig. 3 Flow Chart Representation

The control system of the Automatic Waste Sorter operates on a closed-loop decision-making algorithm implemented on the microcontroller. The algorithm coordinates sensor inputs, waste classification, and actuator motion to ensure accurate sorting.

VIII. EXPERIMENTAL SETUP

The experimental setup of the Automatic Waste Sorter consists of a rotating plate mounted on a central shaft with bearings, supported by an aluminum frame, and positioned above three waste bins for metal, dry, and wet waste. A DC gear motor or stepper motor, controlled by a microcontroller (Arduino/ESP32/STM32), rotates the plate to align with the appropriate bin based on sensor inputs. An inductive proximity sensor detects metallic waste, while a moisture sensor distinguishes dry and wet waste.

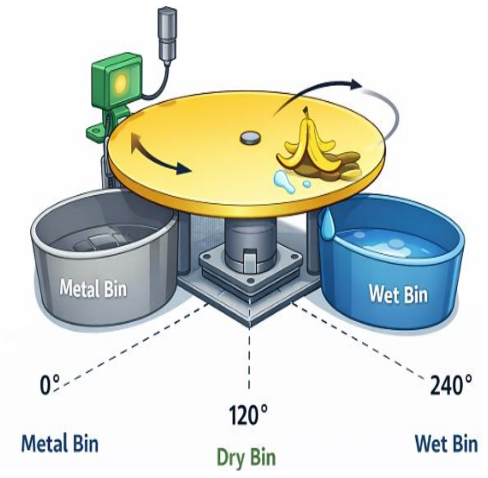

Fig. 4 Experimental Setup

The system is powered by a 12–24 V DC supply for the motor and sensors, with the microcontroller operating at 5 V. During operation, a waste item is placed on the plate, sensors identify the category, and the plate rotates to discharge the item into the correct bin by gravity before returning to its home position. Data on sorting accuracy, sensor performance, motor timing, and power consumption can be collected for analysis, with safety measures including wiring insulation, load limits, protective covers, and an emergency stop switch.

IX. RESULTS AND PERFORMANCE ANALYSIS

A. Segregation Accuracy

Waste Type	**Test Samples**	**Correctly Segregated**	**Accuracy (%)**
Wet Waste	50	47	94
Dry Waste	50	46	92
Metal Waste	50	49	98
Overall	150	142	94.7

B. *Processing Time*

Average processing time per waste object was measured as:
t_{avg}=2.1

C. Power Consumption

Total electrical power consumption during operation was approximately:
P_{total}≈18 W

The experimental results demonstrate that the rotating plate-based segregation system provides reliable classification with high repeatability. Metal detection exhibited the highest accuracy due to the robustness of inductive sensing. Minor misclassification of wet and dry waste occurred when moisture content was marginal or unevenly distributed. This limitation can be addressed by incorporating capacitive sensing or optical reflectance analysis.

The mechanical simplicity of the rotating plate mechanism results in lower wear, reduced maintenance requirements, and improved operational stability compared to conveyor-driven diverter systems. The gravity-assisted discharge eliminates the need for additional actuators, improving energy efficiency and system reliability

X CONCLUSION

This paper presented the design, fabrication, and evaluation of an automatic waste segregation machine based on a rotating plate mechanism. The system effectively segregates waste into dry, wet, and metallic categories using low-cost sensors and simple rotary motion control. Experimental results indicate high segregation accuracy, fast response time, and low power consumption, demonstrating the suitability of the proposed system for decentralized waste management applications. The simplicity and robustness of the design make it a promising solution for improving recycling efficiency and sustainable solid waste handling.

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