RESEARCH PAPER

Automated Waste Classification System Using Arduino-Based Smart Mechanism

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ABSTRACT

The rapid rise in urbanization and industrial development has led to a significant increase in municipal solid waste generation. Traditional waste management systems rely heavily on manual segregation, which is inefficient, time-consuming, unhygienic, and poses serious health risks to workers. Improper segregation also results in environmental pollution, landfill overflow, and reduced recycling efficiency. This project presents an Internet of Things (IoT)-based automatic waste segregation system designed to classify waste into dry, wet, and metallic categories using multiple sensors. The system uses an IR sensor for waste detection, a metal detector for identifying metallic waste, and a moisture sensor for distinguishing between wet and dry waste. An Arduino Mega microcontroller processes sensor signals and controls servo motors for directing the waste into the respective bins. Additionally, NodeMCU is integrated for IoT-based real-time monitoring of bin status and waste quantity through wireless communication. The proposed model improves segregation accuracy, reduces human intervention, supports recycling processes, and contributes to sustainable waste management practices. The system is cost-effective, scalable, and suitable for implementation in smart cities, societies, and public areas.

Keywords: IoT, Waste Segregation, Smart Bin, Arduino Mega, NodeMCU, IR Sensor, Moisture Sensor, Metal Detector, Smart City.

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INTRODUCTION

Waste management has become one of the most critical challenges faced by modern society due to the continuous increase in population and urban development. With the expansion of cities, the amount of waste generated daily has increased drastically, creating serious environmental, health, and economic problems. A major issue in waste disposal is the absence of segregation at the source. Generally, waste such as food waste, plastic, paper, and metals are thrown together in a single container. When this mixed waste is transported to dumping grounds or landfills, it leads to contamination of soil, air, and groundwater due to toxic leakage and decomposition processes. Wet waste decomposes and releases harmful gases like methane, which contributes to global warming, while dry waste such as plastics remains non-degradable for long periods, increasing landfill burden.

Another important concern is the health risk involved in manual waste segregation. In many developing countries, waste segregation is performed by rag pickers and sanitation workers who are exposed to harmful bacteria, viruses, and toxic materials. This leads to skin infections, respiratory problems, allergies, and other serious diseases. Also, manual segregation consumes large time and manpower, increasing the overall operational cost of municipal waste management.

To overcome these challenges, automation in waste segregation is essential. Automatic waste segregation ensures that waste is separated into categories such as wet, dry, and metallic at the initial stage itself. This improves recycling efficiency, reduces landfill load, minimizes pollution, and ensures safe handling of waste. The integration of IoT technology further enhances the system by enabling real-time monitoring of waste levels and system status. With IoT-based monitoring, municipal authorities can plan optimized collection routes and prevent overflow of bins. Hence, this project proposes an IoT-based smart waste segregation system which uses sensors and microcontroller-based automation to provide an efficient, eco-friendly, and scalable solution for sustainable waste management.

LITERATURE REVIEW

The increasing amount of municipal solid waste generation has become a serious environmental and social concern worldwide. Rapid urbanization, industrial development, and population growth have led to an enormous rise in household as well as industrial waste production. Traditional waste management systems largely depend on manual segregation and landfill dumping, which results in inefficient processing, increased pollution, and health hazards for sanitation workers. In order to overcome these limitations, several researchers have proposed automatic waste segregation and IoT-based smart waste management systems. These systems mainly focus on waste identification, classification, segregation, monitoring, and optimized waste collection.

One of the major challenges in waste management is the lack of segregation at the source. When dry waste such as plastics, paper, and glass gets mixed with wet biodegradable waste, the recycling process becomes difficult and expensive. To solve this issue, Ruveena Singh and Dr. Balwinder Singh proposed a “Smart Waste Sorting System” in which the waste level in the bin is detected using an ultrasonic sensor. Their system utilizes an ESP8266 Wi-Fi module to transmit the sensor data to a web-based application, where real-time monitoring is achieved through graphical representation. The system also alerts the authorities whenever the bin reaches its maximum capacity. This work highlights the importance of integrating IoT technology with waste monitoring to avoid overflow and improve collection efficiency. However, their system mainly focuses on monitoring the bin level and does not provide detailed segregation into multiple waste categories.

Narayan Sharma, Nirman Singha, and Tanmoy Dutta proposed a “Smart Bin Implementation for Smart Cities,” which provides a practical model for automatic segregation of waste into wet, dry, and metallic categories. Their system is divided into three compartments, where the first compartment contains an IR sensor and a metal detector, and the second compartment contains another IR sensor and a moisture sensor. The third compartment consists of separate bins for storing segregated waste. Their approach emphasizes that sensor-based segregation combined with automation can reduce human intervention significantly. Their system demonstrates that using a microcontroller such as Arduino allows accurate detection and segregation, but the efficiency of segregation still depends on sensor calibration and the mechanical movement mechanism.

Amrutha Chandramohan and team developed an “Automatic Waste Segregator” system that is capable of segregating waste into four categories namely metallic, wet, dry, and glass waste. Their design uses an IR proximity sensor for detecting waste input and then passes the waste through a metal detection unit. If the waste is non-metallic, it is further analyzed using additional sensing methods to identify wet, dry, and glass materials. Their research shows that increasing the number of sensors and stages in the segregation process can improve classification accuracy and enable more detailed waste separation. However, multi-stage systems increase complexity and cost, making them less suitable for small-scale and low-cost applications.

Kumar L.M. and colleagues proposed an “Embedded Wireless Enabled Low-Cost Plastic Sorting System for Efficient Waste Management.” Their work explains the use of an 8051 microcontroller as the main controller of the segregation system. The system segregates waste into three main categories: dry, wet, and metallic waste. Their research further introduces the use of permanent magnets placed in the metallic bin for separating ferrous and non-ferrous metals. This study highlights the importance of improving recycling efficiency by performing sub-segregation within metallic waste. However, the use of 8051 microcontroller provides limited flexibility and computational capability when compared to modern controllers like Arduino or ESP-based modules.

Another significant contribution is provided by Twinkle Sinha and co-researchers, who proposed a PLC-based smart dustbin system. Their research focuses on industrial waste segregation where automation reliability is critical. PLC systems provide high durability, better control accuracy, and suitability for industrial environments. Their system segregates waste mainly into metal and non-metal categories, ensuring efficiency in industrial waste management. However, PLC-based systems are expensive and require specialized programming knowledge, which makes them less feasible for household and municipal waste segregation applications. Their study indicates that although PLC systems are reliable, low-cost alternatives such as Arduino-based systems are more practical for large-scale implementation in developing regions.

M.K. Pushpa, Aayushi Gupta, Shariq Mohammed Shaikh, Stuti Jha, and Suchitra V proposed a microcontroller-based automatic waste segregator that integrates image processing and classification techniques. Their work suggests the use of a web camera to detect and classify waste based on pixel intensity and object recognition. The system can identify different waste types including glass, metal, and dry waste. This research shows that computer vision and machine learning can improve segregation accuracy, especially for waste materials that cannot be easily classified using simple sensors. However, image processing systems require high computational power, better lighting conditions, and additional processing units, which increases system cost and complexity. Such systems are more suitable for large recycling industries rather than low-cost municipal segregation units.

In addition to segregation, IoT-based waste monitoring has gained significant attention. Many researchers have focused on developing smart bins that provide real-time updates about garbage levels and waste collection requirements. For example, Najaf Ali, M. Muzammul, and Ayesha Zafar proposed an intelligent garbage collection system that uses IoT technology with ultrasonic sensors and Arduino Mega. Their system continuously measures the garbage level and transmits the data using wireless connectivity to the monitoring center. This reduces unnecessary garbage truck trips and helps in route optimization. Their research highlights the importance of integrating IoT with waste management to improve operational efficiency and reduce fuel consumption.

Similarly, Parkash and Prabu V proposed an IoT-based waste management system for smart cities. Their work focuses on connecting multiple smart bins to a central server using IoT communication. This approach allows authorities to track which bins are filled and schedule collection accordingly. Their system aims to reduce overflow problems and maintain cleanliness in urban areas. However, the system mainly concentrates on monitoring and does not provide a detailed segregation mechanism, which is necessary for recycling and sustainability.

Several studies have also highlighted the importance of moisture sensing in waste classification. Moisture sensors are widely used to differentiate wet biodegradable waste from dry waste. Wet waste generally contains water content which increases the dielectric permittivity and conductivity of the material. Moisture sensors measure resistance or capacitance changes and provide analog output to microcontrollers. This technique is simple and cost-effective but requires calibration because some materials such as damp paper or semi-wet plastics may lead to inaccurate readings. Research indicates that moisture-based classification is effective for basic segregation but must be supported by additional detection methods for better accuracy.

Metal detection is another crucial method in waste segregation. Metal detectors work based on electromagnetic induction where metallic objects disturb the magnetic field generated by the sensor. This disturbance is detected and converted into a signal that can be processed by the microcontroller. Metal detection is highly reliable for identifying metallic objects such as aluminum, iron, tin, and steel. Many researchers have suggested that integrating metal detection improves recycling potential because metals have high economic value. However, metal detectors may sometimes detect objects with metallic coatings or mixed waste, which requires advanced classification techniques.

Apart from sensors, mechanical segregation mechanisms also play an important role. Researchers have implemented different mechanical models such as conveyor belts, rotating tables, robotic arms, and servo motor-based bin shifting. The rotating platform method is widely preferred because it is compact, cost-effective, and simple to implement. Servo motors provide precise angular control, making them suitable for aligning bins under the waste outlet. Studies show that servo-based segregation systems reduce time and improve efficiency compared to manual sorting. However, servo systems require accurate timing and calibration for smooth operation.

Recent advancements also include the integration of cloud platforms and mobile applications for monitoring. Similar to IoT-based smart energy meters, waste management systems are now being connected to cloud platforms where bin status data can be visualized. Real-time monitoring allows authorities to identify peak waste generation periods, plan collection schedules, and optimize waste management resources. The use of IoT platforms improves transparency and reduces operational costs. However, IoT-based systems require stable Wi-Fi connectivity and secure data transmission to avoid communication failure.

From the literature, it is clear that automated waste segregation systems are evolving rapidly with the integration of IoT and sensor technology. However, many existing systems suffer from limitations such as high cost, complexity, lack of real-time monitoring, or inability to segregate waste effectively into primary categories. Some systems are designed only for monitoring bin levels, while others focus on segregation without IoT connectivity. Therefore, there is a strong need for a low-cost, reliable, and scalable system that combines both automatic segregation and IoT-based monitoring.

The proposed project addresses these gaps by developing an Arduino Mega-based waste segregation system that classifies waste into wet, dry, and metallic categories using IR sensors, moisture sensor, and metal detector. Additionally, NodeMCU provides real-time monitoring and connectivity for smart city applications. The combination of automation and IoT ensures improved waste segregation accuracy, reduced human involvement, enhanced recycling efficiency, and sustainable waste management.

Methodology

The proposed system is an IoT-based automated waste segregation mechanism designed to classify and separate municipal solid waste into three major categories: metallic waste, wet waste, and dry waste. The methodology is based on a sensor-driven detection and classification approach, followed by a motor-controlled segregation mechanism. The system is developed using Arduino Mega as the primary controller and NodeMCU ESP8266 as the IoT communication module. The entire methodology is divided into multiple sub-sections for better understanding of system design, working flow, and operational logic.

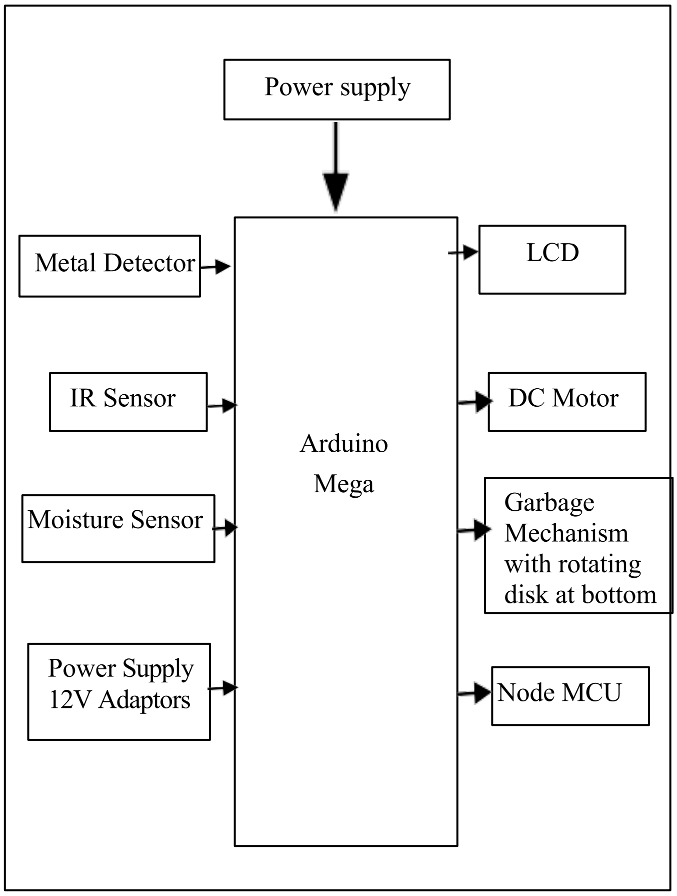

Figure 1. Block Diagram

A. System Architecture and Design

The system architecture consists of a combination of sensing modules, processing unit, output display, segregation mechanism, and IoT monitoring module. The complete system is designed in a modular form so that each part performs a specific

function in the segregation process. The core of the architecture is the Arduino Mega microcontroller, which continuously receives sensor signals, performs decision-making, and generates output control signals.
The overall system includes the following main units:
Waste Detection Unit (IR sensor-based)
Metal Detection Unit (metal detector-based)
Moisture Classification Unit (moisture sensor-based)
Control Unit (Arduino Mega microcontroller)
Segregation Mechanism Unit (rotating disk mechanism controlled by motor)
Display Unit (LCD display for system status)
IoT Monitoring Unit (NodeMCU Wi-Fi module for data transmission)
The segregation process begins only when waste is detected by the sensors, ensuring that the system does not perform unnecessary operations. This improves energy efficiency and enhances system reliability.

B. Power Supply and Hardware Initialization
The system requires a stable and regulated power supply for continuous and accurate operation. The sensors and microcontroller typically require a 5V DC supply, whereas the DC motor or mechanical rotating disk requires a 12V DC supply. Therefore, the system is designed using dual power supply arrangement:
5V regulated power supply for Arduino Mega, sensors, and LCD.
12V adapter supply for DC motor and rotating mechanism.
Once the power supply is switched ON, the Arduino Mega initiates system startup operations. During initialization:
Input pins are configured for IR sensor, metal detector, and moisture sensor.
Output pins are configured for LCD and motor driver circuit.
LCD is initialized and displays startup message such as "System Ready".
Motor mechanism is calibrated to a default home position.
NodeMCU is activated and Wi-Fi connection is established.
Serial communication between Arduino Mega and NodeMCU is initiated.
This initialization stage ensures that all sensors and mechanical components are ready for the segregation cycle.

C. Waste Detection Phase using IR Sensor
The waste detection stage is the first and most important step in the segregation process. In this stage, an IR sensor is placed at the inlet or detection chamber. The IR sensor works based on the principle of infrared light reflection.
The IR sensor consists of:
IR transmitter (IR LED)
IR receiver (photodiode / phototransistor)
When no waste is present, the emitted infrared rays do not reflect back strongly. When waste is inserted into the system, the IR rays reflect back and are detected by the receiver. This reflection generates a digital output signal which is sent to the Arduino Mega.
Once the Arduino Mega receives the IR sensor signal, it confirms that waste has been placed and immediately activates the classification stage. This approach ensures that the system remains in standby mode until waste is detected, improving power efficiency.

D. Metallic Waste Identification using Metal Detector
After detecting waste, the next stage is metallic waste identification. Metallic waste is considered valuable for recycling, therefore it must be separated at the earliest stage. The system uses a metal detector sensor installed in the first compartment.
The metal detector works on the principle of electromagnetic induction. When a metallic object is brought near the detector:
The sensor produces an electromagnetic field.
The metal object induces eddy currents due to the electromagnetic field.
The induced current disturbs the original field.
The sensor detects this disturbance and generates a digital output signal.
The Arduino Mega continuously monitors this output. If the output indicates the presence of metal, the waste is immediately classified as metallic waste. The Arduino Mega then sends a control signal to rotate the segregation mechanism to the metal bin position.
Examples of metallic waste include keys, coins, tin lids, aluminum sheets, and steel objects.
If the metal detector does not detect any metallic content, the waste is treated as non-metallic and is forwarded to the moisture sensing phase.

E. Transfer to Wet/Dry Classification Compartment
When waste is confirmed as non-metallic, it is transferred to the second compartment for wet/dry classification. The second compartment is designed with another IR sensor and moisture sensor.
The second IR sensor ensures that waste has reached the correct position before moisture measurement begins. This step is important because moisture sensors can give unstable output if no waste is in contact with its probes. Therefore, the second IR sensor acts as a confirmation sensor and prevents false readings.
Once waste presence is confirmed in the second chamber, the moisture sensor is activated.

F. Wet and Dry Waste Classification using Moisture Sensor
The moisture sensor is responsible for classifying waste into wet and dry categories. Moisture sensors operate based on conductivity and dielectric constant principles.
Wet waste contains high water content, which increases conductivity between sensor probes. Dry waste has low conductivity due to absence of water.
The moisture sensor provides an analog output, which is read by Arduino Mega through ADC pins. The Arduino Mega converts the analog signal into a digital value (0–1023 range). This value is then compared with a predefined threshold value.
If moisture reading > threshold → Waste classified as Wet Waste
If moisture reading < threshold → Waste classified as Dry Waste
Examples of wet waste include banana peels, vegetable waste,

fruit waste, wet cloth, and food waste. Dry waste includes plastic pieces, paper, wrappers, packaging waste, and cardboard.
This classification process ensures proper separation of biodegradable and non-biodegradable waste, which is essential for recycling and composting.

G. Segregation Mechanism using Rotating Disk and Motor Control
Once the waste category is identified (metal, wet, or dry), the segregation mechanism is activated. The system uses a rotating disk mechanism placed at the bottom of the waste outlet. The disk has three collection bins arranged around it:
Metallic waste bin
Wet waste bin
Dry waste bin
The rotating disk is controlled by a DC motor (or servo motor depending on design). Arduino Mega sends control signals to the motor driver circuit, which rotates the motor in the required direction.
Working Process:
If waste is metallic → rotating disk aligns metallic bin under the outlet.
If waste is wet → rotating disk aligns wet bin under the outlet.
If waste is dry → rotating disk aligns dry bin under the outlet.
After aligning the correct bin, waste is dropped into that bin.
After segregation is completed, the motor rotates the disk back to its default home position. The rotation angle is pre-programmed and controlled through time delay logic or motor calibration values.
This mechanism provides accurate physical separation and ensures that waste categories do not mix.

H. LCD Display for Real-Time Status Monitoring
An LCD is interfaced with Arduino Mega to display system operations in real time. The LCD acts as a local user interface and provides output messages such as:
"Waste Detected"
"Metal Waste Identified"
"Wet Waste Identified"
"Dry Waste Identified"
"Segregation Completed"
This feature increases transparency and helps in understanding system functioning. It also assists in debugging and verifying whether sensor detection and motor actions are correct.

I. IoT Integration using NodeMCU ESP8266
The IoT capability of the system is achieved using the NodeMCU ESP8266 module. NodeMCU provides Wi-Fi connectivity and enables communication with cloud servers or IoT platforms. The NodeMCU is interfaced with Arduino Mega using serial communication.
Working of IoT Module:
NodeMCU connects to Wi-Fi hotspot using IEEE 802.11 protocol.
It receives segregation results and bin status from Arduino Mega.
It transmits the information to an IoT server or application.
Authorities or users can monitor the waste segregation status remotely.
The data transmitted can include:
Total wet waste count
Total dry waste count
Total metal waste count
Bin filling status
System operational status
This IoT monitoring helps municipal corporations optimize waste collection routes and avoid overflowing bins. It also reduces fuel cost and improves cleanliness in urban areas.

J. Software Algorithm and Flow Control
The software algorithm of the system is developed in Embedded C using Arduino IDE. The logic is implemented using conditional statements and loop operations.
Algorithm Steps:
Start system and initialize sensors, LCD, and motors.
Wait for IR sensor detection.
If waste detected → activate metal detector.
If metal detected → rotate disk to metal bin and drop waste.
Else → transfer waste to moisture sensor compartment.
Read moisture sensor value.
If moisture value is high → classify as wet waste.
Else → classify as dry waste.
Rotate disk to required bin and drop waste.
Display results on LCD.
Send data to NodeMCU for IoT update.
Return disk to home position.
Repeat process for next waste.
This algorithm ensures continuous automatic operation and accurate segregation.

K. Continuous Operation and Reset Cycle
After every segregation cycle, the system resets automatically. The disk returns to default position, sensors return to standby monitoring mode, and the system waits for the next waste input. This ensures uninterrupted continuous segregation in real-time conditions.
The complete methodology provides an efficient automated waste segregation model which reduces manual intervention and supports smart waste management.

Moisture Sensor Voltage:

$$V_{out} = \frac{ADC_{value}}{1023} \times 5V$$

Moisture Percentage:

$$Moisture(\%) = \frac{ADC_{value}}{1023} \times 100$$

Waste Classification:

$$\text{If } ADC_{value} > T \Rightarrow \text{Wet}$$
$$\text{If } ADC_{value} \le T \Rightarrow \text{Dry}$$

Rotating Disk Angle:

$$\theta = \frac{360°}{3} = 120°$$

Total Waste Count:

$$W_{total} = W_{wet} + W_{dry} + W_{metal}$$

IV. RESULTS AND DISCUSSION

The proposed IoT-based automatic waste segregation system was implemented and tested under real-time conditions using various household waste samples. The system was evaluated for its capability to detect waste, classify it into metallic, wet, and dry categories, and successfully segregate it into the appropriate bins using the rotating disk mechanism. The results were analyzed based on sensor outputs, segregation accuracy, system response time, and IoT monitoring performance. The experimental setup included an Arduino Mega microcontroller, IR sensors, moisture sensor, metal detector, DC motor-based rotating disk, LCD display, and NodeMCU ESP8266 for real-time data transmission.

A. Sensor Detection Performance

The IR sensor was tested to verify its reliability in detecting the presence of waste at the inlet. During testing, the IR sensor consistently detected the presence of waste objects such as plastic wrappers, paper pieces, banana peels, and metallic keys. The IR sensor output was digital and was recorded as:

$$IR = \begin{cases} 1, & \text{Waste Detected} \\ 0, & \text{No Waste Detected} \end{cases}$$

The system was designed such that the segregation process initiates only when:

$$IR = 1$$

This ensured that the system remained idle when no waste was present, thereby reducing unnecessary power consumption and motor operation.

B. Metal Detection Results

The metal detector was tested using metallic objects such as keys, tin lids, aluminum pieces, and coins. The metal detector successfully identified metallic waste with high reliability. The metal sensor output was represented as:

$$M = \begin{cases} 1, & \text{Metal Detected} \\ 0, & \text{No Metal Detected} \end{cases}$$

The classification condition used was:

If $M = 1 \Rightarrow$ Metal Waste
If $M = 0 \Rightarrow$ Proceed to Moisture Detection

The results confirmed that metallic waste objects were correctly separated into the metallic bin without requiring additional sensing stages.

C. Moisture Sensor Analysis for Wet/Dry Classification

The moisture sensor was tested using wet waste samples such as banana peels, wet cloth, vegetable waste, and food waste, along with dry waste samples such as paper, plastic wrappers, and cardboard. The moisture sensor output was analog and measured through Arduino Mega ADC. Since Arduino Mega has a 10-bit ADC, the moisture reading was obtained in the range:

$$ADC_{value} \in [0,1023]$$

The output voltage corresponding to the moisture sensor reading was calculated using:

$$V_{out} = \frac{ADC_{value}}{1023} \times V_{ref}$$

Where $V_{ref} = 5V$. Hence:

$$V_{out} = \frac{ADC_{value}}{1023} \times 5V$$

The moisture percentage was computed as:

$$Moisture(\%) = \frac{ADC_{value}}{1023} \times 100$$

A threshold value $T$was selected experimentally for classification. The decision rule was:

If $ADC_{value} > T \Rightarrow$ Wet Waste
If $ADC_{value} \leq T \Rightarrow$ Dry Waste

During experimentation, the threshold value was selected as $T = 500$, which provided optimal classification accuracy.

D. Experimental Data Observations

The system was tested using multiple waste samples. Sensor readings and classification outputs were recorded and are presented in Table I.

TABLE I
MOISTURE SENSOR ADC VALUES FOR DIFFERENT WASTE SAMPLES

Waste Sample	Waste Type (Expected)	ADC Value Range	Moisture (%) Range	Classified Output
Banana Peel	Wet	710 – 820	69% – 80%	Wet
Vegetable Waste	Wet	680 – 790	66% – 77%	Wet
Wet Cloth	Wet	760 – 890	74% – 87%	Wet
Lemon Peel	Wet	640 – 750	62% – 73%	Wet
Plastic Wrapper	Dry	180 – 260	17% – 25%	Dry
Paper Piece	Dry	240 – 320	23% – 31%	Dry
Cardboard	Dry	260 – 350	25% – 34%	Dry
Thermocol	Dry	140 – 210	13% – 20%	Dry

From Table I, it is observed that wet waste materials consistently produced higher ADC readings due to high moisture content, while dry waste materials produced low ADC readings. This confirms the reliability of moisture sensor-based classification.

E. Rotating Disk Segregation Mechanism Performance

The rotating disk mechanism was tested for correct angular positioning and smooth segregation. The disk was divided into three equal bins: dry, wet, and metallic. Since the disk has three bins, the angular separation between bins was calculated as:

$$\theta = \frac{360°}{3} = 120°$$

Thus, the bin positions were set as:
Dry waste bin → 0°
Wet waste bin → 120°
Metal waste bin → 240°
The required rotation was given by:

$$\theta_{required} = n \times 120°$$

Where $n = 0,1,2$ based on waste type.
The motor successfully rotated the disk to the required bin position and deposited waste accurately. After segregation, the disk returned to the default position. The system achieved stable operation without mechanical misalignment during multiple segregation cycles.

F. Segregation Accuracy Evaluation
The segregation accuracy was evaluated by performing multiple trials for each waste category. The accuracy formula used was:

$$\text{Accuracy}(\%) = \frac{\text{Correctly segregated waste}}{\text{Total waste tested}} \times 100$$

The experiment was conducted for 50 samples in each category. The results are shown in Table II.

TABLE II
SEGREGATION ACCURACY RESULTS

Waste Category	Total Samples Tested	Correctly Segregated	Incorrectly Segregated	Accuracy (%)
Wet Waste	50	46	4	92%
Dry Waste	50	47	3	94%
Metal Waste	50	49	1	98%
Overall	150	142	8	94.6%

From Table II, it is observed that metallic waste classification achieved the highest accuracy due to the high reliability of metal detector sensing. Wet waste classification showed slightly lower accuracy because semi-wet materials occasionally produced borderline moisture readings. Overall segregation accuracy was found to be approximately 94.6%, which indicates that the proposed system performs effectively for practical applications.

G. IoT Monitoring Results using NodeMCU
The IoT functionality was tested using NodeMCU ESP8266 connected to a Wi-Fi network. The system successfully transmitted segregation updates and bin filling status to the monitoring platform. The total waste count transmitted through IoT was calculated using:

$$W_{total} = W_{wet} + W_{dry} + W_{metal}$$

Where:
W_{wet}= number of wet waste items detected
W_{dry}= number of dry waste items detected
W_{metal}= number of metallic waste items detected
The IoT system provided real-time monitoring capability, enabling users and municipal authorities to check waste quantity and schedule collection accordingly. This reduces overflow issues and improves waste collection efficiency.

H. System Response Time Analysis
The system response time was measured as the time taken from waste detection to final segregation. The total segregation time consisted of:
IR detection time
Sensor decision processing time
Motor rotation time
Waste drop time
Reset time
The average response time was found to be between 3 to 6 seconds depending on waste type. Metal waste segregation required less time as moisture detection stage was bypassed. Wet and dry waste segregation required slightly longer time due to moisture measurement.
Table III presents average response time for each waste type.

TABLE III
SYSTEM RESPONSE TIME FOR SEGREGATION

Waste Type	Average Detection Time (s)	Average Rotation Time (s)	Total Segregation Time (s)
Metal	0.5	2.0	3.0
Wet	0.5	2.5	5.0
Dry	0.5	2.5	5.5

From Table III, it is observed that the system performs segregation efficiently within a short time interval, making it suitable for continuous waste disposal environments.

v. Discussion of Observations
The obtained results demonstrate that the proposed IoT-based waste segregation system is capable of segregating waste effectively into wet, dry, and metallic categories. The use of IR sensor ensures accurate detection of waste input and triggers the process only when waste is present. Metal detector provides high accuracy for metallic waste classification. Moisture sensor-based classification provides reliable wet/dry detection, though semi-wet objects may require improved calibration. The rotating disk mechanism provides efficient mechanical separation with proper angular rotation. IoT integration through NodeMCU enhances system monitoring by providing real-time updates and waste count information.

The overall system provides a cost-effective and efficient solution for sustainable waste management. However, improvements such as additional sensors for plastic and glass detection, improved moisture calibration, and AI-based image processing can further increase segregation accuracy.

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