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Design and Development of Automated Waste Segregation System

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Abstract: The proposed waste segregation system is an automated, sensor-based solution designed to efficiently sort household waste into wet, dry, and metallic categories. It comprises two integrated subsystems that work collaboratively to streamline the segregation process. The first subsystem includes a 12V power supply, voltage regulator, Arduino Nano, IR sensor, wet sensor, and a servo motor, enabling the identification and sorting of wet and dry waste at the point of disposal. The second subsystem features an advanced setup consisting of a power supply, voltage regulator, Arduino Nano, two relays, two servo motors, a conveyor motor with its mechanism, electromagnets, an LCD display, a metal sensor, and an IR sensor. This unit further processes the waste by detecting metallic components and transporting them appropriately using the conveyor system and electromagnets. The system not only automates the classification of waste but also monitors bin levels, reducing the risk to public health and environmental hazards by promoting effective waste handling, management, and disposal. As manual segregation at the domestic level remains largely unimplemented, this project introduces an efficient and economical solution to revolutionize domestic and small-scale waste management practices.
Keywords: Automated Waste Segregation, Wet and Dry Waste, Metal Detection, Arduino Nano, IR Sensor, Electromagnet, Conveyor Mechanism, Waste Management System, Smart Bin, Sensor-Based Sorting.

I. INTRODUCTION

Waste management is one of the most pressing challenges faced by urban and rural communities worldwide. With increasing population and consumption, the volume of waste generated has significantly increased, leading to environmental degradation and health hazards. Effective segregation of waste at the source is critical to facilitate recycling, reduce landfill usage, and minimize pollution. However, in most households and social units, waste is disposed of without proper segregation, making the subsequent processing labor-intensive, inefficient, and costly. The lack of a robust domestic waste segregation system calls for innovative and automated solutions.

This project introduces an automated waste segregation system that classifies waste into three primary categories: wet, dry, and metallic. The system is designed to operate at the household or community level, ensuring the initial point of waste collection is managed effectively. It consists of two interconnected subsystems, each performing distinct but complementary roles in waste classification and management. The use of sensors such as IR, wet sensors, and metal detectors ensures real-time, accurate identification of waste types, thereby improving the efficiency of the overall segregation process.

The first subsystem focuses on the initial sorting of waste into wet and dry categories. It employs a 12V power supply, voltage regulator, Arduino Nano microcontroller, IR sensor, wet sensor, and a servo motor. When waste is placed into the bin, the sensors detect whether the waste is wet or dry. Based on the sensor readings, the servo motor adjusts the orientation of a flap or compartment to direct the waste into the appropriate bin. This reduces human involvement and ensures that recyclable and compostable waste streams are separated at the source.

The second subsystem handles more complex sorting, particularly focusing on the identification and separation of metallic waste from dry materials. It incorporates a conveyor mechanism powered by a conveyor motor, two servo motors, two relays, electromagnets, and sensors including metal and IR sensors. Waste passed through this system is scanned for metal content. If metal is detected, the electromagnets are activated to isolate the metallic objects. An LCD display is integrated to provide real-time feedback on the process, and relay-controlled actuators manage the movement and sorting of the waste efficiently.

In essence, this system aims to transform traditional waste handling by introducing automation and sensor technology into the process. By ensuring proper segregation of waste at the domestic level, it not only contributes to cleaner living environments but also enhances the scope for recycling and responsible waste disposal. The modular design, low-cost components, and reliance on Arduino-based control make this system scalable, maintainable, and highly adaptable for both urban and rural applications.

II. OBJECTIVES

Objectives of the System:

1) To develop an automated system capable of segregating waste into wet, dry, and metallic categories using sensors.
2) To reduce human involvement and error in the waste segregation process at the household or community level.
3) To integrate IR, wet, and metal sensors for accurate real-time waste classification.
4) To use servo motors and a conveyor mechanism for efficient sorting and movement of waste materials.
5) To implement a user-friendly LCD display for monitoring system operations and bin status.
6) To promote eco-friendly practices by encouraging source-level segregation and reducing landfill burden.
7) To design a cost-effective and scalable system suitable for domestic and small-scale waste management.

III. METHODOLOGY

1) *System Design and Power SupplyConfiguration:*

The system is divided into two subsystems. Each subsystem operates on a regulated power supply. The first subsystem uses a 12V power supply regulated to appropriate voltages for components like the Arduino Nano and sensors. The second subsystem is similarly powered with a regulated voltage setup to run motors, relays, electromagnets, and other peripherals. Proper voltage regulation ensures stable operation and protects components from damage.

2) *Initial Waste Detection and Classification (Subsystem 1):*

When waste is inserted into the system, an IR sensor detects its presence and activates the sorting process. A wet sensor then determines the moisture content of the waste item. If the sensor detects moisture, the waste is categorized as “wet”; otherwise, it is considered “dry.” Based on the sensor output, an Arduino Nano processes the data and sends a signal to a servo motor, which mechanically redirects the waste into the corresponding bin for wet or dry waste.

3) *Advanced Waste Processing and Metal Detection (Subsystem 2):*

Waste classified as "dry" is passed onto the second subsystem via a conveyor mechanism. This subsystem includes an IR sensor to confirm the presence of waste and a metal sensor to detect any metallic content. If metal is detected, an electromagnet is activated to attract and separate the metallic item from the rest of the waste. The remaining dry waste continues along the conveyor belt to be disposed into the appropriate dry waste bin.

4) *Servo Motor and Relay Control Mechanism:*

Two additional servo motors are used in the second subsystem to guide waste to the appropriate destination based on sensor inputs. Relays are used to control the activation and deactivation of high-power components like the conveyor motor and electromagnet. The Arduino Nano coordinates the timing and switching through the relays, ensuring safe and efficient operations.

5) *Conveyor System Operation:*

The conveyor mechanism, powered by a motor, ensures smooth and continuous movement of dry waste through the detection and segregation process. It allows for a hands-free approach in directing waste toward sensors and sorting mechanisms, improving the efficiency of the system and reducing the need for manual intervention.

6) *Feedback and Monitoring through LCD Display:*

An LCD display is incorporated to provide real-time feedback on system activity. It displays messages such as the type of waste detected (wet/dry/metallic), the operational status of sensors and actuators, and bin fill levels. This user interface improves transparency and makes the system easier to manage and troubleshoot.

7) *Integration and Automation via Arduino Nano:*

Both subsystems are controlled by separate Arduino Nano microcontrollers, which serve as the core processing units. They read sensor data, make logical decisions based on input values, and control actuators like servo motors, relays, and displays. The Arduino platform is chosen for its ease of programming, affordability, and compatibility with multiple sensors and modules.

8) Scalability and Modularity Consideration:

The system is designed in a modular manner, allowing each subsystem to function independently or as part of a complete solution. This allows for easy upgrades, maintenance, and potential expansion—such as the addition of biodegradable waste detection or integration with IoT platforms for remote monitoring and data analysis.

IV. BLOCK DIAGRAM

The block diagram of the proposed automated waste segregation system is divided into two main sections representing the two subsystems. In the first subsystem, the block diagram begins with a 12V power supply, which is regulated through a voltage regulator to provide suitable voltages to the Arduino Nano, IR sensor, wet sensor, and servo motor. The waste input is first detected by the IR sensor, and then the wet sensor analyzes the moisture content to determine if the waste is wet or dry. The Arduino Nano processes the sensor data and accordingly controls the servo motor to direct the waste into either the wet or dry bin. The second subsystem handles the further processing of the dry waste and is also powered through a regulated supply. This section consists of a metal sensor, IR sensor, conveyor motor, electromagnets, two servo motors, two relays, and an LCD display, all interfaced with another Arduino Nano. The dry waste is moved via the conveyor mechanism, where it is first confirmed by an IR sensor and then analyzed by the metal sensor. If metallic content is detected, the Arduino activates the relay to power the electromagnet and attract the metal waste. The remaining waste is sorted with the help of servo motors into appropriate bins. The LCD display provides real-time feedback about the waste type detected and the operational status. The entire block diagram shows a seamless integration of sensors, actuators, and controllers working together to achieve intelligent waste segregation, offering an efficient and automated alternative to manual sorting.

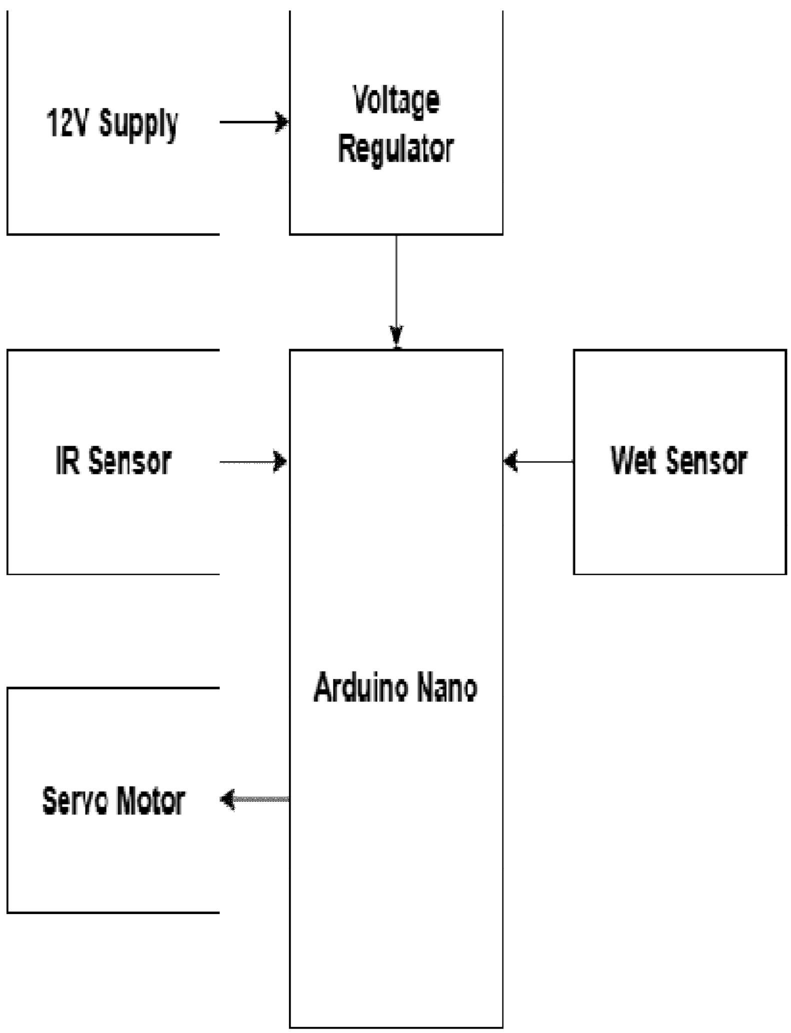

Figure 1: Block Diagram of sorting dry and wet waste

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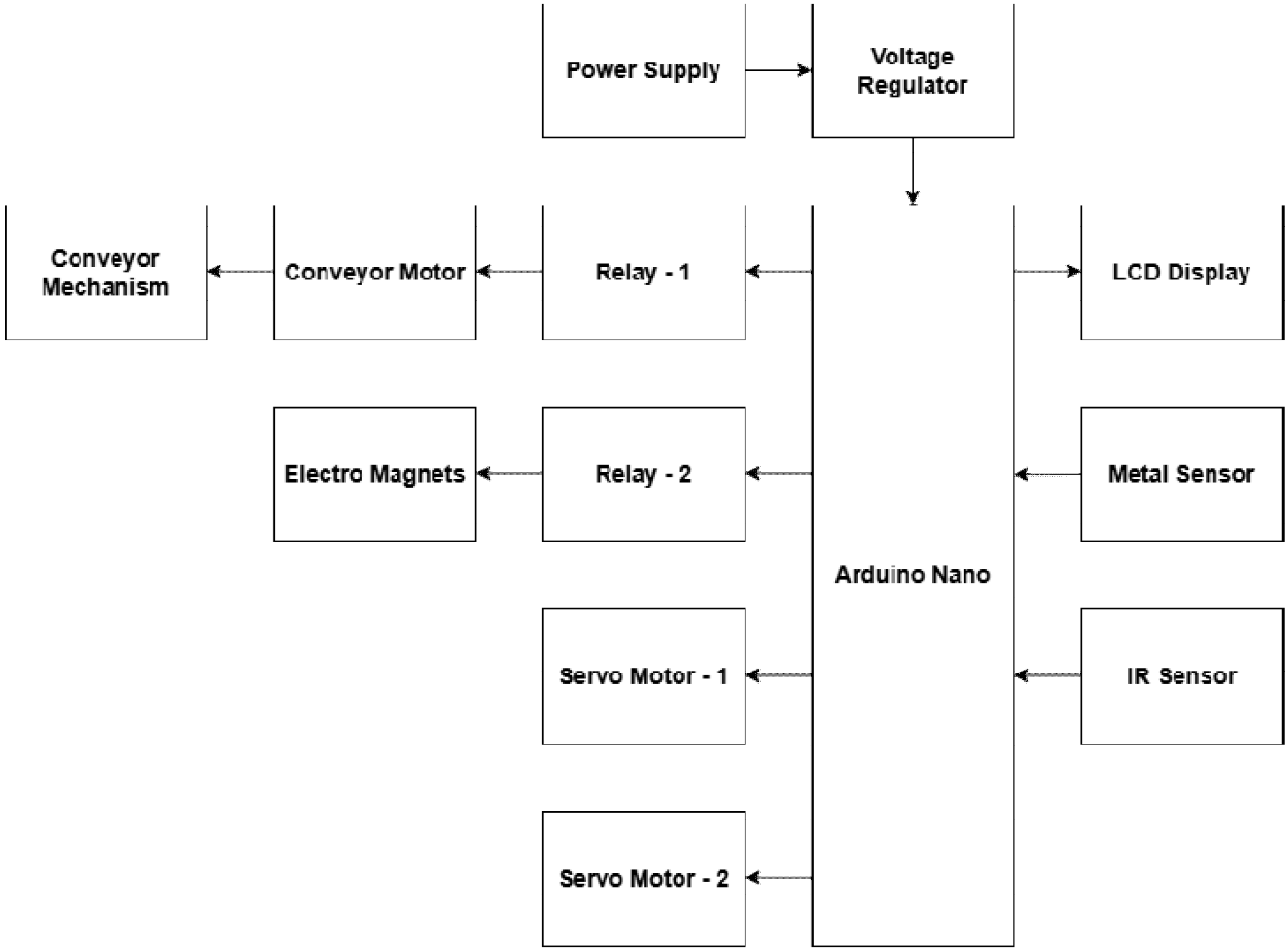

Figure 2: Block Diagram of main waste system

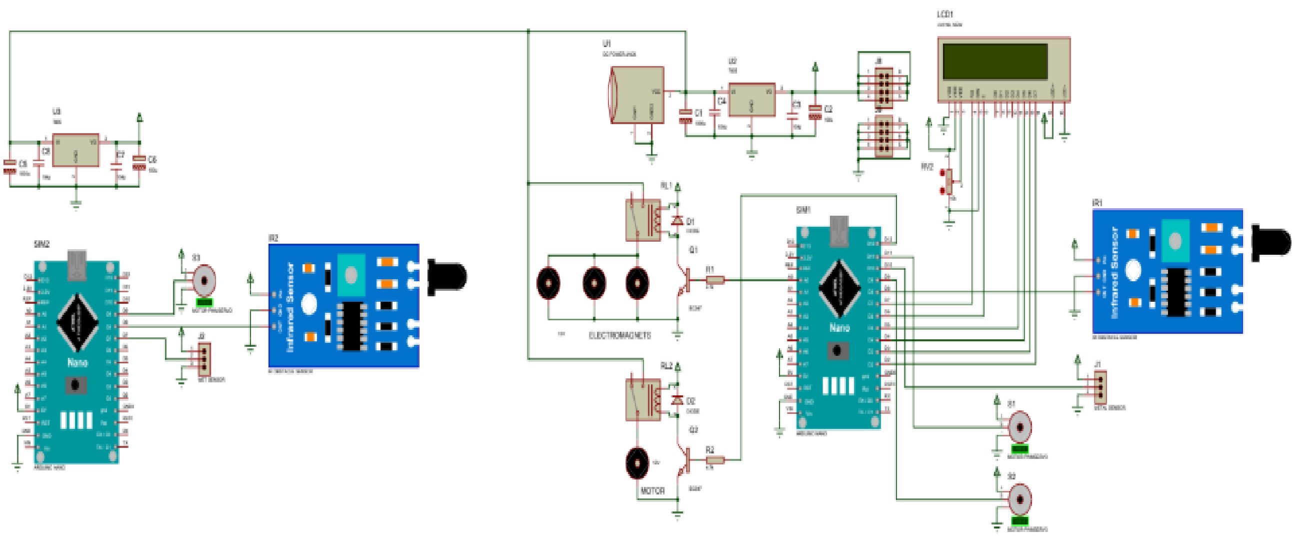

Figure 3: Circuit Diagram of the system

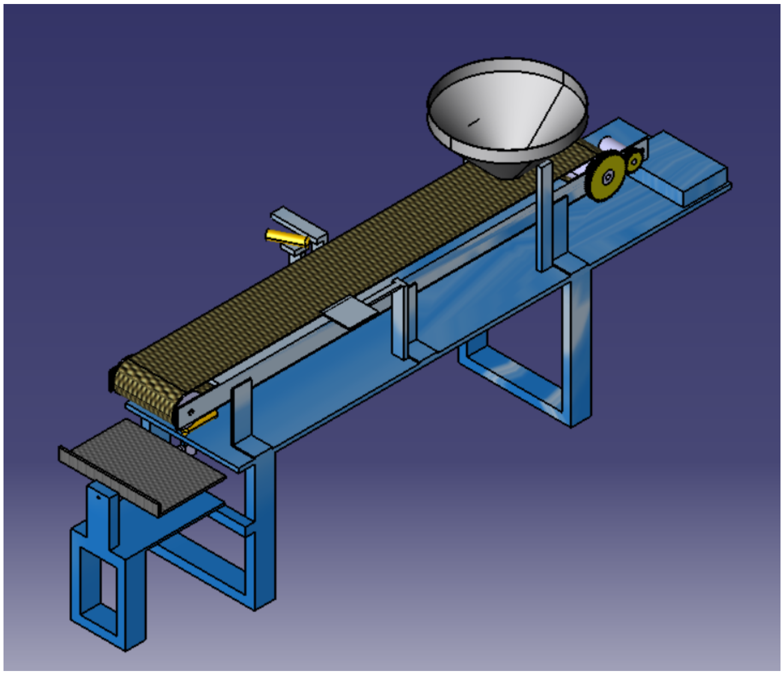

Figure 4: CAD Model of the system

V. COMPONENTS USED

1) *Arduino Nano:*

The Arduino Nano microcontroller acts as the brain of the system. Two Arduino Nano boards are used—one for each subsystem. They read inputs from various sensors, process data, and control the actuators such as servo motors, relays, electromagnets, and the conveyor mechanism. Its compact size and low power consumption make it ideal for embedded applications like this.

2) *IR Sensor:*

Infrared (IR) sensors are used in both subsystems to detect the presence of waste material. These sensors work by emitting and receiving infrared light and are essential for triggering the segregation process when waste is placed into the bin or onto the conveyor.

3) *Wet Sensor:*

The wet sensor is used in the first subsystem to differentiate between wet and dry waste. It detects the moisture content in the waste material and sends the data to the Arduino Nano, which then categorizes the waste accordingly.

4) *Metal Sensor:*

This sensor is utilized in the second subsystem to detect metallic content in dry waste. When metal is identified, it triggers the system to activate the electromagnet, ensuring proper separation of metallic waste from non-metallic dry waste.

5) *Servo Motors:*

Servo motors are used for directing the waste into different bins. One servo motor is used in the first subsystem to direct waste into wet or dry bins, and two servo motors are used in the second subsystem to sort metallic and dry waste further. They provide precise angular movement and are controlled by the Arduino.

6) *Conveyor Motor and Mechanism:*

A motor-driven conveyor belt is used in the second subsystem to transport waste materials for further analysis and sorting. It automates the movement of dry waste across the metal sensor and electromagnet setup, ensuring continuous and efficient processing.

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7) Electromagnets:

Electromagnets are used to attract and separate metallic objects once detected by the metal sensor. When activated by the Arduino via relays, they create a magnetic field that pulls metallic waste away from the conveyor.

8) Relays:

Two relays are used in the second subsystem to control high-power components such as the conveyor motor and electromagnet. These act as electronically controlled switches that allow the low-power Arduino Nano to operate high-voltage devices.

9) LCD Display:

An LCD screen is integrated into the second subsystem to provide real-time updates to the user. It displays information such as the type of waste detected, system status, and bin levels, improving user interaction and system transparency.

10) Voltage Regulator:

Voltage regulators are used to ensure a stable and appropriate voltage supply to all components. They convert the 12V power supply to suitable operating voltages for sensors, microcontrollers, and other electronics to prevent damage and ensure reliable operation.

11) Power Supply (12V):

A 12V DC power source is used to power the entire system. It is regulated down to required levels for different modules and components through voltage regulators, ensuring consistent operation across both subsystems.

These components collectively form a robust and intelligent waste segregation system that can automate the identification and sorting of waste into wet, dry, and metallic categories, significantly improving waste management efficiency at the household or community level.

VI. DESIGN CALCULATIONS

Specifications:

- Belt Size: 900 mm (L) × 600 mm (W)
- Belt Material: Tight cloth
- Maximum Load: 2 kg
- Drive Roller Diameter: 48.5 mm → Radius = 24.25 mm = 0.02425 m
- Gear Train:
  - Gear 1 (Motor side): Ø84 mm, 56 teeth
  - Gear 2 (Roller side): Ø60 mm, 38 teeth

1) Gear Ratio

Gear Ratio (GR) = Teeth on driver gear / Teeth on driven gear
= 38 / 56
= 5638
≈ 0.6786

Roller RPM = Motor RPM × Gear Ratio
= 10 × 0.6786
≈ 6.79 RPM

2) Linear Belt Speed

Belt Speed = Roller Circumference × RPM
= π × 0.0485 × 0.1131
≈ 0.0172 m/s
= 1.72 cm/s

3) Torque Required

- Force due to Load (F):
  $F = m \times g = 2 \times 9.81 = 19.62$ N
- Frictional Force (cloth on rubber, $\mu \approx 0.4$):

Ffriction = μ × N = 0.4 × 19.62 = 7.85

- Torque at Roller:
  Troller = F × r = 7.85 × 0.02425 = 0.19 Nm
- Torque at Motor:
  Tmotor = τroller / GearRatio = 0.19 / 0.6786 ≈ 0.28 Nm

4) Power Required

P= F × v = 7.85 × 0.0172 ≈ 0.135 W

VII. RESULTS

The system was tested using ten different waste items that are commonly found in households, such as paper, plastic caps, steel pins, keys, and organic waste like tea bags and cucumber slices. These items were chosen to reflect typical conditions and include varying levels of moisture, size, shape, and metallic content. The performance of the system was recorded based on response time, detection category, sorting accuracy, and any noticeable delay or error during actuation.

Table no.1: Waste Segregation Trials

Trial No.	Waste Type	Detected Category	Bin Allocated	Time Taken (sec)	Accuracy	Remarks
1	Wet tissue	Wet	Wet Bin	5.2	Accurate	Moisture detected and flat operated smoothly
2	Plastic Cap	Dry (Non-metallic)	Dry Bin	5.8	Accurate	Servo responded after slight delay
3	Steel pin	Dry (metallic)	Metal Bin	6.4	Accurate	Metal sensed but magnet slightly slow
4	Crumpled paper	Dry (Non-metallic)	Dry Bin	5.5	Accurate	Flap redirected correctly
5	Key	Dry (metallic)	Dry Bin	6.5	Inaccurate	Metal sensor failed to detect key
6	Iron nail	Dry (metallic)	Metal Bin	6.2	Slight Delay	Magnet pickup delay
7	Wet cotton	Wet	Wet	5.0	Accurate	High moisture, fast detection
8	Aluminium can lid	Dry (metallic)	Metal Bin	6.3	Slight Delay	Pickup effective but slight magnet lag
9	Cucumber slice	Wet	Wet Bin	4.8	Accurate	Sensor triggered correctly
10	Newspaper strip	Dry (Non-metallic)	Dry Bin	5.6	Accurate	Accurate bin placement

When we look at the overall performance of the system, it’s clear that the design holds up quite well under practical conditions. The average detection time taken per waste item was around 5.73 seconds considering a basic automated system designed for household or small-scale institutional use. This delay includes sensor activation, Arduino processing time, and physical movement by the servo flaps or electromagnet. The IR and moisture sensors worked reliably in all the trials. They consistently detected object presence and could distinguish between wet and dry waste with no major faults.

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The metal sensor also worked well in most cases but did show some limitations with certain items. The servo motors were responsive and quick, directing the waste to the appropriate bin with only minor lag in one or two cases. The electromagnet successfully pulled smaller metallic items like pins and nails but occasionally took an extra second to activate, especially when handling slightly heavier objects.

VIII. CONCLUSION

In conclusion, the proposed automated waste segregation system provides an efficient, sensor-based solution for categorizing waste into wet, dry, and metallic types, significantly improving the current waste management process at the household or community level. By incorporating a dual-subsystem design powered by Arduino Nano microcontrollers, along with IR, wet, and metal sensors, the system successfully identifies and classifies waste materials with minimal human intervention. The integration of servo motors, a conveyor mechanism, relays, and electromagnets further enhances automation, allowing for precise movement and separation of different waste types. The addition of an LCD display ensures real-time monitoring and user-friendly operation. This intelligent approach not only reduces manual labor and health hazards associated with waste handling but also supports environmental sustainability by promoting effective segregation at the source. Overall, the system demonstrates a scalable, cost-effective, and practical solution for revolutionizing domestic and small-scale waste management, paving the way for smarter cities and cleaner communities.

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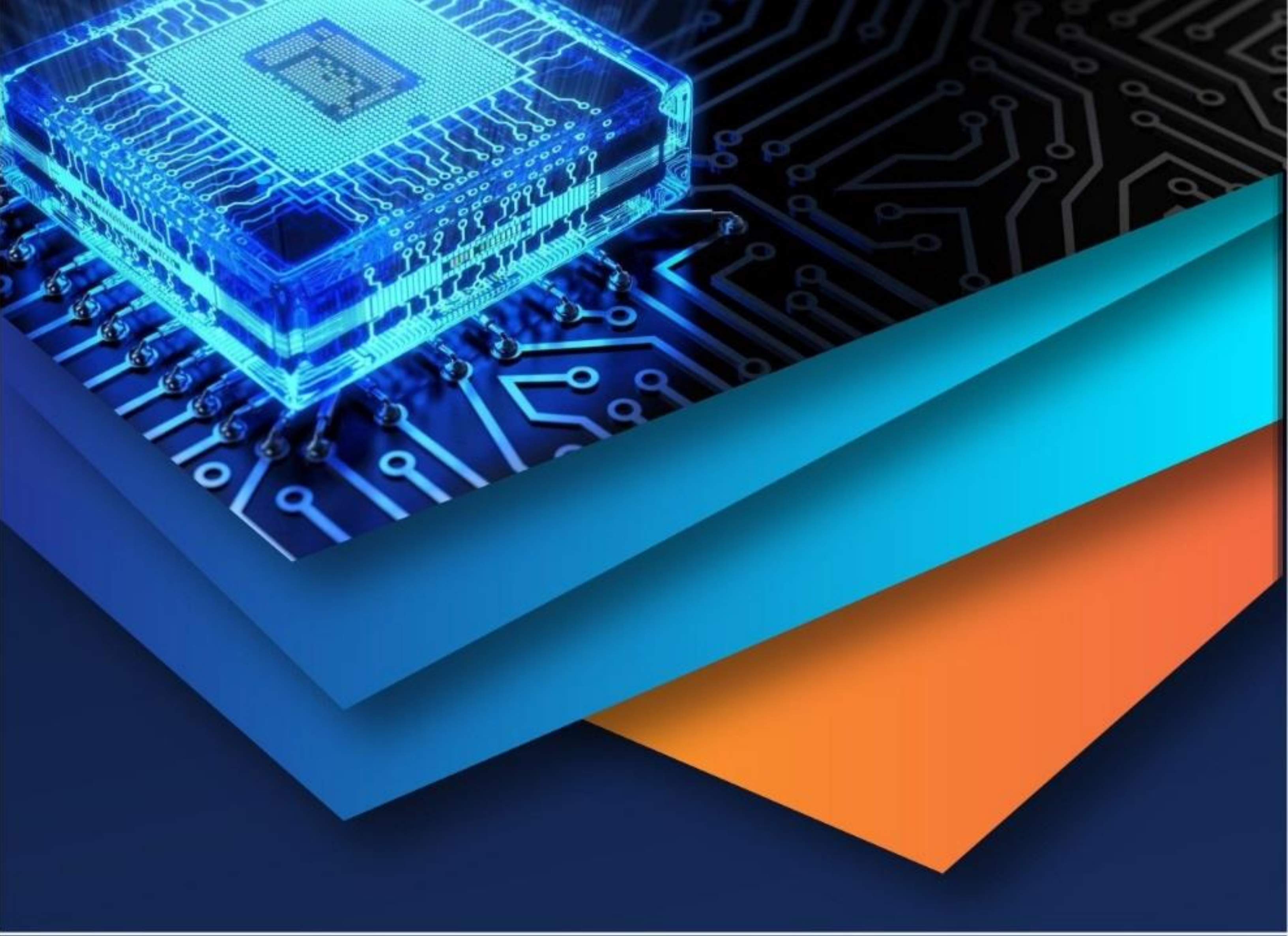

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