Development Of An Arduino-Based Smart Electro-Mechanical Waste Segregation System With Automated Sorting

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Abstract— The rapid increase in municipal solid waste has created an urgent demand for intelligent segregation systems capable of improving recycling efficiency while minimizing manual handling. This study presents the development of an Arduino-based smart electro-mechanical waste segregation system integrating hybrid sensor classification, motorized rotating segregation, and IoT-enabled monitoring. Metallic, wet, and dry waste are identified using inductive proximity sensing and moisture detection, while an ultrasonic sensor continuously monitors bin capacity and enables automated GSM alerts. The proposed system emphasizes compact design, low-cost implementation, and reliable automation suitable for domestic and institutional environments. Experimental evaluation demonstrates segregation accuracy of approximately 91% with stable indoor operation. The developed prototype provides an efficient and scalable solution toward smart waste management systems.

Keywords:

Smart Waste Segregation, Arduino Automation, Electro-Mechanical Design, Electro-Mechanical Sorting, IoT Monitoring

I. INTRODUCTION

Urbanization and population growth have significantly increased waste generation, creating environmental challenges and inefficiencies in traditional waste management practices. Manual segregation exposes workers to health risks and reduces recycling effectiveness due to inconsistent classification. Automated waste segregation systems based on embedded electronics and mechanical actuation provide a practical solution for improving safety and operational efficiency .Arduino-based embedded platforms have gained attention due to their flexibility, affordability, and ease of integration with sensors and actuators. However, many existing designs lack automated sorting mechanisms or involve complex hardware configurations that limit scalability. The present work focuses on developing a compact electro-mechanical waste segregation system capable of automated sorting, real-time monitoring, and efficient material classification.

II. LITERATURE REVIEW

Several researchers have explored automated waste segregation using microcontroller-based systems. Early studies primarily relied on moisture sensors to separate organic waste from dry waste, demonstrating the feasibility of low-cost automation. Later developments introduced servo-motor-based sorting mechanisms to improve automation efficiency, although these systems increased mechanical complexity.

Recent IoT-based smart bin designs utilized ultrasonic sensors to monitor waste levels and optimize collection schedules. While these systems enhanced monitoring capabilities, many lacked automated material classification. Hybrid sensor approaches combining proximity and infrared detection improved accuracy but often resulted in higher hardware costs.

The reviewed literature highlights the need for a compact electro-mechanical system integrating robotic handling, hybrid sensing, and real-time monitoring — which forms the focus of the proposed design.

III. Novelty And Contribution

The Key Contributions Of This Research Include:

- Integration Of Motor-Driven Rotating Segregation Mechanism With Arduino-Based Control.
- Hybrid Sensing Architecture Combining Proximity, Moisture, And Ultrasonic Sensing.
- Compact Electro-Mechanical Structure Reducing Hardware Complexity.
- Gsm-Based Alert Mechanism For Efficient Waste Collection Monitoring.

Unlike Many Earlier Systems That Focused Solely On Monitoring Or Mechanical Sorting, The Proposed Design Achieves A Balanced Combination Of Automation Efficiency, Affordability, And Scalability.

IV.System Architecture

The Overall System Architecture Is Illustrated In **Fig.1**. The Arduino Mega Acts As The Central Controller Interfacing With Infrared, Moisture, Proximity, And Ultrasonic Sensors. Sensor Inputs Are Processed To Determine Waste Type, And The Motor-Driven Rotating Segregation Platform Performs Automated Sorting Into Designated Bins

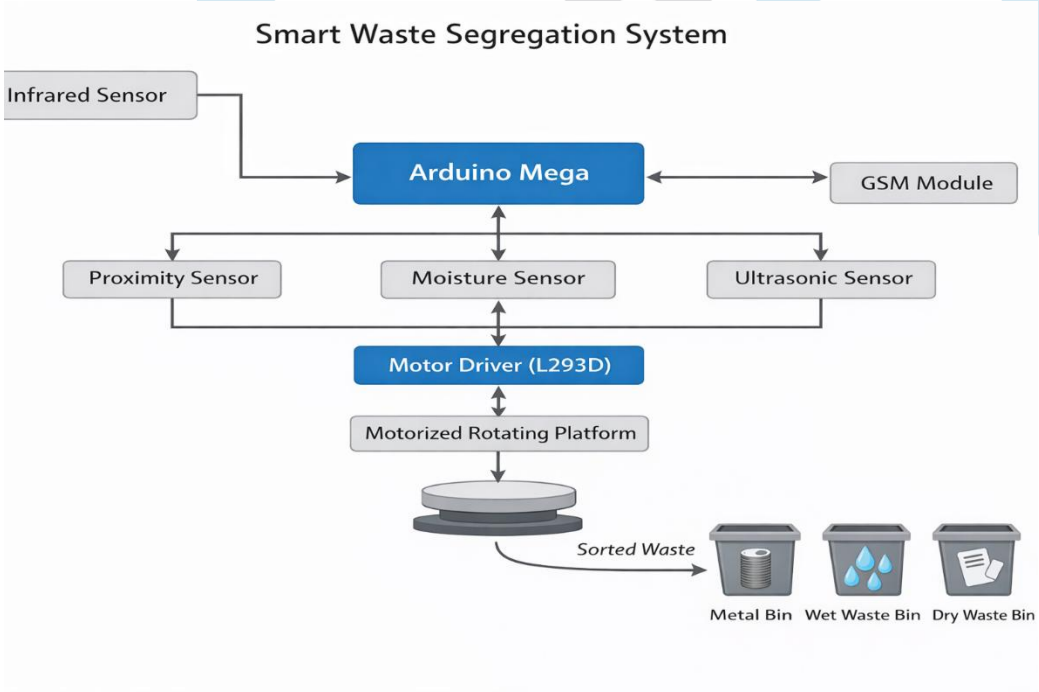

Figure 1 – Block Diagram Of Smart Waste Segregation System

Major Components

- Arduino Mega Microcontroller
- Moisture Sensor
- Inductive Proximity Sensor
- Ultrasonic Sensor
- Dc Motors With L293d Motor Driver
- Gsm Communication Module

Component	Function	Purpose
Arduino Mega	Control Unit	Processes sensor signals
Moisture Sensor	Wet/Dry Detection	Waste classification
Proximity Sensor	Metal Detection	Metallic sorting
Ultrasonic Sensor	Distance Measurement	Bin monitoring
L293D Driver	Motor Control	Rotating Platform Actuation
GSM Module	Communication	Alert notification

Table 1 – Hardware Components and Functions

V.Mathematical Modeling

The Mathematical Modelling Of The Proposed Electro-Mechanical Waste Segregation System Is Carried Out To Evaluate The Performance Of The Motor-Driven Rotating Segregation Platform And Sensor-Based Monitoring System. Basic Engineering Calculations Are Used To Validate The Feasibility And Operational Reliability Of The Developed Prototype.

- **Motor Torque Requirement**

The Torque Required To Rotate The Segregation Platform Is Estimated Using The Relation:

$$T = F \times r$$

Where:

T= Torque (N·M)

F= Applied Force (N)

r= Radius Of Rotating Platform (M)

Assuming The Rotating Platform Carries A Load Of Approximately 1.5 Kg, The Force Acting On The Platform Is Calculated As:

$$F = mg = 1.5 \times 9.81 = 14.7\ N$$

If The Effective Radius Of The Rotating Disc Is 0.1 M, The Torque Requirement Becomes:

$$T = 14.7 \times 0.1 = 1.47\ N \cdot m$$

This Calculated Torque Confirms That The Selected Dc Motor Is Sufficient For Driving The Electro-Mechanical Rotating Segregation Mechanism.

- **Ultrasonic Sensor Distance Measurement**

The Ultrasonic Sensor Measures The Distance Between The Sensor And The Waste Level Using:

$$D = \frac{V \times t}{2}$$

Where:

D= Distance (M)

V= Speed Of Sound In Air (343 M/S)

t= Echo Return Time (S)

For An Example Echo Time Of 0.02 S, The Measured Distance Becomes:

$$D = \frac{343 \times 0.02}{2} = 3.43\ m$$

This Equation Represents The Working Principle Used For Monitoring Bin Capacity In The Proposed System.

- **Segregation Efficiency Evaluation**

The Segregation Efficiency Of The System Is Calculated As:

$$\eta = \frac{N_c}{N_t} \times 100$$

Where:

N_c= Number Of Correctly Segregated Items

N_t= Total Number Of Tested Items

During Experimental Testing, If 45 Items Are Correctly Classified Out Of 50 Samples, The Efficiency Becomes:

$$\eta = \frac{45}{50} \times 100 = 90\%$$

The Obtained Efficiency Validates The Effectiveness Of The Proposed Electro-Mechanical Waste Segregation System.

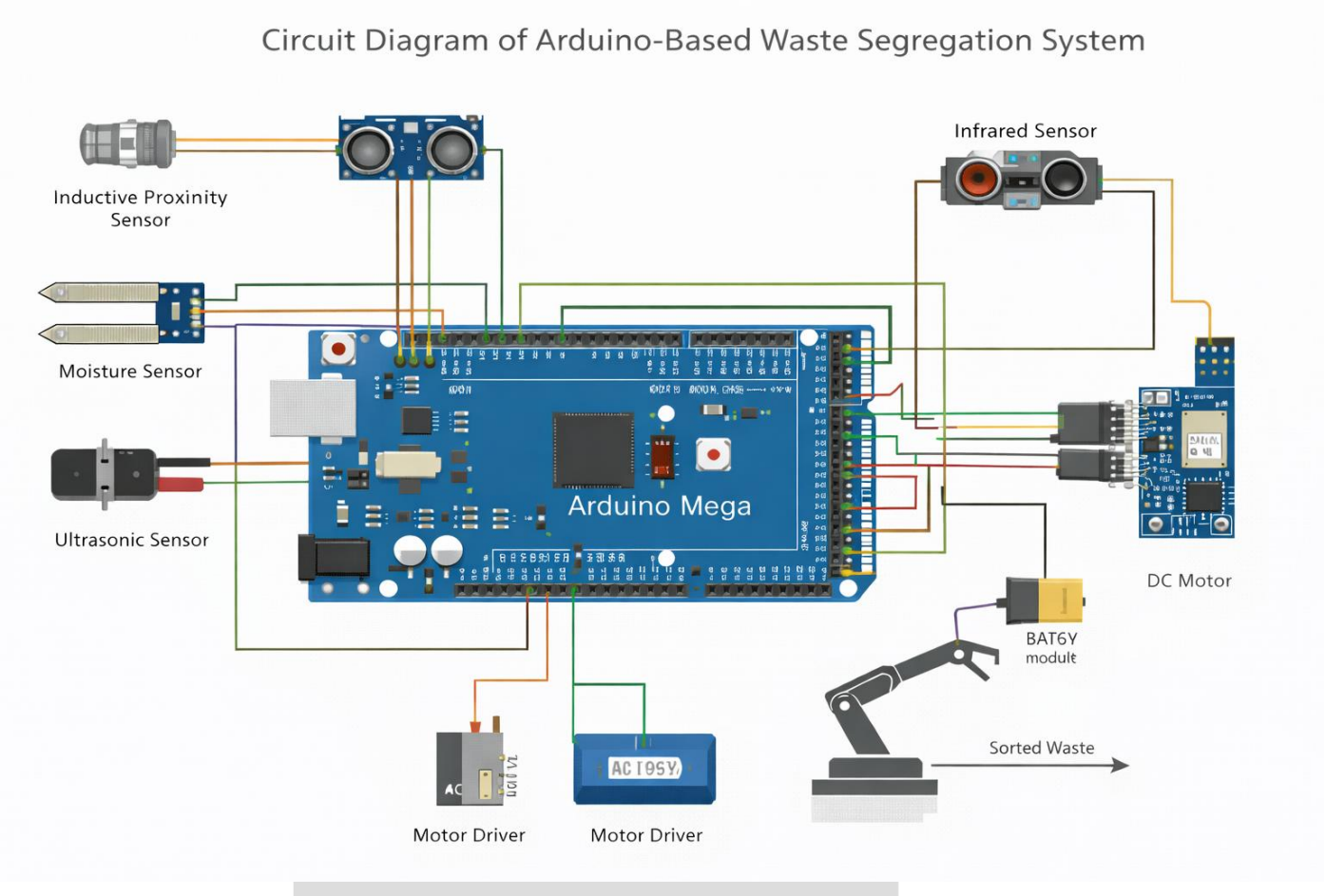

Figure 2 – Circuit Diagram of Arduino-Based Waste Segregation System

VI. Working Methodology

The Operational Workflow Of The Proposed System Is Shown In Fig.3. When Waste Is Detected By The Infrared Sensor, The Rotating Segregation Disc Driven By Dc Motors .Directs The Waste Into Separate Bins. The Waste Object Is Guided To The Sensing Platform Where Moisture And Proximity Sensors Determine The Material Category. Moisture And Proximity Sensors Determine The Material Category, And The Controller Rotates The Bin Mechanism To Deposit Waste Into Metallic, Wet, Or Dry Compartments. The Ultrasonic Sensor Continuously Monitors Bin Level, And Gsm Alerts Are Generated When The Threshold Level Is Reached.

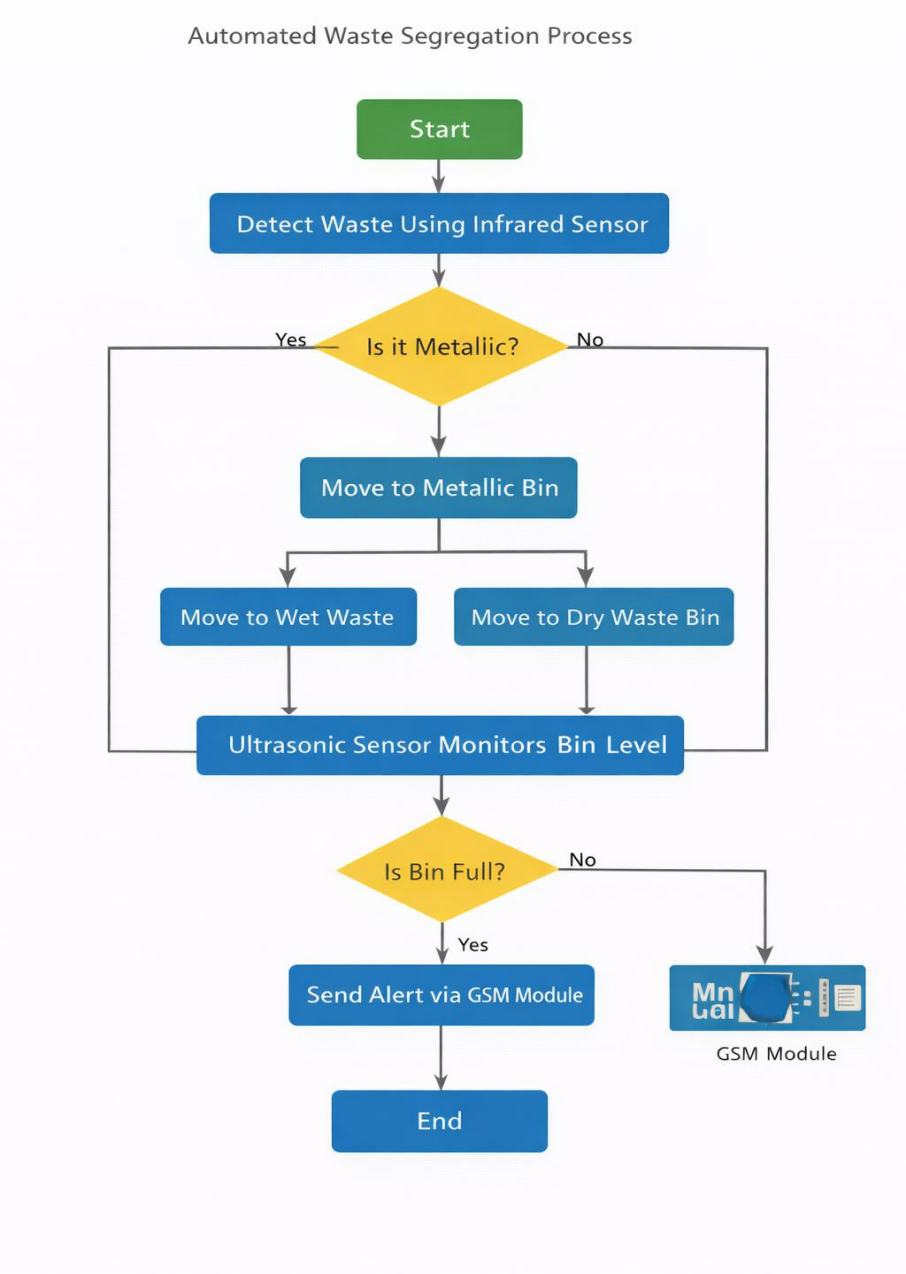

FIG-3 AUTOMATED WASTE SEGREGATION PROCESS

SENSOR CONDITION	OUTPUT
METAL DETECTED	METALLIC BIN
MOISTURE ABOVE THRESHOLD	WET WASTE BIN
OTHERWISE	DRY WASTE BIN

TABLE 2 – SENSOR DECISION LOGIC

VII. RESULTS AND DISCUSSION

EXPERIMENTAL TESTING DEMONSTRATED RELIABLE SEGREGATION PERFORMANCE WITH AN ACCURACY OF APPROXIMATELY 91%. INDUCTIVE SENSING ENABLED PRECISE METALLIC DETECTION, WHILE MOISTURE SENSING EFFECTIVELY DIFFERENTIATED ORGANIC MATERIALS. AUTOMATION SIGNIFICANTLY REDUCED MANUAL HANDLING AND IMPROVED OPERATIONAL SAFETY.

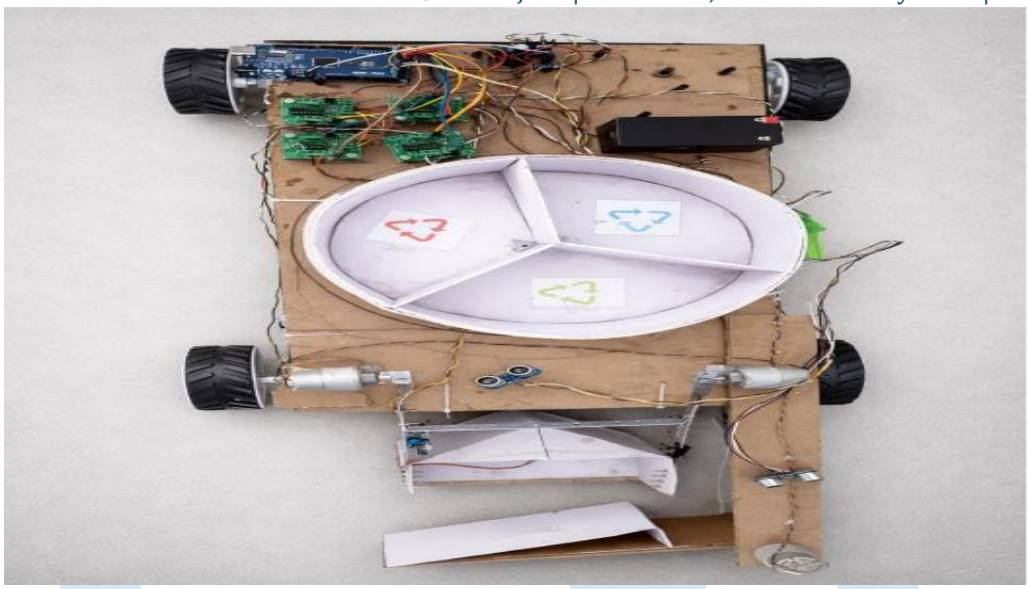

FIG. 4. DEVELOPED HARDWARE PROTOTYPE OF ARDUINO-BASED SMART ELECTRO-MECHANICAL WASTE SEGREGATION SYSTEM.

THE DEVELOPED HARDWARE PROTOTYPE OF THE PROPOSED SMART WASTE SEGREGATION SYSTEM IS ILLUSTRATED IN **FIG. 4**. THE PROTOTYPE INTEGRATES AN ARDUINO-BASED CONTROL UNIT, SENSOR MODULES, MOTOR DRIVERS, AND A ROTATING SEGREGATION PLATFORM WITHIN A COMPACT STRUCTURAL LAYOUT. THE INDUCTIVE PROXIMITY SENSOR AND MOISTURE SENSING ARRANGEMENT ENABLE AUTOMATED MATERIAL CLASSIFICATION, WHILE THE ULTRASONIC SENSOR MONITORS BIN CAPACITY DURING OPERATION. THE EXPERIMENTAL SETUP VALIDATES THE FEASIBILITY OF THE PROPOSED ELECTRO-MECHANICAL DESIGN FOR REAL-TIME AUTOMATED WASTE SEGREGATION

PARAMETER	RESULT
SEGREGATION ACCURACY	91%
RESPONSE TIME	2.5 S
POWER CONSUMPTION	LOW
SYSTEM STABILITY	HIGH

Table 3 – Performance Evaluation

Feature	Conventional System	IoT Monitoring System	Proposed System
Automated Sorting	Limited	No	Yes
Hybrid Sensors	Partial	No	Yes
Electro-Mechanical Sorting	No	No	Yes
GSM Alerts	No	Yes	Yes
Segregation Accuracy	70–80%	Monitoring Only	~91%

Table 4 – Comparison with Existing Systems

VIII.CONCLUSION

The Developed Arduino-Based Electro-Mechanical Waste Segregation System Presents A Compact And Efficient Solution For Automated Waste Management. The Integration Of A Motorized Electro-Mechanical Rotating Segregation Platform With Hybrid Sensor-Based Classification Enables Reliable Separation Of Metallic, Wet, And Dry Waste Materials. The Proposed Design Emphasizes Simplicity, Low Cost, And Practical Implementation While Maintaining Stable Operational Performance Under Experimental Conditions. Furthermore, The Incorporation Of Ultrasonic Monitoring And Iot-Based Alert Mechanisms Enhances System Functionality By Enabling Real-Time Waste Level Tracking. The Experimental Prototype Results, As Illustrated In Fig. 4, Validate The Feasibility Of The Proposed Electro-Mechanical Approach For Small-Scale Smart Waste Management Applications. The Developed System Provides A

Scalable Framework That Can Be Extended For Institutional And Smart City Environments With Further Optimization And Integration Of Advanced Sensing Technologies.

Future Work

•Integration Of Ai-Based Visual Classification For Advanced Material Recognition.
• Implementation Of Solar-Powered Operation To Improve Energy Efficiency.
• Development Of A Cloud-Based Monitoring Dashboard For Remote Waste Management Analytics.
• Structural Optimization Of The Electro-Mechanical Rotating Segregation Platform To Reduce Weight And Improve Durability.

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