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AI Powered Waste Sorting: Real Time Cost Effective Smart Waste Detection and Sorting System

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ABSTRACT

The increasing challenges of waste management, driven by the rapid pace of urbanization and industrialization, have created an urgent need for more effective and innovative solutions for waste segregation and recycling. As cities grow and industrial activity intensifies, the volume and variety of waste generated have escalated, making traditional waste management methods increasingly ineffective. This paper explores an advanced approach to addressing these challenges through the development of a Smart Waste Segregation System. The system leverages capacitive sensing technology to identify and classify waste into categories such as metallic, wet, and other materials. By incorporating machine learning algorithms, the system is able to improve its classification accuracy over time, making it adaptable and efficient for diverse waste types. One of the key advantages of this system is its cost-effectiveness and scalability. This approach not only addresses the immediate needs of waste management but also contributes to the broader goal of sustainable development, supporting eco-friendly practices and promoting recycling as a viable solution to the growing waste crisis.

Keywords: smart waste management, capacitive sensing, machine learning, sustainable solutions, waste segregation technology.

1.INTRODUCTION

The exponential growth of global waste, fuelled by rapid urbanization and economic expansion, has reached unprecedented levels in recent years. As of 2024, global municipal solid waste generation is projected to exceed 2.5 billion tons annually, with a consistent growth rate of approximately 8-10% per year, driven by population growth and increased consumption patterns. Poor waste management practices contribute significantly to environmental crises, including greenhouse gas emissions, water pollution, and habitat destruction, while also posing critical risks to human health. The escalating complexity of waste streams demands the deployment of innovative technological interventions.

This paper introduces the Smart Waste Segregation System, a next-generation framework engineered to address the inefficiencies of outdated waste management methods. By employing capacitive sensing technology and inductive proximity sensors, alongside machine learning algorithms, this achieves accurate classification of waste into metallic, wet, and dry categories. Unlike conventional systems, this advanced solution integrates real-time IoT monitoring, enabling proactive decision-making and efficient operational management. As cities worldwide strive to adopt sustainable practices, this study underscores the transformative role of intelligent automation in modernizing waste segregation, reducing landfill dependency, and advancing global sustainability goals.

2. MATERIALS AND METHOD

2.1 Arduino Components & Pins Used in the Project

Component	Functionality	Connected Pin
Capacitive Moisture Sensor	Detects moisture for wet/dry classification	A0
Inductive Proximity Sensor	Identifies metallic waste	Digital Pin 2
DC Motors	Operates sorting mechanism	Pins 3 & 4
LCD Display	Displays real-time waste classification	Various Digital Pins

Table 1: Components & Pins Used in the Project

2.2 Block Diagram

The flow of operation and component interconnection are illustrated below

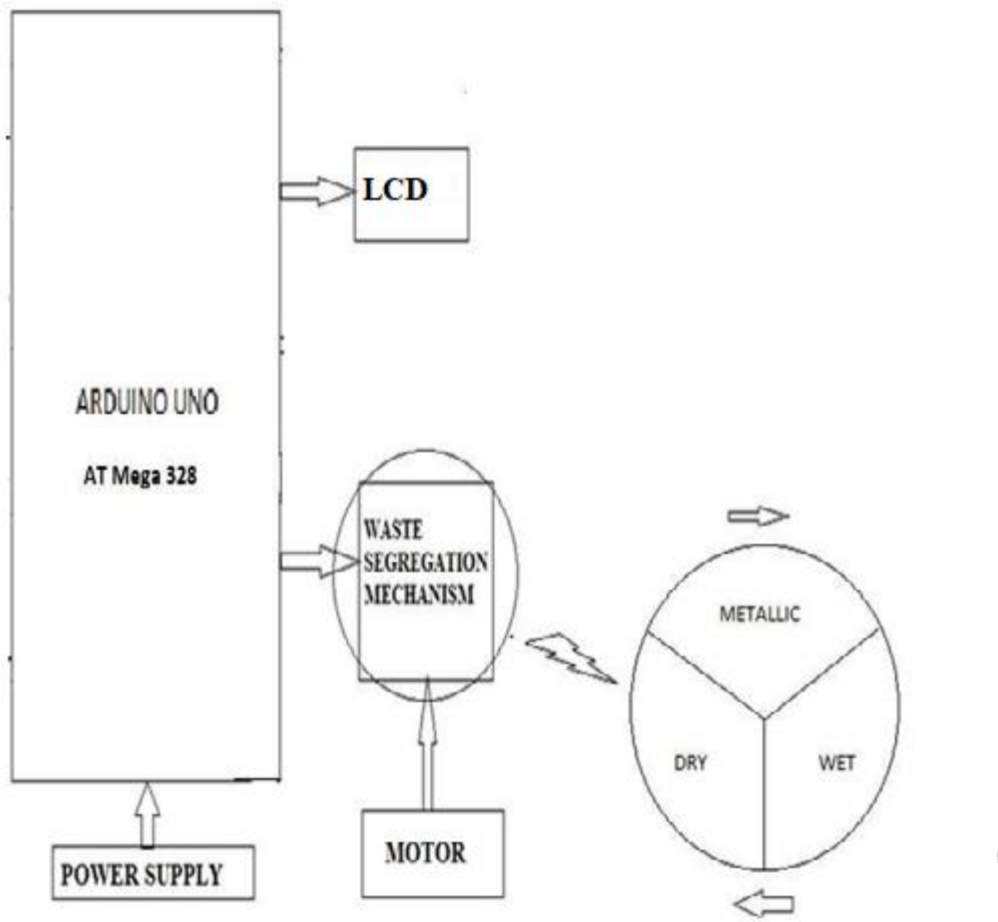

Fig 1 : Block Diagram

2.3 Hardware and Software Implementation

Hardware Components Used

Hardware Component	Purpose
Arduino Uno	Central processing unit
Capacitive Moisture Sensor	Wet/dry waste classification
Inductive Proximity Sensor	Metallic waste detection
DC Motors	Bin sorting
Motor Driver	Controls motor operation
LCD Display	Real-time feedback

Table 2 : Hardware Components

2.3.1 Capacitive Moisture Sensor

The Capacitive Moisture Sensor is designed to measure moisture levels. Its pin configuration includes:

a) VCC Pin: This pin supplies power to the sensor, typically operating between 3.3V to 5V.

b) GND Pin: Connects to the ground, ensuring proper electrical grounding.

c) AOUT Pin: This analog output pin provides a voltage signal proportional to the moisture level in the soil, which can be read by an analog input on a microcontroller.

2.3.2 Inductive Proximity Sensor

The Inductive Proximity Sensor detects metallic objects without physical contact. The typical pin configuration includes:

a) Brown Wire: Positive power supply terminal, usually connected to a voltage source between 6V and 36V.

b) Blue Wire: Ground connection.

c) Black Wire: Output pin that provides a signal when a metallic object is detected; it typically outputs a voltage close to the supply voltage when activated.

2.3.3 DC Motors

DC Motors convert electrical energy into mechanical energy. They have two main terminals:

a)Positive Terminal: Connects to the power supply; when powered, it rotates in one direction.

b)Negative Terminal: When reversed, it allows the motor to rotate in the opposite direction.

2.3.4 Motor Driver (L293D)

The L293D Motor Driver IC is used to control DC motors. It features:

a) Input Pins (IN1, IN2, IN3, IN4): Control the direction of rotation for two motors.

b) Output Pins (OUT1, OUT2 for Motor A; OUT3, OUT4 for Motor B): Connect to the terminals of the motors.

c) Enable Pins (EN1, EN2): Enable or disable the motors; applying a HIGH signal enables them.

2.3.5 LCD Display

The 16x2 LCD Display is commonly used for displaying text information. Its pin configuration includes:

a) VSS Pin: Ground connection.

b) VDD Pin: Power supply pin (+5V).

c) VO Pin: Contrast adjustment pin connected to a potentiometer.

d) RS Pin: Register select pin that determines whether data sent is command or character data.

e) RW Pin: Read/Write mode selection; typically grounded to keep in write mode.

f) E Pin: Enable pin that latches data present on the data pins.

Software Implementation

The software component is implemented using the Arduino IDE, with the following

Functionality	Implementation
Sensor Data Processing	Reads input from capacitive and proximity sensors
Waste Classification Logic	Determines waste type based on sensor thresholds
Motor Control	Activates motors to segregate waste

Table 3 : Software Implementation

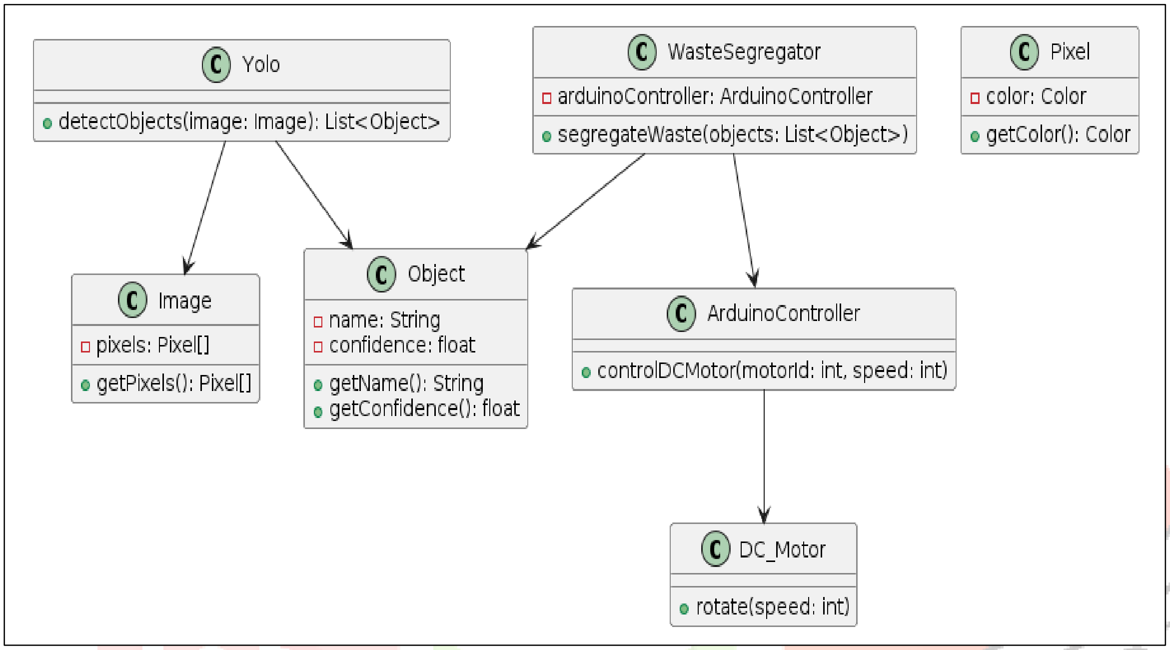

Fig 2 : Flow of Software Implementation

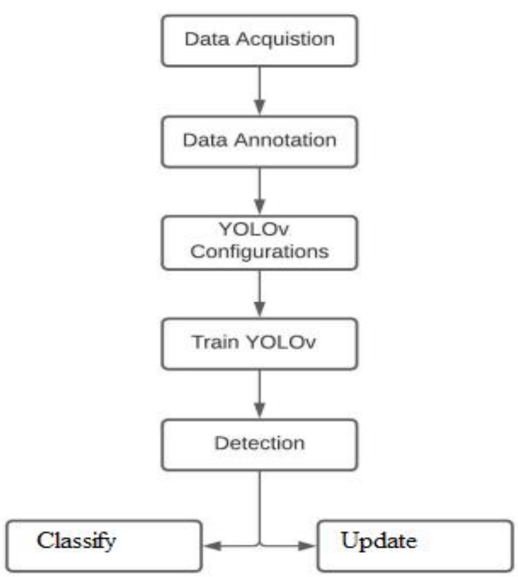

Fig 3: Data Flow Diagram

Hardware Implementation

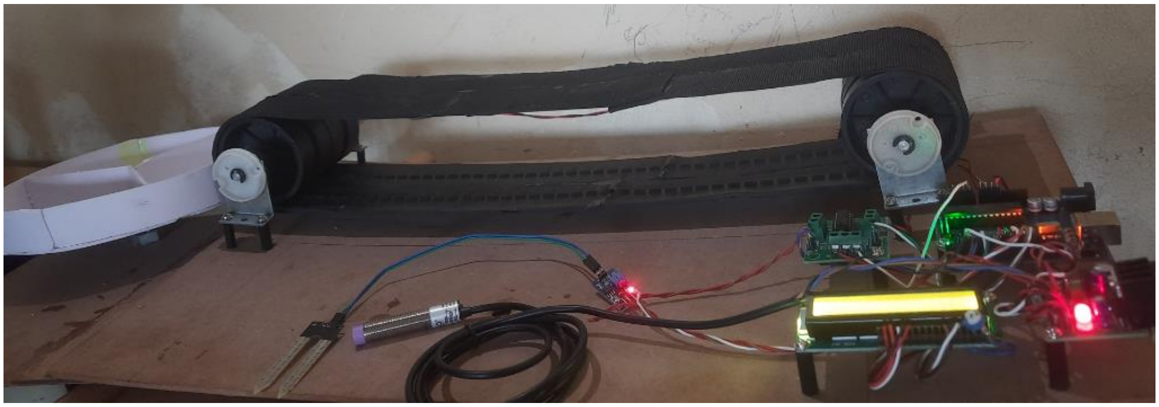

Fig 4 : Hardware Implementation

3. RESULTS AND DISCUSSION

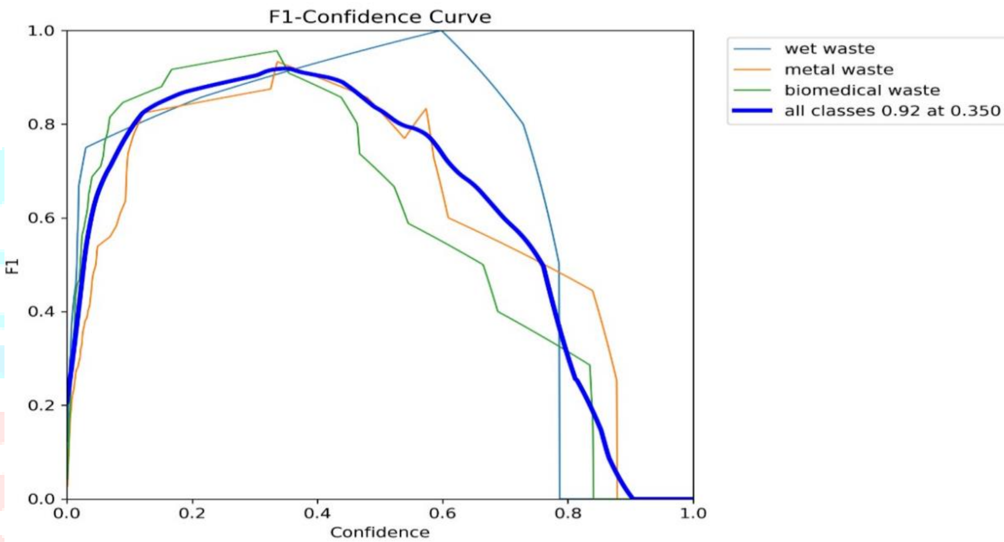

Fig 5 : F1- Confidence Curve

3.1 Accuracy Test Results

The system achieved the following accuracy rates for waste classification:

Waste Type	Accuracy (%)
Metallic	91
Wet	86
Dry	83

Table 4: Accuracy Test Result

3.2 System Behavior in Ideal and Noisy Conditions

The system was tested under two scenarios: ideal and noisy conditions. Performance metrics are summarized below.

Test Condition	Accuracy (%)	Response Time (s)	Error Rate (%)
Ideal	92	<1	8
Noisy	80	<1	20

Table 5 : System Behavior in Ideal and Noisy Conditions

3.3 Waste Classification Timing

The average time taken for waste classification was recorded as follows:

Waste Type	Average Time Taken (s)
Metallic	1.2
Wet	1.5
Dry	1.0

Table 6 : Waste Classification Timing

4. CONCLUSION

The development of the Smart Waste Segregation System marks a significant advancement in sustainable waste management technology. By leveraging capacitive sensing and machine learning, the system provides a cost-effective and reliable alternative to traditional methods. The exclusion of servo motors and robotic mechanisms ensures scalability and simplicity, making the system accessible to households and industries alike.

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