IoT Based Portable Automated Waste Segregation System

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Abstract
Rapid urbanization and population growth have led to an exponential increase in waste generation. Manual waste segregation is time-consuming, inefficient, and poses health hazards. This paper presents the development of an IoT-based portable automated waste segregation machine capable of classifying waste into metallic, dry (plastic/paper), and wet (organic) categories. The system integrates sensors (IR, moisture, inductive) and Arduino microcontroller with IoT features for real-time monitoring. This portable solution aims to enhance domestic and community-level waste management efficiency which focuses on creating a smart and portable device that can automatically separate different types of waste - like plastic, metal, and organic materials, using sensors and the Internet of Things (IoT). The main goal is to make waste management easier, faster, and more efficient, especially in homes, schools, and public places. With application of this system, we can reduce manual work, promote recycling, and help to protect the environment. It's a step toward building smarter, cleaner, and more sustainable cities.

Keywords: Arduino, Automation, IoT, Sensors, Sustainability, Waste segregation

I. Introduction

In this major project work, we tried to state that Waste management is a crucial aspect of maintaining a clean and healthy environment. It involves the collection, transportation, processing, recycling, and disposal of waste materials in a manner that reduces environmental impact. With rapid urbanization and industrialization, the amount of waste generated has significantly increased, making effective waste management more important than ever. Proper waste management not only minimizes pollution but also conserves natural resources by promoting recycling and reuse. One of the biggest challenges in waste management is improper disposal, which leads to air, water, and soil pollution. Landfills, a common method of waste disposal, contribute to greenhouse gas emissions, while plastic waste clogs oceans and harms marine life. To combat these issues, modern waste management techniques focus on segregation at source, recycling, composting, and waste-to energy conversion. Governments and organizations worldwide are implementing sustainable waste management solutions, including the use of smart bins, IoT- based monitoring, and automated sorting systems. The integration of technology in waste management has brought about innovative solutions such as AI-powered waste classification, sensor-based monitoring, and robotic waste segregation. These advancements ensure efficient waste sorting, reducing landfill waste and increasing recycling efficiency. Moreover, public awareness campaigns and government policies play a crucial role in encouraging responsible waste disposal habits among citizens. Sustainable waste management is not just the responsibility of governments but also individuals. Simple actions like reducing single-use plastics, composting organic waste, and participating in recycling programs can significantly contribute to a cleaner environment. As the world moves towards smart cities and sustainable development, adopting advanced waste management systems will be key to protecting the planet for future generations

1.1 Overview of Automated Waste Segregation System

The core components typically include:

- **Sensors:** A variety of sensors are employed to identify waste materials. These might include infrared sensors to detect plastics, capacitive sensors for metals, and optical sensors for colour- based sorting. Advanced systems may incorporate AI-powered image recognition for more complex material identification.
- **Conveyors:** A conveyor belt system transports the waste through the sorting process, allowing for continuous operation and high throughput.
- **Sorting Mechanisms:** Depending on the sensor data and the type of waste, different sorting mechanisms are used. This could range from simple pneumatic systems to more sophisticated robotic arms capable of precise material separation.
- **Control Systems:** A central control system manages the entire process, coordinating sensor readings, activating sorting mechanisms, and monitoring overall system performance. This often incorporates programmable logic controllers (PLCs) or industrial computers.
- **Data Analytics:** Some systems incorporate data analytics capabilities using IoT technology to monitor system performance, track waste streams, and optimize resource allocation.

II. Literature

R. Gupta, A. Verma, S. Iyer, and N. Desai, et al. (2020) [1] They developed a smart IoT-based waste segregation system that classified materials like metal and plastic using real-time sensor data. It enabled remote monitoring, enhancing urban waste handling. However, the system struggled with identifying organic waste due to its complex nature. This limited its use in everyday household waste segregation. The study highlighted the potential and limitations of IoT in smart waste systems.

S. Kumar and A. Sharma et al. (2019) [2] Their Arduino-based low-cost system used metal and IR sensors for basic waste segregation. It worked well for simple items like plastics and metals, suitable for schools and small setups. However, it failed to classify complex or organic waste effectively. Despite its limitations, it served as a foundation for affordable environmental tech. It emphasized the need for balancing cost and capability.

M. Patel, A. R. Joshi, and D. Singh et al. (2021) [3] This study used machine learning and image processing to classify waste with high precision. The system learned from labelled images to identify various types of waste visually. While effective, the model required extensive training data, posing scalability issues. It advanced AI in waste management but highlighted dataset availability as a barrier. Their approach set the groundwork for camera-based smart bins.

L. Tan and J. Wang, et al. (2018) [4] They implemented convolutional neural networks (CNNs) for detailed waste image recognition. The system showed high accuracy with visually similar waste types. However, it demanded high-end hardware like GPUs, limiting portability.

P. Das, R. Ghosh, and M. Chakraborty et al. (2022) [5] Introduced RFID tagging for rapid and trackable waste identification. Effective in commercial and industrial environments with controlled tagging. The system was impractical for mixed municipal waste due to pre-tagging needs. It brought traceability and efficiency but added operational complexity. Best suited for sectors like e-waste or hospitals.

V. Nair and K. Rao et al. (2017) [6] Proposed a conveyor belt system using IR and inductive sensors for dry waste. Designed for continuous sorting in industrial environments. It couldn't handle moist or organic waste accurately due to sensor limitations. Food residue and moisture reduced system reliability. They emphasized the need for sensor fusion in complex waste streams.

H. Li and Z. Chen et al. (2020) [7] Developed a robotic arm guided by CNNs for automated waste sorting. High accuracy and precision made it suitable for recycling plants. The system was costly and needed expert maintenance, limiting accessibility. It highlighted the potential of robotics in smart recycling. Future focus should be on low-cost, modular robotic systems.

D. Singh, M. R. Mehta, and R. Kaur et al. (2021) [8] Created IoT-enabled smart bins for decentralized waste sorting. Suitable for homes and offices, with real-time alerts for bin fill levels. Required frequent maintenance, affecting long-term performance. Beneficial for urban waste collection but sensitive to environmental wear. It demonstrated the need for robust, low-maintenance smart bins.

J. Brown and T. Green, et al. (2019) [9] Implemented edge computing for on-site waste classification to reduce cloud dependency. Enabled faster data processing in low-connectivity areas. Initial setup costs and technical complexity were challenges. Their system was ideal for mobile or rural applications. They emphasized the potential of affordable edge solutions.

A. Roy and S. Mehta et al. (2023) [10] Proposed a hybrid system combining sensors and AI for robust waste classification. Achieved high accuracy by using multiple methods in tandem. Dependent on cloud connectivity, raising privacy and stability concerns. Suitable for advanced environments but requires reliable infrastructure. Future research should explore offline-capable hybrid models.

III. Objectives

The Objectives of the Automated Waste Segregation System are highlights as follows:

- Develop an Automated Waste Segregation System.
- Integrate Sensors for Segregation.
- Integrate Microcontroller-Based Automation System.

IV. Methodology

The step by step Methodology for fabrication of IoT based Automation waste segregation system is as follows and shown in Figure1.below:

- Waste is placed on the conveyor belt.
- Sensors detect the waste type (metal, plastic, organic).
- Microcontroller processes data.
- Actuators sort the waste into bins.
- Waste is collected in separate bins.
- System monitors and displays output

Figure 1: Methodology of Project work

V. Experimental Work

The prototype consists of a conveyor belt system powered by a DC motor, which transports waste through a series of sensors. Moisture, infrared, and metal sensors detect the type of waste material placed on the belt. An Arduino microcontroller processes the sensor data and activates servo motors to divert waste into the appropriate bins. The entire frame is lightweight and portable, built for easy deployment and maintenance. IoT functionality is enabled through an ESP8266 module for real-time monitoring and data logging. Software is developed using Arduino IDE and Blynk for remote interfacing. The system was tested with common household waste, demonstrating effective segregation and reliable sensor performance. The design overview of the automated system is as shown in Figure 2.

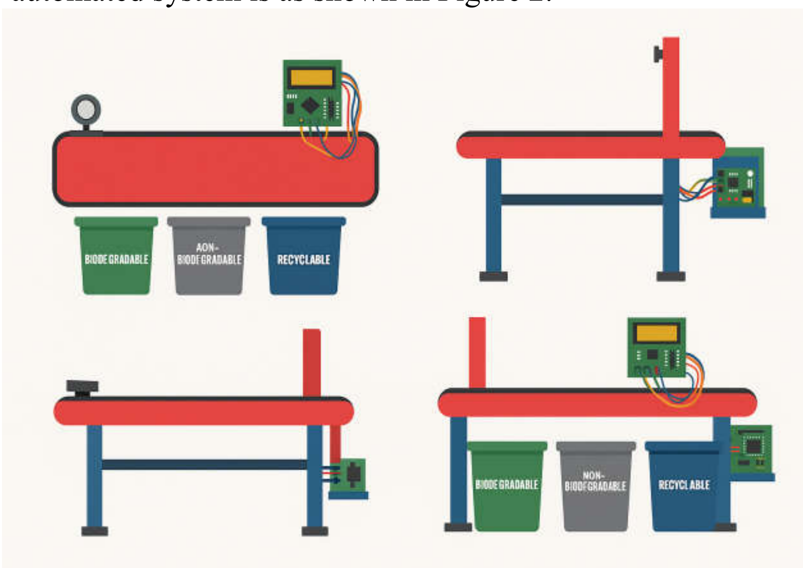

Figure 2: Pictures of Automated Segregation Model System

VI. Components of Experimental Work

6.1 Micro Controller

In an IoT-based waste segregation system, the microcontroller functions as the central processing unit, coordinating sensor inputs, processing data, and controlling actuators to automate waste sorting. Commonly used microcontrollers include Arduino, ESP32, or Raspberry Pi. Sensors such as inductive, infrared, moisture, and weight sensors detect the type of waste—metal, plastic, wet, or dry—which the microcontroller analyses using predefined logic or machine learning algorithms. Based on the classification, it activates motors or servos to direct the waste into appropriate bins (biodegradable, recyclable, or non-recyclable). With IoT integration via Wi-Fi or GSM, the system supports real-time data logging, remote monitoring, and alerts (e.g., full-bin notifications). Advanced systems may also include AI-based image recognition for improved accuracy. Overall, the microcontroller enables smart, efficient, and automated waste management.

6.2 Conveyor Belt

The conveyor belt is a moving platform used to transport waste materials through different stages of segregation. Waste is placed on the belt, which moves at a controlled speed using a motor and rollers. As the waste travels along the belt, various sensors (like metal, infrared, or moisture sensors) scan the items to detect their type. Based on the sensor input, a microcontroller sends signals to actuators or sorters, which then divert each waste item into the correct bin—such as wet, dry, or recyclable. The system allows for continuous, automatic sorting of waste, reduces manual effort, and increases efficiency. Conveyor belts are essential in making the waste segregation process fast, reliable, and hands-free.

6.3 Servo Motor

A servo motor is used in a conveyor belt system to provide precise control of movement, speed, and positioning. In an automated waste segregation machine, the servo motor drives the rollers that move the conveyor belt. Unlike regular motors, a servo motor can rotate to a specific angle or position, which is especially useful when you need the belt to start, stop, or move a certain distance accurately. The motor receives signals from the microcontroller based on sensor inputs. For example, when waste is detected on the belt, the microcontroller activates the servo motor to move the belt forward just enough for the sensors to scan the item. Once the item is sorted, the motor pauses or moves again to. This precise control helps in step-by-step movement rather than continuous rotation, making it ideal for systems where timing and position matter

6.4 Moisture Detector

A moisture detector (or moisture sensor) is used to identify whether the waste is wet or dry. In automated waste segregation machines, it helps in classifying organic (wet) waste like food scraps, and dry waste like paper, plastic, or metal. When waste comes into contact with the sensor (usually placed along the conveyor or at the input point), it measures the electrical conductivity or resistance of the material. Wet materials conduct electricity better than dry ones, so the sensor uses this principle to detect moisture content. Once moisture is detected, the sensor sends a signal to the microcontroller, which then activates a mechanism (like a servo or flap) to direct the waste into the correct bin

6.5 Metal Detector

A metal detector is used to identify and separate metallic waste from other types of waste. In an automated waste segregation system, it plays a crucial role in detecting ferrous (iron, steel) and nonferrous (aluminium, copper, etc.) metals among mixed materials. The sensor works by creating an electromagnetic field around a coil. When a metal object passes through this field (such as on a conveyor belt), it disturbs the field, and the sensor detects this change. This disturbance triggers a signal to the microcontroller, which then activates a sorting mechanism (like a servo motor or magnetic arm) to redirect the metal item into a specific bin.

6.6 Capacitive Sensor

A capacitive sensor is used to detect non-metallic materials, such as plastic, glass, paper, wood, or even liquid-based items. In waste segregation machines, it helps in identifying non-metallic dry waste that might not be detected by metal or moisture sensors. It works by generating an electrostatic field around its sensing surface. When a material with a different dielectric constant (like plastic or paper) enters this field, it causes a change in the capacitance value. The sensor detects this change and sends a signal to the microcontroller, which then classifies the item accordingly and activates sorting components like servo motors or flaps.

VII. Codes to run the Arduino Microcontroller

The code segments include:

7.1 *Sensor Initialization (Arduino)*:

```
cpp

int IRsensor = A0;

int metalSensor = A1;

int wetSensor = A2;

void setup () {

  pinMode (IRsensor, INPUT);

  pinMode (metalSensor, INPUT);

  pinMode (wetSensor, INPUT);

  Serial.begin(9600);

}
```

VIII. Conclusion:

The Automated Waste Segregation System (AWSS) developed in this study offers a smart, efficient, and scalable solution for modern waste management. By integrating IoT, sensors, microcontrollers, and machine learning, the system accurately identifies and separates biodegradable, non-biodegradable and recyclable waste with minimal human intervention. Real-time monitoring and data collection through IoT enhance efficiency, while automation reduces operational costs and manual labour. The system promotes environmental sustainability, supports initiatives like Swachh Bharat Abhiyan and Smart City Missions, and is adaptable for residential, commercial, and industrial use. With further development, its classification accuracy can be improved, making it a valuable tool for sustainable and intelligent waste management.

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