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Design and Development of Portable Waste Collection and Segregation System

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***Abstract*— Uncontrolled accumulation of municipal solid waste has become a critical challenge affecting environmental safety and public hygiene in modern communities. Existing waste management practices often separate collection and segregation, resulting in reduced efficiency and increased contamination. This paper presents a compact and portable automated system that integrates mechanical collection, airflow-assisted transport, and sensor-based segregation within a single platform. An ultrasonic sensor enables waste detection, while a soil moisture sensor differentiates wet and dry waste. An Arduino-based control unit actuates a servo-driven flap mechanism for real-time sorting. The proposed approach offers an efficient and scalable solution for decentralized waste management.**

***Index Terms*— Municipal Solid Waste, Automated System, Mechanical Collection, Sensor-Based Segregation, Ultrasonic Sensor, Soil Moisture Sensor, Arduino-Based Control, Decentralized Waste Management**

I. INTRODUCTION

Growing urban expansion and changing consumption habits have increased the strain of municipal solid waste in cities around the world. Poor disposal practices like uncontrolled dumping and mismanaged landfills lead to environmental harm, air and water pollution, and greater public health issues. Traditional waste systems often focus on collection and disposal instead of proper sorting and recovering resources. This limits recycling opportunities and long-term sustainability. To better align waste practices with global sustainability goals, especially those set by the United Nations Sustainable Development Goals (SDG 11, SDG 12, and SDG 13) [1], we need localized and technology-driven approaches that promote sorting and circular resource use right from the start.

While early waste separation greatly enhances composting and recycling results, manual sorting is still inefficient, dangerous, and unreliable. Improvements in sensor technology, embedded controllers, and automation have made smart waste solutions possible. However, many current models tackle either collection or sorting separately and are often too costly for broad use. To fill these gaps, this work introduces a compact and portable system that combines mechanical collection, suction-assisted transfer, automated detection, and sensor-based sorting in one framework. Designed for decentralized settings such as homes, campuses, and community groups, this system aims to offer a scalable and effective way to improve waste management.

II. LITERATURE REVIEW

Advancing a circular economy relies heavily on good waste identification and high-quality input streams. Recent research shows that poor source-level sorting and limits in classification technologies cut down recycling efficiency and material recovery rates. New sensing methods, including optical imaging, near-infrared analysis, laser-based spectroscopy, and hyperspectral techniques, have shown strong material recognition abilities. Meanwhile, deep learning models like Convolutional Neural Networks (CNNs) [1] have boosted plastic classification performance. However, many of these systems work well only in controlled settings and face practical challenges such as high costs, sensitivity to environmental factors, and complex infrastructure. A key research area focuses on combining various sensing methods with smart algorithms to improve reliability and scalability in real-world situations.

At a decentralized level, embedded automation has shown potential for improving hygiene and operational efficiency through contactless waste sorting [2]. Systems powered by microcontrollers use ultrasonic sensing for detection and moisture sensing for classification, allowing quick and reliable separation of wet and dry waste [3]. Servo-actuated mechanisms enable real-time sorting with minimal human involvement, proving practical for everyday use. Modular and scalable designs further support implementation in homes, institutions, and public areas. New developments like IoT connectivity, renewable energy integration, and AI-driven sensing technologies [5] suggest significant potential for smart, adaptive waste management systems in future urban environments [4].

III. WORKING PRINCIPLE AND DESIGN

A) WORKING PRINCIPLE

The proposed system is a compact, portable, and modular device designed for integrated waste collection and automated segregation. It brings together multiple coordinated subsystems within a single operational platform. The architecture consists of a mechanical pickup assembly,

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an airflow-assisted suction transport unit, a sensor-based detection module, a microcontroller-based control unit, and a servo-actuated sorting mechanism [Fig. 1].

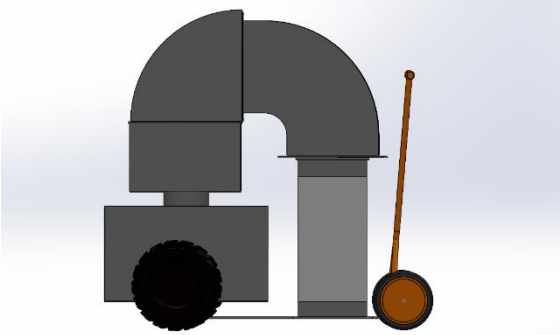


Figure 1: 3D CAD model of Eco-Sweep

The operation starts with ground-level waste entering through a multi-directional intake structure. Collected material is drawn in by a suction unit that uses airflow. It transfers the waste through enclosed ducts to the internal segregation chamber. This pneumatic movement reduces manual handling and improves overall cleanliness during operation. A proximity-based ultrasonic sensor detects incoming waste and starts the sorting process. As the material moves through the channel, moisture sensors check its composition to separate wet and dry categories. A microcontroller interprets the measured data using predefined threshold parameters. Based on this analysis, a servo-actuated flap redirects the waste into the correct storage compartment. The interaction between sensing, processing, and mechanical action creates a continuous automated control loop managed by an embedded Arduino platform.

B) SYSTEM DESIGN

Collection Mechanism and Fan Selection

For the suction-based collection system, the material density was considered as 750 kg/m³, and the inlet dimension was 0.785 × 0.284 m² with two duct bends in the layout. A transport velocity of 15.24 m/s (3000 ft/min) was selected to ensure proper movement of waste through the duct.

Based on the duct cross-sectional area (0.09546 m²), the required volumetric airflow was calculated as:

$$Q = 1.45\ m^3/s$$

Static pressure losses due to duct friction and bends were estimated using the Darcy–Weisbach approach, resulting in a total pressure loss of approximately:

$$P = 36.26\ N/m^2$$

Considering fan efficiency (75%) and motor efficiency (85%), the required power was determined as:

$$P = 82.47\ W$$

To ensure reliable operation with a safety margin, a 95 W axial fan was selected based on manufacturer specifications.

Detection and Segregation Mechanism

The detection system employs a 5V ultrasonic sensor (HC-SR04 type) operating at 40 kHz, with a sensing range of 2–400 cm and a current draw of approximately 15 mA. The sensor provides non-contact distance measurement through trigger and echo digital signals. A rigid mounting structure ensures proper alignment, vibration resistance, and protection from dust and moisture, supporting consistent long-term performance.

Waste classification is performed using four soil moisture sensors positioned along the segregation path to enable multi-point moisture detection. This arrangement improves reliability and minimizes errors caused by uneven moisture distribution, allowing accurate differentiation between wet and dry waste.

A G90 micro servo motor (4.8–6V, 0–180° rotation, ~1.8 kg·cm torque) actuates a pivoted flap inside the chamber to direct waste into the appropriate bin. The entire process is controlled by an Arduino (ATmega328PB, 16 MHz, 5V operation), which receives input from the ultrasonic and moisture sensors and generates PWM signals for precise bidirectional flap movement. This integrated sensing and actuation setup enables automated, contact-free segregation with high positional accuracy and low power consumption.

IV. CONCLUSION

The proposed system provides a combined way to handle urban waste. It uses automated collection, sensor-based sorting, and hygienic processing in a compact and portable setup. By sorting waste at the source, this platform reduces direct human contact with waste, improves sorting accuracy, and boosts material recovery efficiency. The mix of mechanical design, built-in controls, and sensing technologies shows a model that can scale for decentralized waste management. This method aids in smart city development and helps achieve circular economy goals through early waste separation and automation.

Its modular design allows for future improvements like IoT monitoring, cloud data integration, and smart system networking. Upgrades may include artificial intelligence and computer vision for sorting different types of waste. It might also include renewable energy options, such as solar charging, to enhance sustainability. With more development, connected units could work together in a coordinated network. This would allow for central management, better waste routing, and data-driven urban waste planning. The system could become a key part of the next generation of smart waste management infrastructure.

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