International Journal of Multidisciplinary Advent Research and Review (IJMARR)
Vol. 1, No. 2, February 2025
E-ISSN: 3049-1932
Available online at https://www.ijmarr.org/

A Review on Sensor Based Autonomous Waste Sorting System

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Abstract-

Waste management is a critical issue worldwide, with improper disposal leading to pollution, resource depletion, and public health concerns. Traditional waste sorting methods are inefficient, labour-intensive, and prone to errors. Autonomous waste sorting systems equipped with sensor technology offer a promising solution by enhancing accuracy, speed, and efficiency. This review explores various sensor technologies, including infrared, inductive, capacitive, ultrasonic, and vision-based sensors, for sorting different waste categories such as dry, wet, metal, glass, paper, and plastic. A comparative analysis of these technologies is presented, along with their advantages, limitations, and integration possibilities. The paper also discusses existing sensor-based sorting systems, their challenges, and future research directions, highlighting the role of artificial intelligence (AI), machine learning (ML), and robotics in advancing waste sorting technologies.

Index Terms-waste sorting, sensors, autonomous waste sorting system, sensor technologies, waste management, comparative analysis, robotics, sensor-based sorting

1. INTRODUCTION

Waste generation has increased significantly due to rapid urbanization, industrialization, and population growth. Efficient waste segregation is essential for recycling, reducing landfill burden, and minimizing environmental pollution. Manual waste sorting is inefficient and exposes workers to health risks. Automated systems using sensor-based technology provide a reliable alternative by enabling precise, real-time waste classification and separation.

Sensor-based waste sorting systems operate by detecting material properties such as colour, reflectivity, conductivity, density, and moisture content. These properties help in distinguishing different waste types for effective recycling. The primary objectives of this review are:
To explore various sensor technologies used in waste sorting.
To analyse their advantages, limitations, and suitability for different waste types.
To discuss challenges in implementing sensor-based sorting systems.
To identify future trends and research opportunities.

2. LITERATURE REVIEW

Overview of Existing Sensor-Based Sorting Systems
Several researchers have explored sensor-based waste classification techniques. For example:
Kashyap et al. (2021) developed an NIR-based plastic sorting system, achieving 85% accuracy in differentiating PET, HDPE, and PP plastics.
Kim et al. (2020) integrated inductive and capacitive sensors in an automated sorting system to classify metallic and organic waste, improving sorting efficiency by 20% compared to traditional methods.
Zhang et al. (2022) employed hyperspectral imaging (HSI) with AI, enhancing sorting precision for mixed waste streams.

Research gaps and challenges
Lack of Multi-Sensor Fusion: Most studies focus on a single sensor type, leading to misclassification of mixed waste.
Scalability Issues: High costs and complexity hinder the large-scale adoption of AI-driven waste sorting.

Real-Time Processing Limitations: Existing systems struggle with high-speed sorting requirements, limiting industrial applications.

3. SENSOR TECHNOLOGIES FOR WASTE SORTING

Different sensor technologies are used to classify waste materials based on their physical and chemical properties.

3.1. Infrared (IR) sensors

Infrared sensors work by analysing the infrared radiation emitted or reflected by materials. Near-infrared (NIR) spectroscopy is commonly used to identify plastics, paper, and organic waste based on their spectral signatures.
Working Principle: Materials absorb and reflect infrared light at different wavelengths, allowing identification.
Applications: Used in plastic recycling to differentiate PET, HDPE, and PVC.
Advantages: Fast, contactless, and effective for organic material classification.
Limitations: Limited accuracy for dark-coloured plastics and contaminated waste.

3.2. Inductive sensors

Inductive sensors detect metallic objects by generating an electromagnetic field. When a metal object enters the field, it induces an electric current, which is detected by the sensor.
Working principle: Detects conductive materials by sensing changes in electromagnetic fields.

Applications: Used in metal recycling to separate iron, aluminium, and copper.
Advantages: High reliability for detecting ferrous and non-ferrous metals.
Limitations: Cannot distinguish between different metal types; ineffective for non-metallic waste.

3.3. Capacitive sensors

Capacitive sensors work by measuring changes in capacitance when materials with different dielectric properties pass through the sensor.
Working principle: Detects materials based on their ability to store electrical charge.
Applications: Used for wet and dry waste segregation, especially in food waste processing.
Advantages: Effective for detecting moisture content in organic waste.
Limitations: Sensitivity variations due to environmental factors like humidity and temperature.

3.4. Ultrasonic sensors

Ultrasonic sensors use high-frequency sound waves to detect objects and measure their distance, density, or volume.
Working principle: Emits ultrasonic waves and measures the time taken for the waves to reflect back.

Applications: Used in waste volume estimation and bulk material sorting.
Advantages: Non-contact measurement and effective in detecting lightweight waste.
Limitations: Less precise in distinguishing specific materials.

3.5. Optical and vision-based sensors

Vision-based systems use RGB cameras, hyperspectral imaging, and LiDAR to analyse waste based on colour, texture, and shape. Machine learning algorithms enhance their performance.
Working principle: Captures and processes images to classify waste.
Applications: Used for sorting plastics, glass, and paper in automated recycling plants.
Advantages: High accuracy in multi-material identification.
Limitations: Requires advanced image processing and high computational power.

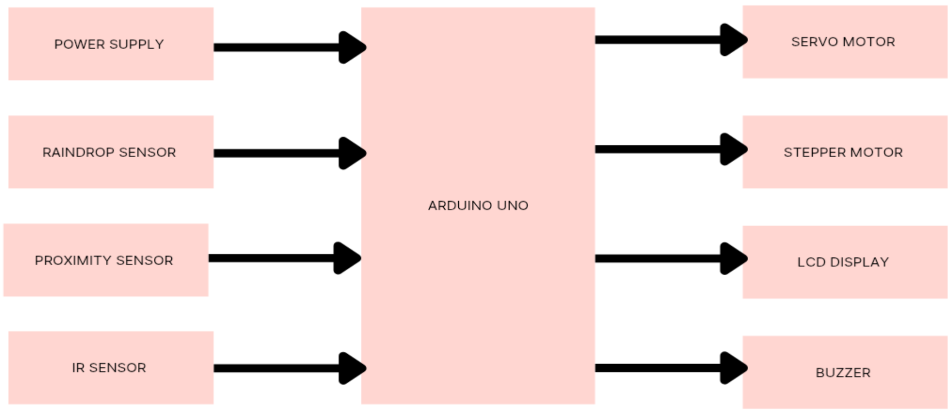

Fig.1 Simple Block Diagram of the System

4. CHALLENGES IN SENSOR-BASED WASTE SORTING SYSTEMS

Despite advancements, several challenges hinder the widespread implementation of sensor-based waste sorting systems:
4.1. **Material overlap:**Certain materials exhibit similar properties, making differentiation difficult.
4.2. **Sensor accuracy:** Environmental conditions, dirt, and contamination can reduce accuracy.
4.3. **Cost &scalability:** High-cost sensors and processing units increase implementation expenses.
4.4. **Real-Time processing:** High-speed sorting requires fast and efficient data processing.
5.5. **System maintenance:** Frequent calibration and maintenance are needed to ensure accuracy.

5. FUTURE DIRECTIONS

To improve the efficiency and adoption of sensor-based waste sorting systems, future research should focus on:

- Multi-Sensor Fusion: Combining different sensors to improve material differentiation.
- AI & Machine Learning: Enhancing sorting accuracy through advanced deep learning algorithms.
- Low-Cost Sensors: Developing affordable yet efficient sensors for large-scale deployment.
- Robotic Integration: Using robotic arms for automated waste handling and disposal.
- IoT-Based Smart Waste Sorting: Implementing real-time monitoring and adaptive sorting through IoT networks.

6. CONCLUSION

Sensor-based autonomous waste sorting systems play a crucial role in modern waste management by improving recycling efficiency and reducing landfill waste. Various sensors, including infrared, inductive, capacitive, ultrasonic, and vision-based sensors, are utilized to classify different waste materials. While these technologies offer significant advantages, challenges such as cost, accuracy, and real-time processing remain. Future advancements in AI, sensor fusion, and robotics will further enhance the efficiency and scalability of these systems, contributing to a more sustainable waste management ecosystem.

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