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Automated Waste Segregation System Using Robotic Arm

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Abstract: ***Waste management has become a critical environmental and social challenge due to rapid urbanization and population growth. Improper segregation of waste reduces recycling efficiency and increases health risks for workers involved in manual sorting. This paper presents an Automated Waste Segregation System using a Robotic Arm, designed to segregate waste into metal and non-metal categories. The proposed system uses an inductive proximity sensor for metal detection, a microcontroller-based control unit, and a servo motor driven robotic arm for physical segregation. The system minimizes human intervention, improves safety, and provides a compact and cost-effective solution suitable for small-scale applications. Experimental results show reliable detection and accurate placement of waste materials into respective bins.***
Keywords: Waste Segregation, Robotic Arm, Inductive Sensor, ESP32, Automation, Recycling

I. INTRODUCTION

Waste generation is increasing rapidly due to industrial growth, urban lifestyles, and rising consumerism. Household, institutional, and industrial waste usually contains a mixture of materials such as metal, plastic, paper, glass, and organic matter. When waste is not segregated at the source, recycling becomes difficult and a large portion of it ends up in landfills, leading to serious environmental pollution. Traditional waste segregation is mostly done manually, which is time-consuming, inefficient, and unsafe, as workers are exposed to hazardous materials like sharp metals, toxic substances, and biological waste. Manual methods also result in inconsistent segregation, reducing the overall quality of recycling.

Automation in waste management provides an effective solution to these challenges. Robotic systems integrated with sensors and microcontrollers can segregate waste accurately without direct human involvement, improving safety and efficiency. Among recyclable materials, metal waste is particularly important because it can be reused multiple times without loss of properties. This project focuses on developing a compact and affordable automated waste segregation system using a robotic arm to separate metal and non-metal waste. The system is suitable for small-scale applications such as homes, offices, institutions, and smart dustbins, and it supports safer waste handling, better recycling efficiency, and environmental sustainability.

II. LITERATURE REVIEW

A. Conventional Waste Segregation Techniques

Conventional waste segregation is mostly carried out manually, where workers separate waste based on visual inspection. This method is slow, unhygienic, and exposes workers to hazardous materials. Improper manual segregation also reduces recycling efficiency and increases landfill waste.

B. Sensor-Based Automated Waste Segregation Systems

Sensor-based automated systems use ultrasonic, moisture, capacitive, and inductive sensors to identify different types of waste. These systems reduce human intervention and improve segregation accuracy. However, many such systems are mechanically complex and offer limited classification capability.

C. Robotic Arm-Based Waste Segregation Approaches

Robotic arm-based waste segregation systems use mechanical arms to pick and place waste into designated bins. These systems improve accuracy and reduce direct human contact with waste. High cost and stability issues restrict their application in small-scale environments.

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D. Identified Research Gaps

Most existing waste segregation systems focus mainly on dry and wet waste classification. Metal waste segregation is often neglected, reducing recycling effectiveness. Additionally, many systems are bulky, expensive, and unsuitable for small-scale applications.

E. Motivation for the Proposed System

The limitations of existing systems highlight the need for a compact and affordable solution. The proposed system aims to reduce health risks and improve recycling efficiency. It focuses on automated metal and non-metal waste segregation using a robotic arm.
Automated waste segregation systems using sensor-based and robotic approaches have shown improved accuracy and reduced human involvement. Overall, literature indicates that robotic arm-based systems with efficient sensing provide a reliable and practical solution for modern waste management applications.

III. PROJECT OBJECTIVES

The growing amount of mixed waste and the limits of manual sorting create the need for a reliable automated solution. This project aims to develop a system that efficiently segregates waste while reducing human involvement, improving safety, consistency, and recycling efficiency in small-scale environments.

1) To automatically classify waste into metal and non-metal categories.
2) To accurately place waste into the appropriate bins.
3) To reduce human contact and improve safety.
4) To deliver a compact, low-cost solution for small-scale use.

IV. RESEARCH METHODOLOGY

A. Detection of Waste Object Presence

A proximity or IR sensor detects the presence of a waste object and activates the system for further processing.

B. Identification of Waste type (Metal or Non-metal)

An inductive proximity sensor determines whether the detected object is metallic or non-metallic.

C. Decision Making using Microcontroller

The microcontroller processes sensor data and decides the movement of the robotic arm based on the waste type.

D. Physical segregation using Robotic Arm

The robotic arm picks the waste object and places it into the appropriate bin according to the decision made.

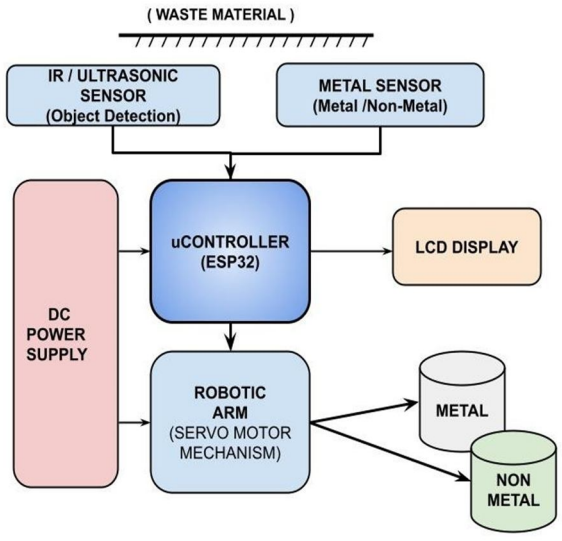


Figure 1: Block diagram of the proposed automated waste segregation system

The system consists of the following blocks:

- Power Supply: Provides regulated DC power to all components
- IR / Ultrasonic Sensor: Detects presence of waste
- Inductive Proximity Sensor: Detects metallic objects
- Microcontroller (ESP32): Processes sensor data and controls motors
- Servo Motor Driver (PCA9685): Controls multiple servo motors
- Robotic Arm: Picks and places waste into bins
- Output Units: LEDs, buzzer, OLED display for status indication

VI. FLOW CHART

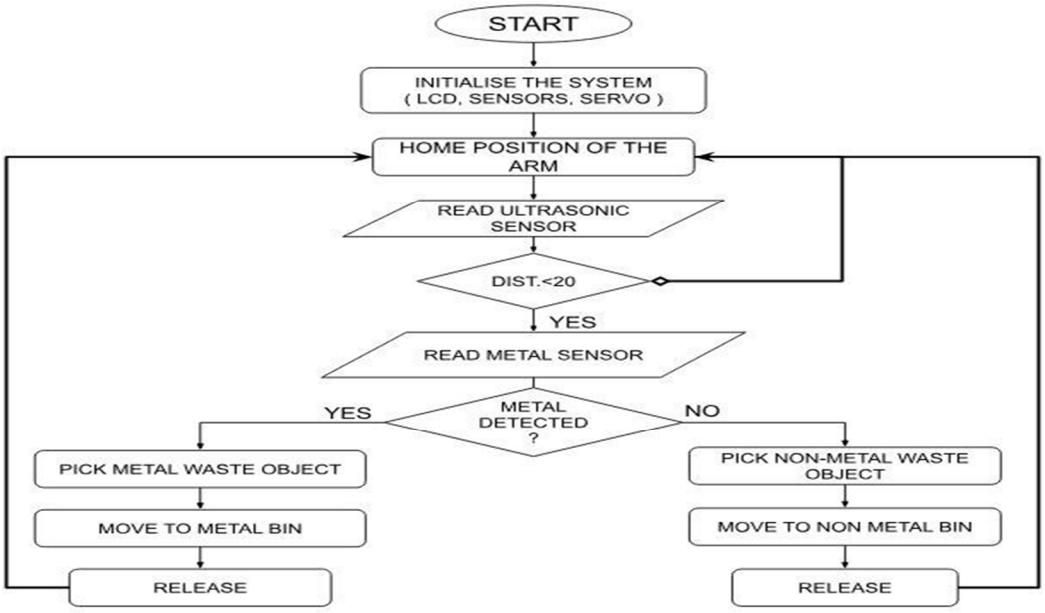


Figure 2: Operational flow of the proposed waste segregation system

VII. PROPOSED SYSTEM



VIII. RESULTS

A. *Insights*

1) Accurate waste detection
2) Reliable metal identification
3) Effective robotic arm operation
4) Reduced human involvement

B. *Applicability*

This framework can be implemented by:

1) Household waste management systems
2) Small-scale recycling units
3) Public places and smart bins
4) Industrial workshops

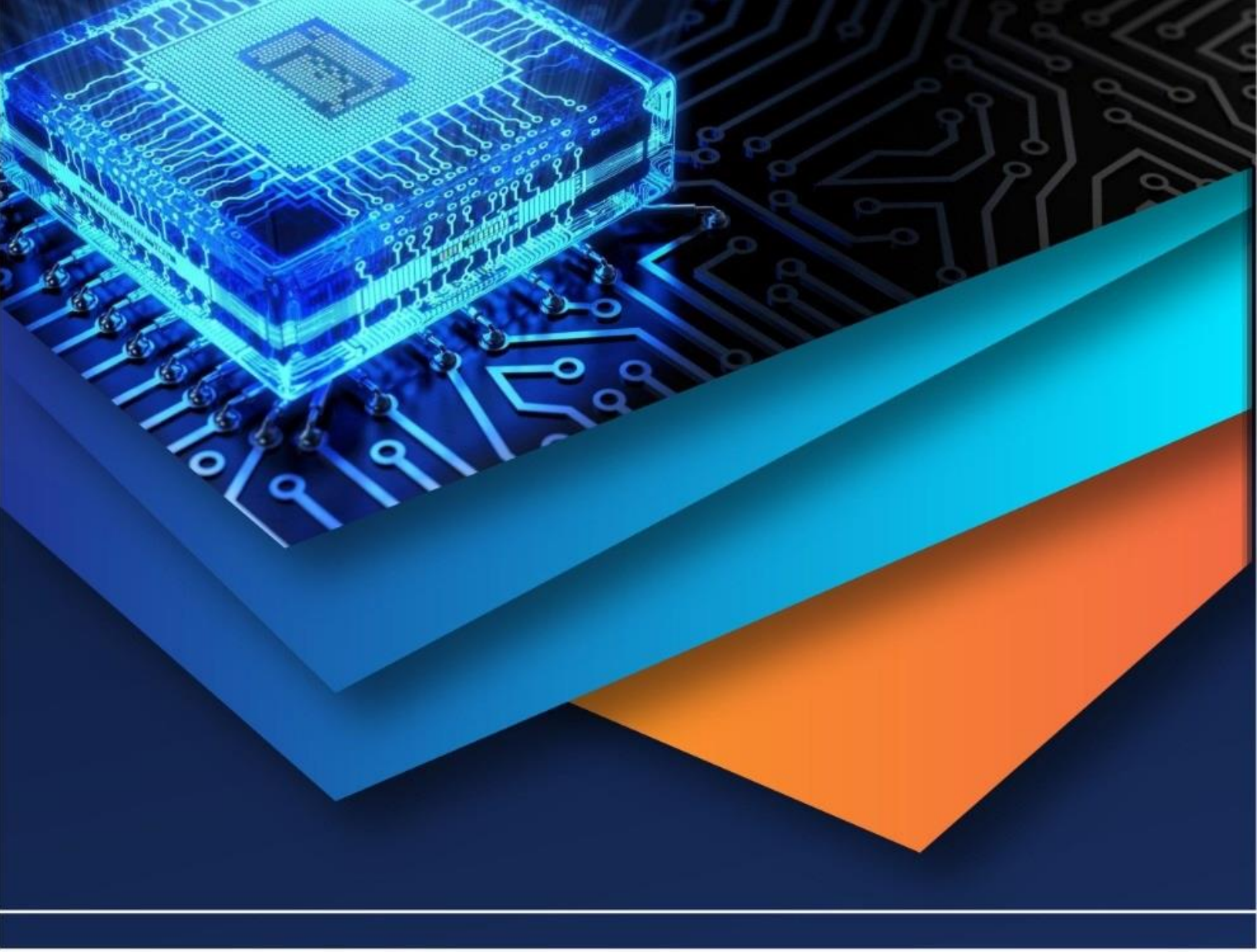
IX. CONCLUSION

The Automated Waste Segregation System Using a Robotic Arm successfully demonstrates an efficient and hygienic approach to basic waste management by automating the segregation of metal and non-metal waste. The system integrates sensors, an ESP32 microcontroller, and a servo-driven robotic arm to accurately detect, identify, and place waste into the appropriate bins in real time, thereby reducing human involvement and associated health risks. Experimental results show reliable sensor performance, smooth robotic arm operation, and consistent segregation under controlled conditions. The compact design, low-cost components, and ease of implementation make the system suitable for small-scale applications such as households, institutions, and recycling units. Overall, the project establishes a strong foundation for future advancements in smart and intelligent waste segregation systems that support environmental sustainability and improved recycling efficiency.

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