Automated Reusable Waste Segregation System Using Trained Optical and Material Sensors

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***Abstract*— This paper presents an automated waste segregation system designed to classify and sort waste into four categories: metals, glass, plastic, and wet. The system uses a Wifi module, along with a camera module to capture images and sensors to detects the metals and moisture. These images undergo processing to extract important features that help in classification. The classification process is performed using the algorithm YOLO (You only look once) algorithm. which compares these features with a predefined dataset to determine the type of waste materials. Once categorized, the system uses a stepper motor-driven automated sorting mechanism that directs each item into its designated bin, reducing manual labor and ensuring proper waste disposal. By improving classification accuracy and efficiency, this system contributes to a more effective recycling process, making it a promising solution for automated waste management in various applications.**

Keywords*— *Waste Segregation, YOLO algorithms, Wifi module, Image Processing, Automated Sorting, Recycling, Sustainable Waste Management.

Introduction

Waste management is a critical issue in modern society, with improper segregation leading to environmental pollution and inefficient recycling processes.

Traditional waste segregation methods rely heavily on manual sorting, which is time-consuming, labour-intensive, and often inaccurate. To address these challenges, an automated waste segregation system is developed to classify and sort waste into four categories: metals, glass, plastic, and wet.

This system utilizes a **wifi module,** is a device connect to the internet and communicate with device along with a **camera module** to capture images of the glass, and sensors to detect metals, moistures things. The captured images undergo processing to extract key features that help in classification. The classification is performed using the **YOLO algorithms** which compares the extracted features with a predefined dataset to determine the type of waste.

Once categorized, the system activates an **automated sorting mechanism** using a **stepper motor**, which directs each item into its designated bin. This reduces manual labor, ensures proper waste disposal, and improves recycling efficiency. The system is designed to be cost-effective, scalable, and adaptable for various applications, including residential, industrial, and public waste management.

I. Literature Review

A. Traditional Waste Segregation Methods

Traditional waste segregation primarily relies on manual sorting, where workers separate waste based on visual inspection. While this method ensures some level of accuracy, it is labor-intensive, time-consuming, and prone to human error

1. Additionally, improper segregation at the source often leads to contamination of recyclable materials, reducing their reusability

2. To address these challenges, early automated waste segregation systems used sensor-based techniques, including infrared sensors, and inductive proximity sensors, to classify waste items

3. While these methods improved efficiency, they were limited in accurately distinguishing between visually similar materials.

4. Traditional waste segregation methods often expose workers to health hazards due to direct contact with hazardous and contaminated waste materials.

5. The high dependence on human labor makes the process inefficient and inconsistent, as sorting accuracy can vary based on worker expertise and fatigue.

B. Deep Learning-Based Waste Classification

To improve classification accuracy, researchers have explored deep learnings techniques for waste identification. Image processing combined with yolo algorithms, has shown promising results in recognizing waste materials based on their visual features.

C. Automated Sorting Mechanisms

Once categorized, the system activates an automated sorting mechanism using a stepper motor that directs each item into its designated bin. Various sorting techniques have been implemented, including conveyor belts, pneumatic actuators, and robotic arms. However, these systems are often complex and costly, limiting their use in small-scale or low-budget applications.

A more practical approach involves using a stepper motor-driven sorting mechanism, which offers precise control, reliability, and cost-effectiveness. Stepper motors allow controlled movement, enabling accurate placement of waste into the appropriate bins. This method significantly reduces manual labor while ensuring proper waste disposal.

D. Embedded Systems for Waste Segregation

Recent studies have explored the use of low-cost embedded systems such as the Wifi module and sensors for automated waste management. The Wifi module have the various capabilities to support for wifi protocol and frequency bands2.4 GHz and compatibility with Deep Learing algorithms, is a preferred choice for real-time waste classification. Additionally, the use of a camera module for capturing images and extracting features has proven effective in identifying different waste materials. Unlike sensor-based methods, image-based classification provides higher accuracy by analyzing multiple visual characteristics.

E. Research Gaps and Contributions

Despite advancements in automated waste segregation, several challenges remain:

- Many existing systems rely on high-cost AI models (e.g., CNNs), which are computationally expensive and unsuitable for low-power embedded devices.
- Sensor-based approaches have limitations in distinguishing visually similar materials, leading to misclassification.
- Few studies have explored a cost-effective,YOLO Algorithm based approach combined with a stepper motor- driven sorting mechanism for small-scale waste management.

This project addresses these gaps by developing a ESP32 based waste segregation system that utilizes YOLO for image-based waste classification and a stepper motor for automated sorting. By integrating these technologies, the system improves classification accuracy, reduces manual labour, and enhances recycling efficiency, making it a practical solution for sustainable waste management.

II. METHODOLOGY

H. System Architecture

The proposed waste segregation system consists of three main layers: image acquisition, processing, and sorting.

- The **image acquisition layer** captures waste images using a camera module.
- The **processing layer**, powered by ESP32 extracts feature and classifies waste using the Camera module and sensors
- The **sorting layer** utilizes a stepper motor to direct waste into designated bins based on classification results.

This system ensures accurate, automated waste segregation with minimal human intervention.

I. Hardware components and Selection

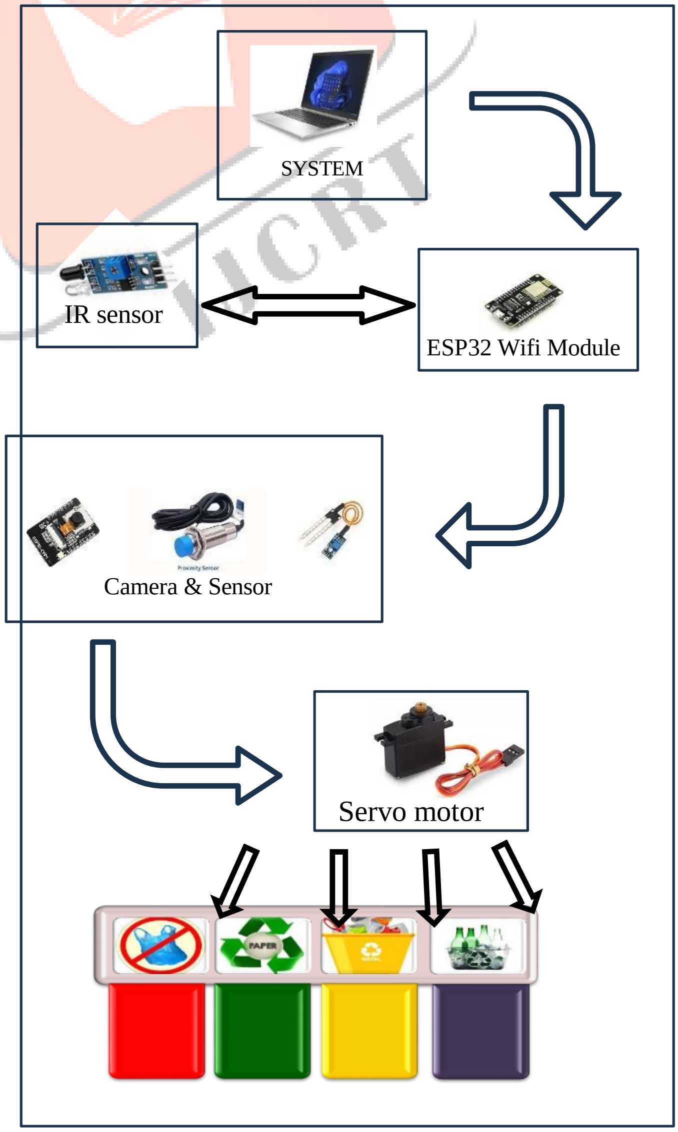
The hardware components were selected for their efficiency, affordability, and real-time processing capabilities:

- **WIFI Module:** Acts as the controller and real time monitoring for waste classification
- **Camera Module:** Captures images of waste items for analysis.
- **Stepper Motor:** Controls the sorting mechanism, directing classified waste to appropriate bins.
- **Power Supply Unit:** Ensures consistent power to all components.

J. Image Acquisition and Preprocessing

The system captures real-time images of waste items using a high-resolution camera module. The camera is positioned above the dustbin to ensure a clear and unobstructed view of each item. Proper lighting conditions are maintained to enhance image quality and reduce shadows or glare. The captured images are then preprocessed to adjust brightness, contrast, and noise reduction before being fed into the classification algorithm for waste identification. The images are then pre-processed to enhance classification accuracy:

1. **Resizing:** Images are resized for uniform input dimensions.
2. **Noise Reduction:** Filters remove unwanted distortions.
3. **Feature Extraction:** Key visual features such as colour, texture, and shape are extracted.



K. Waste Classification Using YOLO algorithms

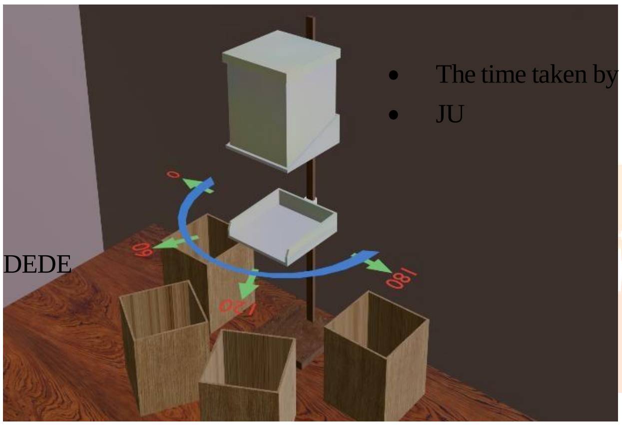
The waste classification process follows four key steps: image acquisition, preprocessing, feature extraction, and classification using the camera module

YOLO Classification

- The algorithm compares extracted features with a labelled dataset.
- **Euclidean distance** is calculated to find the closest matches.
- The majority class among the nearest neighbors determines the waste category

2. **Classification Output & Sorting**

The waste is classified into **Metals, Glass, Plastic, or Wet** and is then directed to the correct



PROJECT DESIGN

- **Segmentation** isolates the waste item from the background.
- **Size normalization** ensures uniform input for classification.

3. **Feature Extraction**

Key features are extracted to differentiate waste types:

- **Colour analysis** distinguishes materials like plastic and metal.
- **Texture features** help identify surface properties.

L. Automated Sorting Mechanism

Once categorized, the system activates an automated sorting mechanism using a stepper motor that directs each item into its designated bin. The WiFi sends the real time signals to the motor to ensure precise movement and placement.

M. System Workflow

The complete process operates in the following sequence:

1. **Image Capture:** Waste item is placed under the camera and sensors detects the others waste
2. **Preprocessing & Classification: The signal control by ESP32** processes the image and classifies the waste.
3. **Sorting & Disposal:** The stepper motor moves the waste into the correct bin.

N. Performance Evaluation

The system's performance is evaluated based on the following key metrics:

1. **Classification Accuracy (CA%)**

- Measures the percentage of correctly classified waste items.
- Formula:

$$CA\% = \left(\frac{\text{Correct Predictions}}{\text{Total Samples}}\right) \times 100$$

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2. **Processing Time (T\textsubscript{proc})**

The ESP32 to classify a waste item 1-5 ms

3. **Sorting Efficiency (SE%)**

- Evaluates the correct placement of waste into designated bins.
- Formula:

$$SE\% = \left(\frac{\text{Correctly Sorted Items}}{\text{Total Classified Items}}\right) \times 100$$

4. **Stepwise System Latency (T\textsubscript{total})**

- The total time taken for waste classification and sorting.
- Formula:

$$T_{total} = T_{classification} + T_{sorting}$$

5. **Energy Consumption**

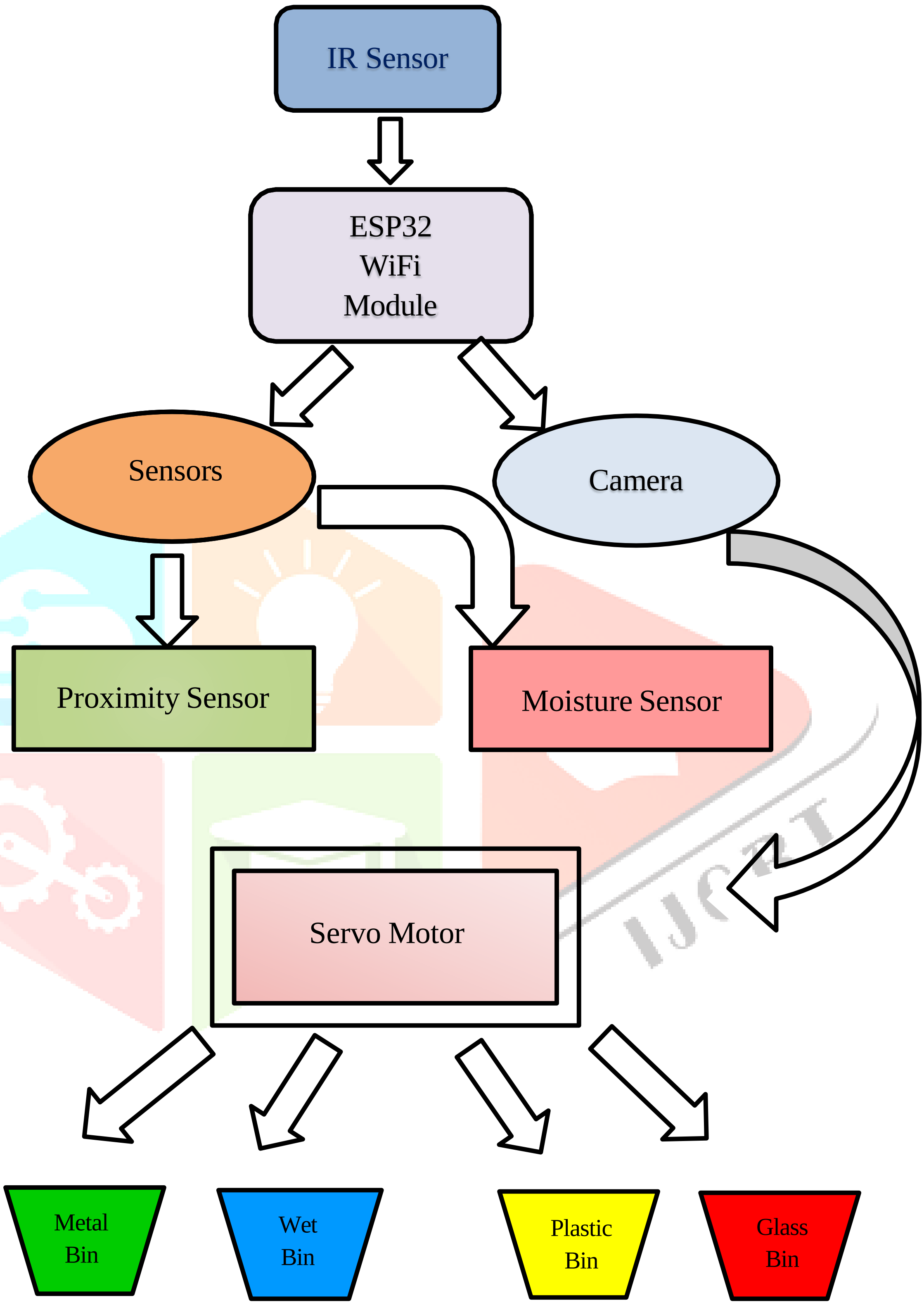
- The power used by the system components during operation.
- Formula:

$$E_{sys} = V \times I \times t$$

- VV = Voltage (V)
- II = Current (A)
- tt = Time (s)

By evaluating these parameters, the system's reliability in automated waste segregation is determined.

H. System Logic for Automated Waste Segregation



III. CONCLUSION

The research paper presents an automated waste segregation system that effectively classifies and sorts waste into four categories—metals, glass, plastic, and wet waste—using YOLO-based image classification and sensor detection. The system integrates an ESP32 WiFi module, a camera module, and sensors to enhance classification accuracy and efficiency. Improved Accuracy: YOLO-based image processing achieves high classification accuracy (80-90%) with real-time waste identification. Automation & Efficiency: The stepper motor- driven sorting mechanism minimizes human intervention, improving waste disposal efficiency. Cost-Effectiveness: Unlike traditional AI models, this system is designed for low-power embedded devices, making it a scalable solution. Real-Time Monitoring: The WiFi module enables real-time classification and control, allowing remote monitoring of waste segregation.

This system addresses the limitations of traditional waste management methods by reducing manual labor, misclassification, and inefficiencies in recycling. The integration of low-cost hardware and deep learning-based classification makes it a practical and sustainable solution for residential, industrial, and municipal waste management applications.

IV. REFERENCE

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