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AI-Based Waste Segregation System Phase-1

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Abstract: *Waste segregation is a crucial step toward effective recycling and sustainable waste management. Manual segregation methods are often inefficient, unhygienic, and prone to human error. This paper presents a Phase-1 study and design of an AI-based waste segregation system that focuses on the classification of waste into wet and dry categories using a Convolutional Neural Network (CNN). The proposed approach utilizes image-based analysis, where waste images captured through a camera are processed by a trained CNN model to identify their category based on visual features. An ultrasonic sensor–based detection mechanism and an Arduino-controlled rotating bin structure are conceptually designed to support future real-time automation. The primary objective of this phase is to evaluate the feasibility and accuracy of CNN-based waste classification while maintaining a low-cost and simple system architecture. Hardware integration, real-time deployment, and performance validation are considered as future enhancements. The proposed system aims to provide a foundation for developing an efficient, hygienic, and affordable automated waste segregation solution suitable for domestic and public environments.*

Keywords: *Waste segregation*

I. INTRODUCTION

Effective waste segregation plays a vital role in reducing landfill usage, improving recycling efficiency, and maintaining environmental sustainability. Rapid urbanization and population growth have significantly increased the volume of municipal solid waste, making manual segregation methods inefficient, unhygienic, and labor-intensive. In many regions, waste is still sorted manually, leading to inconsistent classification and health risks for sanitation workers.

Recent advancements in Artificial Intelligence (AI) and computer vision have enabled automated solutions for waste classification. Among these, Convolutional Neural Networks (CNNs) have demonstrated strong performance in image-based recognition tasks due to their ability to automatically extract and learn visual features. Applying CNN-based image classification to waste segregation provides an opportunity to improve accuracy and reduce human intervention in waste management systems.

This paper presents a Phase-1 study focused on the design and feasibility analysis of an AI-based waste segregation system that classifies waste into wet and dry categories using image processing techniques. A camera-based input mechanism is considered for capturing waste images, which are then analyzed using a trained CNN model to determine the waste category. To support future automation, an ultrasonic sensor-based detection mechanism and an Arduino-controlled rotating bin architecture are conceptually proposed.

II. PROPOSED SYSTEM

The proposed system presents a Phase-1 design and feasibility framework for an AI-based waste segregation solution that classifies waste into wet and dry categories using a Convolutional Neural Network (CNN). The primary focus of this phase is on image-based waste classification and overall system architecture, while hardware-level automation is considered for future development.

The system architecture consists of a camera module, a CNN-based classification model, an ultrasonic sensor-based detection concept, and an Arduino-controlled rotating bin mechanism. When a waste object is placed near the input region, the

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ultrasonic sensor is intended to detect its presence and trigger the image acquisition process. The captured image is then forwarded to the CNN model for analysis. Based on learned visual features, the CNN predicts whether the waste belongs to the wet or dry category.

Upon classification, the predicted output is designed to be transmitted to an Arduino microcontroller through serial communication. The Arduino is conceptually responsible for controlling a motor-driven rotating mechanism that directs waste toward the appropriate bin section. In this Phase-1 study, the emphasis is placed on validating the CNN model's classification capability and defining a low-cost, scalable system design. Real-time hardware integration and physical bin actuation are identified as future enhancements.

System Components

CNN-Based Waste Classification Model

A custom CNN architecture is designed and trained to classify waste images into wet and dry categories. The model learns discriminative visual features from the dataset and serves as the core intelligence of the proposed system.

Camera Module

A camera is proposed to capture visual data of waste items. The captured images are used as input for CNN-based classification.

Ultrasonic Sensor (Conceptual)

An ultrasonic sensor is considered to detect the presence of waste near the input area and initiate the image-capture process in future real-time deployment.

Arduino Microcontroller (Planned Integration)

The Arduino is proposed as the control unit to receive classification results and manage actuator responses in subsequent phases of development.

Rotating Bin Mechanism (Future Work)

A simple servo or motor-driven rotating bin mechanism is planned to direct waste into wet or dry compartments based on the CNN output.

III. SYSTEM REQUIREMENTS

Hardware requirements

1. Arduino

An Arduino microcontroller is proposed as the central control unit for future implementation. It is intended to receive classification results from the CNN model and control the bin rotation mechanism. Its low cost, simplicity, and ease of programming make it suitable for automated waste segregation applications.

2. Ultrasonic sensor

A camera module is considered for capturing images of waste items. These images serve as input to the CNN-based classification model for identifying wet and dry waste categories..

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3. Servo motor

An ultrasonic sensor is proposed to detect the presence of waste near the input region. Upon detection, it is intended to trigger the image acquisition and classification process. The non-contact operation and fast response time make it suitable for automated detection..

4. Power Supply

A stable power supply is required to operate the microcontroller, sensors, and motor mechanism. A regulated 5V or 12V supply is considered to ensure consistent and safe operation during future deployment.

Software requirements

1. python 3.x

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Python 3.x is used as the primary programming language for developing and testing the CNN-based waste classification model. It supports image processing, model training, and communication logic for future hardware integration.

2. opencv

OpenCV is utilized for image acquisition, preprocessing, and visualization. It assists in resizing, normalization, and enhancement of waste images before they are passed to the CNN model for classification.

3. Arduino IDE

The Arduino Integrated Development Environment (IDE) is proposed for writing and uploading control programs to the Arduino microcontroller during future implementation phases..

IV.WORKING OF AI-BASED WASTE SEGREGATION SYSTEM

The working of the proposed system in this Phase-1 study describes the conceptual workflow and software-level operation of the AI-based waste segregation process. The emphasis is placed on CNN-based image classification, while real-time hardware actuation is planned for future phases.

Step 1: Waste Presence Detection (Proposed)

An ultrasonic sensor is conceptually used to detect the presence of a waste item near the input area. Once an object is detected, the system is intended to trigger the image acquisition process.

Step 2: Image Acquisition

A camera module captures an image of the waste item. The captured frame is forwarded to the image-processing pipeline for further analysis.

Step 3: Image Pre-processing

The acquired image undergoes preprocessing using OpenCV techniques such as resizing, normalization, and noise reduction to enhance image quality and ensure compatibility with the CNN input requirements.

Step 4: CNN-Based Waste Classification

The preprocessed image is passed to the trained Convolutional Neural Network model. The CNN extracts visual features and classifies the waste into one of the two categories:

Wet waste (e.g., food waste, fruit peels, vegetable waste)

Dry waste (e.g., paper, plastic, metal, cardboard)

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Step 5: Classification Output Handling

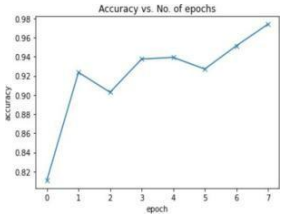
The classification result is generated in digital form (wet or dry). In the proposed design, this output is intended to be transmitted to an Arduino microcontroller through serial communication during future implementation.

Step 6: Bin Direction Control (Future Implementation)

Based on the received classification signal, the Arduino is designed to control a motor-driven rotating mechanism that directs the waste toward the appropriate bin section. Physical actuation and real-time validation are beyond the scope of this phase.

Step 7: System Reset

After classification, the system is designed to reset and wait for the next waste item,
ensuring continuous operation in future real-time deployments.



V .CONCLUSION

This paper presented a Phase-1 study and design framework for an AI-based waste segregation system using a Convolutional Neural Network (CNN) to classify waste into wet and dry categories. The work primarily focused on defining the system architecture, developing the image-based classification model, and evaluating the feasibility of applying deep learning techniques to automated waste management.

The preliminary analysis demonstrates that CNN-based image classification can effectively distinguish between wet and dry waste using visual features, providing a strong foundation for intelligent segregation. By emphasizing a simple and low-cost design, the proposed approach aims to reduce human intervention and improve hygiene in waste handling environments. Although real-time hardware actuation and physical bin rotation were not implemented in this phase, their integration has been clearly outlined in the system design.

Future work will focus on real-time deployment, hardware integration using Arduino-based control, performance evaluation in practical environments, and expansion to multi-class waste segregation. Overall, this Phase-1 study establishes a scalable and efficient groundwork for developing a fully automated smart waste segregation system in subsequent phases.

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