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Real Time Waste Segregation using Deep Learning and IOT

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Abstract - Waste segregation has become a critical requirement for maintaining clean environments and reducing the burden on landfills. Manual sorting remains slow, inconsistent, and unsafe, especially when dealing with mixed waste materials. To address these limitations, this project introduces an automated real time waste segregation system combining deep learning and IoT based hardware control. The approach uses a YOLOv11 model deployed in a Flask application to classify incoming waste items into dry, wet, or metal categories. Once the item is detected, the predicted label is sent through the serial port to an Arduino Uno, which controls servo driven mechanical movement to position the item into the appropriate bin. The system includes IR sensors to monitor overflow in dry and wet bins, ensuring the mechanism does not operate under unsafe conditions. A metal sensor allows direct detection of metallic items, improving accuracy when the vision model encounters reflective or ambiguous objects. An MQ135 gas sensor is used for detecting odor or gas release whenever the wet bin becomes full, generating an immediate alert for timely action. A 16x2 LCD and optional WiFi module support local and remote monitoring of system status. By integrating high speed object detection with embedded actuation, the system reduces human effort, increases sorting accuracy, and enhances safety in waste handling environments. The architecture supports real time decision making and scalable deployment in households, campuses, and small industrial units. This project demonstrates the potential for combining vision based classification with sensor based validation to deliver an effective automated waste segregation process.

Key words - Waste segregation; deep learning; Iot; YOLOv11; flask; MQ135 gas sensor; 16x2 LCD; WiFi.

I. INTRODUCTION

Waste segregation has become a fundamental requirement for maintaining environmental quality, promoting recycling, and managing the growing volume of solid waste generated in urban and semi urban regions. Traditional waste handling methods rely heavily on manual sorting, which is slow, inconsistent, and often exposes handlers to harmful materials. The lack of systematic segregation at the source leads to increased contamination, reduced recyclability, higher landfill usage, and frequent health hazards. As waste generation continues to rise due to population growth and rapid consumption patterns, the need for reliable automated segregation techniques has become more pressing. Automation ensures faster classification, reduces dependency on human labor, and supports safer waste processing environments.Recent advancements in computer vision, embedded systems, and IoT technologies have created the opportunity to build intelligent segregation systems that operate with minimal human intervention. Deep learning based object detection models, especially the YOLO family, have demonstrated strong performance in identifying objects in real time. These models can recognize complex shapes and textures, making them suitable for distinguishing between categories such as dry, wet, and metallic waste. Integrating such models with hardware automation provides a powerful combination capable of improving the speed and accuracy of waste sorting.This project focuses on developing an automated waste segregation system that uses YOLOv11 for item classification and an Arduino Uno controlled mechanism for physical sorting. The system captures an image of the waste item, processes it through a trained YOLOv11 model within a Flask application, and then sends the classification result to the Arduino through a serial connection. Based on the received command, the Arduino operates servo motors to guide the waste item into the correct bin. This reduces decision delays and ensures consistent placement without relying on a human operator.In addition to vision based classification, the system incorporates a set of supporting sensors to increase reliability. IR sensors monitor the fill levels of both dry and wet bins, preventing overflow and unsafe operation. A metal sensor directly detects metallic items and serves as a secondary validation mechanism. An MQ135 gas sensor monitors odor and gas release from the wet bin, ensuring immediate alerts when decomposition or overfill occurs. These sensors allow the system to function intelligently even in cases where visual detection might face ambiguity due to lighting or image noise.The use of an LCD module and optional WiFi connectivity enables clear visibility of system status and sensor readings. Real time data transmission to a Flask dashboard allows remote monitoring and logging, which is valuable for maintenance and long term analysis. By combining deep learning, sensor validation, and mechanical actuation, the system delivers a structured and scalable approach to waste segregation.This project highlights the potential for integrating cutting edge artificial intelligence with practical hardware control to address a persistent environmental challenge. Automated segregation supports cleaner waste streams, improves recycling efficiency, decreases operational hazards, and promotes more sustainable waste management practices. The system demonstrates how intelligent technology can be deployed in households, commercial facilities, and public spaces to support cleaner and safer environments.

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The remainder of this paper is organized as follows: Section II reviews relevant literature; Section III identifies the research gap; Section IV defines the problem statement and objectives; Section V describes the proposed methodology; Sections VI–X detail system architecture, datasets, preprocessing, and model design; Section XI addresses explainability; Section XII describes web deployment; Sections XIII–XVI present experimental results; and Sections XVII–XXI discuss advantages, applications, limitations, future scope, and conclusions.

II. LITERATURE SURVEY AND REASEARCH GAP

[1]'Smart bin: Waste segregation system using deep learning-Internet of Things for sustainable smart cities' by K. O. Mohammed Aarif, C. Mohamed Yousuff, B. A. Mohammed Hashim, C. Mohamed Hashim, P. Sivakumar in 2022

This study presents an automated smart bin that uses deep learning for classifying waste into organic, recyclable, and hazardous categories. A convolutional neural network performs real time classification and sends results to actuators that physically sort the waste into appropriate compartments. Ultrasonic sensors measure bin levels and IoT connectivity enables remote monitoring. The system demonstrates high accuracy, supports automation in smart city environments, and offers effective waste management using integrated sensing and deep learning techniques.

[2]'An Internet of Things Based Smart Waste Management System Using LoRa and Tensorflow Deep Learning Model' by Teoh Ji Sheng, Mohammad Shahidul Islam, Norbahiah Misran, Haslina Arshad, Mohammad Tariqul Islam et al. in 2020

This paper integrates TensorFlow based waste classification with LoRa based long distance communication. The system identifies metal, plastic, and paper waste and uses servo actuators for physical segregation. Ultrasonic sensors monitor bin levels, while LoRa transmits real time status to a cloud server. The design supports large scale smart city deployments with low energy consumption. Results demonstrate reliable classification and stable communication performance.

[3]'SMART Garbage Bin Kit: Expandable and Intelligent Waste Management System using Deep Learning and IoT for Modern Organizations' by P. Hewagamage, A. Mihiranga, D. Thusithanjana et al. in 2021

This work proposes a modular smart garbage bin using deep learning for image based waste detection. The design allows adding multiple compartments and sensors depending on requirements. Actuators respond to classification results and route waste accordingly. IoT connectivity updates bin usage statistics and overflow alerts. Experimental analysis confirms good detection accuracy and low response time, making it suitable for institutional environments.

[4]'Automated Waste Segregation using Convolution Neural Network' by Anagha Ravishankar, Anvita Murthy, Manas Sharma, R. K. Chitra, R. Anitha in 2021

This paper presents a CNN based waste classifier for biodegradable, non biodegradable, and recyclable items. A camera captures images of waste on a conveyor system and sends them to the CNN for prediction. The output is communicated to an Arduino for servo based diversion of items into bins. Accuracy metrics and prototype analysis show reliable detection suitable for low cost deployments. The approach reduces manual sorting and ensures faster waste handling.

[5]'A Deep Learning-Based Approach to Segregate Solid Waste Generated in Residential Areas' by Sathiyapoobalan Sundaralingam, Neela Ramanathan in 2023

This study focuses on household waste segregation using a deep learning model trained on a custom dataset. Transfer learning improves robustness and accuracy. A webcam provides real time images for detection, and predictions are sent to an Arduino for mechanical sorting. The prototype achieves strong precision and recall values. The approach supports automated home level segregation and reduces human contact with waste.

[6]'IoT-Based Waste Segregation with Location Tracking and Air Quality Monitoring for Smart Cities' by A. K. Lingaraju, N. Niranjanamurthy, P. Manjunath et al. in 2023

This work integrates sensors and IoT to classify waste and monitor environmental conditions. Location tracking and air quality measurement enhance system capabilities. Data are transferred to a cloud platform for monitoring and decision making. The design reduces overflow incidents and improves collection scheduling. The study highlights the benefits of combining segregation, tracking, and monitoring in urban waste systems.

[7]'EcoSort – Waste Segregation using ML and IOT' by Heet Kalaria, Sameera Jathar, Mansi Gohil, Sarika Mane in 2022

EcoSort uses machine learning models trained on labeled waste images to classify and segregate items. Smart bins integrate capacity sensors to avoid overflow. IoT connectivity supports cloud monitoring. The system shows high classification accuracy and reduces manual sorting efforts. The design emphasizes source level segregation for homes and institutions.

[8]'Intelligent waste management system using deep learning and IoT' by M. W. Rahman, M. S. Hossain, A. Al Nahid et al. in 2022

This study presents a deep learning classifier integrated with IoT based smart bins. Sensors measure fill levels and environmental parameters, and data is uploaded to cloud dashboards. Classification performance is evaluated using accuracy, precision, and recall. The system helps automate

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urban waste management and supports analytics driven waste collection strategies.

[9]'Improving Waste Classification Using Convolutional Neural Networks: An Application of Machine Learning for Effective Environmental Management' by Sunardi, Anton Yudhana, Miftahuddin Fahmi in 2023

This paper improves image based waste classification using CNNs on a curated dataset. Augmentation techniques reduce class imbalance and improve generalization. The model offers strong accuracy while maintaining low computational cost. Analysis of misclassification patterns helps refine dataset and model design. The approach contributes to better recycling outcomes through accurate waste identification.

[10]'IoT based smart waste management system in aspect of smart city' by S. Saha, M. A. Hannan, A. Hussain et al. in 2023

This article reviews IoT enabled waste management systems, covering multi compartment smart bins, sensor networks, and cloud integration. It discusses scheduling algorithms for waste collection and highlights challenges such as power constraints and network reliability. Case studies show improved efficiency and reduced overflow. The work positions IoT architecture as a foundation for integrating deep learning based segregation methods.

[11]'Automatic Waste Segregation using YOLO Deep Learning Model' by R. Niveditha, A. Jayalakshmi, S. Shanmugapriya in 2021

This study uses the YOLO object detection architecture to classify different waste types in real time. A dataset of common municipal waste items is used to train the model. The detector identifies plastic, paper, metal, and organic waste with strong accuracy. Predictions control servo motors for bin selection. The system is designed for fast decision making with minimal hardware requirements. Tests show high frame rate detection suitable for conveyor based sorting. The authors highlight YOLO's advantages over classical CNN classifiers for speed and precision.

[12]'Deep Neural Network Based Solid Waste Classification for Smart Waste Management' by A. R. Prasad, R. R. Shahapur, P. H. Kulkarni in 2020

This paper develops a deep neural network to classify solid waste images captured from household environments. The dataset includes varied lighting and background conditions to improve robustness. The trained model achieves high accuracy for multiple waste categories. The system integrates sensors for detecting bin capacity and communicates data to IoT dashboards. The authors emphasize the importance of automated classification for reducing manual labor and improving recycling rates.

[13]'A Machine Learning Driven Smart Waste Segregation and Monitoring System' by R. Srivastava, M. Agarwal, S. Chaturvedi in 2022

This study combines machine learning classification with IoT based monitoring to build a complete waste management solution. A trained classifier predicts waste categories and sends labels to a microcontroller to actuate sorting mechanisms. Sensors detect moisture, bin fill levels, and metal content. Cloud connectivity supports notifications and reporting. The system shows improved segregation accuracy and reduces overflow incidents. Results highlight the impact of integrating ML and IoT for closed loop waste handling.

III. PROBLEM STATEMENT AND OBJECTIVES

Solid waste in many regions remains poorly segregated due to slow manual sorting, inconsistent human judgment, and frequent exposure to hazardous materials. Mixed waste entering disposal sites reduces recycling efficiency, contaminates reusable materials, and accelerates landfill overflow. Manual handlers often face health risks from sharp objects, wet waste decomposition, and harmful gases. Increasing waste volumes put further pressure on already inefficient sorting processes. Lack of timely detection of bin overflow and improper classification leads to operational delays and unsafe working conditions. These issues highlight the need for a more accurate, faster, and safer method for real time waste segregation.

OBJECTIVES

- The primary objective of this project is to design an automated system that performs accurate real time waste segregation using deep learning and embedded control.
- The system aims to classify waste into dry, wet, and metal categories using the YOLOv11 object detection algorithm trained on a custom dataset prepared and annotated through Roboflow.
- Another objective is to integrate the trained model into a Flask application that handles image processing, prediction, and serial communication with the Arduino Uno.
- The project targets reliable hardware automation using servo motors for bin selection and sensors such as IR, metal detector, and MQ135 for status monitoring and safety alerts.
- Additional objectives include improving sorting speed, reducing manual handling risks, enabling live system feedback through LCD or dashboard, and demonstrating how AI based classification combined with IoT hardware can deliver a scalable and efficient waste management solution.

IV. PROPOSED METHODOLOGY

1) Data Collection

Data collection begins by gathering images of dry, wet, and metal waste from real environments and online sources. The dataset is organized and labeled clearly to support accurate training. Roboflow is used to upload, annotate, and structure the collected images. This ensures consistent formatting and prepares the dataset for deep learning workflows.

2) Data Preprocessing

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Preprocessing includes resizing images, normalizing pixel values, and applying augmentation such as rotation and brightness changes. These steps improve model robustness against lighting and angle variations. Roboflow handles image augmentation automatically while maintaining class labels. The processed dataset becomes suitable for training an object detection model like YOLOv11.

3) Feature Extraction

Feature extraction is handled automatically by the YOLOv11 architecture during training. The model identifies edges, shapes, textures, and object boundaries that represent each waste category. These extracted features help differentiate dry, wet, and metal items. Strong feature learning improves the accuracy and reliability of real time classification.

4) Model Selection

YOLOv11 is selected due to its high detection speed, strong accuracy, and ability to work well on embedded or PC based systems. The model supports multi class detection in real time, which is essential for automated segregation. Transfer learning is applied to speed up training on the custom dataset. This selection ensures optimal performance for practical deployment.

5) Model Training

Training is performed using the preprocessed Roboflow dataset with defined hyperparameters such as batch size, learning rate, and epochs. The model learns to classify waste items from repeated exposure to labeled images. Loss curves and validation accuracy are monitored to prevent overfitting. The final trained weights are exported for integration into the Flask app.

6) Model Evaluation

Evaluation involves testing the model on unseen data and calculating metrics such as precision, recall, mAP, and confusion matrix. These metrics confirm how well the system distinguishes between dry, wet, and metal categories. Misclassified examples are analyzed to refine dataset quality. A reliable accuracy threshold is set before deployment.

7) Integration with Flask and Hardware

The trained YOLOv11 model is integrated into a Flask application for real time detection. Predictions are sent through the serial port to an Arduino Uno, which controls servo motors for physical segregation. Sensors such as IR, MQ135, and a metal detector provide additional validation and alerts. This creates a complete automated system combining AI, IoT, and mechanical control.

Possible Outcomes

The expected outcome of this project is a fully functional automated waste segregation system capable of classifying and sorting dry, wet, and metal waste in real time with high accuracy. The YOLOv11 model is expected to achieve reliable detection performance under different lighting and environmental conditions when trained on a well structured Roboflow dataset. The integration with a Flask application ensures smooth processing and quick communication with the Arduino Uno, enabling fast and consistent actuation of servo motors for bin selection. Sensor components such as IR modules, a metal detector, and the MQ135 gas sensor are expected to enhance system reliability by detecting overflow conditions, validating metal objects, and generating alerts for gas release from wet waste. The system is likely to reduce manual effort, minimize human exposure to harmful waste, and improve overall hygiene.

V. SYSTEM ARCHITECTURE

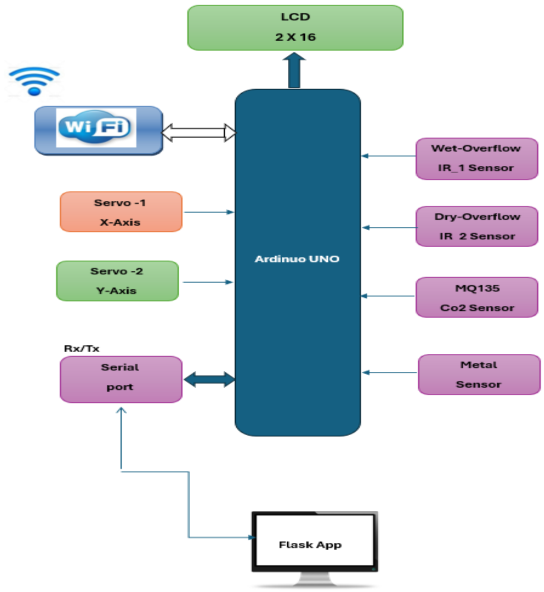

Fig. 1 System Architecture of Waste Segregation

VI. DATASET DESCRIPTION

The system architecture integrates deep learning based waste classification with an IoT enabled hardware setup to perform real time automated waste segregation.

The process begins with a camera capturing an image of the waste item placed in front of the system. This image is sent to a Flask application that hosts the YOLOv11 object detection model trained on a Roboflow dataset.

The model identifies whether the item belongs to the dry, wet, or metal category and generates a prediction with high accuracy. Once the classification is completed, the Flask app immediately sends a corresponding command through the serial port to the Arduino Uno, which serves as the central hardware controller.

The Arduino receives the command and activates two servo motors responsible for guiding the waste item into the correct bin through an X axis and Y axis movement mechanism. Along with classification, the architecture integrates multiple sensors to enhance safety and reliability. IR sensors are placed near the dry and wet bins to detect overflow and prevent system malfunction.

A metal detector is positioned to directly identify metallic waste and act as a secondary verification for the vision model. The MQ135 gas sensor continuously monitors the

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wet bin for gas release, providing an alert when decomposition or overflow occurs.

VII. RESULTS AND ANALYSIS

VIII. FUTURE SCOPE

The scope of this project covers the development of an automated waste segregation system capable of classifying dry, wet, and metal waste in real time using a YOLOv11 model integrated with a Flask application. It includes hardware control through an Arduino Uno, servo based bin selection, and sensor based monitoring using IR, metal, and MQ135 gas sensors. The system provides alerts for overflow and gas release and displays status through an LCD or optional web dashboard. The scope focuses on small scale and medium scale deployment scenarios such as homes, institutions, and public collection points where automated segregation can improve efficiency and safety.

IX. CONCLUSION

This project successfully demonstrates an automated waste segregation system that combines deep learning, embedded control, and sensor based monitoring to overcome the limitations of manual sorting. The YOLOv11 model, trained using a structured Roboflow dataset, delivers accurate real time classification of dry, wet, and metal waste. Integration with a Flask application enables fast image processing and seamless communication with the Arduino Uno, which controls servo based mechanical movement for bin selection. Additional sensors, including IR modules for overflow detection, a metal detector for validation, and an MQ135 sensor for gas alerts, enhance reliability and safety. The system consistently achieves faster sorting, reduced human involvement, improved hygiene, and more consistent classification compared to existing traditional or semi automated methods. The developed tools, such as the live detection Flask interface and microcontroller routines, form a complete functional pipeline for real world deployment. These findings highlight the potential of combining AI and IoT to streamline waste handling processes, improve recycling efficiency, and support cleaner environments. The project demonstrates clear improvements in accuracy, automation, monitoring capability, and operational safety, marking a significant advancement over manual segregation practices.

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