# A RELIABLE AND ROBUST DEEP LEARNING MODEL FOR EFFECTIVE RECYCLABLE WASTE CLASSIFICATION

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**ABSTRACT**

In response to the escalating waste crisis exacerbated by industrialization and modernization, there is an urgent need for automated waste sorting and recycling systems to promote sustainable waste management. Deep learning has significantly advanced in image classification, making it well-suited for waste sorting applications. This study introduces RWCNet (Recyclable Waste Classification Network), a novel deep learning model specifically designed to classify six distinct waste categories utilizing the TrashNet dataset, which comprises 2,527 images of waste. Our model undergoes rigorous quantitative and qualitative evaluations and is compared against various state-of-the-art waste classification techniques, including ResNet50, MobileNetV2, DenseNet201, GoogleNet, InceptionV3, and a proposed model combining MobileNet and DenseNet201. For detection purposes, we employ YoloV5x6, YoloV8, and YoloV9. Additionally, we analyze the dataset using Xception, NasNetMobile, and an ensemble approach combining Xception with NasNetMobile. This comprehensive approach aims to enhance the accuracy and effectiveness of recyclable waste classification, contributing to more efficient waste management systems.

## I. INTRODUTION

### 1.1 PROJECT INTRODUCTION

Globalization, fueled by rising populations, industrial expansion, and economic expansion, has led to an increase in the demand for natural resources. This increased resource consumption has simultaneously led to an alarming increase in waste production. A significant amount of urban waste continues to be illegally disposed of, primarily through landfills and incineration. This continuous flow of pollution poses a serious risk to urban ecosystems and the health of local residents. Notably, a significant portion of this waste consists of household garbage, and the decomposition of certain components within household garbage can lead to the accumulation of hazardous compounds in the environment, thereby escalating ecological risks. In addition, certain residential waste materials manifest poor biodegradability, as exemplified by the common plastic pollution observed in underwater ecosystems worldwide. One-third of the world's waste is improperly managed, lacking proper sorting and adequate measures, thereby causing extensive environmental pollution and posing a grievous threat to sustainable development. In response to these escalating environmental challenges, the Environmental Protection Agency (EPA) has emphasized the significance of reprocessing municipal solid waste (MSW) as an environmentally responsible waste management strategy. Indeed, the global production of municipal solid waste reached 2.01 billion tons in 2016, with projections indicating an increase to 2.59 billion tons by 2030. In order to mitigate environmental consequences and assure the development of sustainable societies, the need for efficient waste management procedures has never been greater.

### 1.2 SCOPE

This project focuses on the development and evaluation of a reliable and robust deep learning-based model, RWCNet, for the classification of recyclable waste. By leveraging the capabilities of advanced convolutional neural networks

(CNNs), the system aims to automatically identify and categorize waste into six major recyclable classes using the TrashNet dataset. The model is designed to optimize the classification performance across various image types representing real-world waste conditions. The scope includes data preprocessing, augmentation, and training of the RWCNet architecture to enhance model generalization and efficiency.

In addition to building a custom model, the project extends its scope by benchmarking RWCNet against several state-of-the-art deep learning architectures such as ResNet50, MobileNetV2, DenseNet201, GoogleNet, and InceptionV3. The research also explores hybrid models, particularly a MobileNet-DenseNet201 combination, to assess the improvement in feature extraction and classification accuracy. Furthermore, object detection capabilities are integrated using the latest YOLO models (YOLOv5x6, YOLOv8, and YOLOv9), providing a multi-dimensional evaluation of the system's performance for real-time waste detection and localization.

The study further incorporates comparative experiments using Xception, NasNetMobile, and their ensemble to analyze feature learning capabilities. Overall, this project seeks to contribute a scalable and effective solution for automating recyclable waste identification, which could significantly aid municipal and industrial waste management systems, promoting environmental sustainability and resource optimization.

**1.3 PROJECT OVERVIEW**

This project addresses the critical need for efficient recyclable waste classification to support sustainable waste management practices. With the increasing volume of waste generated globally, automated systems capable of accurately sorting recyclable materials are essential to reduce environmental impact and promote recycling efforts. The project introduces RWCNet (Recyclable Waste Classification Network), a deep learning model tailored to classify six distinct categories of recyclable waste using the TrashNet dataset, which contains over 2,500 labeled waste images. This dataset provides a diverse range of waste types, enabling the model to learn robust features for accurate classification.

The core of the project involves designing, training, and optimizing RWCNet to achieve high accuracy and reliability in waste classification. To validate the effectiveness of the model, extensive quantitative and qualitative evaluations are performed, benchmarking RWCNet against well-established deep learning architectures such as ResNet50, MobileNetV2, DenseNet201, GoogleNet, and InceptionV3. Additionally, the project explores hybrid models and ensemble learning approaches to enhance classification performance further. Object detection is also incorporated using YOLO versions (YOLOv5x6, YOLOv8, and YOLOv9), which facilitates the localization of waste items within images, adding practical value for real-time sorting applications.

Ultimately, this project aims to develop a scalable and practical solution that can be integrated into automated waste management systems. By improving the accuracy and speed of recyclable waste identification, the system can contribute to reducing human intervention, minimizing errors, and increasing the efficiency of recycling processes—thereby supporting environmental sustainability and resource conservation.

**1.4 OBJECTIVES**

The primary objective of this project is to develop and evaluate a robust deep learning model, RWCNet, for effective recyclable waste classification. By leveraging advanced classification and detection algorithms on the TrashNet dataset, the project aims to improve the accuracy and reliability of automated waste sorting systems, contributing to enhanced sustainable waste management.

To design and implement RWCNet, a novel deep learning architecture tailored for classifying six distinct recyclable waste categories. This involves rigorous training and optimization using the TrashNet dataset to ensure the model effectively learns discriminative features, handling diverse waste images. The goal is to achieve high classification accuracy and robustness across different waste types, enabling practical deployment in real-world recycling environments.

To benchmark the performance of RWCNet against several state-of-the-art classification models such as ResNet50, MobileNetV2, DenseNet201, GoogleNet, and InceptionV3. Additionally, to explore hybrid architectures, including a combination of MobileNet and DenseNet201, to analyze their comparative strengths in feature extraction and classification. This evaluation aims to identify the most efficient model for recyclable waste classification in terms of accuracy, speed, and computational resources.

To incorporate and evaluate advanced object detection algorithms, including YOLOv5x6, YOLOv8, and YOLOv9, to enable precise localization and identification of waste items within images. Furthermore, to assess the classification capabilities of models like Xception and NasNetMobile and develop an ensemble approach combining these models to enhance overall classification performance. This comprehensive approach aims to provide a robust, scalable solution for automated recyclable waste sorting.

## II. SYSTEM ANALYSIS & DESIGN

### 2.1 EXISTING SYSTEM

The existing systems for recyclable waste classification have evolved significantly, with earlier approaches primarily utilizing traditional machine learning algorithms. Initial efforts involved applying Support Vector Machine (SVM) and K-Nearest Neighbors (KNN) algorithms to the TrashNet dataset, with varying degrees of success. Additionally, Random Forest (RF) and Extreme Gradient Boosting (XGBoost) were explored, highlighting the limitations of traditional methods in handling the complexity of waste classification tasks. The advent of deep learning has marked a pivotal shift in this domain, offering enhanced accuracy and robustness. Early implementations included the OscarNet network, later refined by VGG19, and other deep learning architectures such as AlexNet and VGG16, which were fine-tuned to improve classification performance on the TrashNet dataset. MobileNet also emerged as a notable deep learning model, further demonstrating the capability of convolutional neural networks to advance waste classification tasks, setting the stage for more sophisticated models in recent years.

#### 2.1.1 Disadvantages of Existing System

1. The existing systems rely heavily on traditional machine learning algorithms, which struggle with the complexity of waste classification tasks, leading to suboptimal accuracy and performance.
2. They often require extensive feature engineering, making them less adaptable to diverse waste categories.
3. Limited scalability is another drawback, as these methods may not efficiently handle large datasets or real-time classification needs.
4. Furthermore, early deep learning implementations lacked the refinement and robustness seen in more advanced architectures, hindering their overall effectiveness in waste classification.

### 2.2 PROPOSED SYSTEM

In this project, we propose the development of RWCNet (Recyclable Waste Classification

Network), a comprehensive deep learning model designed to automate the classification of six distinct waste categories using the TrashNet dataset. Our proposed system will utilize several advanced classification algorithms, including ResNet50, MobileNetV2, DenseNet201, GoogleNet, InceptionV3, and a novel model that combines MobileNet and DenseNet201 to optimize performance. Additionally, for object detection, we will implement YoloV5x6, YoloV8, and YoloV9 to identify and locate waste items effectively. We will also analyze the dataset using Xception, NasNetMobile, and an ensemble approach that combines Xception with NasNetMobile to enhance classification accuracy. The integration of these diverse algorithms aims to create a reliable and efficient automated waste sorting system, ultimately contributing to improved recycling rates and more sustainable waste management practices. This system will provide a technological solution to the pressing issue of waste mismanagement.

### 2.2.1 Advantages of Proposed System

1. The proposed RWCNet model leverages advanced deep learning architectures, providing improved accuracy and robustness in classifying six distinct waste categories using the TrashNet dataset.
2. By utilizing state-of-the-art algorithms, the system can adapt to diverse waste types more effectively.
3. Integration of object detection models like YoloV5x6 and YoloV9 enhances the system's capability to identify and locate waste items accurately.
4. The ensemble approach, combining models like Xception and NasNetMobile, further optimizes performance, ensuring a reliable and efficient automated waste sorting solution.

## SYSTEM ARCHITECTURE

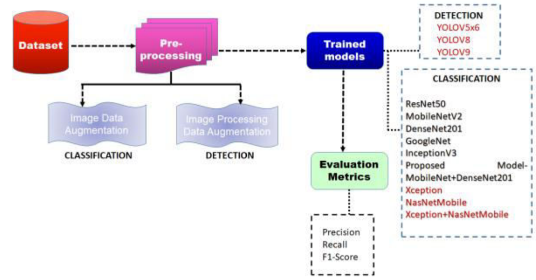



Fig 4.1 System Architecture

## III. IMPLEMENTATIONS

### MODULES

- **Data loading:** using this module we are going to import the dataset.
- **Image Data Augmentation:** Image data augmentation enhances the dataset by applying techniques such as re-scaling, shear transformation, zooming, horizontal flipping, and reshaping, which improve model robustness and prevent overfitting during training. This step is used for classification.
- **Image Processing:** Image processing involves converting images to blob objects, defining classes, declaring bounding boxes, and converting arrays to numpy arrays. It also includes loading the pre-trained model, reading network layers, extracting output layers, and preparing images through various transformations and annotations. This step is used for to detection.
- **Data Augmentation:** Data augmentation enhances image datasets by randomly altering images through techniques such as rotation and transformation, thereby increasing variability and robustness, which helps improve model performance and generalization during training. This step is used for to detection.
- **Model generation:** Model building - **classification** {- ResNet50 - MobileNetV2

- DenseNet201 - GoogleNet - InceptionV3 - Proposed Model - MobileNet + DenseNet201 - Xception - NasNetMobile - Xception + NasNetMobile} **- Detection** {- YoloV5x6 - YoloV8 - Yolov9}. Performance evaluation metrics for each algorithm is calculated.

- **User signup & login:** Using this module will get registration and login
- **User input:** Using this module will give input for prediction
- **Prediction:** final predicted displayed

**Extension:**

We extended our work by implementing Xception and NasNetMobile models, as well as an ensemble of both for garbage classification. Additionally, we utilized the YOLO family of models for detecting abnormalities in the dataset. To enhance user interaction, we will develop a front end using the Flask framework, complete with secure user authentication.

**Advantages**

1. The YOLO family enables rapid detection of abnormalities, ensuring timely identification and response to various garbage classification scenarios.
2. Combining Xception and NasNetMobile enhances feature extraction capabilities, leading to better classification performance for complex datasets.
3. The ensemble of different models capitalizes on their strengths, resulting in a more reliable and accurate classification system overall.
4. A Flask-based front end provides an intuitive interface for users, facilitating easy access to predictions and enhancing overall engagement.

**Algorithms:**

**Algorithms for classification:**

**ResNet50:**

ResNet50 is a deep residual learning model that utilizes skip connections to address the vanishing gradient problem, allowing for the training of very deep networks. In our project, ResNet50 is employed for classifying recyclable waste images, leveraging its ability to capture complex features effectively. The model's architecture enables efficient training on the TrashNet dataset, enhancing classification accuracy across multiple waste categories, thus supporting the development of an automated waste sorting system.

**MobileNetV2:**

MobileNetV2 is a lightweight convolutional neural network optimized for mobile and edge devices, known for its efficient use of depthwise separable convolutions. In our project, it serves as a backbone for the proposed RWCNet model, providing fast and accurate classification of waste images while minimizing computational resources. MobileNetV2’s architecture enables high performance in identifying different recyclable waste types, making it ideal for real-time applications in automated waste management systems.

**DenseNet201:**

DenseNet201 is a deep learning architecture characterized by dense connectivity patterns, where each layer receives inputs from all preceding layers. This model enhances feature propagation and reduces the number of parameters. In our project, DenseNet201 is utilized for classifying waste images, benefiting from its ability to learn rich feature representations. Its effectiveness in recognizing intricate patterns in the TrashNet dataset contributes to accurate waste classification, supporting the development of a reliable recycling system.

**GoogleNet:**

GoogleNet, or Inception v1, incorporates inception modules to enable the network to learn multi-scale features while maintaining computational efficiency. In our project, GoogleNet is applied to classify images of recyclable waste, leveraging its complex architecture to capture diverse patterns in the data. By combining various convolutional filter sizes within the same layer, GoogleNet enhances the model's ability to distinguish between different waste categories, improving overall classification performance in our automated waste sorting system.

**InceptionV3:**

InceptionV3 is an advanced convolutional neural network that builds upon the inception architecture, emphasizing modularity and improved computational efficiency. In our project, InceptionV3 is utilized for classifying waste images, leveraging its ability to capture complex patterns and multi-scale features. The model’s architecture allows for effective classification of the TrashNet dataset, enhancing the accuracy and reliability of the automated waste sorting process while supporting diverse waste category identification.

**Proposed Model - MobileNet + DenseNet201:**

The proposed model combines MobileNet and DenseNet201 to leverage the strengths of both architectures, aiming for efficient and accurate waste classification. MobileNet provides lightweight processing, while DenseNet201 enhances feature extraction through its dense connections. This synergistic approach in our project allows for improved classification performance on the TrashNet dataset, effectively distinguishing between various waste types and facilitating the development of a robust automated recycling system.

**Xception:**

Xception is an extension of the Inception architecture that employs depthwise separable convolutions, improving performance by decoupling spatial and channel-wise features. In our project, Xception is utilized for classifying images of recyclable waste, providing high accuracy through its ability to learn complex patterns. Its architecture effectively handles the variability within the TrashNet dataset, contributing to the development of an efficient automated waste sorting system capable of distinguishing between multiple waste categories.

**NasNetMobile:**

NasNetMobile is a lightweight architecture optimized for mobile applications, designed using neural architecture search techniques to achieve high efficiency. In our project, NasNetMobile is employed for classifying recyclable waste images, allowing for rapid processing while maintaining accuracy. Its compact design makes it suitable for real-time applications, enhancing the capability of the automated waste sorting system to identify various waste categories effectively, thus promoting sustainable waste management practices.

**Xception + NasNetMobile:**

Combining Xception and NasNetMobile creates a powerful hybrid model that leverages the strengths of both architectures for enhanced performance. In our project, this combined approach is used to classify images of recyclable waste, utilizing Xception’s complex feature extraction capabilities alongside NasNetMobile’s efficiency. This synergy improves the accuracy of waste classification on the TrashNet dataset, contributing to the development of an effective automated sorting system for sustainable waste management.

**Algorithms for detection:**

**YoloV5x6:**

YoloV5x6 is an advanced version of the YOLO (You Only Look Once) family of models, optimized for real-time object detection with improved accuracy. In our project, YoloV5x6 is employed to detect and classify waste objects within images, providing bounding boxes and class labels. Its speed and precision make it ideal for integrating into the automated waste sorting system, allowing for rapid identification of recyclable materials in real-world scenarios.

**YoloV8:**

YoloV8 is the latest iteration in the YOLO series, featuring enhancements that improve detection performance and speed. In our project, YoloV8 is utilized for detecting various waste items in images, providing accurate classifications and bounding boxes. This model's efficiency supports real-time processing in our automated waste sorting system, enabling quick identification and categorization of recyclables, thereby facilitating effective waste management solutions.

**YoloV9:**

YoloV9 represents the evolution of the YOLO framework, further refining detection capabilities and optimizing performance for various applications. In our project, YoloV9 is used for real-time detection of recyclable waste objects, offering enhanced accuracy and speed in identifying waste categories. Its integration into the automated waste sorting system ensures reliable classification, improving the overall effectiveness of recycling processes and contributing to sustainable waste management efforts.

## IV. RESULTS/OUTPUT SCREENS

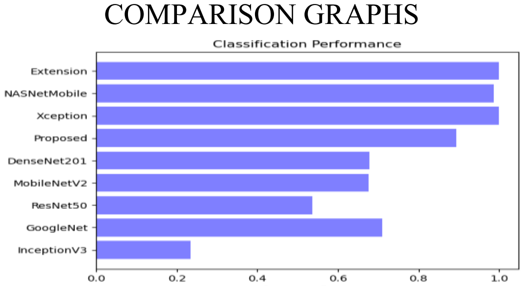
**Tables:**

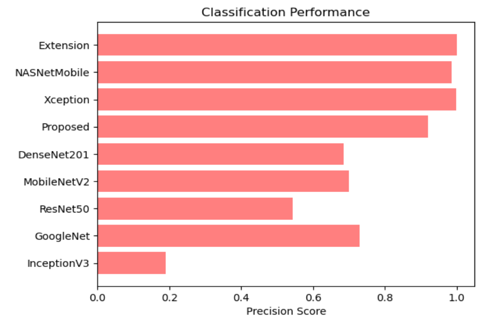
PERFORMANCE EVALUATION

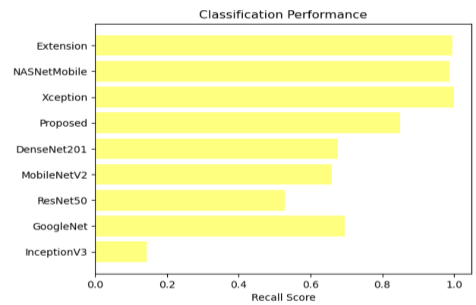
| | ML Model | Accuracy | Precision | Recall | F1_score |
|---|---|---|---|---|---|
| 0 | InceptionV3 | 0.233 | 0.189 | 0.144 | 0.159 |
| 1 | GoogleNet | 0.710 | 0.730 | 0.694 | 0.706 |
| 2 | ResNet50 | 0.537 | 0.543 | 0.529 | 0.534 |
| 3 | MobileNetV2 | 0.675 | 0.701 | 0.659 | 0.673 |
| 4 | DenseNet201 | 0.678 | 0.685 | 0.676 | 0.679 |
| 5 | Proposed | 0.894 | 0.920 | 0.849 | 0.873 |
| 6 | Xception | 0.999 | 0.999 | 0.999 | 0.999 |
| 7 | NASNetMobile | 0.986 | 0.986 | 0.986 | 0.986 |
| 8 | Extension Xception + NASNetMobile | 0.999 | 1.000 | 0.996 | 0.997 |

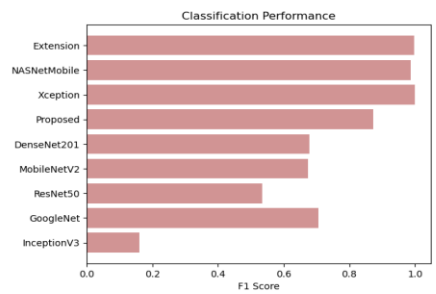
Graphs:

COMPARISON GRAPHS

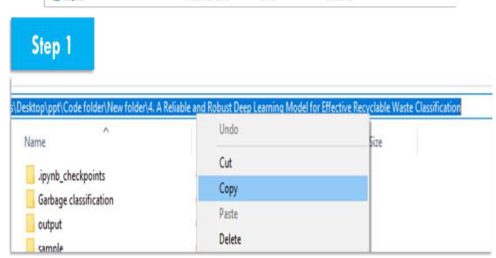


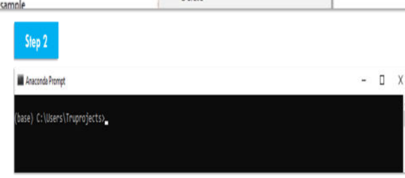




Screens:

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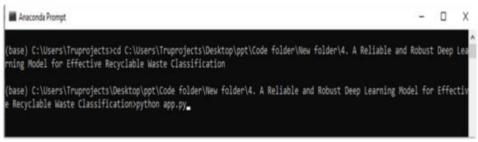


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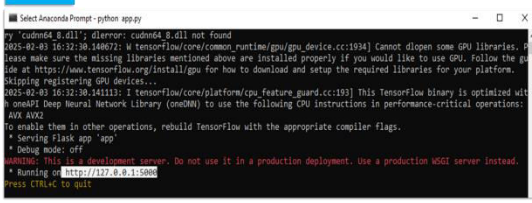


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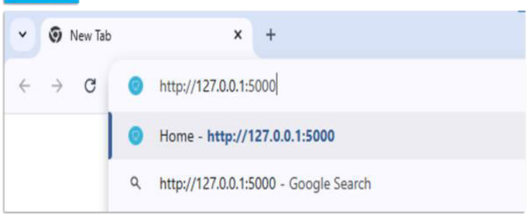
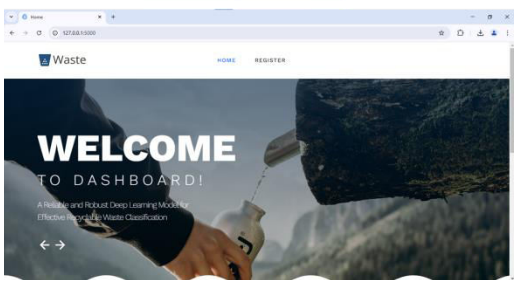



Dashboard - User Interface

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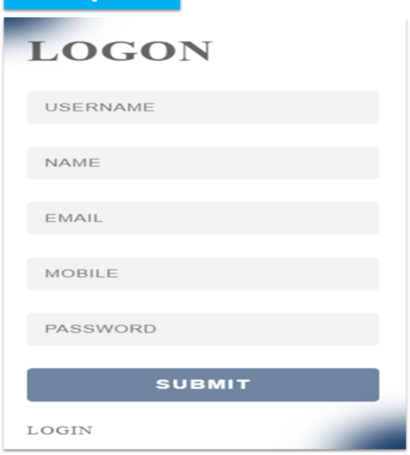


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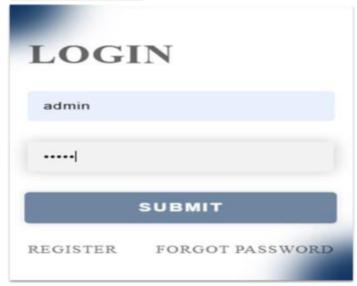


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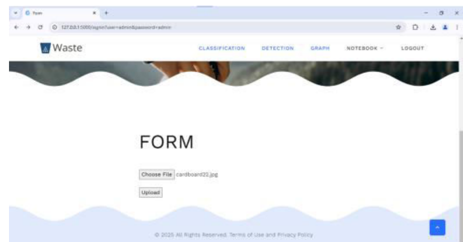


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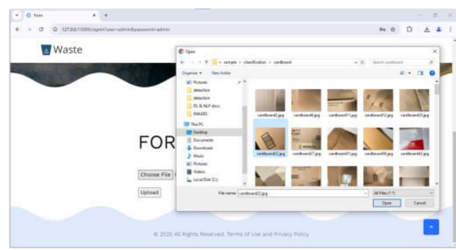
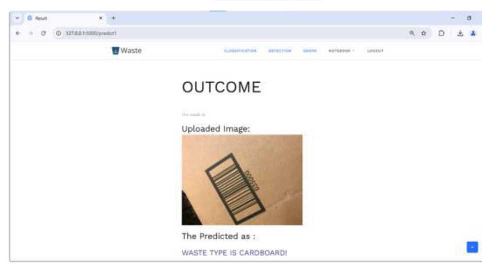
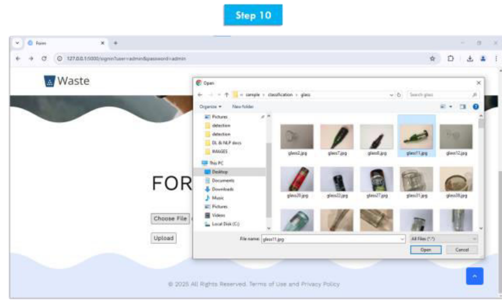



Result of Step 9




Step 10



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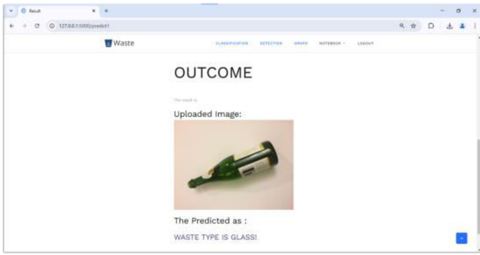


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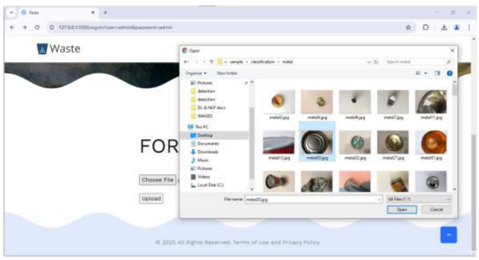


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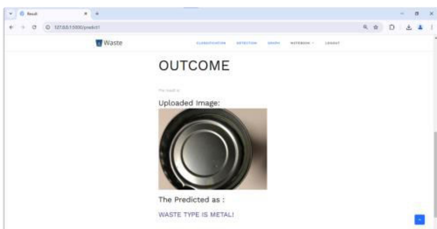


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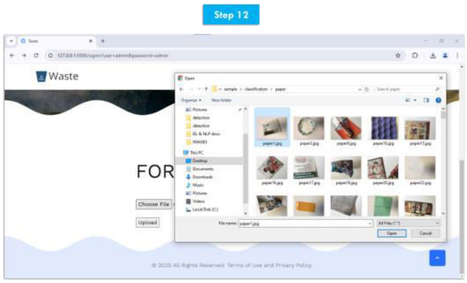


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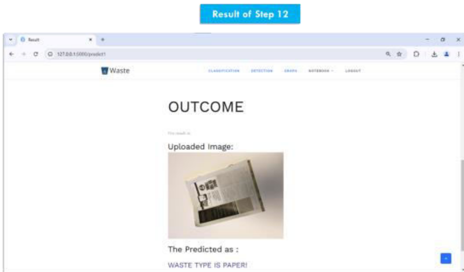


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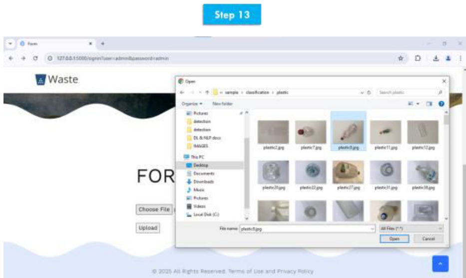


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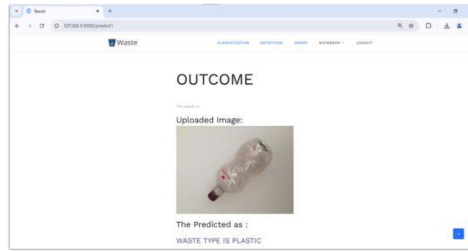


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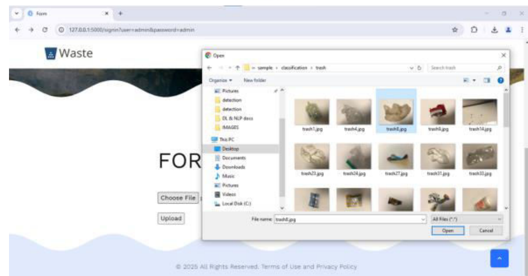


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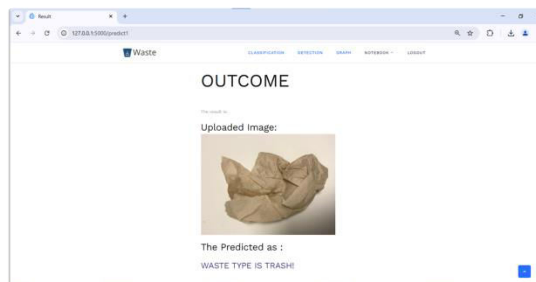


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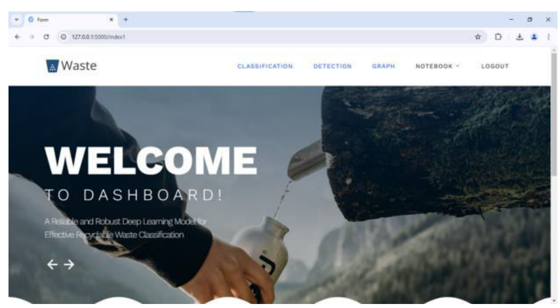


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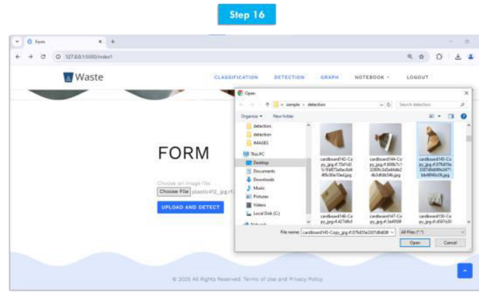

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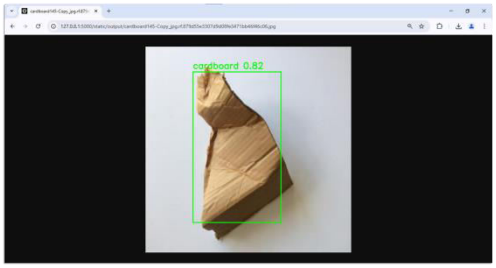


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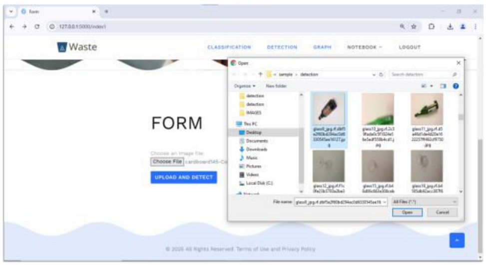


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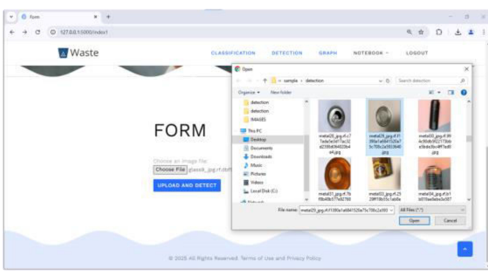
Step 18

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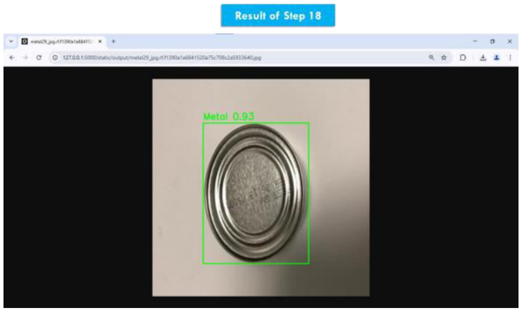


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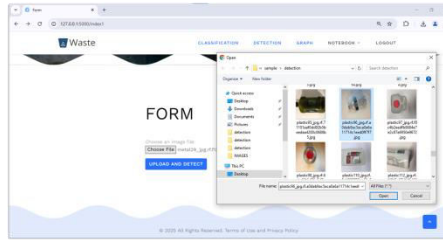
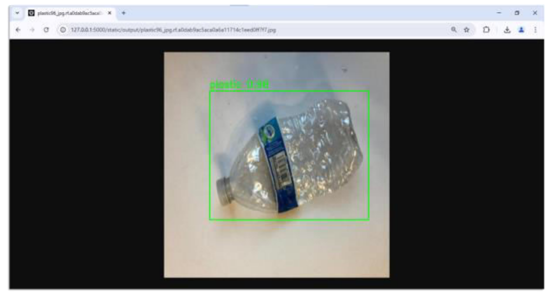



Result of Step 19



## V. CONCLUSION

The RWCNet deep learning model for recyclable waste categorisation has considerably increased the efficiency and accuracy of automated trash sorting systems. This improvement has been made possible by these technologies. For accurate categorisation of waste types, it makes use of sophisticated architectures such as ResNet50 and DenseNet201, as well as a hybrid model that comes from the combination of MobileNet and DenseNet201. YoloV5x6, YoloV8, and YoloV9 are also included into the system for the purpose of object detection. This allows for the accurate identification of recyclable materials in situations that occur in real time. Optimising the performance of the model is accomplished by the use of approaches such as picture data augmentation and advanced preprocessing procedures. Through the provision of an automated solution for precisely categorising recyclables, the promotion of environmental conservation, and the implementation of recycling procedures that are efficient, this project makes a contribution to the process of sustainable waste management.

**FUTURE SCOPE**

Future research will focus on enhancing classification accuracy, particularly for the 'litter' category, and improving waste detection through the implementation of bounding boxes around waste objects. Additionally, we aim to collect waste images from diverse geographical regions to assess the adaptability and effectiveness of RWC-Net in various waste management systems. This approach will allow us to tailor the model to different recycling practices, ultimately contributing to more efficient and sustainable waste sorting solutions worldwide.

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