Eco Vision: A Deep Learning Framework for Intelligent Waste Classification and Sustainable Management

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Abstract - *The growing amount of waste generated due to rapid urbanization and industrial development has created serious environmental challenges, making efficient waste segregation an important requirement for sustainable management. Traditional waste sorting methods mainly depend on manual segregation, which is time-consuming, labor-intensive, and often leads to inaccurate classification. To address this problem, this research proposes Eco Vision, an intelligent deep learning framework designed for automatic waste classification using computer vision techniques. The proposed system classifies waste materials into six categories including organic, plastic, paper, glass, metal, and cardboard. The waste image dataset collected from Kaggle is preprocessed using image resizing, normalization, and data augmentation techniques such as rotation, flipping, and zooming to improve model performance and generalization. Multiple deep learning architectures including Convolutional Neural Network (CNN), VGG16, and MobileNetV2 were implemented and evaluated for performance comparison. Experimental analysis showed that MobileNetV2 achieved superior performance due to its lightweight architecture, faster processing capability, and classification accuracy of nearly 99 percent F1-score. The trained model was deployed using Streamlit for real-time waste image prediction. The proposed framework provides an efficient solution for intelligent waste segregation and supports future smart recycling and sustainable waste management applications.*

Key Words: Deep Learning, Waste Classification, MobileNetV2, Computer Vision, Sustainable Waste Management, Recycling, CNN, VGG16.

1. INTRODUCTION

The rapid increase in population growth, urbanization, and industrial development has led to a significant rise in waste generation across the world. Improper waste disposal and inefficient segregation practices have become major environmental concerns, contributing to land pollution, increased greenhouse gas emissions, and reduced recycling efficiency. Effective waste management requires accurate identification and separation of waste materials before disposal or recycling.

Waste classification systems have applications in various domains including smart city infrastructure, automated recycling plants, intelligent waste bins, environmental monitoring systems, and public waste management services. Most traditional automated systems rely on conventional machine learning algorithms or basic image processing techniques, which often provide limited accuracy when handling complex real-world waste images.

To address these challenges, this paper proposes Eco Vision, a deep learning based intelligent waste classification framework designed to automatically identify waste materials and classify them into six categories including organic, plastic, paper, glass, metal, and cardboard. The proposed system utilizes advanced deep learning architectures such as CNN, VGG16, and MobileNetV2, where MobileNetV2 is selected as the optimized lightweight model due to its faster computation speed, lower memory consumption, and suitability for deployment on mobile and low-power devices.

The proposed framework is implemented using Python, TensorFlow, Keras, OpenCV, and Streamlit. Experimental results demonstrate high classification performance, with MobileNetV2 achieving nearly 99 percent F1-score while maintaining efficient real-time prediction capability. The developed system provides an intelligent, scalable, and efficient solution for automated waste segregation, making it suitable for future smart recycling systems and sustainable waste management applications.

2. LITERATURE SURVEY

Waste classification has become an important research area due to the growing demand for efficient recycling systems and sustainable environmental management. Several researchers have proposed different techniques for automated waste segregation using computer vision, machine learning, and deep learning algorithms. Accurate waste classification plays a major role in improving recycling efficiency, reducing environmental pollution, and minimizing human effort in waste management processes.

Early waste classification systems mainly relied on manual segregation methods where workers physically separated waste materials into biodegradable and recyclable categories. Although these traditional methods were widely used, they were time-consuming, labor-intensive, and highly prone to human error.

To overcome these limitations, researchers introduced computer vision based waste classification systems that used image processing techniques such as edge detection, segmentation, color extraction, and texture analysis to identify waste categories automatically Recent studies have focused on machine learning and deep learning techniques for improving waste classification performance. Traditional machine learning algorithms such as Support Vector Machine (SVM), Random Forest, and K-Nearest Neighbor (KNN) have been used for classifying waste materials after extracting handcrafted image features

With the advancement of deep learning, Convolutional Neural Networks (CNN) have been widely adopted for automatic image classification tasks because of their ability to learn complex image features directly from raw image data. Transfer learning architectures such as VGG16 further improved classification accuracy by using pretrained feature extraction layers.

The proposed work addresses these limitations by introducing Eco Vision, a deep learning based intelligent waste classification framework that utilizes CNN, VGG16, and MobileNetV2 for automated waste identification. The system classifies waste into six categories including organic, plastic, paper, glass, metal, and cardboard. MobileNetV2 is selected as the optimized lightweight architecture because of its faster computation speed, lower memory consumption, and suitability for real-time deployment.

3. PROBLEM STATEMENT

Waste management has become a major environmental concern due to the rapid increase in waste generation caused by population growth, urbanization, and industrial development. Proper waste segregation is an essential step in recycling and sustainable environmental management, but most existing waste management systems still rely heavily on manual waste sorting methods. Manual segregation requires significant human effort, consumes more time, and often results in incorrect classification of waste materials, reducing the overall efficiency of recycling processes Several existing automated waste classification systems have been developed using traditional image processing and machine learning techniques. However, these systems often provide limited classification accuracy because they depend on handcrafted image features and struggle to handle complex waste images under varying environmental conditions. Factors such as poor lighting conditions, background noise, overlapping waste objects, and variations in waste appearance often reduce system reliability and overall classification performance in real-world applications.

Although recent deep learning models such as Convolutional Neural Networks and transfer learning architectures have improved waste classification accuracy, many existing solutions require high computational resources and large memory consumption, making deployment difficult on mobile devices, embedded systems, and real-time smart waste management applications.

The proposed system aims to overcome the limitations of traditional waste classification methods by enabling automatic classification of six waste categories, improving recycling efficiency, reducing human intervention, and supporting future smart waste management and sustainable environmental applications.

3.1 System Architecture

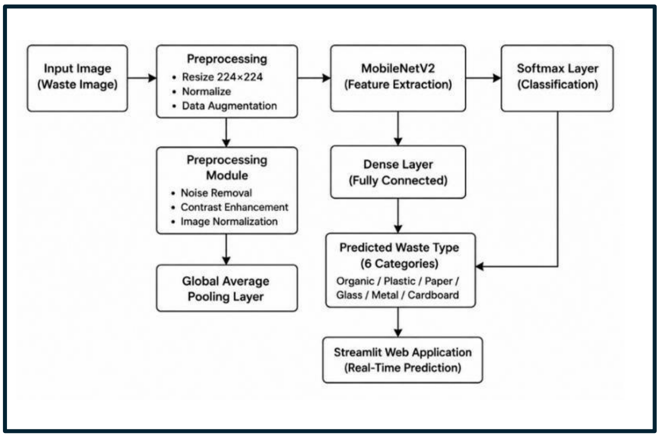

Fig 1: System Architecture

3.2 Dataset Description

The dataset used in this work was collected from publicly available waste classification datasets obtained from Kaggle. The dataset contains labelled waste images collected under different environmental conditions, backgrounds, lighting variations, object positions, and viewing angles to improve classification accuracy and model robustness
learning models for intelligent waste identification and sustainable waste management applications.

The images represent different types of waste materials commonly found in daily life and were organized into multiple categories for automated waste classification. The dataset was prepared to support image-based deep

The proposed system focuses on classifying waste materials into six categories, namely Organic, Plastic, Paper, Glass, Metal, and Cardboard.

Fig -2: Dataset

3.3 Module Building

The proposed intelligent waste classification system is divided into several functional modules that work together to achieve accurate automated waste identification and sustainable waste management. The Dataset Collection Module gathers waste image data from publicly available Kaggle waste classification datasets containing multiple waste categories. The collected dataset includes images captured under different lighting conditions, backgrounds, object orientations, and waste appearances to improve model accuracy and robustness. These images are then prepared for training and testing the deep learning models.

The collected dataset is passed to the Pre-processing Module, where image processing techniques are applied to improve data quality and consistency before model training. In this stage, all images are resized to a fixed dimension of 224 × 224 pixels, normalized to standardize pixel values, and augmented using techniques such as rotation, flipping, and zooming.

The processed images are then forwarded to the Feature Extraction and Model Training Module, where deep learning architectures including Convolutional Neural Network (CNN), VGG16, and MobileNetV2 are implemented for waste classification. These models automatically learn important image features from the dataset and classify waste materials into six categories including organic, plastic, paper, glass, metal, and cardboard. MobileNetV2 is used as the optimized lightweight model due to its faster computation speed, reduced memory consumption, and suitability for real-time applications.

3.4 Results

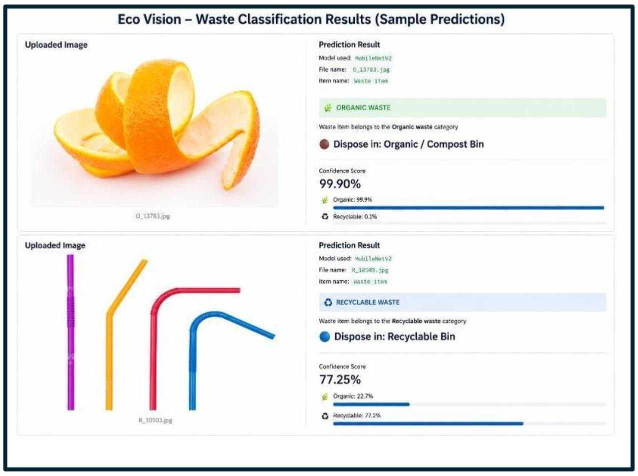

Fig: 3 Results

Table 1: Performance Evaluation of the Proposed Multi-Hand Gesture Recognition System

Performance Metric	Value
Training Accuracy	94.47%
Validation Accuracy	93.19%
Testing Accuracy	92.36%
Precision	93%
Recall	92%
F1-Score	92%
Model Used	MobileNetV2
Total Classes	Organic / Recyclable

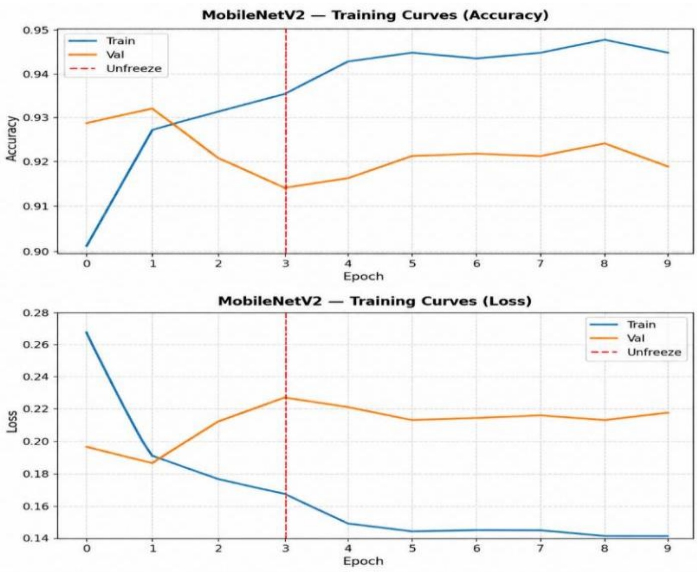

Fig-4: Accuracy and loss curve

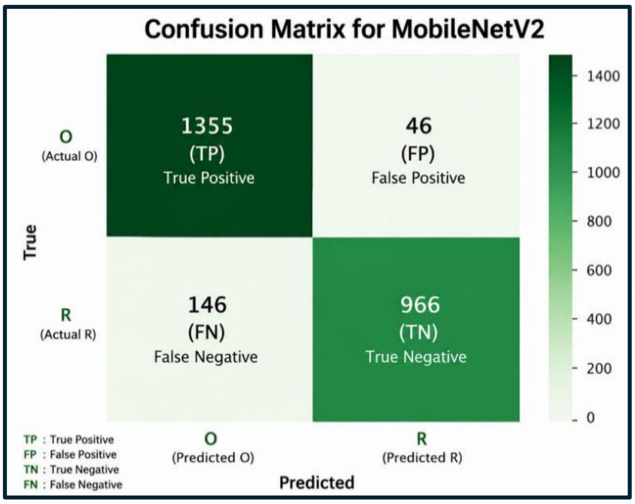

Fig -5 : Confusion matrix

3.4 Comparison of deep learn

Module	Accuracy	Performance	Remarks
CNN Model	88.42%	Good	Basic deep learning model
VGG16	87.23%	Very Good	Higher accuracy, heavy model
MobileNetV2	92.36%	Excellent	Lightweight & optimized

Fig-6: Model comparison

4. CONCLUSION

This paper presented Eco Vision, an intelligent deep learning based waste classification framework developed to improve automated waste segregation and support sustainable environmental management. The proposed framework combines advanced computer vision techniques with deep learning models for accurate identification and classification of waste materials. By automatically classifying waste into categories such as organic, plastic, paper, glass, metal, and cardboard, the system provides a more efficient and intelligent waste management solution compared to traditional manual waste segregation methods.

A waste image dataset collected from Kaggle was used to train and evaluate multiple deep learning models including Convolutional Neural Network (CNN), VGG16, and MobileNetV2. The dataset was preprocessed using resizing, normalization, and augmentation techniques to improve model learning capability and classification performance. Experimental results demonstrated that the MobileNetV2 model achieved superior performance with high classification accuracy, faster computation speed, and lower computational complexity compared to other implemented models.

The proposed system was successfully deployed using Streamlit, enabling real-time waste image classification through a user-friendly interface. The developed framework provides an efficient, scalable, and cost-effective solution for intelligent waste segregation applications. Its ability to perform accurate classification and support automated recycling processes makes it suitable for applications in smart waste bins, recycling systems, environmental monitoring, and future smart city infrastructure. Future work can focus on expanding waste categories, improving real-time object detection, and integrating IoT based smart waste management systems. The results confirm that deep learning techniques provide an effective framework for intelligent waste classification and sustainable waste management applications.

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