iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** III **Month of publication:** March 2025

DOI: https://doi.org/10.22214/ijraset.2025.68067

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

EnviroSmart – A Waste Management System using CNN.

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***Abstract:** "EnviroSmart" is an intelligent waste management system designed to address the growing need for efficient waste disposal and recycling solutions. Utilizing advanced machine learning algorithms, the system detects and classifies waste items by analyzing their images. Once an image is uploaded, EnviroSmart identifies the type of waste, such as plastic, glass, paper, or organic materials, and provides users with detailed instructions on how to properly manage it. This may include guidance on recycling, composting, or proper disposal methods, promoting environmentally responsible behavior. To ensure optimal accuracy and efficiency, multiple machine learning algorithms will be implemented and tested, including convolutional neural networks (CNNs) and other image recognition models. The performance of each algorithm will be evaluated and compared based on criteria such as classification accuracy, speed, and robustness. By identifying the most effective algorithm, EnviroSmart aims to create a highly reliable waste management tool. The goal of this project is to simplify the waste management process for individuals and organizations, reducing human error and promoting sustainable practices. EnviroSmart not only helps in educating users about proper waste disposal but also contributes to the larger effort of reducing pollution and conserving natural resources.*
***Keywords:** Convolutional Neural network, Deep Learning, Waste Management, Computer Vision, Machine Vision, Machine Learning.*

I. INTRODUCTION

Embracing innovative waste management solutions is a transformative step towards environmental sustainability, with benefits that extend far beyond simple waste disposal. Proper waste classification and disposal are essential for preserving natural resources, minimizing pollution, and fostering ecological well-being. In recent years, waste management practices have undergone a significant shift, with increasing awareness of environmental responsibility. This trend reflects a growing recognition of the need for more effective, data-driven waste management strategies.

EnviroSmart, a cutting-edge waste management system powered by computer vision, artificial intelligence, and machine learning, offers a sophisticated solution to these challenges. The system can analyse, identify, and interpret different types of waste, making it a valuable tool for individuals, households, and organizations striving for more efficient waste disposal practices. It addresses modern waste management complexities such as the diversity of waste materials, recycling needs, and environmental sustainability. By providing quick, accurate, and actionable information on how to manage waste—whether it's recycling, composting, or proper disposal—EnviroSmart supports environmentally conscious decision-making. Moreover, its potential extends to revolutionizing various sectors involved in waste processing, contributing to improved environmental health, resource conservation, and operational efficiency.

In summary, EnviroSmart is designed to meet the evolving needs of today's society by delivering a user-friendly, intelligent solution for smarter waste management. With increasing global waste production and the complexity of modern waste streams, individuals and communities often struggle with correctly identifying and managing waste. This leads to improper disposal, which contributes to environmental pollution, resource depletion, and inefficiencies in waste management processes. There is a critical need for an accessible and intelligent system that can accurately classify waste items, provide appropriate disposal or recycling guidance, and promote sustainable practices. EnviroSmart aims to address this challenge by leveraging machine learning and computer vision to simplify waste management, reduce human error, and encourage environmentally responsible behaviour. It will empower individuals to take responsibility for their waste and reduces the burden on local governments, allowing them to focus on broader environmental initiatives.

II. LITERATURE SURVEY

1) Rijwan Khan et al. [1] Traditional swaste collection methods are insufficient, as waste collection trucks typically operate only once or twice a week, leading to waste accumulation and spillage on the streets due to inadequate collection practices. A smart and efficient waste management system leveraging Machine Learning (ML) and the Internet of Things (IoT) is proposed to address this issue. The proposed solution incorporates an Arduino UNO microcontroller, ultrasonic sensors to detect the level of waste, and moisture sensors to differentiate between dry and wet waste. Image processing techniques are utilized to measure the waste index of specific dumping areas, enabling more effective management. A hardware prototype was developed to demonstrate the feasibility of this approach. Overall, the system aims to optimize waste management operations, minimize environmental pollution, and contribute to the development of cleaner and healthier urban areas.
2) Suveer Sharma et al.[2] The project focuses on tackling waste management at the source by providing an efficient solution for proper waste segregation before disposal. It utilizes Machine Learning and Deep Learning techniques, specifically TensorFlow and Keras-based Convolutional Neural Network (CNN) architectures, to categorize waste accurately based on user input. By implementing an ensemble model combining ResNet50, EfficientNet-small, and EfficientNet-large, the proposed system enhances classification accuracy. This software solution can be integrated with various hardware devices, ensuring flexibility, user convenience, and widespread deployment for effective waste management and environmental sustainability
3) Khan Nasik Sami et al.[3] The current manual segregation of waste, handled by unskilled workers, is ineffective, time-consuming, and impractical due to the sheer volume of waste. To address this, an automated waste classification system leveraging Machine Learning and Deep Learning algorithms is proposed. The solution involves creating a dataset and categorizing waste into six classes: glass, paper, metal, plastic, cardboard, and general waste. Comparative analysis was conducted using three Machine Learning algorithms—Support Vector Machine (SVM), Random Forest, and Decision Tree—along with one Deep Learning algorithm, Convolutional Neural Network (CNN). The results showed that CNN achieved the highest classification accuracy at 90%, while SVM performed well with an 85% accuracy rate. Random Forest and Decision Tree yielded 55% and 65% accuracy, respectively.
4) Sonali Dubey et al.[4] has proposed IoT and Machine Learning-based household waste management system aims to optimize waste management in residential societies using advanced technology. This system enables efficient waste collection and decomposition, minimizing actual waste and maximizing its utility. The solution focuses on a two-level waste segregation process: the first level occurs at the individual household, while the second level is implemented at the society level. Biodegradable waste is recycled to produce compost, contributing to sustainable waste management practices. The system utilizes the K-Nearest Neighbors (KNN) machine learning algorithm to generate alert messages based on combinations of three sensor readings, including the levels of biodegradable and non-biodegradable waste and the concentration of poisonous gases. This approach supports green technologies by reducing pollutants and promoting energy conservation, recycling, and reuse, ultimately fostering a cleaner and more sustainable smart society.
5) Gayathri Rajakumaran et al.[5]This paper proposes an enhancement through the implementation of image classification and multi-object detection for more precise waste identification and segregation. The improved system achieves 95% classification accuracy with a mean average precision of 87.4%, demonstrating its efficiency in minimizing manual labor and associated costs while enabling effective waste management.
6) Vishal Verma et al.[6] This research presents an intelligent garbage detection system utilizing a low-cost Unmanned Aerial Vehicle (UAV) equipped with deep learning capabilities for efficient waste management. The goal is to provide an accurate, automated solution for identifying and managing waste in remote areas, assisting municipal corporations in monitoring garbage-prone regions. The system employs two Convolutional Neural Network (CNN) models trained on an image dataset of solid waste captured by the UAV. Both models were optimized using different learning rates, optimizers, and epochs, with symmetry applied during image sampling to maintain homogeneity in resizing.
7) Ayaz Hassain Et al.[7] This paper introduces an IoT-based smart bin system that integrates machine learning and deep learning models for efficient garbage disposal management and air quality forecasting around the bin. The smart bin is connected to a Google Cloud Platform (GCP) server, which processes real-time data to predict the bin's status and forecast air pollutants in its surrounding environment. The system utilizes both traditional machine learning models, such as k-Nearest Neighbors (k-NN) and logistic regression, and a non-traditional Long Short-Term Memory (LSTM) network-based deep learning model. These models generate alert messages related to the bin's status and predict the concentration of carbon monoxide (CO) in the air. In a real-time testing environment, logistic regression and k-NN achieved recall scores of 79% and 83%, respectively, for bin status prediction. Meanwhile, modified LSTM and simple LSTM models attained 90% and 88% accuracy, respectively, for

forecasting future air pollutant concentrations, making this smart bin system a robust solution for waste management and environmental monitoring.

8) Koushik Paul et al.[8]The paper titled "A Comprehensive Optimization Model for Integrated Solid Waste Management System: A Case Study on Kolkata City, India" provides a detailed mathematical framework for optimizing municipal solid waste management. The study integrates various elements of an Integrated Solid Waste Management (ISWM) system, including waste generation rates, composition, transportation modes, and processing techniques, alongside potential revenues from waste processing. The optimization model uses linear programming to simulate real-world waste management scenarios while considering constraints such as waste flow and mass balance, processing plant capacities, landfill limits, vehicle load capacities, and the required trips. Solved using LINGO optimization software, the model serves as a decision-support tool, facilitating the evaluation of different waste management alternatives to identify the least-cost combination of technologies for efficient waste handling, treatment, and disposal.
9) Roshan Issac et al.[9]The paper addresses the challenges posed by rapid urbanization in Kerala, specifically focusing on the increased generation of municipal solid waste (MSW) and its negative impact on society and the environment. Despite governmental efforts, ineffective waste management has resulted in pollution and greenhouse gas emissions. The study presents a case study on Thiruvalla Municipality in Pathanamthitta district, Kerala, and introduces a system called SVASTHA, which leverages RFID and GPS technology for efficient waste collection management. The system offers real-time monitoring of waste collection, live tracking of trucks and trash bins, and provides a platform for residents to report uncollected waste and illegal dumping. One of its key features is the smart shortest-path detection technique, which minimizes vehicle travel distance and optimizes collection routes. Developed as an Android application, SVASTHA can be adopted in other municipalities to streamline waste management operations and improve overall efficiency.
10) Samuel Prabakaran M et al.[10]This study explores advanced waste management and pollution control system using modern technologies like YOLOv7, Faster R-CNN, and SVM algorithms. The system applies YOLOv7 for real-time rubbish classification, allowing quick and accurate sorting of waste. Faster R-CNN is used for fog density analysis, which helps estimate air pollution levels. At the same time, the SVM algorithm calculates the Air Quality Index (AQI) by analyzing various air quality indicators for accurate assessments. The integration of trash classification, fog density monitoring, and AQI calculation offers a comprehensive approach to analyzing pollution trends. Additionally, the system evaluates soil quality, enhancing its overall functionality for sustainable environmental management. However, challenges like data acquisition, model training, and integration remain significant hurdles for full-scale real-world implementation.

TABLE I
LITERATURE SURVEY

Author	Technology Used	Year	Accuracy
Rijwan Khan et al. [1]	Arduino UNO, Ultrasonic & Moisture Sensors, Image Processing, IoT	2021	97.49%
Suveer Sharma et al. [2]	TensorFlow, Keras, CNN (ResNet50, EfficientNet-small & EfficientNet-large)	2023	99.34%
Khan Nasik Sami et al. [3]	CNN, SVM, Random Forest, Decision Tree	2021	CNN: 90%, SVM: 85%
Sonali Dubey et al. [4]	IoT, K-Nearest Neighbors (KNN)	2020	93.3%
Gayathri Rajakumaran et al. [5]	Image Classification, Multi- Object Detection	2023	95%
Vishal Verma et al. [6]	Unmanned Aerial Vehicle (UAV), CNN	2022	94%
Ayaz Hassain et al. [7]	IoT, k-NN, Logistic Regression, LSTM	2020	LSTM: 90%, k-NN: 83%
Koushik Paul et al. [8]	Linear Programming, LINGO Optimization Software	2019	80-85%
Roshan Issac et al. [9]	RFID, GPS Technology	2013	90%
Samuel Prabakaran M et al. [10]	YOLOv7, Faster R-CNN, SVM	2024	92%

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

III. LIMITATION OF EXISTING SYSTEM

Despite their innovative approaches, many existing waste management systems face several limitations that hinder their effectiveness and scalability. These challenges arise from dependency on hardware, high computational requirements, and specific system designs that may not be adaptable across different environments. Below are some key limitations observed in current systems:

1) Uses hardware components such as Arduino and sensors, which can limit scalability and lacks features like waste prediction and recycling recommendations.
2) The system that focus only on waste classification, without offering additional functionalities.
3) The dependence on sensors makes the system vulnerable to inaccurate readings, especially in noisy data environments
4) Complex image processing techniques increase operational costs and make the system harder to implement.

IV. METHODOLOGY

A. *Project flow*

1) Image dataset collection: - The first and the very important step in ML/DL projects is collecting / importing datasets. For our project "EnviroSmart" we have collected various waste images from google and other sites and categorized them into 10 categories.
2) Data Preprocessing: - The data in the Datasets requires adjustments as it is in the wrong data format, contains images of varying sizes, and pixel values ranging from 0 to 255. Machine learning models prefer float32 format, consistent image sizes, and values between 0 and 1. Therefore, we must convert, resize, and normalize the data to make it suitable for these models. We Reshaped dimensions to facilitate array processing, initiating image processing procedures.
3) Exploratory Data Analysis (EDA): - Conducted exploratory data analysis (EDA) to gain insights and understanding from the collected food images dataset. Exploratory data analysis (EDA) is a statistical method for summarizing the main characteristics of datasets. It is often used for data visualization methods.
4) Training model: - A Convolutional Neural Network (CNN) is built to classify the images based on patterns and features. We have used various pre-trained models like Inception, Efficient Net, and VGG16, etc. are tested to see which gives the best performance.
5) Comparing accuracy: - The accuracy of different models is compared to determining which performs best for the classification task. The model with the highest accuracy and best performance metrics is selected for further testing.
6) Testing Model: - The chosen model is rigorously tested with unseen data to validate its performance. We had used test data for testing purpose.
7) Prediction: - The model predicts the category of new waste images, classifying them based on learned patterns.
8) Classification of Waste Images: - The waste images are categorized into specific types (e.g., plastic, glass, organic) based on the model's predictions. Our model can predict 10 categories of waste types. Details of this are given in section 6.1
9) Recycling Ways: -For each classified waste type, relevant recycling or disposal methods are suggested to ensure proper waste management.

B. *Design Details*

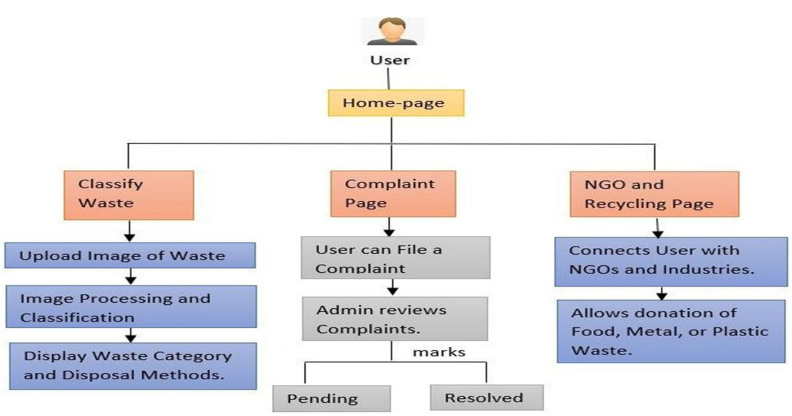

Fig. 1 Project Flow

1) Classify the Waste: Users can upload an image of waste, and the system utilizes a CNN-based model to identify whether the waste is organic, recyclable, or hazardous. This helps in proper disposal and promotes recycling.
2) Complaint Registration: If users notice uncollected garbage or illegal dumping, they can file a complaint directly through the app. The complaint form captures details such as location, description, and images to be reviewed by the authorities.
3) NGO & Recycling Connections: The app provides contact details of NGOs and recycling companies to help users donate excess food, plastic, and metal waste. This ensures reusable resources do not end up in landfills.
4) Educational Videos on Recycling: Once waste is classified, the app displays informative videos on how to recycle or reuse the classified waste. This feature promotes eco-friendly habits.
5) Homepage Waste Management Awareness: The homepage provides essential guidelines on waste management, segregation techniques, and the impact of improper disposal on the environment, encouraging users to be more responsible.

V. TECHNOLOGIES USED

A. Algorithms Used

1) Vgg-16

The VGGNet is a CNN that supports 16 layers. The convolution layers leverage minimum perceptive fields, followed by linear transformation and ReLU (Rectified Linear Unit) units. Few convolution layers are followed by a pooling layer that reduces the height and width. The hidden layers leverage ReLU and the network only consists of three fully connected layers. The first and second layers use the most recent feature vector as input and have a channel size of 4096. The third layer creates 1000 channels for 1000 classes. In other words, the third fully connected layer is used to implement the SoftMax function to categorize 1000 classes. Every hidden layer uses ReLU as its activation function. This encourages speedier learning and decreases the possibility of vanishing gradient problems; hence it is more computationally efficient.

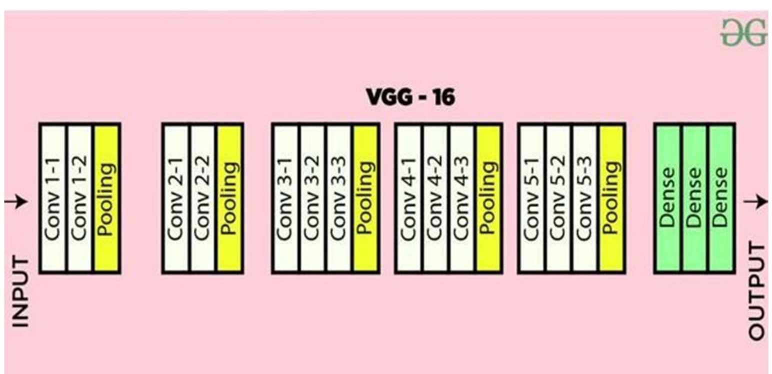

Fig. 2 VGG-16 architecture

2) ResNet50

Residual Network (ResNet) is a deep CNN architecture designed to support hundreds and thousands of convolution layers. The ResNet architecture stacks multiple identity mapping, skips those layers, and reuses the activation function of the previous layers. Then, on retraining, the network expands and the remaining parts, known as residual parts, are allowed to explore more of the feature space of the input image. This solves the problem of vanishing gradient that occurs by increasing the number of convolution layers. Multiple versions of ResNet use the same basic principle but have various numbers of layers. The model that operates with 50 neural network layers is referred to as Resnet50. In a study by Suveer Sharma et al. [2], the combination of TensorFlow and Keras with CNN models, including ResNet-50, achieved an impressive accuracy of 99.34% in waste classification, demonstrating the effectiveness of this approach.

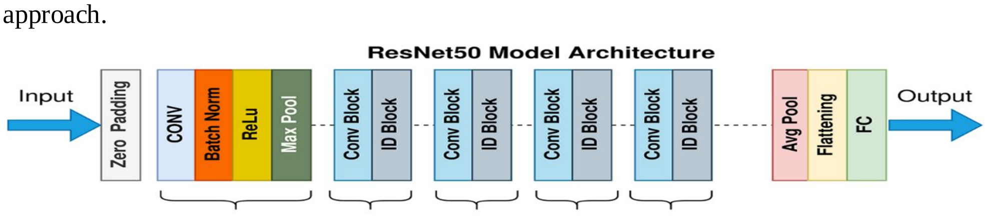

Fig. 3 ResNet50 Model Architecture

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue III Mar 2025- Available at www.ijraset.com

3) DenseNet

A DenseNet is a type of CNN that utilizes dense connections between layers through Dense Blocks, where all layers are directly linked with matching feature-map sizes. Each layer in a DenseNet receives additional inputs from all preceding layers and forwards its feature maps to all subsequent layers, maintaining the feed-forward nature of the system. This dense connectivity pattern allows for efficient information flow across layers, promoting feature reuse and improving the network's ability to capture complex patterns in the data. **DenseNet-121**, a densely connected convolutional network characterized by its unique architecture, where each layer receives input from all preceding layers. This dense connectivity facilitates better gradient flow during training and promotes feature reuse, which can significantly reduce the number of parameters compared to traditional convolutional networks. DenseNet-121 has around 8 million parameters, making it relatively lightweight while still achieving impressive performance.

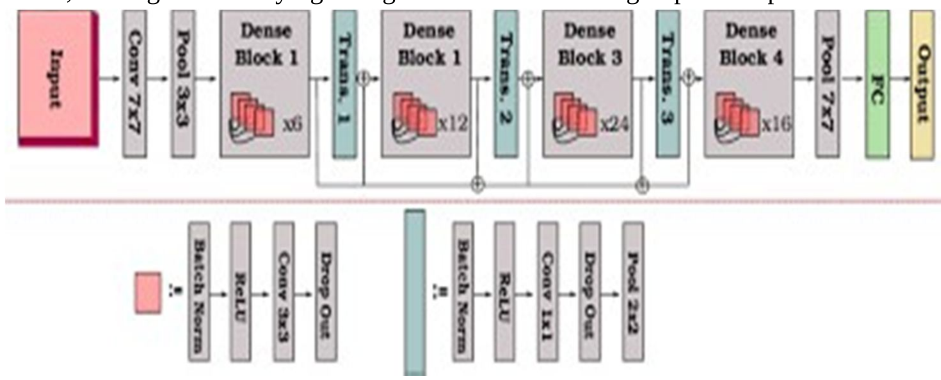

Fig. 4 DenseNet 121 Architecture

4) Hybrid Model

Hybrid Model that combines EfficientNet-B0 and ResNet-50. EfficientNet-B0 is known for its compound scaling method, which balances the depth, width, and resolution of the network, resulting in improved efficiency and accuracy while using fewer parameters. This model excels at optimizing performance on various image classification tasks. When paired with ResNet-50, which provides robust feature extraction through its residual connections, the hybrid model achieves an optimal balance between computational efficiency and classification accuracy. The use of EfficientNet-based models has shown remarkable results, as highlighted by Suveer Sharma et al. [2].

5) InceptionV3

Inception V3 is a powerful deep learning model that utilizes inception modules to perform convolutions with multiple filters of different sizes in parallel. This architecture captures various features of the input images effectively. With around 24 million parameters, Inception V3 is optimized for both speed and accuracy, allowing for quick inference times while maintaining high classification performance. It incorporates advanced techniques, such as factorized convolutions and auxiliary classifiers, to mitigate overfitting and enhance learning. This makes Inception V3 particularly suitable for large-scale image classification tasks, including waste management applications, where quick and accurate identification of waste types is crucial.

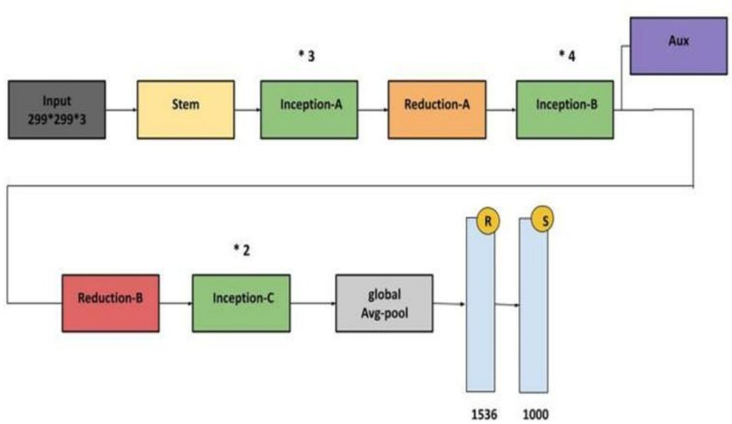

Fig. 5 Inception V3 Architecture

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Volume 13 Issue III Mar 2025- Available at www.ijraset.com

B. Dataset used

For this project, I personally collected and filtered data from various sources, primarily Google Images and Dreamstime.com. The dataset consists of approximately 9,000+ images, categorized into 10 distinct classes of waste materials: light bulbs, paper, plastic, organic waste, glass, batteries, clothes, metal, e-waste, and medical waste. These categories represent common waste types that are used for recycling purposes. Each class has a sufficient number of images to ensure a robust training process for the model. This dataset forms the foundation for building an efficient classification system to help identify and suggest proper recycling methods for different types of waste.

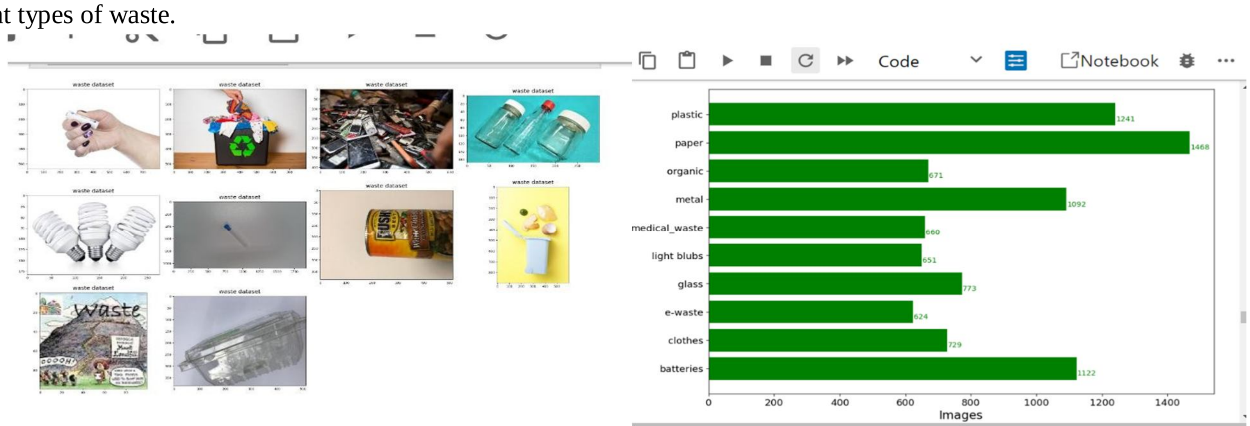

Fig. 6 Insights of Dataset

C. Evaluation Parameter

For this project, multiple deep learning algorithms were evaluated based on their performance in classifying waste images. The models tested include RestNET50, DenseNet121, VGG16, InceptionV3, and a hybrid model combining EfficientNetB0 and ResNET50. Each model was trained for a different number of epochs, and the accuracy achieved by each was recorded.

TABLE II COMPARISON OF MODELS

NAME	NO. OF EPOCHES	ACCURACY
ResNet50	9	15%
DenseNet121	29	87%
Vgg-16	28	69%
InceptionV3	20	90%
Hybrid(efficientNetB0 & ResNet50)	11	37%

InceptionV3 provided the highest accuracy with fewer epochs, it was selected as the final model for the waste classification system, ensuring better performance and efficiency in identifying the 10 waste categories.

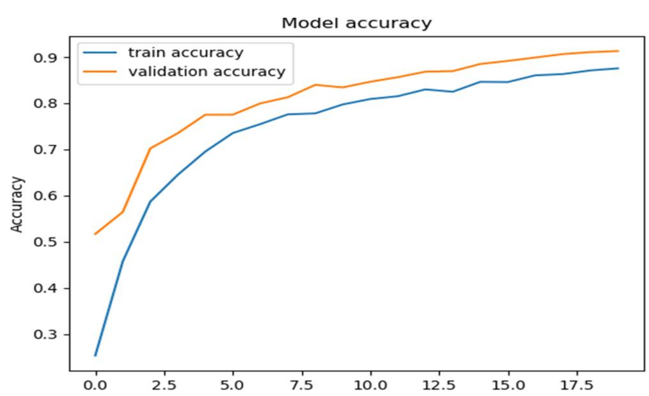

Fig. 7 Accuracy graph

D. Hardware used

1) Processor: Intel Core i7 (or equivalent), ensuring high-speed computation for deep learning model training and testing.
2) RAM: 16 GB, providing sufficient memory to handle large datasets and run multiple processes simultaneously.
3) Storage: 512 GB SSD for faster data access and read/write speeds, ensuring smooth handling of the 9000+ image dataset.
4) Operating System: Windows 10 (or Ubuntu 20.04), offering a stable environment for development and execution of the project.

E. Software used

1) Python: The core programming language used for implementing machine learning models, data preprocessing, and evaluation.
2) TensorFlow/Keras: Deep learning frameworks used for building, training, and testing the CNN models, including InceptionV3, DenseNet121, VGG16, and others.
3) Jupyter Notebook: Used for coding, experimenting with models, and visualizing results during the development phase.
4) Flask (Python Backend): Flask was used to develop the backend of the application, handling image classification requests, complaint submissions, and data processing.
5) HTML, CSS, JavaScript: The frontend was built using standard web technologies to ensure a responsive and user-friendly experience. CSS animations and UI enhancements were added for better engagement.
6) Database (JSON-based storage): Complaints and NGO contacts are stored and managed in a structured format to ensure easy retrieval and updates.
7) Video Embedding: The app integrates videos on recycling techniques, helping users learn how to process waste effectively.

VI. IMPLEMENTATION AND RESULTS

The following images demonstrate the implementation of various features of the EnviroSmart project. Each section showcases the functionality implemented:

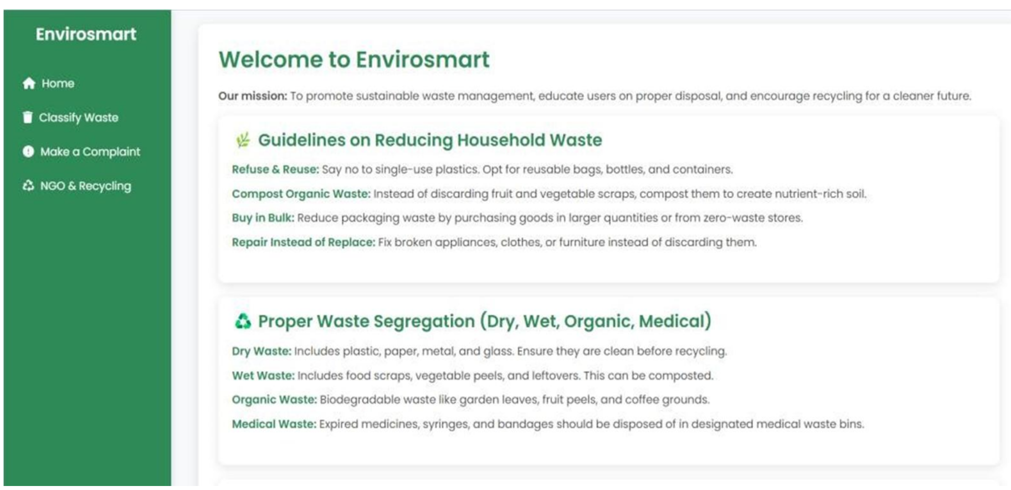

Fig. 8 Homepage Awareness Section

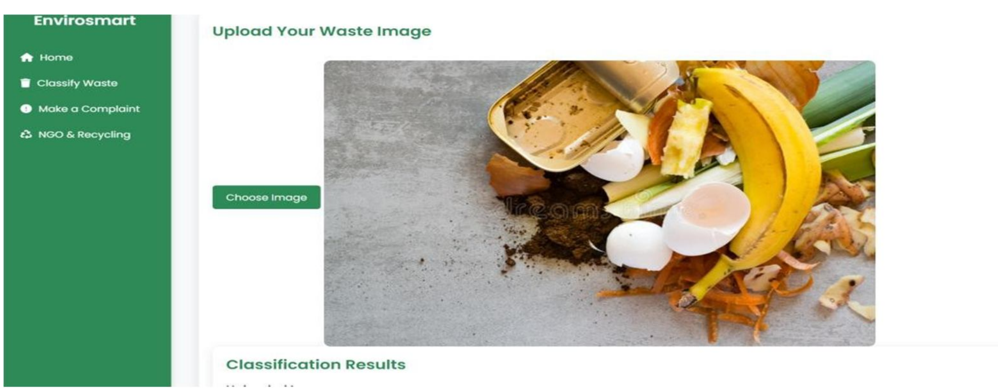

Fig. 8 Waste Classification System: uploading your image

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Fig. 9 Screenshot showing an image being classified as organic

Fig. 10 Complaint Submission Form

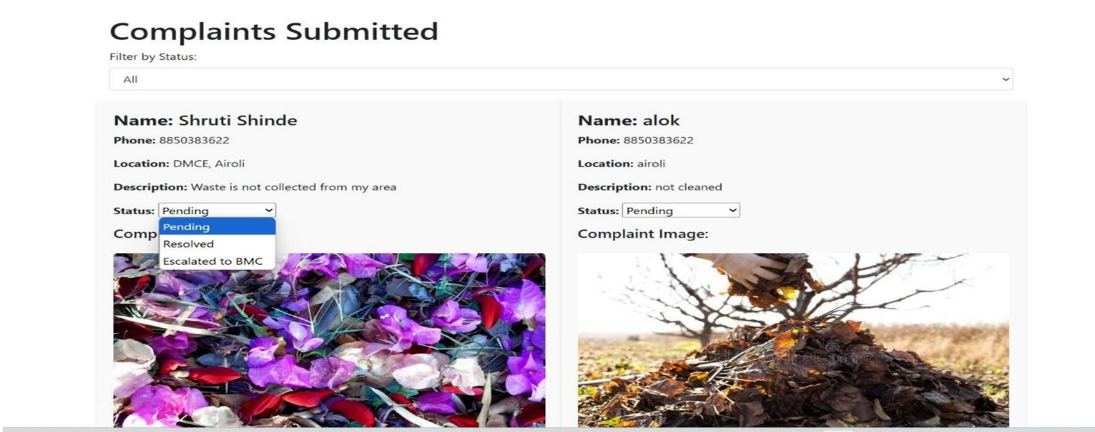

Fig. 11 Submitted complaints and their status

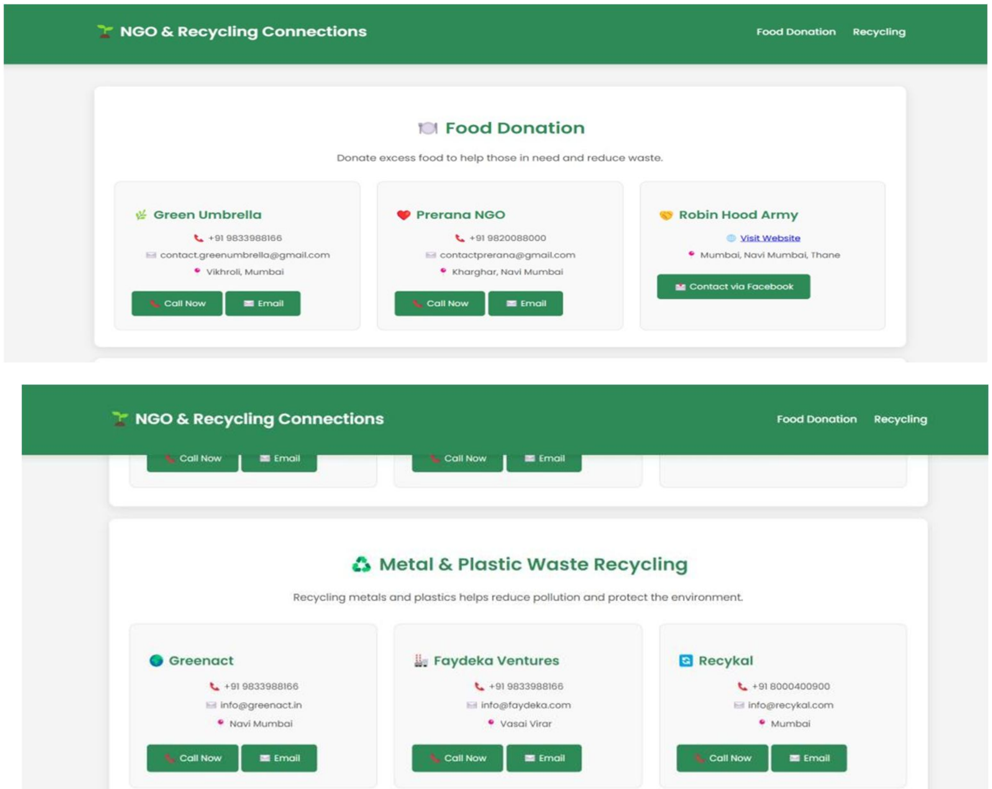

Fig. 11 contact information of NGO for organic waste & Recycling waste

VII. CONCLUSION

EnviroSmart is a smart waste management solution that simplifies waste classification, complaint filing, and recycling facilitation through technology. The AI-powered classification system accurately identifies waste as organic, recyclable, or hazardous, enabling proper disposal. Users can also report waste-related issues directly through the app, helping authorities take necessary action. Additionally, the NGO and recycling network ensure that reusable materials like food, plastic, and metal are redirected for better use rather than being discarded. To further promote sustainability, the platform integrates educational videos and awareness resources, providing users with practical knowledge about waste segregation and environmental impact. The homepage reinforces responsible waste management by offering essential guidelines. By combining technology and awareness, EnviroSmart encourages individuals to take an active role in reducing waste mismanagement. Future enhancements, such as real-time waste tracking and AI-based waste reduction strategies, can further strengthen its impact, contributing to a greener and more eco-conscious society.

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