Eco Sort: AI-Driven Waste Segregation System

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***Abstract*— An important environmental problem is waste mishandling, which calls for effective and automated segregation systems. An AI-driven garbage segregation system that uses deep learning and image processing techniques to separate waste into biodegradable and non-biodegradable categories is shown in this research. To achieve precise categorization based on visual cues, a Convolutional Neural Network (CNN) is trained on a variety of trash datasets. The system processes garbage photos using OpenCV to ensure accurate identification. Under many circumstances, image preprocessing methods like scaling and normalization improve model performance. Over time, the algorithm learns from new trash data, increasing the accuracy of its classifications. Effective trash disposal management is also made possible by a real-time monitoring tool that keeps track of the amount of waste in bins and updates users through an interactive interface. By integrating cloud storage, waste management authorities may access and analyze data remotely, which helps them make better decisions. Deep learning, automation, and real-time monitoring are all combined in this system to improve trash management effectiveness, encourage recycling, and support environmental sustainability.**

***Keywords*— Deep Learning, Image Processing, Convolutional Neural Network (CNN), OpenCV, Waste Classification and Artificial Intelligence.**

I. INTRODUCTION

Sustainable development, resource conservation, and the reduction of environmental degradation are intrinsically linked to efficient waste management practices. Waste segregation, particularly the classification of materials as biodegradable or non-biodegradable, plays a pivotal role in this process. Proper segregation enables more effective recycling, disposal, and repurposing of materials, which ultimately helps mitigate the environmental impacts of waste accumulation, reduces landfill space, and contributes to the overall circular economy [6]. However, despite its importance, traditional waste management methods are often inefficient, costly, and labor-intensive. The manual sorting of waste is not only time-consuming but also prone to errors, leading to contamination and significant inefficiencies in recycling operations [9][7]. This issue is exacerbated in urban areas, where the sheer volume of waste generated daily puts considerable pressure on municipal systems. As the global population continues to rise, the demand for more efficient and scalable waste management solutions becomes even more critical. In response to these challenges, the application of advanced technologies such as automation, artificial intelligence (AI), and machine learning offers promising avenues for improving waste segregation processes. These technologies enable faster, more accurate classification of waste materials, reducing the need for human intervention and minimizing the errors associated with manual sorting [8][5]. AI-based approaches, such as Convolutional Neural Networks (CNNs), have been particularly effective in automating the detection and categorization of waste materials by analyzing images captured by cameras and sensors. These systems can differentiate between biodegradable and non-biodegradable waste with a high degree of accuracy, even in complex real-world environments where waste objects may vary in size, shape, and composition [1][3]. CNN models, specifically trained on large datasets of waste images, learn to identify key features and patterns that distinguish between different categories of waste, thus improving the overall efficiency and precision of the segregation process [10]. Moreover, image processing techniques such as normalization, downsizing, and enhancement further refine the performance of these models, ensuring that they remain robust under various lighting conditions, waste textures, and backgrounds [9]. Beyond the initial classification, the integration of Internet of Things (IoT) devices in smart waste management systems provides real-time monitoring and data analysis capabilities that are essential for optimizing waste collection and disposal strategies. IoT sensors placed in waste bins can detect the fill levels of containers, triggering alerts when they need to be emptied. This allows for more efficient scheduling of waste collection services, reducing unnecessary trips and minimizing the operational costs of waste management [7][5]. The data gathered from these IoT-enabled systems can be transmitted to cloud-based platforms, where it can be analyzed and used to inform decisions about waste disposal, recycling, and resource allocation [4]. Additionally, cloud analytics can offer valuable insights into waste generation patterns, helping municipalities and businesses adjust their waste management strategies to align with sustainable goals [2]. This real-time data also contributes to the broader objectives of smart city initiatives, where integrated technologies improve the efficiency of urban systems, including waste management, energy use, and transportation [4]. By adopting automated waste segregation systems within the framework of smart cities, municipalities can not only enhance the accuracy and speed of waste classification but also foster more sustainable urban environments. Such systems can help reduce landfill usage, promote recycling and composting, and ultimately lower carbon emissions [5][8].

II. METHODOLOGY

To effectively classify waste, the automated waste segregation system combines deep learning, image processing, and Internet of Things-enabled monitoring. Resizing and normalization techniques are used to preprocess a collection of photographs of rubbish that are both biodegradable and non-biodegradable. Using this dataset, a Convolutional Neural Network (CNN) is trained to reliably detect waste, with adjustments made to enhance performance and avoid overfitting. The CNN model is used to classify waste photos after they are taken with a camera and processed with OpenCV. When bins fill up, IoT-enabled data transmission to a cloud platform allows for remote tracking and warning generation. By continuously learning from fresh data, the system increases the accuracy of its classifications. Metrics for accuracy, recall, and precision are used to assess performance. The solution improves garbage segregation, lowers manual labor, and encourages sustainable waste management by fusing AI-driven classification with real-time monitoring.

1.Workflow

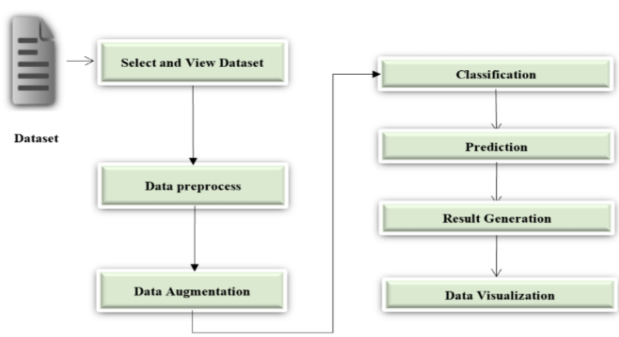

Fig .1.Block Diagram

- **Select and View Dataset** – The dataset consists of images of biodegradable and non-biodegradable waste. These images are collected and loaded into the system for processing.
- **Data Preprocessing** – The raw images undergo preprocessing steps like resizing, noise reduction, and normalization to ensure consistency in the dataset. This step enhances the model's ability to learn effectively.
- **Data Augmentation** – Techniques such as rotation, flipping, brightness adjustment, and contrast enhancement are applied to artificially expand the dataset. This helps improve the model's accuracy and robustness.
- **Classification** – A machine learning model, such as a Convolutional Neural Network (CNN), is used to classify waste images into biodegradable or non-biodegradable categories based on their features.
- **Prediction** – Once trained, the model predicts the waste category for new input images by analyzing their features and comparing them with learned patterns.
- **Result Generation** – The system processes the predictions and generates classification results, showing whether an image belongs to the biodegradable or non-biodegradable category.
- **Data Visualization** – The final results are displayed using graphical tools like charts and confusion matrices, helping users analyze model performance and accuracy effectively.

2. Data Description

Images from two primary classes—biodegradable and non-biodegradable rubbish—make up the dataset for this waste segregation research. Biodegradable trash comprises naturally decomposing organic materials, including wood in the form of logs and twigs, paper goods like cardboard and newspapers, leaves, and food waste like bread and vegetable peels. Non-biodegradable garbage, on the other hand, is made up of materials that are difficult to decompose, such as plastic waste (such as bottles and bags), electronic waste (such as circuit boards and cell phones), metal waste (such as aluminum cans), and glass debris (such as broken bottles). The collection is organized into two folders, BIO (Biodegradable) and NONBIO (Non-Biodegradable), each of which has several photos of various garbage types taken from different perspectives and under varying lighting circumstances to enhance the model's precision and resilience.

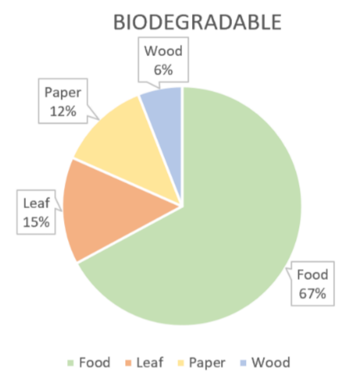

Fig .2. Image distribution between biodegradable class

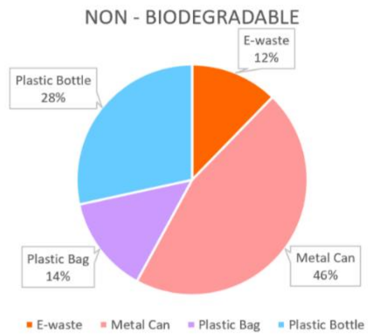

Fig .3. Image distribution between non-biodegradable class

Figure 1 illustrates the distribution of biodegradable waste class and its subclasses including wood, paper, food waste, and leaves. These materials decompose naturally and contribute to sustainable waste management. Figure 2 represents the distribution of non-biodegradable waste class and its subclasses such as plastic bags, plastic bottles, metal cans, and e-waste.2. Image Processing

III. RESULTS AND DISCUSSION

The Eco Sort Waste Segregation System automates the process of classifying and segregating waste using image recognition and machine learning. It integrates TensorFlow for waste classification, OpenCV for real-time image capture and pre-processing, and Blynk IoT for remote monitoring. Below is the detailed explanation of its working principle:

1. Setup and Installation

Library Installation:

- Install necessary libraries:
  - Tensor flow: For building and running the machine learning model.
  - Open cv-python: For capturing and processing images in real time.
- Use Jupyter Notebook for training the model and *Spyder IDE* for running the real-time detection script (Detection.py).

2. Data Preparation

Dataset Collection:

- Gather a dataset of images representing different waste types, such as plastic, metal, and paper.
- Label each image and divide the dataset into training, validation, and testing sets for model robustness.

Dataset Validation:

- Validate and clean the dataset by removing corrupted images to ensure high-quality data for training.

3. Model Training (Jupyter Notebook)

Pre-processing:

- Resize all images to a uniform size of 150x150 pixels and normalize pixel values to a scale of 0 to 1.

Training the CNN:

- Train a *Convolutional Neural Network (CNN)* using TensorFlow:
  - Input: Preprocessed images of waste.
  - Output: Predicted waste category (e.g., biodegradable or non-biodegradable).

Saving the Model:

- Save the trained model (`cnn_model.h5`) for integration into the real-time detection pipeline.

Visualization:

- Visualize batches of training and validation images to confirm the pre-processing steps and check data consistency.

4. Real-Time Detection (Spyder with OpenCV)

Integration with Trained Model:

- Load the trained CNN model into Spyder to classify waste in real time.

Webcam Integration:

- Use OpenCV to capture live images of waste through a camera.

Image Pre-processing:

- Resize and normalize each frame to match the input requirements of the CNN model.

Prediction and Classification:

- The model predicts the category of waste for each frame. Results include:
  - Predicted class (e.g., biodegradable or non-biodegradable).
  - Confidence score of the prediction.

Fig .4. Sample images

Output Display:

- Overlays the class label and confidence score on the live video feed.
- Displays bounding boxes for a clear visual representation of the detected waste.

5. IoT Integration with Blynk

Sending Data to Blynk:

- Integrate with Blynk IoT to send the detected waste category to the cloud in real time using API calls.
- Enables remote monitoring and tracking of waste segregation data.

Feedback on Detection:

- The system confirms successful data transmission to Blynk or alerts if there is an error.

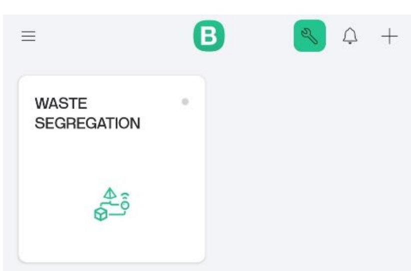

Fig .6. Predicted Output from IOT

6. File Structure

Jupyter Notebook:

- Used for training the model (Waste Segregation Detection.ipynb) and saving the trained model.

Spyder Script (Detection.py**):**

- Combines TensorFlow and OpenCV for real-time waste detection and IoT integration.

Supporting Files:

- Include the saved model (cnn_model.h5), utility scripts for image preprocessing, and a label map for category identification.

7. Execution

Running the System:

- Open and execute Waste Segregation Detection.ipynb in Jupyter Notebook to train the model.
- Switch to Spyder IDE and run `Detection.py` for real-time detection.
- The system begins capturing live images, processes them, predicts the waste category, and displays the results on the live video feed with labels and confidence scores.

This comprehensive system ensures efficient, automated waste segregation using AI, real-time detection with OpenCV, and IoT integration for remote monitoring and data visualization.

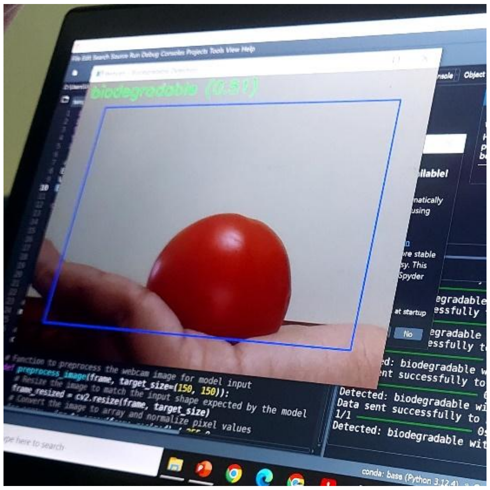

Fig .7. Predicted Output for biodegradable

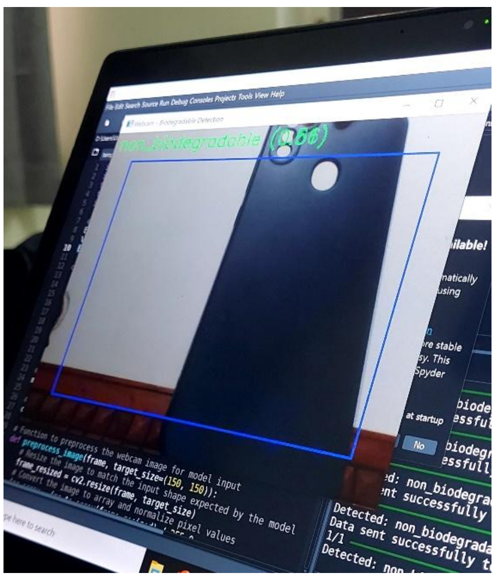

Fig .8. Predicted Output for non-biodegradable

The automated waste segregation system successfully classifies waste into biodegradable and non-biodegradable categories using deep learning and image processing techniques. As shown in the Figure 7, the system correctly identifies a plastic phone case as non-biodegradable with a confidence score of 0.56, and as Shown in Figure 8, the system correctly identifies a tomato as biodegradable with a confidence score of 0.51. The real-time classification is performed using a Convolutional Neural Network (CNN), which processes live images captured from a camera. The system effectively detects waste objects and overlays classification results on the screen, enhancing visualization for users.

IV. CONCLUSION

The automated waste segregation system that makes use of computer vision and deep learning greatly improves waste categorization efficiency and accuracy. The system efficiently separates garbage into biodegradable and non-biodegradable groups by utilizing a Convolutional Neural Network (CNN) model, which minimizes manual labor and enhances waste management procedures. Reliable predictions are ensured by further optimizing model performance through data pretreatment and augmentation strategies. Furthermore, data visualization and real-time monitoring aid in the analysis of system efficiency. By encouraging recycling, lowering landfill waste, and limiting environmental effect, this project supports sustainable waste management. Intelligent waste management solutions for homes, businesses, and municipalities are made possible by the use of AI-driven automation in garbage segregation. Future developments can concentrate on growing the dataset to increase classification accuracy across various trash categories and including IoT sensors for real-time waste tracking.

V. REFERENCES

[1] P Ganesh and K Haridas, "Deep Learning Approach In Separation Of Biodegradable And Non-biodegradable and waste using Faster RCNN", The Indian Journal Of Technical Education Special Issue, June 2023.

[2] “Waste Segregator and Monitoring System using SVM” M. Talha, A. Upadhyayin 2021 International Conference on Multimedia, Signal Processing and Communication Technologies (IMPACT). IEEE, 2021, pp. 175–179.

[3] M. -H. Huynh, P. -T. Pham-Hoai, A. -K. Tran and T. -D. Nguyen, "Automated Waste Sorting Using Convolutional Neural Network," 2020 7th NAFOSTED Conference on Information and Computer Science (NICS), Ho Chi Minh City, Vietnam, 2020, pp. 102-107, doi: 10.1109/NICS51282.2020.9335897.

[4] Asyikin, Arifin N., and Aulia A. Syahidi Subandi. "Design and Implementation of Different Types of Smart Dustbins System in Smart Campus Environments." In International Joint Conference on Science and Engineering (IJCSE 2020), pp. 1-7. Atlantis Press, 2020.

[5] IoT based Waste Collection System using Infrared Sensors H. Poddar, R. Paul, S. Mukherjee, and B. Bhattacharyya, in 2017 Innovations in Power and Advanced Computing Technologies (i-PACT). IEEE, 2019, pp. 1–6.

[6] N. Ferronato and V. Torretta, "Waste mismanagement in developing countries: A review of global issues", International journal of environmental research and public health, vol. 16, no. 6, pp. 1060, 2019

[7] Automatic Waste Segregator and Monitoring System S. Murugaanandam, V. Ganapathy, and R. Balaji, “Efficient IOT based smart bin for clean environment,” in 2021 International Conference on

Communication and Signal Processing (ICCSP). IEEE, 2018, pp. 0715–0720.

[8] Adaptive and Interactive Modelling System (AIMS) D. D. Vu and G. Kaddoum, “A waste city management system for smart cities applications,” in 2019 Advances in Wireless and Optical Communications (RTUWO). IEEE, 2019, pp. 225–229.

[9] Haruna Abdu and Mohd Halim Mohd Noor, "A Survey on Waste Detection and Classification Using Deep Learning", publish in IEEE Access, december 2022.

[10] Shanshan Meng and Wei-Ta. Chu, "A Study of Garbage Classification with Convolutional Neural Networks", 2020 Indo – Taiwan 2nd International Conference on Computing Analytics and Networks (Indo-Taiwan ICAN), pp. 152-157, 2020.