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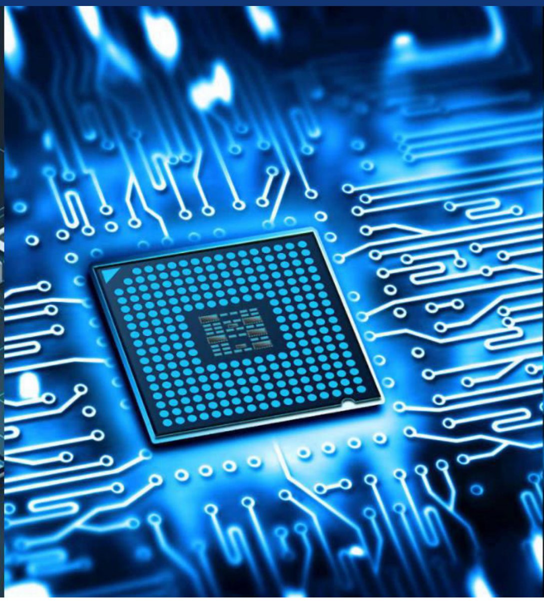


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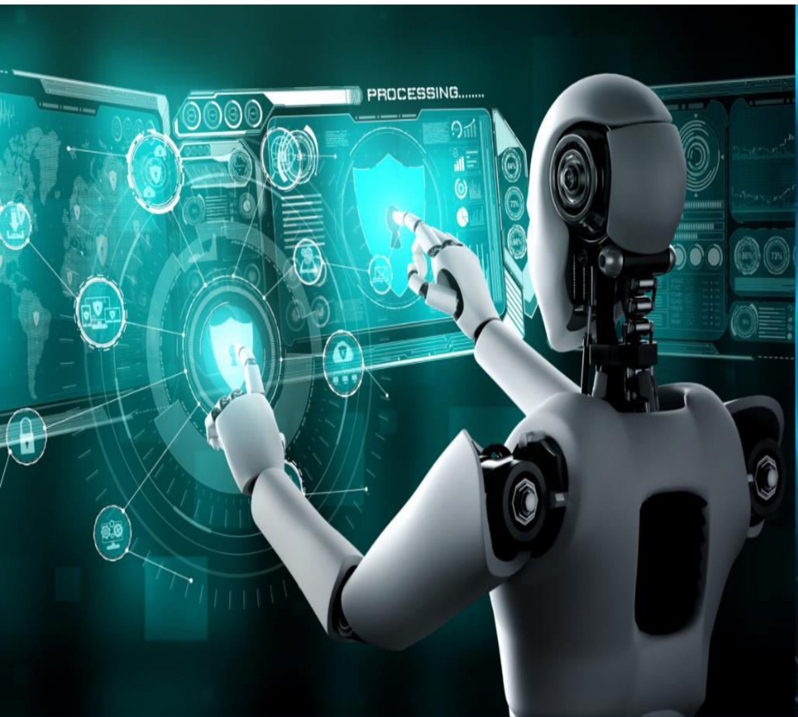

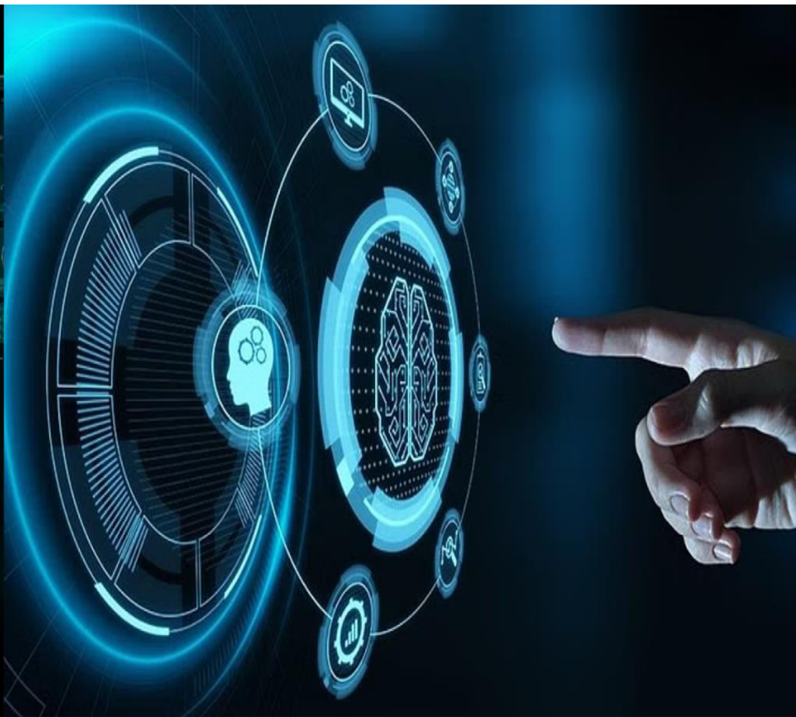

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A Critical Review on Recyclable Waste Classification Using AI Models

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ABSTRACT: This study presents an AI-powered waste classification system using YOLOv8 to enhance recycling efficiency. The system classifies recyclable materials like cardboard, glass, metal, paper, and plastic in real time. A MySQL database is used for data storage and visualization, while a Tkinter-based GUI enables user interaction. Compared to traditional methods, the proposed system offers improved scalability, faster detection, and higher accuracy. Real-time data analysis helps optimize waste management. Future improvements include dataset expansion, IoT sensor integration, and addressing real-world challenges such as mixed waste environments and varying lighting conditions, making waste management more efficient and environmentally friendly.

KEYWORDS: Automated Waste Classification, YOLOv8, Deep Learning, Real-Time Detection, Recycling Efficiency.

I. INTRODUCTION

Growing populations, industrialization, and economic growth have all contributed to globalization and increased demand for natural resources. An worrisome rise in trash output has coincided with this increased resource usage. A substantial quantity of rubbish in the city continues to be unlawfully disposed of, mostly by burning and landfilling. The health of locals as well as urban ecosystems are seriously threatened by this constant flow of pollution. Notably, a sizable amount of this waste is made up of domestic trash, and the breakdown of some of this trash might result in the buildup of dangerous substances in the environment, increasing ecological concerns. Furthermore, as evidenced by the widespread plastic pollution, some household waste materials have limited biodegradability. seen in underwater environments all around the world.

A third of the waste produced worldwide is not effectively sorted or managed, which leads to significant environmental contamination and a serious danger to sustainable development. The Environmental Protection Agency (EPA) has stressed the importance of reprocessing municipal solid waste (MSW) as an environmentally responsible waste management method in response to these growing environmental issues. In fact, 2.01 billion tons of municipal solid trash were produced worldwide in 2016, and estimates suggest that this amount will rise to 2.59 billion tons by 2030. There has never been a greater need for effective waste management practices to reduce environmental effects and ensure the growth of sustainable communities.

II. RELATED WORK

Growing urbanization and industrialization have made waste management a major global concern. Conventional trash segregation techniques are ineffective, time-consuming, and prone to mistakes. Potential remedies include automated garbage classification systems that make use of IoT and machine learning technologies. Current research places a strong emphasis on using machine learning algorithms to precisely identify recyclable materials. These systems seek to decrease human intervention, increase the effectiveness of waste management, and encourage sustainable habits.

Deep Learning Architectures in Waste Classification

Convolutional Neural Networks (CNNs), a type of deep learning, have demonstrated impressive performance in image categorization tasks. Research demonstrates how architectures such as ResNet, Inception, and VGGNet may be used to classify garbage with high accuracy across a range of datasets. Utilizing pre-trained models to improve performance on

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domain-specific datasets and conserve computational resources, transfer learning has gained widespread adoption. For edge deployment, lightweight architectures that strike a compromise between accuracy and efficiency, like MobileNet and EfficientNet, have shown promise. But there are still a lot of obstacles to overcome, such the requirement for big labeled datasets and processing capacity.

Datasets for Waste Classification

Waste classification algorithms have been trained and evaluated in large part using publicly accessible datasets such as TrashNet. Cardboard, glass, metal, paper, plastic, and garbage are the six waste categories that make up TrashNet. Notwithstanding its value, the dataset's small size and lack of diversity make data augmentation and synthetic data generation methods necessary to enhance model generalization.

Integration with IoT and Real-Time Systems

Waste classification systems enabled by the Internet of Things are becoming more popular, especially in automated sorting stations and smart bins. Lightweight models can be deployed on edge devices, allowing for real-time categorization with low latency, according to research. These systems automatically recognize and separate waste by using sensors, cameras, and deep learning algorithms.

III. RESEARCH METHODOLOGY

In order to guarantee a methodical and efficient approach, the research methodology for this study on recyclable garbage classification using AI models entails several crucial elements. First, the issue of ineffective manual garbage sorting is noted, emphasising the necessity of automation based on artificial intelligence. The limitations of current AI models employed in trash classification, such as CNNs and YOLO, are then examined through a thorough literature analysis. In order to improve model performance, a dataset of photos of recyclable and non-recyclable rubbish is then gathered and preprocessed using methods such data augmentation, normalisation, and scaling.To increase accuracy, the chosen AI models are trained and optimised on the dataset by modifying hyperparameters. Using criteria like accuracy, precision, recall, F1 score, and IoU, the models' performance is assessed. Python is used to provide a graphical user interface (GUI) and an admin dashboard for managing and visualising classification data in order to make the system easier to use.

The performance of the AI-based system is compared with current waste categorisation techniques in order to analyse and validate the results. Then, conclusions and suggestions for additional improvements are made in order to increase the system's efficiency and real-world implementation.Analysing the results and talking about the difficulties encountered while using AI models for garbage classification constitute the last stage of the study. The drawbacks are noted and fixed, including inaccurate predictions brought on by overlapping objects, low image quality, and background noise. Additionally, the usefulness of implementing the AI-based trash classification system in actual settings—like recycling facilities or municipal waste management facilities—is investigated. To increase the system's overall efficacy and scalability, suggestions are made for future enhancements, such as expanding the dataset, adding real-time detection, and maximising computational efficiency.

3.1 SYSTEM ARCHITECTURE

The figure 3.1 it represents to the AI-powered waste classification system is structured with multiple integrated components to enhance sorting efficiency. At its core, the system employs the YOLOv8 deep learning model for real-time object detection and classification of recyclable materials such as cardboard, glass, metal, paper, and plastic. A camera captures images of waste items, which are then processed by the YOLOv8 model to identify and categorize them accurately. The classified data is stored in a MySQL database, enabling efficient record-keeping and visualization of waste management trends. A Tkinter-based graphical user interface (GUI) facilitates user interaction, displaying classification results and analytics. Additionally, real-time data analysis optimizes waste management by providing insights for better decision-making. Future enhancements include the integration of IoT sensors for automated waste detection, expansion of the dataset for improved accuracy, and addressing real-world challenges such as mixed waste environments and variable lighting conditions.

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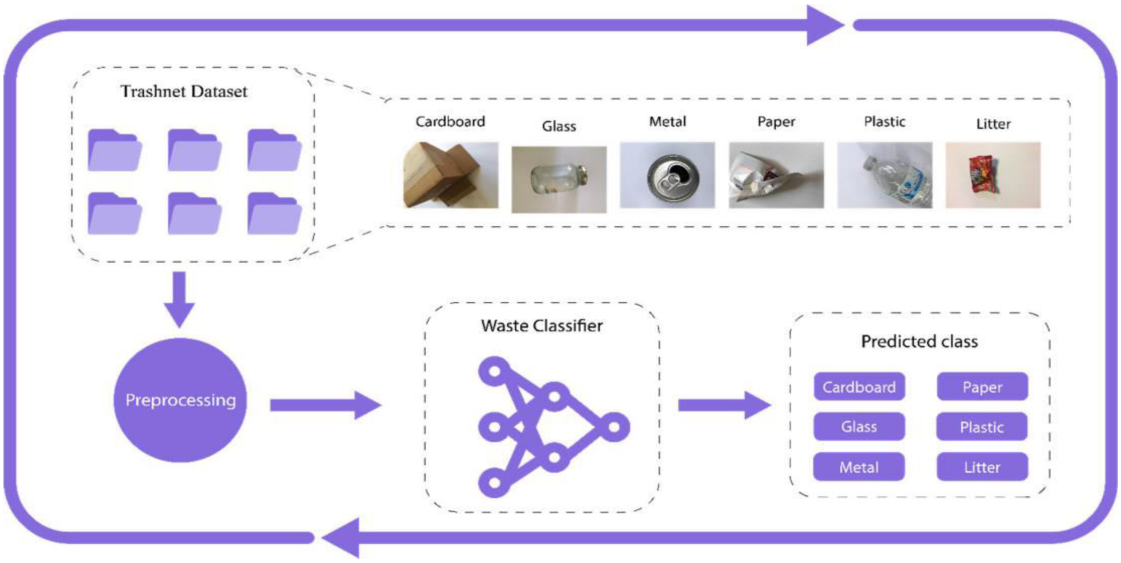

FIGURE 3.1.`:SYSTEM ARCHITECTURE

3.2 MODULES

User module

The **User Module** allows users to upload images of waste along with location details. However, displaying the exact location on a map requires latitude and longitude values, which cannot be obtained without dedicated tracking sensors or GPS-enabled devices. Due to this limitation, the system cannot integrate map-based location visualization. Instead, users manually provide location details when submitting waste images.

Waste collector module

The **Waste Collector Module** enables waste collectors to upload videos, which the system processes as if captured in real time from a webcam or drone. The video player continuously scans frames to detect patterns and match them with previously uploaded waste images. If a match is found, the system highlights the detected waste using bounding boxes and alerts the waste collector. This real-time identification helps collectors efficiently locate and manage waste, improving the overall waste collection process.

3.3. Equations

Accuracy Calculation:
Accuracy=TP+TNTP+TN+FP+FN
Accuracy=TP+TN+FP+FNTP+TN
Where:

- **TP** = True Positives
- **TN** = True Negatives
- **FP** = False Positives″
- **FN** = False Negatives

False Positives (FP), False Negatives (FN), True Positives (TP), and True Negatives (TN) are important metrics used to assess how well artificial intelligence categorisation algorithms perform. When the model successfully classifies an item as falling into a specific category, like correctly detecting a recyclable plastic bottle, this is known as a True Positive (TP). When the model accurately determines that an item does not fall into the target category, such as when it correctly classifies food waste as non-recyclable, this is known as a True Negative (TN). False Positives (FP), on the other hand, happen when the model misclassifies an item that isn't recyclable as recyclable, which causes mistakes in the sorting process. Missed recycling possibilities originate from False Negatives (FN), which occur when the model is unable to detect a recyclable item.

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IV. PROPOSED ALGORITHM

The TrashNet dataset, which includes the most prevalent waste types – cardboard, glass, metal, paper, plastic, and litter – is the focal point of our experiment. Our objective is to develop a robust deep learning framework that can accurately classify these waste types, thereby improving the effectiveness and efficiency of waste sorting and recycling processes. The main contributions of our work can be summarized as follows • Six different categories of waste were classified with high reliability in this study.• A novel deep learning model, recyclable waste classification (RWC-Net) is proposed to classify the wastes.• A saliency map-based visualization generated score- CAM (class activation mapping) was shown as quantitative evaluation.

ADVANTAGES

The proposed RWC-Net model for waste image classification was developed using a combination of two deep convolutional neural network (DCNN) models: DenseNet201 and MobileNet-v2. The motivation for combining them was to leverage the complementary feature extraction and learning capabilities of both networks.

V. RESULTS AND DISCCUSSION

This section discusses how well our deep learning model classified the six waste categories listed above. Both quantitative and qualitative analyses of our experimental results are part of our comprehensive review. Furthermore, we provide a comparison with some cutting-edge models that are discussed in waste management literature. As we examine our results, we also shed light on the constraints we faced during our investigation. We also talk about potential directions for further study and advancement to deal with the problem.

Models	Performance				
	Accuracy (%)	Precision (%)	Recall (%)	Specificity (%)	f1-Score (%)
GoogleNet	92.44 ± 2.31	92.53 ± 2.30	92.43 ± 2.31	98.38 ± 1.10	92.45 ± 2.31
ResNet50	93.11 ± 2.11	93.12 ± 2.21	93.11 ± 2.21	98.52 ± 1.05	93.10 ± 2.11
Inception-v3	93.19 ± 2.20	93.22 ± 2.19	93.19 ± 2.20	98.54 ± 1.05	93.17 ± 2.20
MobileNet-v2	93.50 ± 2.15	93.53 ± 2.15	93.51 ± 2.15	98.52 ± 1.05	93.49 ± 2.15
DenseNet201	94.42 ± 2.00	94.45 ± 2.00	94.42 ± 2.00	98.79 ± 0.95	94.41 ± 2.00
RWC-Net	**95.01 ± 1.90**	**95.04 ± 1.90**	**95.01 ± 1.90**	**98.88 ± 0.92**	**95.01 ± 1.90**

TABLE 5.1 The performance of different models for classifying the waste images with 95% of CI.

The table 5 1 represent RWC-Net model was created with the goal of utilising the distinct feature extraction powers of two different models, Densenet201 and Mobilenet-v2. The RWC-Net model was created as a result of this fusion, surpassing several state-of-the-art models and achieving the highest F1score of 95.01% across a range of performance parameters. Additionally, the model demonstrated remarkable precision (95.04%), recall (95.01%), and specificity (98.88%) in addition to its remarkable total accuracy of 95.01%. These outcomes show that the model is capable of correctly categorising garbage photos.

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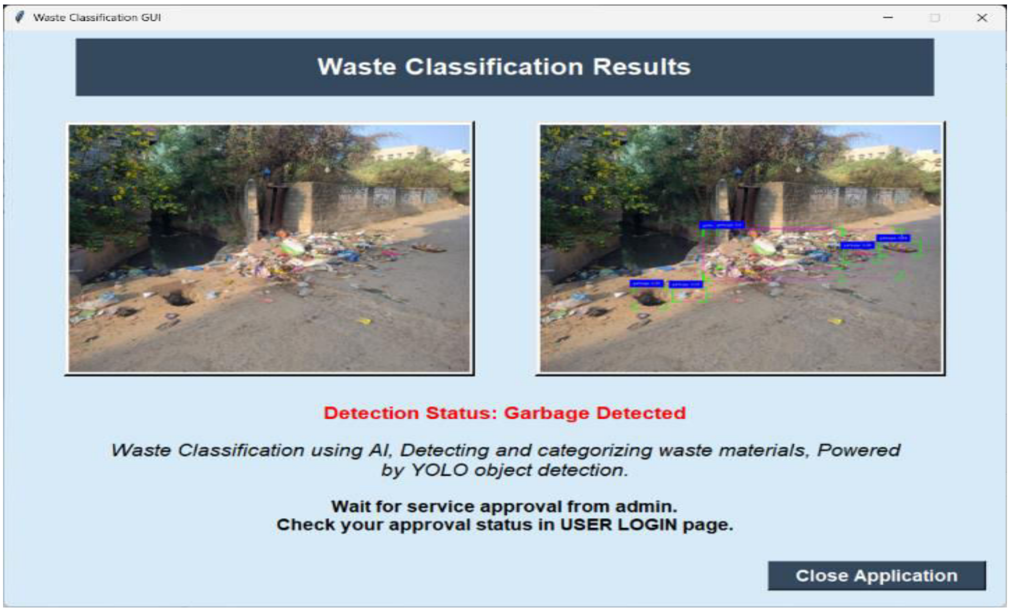
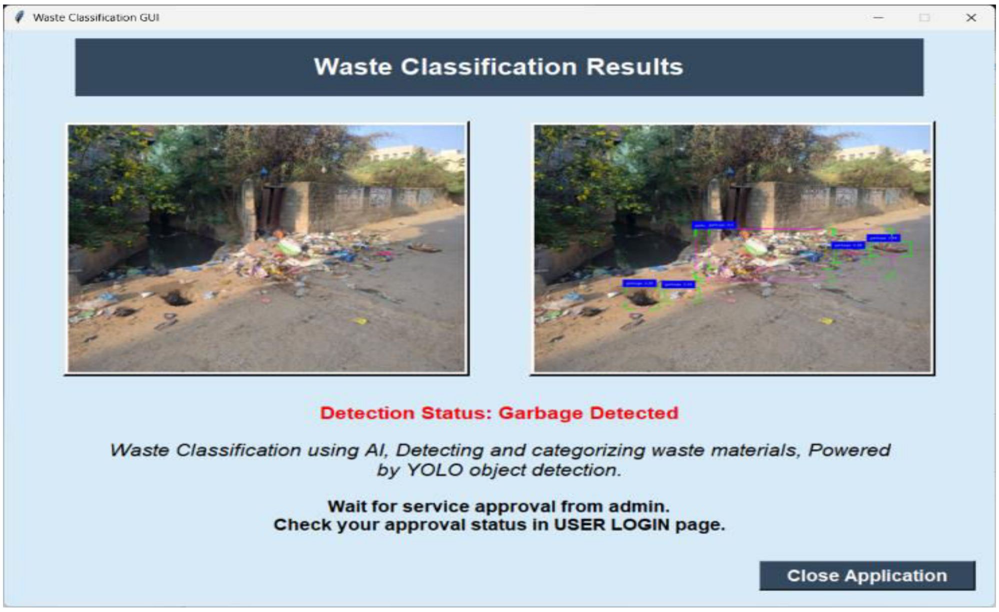
5.2 Output Screens



SCREEN 1: If there is garbage in the image it will show **Garbage detected**



SCREEN 2: - Click close application to User Dashboard

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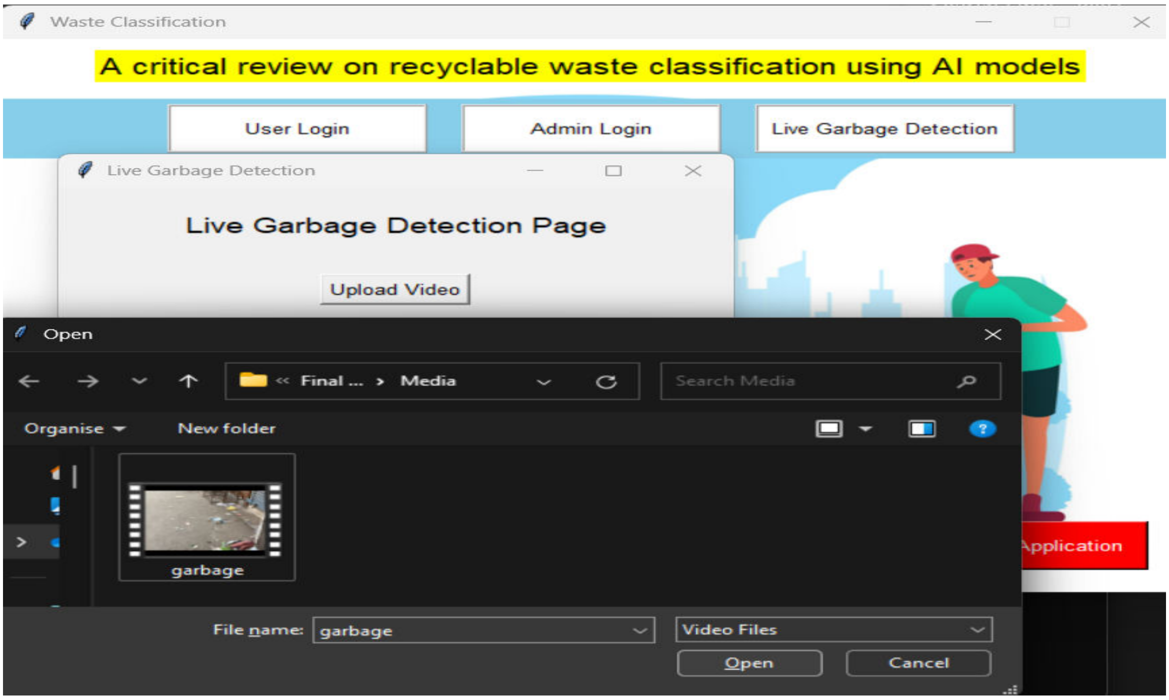
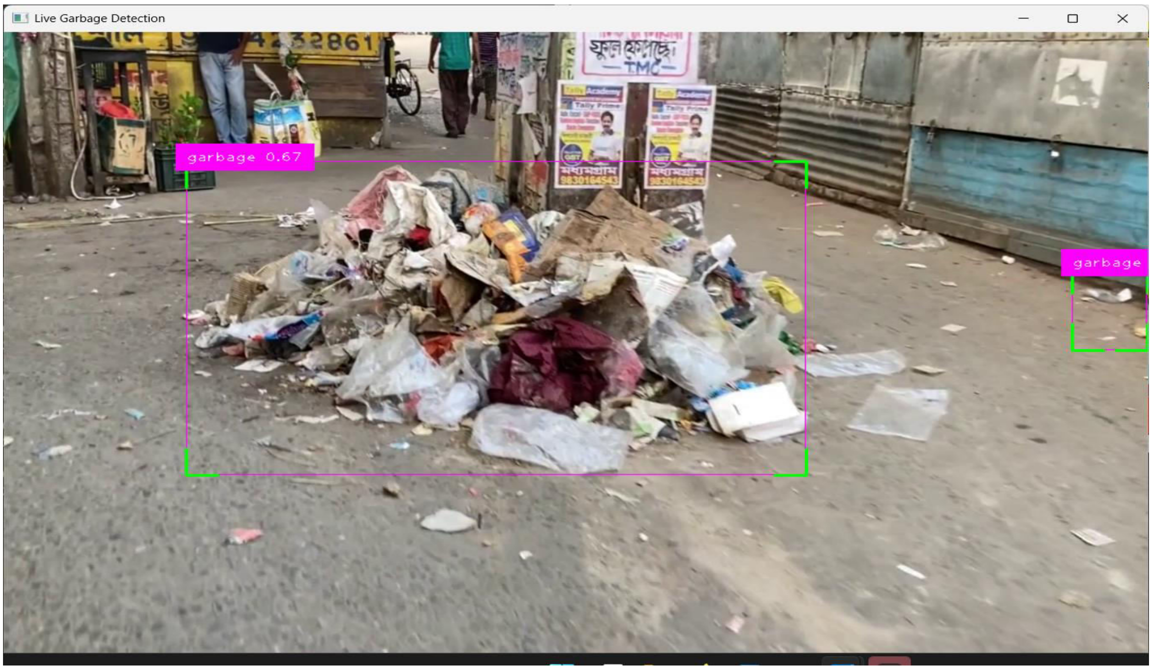


SCREEN 3: Click on Live garbage detection and submit the video path, to detect garbage in live.

SCREEN 4: Video will be playing and Garbage has detected in live



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VI. CONCLUSION AND FUTURE WORK

In this study, I developed a reliable and robust deep learning model for effective recyclable waste classification. Through extensive experimentation and evaluation, our model demonstrated high accuracy and efficiency in distinguishing various types of recyclable materials. By leveraging deep learning techniques, particularly convolutional neural networks (CNNs), our approach enhances automated waste sorting, thereby contributing to improved recycling processes and environmental sustainability. The results indicate that deep learning-based classification significantly outperforms traditional methods, offering a scalable and efficient solution for waste management systems. The robustness of our model ensures adaptability across different waste categories, making it a viable option for real-world applications. Future work can focus on optimizing the model for edge deployment, integrating multimodal data sources, and expanding the dataset to include more diverse waste types. By implementing advanced AI-driven solutions in waste classification, I can take a significant step toward a cleaner environment, reducing landfill waste and promoting a circular economy.

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[4] S. Asif earned his Bachelor's degree in Computer Science (B.Sc.) from Yogi Vemana University in 2023, where he developed a strong foundation in programming, data structures, and software development. Currently, he is pursuing a Master of Computer Applications (MCA) at Annamacharya PG College of Computer Studies, further enhancing his technical expertise and research skills. This publication marks his first contribution to the academic community, reflecting his keen interest in the intersection of technology and healthcare. Her primary research focuses on improve garbage sorting and recycling efficiency by critically analysing and using AI models for recyclable waste classification. It solves important issues, boosts accuracy, and promotes environmentally friendly waste management techniques by combining YOLO-based item identification with an intuitive graphical user interface and administrative dashboard.

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