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A CNN-Based Image Classification Model for Efficient Waste Management

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ABSTRACT :

Urban areas are facing challenges in waste management systems due to growth of population, industrialization and modernization. A huge amount of waste is producing and making difficult to classify them to recycle. This will cause huge harm to our environment. This model classifies waste into 12 categories using advanced deep learning techniques such as Convolutional Neural Networks (CNN), Transfer Learning, TensorFlow and Keras. The model was trained on a Kaggle dataset containing approximately 1,000 images for each category, including battery, biological, brown glass, cardboard, clothes, green-glass, metal, paper, plastic, shoes, trash, and white glass. This model will achieve a classification with accuracy of 95.1%, an F1-score of 96%, and a recall of 97%. By efficiently categorizing waste, this application contributes to improved recycling processes and environmental sustainability, offering a practical solution for automated waste management.

Keywords: CNN, Keras, TensorFlow, image classification, environments sustainability, waste management, Transfer Learning, Automate the waste management system, garbage categorization.

INTRODUCTION

In today's world, urbanization and industrialization have led to a significant increase in waste generation. As cities grow, so does the volume of waste, which often ends up improperly sorted, hindering effective recycling efforts. Improper waste management not only wastes valuable resources but also

harms the environment, contributing to pollution and climate change.

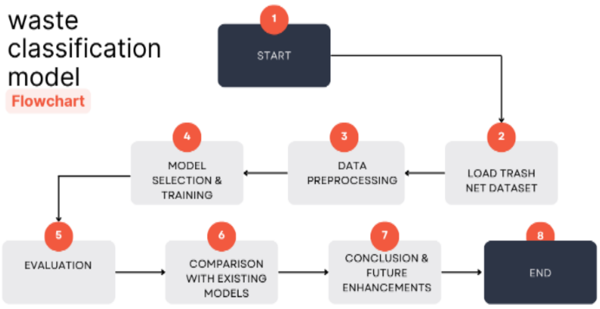
To solve this problem, this project proposes an automated waste classification system that uses advanced deep learning techniques, specifically Convolutional Neural Networks (CNNs), to classify waste more efficiently. The system will be able to sort waste into 12 categories, including paper, plastic, metal, glass, and other common items, based on images of the waste. By using a dataset with thousands of labeled images, the model will be trained to recognize and classify different types of waste with high accuracy.

The goal of this project is to provide a solution that can make the waste sorting process faster, more accurate, and more sustainable. This system can be used in waste management facilities, recycling plants, or even smart garbage bins, helping to reduce environmental harm and improve recycling efforts.

LITERATURE SURVEY

[1]. Hossen, M. M., Majid, M. E., Kashem, S. B. A., Khandakar, A., Nashbat, M., Ashraf, A., ... & Chowdhury, M. E. (2024). A reliable and robust deep learning model for effective recyclable waste classification. *IEEE Access*.

This study addresses the growing need for automated waste management by proposing RWC-Net, a novel deep learning model designed to classify waste into six categories (cardboard, glass, metal, paper, plastic, and litter) using the TrashNet dataset. The authors utilized a hybrid approach combining DenseNet201 and MobileNetV2 models, optimizing performance through auxiliary outputs. With an impressive accuracy of 95.01%, the model surpasses several state-of-the-art techniques and demonstrates robustness through qualitative visualizations like Score-CAM heatmaps. This research highlights the potential of deep learning in improving recycling efficiency and paves the way for future advancements, particularly in adapting to diverse waste management practices worldwide.



Advantages:

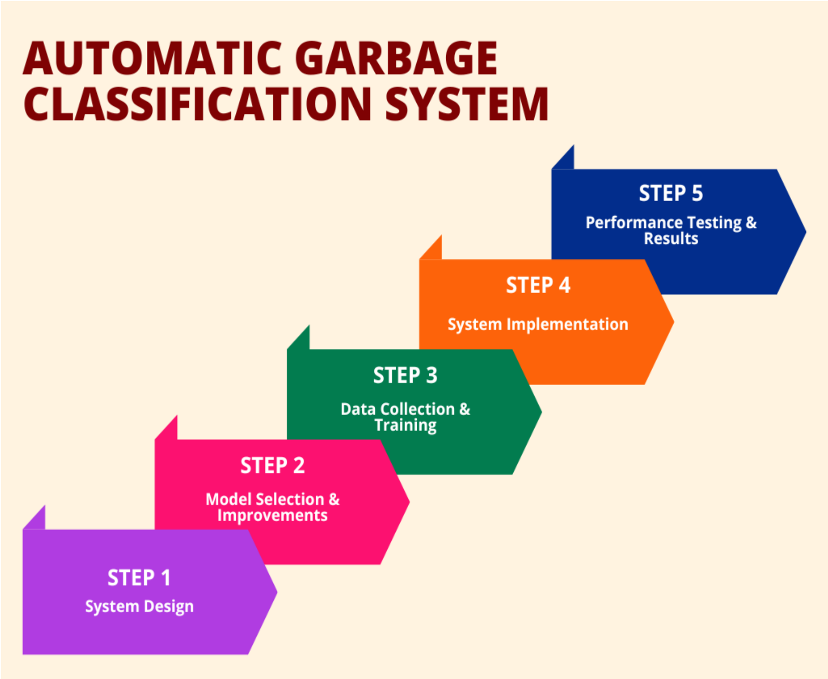
- Scalability
- Effective Use of Pretrained Models

Limitation:

- Litter Category Performance
- Overfitting Risk

[2]. Kang, Z., Yang, J., Li, G., & Zhang, Z. (2020). An automatic garbage classification system based on deep learning. ***IEEE access*****,** ***8*****, 140019-140029.**

This research focuses on improving garbage classification for environmental protection and recycling by developing an automatic system based on deep learning. Using ResNet-34 as the foundational model, the study introduces three enhancements: multi-feature fusion for better input image processing, feature reuse in residual units, and a new activation function for improved performance. These modifications significantly boost classification accuracy, with the final combined model achieving an impressive 99.96% accuracy on a dataset with 10 types of garbage. Additionally, the system demonstrates fast and stable classification, completing tasks in an average of 0.95 seconds. The proposed system integrates these advancements with hardware and a mobile app, showcasing its potential for efficient and accurate waste sorting.



Advantages:

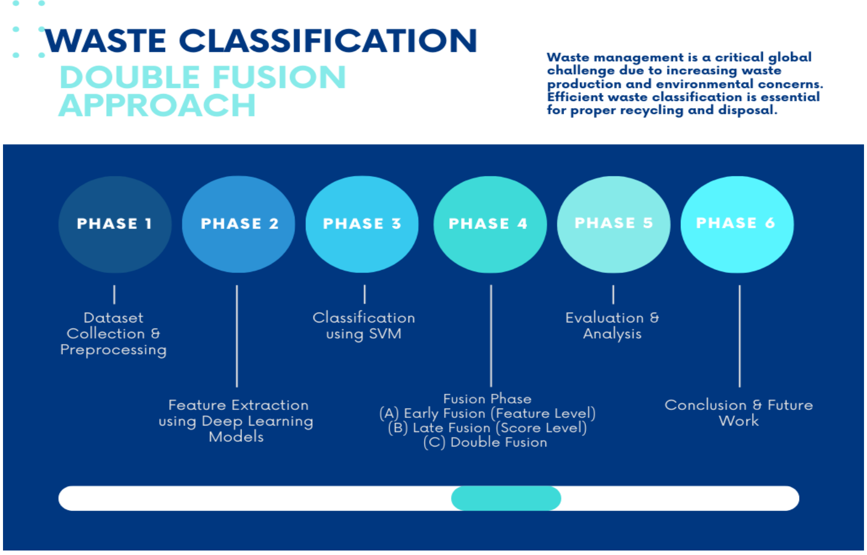
- Fast Classification
- High Accuracy

Limitation:

- Limited Dataset
- Dependency on Hardware

[3].Ahmad, K., Khan, K., & Al-Fuqaha, A. (2020). Intelligent fusion of deep features for improved waste classification. *IEEE access*, *8*, 96495-96504.

Waste classification is crucial for efficient recycling and environmental protection. Early systems, such as Auto Trash, used basic deep learning models like CNNs, while tools like SpotGarbage relied on pre-trained architectures like AlexNet. Advanced techniques later incorporated models like GoogleNet, ResNet, and DenseNet, with some approaches, like RecycleNet, combining these with handcrafted features for better accuracy. Despite these advances, challenges such as class imbalance, overlapping categories, and high computational demands persist. To tackle this, recent innovations introduced double fusion strategies, which merge feature-level and score-level data, significantly improving classification accuracy and handling diverse waste categories more effectively.



Advantages:

- Improved Accuracy
- Scalability

Limitation:

- High Complexity
- Data Dependency

[4].Tian, X., Shi, L., Luo, Y., & Zhang, X. (2024). Garbage Classification Algorithm Based on Improved MobileNetV3. IEEE Access.

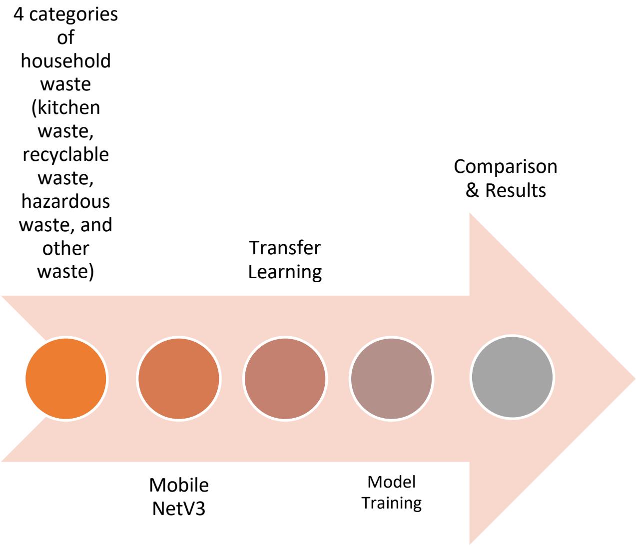
In recent years, the growing issue of household waste has led to the development of smart waste classification systems using machine learning, particularly convolutional neural networks (CNNs). However, many existing models are too large and computationally expensive for use in devices with limited resources. To solve this, lightweight networks like MobileNetV3 have been used for efficient image classification with low memory and computational cost. Researchers also improve accuracy by adding attention mechanisms, like CBAM, which help the model focus on important image areas, and by using activation functions like Mish for better feature extraction. Additionally, replacing fully connected layers with global average pooling reduces model parameters, making the system more efficient for embedded devices.

Advantages:

- High Accuracy
- Efficiency
- Fast Recognition Time

Limitation:

- Limited Generalization
- Data Dependency



[5]. Yang, Z., & Li, D. (2020). WasNet: A neural network-based garbage collection management system. *IEEE Access*, *8*, 103984-103993.

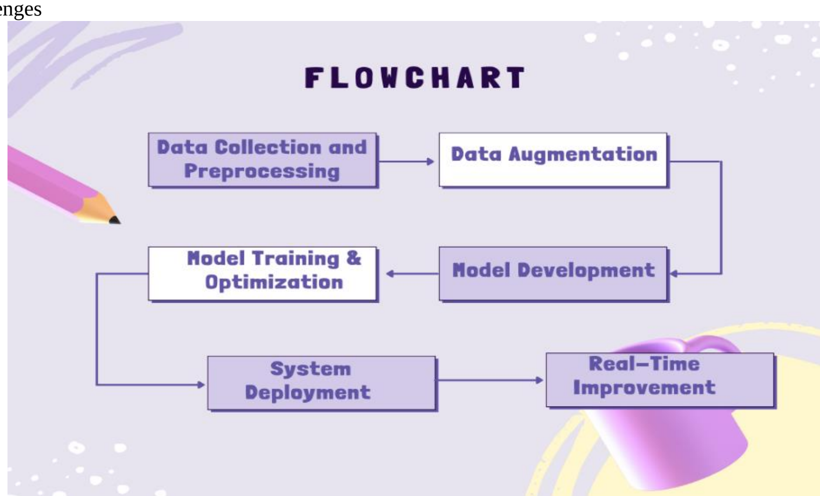
Garbage classification is a critical area of waste management aimed at minimizing pollution and enhancing recycling efficiency. Traditional systems relied on manual sorting, which was labor-intensive and inefficient. Modern advancements employ neural networks, including lightweight models like WasNet, designed to reduce computational requirements while maintaining accuracy. WasNet utilizes data augmentation, transfer learning, and attention mechanisms like CBAM to classify garbage effectively across diverse datasets. Comparisons with models like MobileNetV3 and ShuffleNetV2 demonstrate WasNet's superior accuracy and efficiency. Additionally, the integration of intelligent trash cans, real-time data visualization, and decision-making platforms has enabled seamless end-to-end garbage management.

Advantages:

- High Efficiency
- Customizability

Limitation:

- Class Imbalance:
- Multi-Label Challenges



[6].Feng, J., Tang, X., Jiang, X., & Chen, Q. (2021). Garbage disposal of complex background based on deep learning with limited hardware resources. *IEEE Sensors Journal*, *21*(18), 21050-21058.

Automatic garbage detection is becoming more important as the world faces increased waste management problems. Machine learning, especially deep learning, has been applied to detect and sort garbage automatically. The approach mentioned in the paper focuses on using **MobileNet** as the base network and **Mask R-CNN** for garbage detection on low-cost embedded devices like the Raspberry Pi. Let's break down the advantages and disadvantages of this approach, and provide a simple literature survey.

Advantages:

- Low-Cost Solution
- High-Precision Detection
- Data Efficiency
- Practical Application

Limitation

- Limited Training Data
- Complexity in Dynamic Environments
- Processing Power Constraints
- Limited 3D Perception

[7]. Likotiko, E., Matsuda, Y., & Yasumoto, K. (2023). Garbage content estimation using internet of things and machine learning. *IEEE Access*, *11*, 13000-13012

This study introduces a new approach to improving household waste management using a **Smart Garbage Bin System (SGBS)**, equipped with various sensors to accurately identify and classify garbage content. The system combines **temperature, humidity, gas, and other sensors** with machine learning to sort different types of waste based on sensor data and household annotations. The system was tested in five households for one month and showed impressive results in classifying various types of waste with high accuracy. Below is a summary of the advantages and disadvantages, followed by a short literature survey.

Advantages:

- High Accuracy in Classificatio
- Multiple Sensors for Better Identification
- User-Friendly Annotation App

Limitation

- Sensor Dependency
- Limited Garbage Categories
- Household-Specific Data

[8]. Sheng, T. J., Islam, M. S., Misran, N., Baharuddin, M. H., Arshad, H., Islam, M. R., ... & Islam, M. T. (2020). An internet of things based smart waste management system using LoRa and tensorflow deep learning model. *IEEE Access*, *8*, 148793-148811.

Traditional waste management relies on fixed schedules, which can lead to inefficiency and high costs. While smart bins with sensors can track waste levels, they often use communication methods like Wi-Fi, GSM, or Zigbee, which have limited range and consume a lot of power. Machine learning models can identify different types of waste but don't sort them, so manual effort is still needed. Additionally, systems that monitor bin levels don't use AI for sorting the waste. LoRa (Long Range) communication offers low-power, long-distance data transfer but has mostly been used just for monitoring. This paper combines IoT, LoRa, and AI (TensorFlow) to create a system that can automatically sort, monitor, and collect waste in real-time. This approach makes waste management smarter, more efficient, and cost-effective.

Advantages:

- Cost-Effective
- Real-Time Monitoring

Limitation:

- Initial Setup Cost
- Limited Scope for Complex Waste

[9]. Sallang, N. C. A., Islam, M. T., Islam, M. S., & Arshad, H. (2021). A CNN-based smart waste management system using TensorFlow lite and LoRa-GPS shield in Internet of Things environment. *IEEE Access*, *9*, 153560-153574.

Urban areas are struggling with waste management due to rapid population growth and inefficient traditional methods. To address this, smart waste management systems use the Internet of Things (IoT) and deep learning. These systems employ Convolutional Neural Networks (CNNs) for waste classification, like using the SSD MobileNetV2 Quantized model to identify and sort waste (paper, cardboard, plastic, glass, and metal) with a camera module and Raspberry Pi. IoT sensors, such as ultrasonic and GPS, monitor bin fill levels and locations, with data sent via LoRa to optimize collection schedules and reduce wasted resources. This automation improves efficiency, reduces human error, and saves manpower by minimizing unnecessary collection trips.

Advantages:

- Improved Waste Classification
- Reduced Resource Wastage:
- Security

Limitation

- Limited Dataset
- Hardware Limitations
- Battery Lifespan

[10]. Vo, A. H., Vo, M. T., & Le, T. (2019). A novel framework for trash classification using deep transfer learning. *IEEE Access*, *7*, 178631-178639.

As urbanization increases, efficient waste management becomes crucial. One promising approach is automating trash sorting using computer vision and deep learning. The DNN-TC model, based on the ResNext architecture, classifies trash into categories like organic, inorganic, and medical waste. Trained on the VN-trash dataset of 5904 images from Vietnam, it achieved 98% accuracy. It was also tested on the smaller Trashnet dataset, where it reached 94% accuracy. This method shows great potential for automating waste classification in smart waste management systems.

Advantages:

- High Accuracy
- Real-World Application
- Robustness

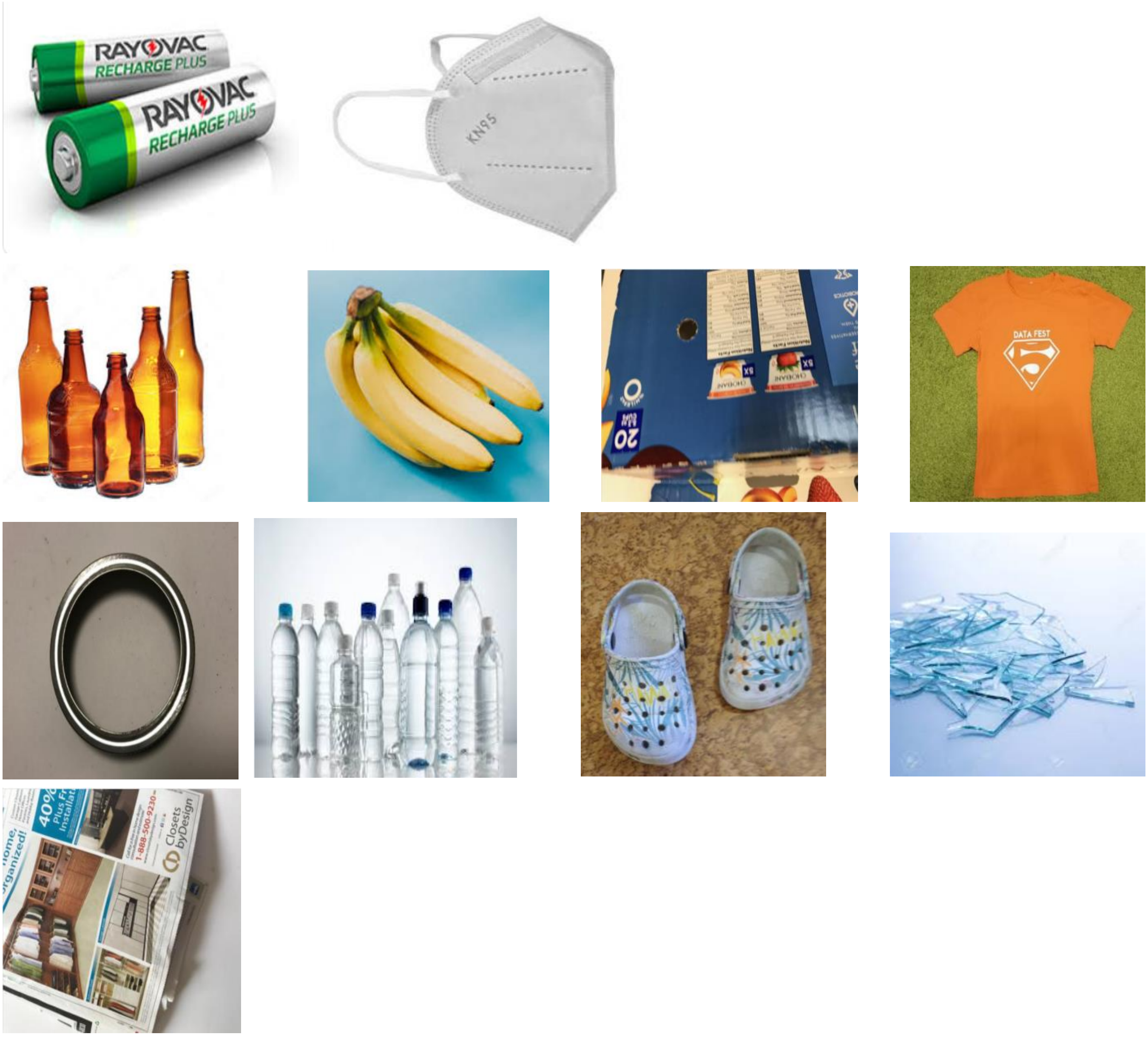
Limitation

- Dataset Imbalance
- Data Dependency
- Complexity

METHODOLOGY

1. Data Collection and Preprocessing

The dataset is sourced from **Kaggle**, containing **1,000 images per category** across **12 waste categories**: Paper, Cardboard, Plastic, Metal, Trash, Battery, Shoes, Clothes, Green Glass, Brown Glass, White Glass, Biological Waste.

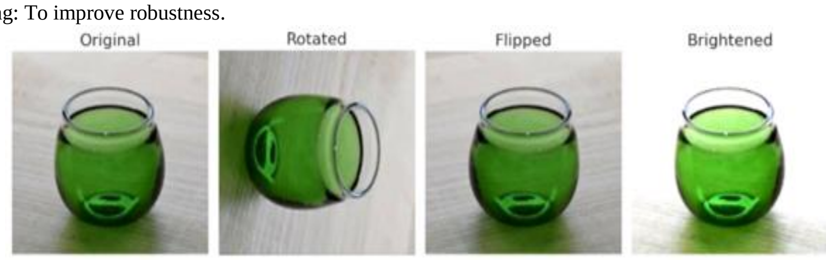


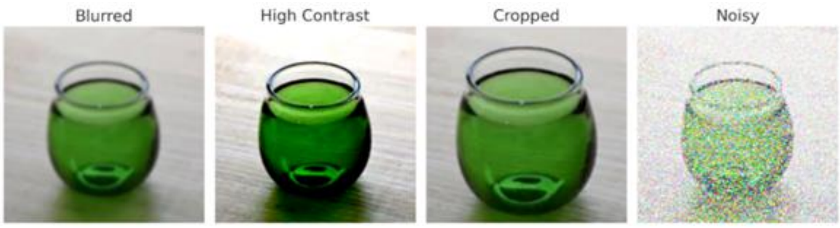
Images are labeled and stored in directories based on their respective waste types. A **pandas DataFrame** is used to manage filenames and labels.

2. Data Augmentation

To enhance model generalization and avoid overfitting, the dataset undergoes real-time augmentation using **ImageDataGenerator**. Transformations include:

- Rescaling: Normalize pixel values to [0,1] by dividing by 255.
- Rotation: Randomly rotate images up to 20°.
- Shifts: Random width/height shifts up to 20%.
- Horizontal Flipping: To improve robustness.



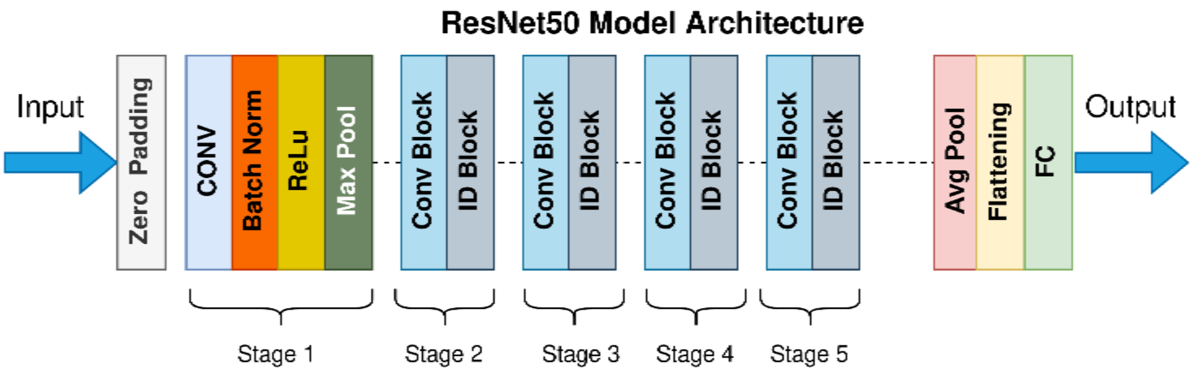


3. Model Selection and Transfer Learning

- The ResNet50V2 model (a pre-trained deep learning model) is used as the base.
- The top layers are removed (include_top=False) to allow for customization specific to waste classification.
- A Batch Normalization layer is added to stabilize and speed up training.
- A Global Average Pooling layer is used to extract meaningful features from the convolutional base.
- A Dense layer with ReLU activation and dropout is added to learn complex patterns and prevent overfitting.
- A final Dense layer with Softmax activation maps the extracted features to the 10 waste categories.

Why ResNet50V2?

ResNet50V2 is chosen because it effectively extracts generalized and deep hierarchical features from images using its residual connections, which help prevent vanishing gradients. Compared to other models, it offers a good balance between accuracy and computational efficiency, making it well-suited for real-world waste classification tasks.



4. Training and Optimization

The model is compiled using:

- Optimizer: Adam
- Loss Function: Categorical Crossentropy
- Metrics: Accuracy

The dataset is split into:

- 80% for Training
- 20% for Testing

Early Stopping is applied to prevent overfitting by monitoring validation accuracy.

5. Evaluation and Performance Metrics

Accuracy, F1-score, Precision, and Recall are used to evaluate the model.

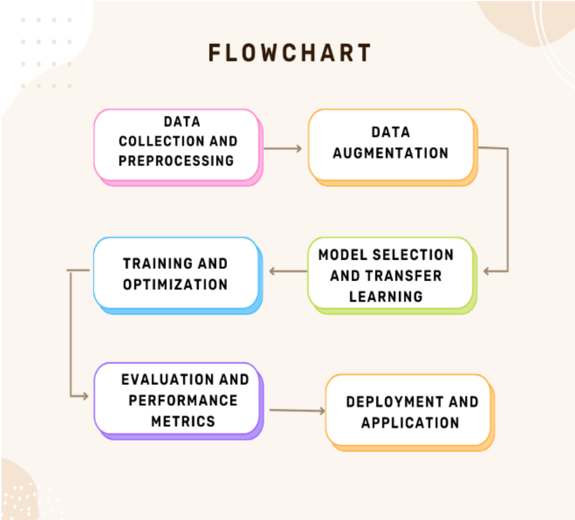
The trained model achieves:

- 95.1% Accuracy
- 96% F1-score
- 97% Recall

A Confusion Matrix is generated to analyze misclassifications.

6. Deployment and Application

- The trained model is saved using Pickle (.pkl format) for easy deployment.
- The final system will be deployed as a Web Application, allowing users to upload waste images and receive predictions.



RESULT

The proposed system, WasteClassify, successfully classifies waste materials into ten different categories using deep learning techniques. The model was trained on a dataset comprising over 26,000 labeled images of waste items, ensuring diverse exposure to different types of recyclable and non-recyclable waste.

To validate the model, various test images were uploaded through the web application. One such example includes an image of a glass bottle (as shown in Figure 1).

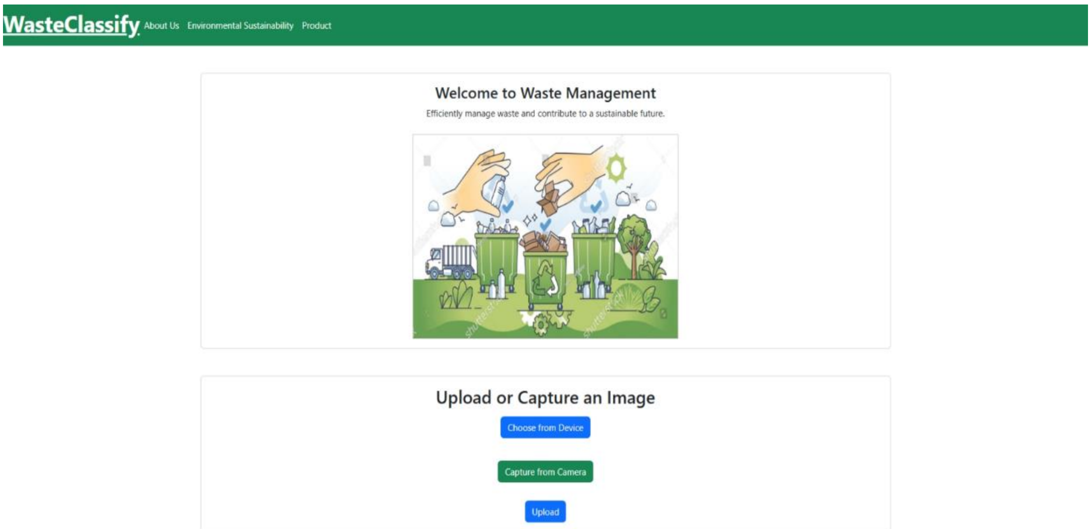


Figure 1: Input image of a glass bottle uploaded to the system.

When uploaded, the system correctly identified the object as “Glass”, and the output page displayed the predicted class along with the recommended disposal method — Green bin — which aligns with municipal solid waste guidelines. The visual results, including the uploaded image and the prediction, are displayed on the web interface, providing users with an intuitive and user-friendly experience (see Figure 2).

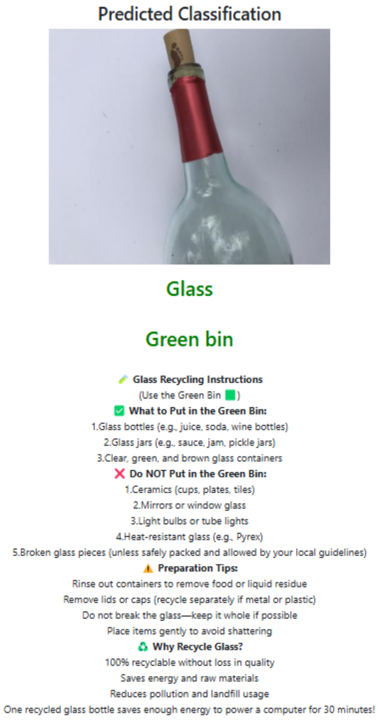


Figure 2: Output display showing prediction as “Glass” and disposal recommendation as “Green bin”.

The classification interface not only provides the predicted waste type but also offers actionable disposal suggestions to educate users on sustainable waste segregation practices. This makes the system suitable for both domestic and industrial environments.

CONCLUSION

This mini project successfully integrates deep learning with web technologies to build an intelligent waste classification system. The practical utility of the system lies in its ability to automate waste segregation, which can reduce manual effort, minimize contamination in recycling streams, and promote environmentally responsible behaviour. The model’s performance on real-time images shows high accuracy and reliability, especially when integrated into a responsive web application. The deployment of the model through a user-friendly web application further enhances its accessibility and real-world applicability. Users can upload images of waste items and receive instant predictions along with disposal instructions, making the system suitable for educational purposes, households, industries, and municipal bodies. The prediction results, paired with clear visual output, offer a seamless experience and promote awareness about proper recycling habits. n conclusion, WasteClassify is a valuable prototype with both **technological depth and societal relevance**. With future improvements such as multilingual support, mobile integration, and real-time deployment, this system can play a crucial role in achieving cleaner cities and more efficient recycling systems, contributing to the broader goals of smart city development and environmental sustainability.

Future Scope

The proposed system, *WasteClassify*, demonstrates strong performance in automated waste classification using deep learning. However, several enhancements and extensions can be pursued to broaden its impact and make it more robust for real-world deployment:

1. **Integration with IoT for Smart Waste Bins**
   By combining this classification model with IoT-enabled smart bins, the system can automatically detect and categorize waste as it is deposited. This real-time sorting can significantly enhance efficiency in both public and industrial waste management systems.
2. **Mobile Application Development**
   Expanding the web application into a lightweight mobile app with TensorFlow Lite can allow users to classify waste using smartphone cameras. This would make the system more accessible to households, schools, and small businesses.
3. **Multilingual and Voice Interaction Support**
   Adding support for regional languages and voice-based instructions can make the system user-friendly in multilingual communities, improving adoption in rural or semi-urban areas.
4. **Expanded Dataset and Continuous Learning**
   Integrating larger, more diverse datasets with images under varied lighting, angles, and occlusions will improve model generalization. Implementing continual learning can help the system adapt to new waste types and classification challenges.
5. **Real-Time Segmentation and Detection** Future versions can adopt object detection and instance segmentation models like YOLOv8 or Mask R-CNN to not only classify but also locate waste items in real-time, making it suitable for conveyor-belt-based sorting in recycling

plants.

6. **Integration with Municipal Waste Systems**
   By linking the system with municipal databases, it can provide analytics on waste types and volumes per region, enabling data-driven policy-making and targeted recycling campaigns.
7. **Edge Deployment for Low-Power Devices**
   Optimization for embedded systems such as Raspberry Pi with camera modules can help deploy the system in low-resource environments like villages, parks, or mobile collection units.
8. **Waste Value Prediction and Sorting for Recycling**
   Adding a predictive model to estimate the recyclability or economic value of the waste can assist recycling centers in prioritizing items that yield higher return or are environmentally sensitive (e.g., batteries, electronics).
9. **Gamification and Community Engagement**
   Implementing gamification features like points or rewards for correctly classifying waste through the app can foster better user engagement and encourage eco-friendly behavior.
10. **Support for Multi-Label Classification**
    Many real-world waste items belong to multiple categories (e.g., a cardboard box with plastic tape). Enhancing the system to handle multi-label scenarios would make classification more practical.

REFERENCES

[1]. Hossen, M. M., Majid, M. E., Kashem, S. B. A., Khandakar, A., Nashbat, M., Ashraf, A., ... & Chowdhury, M. E. (2024). A reliable and robust deep learning model for effective recyclable waste classification. *IEEE Access*.

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[3]. Sheng, T. J., Islam, M. S., Misran, N., Baharuddin, M. H., Arshad, H., Islam, M. R., ... & Islam, M. T. (2020). An internet of things based smart waste management system using LoRa and tensorflow deep learning model. *IEEE Access*, *8*, 148793-148811.

[4]. Yang, Z., & Li, D. (2020). WasNet: A neural network-based garbage collection management system. *IEEE Access*, *8*, 103984-103993.

[5]. Kang, Z., Yang, J., Li, G., & Zhang, Z. (2020). An automatic garbage classification system based on deep learning. *IEEE access*, *8*, 140019-140029.

[6]. Feng, J., Tang, X., Jiang, X., & Chen, Q. (2021). Garbage disposal of complex background based on deep learning with limited hardware resources. *IEEE Sensors Journal*, *21*(18), 21050-21058.

[7]. Likotiko, E., Matsuda, Y., & Yasumoto, K. (2023). Garbage content estimation using internet of things and machine learning. *IEEE Access*, *11*, 13000-13012.

[8]. Tian, X., Shi, L., Luo, Y., & Zhang, X. (2024). Garbage Classification Algorithm Based on Improved MobileNetV3. *IEEE Access*.

[9]. Sayem, F. R., Islam, M. S. B., Naznine, M., Nashbat, M., Hasan-Zia, M., Kunju, A. K. A., ... & Chowdhury, M. E. (2024). Enhancing waste sorting and recycling efficiency: robust deep learning-based approach for classification and detection. *Neural Computing and Applications*, 1-17.

[10]. Sallang, N. C. A., Islam, M. T., Islam, M. S., & Arshad, H. (2021). A CNN-based smart waste management system using TensorFlow lite and LoRa-GPS shield in Internet of Things environment. *IEEE Access*, *9*, 153560-153574.

[11]. Vo, A. H., Vo, M. T., & Le, T. (2019). A novel framework for trash classification using deep transfer learning. *IEEE Access*, *7*, 178631-178639.

[12]. Chhabra, M., Sharan, B., Elbarachi, M., & Kumar, M. (2024). Intelligent waste classification approach based on improved multi-layered convolutional neural network. *Multimedia Tools and Applications*, 1-26.

[13]. Naf'an, E., Sulaiman, R., & Ali, N. M. (2023). Optimization of trash identification on the house compound using a convolutional neural network (CNN) and sensor system. *Sensors*, *23*(3), 1499.

[14]. Malik, M., Sharma, S., Uddin, M., Chen, C. L., Wu, C. M., Soni, P., & Chaudhary, S. (2022). Waste classification for sustainable development using

image recognition with deep learning neural network models. *Sustainability*, *14*(12), 7222.

[15]. Ahmed, M. I. B., Alotaibi, R. B., Al-Qahtani, R. A., Al-Qahtani, R. S., Al-Hetela, S. S., Al-Matar, K. A., ... & Krishnasamy, G. (2023). Deep learning approach to recyclable products classification: Towards sustainable waste management. *Sustainability*, *15*(14), 11138.