International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 12 December 2024
Page No: 2774- 2780
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0384

# Garbage Classification: A Deep Learning Perspective

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## Abstract
*Garbage Classification using deep learning focuses on techniques to automate and improve the sorting of waste materials. The objective is to enhance recycling processes and promote environmental sustainability by accurately categorizing waste into six types: glass, paper, cloth, trash, cardboard, and plastic. The study implements advanced convolutional neural networks (CNNs) to analyze and classify images of garbage, automating a task that is traditionally manual and labor-intensive.To achieve this, several deep learning models were used, including MobileNet, NASNet, LeNet, Inception, and DenseNet. These models were trained on a carefully curated dataset to ensure balanced representation across all waste categories, allowing them to extract complex features from the images and make precise classifications. Each model was evaluated based on its performance, with NASNet delivering the highest accuracy, making it the most suitable for real-world applications where resources might be limited, such as mobile or edge devices.The results demonstrate that NASNet is the most effective algorithm for garbage classification, outperforming the other models in terms of accuracy. By automating the classification process, this research offers a practical solution to improve recycling efficiency, reduce the need for manual sorting, and contribute to sustainable waste management. The study highlights the significant role that deep learning can play in transforming waste management systems for a cleaner and more sustainable environment.*
***Keywords:*** *Garbage Classification, CNN, NASNet, MobileNet, Recycling, Sustainability*

## 1. Introduction

Sorting garbage effectively is crucial for improving recycling, minimizing waste generation, and protecting the environment. This study focuses on categorizing garbage into six main groups: glass, paper, cloth, trash, cardboard, and plastic. Accurate sorting is essential for optimizing recycling processes, ensuring that materials are properly segregated to maintain their usability and quality. Traditional manual sorting methods are labor-intensive and costly. However, advancements in technology, particularly in computer vision and deep learning, offer promising solutions for automating this process. In this research, we explore the use of various advanced deep learning algorithms, including MobileNet, NASNet, LeNet, InceptionV3, and DenseNet121. These algorithms are designed to analyze images and distinguish between different types of waste materials efficiently. By leveraging convolutional neural networks (CNNs), these models can automatically extract complex features from images, enabling precise classification of garbage. A carefully curated dataset was employed in this study to ensure a diverse and representative sample of waste materials across all categories. This meticulous selection process enhances the reliability and effectiveness of our models. Our experimental results indicate that Inception consistently outperforms other models, demonstrating superior accuracy in classifying diverse waste types. Inception's architecture allows it to capture intricate patterns and variations in the data, leading to more accurate and efficient classification. This research underscores the potential of advanced deep learning techniques to revolutionize waste management practices. By automating the sorting process, these models have the potential to significantly reduce the need for manual labor, leading to more efficient recycling workflows and cost savings. Implementing automated sorting systems can streamline recycling efforts, reduce operational expenses, and contribute to a cleaner, more sustainable environment. Overall, this study highlights the transformative impact of utilizing smart technology in waste management. By harnessing the power of deep learning algorithms, we can make significant strides towards achieving more efficient and effective recycling practices, ultimately leading to a healthier planet for future generations.

## 2. Related Works

Integrating IoT and AI, the research employs CNNs to predict waste types. Gas and ultrasonic sensors monitor methane levels. The system achieves a 96% classification accuracy, aiding sustainable waste management practices[1].Modern waste management systems must incorporate efficient classification for sustainability. ResNet-101 outperforms other deep learning models in rubbish classification. A ResNet101-SVM ensemble combines ResNet101 for feature extraction and SVM for classification, offering insights for effective waste management.[2] An improved YOLOv8s-based method enhances recyclable garbage detection and classification in complex environments, achieving 96.3% MAP, a 3.9% improvement over the original network.[3]. Waste management proposed an automated system using Deep Learning to detect, sort, and classify recyclable waste, aiming to reduce manual classification costs and environmental impact. We evaluate effectiveness using Convolutional Neural Networks like ResNet50, MobileNetV2, and DenseNet. [4].Implementing image - based waste classification alleviates manual sorting challenges, enhancing hygiene and efficiency. Utilizing Convolutional Neural Networks, Tensor Flow, and Transfer Learning, it categorizes waste objects accurately, streamlining processes and reducing health risks.[5].Waste segregation in Indian cities poses a significant challenge, with 62 million tons of annual garbage, including 5.6 million tons of plastic waste, of which 60% is recycled. However, manual segregation remains a hurdle. To address this, an image classifier utilizing Convolutional Neural Networks (CNN) is proposed. Four CNN models (ResNet50, DenseNet169, VGG16, and AlexNet) trained on ImageNet are employed to classify waste types. Experimental results highlight DenseNet169's superior performance, with ResNet50 closely trailing.[6].Garbage classification technology is crucial for waste treatment and resource recovery. A lightweight model, GCNet, achieves 97.9% accuracy on a self-built dataset. With improved real-time performance, it facilitates efficient waste classification and collection, promoting advancements in resource and environmental fields.[7].The proposed system merges IoT, Deep Learning, and Image Processing for efficient waste management. Utilizing a Raspberry Pi camera and the 'Histogram of Oriented Gradients' algorithm, objects are classified by a Faster R-CNN, ensuring accurate waste segregation.[8].An automatic waste classification robot employing DenseNet121 achieved 99.6% accuracy on TrashNet dataset. Utilizing genetic algorithm to optimize its fully-connected-layer, the model surpassed other CNNs in performance, demonstrating improved efficiency in waste image classification.[9].Intelligent garbage classification is crucial for waste management. A CNN-based algorithm, PublicGarbageNet, is proposed, classifying four major garbage categories and ten subclasses with a 96.35% accuracy on a newly constructed dataset.[10].In is propose an advanced waste classification system using a ResNet-50 CNN for feature extraction and an SVM for classification, achieving 87% accuracy on Thung and Yang's trash image dataset. This system aims to automate and streamline the waste separation process, significantly reducing the need for manual sorting.[11].In this work presents an automatic garbage classification system using an optimized ResNet-34 algorithm, incorporating multi-feature fusion, feature reuse, and a new activation function. The system achieves a classification accuracy of 99% and operates with a quick classification cycle of 0.95 seconds.[12].This is a deep learning-based method for automatically classifying recycled garbage, aiming to enhance classification efficiency and accuracy while reducing manpower and resource

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costs. The proposed approach leverages advanced image classification techniques to improve the recycling process in Kwangju, South Korea.[13].This study introduces the DLSODC-GWM technique, a novel deep learning-based model for small object detection and classification in waste management, aimed at enhancing intelligent recycling systems in smart cities. The technique combines an arithmetic optimization algorithm with an improved RefineDet model for object detection and uses a functional link neural network for classification. Experimental results show that DLSODC-GWM outperforms existing methods, achieving a maximum accuracy of 98.61%.[14].This study introduces the DLSODC-GWM technique, a novel deep learning-based model for small object detection and classification in waste management, aimed at enhancing intelligent recycling systems in smart cities. The technique combines an arithmetic optimization algorithm with an improved RefineDet model for object detection and uses a functional link neural network for classification. Experimental results show that DLSODC-GWM outperforms existing methods, achieving a maximum accuracy of 98.61%.[15].This study employs MobileNet for garbage classification, achieving 87.2% accuracy after transfer learning from ImageNet. The optimized model, with 89.34% confidence, outperforms the quantized model (1.47% confidence) in an Android app, successfully identifying materials like cardboard. The study suggests rerunning training with more steps to potentially enhance the quantized model's performance, suitable for mobile applications.[16].A municipal waste management system integrates deep learning classifiers and cloud computing to streamline waste classification and collection. Seven CNNs were evaluated, with MobileNetV3 demonstrating high accuracy (94.26%), compact size, and fast processing. IoT devices enable real-time monitoring, facilitating adaptive resource allocation and waste collection planning for effective municipal waste management.[17]. This paper introduces an X-DenseNet garbage classification model, combining Xception and DenseNet concepts, achieving a testing set accuracy of 94.1%. The model aims to enhance garbage recovery rates by automating classification tasks, reducing manual effort, and demonstrating scientific and practical significance.[18].This study addresses waste management challenges through automated classification using ML and DL algorithms. Four algorithms—CNN, SVM, Random Forest, and Decision Tree—are compared, with CNN achieving the highest accuracy at 90%, followed by SVM at 85%. Random Forest and Decision Tree achieved accuracies of 55% and 65% respectively, indicating their potential in waste classification tasks.[19].This paper proposes a waste classification architecture using EfficientNet-B0, enhancing it for regional-specific litter images. The model achieves comparable accuracy to EfficientNet-B3 but with significantly fewer parameters, resulting in 4X efficiency in terms of FLOPS. Fine-tuning over region-specific images improves classification performance, addressing the challenges of waste management efficiently.[20].Garbage classification algorithm using EfficientNet with data augmentation and group normalization to address small dataset sizes and varying image dimensions. Incorporating an attention mechanism enhances feature extraction and classification accuracy. Results demonstrate the model's effectiveness in accurately identifying garbage types, showcasing high classification performance and robustness, with potential applications in both human and robot-assisted waste sorting.

## 3. Dataset Description

The Garbage Classification dataset contains a collection of 15,555 images organized into distinct categories for the purpose of training,validating, and testing machine learning models in the task of garbage classification. This dataset contains six major classes like cardboard, glass, metal, paper, plastic, trash that can correctly identify and categorize different types of waste, which is a critical step towards efficient waste management and recycling processes, shown in table 1.

**Table 1 Garbage Classification Dataset**

| Dataset | No. of files |
|---|---|
| Train | 2019 |
| Test | 508 |

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## 4. Proposed Work

In garbage classification using deep learning techniques we delve into the realm of waste management by employing cutting-edge deep learning algorithms. By leveraging advanced architectures like MobileNet, DenseNet, LeNet, NASNet, and Inception, our research focuses on automating and refining the classification of various waste materials. Through the utilization of convolutional neural networks (CNNs), we aim to bolster the accuracy and efficacy of waste sorting procedures, thereby making significant strides toward environmental sustainability and resource optimization.

### 4.1. MobileNet

MobileNet is a lightweight convolutional neural network (CNN) architecture designed for efficient mobile and embedded vision applications. Its architecture enables fast inference while maintaining competitive accuracy. In garbage classification, MobileNet's efficiency makes it suitable for deployment in resource-constrained environments, such as mobile devices used for real-time waste sorting.

### 4.2. DenseNet121

DenseNet121 revolutionizes deep learning with its dense connectivity, ensuring each layer is directly connected to every other layer. This fosters improved gradient flow and parameter efficiency, enabling superior feature reuse and propagation. This architectural innovation empowers DenseNet121 to excel in various deep learning tasks while maintaining a relatively low number of parameters.

### 4.3. LeNet

LeNet, introduced by Yann LeCun et al., is one of the pioneering CNN architectures. Although simpler than modern networks, it demonstrates strong performance in various image classification tasks. Its architecture consists of convolutional and pooling layers followed by fully connected layers. In garbage classification, LeNet can serve as a baseline model or be adapted to meet specific requirements due to its simplicity and effectiveness.

### 4.4. NASNet

NASNet (Neural Architecture Search Network) is a family of CNN architectures developed using neural architecture search (NAS) techniques. It explores a vast search space to automatically design architectures optimized for specific tasks. In garbage classification, NASNet can identify novel architectures that efficiently extract features from waste images, potentially enhancing classification accuracy.

### 4.5. InceptionV3

InceptionV3 stands out for its sophisticated approach to image classification, leveraging Inception modules that incorporate multiple convolution filters of varying sizes. Alongside factorized convolutions and auxiliary classifiers, InceptionV3 achieves remarkable accuracy and efficiency. These architectural enhancements optimize computational resources, making it an ideal choice for demanding computer vision applications, shown in Figure 1.

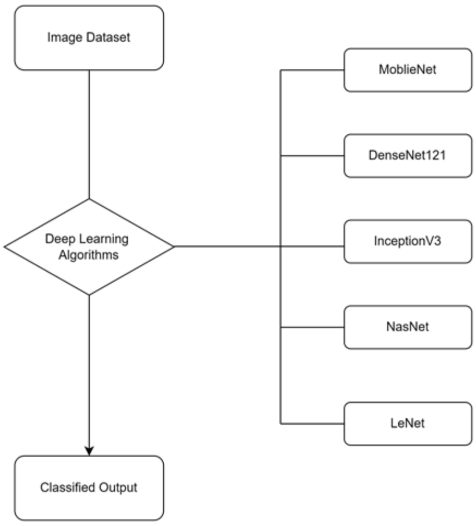


**Figure 1 Proposed System Workflow**

## 5. Results

The results for the garbage classification using various deep learning techniques of Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 & Figure 10

**Table 2 Accuracy**

| Algorithm | Result |
|---|---|
| MobileNet | 0.953 |
| DenseNet121 | 0.927 |
| NasNet | 0.997 |
| LeNet | 0.995 |
| InceptionV3 | 0.996 |

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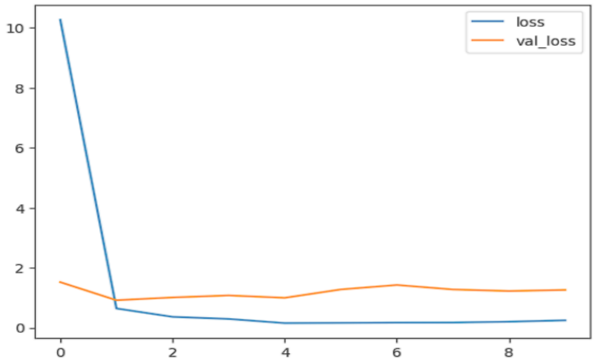


Figure 2 MobileNet- Loss

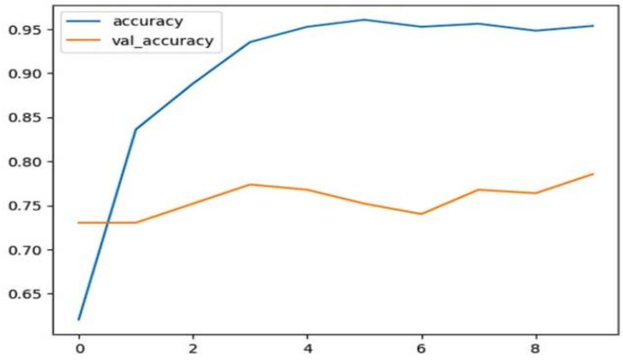


Figure 3 MobileNet-Accuracy

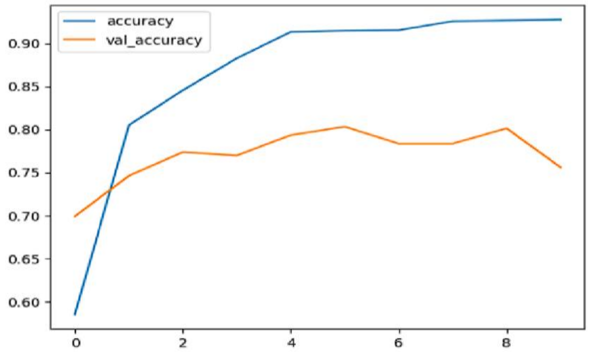


Figure 4 DenseNet121-Accuracy

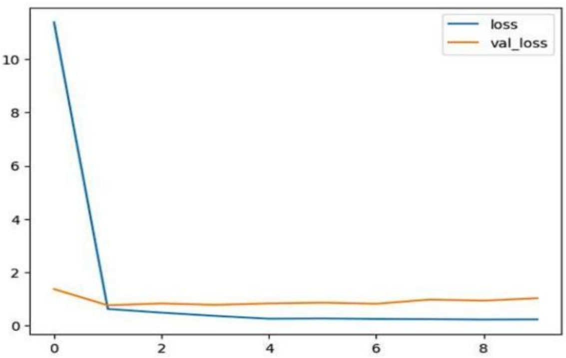


Figure 5 DenseNet121-Loss

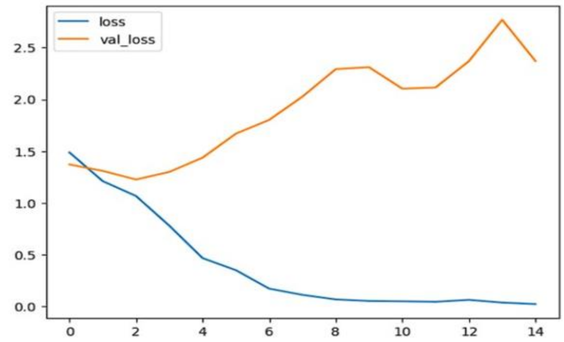


Figure 6 LeNet-Loss

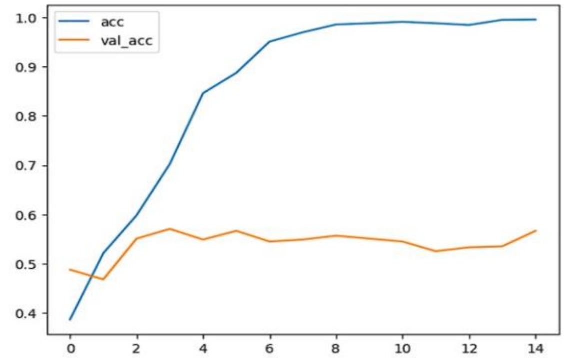


Figure 7 LeNet-Accuracy

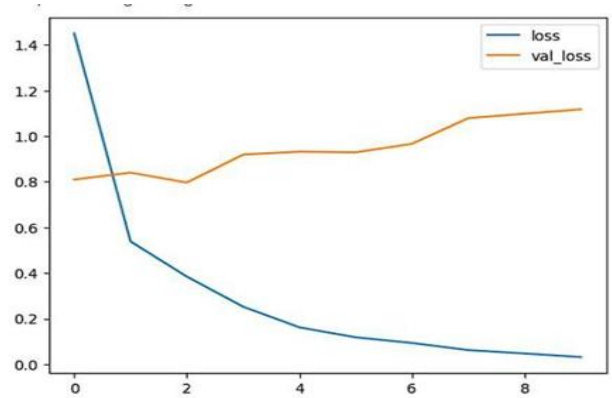


Figure 8 InceptionV3-Loss

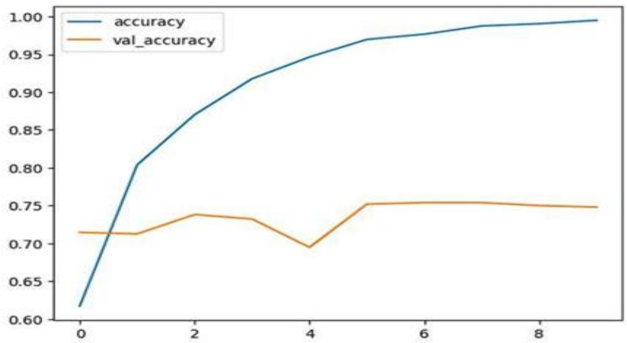


Figure 9 InceptionV3-Accuracy

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https://doi.org/10.47392/IRJAEH.2024.0384

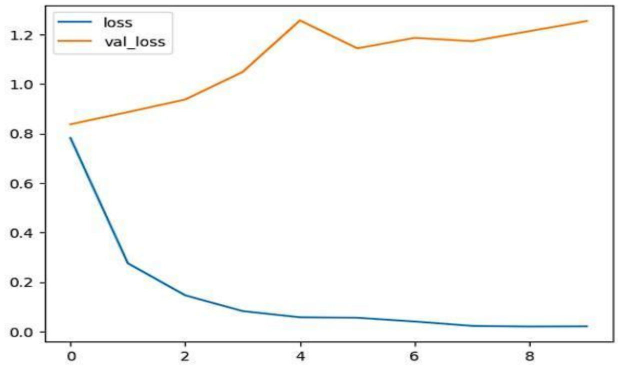


**Figure 10** **Nas-Net – Loss**

## Conclusion

The growing challenge of urban waste management necessitates innovative solutions for efficient garbage classification, shown in Table 2. This research explored deep learning techniques, specifically convolutional neural networks (CNNs), to automate and enhance waste sorting accuracy. Advanced models like MobileNet, DenseNet121 NASNet, LeNet, InceptionV3, and DenseNet were employed, with MobileNet, noted for its lightweight architecture and suitability for deployment on low-computational devices, outperforming others in accuracy. The curated and augmented dataset ensured balanced representation across waste categories, further improving model robustness. The results showed that deep learning models, especially NasNet significantly streamline waste sorting, reducing manual intervention, labor costs, and health risks. This automation leads to efficient recycling workflows, contributing to environmental sustainability by accurately identifying recyclable materials. The integration of deep learning and computer vision in waste management represents a substantial advancement, promising a cleaner and more sustainable future. This research underscores the potential of these technologies in enhancing global waste management practices and paves the way for further refinement and real-world deployment to maximize their impact.

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International Research Journal on Advanced Engineering Hub (IRJAEH)
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Vol. 02 Issue: 12 December 2024
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