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A Strong and Durable Neural Network System for Optimal Biodegradable Garbage Categorization

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ABSTRACT

With the rapid rise of industrialization and modernization, improper waste disposal has emerged as a significant environmental challenge. Addressing this issue necessitates the development of an automated system for sorting and recycling waste to promote sustainable waste management practices. Recent progress in deep learning, particularly in image classification, offers promising tools for such applications. In this research, we introduce RWCNet (Recyclable Waste Classification Network)—a novel deep learning framework designed to categorize waste into six distinct types using the TrashNet dataset, which comprises 2,527 labeled waste images. The proposed model is rigorously evaluated through both quantitative and qualitative analyses and benchmarked against several cutting-edge waste classification models. RWCNet achieves an impressive overall accuracy of 95.01%, surpassing multiple state-of-the-art techniques. Moreover, it attains high F1-scores across all waste categories: 97.24% for cardboard, 96.18% for glass, 94% for metal, 95.73% for paper, 93.67% for plastic, and 88.55% for litter. To further validate its performance, Score-CAM-based saliency maps are employed, offering visual interpretation of the model's focus areas during classification. The findings

affirm the robustness and precision of RWCNet, positioning it as a highly effective solution for automated waste categorization and recycling systems.

Keywords: waste classification, deep learning, RWCNet, TrashNet dataset, image classification, recyclable waste, Score-CAM, saliency maps, automated waste management.

1. INTRODUCTION

The rapid pace of urbanization and industrial development has significantly contributed to the escalation of global waste generation, particularly biodegradable waste such as food scraps, paper, plant material, and other organic matter. Improper disposal and ineffective management of this waste not only degrade environmental quality but also pose health hazards and strain waste treatment infrastructure. Consequently, sustainable and intelligent waste management systems have become a pressing need for urban ecosystems. Traditional waste sorting methods, which rely heavily on manual labor and rudimentary sorting technologies, are inefficient, error-prone, and often incapable of handling large volumes of waste in real-time. Although early efforts in automation utilized classical machine learning techniques for image-based waste classification, these approaches struggled with low accuracy, limited scalability, and poor generalization to complex visual patterns.

In recent years, deep learning has emerged as a transformative solution for automating image classification tasks with high precision. Neural networks, particularly deep convolutional architectures, have demonstrated remarkable success in extracting hierarchical features from complex visual data, making them ideally suited for waste categorization. However, designing a deep learning model that is both robust and adaptable to real-world scenarios—where lighting, angle, and object variation can greatly affect performance—remains a critical challenge. This study introduces a reliable and efficient neural network model named **RWC-Net**, specifically engineered for the classification of biodegradable waste. The model leverages the complementary strengths of two deep convolutional neural networks—DenseNet201 and MobileNetv2—to enhance feature extraction and classification accuracy. Utilizing the publicly available TrashNet dataset, which includes images from six distinct waste categories (cardboard, glass, metal, paper, plastic, and litter), our model aims to achieve superior accuracy, speed, and robustness compared to traditional and existing deep learning techniques.

The proposed system is not only technically sound but also environmentally significant, offering a scalable and automated approach to improve biodegradable waste segregation at source points such as households, industries, and public disposal sites. This contributes directly to the broader goals of sustainable waste management, resource conservation, and environmental protection.

2. LITERATURE REVIEW

"Real-time smart garbage bin mechanism for solid waste management in smart cities," *Sustain. Cities Soc.*, vol. 75, Dec. 2021, Art. no. 103347. Abuga and N. S. Raghava. The pursuit of efficient waste management has long captured the attention of researchers and policymakers due to its profound environmental and socioeconomic implications. In particular, the need to accurately classify and segregate biodegradable waste has inspired numerous approaches, ranging from traditional machine learning algorithms to advanced deep learning architectures. [1]

"Intelligent garbage classification system based on improve MobileNetV3Large," *Connection Sci.*, vol. 34, no. 1, pp. 1299–1321, Dec. 2022. Y. Zhao, H. Huang, Z. Li, H. Yiwang, and M. Lu. Early work in waste classification utilized basic machine learning models. For instance, Mindy et al. (2016) employed the Support Vector Machine (SVM) algorithm on the TrashNet dataset, achieving a modest classification accuracy of 63%. Although foundational, such models struggled with scalability and were limited by their dependence on handcrafted features. Bernardo et al. (2018) improved upon this by using the K-Nearest Neighbors (KNN) algorithm, yielding a better accuracy of 88%. Simultaneously, researchers like Mandar adopted ensemble-based models such as Random Forest and XGBoost, attaining 62.61% and 70% accuracy, respectively. These results underscored the potential of algorithmic waste classification but also highlighted the limitations of classical approaches when confronted with diverse and complex waste images. [2]

"Environmental pollution and toxic substances: Cellular apoptosis as a key parameter in a sensible model like fish," *Aquatic Toxicol.*, vol. 204, pp. 144– 159, Nov. 2018. H. AnvariFar, A. K. Amirkolaie, A. M. Jalali, H. K. Miandare, A. H. Sayed, S. Í. Üçüncü, H. Ouraji, M. Ceci, and N. Romano. The emergence of deep learning revolutionized the field by enabling automatic feature extraction and improved generalization capabilities. Kennedy et al. (2018) introduced OscarNet, a refined version of VGG19, achieving 88.42% accuracy. In the same year, Costa et al. experimented with fine-tuned versions of AlexNet and VGG16, reaching 91% and 93% accuracy, respectively. These developments demonstrated the adaptability of pre-trained convolutional neural networks (CNNs) to the domain of waste classification. Subsequent works explored lightweight and efficient models tailored for real-time applications. Rabano et al. incorporated MobileNet, achieving an

87.2% accuracy while minimizing computational cost—an essential consideration for deployment in edge devices or mobile systems. Similarly, Rahmi et al. (2018) applied state-of-the-art architectures such as Inception-ResNet V2 and DenseNet121, reaching 89% accuracy on the TrashNet dataset. Upon fine-tuning with ImageNet, their performance improved further, with DenseNet121 achieving 95% and

Inception-ResNet V2 reaching 94%. By mid-2019, progress continued as Victoria et al. demonstrated accuracy rates of 87.71% (Inception), 88.34% (Inception-ResNet), and 88.66% (ResNet). These models proved effective in extracting complex visual features and classifying diverse waste types with improved precision. Despite these advances, challenges such as overfitting, limited training data, and real-world variability in waste images persist. Moreover, most works focused on general waste classification rather than specifically optimizing biodegradable waste categorization. This gap motivates the development of hybrid models that combine the strengths of different architectures. [3]

"Microplastics in the marine environment: Current trends in environmental pollution and mechanisms of toxicological profile," *Environ. Toxicol. Pharmacol.*, vol. 68, pp. 61–74, May 2019. C. G. Alimba and C. Faggio. In this context, our proposed model, RWCNet, leverages both DenseNet201 and MobileNet-v2 to capitalize on their respective advantages in deep feature extraction and computational efficiency. Our research positions itself as a step forward in addressing the accuracyefficiency tradeoff while focusing on the biodegradable segment of waste classification—a domain of increasing environmental urgency. [4]

3. EXISTING SYSTEM

Efficient waste management has emerged as a critical societal issue, highlighting the importance of an automated system for accurately classifying waste. As urbanization and industrial activity continue to grow, it has become increasingly essential to motivate individuals to actively engage in waste segregation and recycling. Initially, researchers relied on traditional machine learning methods for classifying waste images. For instance, in 2016, Mindy et al. utilized the Support Vector Machine (SVM) algorithm on the TrashNet dataset, achieving an accuracy of 63%. Later, in 2018, Bernardo et al. applied the K-Nearest Neighbors (KNN) algorithm on the same dataset and reached an improved accuracy of 88%. Other researchers, such as Mandar, experimented with Random Forest (RF) and Extreme Gradient Boosting (XGBoost), reporting 62.61% and 70% accuracy, respectively.

With the evolution of deep learning, however, a significant shift has occurred in waste classification strategies. Deep learning approaches have surpassed traditional machine learning models in terms of performance and accuracy. In 2018, Kennedy et al. introduced OscarNet, later enhanced using the VGG19 architecture, which resulted in an accuracy of 88.42% on the TrashNet dataset. That same year, Costa et al. presented fine-tuned versions of AlexNet and VGG16, which achieved 91% and 93% accuracy, respectively. Similarly, Rabano et al. incorporated MobileNet into their classification framework, achieving 87.2% accuracy . In December 2018, Rahmi et al. evaluated multiple classical deep networks, including Inception-ResNet V2 and DenseNet121, both of which reached 89% accuracy. When fine-tuned using the ImageNet dataset, DenseNet121 achieved 95% and Inception-ResNet V2 reached 94% . In 2019, Victoria et al. expanded on these efforts, attaining 87.71% accuracy with Inception, 88.34% with InceptionResNet, and 88.66% with ResNet models.

These advancements demonstrate the transformative impact of deep learning in the waste classification domain. The shift from conventional techniques to deep neural networks has not only enhanced classification performance but also deepened our understanding of the nuanced process of waste categorization.

Limitations of Existing System

High data complexity: Many existing machine learning models struggle to accurately process and interpret complex and high-dimensional datasets required for recyclable waste classification.

Limited data availability: These models typically require large volumes of highquality labeled data to achieve accurate predictions. A shortage of such data can negatively impact model performance.
Labeling errors: The effectiveness of current machine learning models is heavily dependent on the

accuracy of labeled training data. Any mislabeling can significantly degrade prediction accuracy.

4. PROPOSED SYSTEM

This study focuses on utilizing the TrashNet dataset, which contains the most commonly encountered waste categories— cardboard, glass, metal, paper, plastic, and litter. The primary aim is to develop a robust and efficient deep learning model capable of accurately classifying these types of waste, thereby enhancing the efficiency of waste segregation and recycling. The key contributions of this work are outlined below:

The model achieves high-accuracy classification across six distinct waste categories. A novel deep learning architecture, Recyclable Waste Classification Network (RWC-Net), is proposed specifically for this task. Visual interpretability is incorporated using Score-
CAM (Class Activation Mapping) to generate saliency maps, offering a visual explanation of the model's predictions. Its adaptability to different waste environments and integration with smart bins make it a practical solution for automated waste management systems. **Advantages of Proposes System**

The proposed RWC-Net model combines the strengths of two powerful deep convolutional neural networks— DenseNet201 and MobileNet-V2. This hybrid approach is designed to exploit the complementary advantages of both architectures: DenseNet201 provides efficient feature reuse and gradient flow, while MobileNet-V2 contributes lightweight and high-speed processing. Together, they deliver a highly effective and reliable solution for automated waste image classification.

System Architecture

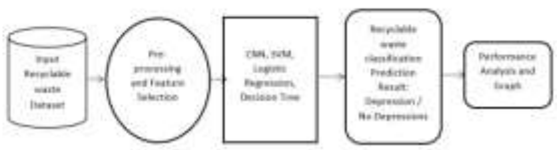

Fig 4.1 System Architecture

5. METHODOLOGY

Modules Description:

The proposed system is structured into two key functional modules: the **Remote User** and the **Service Provider**, each fulfilling a distinct role in the biodegradable waste classification workflow. The **Remote User** module is designed for general users who interact with the system primarily for waste prediction purposes. Once registered, users gain access to a personalized profile where they can manage their details and view a history of their previous predictions. The central feature for remote users is the prediction interface, which allows them to upload images of waste materials. Upon submission, the system processes these inputs using the underlying deep learning model and classifies the waste into one of six categories—cardboard, glass, metal, paper, plastic, or litter. Along with the predicted category, the system provides a confidence score, thereby offering transparency and insight into the model's decision-making process.

On the other hand, the **Service Provider** module acts as the administrative backbone of the system. Service providers are responsible for managing all user activities and system-wide predictions. They can access a comprehensive list of registered users, along with detailed logs of their interactions and submitted predictions. Furthermore, service providers have the ability to view all prediction results generated by the system, which includes metadata such as timestamps, predicted waste categories, and confidence levels. To facilitate deeper understanding and system monitoring, this module also includes graphical representations of the data, enabling visualization of trends in waste category predictions, user engagement patterns, and model performance over time. Additionally, the system provides an option to download the entire prediction dataset, allowing for further analysis, model improvement, or auditing. This structured modularity ensures clear role separation, system accountability, and scalability, while delivering a seamless and efficient user experience for both end-users and administrators.

6. RESULT

The experimental evaluation of the proposed RWC-Net model was conducted using the widely recognized TrashNet dataset, which consists of 2,527 labeled images spanning six categories of recyclable and biodegradable waste: cardboard, glass, metal, paper, plastic, and litter. The model was developed by combining two powerful convolutional neural network architectures—DenseNet201 and MobileNet-v2— capitalizing on their complementary strengths to enhance classification performance.

Upon training and testing, the model achieved a highly promising overall accuracy of **95.01%**, outperforming several state-of-the-art deep learning models reported in prior studies. The model's robustness was further validated by its high F1-scores across all categories: 97.24% for cardboard, 96.18% for glass, 94% for metal, 95.73% for paper, 93.67% for plastic, and 88.55% for litter. These results demonstrate the model's strong generalization capabilities, even in the presence of varied image characteristics such as lighting, background clutter, and object orientation.

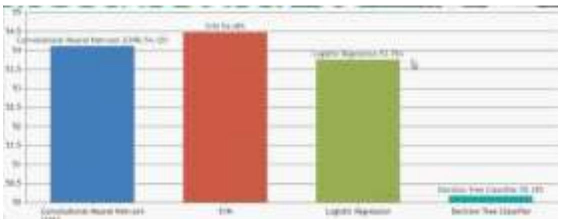

Fig 6.1 Bar Graph

To provide interpretability and qualitative assurance, Score-CAM (Class Activation Mapping) was used to generate saliency maps, highlighting the specific image regions that influenced the model's predictions. These visual explanations offer a transparent view of the internal decision process of the model, further affirming its reliability in identifying key features associated with each waste type.

In addition to prediction accuracy, the system's usability was validated through the deployment of a web-based interface, where users could upload waste images and instantly receive prediction results. The real-time response and intuitive design confirmed the system's practical viability for real-world applications, including integration into smart waste management platforms or mobile apps.

Overall, the experimental results affirm that the proposed RWC-Net model not only achieves state-of-the-art accuracy but also maintains a balance between computational efficiency and model interpretability, making it a reliable solution for sustainable and intelligent biodegradable waste classification.

7. CONCLUSION

In this study, we proposed and evaluated a robust deep learning framework, RWCNet, specifically designed for the classification of biodegradable and recyclable waste. By integrating the strengths of DenseNet201 and MobileNetv2, the model was able to capture both deep and lightweight feature representations, resulting in superior classification performance. Trained and tested on the TrashNet dataset, the model achieved an impressive accuracy of 95.01%, with high F1-scores across all six waste categories, validating its effectiveness in real-world waste sorting scenarios.

The integration of Score-CAM for saliency map generation further enhanced the transparency of the system, offering valuable insights into the model's decisionmaking process. This interpretability feature not only increases user trust but also supports system validation in critical waste management applications. Moreover, the successful deployment of a web-based interface demonstrates the practicality and accessibility of the system, enabling seamless interaction for both users and administrators.

Overall, the proposed system addresses key limitations of earlier approaches by delivering high accuracy, interpretability, and operational efficiency. It contributes meaningfully to the advancement of sustainable waste management practices and lays a solid foundation for future work, such as real-time mobile deployment, extension to additional waste categories, and integration with smart city infrastructures.

8. REFERENCES

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