

المهمة الاولى : خطوات البحث العلمي التي اتبعتها في رسالة الماجستير.

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المادة : مهارات بحثية 2
إشراف : د نرمين موسى



عنوان البحث والبيانات الأساسية

•العنوان: تعزيز تصنيف النفايات البلاستيكية
باستخدام الذكاء الاصطناعي من أجل
الاستدامة.

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•الجامعة: جامعة ميدأوشن - كلية المعلوماتية.

Midocean University
College of Informatics

Master of Science in Artificial Intelligence

Master Thesis Proposal:

***"Enhancing Plastic Waste Classification
with AI for Sustainability "***

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الشعور بالمشكلة وتحديها

• **المشكلة:** أزمة النفايات العالمية وزيادة حجم النفايات الصلبة في السعودية (15 مليون طن سنوياً).

• **التحدي المحلي:** انخفاض معدلات إعادة التدوير في المملكة (أقل من 5%) والاعتماد على الفرز اليدوي غير الفعال.

• **الأثر:** التلوث البيئي وزيادة الانبعاثات الكربونية.

Chapter 1: Introduction

The global waste crisis, driven by rapid urbanization and industrial expansion, poses significant environmental challenges, particularly in Saudi Arabia, where the country generates approximately fifteen million tons of solid waste annually [22]. Plastic waste, a major component of this volume, contributes to soil degradation, groundwater pollution, and marine ecosystem damage when improperly managed [21]. In Jeddah, for instance, the largest landfill receives over 5,000 tons of waste daily, threatening nearby communities with pollution-related health risks [16]. The recycling rate in Saudi Arabia remains below 5%, a stark contrast to global standards [17], due to inadequate infrastructure, limited public awareness, and reliance on inefficient manual sorting methods.

Figure 1. Plastic Recycling Rates: Saudi Arabia Vs. Global Average Vs. Germany (Packaging)



1.2 Thesis Objectives

The main objective of this study is to develop an intelligent classification system for plastic waste using AI to enhance waste management in Saudi Arabia, aligning with Vision 2030 sustainability goals [16]. The specific objectives are as follows:

- Apply Convolutional Neural Networks (CNNs) to classify plastic waste based on image data [26].
- Evaluate the accuracy of classifying several types of plastic waste using CNNs in real-world scenarios [26].
- Compare the AI-based classification system with traditional manual sorting methods in terms of accuracy and efficiency [2].
- Identify key challenges in training a CNN model for plastic waste classification, particularly regarding data quality and availability [25].
- Apply optimization techniques to enhance the accuracy of the CNN-based classification system in diverse scenarios [29].
- Assess the quantitative and qualitative impacts of AI integration on environmental sustainability and economic outcomes in Saudi Arabia [6].

الخطوة 2: أهداف البحث (ماذا نريد أن نحقق؟)

• تطوير نظام ذكي لتصنيف البلاستيك باستخدام شبكات CNN

• مقارنة كفاءة الأنظمة الذكية بالفرز اليدوي التقليدي.

المساهمة في تحقيق مستهدفات رؤية المملكة 2030 للاستدامة.

أهمية البحث (لماذا نقوم به؟)

• الأهمية العلمية: سد الفجوة في الأدبيات المتعلقة بتصنيف الصور في البيئة السعودية.

الأهمية العملية: تقليل التكاليف التشغيلية بنسبة 25% ورفع كفاءة التدوير بنسبة 30

1.3 Thesis Contribution

This study holds both scientific and practical significance. Scientifically, it contributes to the growing body of research on AI applications in waste management by developing a tailored classification system for plastic waste using CNNs, addressing a critical gap in the literature on image-based waste sorting in the Saudi context [30]. The integration of advanced AI techniques, such as CNNs, GANs, and IoT, provides a robust framework for future research on intelligent waste management systems [28]. Practically, the study offers a scalable solution to improve recycling efficiency in Saudi Arabia [17], reducing operational costs by 25% and increasing recycling rates by 30%, which aligns with Vision 2030's goals of environmental sustainability [22]. By reducing landfill dependency and greenhouse gas emissions, this research benefits Saudi society by promoting a cleaner environment and supporting the circular economy [21]. Additionally, the proposed system can create job opportunities in data analysis and system maintenance, contributing to economic development.

إطار النظري (الأسس العلمية)
التعلم العميق: استخدام الشبكات العصبية التلافيفية CNN لاستخراج ملامح الصور تلقائياً.

تقنيات مساندة: شبكات GANs للتغلب على نقص البيانات، وإنترنت الأشياء IoT لتحسين مسارات الجمع.

This thesis is organized into several chapters to systematically address the research objectives. Chapter 1 introduces the global waste crisis, particularly in Saudi Arabia [22], and outlines the research problem, objectives, and contributions. Chapter 2 presents an overview of theoretical literature underpinning the study, including deep learning, CNNs , GANs , and IoT applications in waste management. Chapter 3 reviews previous studies on AI in waste management, identifying research gaps [24]. Chapter 4 details the proposed AI-based classification system and its architecture. Chapter 5 discusses experimental results and their implications. Finally, Chapter 6 provides a conclusion and suggests directions for future work.

Table 4: Synthesis Matrix for Literature Review:

Study	Author s	Year	Research Design	Key Findings/Results	Methodology	Limitations
Advancing Plastic Waste Classification	Choi et	2023	Experimental study on YOLO models	Achieved 91.7% classification accuracy; improved precision for PET and PET-G plastics over traditional methods.	YOLO deep learning algorithm with image sensors and pneumatic systems.	Scalability issues; high sensitivity to lighting conditions.
Automation of Plastic Recycling	Bin Daej	2024	Case study of sorting facility	Automated sorting improved accuracy by 30%, reduced manual labor, enhanced efficiency in specific facilities.	Laser and optical sorting in controlled facility.	Limited to one facility; findings lack generalizability.
Deep Learning for Recyclable Products	Ahmed	2023	Experimental CNN model	88% accuracy in recyclable product classification; reduced errors and improved operational efficiency.	CNN model trained on labeled datasets.	Small dataset size; limited diversity in training data.
WasteGAN for Robotic Sorting	Bacchi n	2024	Experimental GAN model	WasteGAN enhanced sorting accuracy by 15% via synthetic training data.	GAN-generated data for robotic sorting systems.	High computational complexity; costly training processes.
AI for Circular Economy	Božić	2023	Policy and case study analysis	Emphasized AI's role in resource optimization, cost savings, and addressing policy gaps for circular economy.	Case study reviews and policy framework analysis.	High implementation costs; lack of cohesive global policies.
AI and IoT for Sustainability	Yadav	2024	Framework design for IoT + AI	Improved waste management efficiency by 40%; reduced processing times with IoT and AI integration.	IoT sensors and AI-based real-time monitoring framework.	Integration challenges with heterogeneous technologies.
Deep Learning for E-Waste Management	Oise & Kony Eha	2024	Supervised learning for e-waste	High accuracy in identifying recyclable e-waste components; cross-applicability for plastic recycling.	Supervised learning on labeled e-waste datasets.	Material complexity; reliant on high-quality datasets.
Commercial Automated Sorting	Alexandridis	2022	Analysis of sorting technologies	Increased throughput with automation but struggled with complex materials like multilayer plastics.	Data-driven analysis in Material Recovery Facilities (MRFs).	U.S.-focused findings; limited global relevance.
AI in Underserved Communities	Nwoke di	2024	Surveys and case studies	Enhanced segregation accuracy and community participation; cost barriers hindered scalability.	Surveys and AI implementations in low-resource areas.	High costs limited scalability in underserved settings.
Bibliometric Analysis of Recycling Trends	Tsutomoto & Kajikawa	2022	Bibliometric analysis	Highlighted interest in AI for recycling; need for practical applications and interdisciplinary approaches.	Analysis of 35,000+ studies on recycling trends and technologies.	Lack of practical case studies or real-world application insights.

الدراسات السابقة (ماذا فعل الآخرون؟)

•مراجعة دراسات مثل (Choi et al., 2023) الذي حقق دقة 91.7%.

تحديد الفجوة المعرفية: ندرة الأنظمة المصممة خصيصاً للسياق السعودي والمجربة في ظروف ميدانية حقيقية.

Chapter 4: Experimental Methodology, Results, and Discussion

4.1 Introduction

This chapter presents a comprehensive empirical framework for the development and evaluation of deep learning models for the automated classification of waste. In a consolidated approach, this chapter integrates the description of the followed methodology with a thorough analysis of the experimental results, ensuring a cohesive and logically consistent scientific narrative. The chapter begins with a detailed description of the dataset and the preprocessing pipeline, followed by the training and evaluation strategy. Subsequently, the performance of each individual and hybrid model is presented and analyzed, culminating in a comprehensive comparative analysis aimed at identifying the optimal solution that balances accuracy, efficiency, and stability.

These experiments were designed to achieve two primary objectives: first, to rigorously evaluate the efficacy of the Transfer Learning strategy using a range of well-established Convolutional Neural Network (CNN) architectures. Second, to explore the performance of advanced hybrid architectures, thereby pushing the boundaries of classification accuracy in this domain. All experiments were conducted on a public dataset comprising 22,564 images for training and 10,617 images for testing and validation, classified into two primary categories: "Organic (O)" and "Recyclable (R)". A computing environment equipped with an NVIDIA GeForce GTX 950M Graphics Processing Unit (GPU) was utilized to accelerate the computationally intensive training process. A standardized training methodology, including the Adam optimizer, Cross-Entropy loss function, and an early stopping mechanism, was uniformly applied to ensure a fair and robust comparison across all models.

منهج البحث (خطة العمل)
المنهج: منهج تجريبي تطبيقي.

البيانات: استخدام 22,564 صورة للتدريب و 10,617 صورة للاختبار (فئات عضوية وقابلة للتدوير).

الأدوات: استخدام لغة Python، مكتبات OpenCV وPyTorch، ومعالج رسومي NVIDIA GTX 950M.



4.3 Experimental Design and Training Methodology

4.3.1 Architectures Under Investigation

To provide a comprehensive evaluation, a diverse set of architectures representing different generations of CNN evolution and advanced hybrid models were selected:

- Single Models: ResNet18, VGG16, DenseNet121, EfficientNet-B0, MobileNetV3.
- Hybrid Models: An Ensemble Model (combining the top three single models) and an innovative CNN-Transformer architecture.

4.3.2 Transfer Learning and Fine-Tuning Strategy

The transfer learning strategy was applied to all single models. All parameters of the pre-trained network were initially frozen by setting their requires_grad attribute to False to preserve the learned generic features. The final classifier layer was then replaced with a new layer tailored to the binary classification task. For certain models like ResNet18, a fine-tuning approach was implemented by unfreezing the final convolutional blocks to allow the model to adapt its high-level features to the specific nuances of waste imagery.

تحليل البيانات والنتائج (النتائج التجريبية)
اختبار عدة نماذج: ResNet18, VGG16, MobileNetV3.

النتيجة الأبرز: تفوق نموذج (CNN-Transformer) الهجين.

الدقة المحققة: وصول دقة التصنيف إلى 97.65%.

عرض البيانات (مقارنة النماذج)

توضيح العلاقة بين الدقة ووقت التدريب والاستقرار لكل نموذج.

Table 5: Comparative Performance Metrics of Tested Models

Model	Best Validation Accuracy (%)	Approx. Training Time	Precision	Recall	F1-Score
CNN-Transformer	97.65%	~1.3 hours	0.98	0.98	0.98
ResNet18	96.22%	~5 hours	0.94	0.94	0.94
Ensemble Model	96.00%	(Evaluation Only)	0.96	0.96	0.96
DenseNet121	95.46%	~2.2 hours	0.95	0.95	0.95
VGG16	95.13%	~1.3 hours	0.96	0.96	0.96
EfficientNet-B0	94.22%	~44 minutes	0.94	0.94	0.94
MobileNetV3	93.79%	~18 minutes	0.94	0.94	0.94

النتائج والتوصيات

الخلاصة: النماذج الهجينة هي الحل الأمثل لتحقيق التوازن بين الدقة والاستقرار.

التوصية: تطبيق النظام في مرافق إعادة التدوير السعودية وإطلاق حملات توعية مجتمعية.

4.7 Final Recommendation

Based on its superior performance across all key metrics—accuracy, stability, and innovation—the hybrid CNN-Transformer model is the definitive recommendation for the proposed system. This choice is justified by its high accuracy of 97.65%, its excellent training stability, and its alignment with the research theme of utilizing emerging technologies. This research successfully demonstrates that applying advanced hybrid architectures can achieve state-of-the-art results in automated waste classification, paving the way for effective, real-world applications that contribute to sustainability goals.

References

- [1] Alexandridis, G., et al. (2022). Assessment of commercial automated sorting technologies for plastic waste. *Recycling*, 7(2), 11. <https://doi.org/10.3390/recycling7020011>
- [2] Nwokedi Egwu, Z. Q. S., & Ugwuanyi, E. D. (2024). Implementing AI-driven waste management in underserved communities. *Engineering Science & Technology Journal*. <https://www.fepbl.com/index.php/esti/article/view/903>
- [3] Oise, G. P., & Konyeha, S. (2024). Deep learning system for e-waste management. *Engineering Proceedings*. <https://www.researchgate.net/publication/381708613>
- [4] Ahmed, M., et al. (2023). Deep learning approach to recyclable product classification. *Sensors*, 15(14), 11138. <https://www.mdpi.com/2071-1050/15/14/11138>
- [5] Bacchin, M., et al. (2024). WasteGAN: Data augmentation for robotic waste sorting. *Journal of Physics: Conference Series*. <https://arxiv.org/abs/2409.16999>
- [6] Božić, V. (2023). Leveraging AI for a circular economy. *International Journal of Science and Research Archive*. <https://www.researchgate.net/publication/371417616>
- [7] Choi, et al. (2023). Advancing plastic waste classification and recycling efficiency. *Applied Sciences*, 13(18), 10224. <https://doi.org/10.3390/app131810224>
- [8] Abiodun, O. I., et al. (2018). State-of-the-art in artificial neural network applications: A survey. *Heliyon*, 4.
- [9] Goodfellow, I., Bengio, Y., & Courville, A. (2016). *Deep learning*. MIT Press.
- [10] LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature*, 521(7553), 436–444.
- [11] Ellen MacArthur Foundation. (2013). *Towards the circular economy*.



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