Waste Segregation

*Abstract*—This research addresses the challenge of manual waste segregation by proposing the development of a computer vision-based automated waste segregation system. The system aims to accurately identify and segregate recyclable materials, including plastic, glass, paper, and metal, in real-time. The objectives encompass the creation of a robust material identification algorithm, implementation of real-time image processing, establishment of a comprehensive data logging system, and designing for scalability and integration with existing waste management infrastructure. The project also emphasizes accuracy and reliability testing under diverse waste scenarios. This work contributes to advancing sustainable waste management practices, offering a scalable solution for modernizing global waste processing.

# Introduction

The escalating challenges posed by mounting global waste volumes and environmental concerns necessitate innovative solutions for effective waste management. Recognizing the limitations of traditional methods, this project endeavours to design and implement an advanced automated waste sorting and recycling system. Leveraging cutting-edge computer vision and deep learning techniques, the proposed system aims to revolutionize waste classification, enhance recycling processes, and seamlessly integrate with existing waste management infrastructure. The critical aspects of this project encompass a comprehensive spectrum of considerations, each contributing to the system's robustness and adaptability. From the development of an automated recycling bin to real-world implementation, user interaction design, and continuous model improvement, this project unfolds as a multifaceted initiative. A primary focus lies in achieving robustness in complex environments, particularly addressing the intricacies of cluttered scenarios, such as construction waste sites. By delving into the challenges specific to these environments, the project seeks to optimize the system's performance, ensuring accurate waste classification even in demanding settings. Recognizing the diversity of waste streams encountered in reality, the project extends its scope beyond single-label classification. The aim is to accommodate scenarios where multiple types of waste coexist in a single image, providing a more nuanced and accurate representation of real-world waste scenarios. Dynamic adaptation is a core consideration, with the project focusing on mechanisms that allow the system to evolve alongside changing waste patterns and materials. The implementation of continuous model training ensures the system remains up-to-date and resilient, adapting seamlessly to variations in waste composition over time.

Quantitative analysis methods, including precision, recall, and F1 score metrics, are integrated to provide a comprehensive evaluation of the system's efficiency and effectiveness in waste sorting. This quantitative approach ensures that the system not only meets but exceeds performance expectations, fostering confidence in its real-world application. End-to-end system integration is a central goal, emphasizing the importance of compatibility and collaboration with existing waste management infrastructure. By striving for seamless integration at various stages of waste processing, the project aims to position the automated waste sorting and recycling system as a transformative force in modern waste management practices. This project emerges as a holistic and forward-thinking endeavour, poised to address the complexities of waste management through advanced technology. By amalgamating expertise in computer vision, deep learning, and real-world implementation, the project aspires to contribute to a sustainable and efficient waste management paradigm.

# Dataset Used

In this study, we utilized a waste segregation image dataset sourced from Kaggle. The dataset has been systematically organized into training (train) and validation (val) subsets, each further divided into Biodegradable and Non-Biodegradable classes. The Biodegradable class encompasses four distinct categories: Paper, Leaf, Food, and Wood. Conversely, the non-biodegradable class includes Waste, Plastic Bags, Plastic Bottles, and Metal Cans. This classification scheme provides a granular representation of waste materials, enabling our model to discern between different types of biodegradable and non-biodegradable items. The dataset is publicly accessible at the following link: Waste Segregation Image Dataset.

# Literature review

The prevailing issue in Morocco revolves around the inefficiencies in waste collection, leading to not only high operational costs but also the wastage of valuable resources such as fuel and time. Furthermore, the challenge extends to the complexities of ensuring proper recycling and effective separation of materials. In response, we propose a comprehensive solution in the form of a smart waste management system that harnesses the power of machine learning (ML) and the Internet of Things (IoT). Machine learning algorithms will play a pivotal role by optimizing collection routes based on predictive models of waste generation. This not only reduces the overall cost of collection but also minimizes unnecessary trips, consequently saving resources and reducing the carbon footprint associated with fuel consumption. Additionally, ML will enhance recycling accuracy through the precise classification of waste materials, contributing to improved waste management practices. Simultaneously, the integration of IoT will be instrumental. By attaching sensors to waste bins, real-time data on fill levels can be obtained, providing a dynamic understanding of waste accumulation. This information will enable the implementation of flexible and responsive collection schedules, ensuring that collection activities align with the actual needs of each location. The result is a more adaptive and efficient waste collection process. The envisioned benefits of this smart waste management system extend beyond operational efficiency. It promises a reduction in resource waste, both in terms of fuel and time, through optimized collection routes. The improved recycling accuracy contributes to overall better waste management practices, aligning with sustainability goals. Moreover, real-time data insights derived from the IoT sensors empower decision-makers with the information needed for proactive and informed waste management strategies. In considering the implementation, it is essential to evaluate and select specific ML algorithms tailored to the optimization and classification requirements. Additionally, a thorough cost-benefit analysis is imperative to gauge the economic feasibility of introducing this transformative waste management solution. Ultimately, the proposed system not only addresses the immediate challenges but also holds the potential to bring about positive environmental impacts through reduced fuel consumption and emissions.

The issue of inefficient waste segregation leading to mixed waste streams, increased dependence on landfills due to limited space, and economic inefficiencies resulting in escalated waste management costs and potential loss of valuable resources necessitates a comprehensive solution. This paper proposes the implementation of an image classification model utilizing Capsule Neural Networks (CapsNets) to categorize solid waste into six distinct classes: cardboard, glass, metal, paper, plastic, and trash. The key elements of this proposed solution include multi-label image classification, allowing simultaneous categorization into multiple waste classes, and the utilization of CapsNets to capture spatial relationships and pose information within images. This approach is particularly advantageous in enhancing accuracy, especially when dealing with smaller datasets. Dataset augmentation is also incorporated to extend the existing dataset, promoting better model generalizability and robustness. The anticipated benefits of this model are substantial. By improving waste segregation, the increased accuracy leads to a cleaner separation of waste materials. The enhanced recycling efficiency that follows enables better outcomes in recycling processes and mitigates contamination. Furthermore, the reduction in landfill dependence is a critical environmental benefit, as diverting recyclable materials from landfills minimizes the overall environmental impact. Additionally, there is potential for economic benefits, as increased recycling could create new job opportunities and open market possibilities for recovered materials. Despite these promising benefits, certain considerations should guide further research and implementation. Firstly, there is room for exploring finer-grained classification to refine waste categorization further, potentially enhancing the effectiveness of recycling processes. Additionally, while the focus of this research is on classification, seamless integration with existing recycling infrastructure and automation systems is essential for practical implementation. Ethical considerations, including potential biases in training data or algorithms, accessibility and inclusivity aspects of implementation, and responsible data management practices, also need thorough attention to ensure the fair and equitable deployment of such technologies.

Waste management in smart cities presents a critical challenge, with existing solutions proving ineffective in meeting recycling requirements and hindering the realization of a circular economy vision. This paper proposes a digital model to address inefficiencies in waste sorting by leveraging artificial neural networks (ANN) and features fusion techniques. Through image processing, diverse features are extracted from waste images, contributing to the construction of multiple models, each providing a singular decision. Machine learning is then employed to determine the waste type class, enabling automated sorting and classification based on recycling requirements. The benefits of the proposed model are substantial. Achieving a high accuracy rate of 91.7%, the model demonstrates its capability to automatically sort and classify waste, thereby enhancing overall waste management efficiency. By classifying waste types based on recycling requirements, the model contributes to optimizing recycling decisions, aligning with the circular economy vision. This, in turn, promotes a more sustainable and environmentally friendly waste management approach. Furthermore, the integration of digital technologies, ANN, and features fusion not only addresses the immediate waste management challenge but also supports the broader vision of a circular economy in smart cities. The proposed model paves the way for smarter, technology-driven waste management practices, aligning with sustainability goals and fostering a digital-enabled circular economy vision. As this research progresses, several considerations are crucial. The scalability of the model for implementation in larger smart city environments should be explored, ensuring seamless integration with existing waste management infrastructure for widespread adoption. Additionally, adaptability is key, and further exploration is needed to make the model responsive to evolving waste patterns and emerging recycling requirements. This could involve continuous learning mechanisms and updates based on real-world data, ensuring the continued relevance and effectiveness of the proposed digital waste management solution.

The escalation of construction activities has given rise to a surge in construction waste (CW), posing a critical challenge for waste processing and management in smart cities. The inadequacy of existing waste management efforts, stemming from the lack of timely and accurate information about the composition of CW crucial for proper segregation and disposal, underscores the need for innovative solutions. This paper addresses the challenges posed by the mixture and clutter nature of CW through the proposition of a computer vision (CV) approach for automating CW composition recognition. The proposed solution leverages CV technologies, specifically employing the state-of-the-art semantic segmentation technique known as DeepLabv3+. This method involves meticulous efforts in data collection, cleansing, and annotation to construct a high-quality CW dataset consisting of 5,366 images. The semantic segmentation model is trained to identify and segment nine types of materials/objects present in CW. Extensive testing of various training hyperparameters is conducted, resulting in a calibrated model performance with a mean Intersection over Union (mIoU) of 0.56 and a time performance of 0.51 seconds per image. The approach proves to be robust in recognizing the composition of CW mixtures in complex and cluttered environments, including variations in illumination and vehicle types. The benefits of the proposed CV model are multifaceted. It enhances the efficiency of waste processing by providing detailed composition information, thereby facilitating proper waste segregation and disposal. Furthermore, the research lays the groundwork for automated waste segregation using intelligent robots. By recognizing specific material types, positions, and dimensions, robots can replace human workers, leading to higher throughput, reduced occupational hazards, and improved recycled material quality. Importantly, the proposed semantic segmentation approach is designed for real-life scenarios with unstructured and cluttered backgrounds, addressing the challenges specific to CW composition recognition in diverse construction environments. As this research advances, several considerations are paramount. Future studies should explore the scalability and generalization of the proposed CV model to handle diverse CW scenarios and materials, ensuring its applicability in various real-world environments. Additionally, incorporating adaptive mechanisms into the CV model would enable it to perform effectively in dynamic and changing environments, reflecting the realities of construction sites and ensuring sustained effectiveness over time.

The persistent environmental threat posed by non-biodegradable polythene remains a significant concern, with current waste management practices struggling to efficiently segregate polythene bags from other waste. Manual handpicking, the primary method employed, not only poses health hazards to workers but also proves inefficient due to human errors. In response, the proposed solution advocates for the implementation of an image-based classification system utilizing a deep-learning model. This model is meticulously designed to accurately identify and classify polythene bags within a given dataset, with a focus on the architecture and statistical analysis of its performance. The anticipated benefits of this solution are substantial. The automated image-based classification system is expected to significantly improve the efficiency of polythene bag segregation, reducing reliance on manual labor and minimizing errors. This not only enhances operational efficiency but also addresses health hazards associated with manual handling of waste, particularly polythene bags, thus ensuring the well-being of workers involved in waste management. Moreover, accurate classification and segregation of polythene bags contribute to better recycling processes, promoting environmental conservation. Proper disposal and recycling can substantially reduce the negative impact of polythene on ecosystems, aligning with broader sustainability goals. As this solution is considered for implementation, several crucial considerations are highlighted. A comprehensive cost-benefit analysis is essential to evaluate the economic feasibility of adopting the proposed image-based classification system compared to existing waste management practices. This analysis should encompass initial setup costs, operational expenses, and long-term benefits to provide a holistic understanding of the economic implications. Furthermore, collaboration with environmental organizations, governmental bodies, and community stakeholders is paramount. Advocacy for the adoption of the image-based classification system in wider waste management policies and practices is crucial for its successful integration into existing frameworks. This collaborative approach ensures a more holistic and impactful solution to the challenges posed by polythene waste, fostering a sustainable and environmentally conscious waste management system.

The escalating volume of domestic waste in China, coupled with low resource utilization rates, presents a pressing environmental challenge. The recent enactment of new Waste Management Regulations in Shanghai underscores the critical importance of effective waste management, particularly the need for efficient waste classification to address pollution and land occupation issues. In response, the proposed solution advocates for the implementation of an image-based classification system using a deep-learning model. This model is meticulously designed to accurately identify and classify various waste materials within a given dataset, with a specific focus on polythene bags. The emphasis is on the architecture and statistical analysis of the model's performance, addressing challenges encountered during the classification process. The benefits of this solution are profound. The Recognition-Retrieval Model (RevM) demonstrates a significantly higher average accuracy of 94.71% compared to the one-stage ClfM (69.66%) and Manual Sorting (MS) by participants (72.50%). This high accuracy contributes to the efficient sorting of domestic waste, reducing reliance on manual labor and improving overall sorting accuracy. Moreover, the proposed algorithm and models align with Waste Management Regulations, ensuring proper waste classification according to the four-category system. This compliance with regulations enhances the sustainability and effectiveness of waste management practices. As this solution is considered for wider implementation, several key considerations are highlighted. A comprehensive cost-benefit analysis is essential to assess the economic feasibility of scaling up the proposed system. This analysis should consider factors such as initial setup costs, operational expenses, and long-term benefits to provide a holistic understanding of the economic implications. Additionally, ensuring a user-friendly interface for the automatic sorting machine is crucial for easy integration into existing waste management infrastructure. A user-friendly interface enhances the practicality and accessibility of the system, contributing to its successful adoption on a larger scale.

The detection and assessment of segregation in asphalt mixtures, a crucial factor influencing the early-stage failure of asphalt pavements, currently face challenges with subjective visual observation or inefficient traditional recording methods. This paper presents a comprehensive framework that integrates Digital Image Processing (DIP) and Building Information Modeling (BIM) technologies to address these challenges and enhance accuracy, efficiency, and objectivity in segregation assessment. The DIP component introduces a new algorithmic language capable of extracting detailed image information, including segmentation number and edge length, providing a more detailed and accurate analysis of asphalt mixture segregation. A quantitative index is introduced to objectively evaluate the extent of segregation, categorizing it into mild, moderate, and severe levels, reducing subjectivity in assessment. The framework leverages BIM for 3D visualization of segregation detection results, offering an intuitive representation of findings to aid in result interpretation and decision-making during the construction phase. The proposed solution provides several benefits. The incorporation of DIP enhances accuracy in segregation analysis, providing parameters for improved detection. The quantitative index introduces objectivity and standardization in assessing the extent of segregation. Integration with BIM enables efficient 3D visualization, improving productivity and aiding in intuitive result interpretation. Additionally, the framework offers a cost-effective and operationally straightforward solution compared to traditional methods, reducing time-consuming tasks in asphalt pavement management. As this solution is considered for wider adoption, continuous technological integration is recommended to stay abreast of advancements in DIP and BIM, enhancing the framework's capabilities. Exploring the incorporation of emerging technologies can further improve accuracy and efficiency in segregation detection. Encouraging industry adoption is crucial for the success of the proposed framework. Advocating for standardized methodologies and collaborating with relevant stakeholders can contribute to widespread acceptance and utilization. Establishing industry standards will facilitate the seamless integration of the framework into asphalt pavement management practices, ensuring its effectiveness and longevity in addressing the challenges associated with asphalt mixture segregation.

Accurate waste classification is pivotal for effective waste management, yet existing studies primarily focus on single-label waste classification, diverging from real-world scenarios where multiple waste types may coexist in an image. Additionally, suboptimal quality in existing waste classification datasets poses challenges in model training and evaluation. This paper proposes a Multi-Task Learning Architecture (MTLA) based on a convolutional neural network (CNN) to overcome these limitations. The MTLA is intricately designed to simultaneously identify and locate waste items in images, introducing a shared backbone network with attention modules, a novel feature pyramid network, and a group of joint learning multi-task subnets. Tailored loss functions emphasize joint optimization of waste identification and location, incorporating the concepts of focusing and joint learning. The framework utilizes a new dataset with bounding box annotations and multiple labels for training, aiming to enhance the realism and complexity of waste classification scenarios. The benefits of this proposed solution are manifold. The MTLA allows for the simultaneous identification and localization of various waste items in images, offering a more realistic approach to waste management than single-label classification. Notably, the framework achieves high performance while maintaining low computation requirements, rendering it practical for real-world applications and enhancing efficiency in waste management systems. The introduction of a new dataset with improved annotations contributes to enhancing the quality of data available for training and evaluating waste classification models. A simple and effective visualization method using heatmaps is introduced, enabling the interpretation of the framework's high discriminative and localization abilities. This enhances transparency and understanding of the model's decision-making process, contributing to its interpretability. As the proposed solution progresses, continuous dataset expansion and diversification are recommended to capture a broader range of waste scenarios, ensuring the model's adaptability to diverse real-world situations. Addressing dataset challenges, such as incorrect labeling and multi-labeling, is imperative to improve the realism and reliability of the training data, fostering the development of a more robust waste classification model.

Recycling solid waste is imperative for mitigating environmental impact, but the complex and expensive sorting process poses a significant challenge. Manual sorting is labor-intensive, and traditional methods struggle to efficiently classify recyclable waste into specific categories. The proposed solution introduces an automated recycling bin system that accurately identifies and classifies recyclable waste, contributing to more effective and sustainable waste management.The system focuses on five main categories: plastic, metal, paper, cardboard, and glass. An automated recycling bin is conceptualized, equipped with the ability to identify waste types and automatically open the lid corresponding to the identified category. The core of the system relies on Machine Learning algorithms, particularly Convolutional Neural Networks (CNN), to efficiently recognize and classify waste items. Experimentation with pre-existing images involved training a minimum of 12 variants of the CNN algorithm using three classifiers: Support Vector Machine (SVM), Sigmoid, and SoftMax. The VGG19 architecture with the SoftMax classifier demonstrated promising results, achieving an accuracy of around 88%. The benefits of this proposed solution are substantial. By automating waste identification and classification, the system streamlines the recycling process, reducing the reliance on manual sorting and enhancing overall efficiency. The utilization of Deep Learning algorithms, specifically CNN, improves the accuracy of waste classification, leading to more precise sorting of recyclable materials into distinct categories. This, in turn, contributes to reducing environmental impact by promoting better recycling practices, minimizing the use of landfills, and fostering sustainable waste management. As the proposed solution progresses, continuous dataset expansion and diversification are recommended to capture a broader range of waste scenarios, ensuring the model's adaptability to diverse real-world situations. Addressing challenges in the dataset, such as incorrect labeling and multi-labeling, is crucial to enhance the realism and reliability of the training data, fostering the development of a more robust waste classification model.

# Proposed Method

To address the challenges in waste management and enhance recycling efficiency, our proposed method focuses on developing a computer vision-based automated waste segregation system. The method encompasses the following key components:

1. Automated Material Identification:

Utilize state-of-the-art computer vision techniques, including convolutional neural networks (CNNs), to create a robust material identification model. Train the model on a diverse dataset containing images of various recyclable materials such as plastic, glass, paper, and metal. Augment the dataset to enhance the model's adaptability to different scenarios. Implement transfer learning to leverage pre-trained models, accelerating the training process and enhancing the model's ability to generalize across different materials.

2. Real-time Processing:

Employ real-time image or video processing algorithms, optimizing for speed and accuracy, to ensure swift analysis of waste materials as they flow through the system. Explore parallel processing techniques and hardware acceleration to enhance the system's efficiency and minimize processing delays. Continuously optimize and fine-tune algorithms to achieve a balance between processing speed and accurate material identification.

3. Data Logging and Reporting:

Implement a comprehensive data logging system to record the types and quantities of materials processed by the system in real-time. Develop a reporting mechanism that generates detailed reports on recycling efficiency, providing insights into the composition of processed waste and the performance of the segregation system. Utilize visualization tools to present data in a user-friendly format, facilitating easy interpretation of recycling metrics.

4. Scalability and Integration:

Design the system architecture with scalability in mind, allowing it to handle varying quantities and types of waste. Ensure compatibility with existing waste management infrastructure by employing open standards and protocols Integrate the system seamlessly into different waste processing setups, considering variations in scale and operational requirements.

5. Accuracy and Reliability Testing:

Conduct thorough testing using diverse datasets that simulate challenging waste scenarios, including cluttered and mixed waste streams. Implement a rigorous evaluation framework, measuring accuracy, precision, recall, and F1 score to assess the model's performance in material identification. Validate the physical segregation process under diverse waste scenarios, ensuring reliable separation of recyclable and non-recyclable materials.

By integrating these components into a cohesive system, our proposed method aims to provide an efficient, accurate, and scalable solution for automated waste segregation, contributing to the advancement of sustainable waste management practices.At the core of our research is a groundbreaking methodology that fuses the analysis of eye, mouth, and head movements. The input for our Convolutional Neural Network (CNN) model, a cutting-edge architecture inspired by advancements like LeNet-5, AlexNet, VGG, and ResNet, consists of meticulously captured images. These images undergo classification into six distinct classes: "eye open," "eye close," "yawn," "no yawn," "head down," and "head up."

Our dataset, comprising 3,598 carefully curated images with an approximate distribution of 720 images per class, forms the empirical foundation of our research. Empirical results underscore the efficacy of our model, achieving a notable 95% accuracy after 50 epochs and an impressive 97% accuracy following 100 epochs of intensive training.

# References

1. G. Lahcen, E. Mohamed, G. Mohammed, H. Hanaa and A. Abdelmoula, "Waste solid management using Machine learning approch," 2022 8th International Conference on Optimization and Applications (ICOA), Genoa, Italy, 2022, pp. 1-5, doi: 10.1109/ICOA55659.2022.9934356. keywords: {Waste management;Waste materials;Machine learning algorithms;Costs;Smart cities;Machine learning;Containers;machine learning;smart city;Internet of Things;waste management},
2. Verma, R.K., Agarwal, S. (2021). Waste Segregation to Ease Recyclability. In: Singh, B., Coello Coello, C.A., Jindal, P., Verma, P. (eds) Intelligent Computing and Communication Systems. Algorithms for Intelligent Systems. Springer, Singapore. <https://doi.org/10.1007/978-981-16-1295-4_25>
3. A. Aishwarya, P. Wadhwa, O. Owais and V. Vashisht, "A Waste Management Technique to detect and separate Non-Biodegradable Waste using Machine Learning and YOLO algorithm," 2021 11th International Conference on Cloud Computing, Data Science & Engineering (Confluence), Noida, India, 2021, pp. 443-447, doi: 10.1109/Confluence51648.2021.9377163. keywords: {Machine learning algorithms;Webcams;Biological system modeling;Machine learning;Data models;Testing;Biomedical imaging;waste separation;non-biodegradable waste;image processing;image detection},
4. Mohammed, M.A., Abdulhasan, M.J., Kumar, N.M. et al. Automated waste-sorting and recycling classification using artificial neural network and features fusion: a digital-enabled circular economy vision for smart cities. Multimed Tools Appl 82, 39617–39632 (2023). <https://doi.org/10.1007/s11042-021-11537-0>
5. Weisheng Lu, Junjie Chen, Fan Xue, Using computer vision to recognize composition of construction waste mixtures: A semantic segmentation approach, Resources, Conservation and Recycling, Volume 178, 2022, 106022, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2021.106022.
6. D. Singh, "Polyth-Net: Classification of Polythene Bags for Garbage Segregation Using Deep Learning," 2021 International Conference on Sustainable Energy and Future Electric Transportation (SEFET), Hyderabad, India, 2021, pp. 1-4, doi: 10.1109/SeFet48154.2021.9375766. keywords: {Technological innovation;Statistical analysis;Transportation;Manuals;Feature extraction;Hazards;Recycling;Artificial Intelligence;Deep Learning;Environment protection;Garbage Segregation;Polythene Identification;Polythene Recycling;Sustainable development.
7. Song Zhang, Yumiao Chen, Zhongliang Yang, Hugh Gong, Computer Vision Based Two-stage Waste Recognition-Retrieval Algorithm for Waste Classification, Resources, Conservation and Recycling, Volume 169,2021,105543,ISSN 0921-3449, <https://doi.org/10.1016/j.resconrec.2021.105543>.
8. Fanlong Tang, Chengjia Han, Tao Ma, Tian Chen, Yanshun Jia, Quantitative analysis and visual presentation of segregation in asphalt mixture based on image processing and BIM, Automation in Construction, Volume 121, 2021, 103461, ISSN 0926-5805, https://doi.org/10.1016/j.autcon.2020.103461.
9. Shuang Liang, Yu Gu, A deep convolutional neural network to simultaneously localize and recognize waste types in images, Waste Management, Volume 126, 2021, Pages 247-257, ISSN 0956-053X, <https://doi.org/10.1016/j.wasman.2021.03.017>.

[10] N. Ramsurrun, G. Suddul, S. Armoogum and R. Foogooa, "Recyclable Waste Classification Using Computer Vision And Deep Learning," 2021 Zooming Innovation in Consumer Technologies Conference (ZINC), Novi Sad, Serbia, 2021, pp. 11-15, doi: 10.1109/ZINC52049.2021.9499291. keywords: {Support vector machines;Deep learning;Computer vision;Machine learning algorithms;Glass;Recycling;Plastics;Waste Classification;Recycling;Deep Convolutional Neural Network;Classifiers;Machine Learning;Computer Vision},.