Landfill Waste Classification using Deep Learning

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***Abstract*— Effective resource management is often hindered by traditional waste management methods such as visual inspection and manual sorting, which are subjective, labour-intensive, and not scalable. Machine learning, especially Convolutional Neural Networks (CNNs), offers a powerful alternative. Our work focused on waste disposal classification using a dataset with images of various waste types, including metal, plastic, paper, and glass. Initially, we trained a CNN, achieving high accuracy in classifying waste as biodegradable or non-biodegradable. To handle multiple complex waste objects in a single image, we used YOLOv8 for object recognition. Using the Aniopestra.v4i dataset, we achieved 95.1% mAP@50 and 76.3% mAP@50-95 in classifying materials into biodegradable and non-biodegradable categories. This approach promises to enhance waste management by providing more efficient and accurate waste classification, contributing to improved waste segregation and sustainability efforts.**

Keywords*— *Landfill waste detection, deep learning, machine learning

I. INTRODUCTION

Efficient and correct identification methods are essential for the management of modern waste management systems because landfill handling is a continuous issue. Today's techniques mainly involve manual sorting, which is not only time-consuming but also error-prone: laborious and error prone measures that consume a lot of time as well as reduce the accuracy in waste classification as waste management tools. These limitations prevent efficient operations and hinder sustainable development initiatives, hampering the implementation of effective waste segregation and recycling strategies. This solution addresses these problems:

- Addresses the issue of time-consuming manual sorting in current waste management techniques.
- Tackles the problem of error-prone methods that lead to inefficiencies in waste classification.
- Resolves the labour-intensive nature of manual sorting, which adds to the operational burden.
- Mitigates the reduced accuracy caused by human error in manual sorting.
- Overcomes the inefficiencies that prevent efficient operations in waste management.
- Aids in implementing effective waste segregation and recycling strategies, crucial for sustainable development.

A new approach to solid waste management that offers a systematic and comprehensive solution is the Automated Waste Classification System. The system has intelligent object detection and its deep learning algorithms enable it to analyze real-time images of mixed waste streams, thereby enabling fast and accurate classification. This can be done as the reliance on manual labor is reduced, therefore error is minimized and accuracy in identification of solid wastes increased, leading to improved overall operational efficiency.

In addition, the system's capacity to distinguish between materials that are biodegradable from those that are not has significant sustainability implications. Appropriate waste separation is key for efficient recycling and minimizing ecological footprints. The innovation therefore promotes sustainable waste management practices by automating it, which aligns with global environmental conservation initiatives and resource optimization.

To sum up, the Automated Waste Classification System Using Deep Learning for Landfill Management represents a major leap forward in waste management technology. It implements deep learning algorithms, offers real-time analysis capabilities, and emphasizes sustainability making it a milestone in the progression of waste management practices towards efficiency, accuracy and environmental stewardship.

II. RELATED WORKS

In the domain of waste classification, different ways and technologies aimed at enhancing preciseness and efficacy have been investigated in previous studies. Techniques of machine learning, for example Convolutional Neural Networks (CNN), have been used in classifying waste automatically; hence many researchers have succeeded in distinguishing several materials. Furthermore, by using sensors it is possible to improve the object disclosed.

Nafiz et al. presented ConvoWaste[1], at ICREST'23. The ConvoWaste uses Image Processing techniques and Convolutional Neural Networks (CNNs) to segregate garbage into classes such as plastics, metals, glass, organics, medicals and the electronics with an accuracy level of 98%. It has a servo motor-based mechanism for accurate disposal of waste; also fitted with ultrasonic sensors along with GSM based communication for alerting authorities when bins are filled up. This provides for efficient waste management through an Android application operated remotely. With its deep learning embedded within real-time image processing, ConvoWaste becomes a formidable solution for managing wastage. The system also makes use of a dual-band GSM module which ensures reliable remote monitoring thus overriding any limitations posed by shorter range communication protocols like LoRaWAN. Such operating features make it highly practicable in urban areas.Recycling and resource optimization are significantly enhanced by the system's automation capabilities and high accuracy, which in turn contribute to sustainable urban waste management. ConvoWaste illustrates the development of waste segregation technology that embraces sustainability and the concept of a circular economy.

Mahesh et al. presented Accurate and High-Speed Garbage Detection [2] at IOP Conference 2022 .It includes a smart waste management approach, addresses these challenges. This system uses a real-time object detection algorithm called YOLO (You Only Look Once) that uses deep learning models implemented in TensorFlow to classify different types of garbage like paper, cardboard, glass, metal, plastic etc. The system incorporates several technologies such as Raspberry Pi, TensorFlow Lite as well as ultrasonic sensors for monitoring fill levels of garbage bins in an IoT (Internet of Things) environment. The YOLO method improves both the speed of detection and accuracy; it employs convolutional neural networks to decrease noise interference from non-relevant background materials thus enhancing object detection. It operates at 915 MHz with location tracking enabled through GPS module while long-range communication is enabled through LoRa module. RFID-based locker systems are used for maintenance and upgrade purposes. By combining deep learning methods with IoT technology for waste management purposes, the process becomes highly efficient and accurate.

Gauli et al. presented YOLO Based Abandoned Garbage Detection[3] at the 13th IOE Graduate Conference. This study presents a YOLOv7 (You Only Look Once) real-time object detection algorithm-based system for identifying and classifying abandoned garbage on video streams. The system has been designed specifically for smart waste management which analyses video frames to identify different types of garbage into six classes: trash, solid waste, organic waste, dustbin, garbage bag and garbage blob. The research points out the supremacy of YOLOv7 model based on Extended-ELAN architecture as its backbone when it comes to speed and accuracy while dealing with garbage detection and classification tasks. Robustness is ensured by training the model using custom dataset collected from various locations within Pokhara Nepal under varying weather conditions. Having more than 2000 images that are annotated within the dataset significantly improves effectiveness of the model. This approach shows a significant improvement in real-time detection and classification and adds something valuable to the smart city. The integration of deep learning techniques, especially the YOLOv7 model, offers a promising solution to the critical issue of urban garbage management by ensuring the time of abandoned garbage mouth and perfectly designed.

Ouedraogo et al. Presented Landfill Waste Segregation [4] in 2023.In this research paper,they have proposed a CNN model using transfer and ensemble learning to classify landfill waste into nine classes: aluminium, carton, e-waste, glass, organic waste, paper and cardboard, plastics, textiles, and wood.There are about 8300 images in the dataset. Four models were used by them i.e. InceptionResNet, EfficientNetb3, DenseNet201 and combination of all three models. Four CNN models (Model 1: Inception–ResNet-v2 based, Model 2: EfficientNetB3 based, Model 3: DenseNet201 based, and Model 4: the Ensemble Model) were run with the waste dataset of 8346 images containing nine classes of waste. CNNs. The training was completed on 80% of the waste dataset and the remaining 20% was used for testing and validation. The networks were trained in 80 epochs. From the results they got that the Ensemble Model was the most performant model accuracy: 90% and precision: 90%) and was followed by Model 3 (accuracy: 88% and precision: 88%). Model 2 (accuracy: 87% and precision: 87%) and Model1(accuracy:86% and precision: 86%) were the poorest performing models. These results proved that combining multiple pre-trained CNNs as base models increased feature extraction abilities and led to higher prediction accuracy. The effect of waste class number on the Ensemble Model's performance was investigated by training and testing the model to predict six waste classes. The model showed a prediction accuracy of 93%, leading to the conclusion that the model's performance increases as the number of classes decreases.

Olugboja et al. presented Intelligent Waste Classification [5] in 2019.]The proposed method was developed based on the ResNet-50 pre-trained model. Dataset used was the trash image dataset which was developed by Gary Thung and Mindy Yang. They used 4 classes i.e glass,metal , paper and plastic. In conclusion, they proposed a waste classification system that is able to separate different components of waste using the Machine learning tools. This system can be used to automatically classify waste and help in reducing human intervention and preventing infection and pollution. From the result, when tested against the trash dataset, they got an accuracy of 87%. The separation process of the waste will be faster and intelligent using our system without or reducing human involvement. If more image is added to the dataset, the system accuracy can be improved.

Our project revolutionizes waste management by integrating advanced deep learning algorithms for automated waste classification, addressing the limitations of manual sorting. By leveraging CNNs for accurate material identification and YOLOv8 for robust object detection, our system ensures high precision in categorizing waste into biodegradable and non-biodegradable types. This approach reduces human error, enhances processing speed, and decreases operational costs. Ultimately, it fosters improved recycling efficiency and supports sustainable waste management practices, aligning with global environmental goals.

Paper	Model Used	Accuracy	Dataset
ConvoWaste: An Automatic Waste Segregation [1]	Inception ResnetV2 with multiple layers	98 %	Six different waste categories dataset
Intelligent Waste Classification System Using Deep Learning [5]	ResNet 50	87 %	Six different waste categories dataset
Accurate and High-Speed Garbage Detection	Yolo Model	85.7%	Different categories of waste
YOLO Based Abandoned Garbage Detection	Yolo v7	76.4% mAP	Novel custom garbage dataset
Landfill Waste Segregation Using Transfer and Ensemble Machine Learning	Ensemble model (Inception-ResNet, EfficientNetb3, and DenseNet201)	93% for 6 classes 90% for 9 classes	Nine different class waste dataset
Our Model	Yolo v8	95.1 % mAP	20 class dataset (merged in 2 classes)

III. METHODOLOGY

The automated waste classification system using deep learning for landfill management consists of several interconnected modules, each designed to contribute to the overall efficiency and accuracy of waste classification. The Image Capture Module serves as the initial component, capturing images of mixed waste on a conveyor belt. These captured images are then seamlessly transmitted to the subsequent Object Detection and Classification Modules. These models identify and localize potential waste objects within the images, proposing bounding boxes around the detected objects. The Classification Module is a pivotal component that utilizes a machine learning model trained on labelled waste images, ensuring accurate categorization into biodegradable and non-biodegradable categories. Finally, the Display Module presents the classification results, offering a visual representation for further analysis and decision-making in the waste management process.

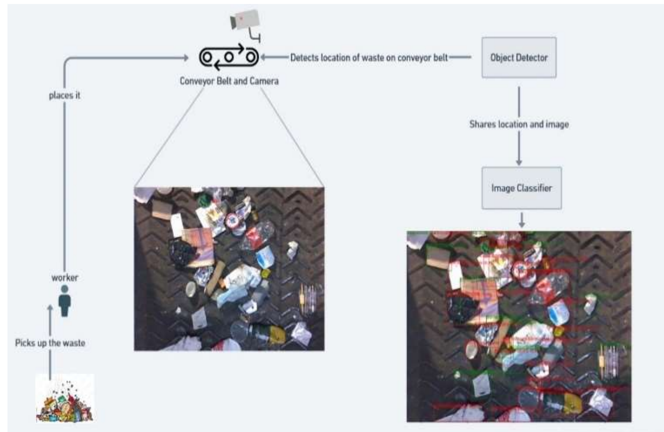

Fig. 1. Block Diagram

YOLOv8 is an improved version of the YOLO algorithm which offers spatial attention, feature fusion, and context aggregation to achieve faster and more accurate object detection. YOLOv8 architecture has a backbone which is based on a modified CSPDarknet53 with 53 convolutional layers and cross-stage partial connections to improve information flow, and a head made up of convolutional and the fully connected layers for predicting bounding boxes, objectness scores, and class probabilities. It also includes self-attention technology, which allows the model to consume on the most meaningful parts of the image for detection and a feature pyramid network that reviews the image at various levels to find items of varied sizes.

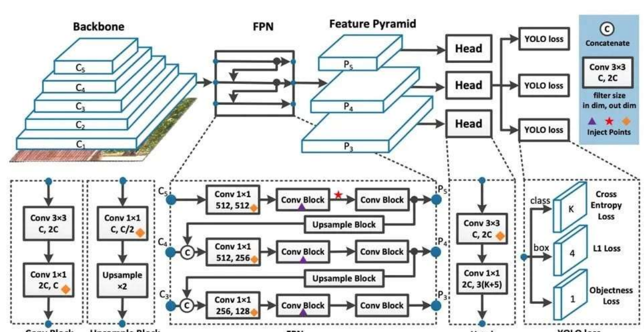

Fig. 2. Architecture of YOLOv8

IV. Dataset

Fig. 3. Dataset Image

For our object detection model training, we utilized a Aniopestra.v4i dataset consisting of 1136 training images, 226 validation images, and 153 test images. The dataset encompasses various waste items categorized into biodegradable and non-biodegradable classes. This comprehensive dataset facilitated the training of our object detection model, enabling it to accurately detect and classify waste items into their respective categories for effective waste management solutions.

Biodegradable	Non-Biodegradable
Colored paper, corrugated cardboard, mixed cardboard, and white paper.	Aluminum foil, cat food cans, clear plastic, food cans, glass, HDPE clear, HDPE color, PET clear-blue, PET colored, polypropylene, polystyrene food trays, polystyrene (other), Tetra Pack, thermoforms, universal beverage cans, and non-recyclable plastic

V. Evaluation and Results

Evaluation was done to assess the performance of the YOLOv8 model using standard object detection metrics that are tailored to automatic waste separation. Below are the results:

- Precision (P): 95.7%

  This is a measure of how well the model can correctly identify classifications of trash, which also indicates low false-positive rate. It's very precise and suggests that it has useful detection capability in order to minimize misclassification in inappropriate garbage disposal systems.
- Recall (R): 89.5%

  Recall captures on ground instances of what makes up waste materials. A recall value of 89.5% indicates little or no false negatives, thus demonstrating a good performance by the model since it can detect most rubbish present in the scene.
- Mean Average Precision (mAP) at IoU 0.50 (mAP@50): 95.1%.

  It determines how accurate a model is when detecting and classifying garbage with moderate overlap considerations at an intersection over union (IoU) threshold of 0.50; Therefore, this mAP@50 of 95.1% means that it has performed outstandingly well while focusing on its ability to be able to detect under typical operating conditions within which there are many dangerous objects around it.
- mAP@50-95: 76.3%

  Mean Average Precision across IoU thresholds ranging between 0.50 and 0.95 provides a full view of how well the model works across different levels of overlap criteria. A bit lower than mAP@50, the mAP@50-95 of 76.3 percent means performance consistent and dependable across a range of IoU thresholds.

These metrics all combine to indicate the high accuracy and real-world effectiveness of the YOLOv8 model in detecting waste items. These results put a strong accent on its good points related to the realization of accurate detections while keeping light false positives and negatives, but at the same time, further scope remains for improvement at stricter IoU thresholds.

Fig. 4. Output

Figure 5 displays the output of Waste on Conveyor Belt in two classes: Biodegradable and Non-Biodegradable. Each object in the conveyor belt is surrounded with a bounding box having a label and confidence score.

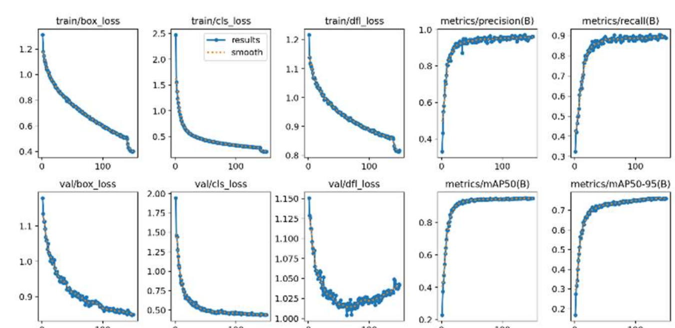

Fig. 5. YoloV8 Metrics

The model's performance is evaluated using several metrics. The training loss for bounding boxes (train/box_loss) and the classification loss during training (train/cls_loss) both show a decrease over epochs, suggesting improvements in predicting bounding boxes and classifying objects within these boxes. The detection-related training loss (train/dfi_loss) also decreases, indicating an overall enhancement in the model's detection capabilities. On the validation set, the model's precision (metrics/precision(B)) and recall (metrics/recall(B)) ideally increase over epochs, representing an improvement in the proportion of correct positive detections and the proportion of actual positive examples correctly detected by the model, respectively. The mean average precision (mAP) at a specific Intersection over Union (IoU) threshold of 0.5 (metrics/mAP50(B)) and between IoU thresholds of 0.5 and 0.95 (metrics/mAP50-95(B)) are used to evaluate the model's object detection performance, considering both precision and recall. A higher mAP indicates better model performance.

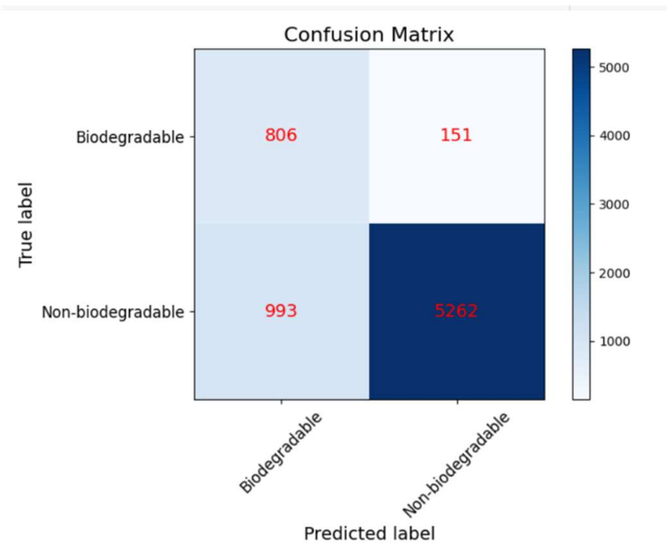

Fig. 6. Confusion Matrix

The confusion matrix shows how many times the model correctly classified each class (true positives and true negatives) , and how many times it misclassified each class (false positives and false negatives). The Matrix has 2 categorical classes: Biodegradable and Non-Biodegradable. Out of 7212 total objects, 806 objects are classified as True-Positive, 993 as False-Positive, 151 as False- Negative and 5262 as True-Negative. False positives are happening because of similar visual features between biodegradable and non-biodegradable items, insufficient training data for biodegradable items, class imbalance, poor-quality images, and suboptimal model tuning.

VI. CONCLUSION

In conclusion, the Automated Waste Classification System using Deep Learning for Landfill Management represents a major advancement in waste management. By integrating the YOLOv8 object detection model, the system significantly enhances efficiency, accuracy, and sustainability in waste classification. The project successfully demonstrated the feasib ility and effectiveness of automating waste categorization, reducing reliance on manual labor, and improving waste segregation and recycling efforts.This innovation streamlines operations for waste management facilities and enhances decision-making processes. It also aligns with global sustainability goals, highlighting the potential of deep learning technologies to revolutionize waste management and contribute to a more sustainable future. By promoting proper waste segregation and recycling, the system helps reduce environmental impact and optimize resource use. The insights gained from this project lay the groundwork for future advancements, promising even greater efficiency, accuracy, and environmental stewardship in waste management practices.

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