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# Deep Learning based Image Recognition for Separation of Recycling Waste

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**ABSTRACT**

Recycling waste sorting with high accuracy has become a significant area of research in recent years due to its direct effect on environment and economy. Computer-aided approaches are able to provide effective performances in recycling processes which consist of big data sizes. In this work, a deep learning (DL) based image analysis approach has been improved by using Python programming language and the YOLOv8x DL algorithm to optimize the recycling processes. From the simulation results, it can be concluded that DL-based approaches are able to provide high accuracy in image recognition and can successfully be used in processing of big data sets.

***Keywords:*** Deep learning, Image recognition, Recycling waste sorting, YOLOv8x

## Geri Dönüşüm Atıklarının Ayrıştırılması için Derin Öğrenme Tabanlı Görüntü Tanıma



**ÖZ**

Geri dönüşüm atıklarının yüksek doğrulukla ayrıştırılması, çevreye ve ekonomiye doğrudan etkisi nedeniyle son yıllarda önemli bir araştırma alanı haline gelmiştir. Büyük veri boyutlarından oluşan geri dönüşüm süreçlerinde bilgisayar destekli yaklaşımlar etkin performanslar sağlayabilmektedir. Bu çalışmada, geri dönüşüm süreçlerini optimize etmek için Python programlama dili ve YOLOv8x DL algoritması kullanılarak derin öğrenme (DL) tabanlı bir görüntü analizi yaklaşımı geliştirilmiştir. Benzetim sonuçlarından, DL tabanlı yaklaşımların görüntü tanımada yüksek doğruluk sağlayabildiği ve büyük veri setlerinin işlenmesinde başarıyla kullanılabileceği sonucuna varılabilir.

***Anahtar Kelimeler:*** Derin öğrenme, Görüntü tanıma, Geri dönüşüm atıklarının ayrıştırılması, YOLOv8x

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## Introduction

Reducing environmental pollution and dependence on virgin raw materials through recycling is crucial in terms of sustainable development. In addition, distinguishing waste materials with high accuracy contributes to resource conservation and addressing significant environmental issues. In recent years, recycling processes with higher accuracy and higher speeds have emerged with the integration of artificial intelligence based image processing approaches.

In literature, there are several works related to DL-based image recognition. In [1], Haque and Neubert presented a detailed review work analyzing the deep learning based medical imaging applications. Kodipalli et al. improved a custom deep learning architecture for the classification of ovarian tumours into the two categories of benign and malignant [2]. In work [3], a Convolutional Neural Network (CNN) algorithm was improved by Momeny et al. in order to detect the appearance of cherries and provide an efficient system for their grading. Zekiwos and Bruck, in their work [4], focused to improve a model to boost the detection of cotton leaf disease and pests using the deep learning technique. In another similar work, Huixian proposed a deep learning based approach to extract plant leaf features and identify plant species based on image analysis [5]. A detailed performance comparison was realized between the traditional machine learning algorithms and deep learning approach in the classification of high dimensional images by Wang et al. in [6]. Finally, Shen et al. proposed a modified YOLOv8 model which is able to to detect multi-scale occluded and small objects with high accuracy [7].

In this work, detailed analysis have been carried to improve a DL-based artificial intelligence approach for waste sorting process.

## Materials and Methods

In the first step, a dataset containing 4470 images has been created by using real waste images taken from recycling facilities. 25% of the image dataset have been obtained by using a camera having 12-megapixel contrast and Ultra-Wide-Angle lens with an aperture of f/1.8 and then remaining 75% have been taken from the Roboflow platform. The image dataset consists of four image groups as glass, metal, paper and plastic. In addition, each image within the dataset has the resolution of 640x640. Figure 1 shows the distribution of each image group in the dataset.

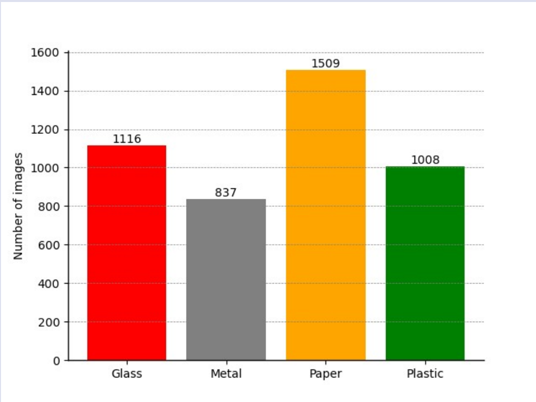


*Figure 1. Distribution of each image group in the entire dataset.*

Figure 2 represents the sample images taken from the glass, metal, paper and plastic groups.

*Figure 2. Sample images for the groups of glass, metal, paper and plastic.*

The labeling of the image dataset has been performed via Roboflow platform due to its higher performance in inspection and recognition of waste images. In the labelling process, randomly selected 1983 images of the entire dataset have been labelled. The training phase has been realized by using 3129 images which corresponds to 70% of the entire data set and containing 1.281.638.400 pixels.

The simulations in the training phase have been carried out for 100 epochs to enhance the recognition ability of the YOLOv8x model. As an optimization algorithm, the Adam Optimization approach [8] which provides adaptive learning rates and takes into account both first moment estimates (average) and second moment estimates (variance) has been preferred. The expressions of the average and variance metrics can be given as in Equations 1 and 2, respectively.

$$m_t = \beta_1 m_{t-1} + (1-\beta_1)\, g_t \quad (1)$$

$$v_t = \beta_2 v_{t-1} + (1-\beta_2)\, g_t^2 \quad (2)$$

where; $g_t$ defines the gradient value at time $t$, $\beta_1$ and $\beta_2$ are the control parameters used to optimize the moment estimation process and, finally, $\alpha$ represents the learning rate. As a result of the optimization process the bias corrected versions $\hat{m}_t$ and $\hat{v}_t$ can be defined as given in the Equations 3 and 4, respectively. Here, $\hat{m}_t$ defines the exponentially decaying average of the gradients while $\hat{v}_t$ defines the exponentially decaying average of the squared gradients.

$$\hat{m}_t = \frac{m_t}{1-\beta_1^t} \quad (3)$$

$$\hat{v}_t = \frac{v_t}{1-\beta_2^t} \quad (4)$$

Furthermore, the updated parameter values can be obtained by using Equation 5.

$$\theta_{t+1} = \theta_t - \frac{\alpha}{\sqrt{\hat{v}+\varepsilon}}\hat{m}_t \quad (5)$$

where; $\alpha$ can be determined as the learning rate and and $\varepsilon$ is a constant that takes small values to prevent division by zero.

In the simulations, the value of the control parameters have been taken as; $\beta_1 = 0.9$, $\beta_2 = 0.999$, $\alpha = 0.001$ and $\varepsilon = e^{-9}$ in line with the literature.

Adam Optimization is recognized with its ability to adapt to various types of datasets and complex model structures while training DL models. It also provides effective performances in terms of the convergence rate and training efficiency.

## Simulation results

DL-based analysis have been performed for the YOLO network architecture which is one of the most novel and effective deep learning algorithms. When the performance analysis results given in Table 1 examined, it is seen that YOLOv8x produces the best results. The YOLOv8x model is a Convolutional Neural Network (CNN) based deep learning architecture used for image recognition. The model has been trained on the Google Colab platform which provides a cloud-based computing environment. Google Colab platform has also an NVIDIA A100 GPU which is a highly advanced graphics processing unit and optimizes the entire process.

As a result of the simulations, the accuracy of the YOLOv8x model has been obtained as 98.72% on the recycling waste classification. The accuracy rate obtained proves the success of the improved model in image recognition. On the other hand, Figure 3 demonstrates the sample training results obtained for each of the four material classes.

*Table 1. Performance Benchmark results obtained for YOLO network architectures.*

| YOLO Model | Size (*pixels*) | $mAP^{val}$ 50-95 | Speed CPU ONNX (*ms*) | Speed A100 TensorRT (*ms*) | Params (M) | FLOPs (B) |
|---|---|---|---|---|---|---|
| v8n | 640 | 37.3 | 80.4 | 0.99 | 3.2 | 8.7 |
| v8s | 640 | 44.9 | 128.4 | 1.2 | 11.2 | 28.6 |
| v8m | 640 | 50.2 | 234.7 | 1.83 | 25.9 | 78.9 |
| v8l | 640 | 52.9 | 375.2 | 2.39 | 43.7 | 165.2 |
| v8x | 640 | 53.9 | 479.1 | 3.53 | 68.2 | 257.8 |


*Figure 3. Training results obtained for (a) glass; (b) metal; (c) paper; (d) plastic.*

## Conclusion

In this work, a DL-based image recognition approach has been improved for the aim of sorting the waste materials with high accuracy. As a result of the performance benchmarks performed, it has been observed that YOLOv8x network architecture produces better results when compared to YOLOv8n, YOLOv8s, YOLOv8m and YOLOv8l architectures. When the simulation results obtained for different material groups evaluated, it has been observed that DL-based approaches having YOLOv8x network architecture are able to perform image recognition with high accuracy. Consequently, it can be expressed that deep learning based approaches can successfully be used in recognition of waste materials.

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