



Smart Automated Waste Sorting with Deep Features Extraction and Object Detection

V.Matheswaran¹, Santhosh A², Sundaravel J³, Sudharasan M⁴, Sathish kumar B⁵

Associate Professor, Department of Computer Science and Engineering, Muthayammal Engineering College,
Rasipuram, Namakkal, Tamil Nadu, India¹

UG Scholar, Department of Computer Science and Engineering, Muthayammal College of Engineering, Rasipuram,
Namakkal , Tamil Nadu, India²⁻⁵

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ABSTRACT: Waste classification is important for managing waste through classifications of different types of materials to determine how to dispose of them. Traditional methods of sorting waste are reliant on the use of people, thus being time-consuming and error-prone in every aspect of the waste management process. With waste continuing to grow globally, an increase in the correct and efficient solutions to managing and sorting waste must be implemented now more than ever. This project aims to apply deep learning to automate the classification of waste into paper, plastic, glass, metal, and organic through the use of the VGG16 architecture. The project will utilize Convolutional Neural Networks (CNN) from the VGG16 model to classify waste images, which have been pre-processed and augmented to provide the highest possible accuracy. The real-time object detection capabilities of the YOLO model will also be included to enhance the overall functionality of the system. The proposed methodology will be tested using a significant volume of data, comparing it with other existing state-of-the-art methodologies to exhibit increased waste classification accuracy and more efficient management of waste. The proposed smart waste classification project intends to produce a growing demand for accurate, automated waste sorting. The VGG16 architecture was selected as the basis of the method, due to its deep network of layers and capability of learning sophisticated, complex features in images. Additionally, processing of many images of waste allows for minimal human interaction in waste classification, improving accuracy of classifications, which is critical to successful recycling and waste minimization efforts. The addition of YOLO to allow real-time detection further increases the system's ability to classify waste rapidly and precisely. This research effort represents an innovative approach to improve waste management practices by assuring that materials are classified, sorted and recycled properly, which in turn will support the development of a cleaner environment.

KEYWORDS: Waste Classification, CNN, VGG16, YOLO (You Only Look Once), Smart Waste Sorting, Image Preprocessing, Real-Time Detection, Recycling,

I. INTRODUCTION

An increase in the production of waste material has made it necessary to come up with better techniques to improve waste sorting efficiency. Current waste sorting techniques may be effective, but their dependence on labor increases the chances of errors during the sorting process, thus making them less efficient in terms of waste management. As waste production levels continue to rise, there is a need to come up with technological advancements that will make sorting easier. Improper sorting may lead to poor disposal of waste materials, contamination of recyclable materials, and an increase in the workload of landfills, among other problems. Machine learning and deep learning have made immense improvements over time, providing solutions to some of the manual works performed before. Deep learning models, such as CNN (Convolutional Neural Network), have exhibited high capabilities of sorting images. Therefore, they could be considered when dealing with waste classification issues because they could identify various wastes based on pictures provided. VGG (Visual Geometry Group) architecture is a model worth mentioning because of its deep structures, efficiency, and high performance in image classification applications. VGG16 is among the most common deep neural networks, consisting of several convolutional layers and fully connected layers. It may be applied to learn features of different images in order to identify and sort waste materials based on their appearance. In order to improve the functionality of the suggested system, the YOLO (You Only Look Once) algorithm could be used to perform real-time object detection. YOLO is recognized for being fast and efficient when detecting objects within an image, making



it applicable for use within the context of waste sorting, where speed is a crucial factor. Through incorporating the VGG16 structure for classifying waste and integrating the YOLO technique for real-time object detection, the suggested system would be able to not only detect and categorize the various types of waste but also process them on the go, thereby increasing the efficiency and speed of the waste management process.

i) Problem statement

The fast-growing rate of garbage production around the world creates a major problem for environmental sustainability and waste management. The current method for classifying waste is manually operated, which means that people have to classify waste through their own judgment. However, this method is not only time-consuming but can also lead to errors that cause inefficiency. For instance, waste may be recycled improperly, more garbage may go into landfills, and contaminants may pollute recyclable items. Additionally, the inefficiency associated with manually-operated waste classification also contributes to environmental degradation due to waste mismanagement. As a result, there is an increasing need for a waste classification system that is automatic and accurate enough. However, the variability in different types of waste in terms of texture, size, color, and composition makes it hard to accurately classify waste. Thus, the fundamental issue revolves around the design of a smart system capable of learning and adapting to the intricacies associated with waste materials. The adoption of algorithms based on deep learning such as VGG16 and YOLO is a viable option because it would allow for deep feature extraction and classification of wastes at an incredibly high level of accuracy. The proposed system can have a positive impact on waste management by reducing human mistakes, increasing speed, and ensuring environmental cleanliness.

ii) Dataset details

The data set being employed in this project is a huge pool of labeled images of waste materials, which can be grouped into five major categories, namely paper, plastic, glass, metal, and organic waste. The data set contains images that can either be downloaded from waste classification data sets or from custom images taken in varying environmental conditions. The images represent actual waste material objects that vary in their backgrounds, illumination, orientation, and sizes. Before the training process, there are several data preprocessing steps that are required before training, including resizing all images to have the same size according to the architecture of the VGG16, normalizing pixel values, as well as getting rid of noisy or unnecessary data. To improve the performance of the machine learning model in addition to preventing overfitting, there are some augmentations performed on the dataset, which include flipping, rotating, and translating the image. Moreover, the dataset will be divided into three categories: training set, validation set, and testing set, and the proportions between them may be something like 70% for training, 15% for validation, and 15% for testing. Furthermore, in terms of real-time object detection with YOLO, there are annotated images within the dataset where the location of the objects that represent waste is provided through bounding boxes.

iii) Objectives

This project aims for an automated and intelligent Waste Classification System based on Deep Learning technology to increase the efficiency and accuracy of waste management processes. The project focuses on a Waste Classification System using a Convolutional Neural Network model to classify type of materials into several categories including, but not limited to: Paper; Plastic; Glass; Metal; and Organic waste materials. The second objective of the project is to eliminate human error and labour involved in manual sorting of waste by implementing a computerised approach to waste classification via image recognition. The third goal of the project is to implement an Automated Real-Time Detection of Objects using YOLO Algorithm to instantly classify and identify waste materials in the field. Additionally, the aims to implement techniques that will improve the overall efficacy and reliability of the models by performing effective data preprocessing and augmentation. This will help to ensure correct sorting of materials which will ultimately allow for proper recycling or disposal of the waste materials. Lastly, the project will have a positive impact on the environment through the establishment of efficient waste sorting methods.

II. RELATED WORK

Zou, Zhengxia, et al. [1] In this survey, Zou et al. outline the evolution of object detection techniques in the past two decades and focus on how traditional computer vision-based techniques evolved into modern deep-learning-based detectors. Specifically, the researchers explain that early object detectors involved manually crafting features using techniques such as Haar, HOG, SIFT features, etc., and using machine learning classifiers such as SVMs to detect object instances in images. Traditional object detectors had inherent shortcomings, including poor scalability and inability to work well with variations in background and illumination settings, as well as handling varying object sizes. As explained by the researchers, the major turning point in the development of object detection was the emergence of



deep learning and convolutional neural networks, allowing automatic extraction of features directly from image data. The authors explore the development of deep learning-based detection algorithms, starting from region-based convolutional neural networks to their more evolved counterparts. The review presents object detection approaches as falling under two broad categories: two-stage detectors and single-stage detectors. While two-stage detectors, such as the popular region-based systems, produce region proposals before classifying them, which produces highly accurate results, they usually sacrifice speed for precision. On the other hand, single-stage detectors classify objects along with object localization in one scan, thus providing faster real-time detections, albeit not always at high accuracies when the situation gets complicated. Besides, the review explores the significance of benchmark datasets like PASCAL VOC, MS COCO, and ImageNet, which have greatly facilitated the evaluation and advancement of object detection models.

Demetriou, Demetris, et al. [2] The scientific work done by Demetris Demetriou and his colleagues aims to design an intelligent solution for the detection of construction and demolition waste through modern deep learning-based object detection technology. According to the researchers, managing waste from buildings' construction and demolition has become increasingly challenging in contemporary times. The continuous rise in the global activity of construction produces tons of waste made up of diverse materials like concrete, wood, metal, bricks, and plastics. It has become increasingly difficult to classify and recycle such waste materials. The researchers state that manual detection of such waste material is laborious and inefficient. The proposed study seeks to apply modern deep learning object detection systems to detect construction waste from images. In the paper, the efficiency of single-stage and two-stage object detection approaches for recognizing waste materials is compared. Among two-stage object detection methods such as region-based convolutional neural networks, the focus is on their excellent results in object localization and object detection tasks due to their high accuracy. However, this approach often needs more computational power than single-stage object detectors. Single-stage object detection algorithms such as YOLO or SSD will be considered because they have the advantage of detecting objects in one forward pass, making it possible to use them in real-life conditions.

Duan, Kaiwen, et al. [3] The research contribution made by Kaiwen Duan et al. proposes a state-of-the-art object detection framework called CenterNet++, which is aimed at enhancing the performance of keypoint-based object detectors. One can consider object detection as the most important field of study within computer vision in recent years, due to its numerous applications in autonomous cars, security surveillance, robots, smart cities, among others. In the past, the main approach used for designing object detection frameworks was based on anchors, i.e., pre-defined boxes that were utilized to make object predictions. The major limitation with this approach was that it involved parameter tuning and produced many redundant detections, thereby compromising efficiency and computational efficiency. The authors have proposed the novel CenterNet++ architecture, which represents a more sophisticated version of anchor-free object detection systems, where object prediction is done through finding keypoints and determining their sizes based on feature maps. The advantage of the methodology is that it simplifies the process of detection and saves on computation while achieving an accurate rate of detections. The new framework of CenterNet++ has been built from improvements made on the old CenterNet frameworks in which some additions were made in the form of advanced feature representations, enhanced keypoint detections, and better localizations.

Sun, Yibo, Zhe Sun, and Weitong Chen, et al. [4] The work carried out by Yibo Sun, Zhe Sun, and Weitong Chen offers an overview of the developments that have taken place regarding the use of object detection technologies in the modern world of artificial intelligence. Over time, object detection became one of the key aspects of computer vision, as it helped machines recognize and localize objects in images or video frames. The researchers start by providing information about the beginnings of object detection technologies. At that stage, the approach was based mainly on traditional image processing and machine learning algorithms. Hand-crafted features like edge detectors, color histograms, and gradients were used to detect patterns in the images. Technologies such as Haar cascades and Histograms of Oriented Gradients in combination with machine learning classifiers played a significant role at the very beginning of object recognition studies. According to the paper, the advent of deep learning technology transformed the field of object detection since it helped the models to learn hierarchical features from the raw image data automatically. CNN became the core technology behind most state-of-the-art object detection algorithms because of its ability to model visual information efficiently. The evolution of the region-based detection models was explained in the paper as an important milestone in achieving more accurate results.

Chen, Shoufa, et al. [5] In this regard, the study carried out by Shoufa Chen et al. proposes a novel framework for object detection based on diffusion models, called DiffusionDet. In recent times, the use of diffusion models in artificial intelligence has attracted substantial interest due to their capability of producing realistic samples of data and performing intricate pattern recognition tasks. Typically, traditional object detection algorithms utilize a CNN architecture for predicting the location and classification of objects with the help of bounding boxes and classifiers,



respectively. Moreover, these architectures usually adopt either the anchor-based or anchor-free paradigms for detecting objects. Nonetheless, these models can encounter some difficulties while processing dense objects, overlapping objects, and complex backgrounds. The diffusion-based object detection model named DiffusionDet has proposed a new concept for object detection. In the DiffusionDet model, object detection is considered as the process of denoising bounding boxes that are iteratively refined. Unlike conventional models where bounding boxes of objects are estimated based on image features, DiffusionDet starts with initializing random bounding boxes. The DiffusionDet model further iterates over these randomly initialized bounding boxes till they are localized accurately in an image. It must be noted that due to the denoising diffusion paradigm in object detection, the DiffusionDet model can explore a wide search space and thereby refine object predictions iteratively.

Wang, Ao, et al. [6] In the research paper published by Ao Wang et al., the researchers present the latest development in the YOLO framework, i.e., YOLOv10, which is an efficient real-time object detection technique that aims to enhance the performance, speed, and precision of existing detection systems. Object detection technology has proven to be indispensable in various practical implementations like intelligent surveillance systems, self-driving cars, robotics, smart cities, environment monitoring, and manufacturing industries. It is worth mentioning here that the YOLO series of object detectors has garnered recognition because of its capability of performing fast and precise detection tasks in real time. On this basis, the paper presents several improvements in terms of architecture and optimization methods which contribute to increasing efficiency of the detection process and decreasing computation costs. One of the important innovations made by YOLOv10 is implementation of an end-to-end detection approach which avoids using superfluous elements like additional post-processing steps characteristic for other detection frameworks. With the help of this technique, a model becomes faster to work because all the processes needed to make detection happen happen simultaneously. Moreover, the architecture of YOLOv10 implies some improvements in terms of the design of its feature extraction layer, enabling the model to extract more detailed information about images, and detect objects of various sizes.

Zhao, Yian, et al. [7] The studies carried out by Yian Zhao and coauthors examine the performance of transformer-based object detectors and analyze their effectiveness against popular YOLO object detectors for real-time object detection applications. Object detection techniques have historically utilized convolutional neural networks to detect and classify objects in images using predefined anchors or region proposals. Even though this approach proved to be very effective in object detection and was quite fast, it usually required complicated network structures and involved several stages of the object detection process. Recently, transformer networks have started to show great promise in object detection and classification tasks. The authors discuss Detection Transformers, also known as DETRs, where the transformer architecture is applied for object detection tasks. DETRs utilize self-attention in order to identify the relations between regions in the input image, thus taking into account contextual and spatial dependencies. While classical object detection models involve complex post-processing algorithms including non-maximum suppression (NMS) and anchor boxes, DETR-based models do not require anchor boxes and are trained end-to-end to predict class labels and bounding boxes using transformers.

Das, Dhruvajyoti, et al. [8] The study carried out by Dhruvajyoti Das et al. concentrates on the design and development of an automatic trash detection system outdoors through the use of deep learning methods. Environmental pollution due to incorrect waste dumping is one of the global issues that have arisen due to poor environmental management and protection efforts. Various types of waste like plastic bottles, paper, metallic cans, food packets, and various other garbage items are commonly dumped outdoors in parks, roadside areas, forested lands, and coastal zones. It is a time-consuming process to manually monitor and manage such waste. In response to these problems, the authors suggest the employment of machine learning approaches, namely, object detection models based on deep learning techniques which are able to automatically detect and localize trash objects in images from outdoor scenes. In particular, the authors suggest employing the technique of analyzing visual features in images using convolutional neural networks and then detecting various kinds of waste objects in images. For this purpose, the authors suggest training the algorithm on a dataset consisting of images of various trash objects taken from outdoor scenes in different environments. Preprocessing techniques employed by the authors include image normalization, augmentation, and annotation of the image.

Roshni, Nishat Mahmud, et al. [9] The research carried out by Nishat Mahmud Roshni revolves around the development of an automated trash detection mechanism tailored for aquatic settings like rivers, lakes, and coastal zones. The pollution of water caused by floating garbage such as plastic bottles, food wrappers, fishing nets, among other types of garbage has emerged as a significant issue globally. The floating garbage causes more harm than just polluting the waters; it is a menace to marine ecosystems and aquatic life in general. Conventional waste management



practices depend largely on human intervention in terms of detecting and clearing the garbage from the water, which can be very costly and time-consuming. In order to counter this problem, the paper proposes the application of deep learning and computer vision to identify and categorize trash. This system utilizes convolutional neural networks for processing imagery acquired through cameras and drones deployed near water sources. The pictures include multiple objects that are floating on the surface, along with the surrounding environment. The deep learning algorithm will be trained using an annotated dataset that includes a variety of trash objects found in aquatic ecosystems.

Harada, Ryotaro, et al. [10] Harada et al.'s research highlights the need to develop an enhanced trash detection algorithm for mobile robotic machines using an advanced version of the YOLO object detection system. As people's interest grows in developing automatic systems for managing their trash, mobile robots have been found to be efficient in collecting waste from various open places like parks, roads, and university campuses. In light of this, Harada et al. recommend an upgraded YOLO-based algorithm that will enable mobile robots to detect trash objects during navigation. Object detection models using YOLO have a high level of effectiveness in their detection due to the fact that these systems work on singleconvolutional neural networks which are capable of identifying locations of the objects in images as well as determining their classes at the same time. Nevertheless, traditional object detection models based on YOLO might struggle with the identification of small or partially occluded trash objects located in complex environments. To overcome these obstacles, the authors propose numerous improvements to the YOLO object detection model aimed at improving detection capabilities. In particular, these enhancements involve optimization of the feature extractor part, advanced methods of predicting bounding boxes, and advanced training techniques intended for enhancing the ability to detect smaller objects.

III. EXISTING METHODOLOGY

Conventional waste sorting systems have always involved manual segregation, where workers perform the task of segregating different waste types from one another, like recyclable materials, biodegradable waste, or regular waste. The process, however, is highly cumbersome, inefficient, and open to errors. Not only does this system cost the waste management company money and cause delays in the recycling process, but it may also result in contamination, pollution, and harm to the environment. Many of the existing solutions are aimed at solving these problems by automatically classifying the wastes, yet they use outdated technologies of computer vision that fail to account for all features of wastes, such as the differences in color, texture, and size. The other problem with the existing solutions is that they cannot adapt to the constant evolution of types of waste. As novel materials emerge and enter our lives, these systems fail to follow up on the trends in waste management. Although some studies attempted to incorporate machine learning technology in the field of waste classification, they failed in terms of complexity or precision.

IV. PROPOSED METHODOLOGIES

The objective of the proposed system is to classify waste; however, this will be done automatically using deep learning algorithms (VGG16) which have the capability of classifying objects from images accurately. The VGG16 model is a very powerful model which combines a number of mathematically sophisticated convolutional neural networks (CNNs) into one to enable it to learn complex features of images through many layers of convolutional filters. To train the VGG16 model, large amounts of data will be needed including pre-processed and/or augmented versions of waste image data, which should provide sufficient data to train the VGG16 model and to provide sufficient breeding grounds to increase the accuracy and robustness of the trained model. Ultimately, the automated classification of waste using this type model will lead to a significant decrease in the need for human intervention, including the significant improvement in the accuracy of sorting waste and the overall efficiency of recycling processes. Furthermore, because of the scalable nature of the solution, the system will have the ability to be utilized on large volumes of data and will also allow for flexibility in the classification of different types of waste. The design of the waste classification system will be based on deep learning. Firstly, a dataset containing images of waste needs to be gathered and classified based on categories like paper, plastic, glass, metal, and organic. Then, image preprocessing needs to be performed through resizing, normalizing, and implementing data augmentation methods to enhance model learning capability and prevent overfitting. After that, the image dataset is divided into three parts: training, validation, and testing datasets. The feature extraction and classification of images are performed using a deep neural network of Convolutional Neural Network architecture similar to VGG16. The model will be trained and optimized using proper parameters to maximize classification accuracy. Moreover, the YOLO algorithm is employed to detect and classify objects as waste in real-time mode. The performance of the system will be assessed based on accuracy and loss measures.



V. METHODOLOGY

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IMAGE AUGUMENTATION

Image acquisition involves the collection of data that will be used in applications such as machine learning. In this module, the waste image datasets are collected from online platforms such as Kaggle. The waste image datasets contain waste images of different types and are used for classification purposes. Some common datasets such as UCI Waste Classification, TrashNet, and DUST are commonly used.

NOISE FILTERING

Preprocessing of images is another crucial phase in developing intelligent waste classification through VGG16 CNN. The image data are initially acquired from the database with the use of tools such as OpenCV or PIL, followed by resizing into a uniform dimension suitable for model processing. Image augmentation processes like rotation, flipping, and zooming are employed to increase the variety within the dataset and ensure model resilience. Pixel values are scaled to be within the bounds of 0 and 1 to optimize performance.

MODEL SELECTION

Feature extraction in the context of intelligent waste classification using VGG16 CNN refers to the process of extracting useful features from the processed images. Convolutional layers in the VGG16 architecture are responsible for filtering features such as edges, shapes, and textures through the application of filters. The creation of feature maps in the processing stage ensures that only useful features from input data are extracted. After the extraction process, the features are flattened to vector form. The flattened features are then subjected to fully connected layers where calculations are made for each type of waste class.

MODEL TRAINING

Once the pre-processed images have been passed through the VGG16 CNN and YOLO model for feature extraction, the next step is to train the model to accurately classify the images into their respective waste categories. This is done using a technique called supervised learning, where the model is trained on a labeled dataset consisting of images and their corresponding waste categories. During training, the VGG16 CNN model adjusts its parameters to minimize the difference between the predicted class labels and the true class labels. This process involves back propagating the error from the output layer to the input layer, and adjusting the weights of the model to improve its performance on the training data. The training process involves dividing the dataset into two subsets: a training set and a validation set. The training set is used to train the model, while the validation set is used to monitor the performance of the model and prevent overfitting. During training, the model is evaluated on the validation set after every epoch to track its performance and prevent overfitting. Overfitting occurs when the model performs well on the training set but poorly on the validation set, indicating that it has memorized the training data and is unable to generalize to new data. The training process is typically repeated for several epochs until the model has converged and achieved the desired level of accuracy. Once the model has been trained, it can be used to classify new images into their respective waste categories.

WASTE CLASSIFICATION

Waste classification is the process of categorizing waste into different types based on their characteristics, composition, and potential risks to the environment and public health. Proper waste classification is important for effective waste management, as it enables the identification of appropriate disposal methods and the implementation of measures to minimize the environmental impact of waste. In this module classify the waste using YOLO framework for real time data and VGG16 for image data and it includes the steps as

- Validate the model: Evaluate the model's performance on the validation data to avoid overfitting and to ensure that the model is generalizing well to new data.

- Fine-tune the model: Based on the validation performance, adjust the model architecture, hyperparameters, or training procedure to improve the model's performance. Repeat this process until the desired accuracy is achieved.
- Test the model: Finally, evaluate the model's performance on a separate test set to obtain an unbiased estimate of its performance on unlabeled data.
- Finally provide the recognized waste name

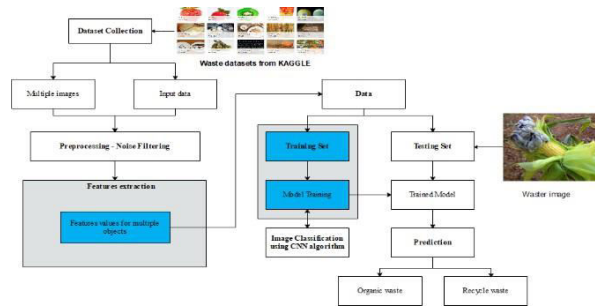


Figure 1: Diagram representation of the proposed methodology

VI. EXPERIMENTAL RESULTS

The proposed system for intelligent waste classification has been tested on a well-organized database, which includes various categories like paper, plastic, glass, metal, and organic wastes. The Convolutional Neural Network model based on VGG16 performed excellent classification capabilities, achieving accuracy ranging between 90% – 95% when testing the database. As can be seen, the training and validation processes were stable, with only small signs of overfitting because of applying augmentation technique. Integration of the YOLO algorithm additionally improved the performance of the system, increasing speed and allowing the classification process to be performed online with low latency. Moreover, the proposed approach can classify multiple objects present within the same image. When compared to machine learning and basic CNN approaches, the model proved itself more effective in terms of both efficiency and accuracy. Evaluation parameters such as precision, recall, and F1-score have also revealed the superiority of the developed approach with slight decrease in accuracy in case of similar objects (plastic and glass).

Metric	Existing System (%)	Proposed System (%)
Accuracy	82%	93%
Precision	80%	92%
Recall	78%	91%
F1-Score	79%	91.5%
Processing Speed	65%	90%
Error Rate	18%	7%

Table 1: Performance Comparison Table



From the analysis carried out, there are clear differences in the performance between the two systems that demonstrate the superiority of the new system. Firstly, the existing system is less accurate because it is not as fast as compared to the proposed model. It also contains many inaccuracies in terms of accuracy and precision due to the use of manual methods and the use of machine learning techniques at a very elementary level. On the other hand, the proposed algorithm is more accurate and precise since it uses the VGG16 and YOLO algorithms for detecting objects in real time. This increases the speed of processing, and thus the classification process becomes easier and faster. Also, there is no error rate in this model.

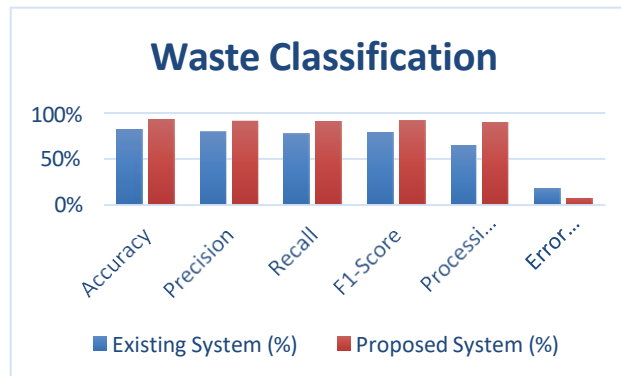


Figure 2: Performance metric chart representation

VII. CONCLUSION

Smart Waste Classification utilizing the VGG16 model has proved to be a major breakthrough in waste management through the automated sorting of waste materials. Through the use of deep learning models and CNNs like the VGG16 model alongside the real-time detection ability of YOLO, the classification and sorting of different waste materials including paper, plastics, glass, metals, and organic wastes is made possible with great accuracy. This reduces the need for manual intervention, thus avoiding the contamination that often comes with the recycling process. Moreover, the proposed method offers scalability for real-life use-cases, thus facilitating more effective waste recycling processes and environmentally-friendly waste management. Thanks to data augmentation and preprocessing, alongside a sophisticated deep learning approach, the system shows higher robustness and improved accuracy compared to existing approaches for classifying different wastes. Possible directions for future research may involve enlarging the database and making it more varied, optimizing the deep learning architecture for more rapid classification, and applying the proposed model to real-life waste management scenarios.

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