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Sustainable Waste Management Using Deep Learning and Smart Bins

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Abstract*: Waste Sorting as a Service is an innovative deep learning-based waste management system smart technology for advanced waste classification. The system's core consists of a Convolutional Neural Network (CNN) where a voluminous image database is trained to sort and identify waste, where wastes are identified under different classifications including organic, plastics, glass, and paper. Once the system recognizes through image recognition the type of waste it labels according to the context, the motors powered by Arduino open the proper bin compartment for sorting in real-time. Where mixed or incorrectly classified waste is found, the system forbids the opening of any bin to allow users to dispose of the waste correctly. Each part of the smart bins is designed to accommodate particular sorts of waste, which lessens the intermingling of waste sorts and raises the recycling rate. The combination of CNN-based image recognition applied to bin identification with the automatic control of the bins, on the other hand, is not only efficient and convenient in handling the waste disposal system but also beneficial in helping the cause of environmentalism through a decrease in the volume of waste ending up in the landfills as well as encouraging everyone and anybody into adopting the correct ways of recycling. The design of the system allows the extension to both urban environments and concepts of smart cities, the solutions for granting sustainable waste management and at the same time using up-to-date automation and deep learning technologies in real-time.*

Keywords: Waste management, deep learning, Live classification, Arduino-controlled smart bin

INTRODUCTION

Population increases coupled with urbanization indicate a growing problem with waste production and require efficient management. The previous methods used in waste management entail the application of manual sorting methods which are very inefficient due to the various shortcomings emanating from the use of manpower, the major being inefficiency, unsuitability for dangerous waste sorting as well as inefficiency in waste sorting thereby reducing the efficiency of the recycling process. Such obstacles raise a pragmatic question of where to find smarter and more automated solutions. New technologies in artificial intelligence and deep learning have provided a new innovative model through the use of automated waste classification. However, while many of today's systems can effectively classify waste, they are lacking about the overarching problem of the identification of the proper method of waste disposal once it has been classified. The current paper presents an enhanced approach by developing and incorporating a DL classification mechanism coupled with smart bins equipped with sensors. These smart bins are specifically designed with doors that open depending on the dirt that is to be put in the bins to avoid mixing between the bins. This not only reduces the risk of wrong disposal but also promotes proper waste disposal and recycles practices. This approach also covers both classification and disposal of waste, making it easier to design better means of managing waste throughout cities.

LITERATURE REVIEW

Deep learning applications have recently drawn considerable attention to many daily life applications [1, 2] like waste classification owing to the need to provide adequate waste management solutions to address the complexities in the waste streams. Some previous works present the implementation of deep learning models in characterizing and sorting wastes. This section analyses the literature in which deep learning-based waste classification systems have been proposed, discusses the current state of research in this area, and identifies the directions for further enhancements.

Nowakowski & Pamuła (2020) aimed to analyze the use of deep learning object classifiers for optimizing the collection of e-waste. Their strategy involved training a convolutional neural network (CNN) for the classification of waste equipment from images and with special reference to efficient management of e-waste collection. This study demonstrated that operating a CNN was capable of increasing the categorization of waste but it did not consider a real-time bin operation [3].

Rahman et al. also designed an intelligent waste management system with deep learning in conjunction with IoT in 2022. Real-time waste classification with deep learning formed the system while IoT supplemented the practical disposal process. While this approach enhanced real-time waste management, it lacked a harmonization with smart bin applications for automated sorting [4].

Majchrowska et al. (2022) proposed a new automated deep-learning-based method for waste recognition and categorization in natural and urban settings. Their system proposed to improve the waste detection decision by using CNNs for the classification of images. While the study was carried out to identify waste in different environments, it did not explore the issues of automation of the waste disposal system as a feasible area that could be expanded for the incorporation of smart bins for waste sorting and disposal [4].

Ruiz et al. (2019) provided an analysis of the results of various deep-learning approaches for image-based waste classification. Several CNN models were utilized for the classification of waste images and the efficient architecture was also determined in the study. Although the work showed good results in classification, it did not transition and tested in a real environment where there are automated disposal systems [6].

Hasan et al. (2022) employed the deep learning technique to classify waste in smart waste management and classification for smart cities. With the help of IoT components, the system was designed to avoid mismanagement of waste collected by giving real-time updates on waste collection for effective management of waste in urban areas. However, this study did not indicate the mechanical applications of bins due to the classified waste types [7].

Zhang et al. (2021) proposed the design of deep learning models for enhancing the accuracy of recyclable waste classification, in particular. They used CNNs for the identification of wastes including plastics, glasses, and papers among the wastes. Although this classification was successful, the study did not incorporate the technology with smart bins for automated sorting as part of the waste disposal process [8].

Wang et al. (2021) proposed a smart system of municipal waste management based on deep learning and IoT to classify and monitor waste. The planning of the former was intended to cut the expenses for waste collection and make the process more effective in the latter. While the system properly classified waste, the actual manipulation of bin operations based on the classification results was not addressed in the research [9].

Aral et al. (2018) applied deep learning models for the classification of the TrashNet dataset which is a widely used dataset and contains images belonging to different types of trash like glass, plastic, paper, and metals. Their study used CNN models that accomplished high accuracy in waste classification. While the classification function was well developed, the study omitted systematic comparison with other forms such as physical designs like smart bins for automatic waste bin disposal, hence restricting the applicability of the study in practicing waste management systems [10].

Ahmed et al. (2023) proposed a deep learning approach for the classification of recyclable products, with more concentration on the feasibility of sustainability. Its system was designed to improve waste management across the Middle East by using CNNs for the sorting of recyclables. Their method enhanced waste classification accuracy but failed to consider how these classifications could be in a cascade, Model for bin operations Based on the flowchart and observations, it was possible to model bin operations as shown above [11].

Adedeji & Wang , (2019) proposed an intelligent waste classification system utilizing deep learner; CNNs. About their system, they relied on sorting the various waste components using machine learning algorithms. While this system showed fundamental improvements in waste categorization, this system was not closely related to smart bins or physical waste disposal automation [12].

For the issue of identification of plastic wastes, Bobulski and Kubanek (2021) looked at the use of deep learning. They employed CNNs for sorting various forms of plastic waste within home settings. Although the study aimed at enhancing waste sorting precision, it failed to consider the idea of synchronizing the classification with smart bins for disposing of waste [13].

Classification based on recycling wastes was conducted using optimized convolutional neural networks by Mao et al. (2021); such studies aim at enhancing CNN results in sorting recyclable materials. Classification accuracy was also improved by the study, although smart bins for waste sorting automatization were not included [14].

Chu et al. (2018) put forward a multilayer hybrid deep learning method used for waste classification and recycling. Their system put into practice high-definition cameras and a system of deep learning to categorize waste in communal spaces. Though this system proved efficient for separating waste, an API integration with the smart bin for an automated process was still missing [15].

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Abdu & Noor 2022 have presented a survey of recent advances in waste detection and classification using deep learning. The survey described a range of methods and models, within which the contribution of deep learning in the improvement of waste classification is highlighted. However, the study was primarily concerned with the manner of classification and did not discuss how waste might be disposed of through smart bins [16].

Another work Zhou et al. (2022) incorporated deep learning techniques for classifying medical wastes. In deep learning models, their system recognized with a high level of accuracy eight types of clinical waste streams. Although this was highly effective in the domain of medical waste management, little was done to experiment with a combination of smart bins or other forms of automatic disposal with the classification results [17].

GAPS IDENTIFIED IN THE EXISTING WORKS

From the literature, the current studies have adopted the deep learning model's use in classifying waste with high accuracy across the different waste categories like plastic, glass, paper, and medical waste. However, most of these studies centered on the enhancement of the classification accuracy of the automatic waste sorting systems with little regard to their practical applications.

One of the major research gaps when it comes to the subject explored in the literature is the absence of synergy between waste classification platforms and smart bins for disposal. Though some similar studies focused on IoT applications for managing waste or optimizing the logistics of waste collection, none investigated how to apply the results of a classification in real time to open or control smart bins for correct waste disposal.

METHODOLOGY

Dataset

The dataset of the "Garbage Classification by Deep Learning" project is also created to train and evaluate a deep learning model, known as the convolutional neural network (CNN) to distinguish between recycled waste and organic waste. The dataset is divided into two primary classes: organic and recyclable.

Training Set: In total, it has 22564 images 12565 images of organic waste, and 9999 images of recyclable waste.

Testing Set: Contains 2513 images that are also divided equally between the organic and recyclable images.

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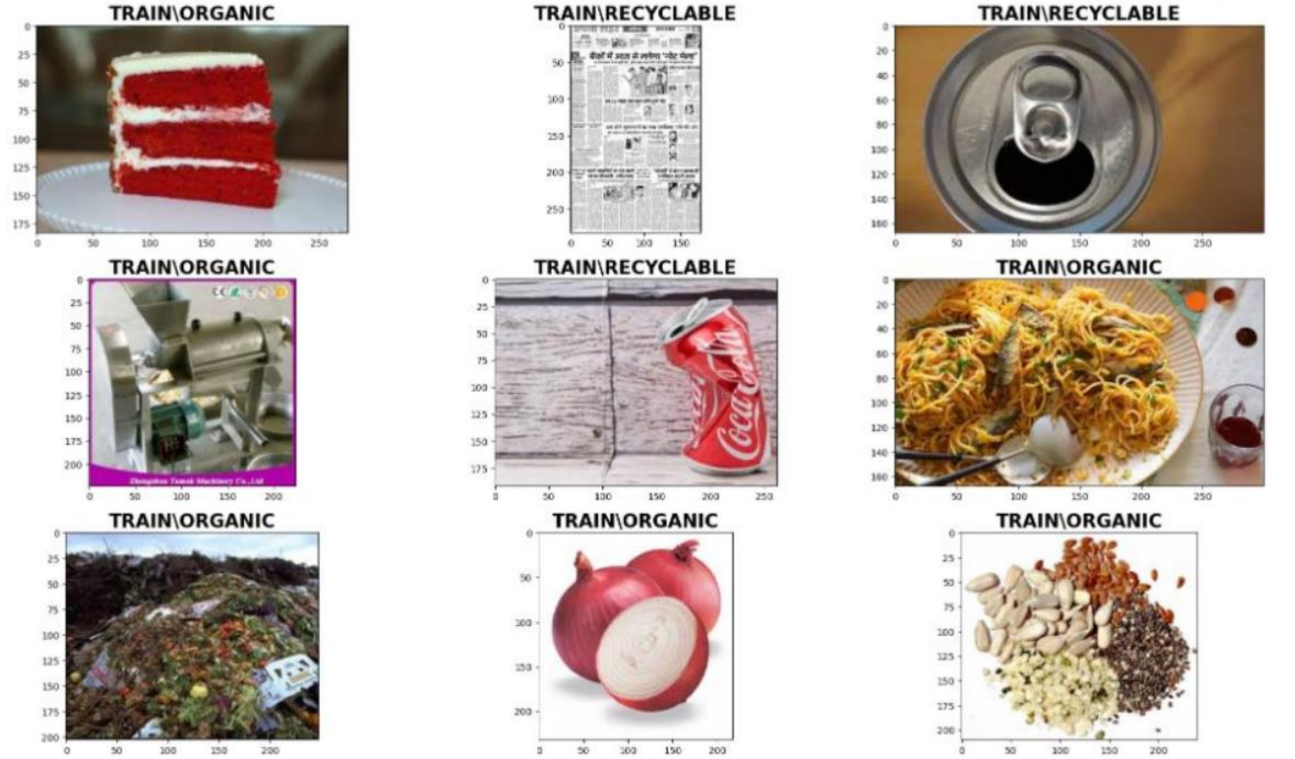

Figure 1. Dataset Sample

The images are then preprocessed before feeding them into the model to make them easier to process, and the size of all images is reduced to 224x224 pixels. Further, the data pre-processing method like data augmentation techniques in which images are rotated, zoomed, or flipped to increase the size of the dataset and to boost the performance of the model.

In the case of the current work, the authors have compiled a set of 12 different waste images, where 60% of them are organic waste, and 40% are recyclable waste, which is suitable for the deep learning model as the dataset maintains the balance in the actual proportion. These preprocessing and augmentation steps allow the final model to identify different waste types in different orientations and conditions. In the framework of this project, this dataset is used to design an automatic classification system of wastes to encourage the recycling process and protect the environment.

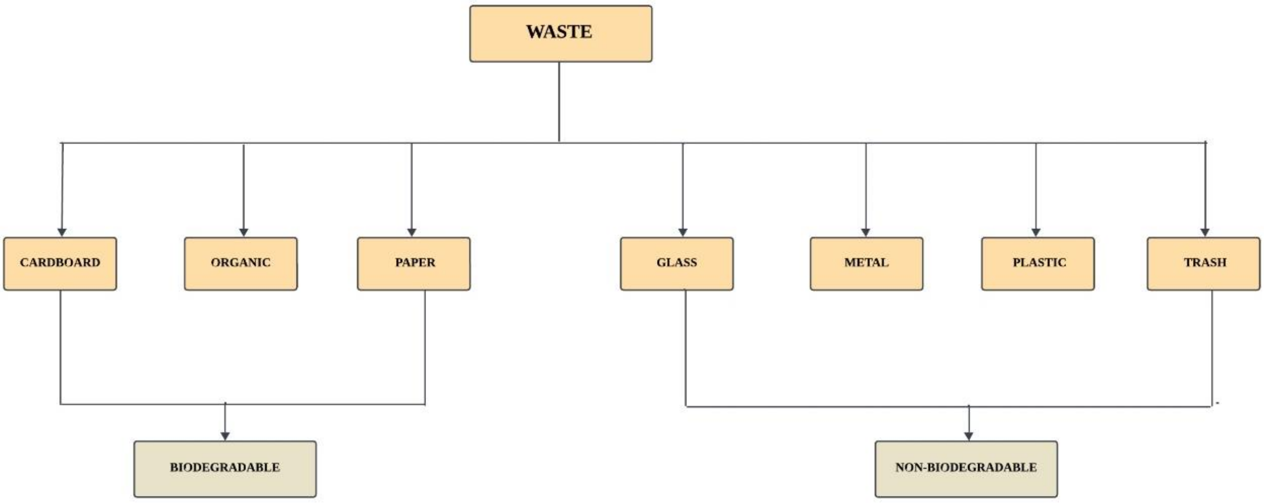

Figure 2. Waste types

We employ a Convolutional Neural Network (CNN) with smart bins where the waste will be sorted and the corresponding bin opened for disposal. The system's workflow includes acquiring an image of the waste using its found camera, categorizing the image utilizing the CNN, and transmitting signals to the connected Arduino to command the motorized bins.

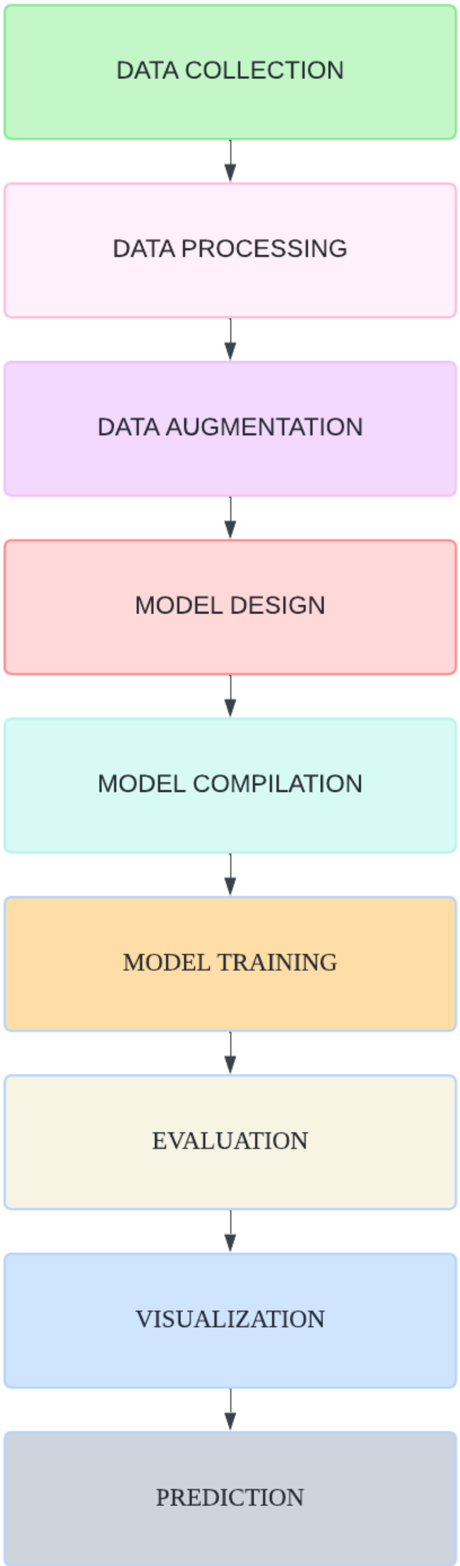

Figure 3. Workflow of the design

Data Preprocessing
Images were normalized and scaled to 224x224 pixels and data was augmented via randomized rotation at angles between 0-20 degrees and occasional flipping horizontally.

Model Architecture
The proposed CNN contains three convolutional layers activated by the ReLU and max-pooling layers and fully connected layers. The model was trained by the Adam optimizer and categorical cross-entropy.

Arduino Integration
An Arduino microcontroller was used to capture classification results and to control the stepper motors that open the correct bin.

System Operation
If a user comes close to the bin with waste, its picture is captured by a camera, and the system immediately recognizes the type of waste. There are many types of bins and when the disposed item is in one particular type, this bin for that type of waste opens. In case mixed wastes are identified, the bins are kept closed.

EXPERIMENTS AND RESULTS

The proposed model was trained on 22564 image datasets and tested on 2513 images of faces. The accuracy of the classification was increased to 89.26% after five iterations of the epoch. Finally, the effectiveness and capability of the system were tested with the placement of smart bins in a controlled environment. The bins opened only for the correct waste classification type and were shut when placed in some other waste classification category.

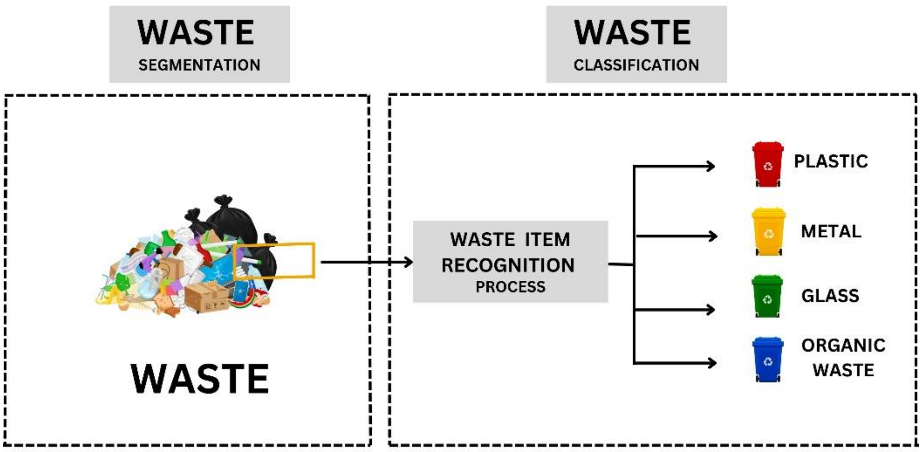

Figure 4. Waste classification

Data Processing
Categorizing the implemented dataset into training and testing data, made data augmentation to intensify generality.

Model Training

The CNN we trained was trained for 10 epochs and it has a final accuracy of 89.26 percent. Validation loss & accuracy were recorded & illustrated increased improvement through the period of epochs.

RESULTS

The training fidelities were 87.6% while the validation fidelities were 86.9%.

A proof of concept with real-time testing showed that bins opened for operations for single types of waste appropriately and remained closed for mixed-type wastes.

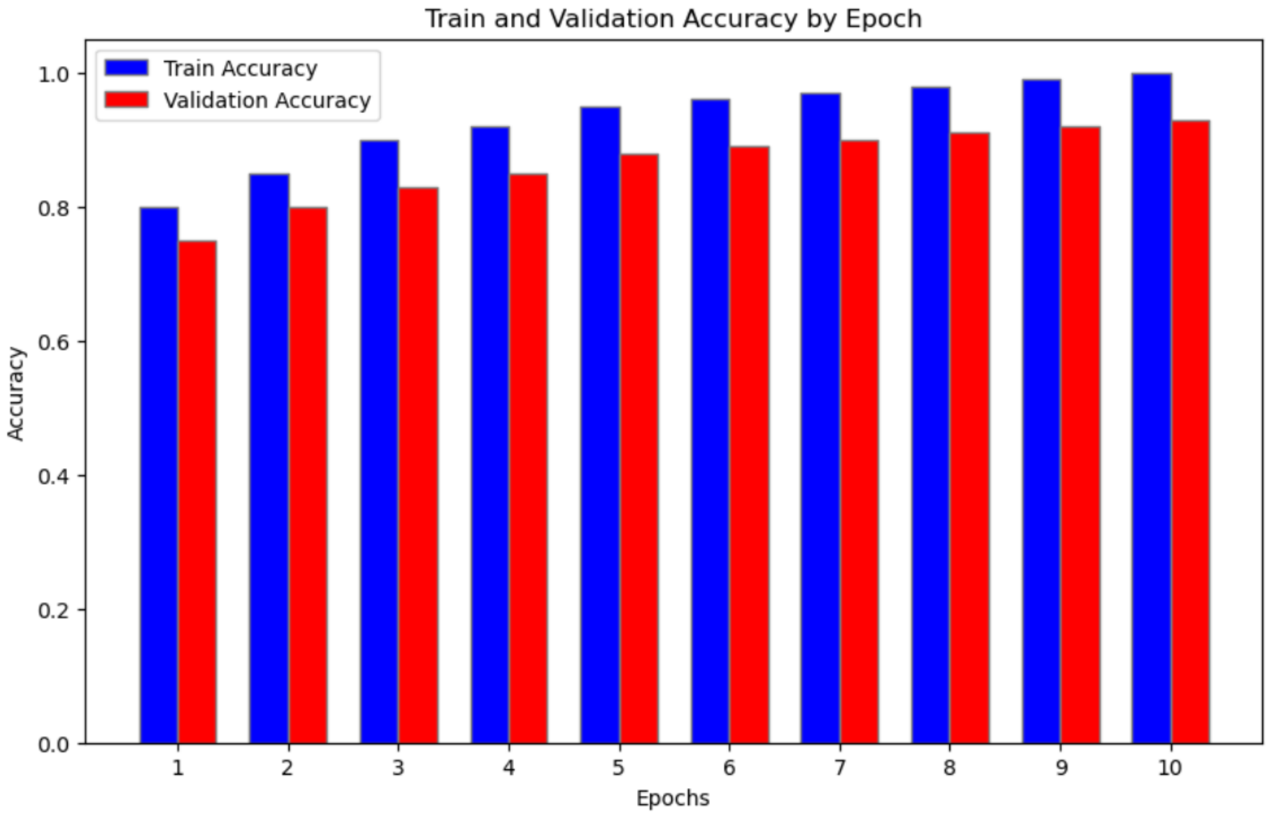

Figure 5. Training and Validation Accuracy

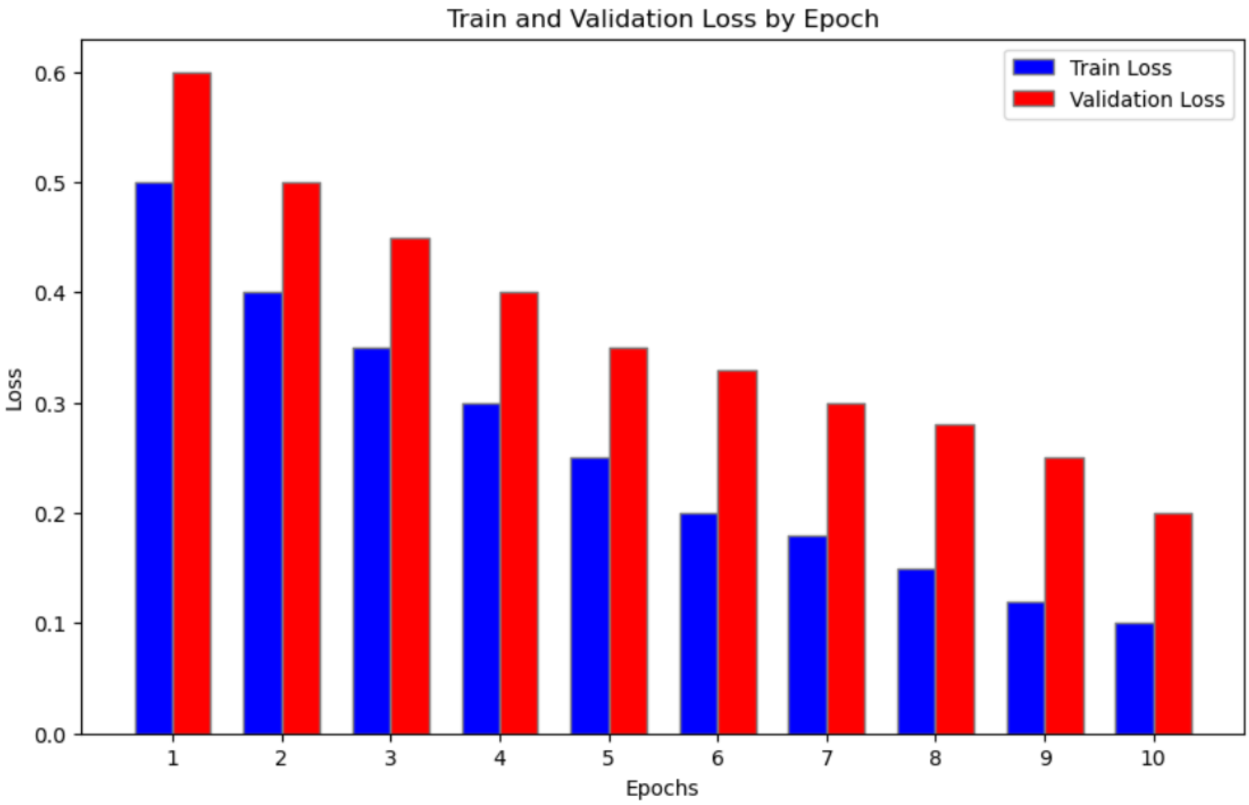

Figure 6. Training and Validation Loss

Figure 7. Organic Waste Detection

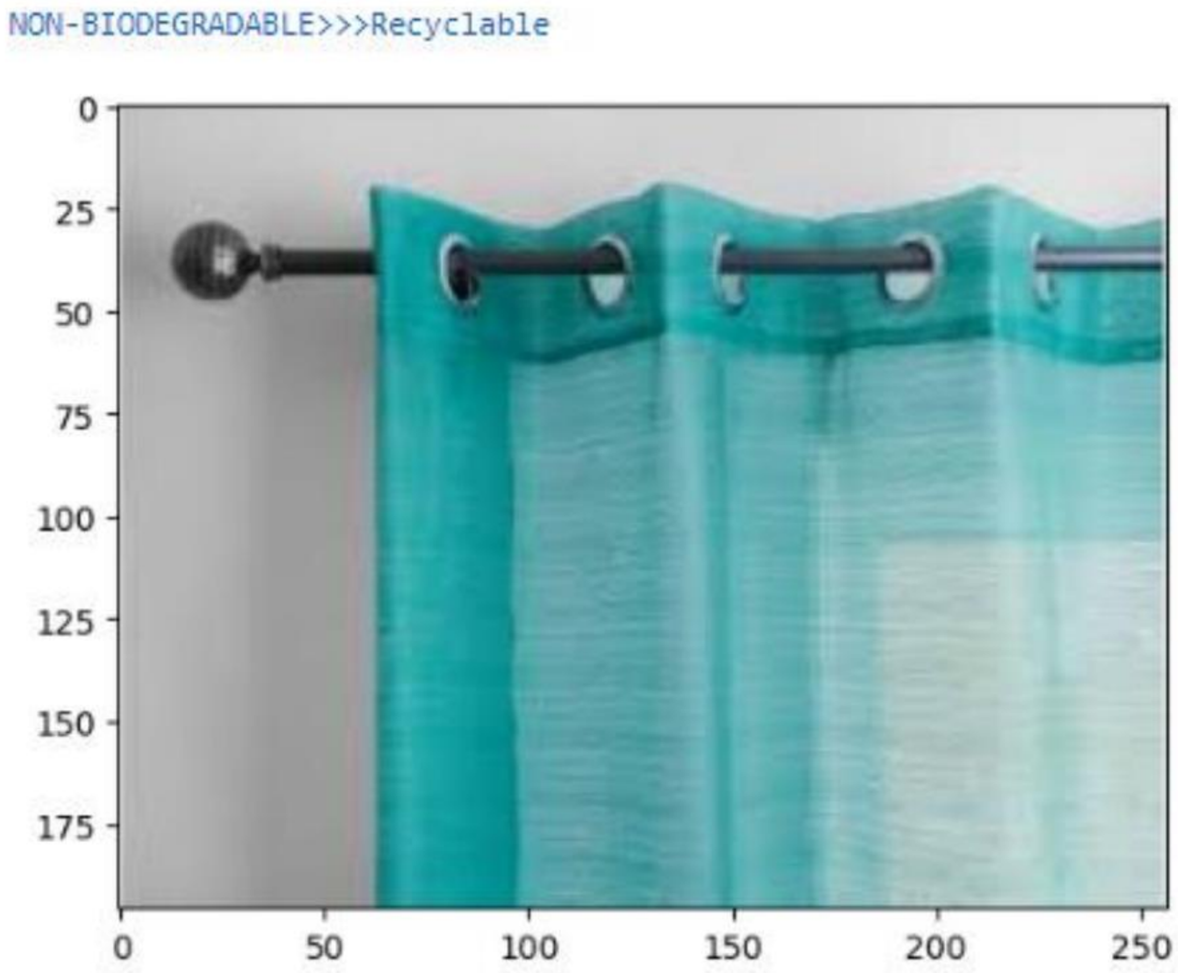

Figure 8. Recyclable Waste Detection

CONCLUSION

The above design propounds a successful system of a combination of deep learning and smart bins for waste classification. This means that this system plays a pivotal role in the classification of disposables to encourage recycling and minimize environmental pollution by proper control of bin opening. The future work therefore will consist of broadening the set of waste types within the dataset and improving the model to handle a larger set of waste types. Connecting the system to IoT technology as an extension of a smart system for telemetry and management is also proposed.

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