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Bottle Recycling Machine Using Convolutional Neural Network

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Abstract

Every day, billions of plastic bottles and cans are used worldwide. Most of these wastes end up in landfills or as litter. These plastic bottles and aluminium cans can be recycled, to transform into other household products. As plastic bottles are cheaper to produce than to recycle, recycling is not preferred. In the meantime, people are neglecting the adverse effects of plastics and cans. For recycling plastic bottles and cans effective segregation is the major issue which requires high accuracy and precision. Most of the segregation is done manually to separate plastic bottles from other waste, which increases labor costs thus, making recycling unreliable economically. Here we have proposed a system that employs machine vision to distinguish bottles and cans using a CNN. There isn’t any sensor that can accurately identify plastic bottles with high accuracy. So, we have tried to complete this task using a deep learning algorithm. Being an automated system, it doesn't require a full-fledged team to manage which makes the recycling process feasible from monetary perspective.
Different compartments are allocated for plastics and cans. When an item is accurately identified by the system, it is placed in the respective compartments. A reward is given to the user as a redeemable code to encourage recycling behavior. The system has an accuracy of 96% in identifying items and proves to be an effective pre-recycling process.

Keywords: Reverse Vending Machine (RVM), Bottle Recycling Machine (BRM), Machine Learning, Convolutional Neural Network (CNN), Solid Waste Management

1. Introduction

Solid waste is becoming a cause of pollution and land acquisition around the world (Abubakar, et al., 2022). Effective solid waste recycling is necessary, which requires a proper sorting system. Solid waste recycling is a problem in developing countries such as Nepal, which has several aspects related to it, such as technological, official, financial, environmental, and communal (Bank, 2013). A standard-sized plastic bag costs less than a rupee (< $0.01) to manufacture, according to the plastics industry, whereas it costs around 4 to 5 rupees (~ $0.04) for a paper bag. A study found that the cost of using plastics is 3.5 times less than the cost of other probable alternatives (Gray, 2018).
The aim of this study is to find out the behavior of people towards recycling when the incentive-based approach is used and also to effectively segregate plastic bottles and cans in order to help in the recycling process. This study will help in solid waste management which is a burning issue of today's world.

The authors E. M. Bennett and P. Alexandridis claimed that the general public does not understand the importance of recycling and the benefits associated with it (Bennett & Alexandridis, 2021). An article published by Jennifer

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Sutton claims that people find producing plastics more favourable than recycling (Suttton, 2009). Another research article published by Wilhemina Asare et al. found that programs such as providing incentives in exchange for recyclable items increased the recycling rate, but the program did not sustain because it required a full-fledged team to manage and it was not economically feasible (Asare, et al., 2022). So, RVM being an automated system, is meant to encourage recycling habits by giving rewards to depositors for every recycled item without any human resources to manage.

Many other approaches have been practiced to solve the issues. Such as barcode scanning, manual segregation, image processing, etc. Each solution is associated with certain discrepancies. With the Barcode scanning process, the wrapper wrapped around bottles and cans may be torn and worn out. So, it is not an effective method. Manual sorting however gives 100% accuracy but comes up with a huge cost. So, CNN has been chosen as the best approach for segregating solid waste.

A reverse vending machine is not a new concept. Many applications of it have been in use for different purposes. In a normal vending machine, a user inserts money (paper or coin) into the system and gets the item in return. Whereas, in Reverse Vending Machine user inserts an item into the system and in return gets the value which could be monetary or non-financial. In our proposed system user gets the value in the form of a redeemable code. Also, information from documentation of hardware components, research papers, similar projects, and guides concludes that the system is technically feasible. The system is reliable and its operations are elastic in nature. Being a small and portable device, it can be used in local-level government offices, malls, schools, etc. So, there is operational feasibility of the system.

2. Literature Review

A novel design was proposed by P. Dhulekar et al. for a Bottle Recycling Machine to collect the used bottles and classify them using CNN (Dhulekar, et al., 2018). It is a reward-based system that gives the user a printed coupon generated using a thermal receipt printer. Only the physical structure of the bottle is used as the criteria for classifying the bottles. The classifier calculates the features of an input image based on pixel values and compares them with known features to produce the result. The system is 80% to 100% accurate with a detection time of 8-9 seconds. BRM is made of a 3*2*5 feet metal body which consists of all electronic circuitry and is placed for bottle storage.

A system proposed by D Mariya aimed to build a Reverse Vending Machine for collecting plastic bottles with reward features (Mariya, et al., 2020). The technology used for identifying plastic bottles is object detection using CNN, R-CNN and Faster-RCNN. Once the number of bottles is identified depositors can claim the points by entering a unique ID and the accumulated points can be used to generate promo codes for online shopping. The user and authority could keep track of their details by maintaining an account in the application software developed. After the machine is filled at particular location it is notified to the authority through messaging.

A recycling machine employing the principle of conveying and heating designed by Ugoamadi and Ihesiulor claimed it is more economical in terms of operational human resources (Ugaomadi & Ihesiulor, 2011). In this method plastics are shredded and melted in the hopper with the help of only two operating personnel and were designed using locally available raw materials which made it cheap and easy to maintain and repair. The system had an accuracy of 97% with approximately 3 minutes of processing a batch.

The work proposed by Wang, et al insisted that image recognition-based classification using position and color recognition is an effective method (Wang, et al., 2019). They categorized bottles as disjoint, adjacent, or overlapping. Disjoint bottles are identified by analyzing concave and convex areas. For adjacent and overlapping bottles, a combination of distance transformation and threshold segmentation was used to determine positions. Color recognition focuses on seven predefined categories using color features from the bottom section. The accuracy of color recognition for recycled bottles reached 94.7%, with the influence of training sample size studied.

3. Methodology

The system is based on CNN to classify bottles and cans. Separate compartments are used to place the segregated items. The system is an integral part of the pre-recycling process which usually is time-consuming and involves manual work.

3.1. System Block Diagram

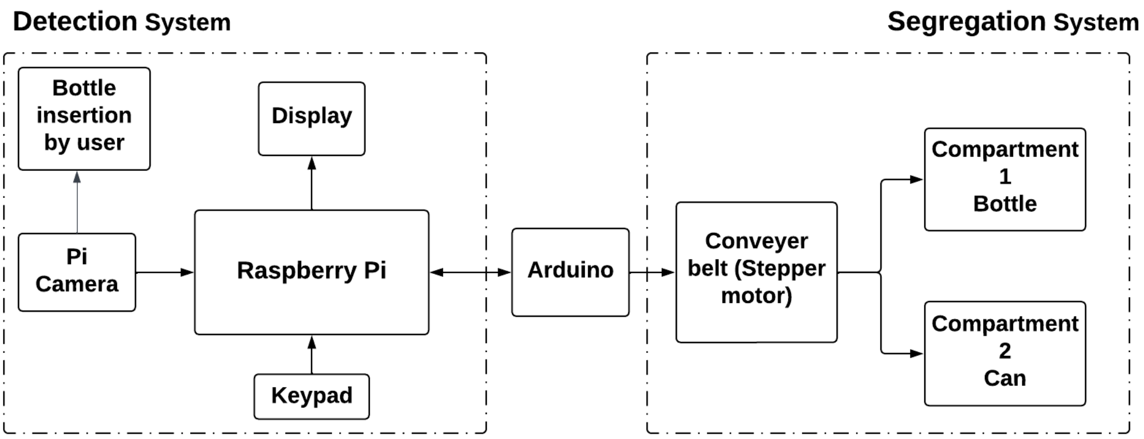

Figure 1. System Block Diagram

The system block diagram is divided into two parts. They are the Detection system and Segregation system. Raspberry Pi performs all the computations required for machine vision. The Pi camera is interfaced to take the image of the item placed in the system. The image taken consists area beside the region of interest. So, pre-processing is done which includes cropping the image and resizing it to 420 * 420 pixels. The Display and Keypad are also directly interfaced with the Raspberry Pi. The Keypad is used to insert the user ID, to which the redeem points get added. An LCD display lets the user see what they press in the keypad and to make the system interactive.

An Arduino microcontroller is utilized to control a stepper motor due to its reliability and ease of use. Universal Asynchronous Reception and Transmission (UART) protocol is used for serial communication between Raspberry Pi and Arduino. There are two compartments in the system, one each for a bottle and a can.

3.2. System Flowchart

The flowchart of the system is shown in Figure 2. Initially, BRM takes user_ID from the user. If the user_ID matches with one of the data in the database, the system waits for the insertion of the bottle. After the bottle is inserted, an image of the bottle is captured. The captured image is fed to the algorithm for the detection purpose. If the output of the bottle identification algorithm is high, an object is identified as a bottle. When an inserted object is a bottle or can, the count is increased by 1. Also, the conveyor belt upon which the bottle is placed rotates in a particular direction. The user is asked if the next insertion is to be made or not. When the user chooses another insertion, the image is taken and the process is again started. If the user opts out from the process the reward is updated on the same ID.

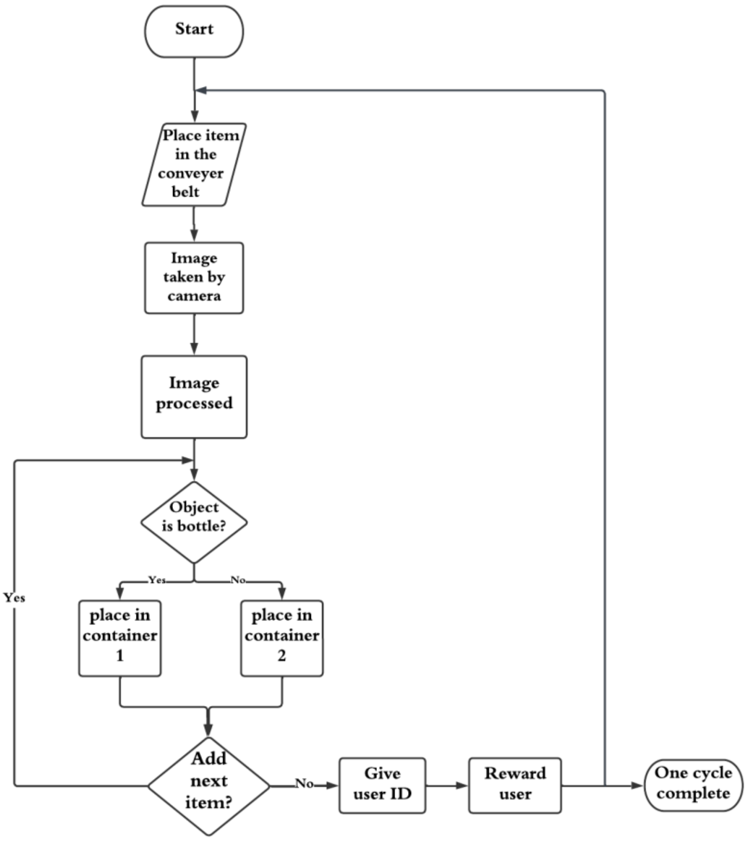

Figure 2. System Flowchart

3.3. Dataset Preparation

Images of various sizes of bottles and cans are taken for training purposes. The images have been collected from different sources such as google and kaggle. The number of images were very few so, in order to get a good se of training data we clicked the pictures of bottles and cans. The pictures are taken such that backgrounds, sizes, lighting and contrast are varied to get a balanced data set for the standardization of the model. The images were augmented to make the training dataset larger with more variances. Some of the techniques used during augmentation were rotation, zooming, tilting and distortion. Finally, all the image is resized to 420 * 420 pixels and fed to the Neural Network so that they can be processed efficiently by the Neural Network.

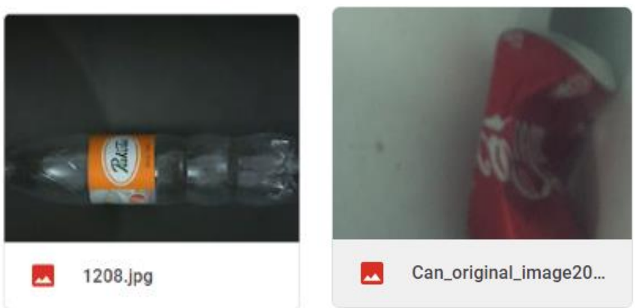

Figure 3 Sample of dataset

Table 1. Number of images in Dataset

SN	Categories	No of images (bottle)	No. of images (can)	Total before Augmentation	Total after Augmentation

1	Train	1500	700	2200	4500
2	Test	525	320	845	2100
	Total	2025	1020	3045	6600

3.4. CNN Architecture

Multiple CNN architectures with the same network architecture but with different parameters were trained to identify the optimum parameters suited for our classification problem. A different classification model was studied to analyze a pattern for our purpose. On testing different architectures, one of the custom models gave a good result. After further tweaking of some parameters, the accuracy increased. After further hits and trials, the model was finalized.

The architecture parameters in each layer are as follows:

- Filter size: (3,3)
- Pool size: (2,2)
- Activation function: ReLu on all layers except sigmoid on the final layer
- Dropout: 0.5 on the dense layer
- Loss: Binary Cross Entropy
- Split ratio: 0.2 (4:1 ratio of training to test dataset)
- Metrics: Accuracy
- Optimizer: Adam
- Batch size: 64
- Epochs: 200

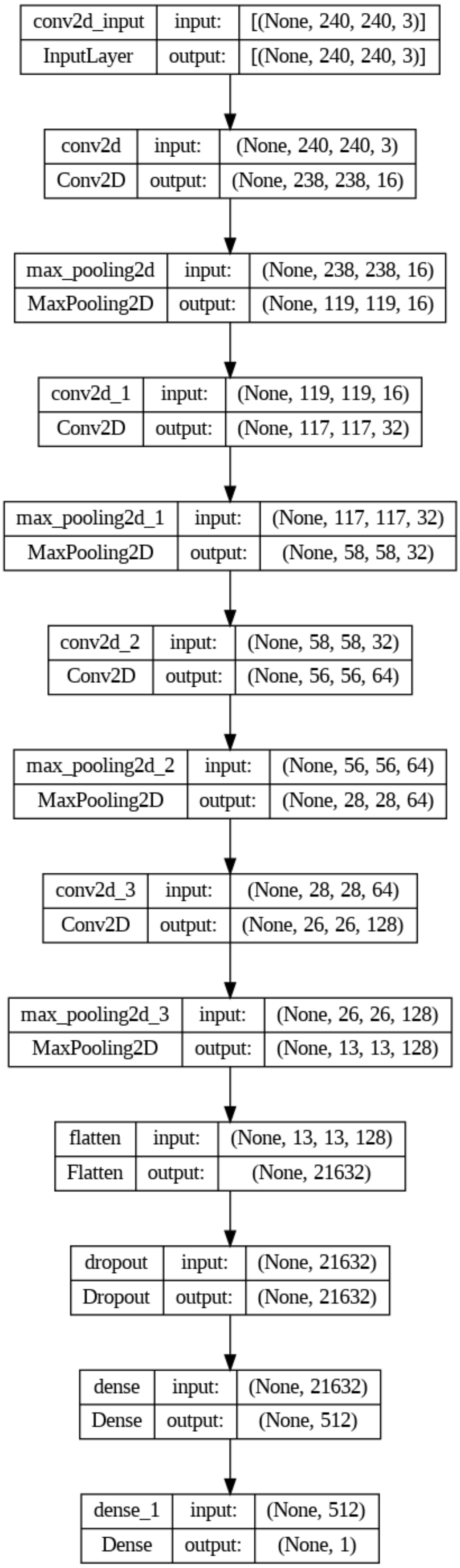

Figure 4. Model Summary

3.5. Mechanical System

Figure 5 System Structure (Front)

Figure 6 System Structure (inside)

The dimension of our model is 48cm *24cm * 48cm. A circular hole of diameter 6 cm is cut to insert a bottle or can. The physical system diagram is shown in Figures 5 and 6. The conveyor belt is axled in two metal rods. The belt moves in Y-axis in both directions. The belt is made using an unstretchable clothing material fixed with the caterpillar wheel. After the detection of an item, it is put into separate compartments. As the belt moves in both directions, the compartments are on each side of the conveyor belt. So, the item gets placed in respective compartments. The camera is placed at the top of the compartment which takes the image of the item placed in the belt.

4. Result

The system has been built to encourage people to recycle bottles and cans, which are the major sources of solid waste by providing rewards. The device is simple, interactive and easy to use. The user doesn't need to have specialized training to operate it and the model works with very high accuracy.

4.1. Performance evaluation of model

This section presents the performance of the proposed model which was trained for a total of 50 epochs. The performance of the model is depicted through two informative curves, namely accuracy and loss, showcased in Figures 7 and 8 respectively. Notably, as the number of epochs progressed, the accuracy displayed a steady rise,

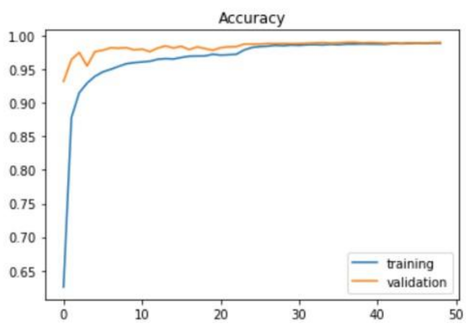

Figure 7 Accuracy curve

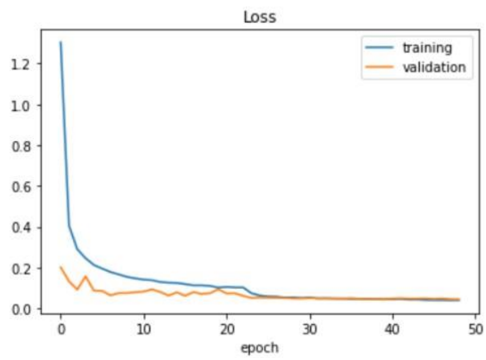

Figure 8 Loss Curve

showcasing an encouraging trend. Figure 7, representing the accuracy curve, demonstrates a minimal disparity between the training accuracy and the validation accuracy. This observation implies that the model did not suffer from overfitting. Moreover, as the epochs progressed beyond the 20-25 mark, the accuracy stabilized, reaching a plateau. An accuracy of about 97% is achieved. In the loss curve shown in Figure 8, we can see that initially, the loss was very high. After 20-25 epochs loss decreased by a greater extent. We can see that the validation loss is lower than the training loss. Also, after certain epochs, the gap between validation and training loss is reduced. It signifies that the model is not under-fitted.

4.2. Analysis

The system has been built to encourage people to recycle bottles, one of the major sources of solid waste by providing rewards. The device is simple, interactive and easy to use. The user doesn't need to have specialized training to operate it. The system has been made friendly with the integration of displays, keypads and other interfacing components.

During training, a very small magnitude of loss and practically high accuracy were observed. Some distinguishable factors that might have caused errors could be fewer epochs of training or invariance in the dataset. On increasing the batch size and training more epochs, the accuracy of the model increased but the model was overfitted. So, the epoch was set to 50 to prevent the model from overfitting and maintain reliable accuracy. Customized CNN and the layers of CNN have been chosen after several trials. Each model with different neuron numbers were validated.

Test Set			
TARGET / OUTPUT	Bottle	Can	SUM
Bottle	1283 61.10%	045 2.14%	1328 96.61% 3.39%
Can	030 1.43%	0742 35.33%	772 96.11% 3.89%
SUM	1313 97.72% 2.28%	787 94.28% 5.72%	2025 / 2100 96.43% 3.57%

Figure 9 Confusion Matrix

Table 2. Metrics of model

Class Name	Precision	1-Precision	Recall	1-Recall	F1-Score
Bottle	0.9661	0.0339	0.9772	0.0228	0.9716
Can	0.9611	0.0389	0.9428	0.0572	0.9519
Accuracy			0.9643		
Misclassification Rate			0.0357		
Macro-F1			0.9617		
Weighted-F1			0.9642		

4.3. Conclusion

The project on the preparation of a reverse vending machine along with bottle and can classification using CNN can be successfully developed and implemented, achieving the desired technical objectives. The CNN model used for the classification of bottles and cans is developed and trained using a large dataset of images. The model achieved high accuracy during testing, demonstrating the effectiveness of deep learning techniques in image classification tasks.

The reverse vending machine has been designed and developed to accommodate the bottle and can classification system, integrating the CNN model seamlessly into the recycling process. The machine can accurately identify and sort different types of bottles and cans, promoting a more efficient and effective recycling process. The system gave the accuracy of 96% on the testing dataset. So, the system is very reliable.

With users getting rewards for the item inserted, it encourages them to recycle more. The system not only fulfills the technical objective but also has a good environmental impact. As these plastic bottles and cans can be recycled into various products, the collection and segregation process become easier. Thus, we also observed an increase in motivation among people when the incentive is provided during recycling.

It has also highlighted some challenges and limitations, including the need for a large and diverse dataset for model training, as well as the need for high-performance computing resources for training and inference. However, these challenges can be addressed through further research and development.

Acknowledgements

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