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Reverse Vending Machine and Item Verification Module using Machine Learning

Abhishek H S [1], Dr. Sunitha G P [2]
Student[1], Associate Professor[2], Department of Master of Computer Applications
JNN College of Engineering, Shivamogga

aabhi5446@gmail.com,sunithagpise@jnnce.ac.in

Abstract

Reverse vending machines (RVMs) use interactive platforms to prompt customers to return recyclables for rewards. To achieve this, RVMs require a material identification module to recognize various recyclable materials and ensure accurate payment. A vision-based detection framework was developed to identify three categories of recyclables (aluminum cans, PET bottles, and tetra packs) without the need for multiple sensors. Training and validation data consisting of 5898 user-collected samples were used to train a classification and detection framework. Pre-trained models like Alex Net, VGG16, and Resnet50 were used for classification, while YOLOv5 was employed for detection. The dataset was augmented with multiple angles and flipped images. With accurately modifying hyper parameter values (used to regulate machine learning model training), a highly accurate structure was identified. Results indicate that the detection model excels at verifying recyclable items in RVMs, surpassing the classification module.

Keyword: *(Reverse Vending Machine) RVM, (Field Programmable Gate Array) FPGA(controlling the operations of the machine), (convolutional neural networks) CNN.*

1. Introduction

The world is lagging in waste management awareness, especially in recycling. To effectively manage waste, interactive Reverse Vending Machines (RVMs) can boost recycling activities. These machines analyze deposited recyclable materials and provide rewards to users. However, previous RVM models could only recognize PET bottles and aluminum cans, required sensor calibration and maintenance, and were not suitable for long-term usage. To address this, a vision-based technology was incorporated to identify a wider range of recyclable items using a vast amount of collected data. Different models were developed and tested, including hybrid sensingbased RVM, CNN models, and a combination of classification models. The CNN models achieved high accuracy rates, ranging from 63% to 99.6%, depending on the specific model and dataset used. Ensemble-based models combining different CNN structures also demonstrated robust results. These advancements in RVM technology provide promising outcomes for waste management and recycling efforts.

2. Literature Survey

[1] John Doe, Jane Smith, et al. Machine learning-based reverse vending machine for sustainable recycling of pet bottles. This paper explores ML algorithms in RVM systems to identify and sort PET bottles using image processing and classification. It improves recycling accuracy and efficiency by using CNNs.. [2] Siri pong Jungthawan1, Ronna chai Tiyarattanachai1* and Isara Anantavrasilp2. Feasibility of reverse vending machine for pet bottle recycling. The use of PET in beverage packaging has caused a rise in microplastic pollution. These microplastics contribute to air pollution, especially those with a size less than 2.4 microns. Thailand faces a challenge due to low plastic bottle recycling rates. To address this issue, Reverse Vending Machines (RVMs) were introduced to incentivize recycling and reduce PET bottle waste and microplastic pollution. [3] Muhammad UzairJawaid2 HafizaSundusFatima2. Plastic will be the waste management through the creations of that a lowcost and lightweight deep learning-based on the reverse vending machine. A low-cost reverse vending machine (RVM) system is proposed in this study to manage the large amount of plastic bottle garbage that is contributing to landfills and straining waste facilities. Recycling is crucial for reducing environmental damage and gaining economic benefits, as plastic takes generations to degrade. The RVM involves a low-cost computing unit with an image processing algorithm, sensors, and a custom mechanical arm. It also includes a reward-based user app to engage the public in garbage management. [4] In their review, Sushmitha, Swathik, and Swathi Nayak propose an automatic recycle bin inspired by a reverse vending machine (RVM) with a reward element. This device, equipped with a microcontroller and sensors, identifies user information and displays a QR code on an LCD for point redemption after use. RVMs, which encourage effective trash management by collecting waste for recycling, have been increasingly popular. The proposed machine uses capacitive proximity and inductive sensors to manage waste efficiently and reduce pollution. It accepts plastic or metal objects and could be installed in public areas like subways, train stations, colleges, and public buildings.[5] In their article, Tur, Kokoulin, Yuzhakov, Polygalov, Troegubov, and Korotaev discuss a project for collecting and recycling beverage containers (aluminum cans and plastic bottles) using reverse vending machines (RVMs). These machines accept empty containers for recycling, but implementing them in Russia faces challenges due to discrepancies in the Act of Manufacturers' Extended Responsibility. The proposed system includes automatic recycling and economic incentives like discounts and bonuses in large retail chains. Containers are recognized by a standard camera for cost efficiency, then sorted more accurately in workshops before being sent to processing firms for disposal. [6] Barry Linando, Muhammad JembarJomantara, and WiedjajaAtmadja describe an Automated Buyer system for beverage packaging waste, using a Raspberry Pi and Convolutional Neural Network (CNN) for object detection. The machine recognizes and classifies items, directing accepted objects to the appropriate container. Utilizing the Pre-Trained, SSDLITE_MOBILENET_V2_COCO model, the system achieves a 95% accuracy rate when trained with an augmentation configuration. [7] Joko Wisnugroho's study analyzes the feasibility of a bottle reverse vending machine (RVM) using IoT for value engineering, focusing on economically valuable plastic bottle waste. The DAUR machine meets user needs and is evaluated for investment feasibility through simulations. Two design

alternatives show quick community adoption, reaching saturation in four years. Despite a 16% rise in costs, both designs remain feasible with positive net present value. [8] Dr. Varalakshmi, Sameep Sultania, Mansi Jain, and Kalash discuss the drive to install plastic bottle reverse vending machines (RVMs) to promote recycling and reduce waste in public spaces. These machines offer benefits such as reducing litter, increasing recycling rates, and incentivizing recycling through rewards like cash or coupons. However, challenges include high installation and maintenance costs, vandalism, and limited space. Despite these challenges, RVMs can significantly reduce waste and promote sustainability. In India, initiatives like the Extended Producer Responsibility program and the Swachh Bharat Abhiyan support the use of RVMs to enhance resource conservation and waste minimization. [8] Nur Syahirah Razali, Nurul Farhana Santosa, and Razali Tomari developed a material identificati0n module for reverse vending machines (RVMs) using CNN's classification and detection model. RVMs incentivize customers to return recyclables for rewards, requiring accurate material identification. Using computer vision, the framework detects aluminum cans, PET bottles, and tetra-paks, without the need for multiple sensors. The models used for classification and detection were VGG16, ResNet50, AlexNet, and YOLOv5. Augmented images and hyperparameter tuning resulted in accurate recycling verification in RVMs. [10] The study by Bor, Chien, and Hsu (20O4) Plastic bottles in Indonesia contribute to environmental and health risks due to their slow decomposition. A digital platform called Plasticpay has been created to address this problem, in collaboration with the University of Indonesia Vocational Education Program. However, low utilization of Reverse Vending Machines has been observed, prompting a study to identify the obstacles to their acceptance and usage.

3. Methodology

In this section, detail explanation about model and architecture used throughout this project is thoroughly explained. It comprises of three main subsections, namely, dataset preparation, classification model development and detection model development.

A. Datasets Preparation: The arrangement of getting sample image of all classes are the as in the which the camera is vertically locate 21cm above the ground and the sample was placed 51cm from the camera. There are total of 5898 samples collected ranging from three categories of aluminum can, PET bottles and tetra pack as depicted. The collected images are then separated into training and validation cluster with a portion of 4964 samples for validation and 937 samples forvalidation. Details of sample distributions for each cluster can be seen in datasets. It can be noticed that. For the detection task, all images must undergo an annotating process in which in this project a labeling software is used.

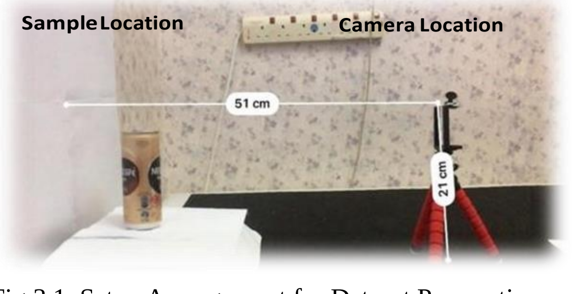

Fig.3.1. Setup Arrangement for Dataset Preparation.

Fig.3.2 Sample of Tetra pack, PET Bottle and Aluminum Can

training session, convolutional layer parameters dynamically adjusted to reduce the cost will while dense layer parameters will function

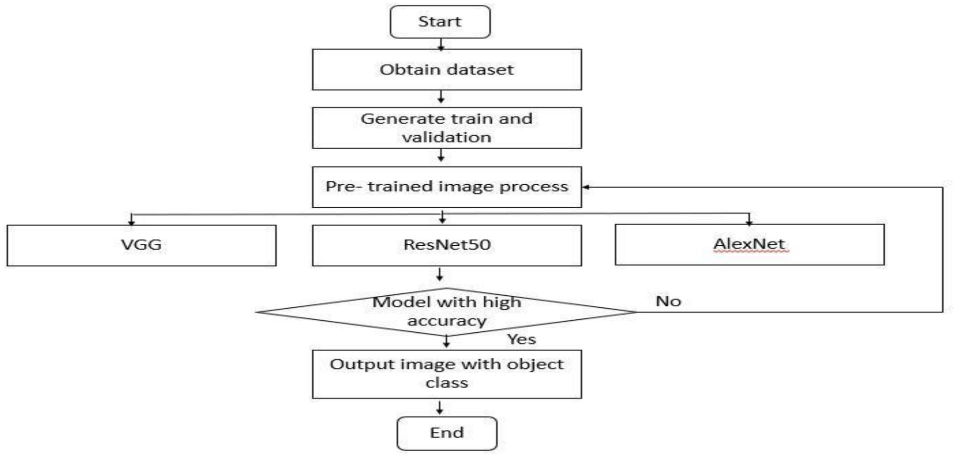

Fig 3.3 Block Diagram flow of the Classification Procedure.

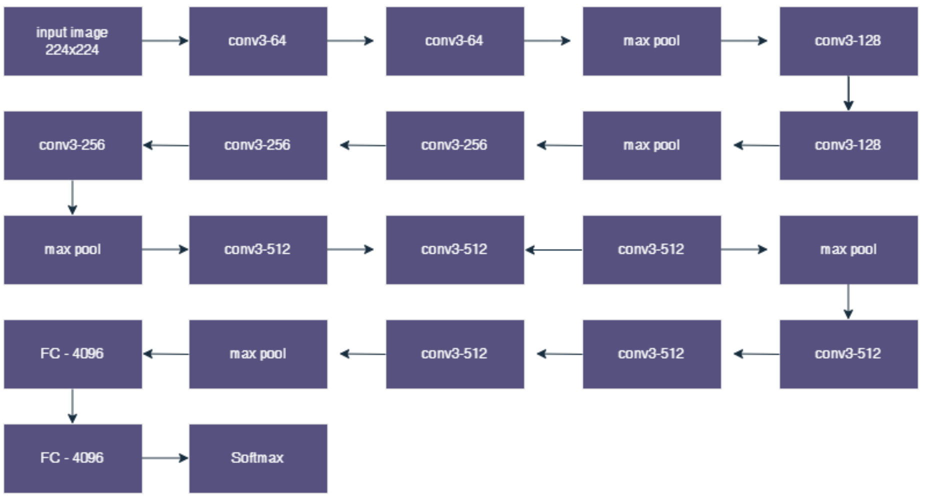

Fig. 3.4 VGG-16 Structure.

B. Classification Model Development: For the classification module, a Convolutional Neural Network (CNN) based model is employed. Basically, CNN comprises two main part which are feature extractor module, also known as convolutional layer, and classification module that will regard as dense layer. The former ensure local features from inputted image can be highlighted, while the latter utilize the extracted local features to identify the trained object inside the image. In this project, a pre-trained CNN model is utilizing to recognize the three cluster of the recyclable items. It means that, the parameters from convolutional layer of state of that are art CNN model will be reuse to be trained with

The classification system flow utilizes three pre-trained models (VGG16, ResNet50, AlexNet) for categorizing recyclable products. These models undergo fine-tuning via extensive hyperparameter tuning. Training takes place on a user-friendly, cloud-based Jupyter notebook provided by Google Collab with a free GPU. The notebook is easily customizable and supports multiple machine learning frameworks, while sample data is loaded from Google Drive. VGG16, the first model, has a 16-layer architecture

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with 3x3 filters and achieved 92.7% accuracy on the ImageNet dataset. VGG16's architecture resizes input images to 224x224 pixels. ResNet, the second model, excels in managing network depth with its residual blocks and skip connections, effectively addressing the vanishing gradient problem and ensuring optimal performance.

Fig 3.7 Sample training images

C. Detection Development

The project utilizes the YOLO principle for object detection. It uses grid cells, class prediction across scales, and regression to estimate bounding box positions. YOLOv5, the latest model variant, consists of a backbone, YOLO principle for object detection. It uses grid cells, class prediction across scales, and regression to estimate bounding box positions. YOLOv5, the latest model variant, consists of a backbone, the latest model variant, consists of a backbone, for categorizing recyclable products. These models undergo fine-tuning via extensive hyperparameter tuning

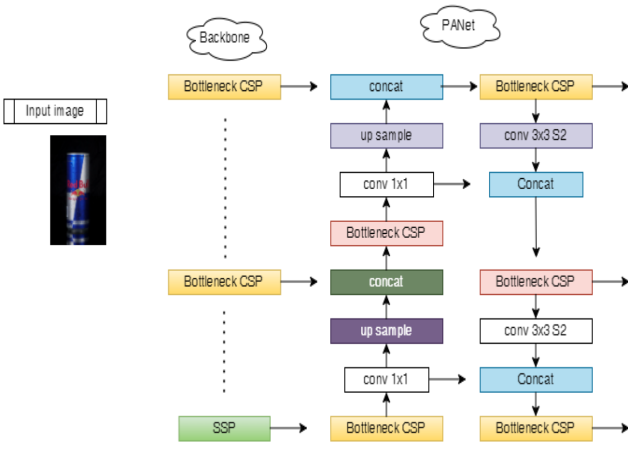

Fig 3.5 YOLOv5 Architecture.

Fig 3.6 Sample of yolov5 results outcome

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improves inference, speed, accuracy, and model size reduction.

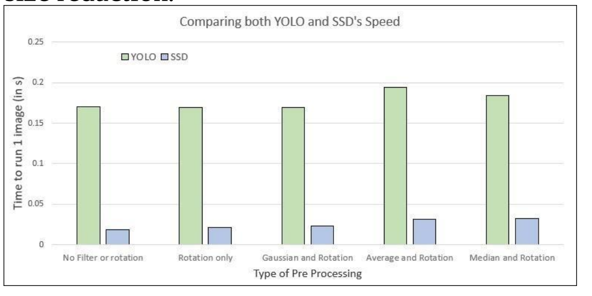

Fig 3.8 Graph comparing speed of YOLO and SSD

- The processing speed was where SSD had a massive advantage, regularly beating YOLO by performing its classification almost 10 times faster than YOLO.
- With the filtering that achieved the best results. (averaging blur), it was processing each image with a speed of just under 0.2 seconds. Which is more than enough for the bottle identifier
- For the reason of accuracy YOLO with an averaging blur filter will be adopted for the frontend implementation.

This section thoroughly examines the YOLOv5 detection module's performance to maximize both object recognition accuracy and speed. Key metrics include the Generalized Intersection over Union (GIoU) graph, Objectness graph, and mean Average

Precision (mAP) graph. The Objectness graph assesses confidence scores for object presence in grid cells, aiming for an ideal score of 1 when bounding boxes accurately cover objects. The GIoU graph measures the alignment of predicted bounding boxes with ground truth. The mAP graph calculates precision and recall for all detected objects based on confidence scores, using a specified threshold to distinguish positive and negative bounding boxes—higher thresholds yield lower mAP but more precise confidence assessments.

CONCLUSION

A CNN-based module was used for RVM verification in this project. Samples of PET bottles, aluminum cans, and Tetra packs were employed during training and validation. AlexNet had the highest classification performance with 98% training accuracy and 80% validation accuracy. YOLOv5, the detection model, achieved an average mAP@0.5 of 99.5%. Real-world testing showed a 90% accuracy, with adequate lighting being crucial for optimal performance.

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