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Using a Yolov8-Based Object Detection Model for an Automatic Garbage Sorting System

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ABSTRACT

This study presents the development of an automatic garbage sorting system based on computer vision techniques and the You Only Look Once version 8 (YOLOv8) algorithm. RGB images of garbage, including cans and plastic bottles, were collected by a camera. The YOLOv8 model, trained on a dataset of both RGB images of cans and plastic bottles, acts as the core for detection and classification. During real-time sorting, the classification results and picking points from the YOLOv8 model are used by a gantry robot. The gantry robot is developed and controlled by a Programmable Logic Controller (PLC) to place each type of garbage into its respective categories. A conveyor tracking algorithm was implemented to pick up garbage moving on the conveyor. The system's performance is evaluated using 20 garbage samples for the can and the plastic bottle category. The accuracy, precision, recall, and F1 score were 92.5%, 90.5%, 95%, and 92.7%, respectively. The system proposed in this study can be modified to sort other garbage types.

1. Introduction

Collection, treatment, and management of domestic waste is a big challenge in managing environmental protection in Vietnam. In recent years, Vietnam has nearly 35,000 tons of domestic solid waste which is transported to designated waste collection and treatment centers daily. Unfortunately, if improperly handled, this process affects the environment and quality of human life. Therefore, recycling waste is one of the tasks to reduce the amount of waste in the environment and improve the national economy. Although properly sorting waste contributes to improved efficiency and accuracy of recycling tasks, it requires many labor costs. Along with the development of modern technology, computer vision and other technologies have been widely used in garbage detection to assist garbage recycling.

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Detecting garbage using machine learning can be approached using various techniques such as Artificial Intelligence (AI), K-Nearest Neighbour (KNN), Logistic Regression (LR), Naive Bayes (NB), and Support Vector Machine (SVM) [1,2]. Recent advances in deep learning have actually outperformed traditional machine learning models in many areas that apply computer vision to garbage classification.

AR *et al.,* [3] classified wastes, including metal, paper, plastic, and non-recyclable waste, based on the AlexNet Convolutional Neural Network (CNN) architecture. The accuracy of the classification model in the study is about 80% when operating in real-time. Chu *et al.,* [4] proposed a multilayer hybrid deep learning system (MHS) with a different approach. The AlexNet CNN architecture was also used for image feature extraction to classify recyclable or other waste. The proposed model achieved an overall accuracy of more than 90%. Waste plastic bottles were identified and segmented based on the Mask R-CNN model pre-trained on the Microsoft COCO dataset [5]. This work achieved a mean average precision (mAP) of 59.4.

Although achieving good detection results, the Mask R-CNN method is computationally demanding and not ideal for real-time object detection for an automatic sorting system. The You Only Look Once (Yolo), widely used in computer vision applications, is a method for real-time object identification and recognition based on CNN. The Yolo algorithm is based on four approaches: Residual blocks, Bounding box regression, Intersection Over Unions (IOU), and Non-Maximum Suppression. Yolo can process images up to 230 frames per second (FPS) depending on the Yolo versions and Graphic Processing Unit (GPU) used.

The Yolo models are more efficient than Mask R-CNN in real-time processing and have higher classification accuracy [6-9]. A few studies have reported the feasibility of the Yolo model in detecting and classifying waste [10-12]. Yolov8 is considered an improved version compared to previous versions in terms of accuracy and has a faster inference time [13-15].

Combining vision systems and grasping robots is a popular solution for pick-and-place tasks in automated sorting systems. The 2D image data from the camera is the classifiers' input to find the robot's picking point [16,17]. A gantry robot is a type of Cartesian robot consisting of axes that are perpendicular to each other. Although, when mentioning grasping robots, manipulator systems such as delta or collaborative robots come to mind first, the gantry robot, designed to have limited mobility, is still suitable for pick-and-place applications for objects on the conveyor due to its simplicity [18]. Ali *et al.,* [19] designed and developed an automatic pepper sorting system with a gantry robot. The system used a camera to detect defective peppers based on color, and the gantry robot sorted the peppers. However, this system needs further improvement before being applied in the industry. For non-stop conveyors, the pick-and-place duty of the robot becomes more complicated when the object's motion changes, especially if the control system does not have feedback from sensors. Therefore, a tracking conveyor solution under the sorting control system is essential, with the advantages of shortening production time and high flexibility. The conveyor tracking task adjusts the robot's operations based on the conveyor's movement. Basic information about the object on the conveyor belt, including position and velocity, is provided to the robot for accurate grasping [20-22].

Python is a high-level programming language widely used in software development, data science, machine learning, and deep learning applications because of its efficiency and ability to run on various platforms. Python provides many options for Graphical User Interface (GUI) development and combines with computer vision in waste classification [23-25]. In addition, Python supports communication protocols for automation applications such as serial port RS232 [26,27], Modbus [28,29], Profinet [30], and OPC UA [31,32].

The main objective of this study was to develop a computer vision-based system for sorting recyclable garbage, including cans and plastic bottles. The Yolov8 model was developed in the Python environment to classify recyclables and obtain the coordinates of the picking point of each recyclable garbage. The coordinate values are then transferred to the Mitsubishi FX5U PLC to control the gantry robot via the Modbus-RTU communication protocol. Conveyor tracking technology is applied to synchronize the gantry robot with the movement of the conveyor, i.e., not stopping the conveyor belt during sorting. A GUI, developed based on the Tkinter library, was used to control and monitor the overall system.

2. Materials and methods

2.1 Samples and Experimental Setup

Recyclable garbage samples, including cans and plastic bottles, were collected at the local waste collection site. Images were captured by placing the object on a conveyor exposed to ambient and/or room lighting. As shown in Figure 1(a), all experimental images have a spatial resolution of 640x480 pixels. The computer vision-based sorting system (Figure 1(b)) consists of three modules: (1) the detection module uses a standard C270 Logitech HD Webcam assembled with a distance of approximately 280mm from the object under inspection, (2) the main conveyor driven by Nema 57 stepper motor with TB6600 driver, and (3) a three-axis gantry robot controlled by a PLC Mitsubishi FX5U-32MT/ES for sorting recyclable garbage.

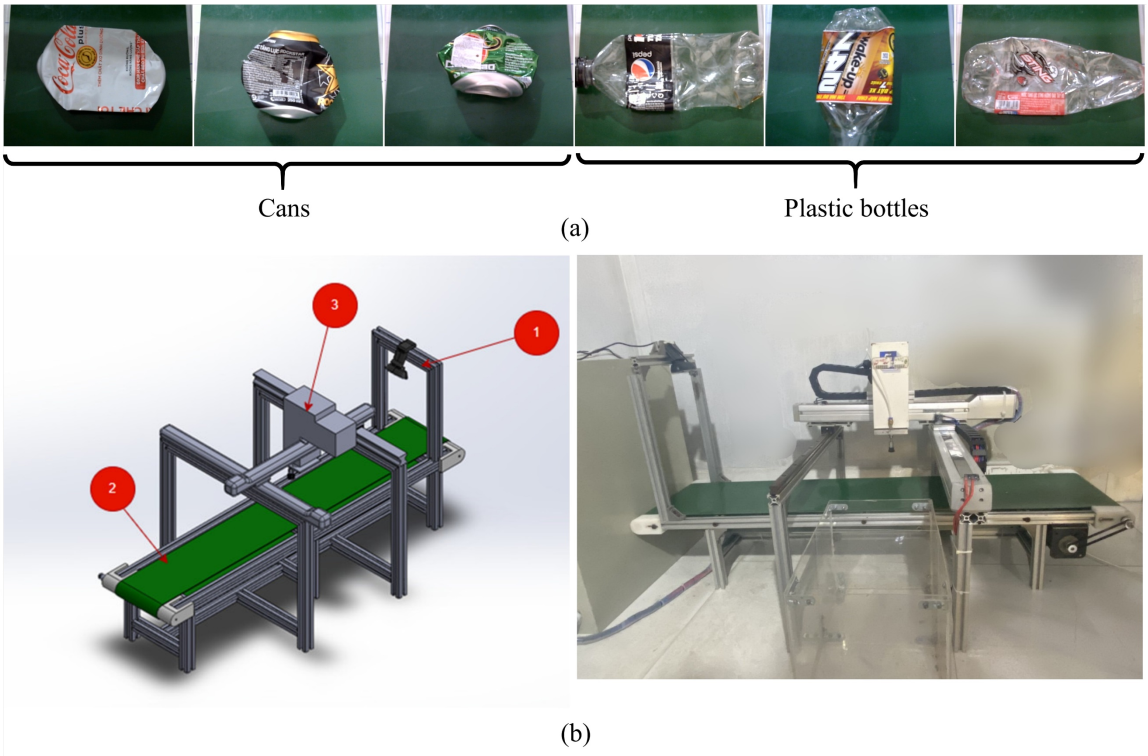

Fig. 1. (a) Categories of garbage images and (b) experimental setup

The detailed procedure of the automatic garbage sorting system is illustrated in Figure 2. The image of the object moving on the conveyor was obtained by the camera via USB. The Yolov8 model was used as a classifier to analyze whether the recyclable garbage was cans or plastic bottles. The three main results of the Yolov8 model, i.e., the bounding box, the class label, and probability, were used for further analysis. The picking points of garbage and garbage class labels were sent to PLC through the Modbus RTU communication protocol. The PLC was used to control the conveyor speed and the gantry robot to perform pick-and-place tasks. The gantry of the robot can move in two horizontal directions, and the suction-based end-effector can move in the vertical axis. The picking points were positioned according to horizontal and vertical coordinates. The GUI program developed in Python was used to operate the automatic garbage sorting system.

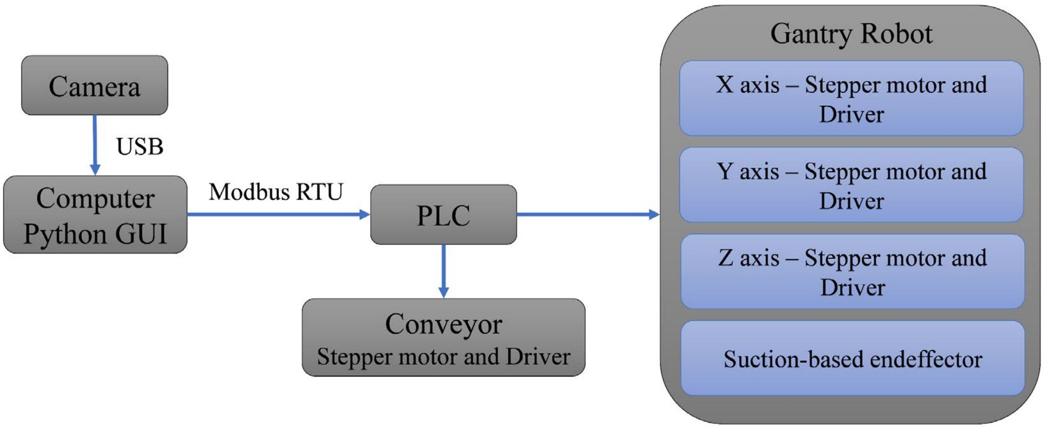

Fig. 2. Schematic of the automatic garbage sorting system

2.2 Yolov8 model

In this study, 200 images were manually collected and labeled as cans and plastic bottles. The collected images were randomly split into two sets: a training set (80%) for the learning process of the model and a validation set (20%) for model verification. Additionally, 20 garbage samples of each can and plastic bottle category were used to evaluate the system's performance. MakeSense.AI was used to annotate images of objects in the YOLO labeling format (Figure 3) and stored as a .txt file that includes the object's class, coordinate, height, and width.

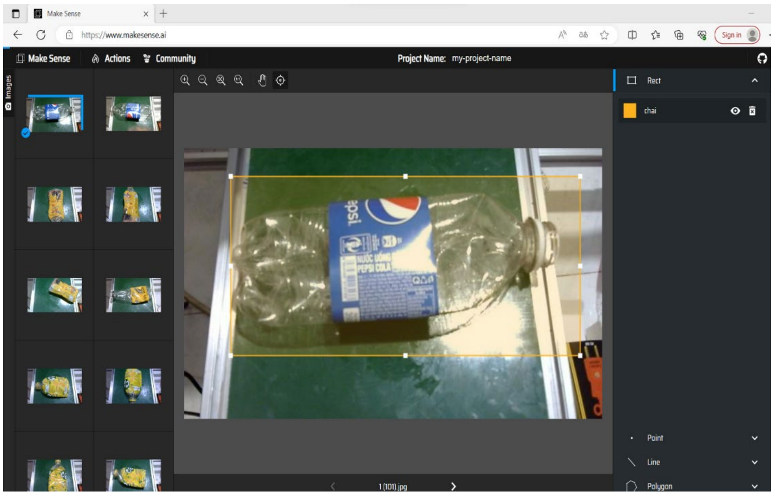

Fig. 3. Annotating Images with MakeSense.AI

The Yolov8 algorithm, developed by Ultralytics and publicly released, has state-of-the-art performance through structural optimization, anchor box optimization, and various data augmentation techniques. In this study, the nano version YOLOv8n classification model was implemented in Python [33] and trained in Google Colab, which provides a free Tesla T4 GPU to speed up model training.

The performance of the proposed model was evaluated using the parameters of accuracy, precision, recall, and F1 score. These metrics provide a measure of how well the model is performing in classifying cans and plastic bottles. If the model performance was unsatisfactory, the hyperparameters were adjusted, or more training data were added. The trained model was then used to run real-time inference for the automatic recyclable garbage sorting system under a computer equipped with an NVIDIA Quadro M1200 graphic card. The center of the bounding box provided by the Yolov8 model was used as the picking point coordinate (Figure 4). Then, the pixel per metric ratio [34] was used to convert the picking point coordinates of the image into physical coordinates and sent to the PLC via Modbus RTU using the Pymodbus library.

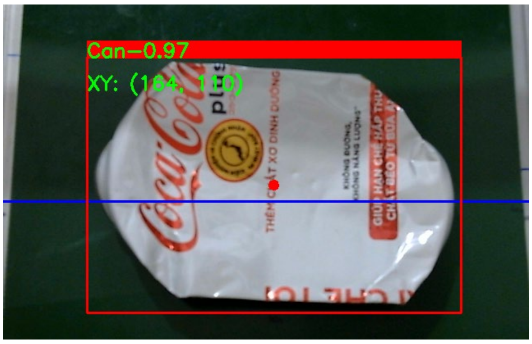

Fig. 4. Determining the coordinates of the picking point

2.3 Tracking strategy

For object tracking, information such as the object's position and the conveyor's velocity should be updated and sent to the gantry robot. Figure 5 shows the physical and camera coordinate systems. First, the center of the object was tracked on each frame in real-time by the Yolov8 model. Then, a straight line in the x-axis direction was passed through the midpoint of the frame (Figure 4) to determine the starting position for tracking P1. In this study, the conveyor speed was constant, and the center of the object within the working range of the gantry robot was used as the coordinate P2, calculated by waiting for a specified time, of the picking point. Furthermore, because the object was flat, the height for the gantry robot to reach and pick up was predetermined and fixed. Finally, the robot used renewed data to complete the picking motion.

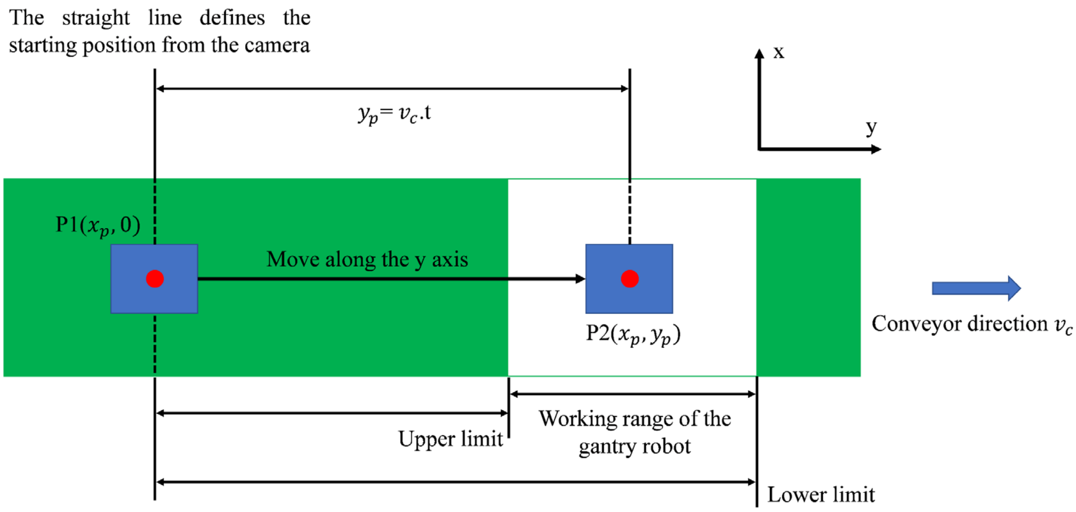

Fig. 5. The procedure of the gantry robot performs conveyor tracking

3. Results and Discussion

Three main library packages, including Ultralytics, OpenCV, and Pymodbus were used to develop software with a GUI program (Figure 6) to integrate computer vision, gantry robot, and conveyor. Ultralytics provides computer vision solutions such as image classification, object detection, image segmentation, and pose estimation. In addition to developing the latest version of the Yolov8 real-time object detection model, Ultralytics also offered pipelines for training, tuning, and applying the model using an easy-to-use API. OpenCV offered powerful computer vision and image processing tools and techniques, and Pymodbus allowed the implementation of the Modbus communication protocol between the computer and the PLC in this study. All parameters of the gantry robot, conveyor, and camera were controlled or shown in the Control Panel group. In addition, the display of the coordinates of P1, and P2 and the inference results of the Yolov8 model were also integrated. The window on the right was used to display images in real-time to assist users in visual observation.

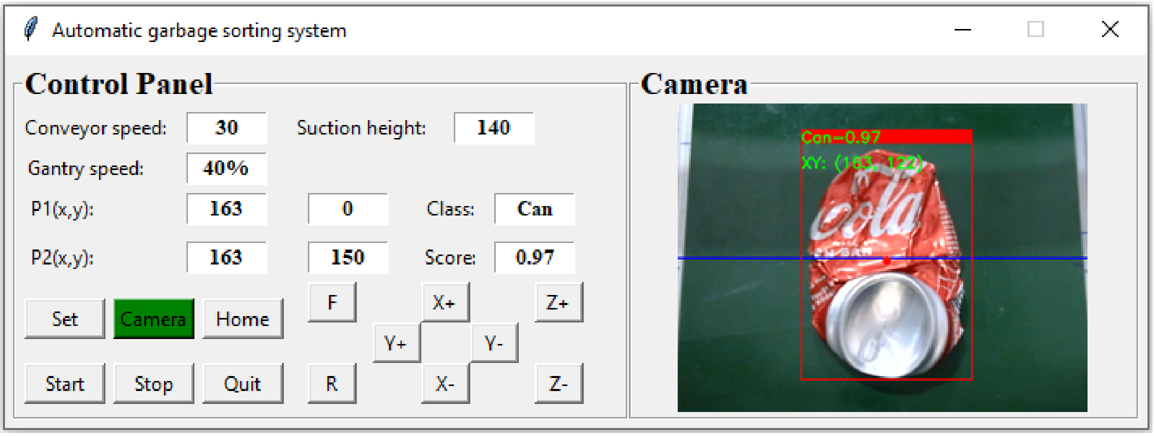

Fig. 6. The user interfaces for sorting system control

To analyze the system's performance, 20 garbage samples of each can and plastic bottle category were used for verification. The confusion matrix of the yolov8 model is shown in Table 1. The rows in this matrix represent the actual class, while the columns are the predicted class. The number of correctly recognized cases is shown on the diagonal entries of the matrix (in the grey background). All entries outside the diagonal represent the number of misclassification cases. There are four possible cases: (1) the plastic bottle is positive and correctly predicted, then it is counted as true positive (TP); (2) Plastic bottle misclassified as can, are counted as false negative (FN); (3) can is negative and correctly classified, it is counted as a true negative (TN) and (4) can misclassified as plastic bottles, is counted as false positives (FP). The accuracy, precision, recall, and F1 score calculated from Table 1, are 92.5%, 90.5%, 95%, and 92.7%, respectively. There are 10% of plastic bottles misclassified as cans. The main reason could be the glare area on the conveyor; furthermore, the plastic bottle samples have shapes and colors similar to cans after being flattened.

Table 1
Confusion matrix of Yolov8 garbage classification model

Actual	Classified as	
	Can	Plastic Bottle
Can	19 TN	1 FP
Plastic Bottle	2 FN	18 TP

This study used the default parameters of the nano version Yolov8n. The returned results of the proposed model consisted of the bounding box and label class and the probability of each class for the classification task. Figure 7 shows the classification results of typical samples. The average inference time for an image is about 70 ms. It can be seen that the Yolov8n model obtained good results in real-time classification. The center of the bounding box of an object was used to determine the coordinate of the picking point while the conveyor moved continuously. Experimentally, the pixel per metric ratio of 2 pixels/mm was converted from pixel to real-world unit in mm.

Fig. 7. Classification results: bounding boxes with the center of the object, label classes, and probability

Yolov8n model plays an important role in this study's computer vision-based real-time sorting system. The picking point information and class label parameters were provided to the gantry robot for sorting. Although, for demonstration purposes, the system developed in this study was only used to detect and sort two typical categories of recyclables, i.e., metal cans and plastic bottles, more sorting categories can be added to make this system commercially viable. Furthermore, the classification category for recyclable and non-recyclable garbage could also be expanded, and the stepper motors used for conveyors and gantry robots could be replaced with AC servo motors for better position and velocity accuracy. Finally, the 2D camera could be replaced with a depth camera or a 3D camera to determine the grasping height for the object instead of using a given height.

4. Conclusions

This study presented a garbage classification application of the Yolov8 model for developing an automatic recyclable sorting system with the following key components: camera, conveyor, and robot gantry. A GUI user interface software was developed in Python to operate the whole system. The system can classify recyclable waste according to the category of cans and plastic bottles while the conveyor moves continuously. The results of the pick point and label class from the Yolov8 model were transferred to the gantry robot for sorting operations via the Modbus RTU communication protocol. The experimental results of 20 garbage samples of each can and plastic bottle category achieved accuracy, precision, recall, and F1 score of 92.5%, 90.5%, 95%, and 92.7%, respectively. The system could be modified to perform classification for other categories of garbage.

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