iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** III **Month of publication:** March 2026

DOI: https://doi.org/10.22214/ijraset.2026.78111

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue III Mar 2026- Available at www.ijraset.com

Automatic Plastic Waste Segregation

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Abstract: An efficient plastic waste segregation system that integrates computer vision and machine learning to achieve accurate and real-time sorting of plastic materials such as PET, HDPE, and PVC. A Raspberry Pi equipped with a camera module captures images of plastic waste transported on a conveyer belt, and a deep learning–based classification model, trained using a labeled dataset divided into training, validation, and testing sets, identifies the plastic type based on visual features. The predicted classification is communicated to an Arduino UNO via serial communication, which performs real-time control of a DC motor and a servo-driven mechanical diverter through motor driver circuit to physically segregate the waste into designated bins. The system is powered by a hybrid energy supply, where solar energy is utilized to operate the entire system during peak sunlight hours, while grid power is automatically used during off-peak or low-sunlight conditions to ensure uninterrupted operation. By reducing manual intervention and improving segregation accuracy, the system not only offers a scalable and cost-effective solution for smart plastic waste management but also promotes sustainability through the effective use of renewable energy resources.
Keywords: Plastic Waste Segregation, YOLOv8, Computer Vision, Raspberry Pi, Renewable Energy, Smart Waste Management

I. INTRODUCTION

The amount of plastic we are producing and using is going up fast and this is a big problem for the environment all over the world. Plastic waste is a part of the trash we throw away it is about 12 to 17 percent of all the waste. When we do not throw away plastic properly and we do not recycle it well it causes a lot of pollution it hurts the land, the oceans and the animals. The old ways of sorting trash are mostly done by hand this takes a lot of time and work. People can make mistakes. Also when people handle trash by hand they can get sick. It makes recycling less efficient. Now we have machines that can help trash this makes the process faster and safer. New computer vision and artificial intelligence technologies can. Sort different kinds of trash on their own. There are algorithms like the You Only Look Once family that can look at pictures and find objects really fast.

We can make a system that sorts trash using computer vision, small computers and machines that sort trash. We can use a Raspberry Pi as the brain of the system and the YOLOv8 algorithm to find and sort trash like PET, HDPE and PVC from pictures taken by a camera. When the system finds and sorts a piece of plastic a small motor can move it to the bin. We can use a conveyor belt to move the trash through the system so it can work all the time without stopping. It is also important that our trash systems are good for the environment. We can use panels to give power to the system this way we do not need to use as much regular electricity. The solar panels turn sunlight into power that can be used by the Raspberry Pi, sensors, motors and other parts. This makes the system better for the environment. It helps us take care of the planet. Plastic waste segregation systems, like this can make a difference. Plastic waste is a problem and we need to solve it so we can use plastic waste segregation systems to help. We need to take care of waste and make sure it does not hurt the environment.

II. PROPOSED SYSTEM

The proposed automated plastic waste segregation system integrates computer vision, embedded processing, and electromechanical automation to efficiently identify and separate plastic waste materials. The main objective of the system is to reduce dependency on manual waste sorting while improving the speed, accuracy, and hygiene of waste management processes. The system operates by detecting plastic waste placed on a conveyor belt, classifying the material using a deep learning model, and automatically diverting the waste into appropriate bins using a mechanical sorting mechanism. The overall architecture of the automated plastic waste segregation system is illustrated in Fig. 1. The system consists of several functional modules including an input module, image acquisition system, processing unit, object detection model, conveyor belt transport system, Arduino-based control unit, servo motor–based sorting mechanism, and a renewable energy power supply unit. These modules work together to achieve real-time detection and automated segregation of plastic waste. Plastic waste materials are initially placed on a conveyor belt that transports them toward the detection region.

A camera module mounted above the conveyor captures images of the plastic objects as they move through the field of view. These images are transmitted to a Raspberry Pi processing unit, where they are analyzed using the YOLOv8 deep learning model.
After identifying the plastic type, the Raspberry Pi sends the classification result to an Arduino UNO through serial communication. The Arduino UNO then generates control signals to operate the servo motor and conveyor motor through a motor driver circuit, enabling the automatic sorting of plastic waste into appropriate collection bins. The entire system is powered using a solar photovoltaic module and battery storage system. A buck converter is used to step down the battery voltage to a regulated 5 V supply, which is required for the operation of the Arduino UNO and other low-voltage electronic components.

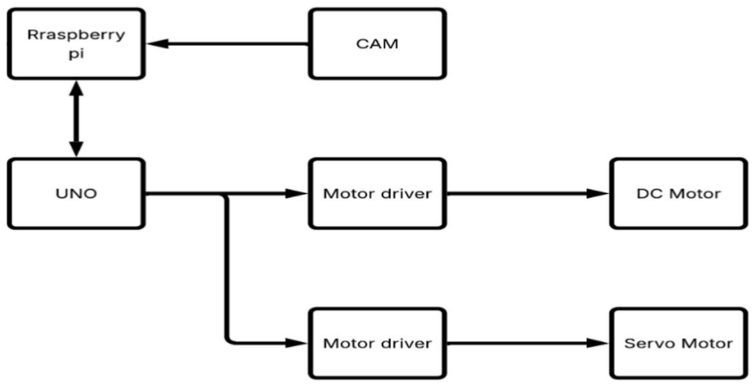

Fig. 1 Block Diagram of Automatic Plastic Waste Segregation

A. Image Acquisition and Processing

The image acquisition module is responsible for capturing visual data required for plastic detection and classification. A Pi Camera Module 3 is mounted above the conveyor belt at a fixed position to monitor plastic waste objects moving along the conveyor surface. Maintaining a fixed camera position and viewing angle ensures consistent image capture under controlled conditions. As plastic objects move through the camera's field of view, high-resolution images are captured and transmitted to the Raspberry Pi processing unit. Before being analyzed by the deep learning model, the captured images undergo preprocessing operations such as resizing, normalization, and noise reduction. These preprocessing steps help improve the detection accuracy of the model. The processed images are then fed into the YOLOv8 object detection model, which analyzes the frames to identify the type and location of plastic materials present in the image.

B. Plastic Detection and Classification Using YOLOv8

The YOLOv8 object detection algorithm is used as the core classification model in the proposed system. YOLOv8 is a modern deep learning algorithm designed for real-time object detection applications. Unlike traditional methods that perform object localization and classification in separate stages, YOLOv8 performs both tasks simultaneously in a single neural network pass, making it highly efficient for real-time applications such as automated waste segregation.

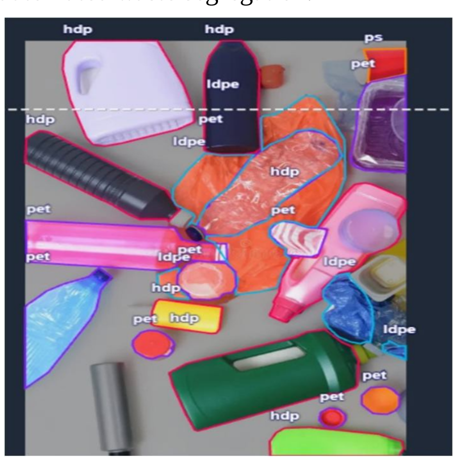

Fig. 2 Image Labelling in ROBOFLOW

The dataset annotation was carried out using the Roboflow computer vision platform. As shown in Fig. 2, bounding boxes are drawn around plastic objects and labeled according to their corresponding plastic type. These annotated images serve as ground truth data for training the YOLOv8 detection model.

The YOLO annotation format stores object class labels and bounding box coordinates using normalized values as shown below:

<class> <center_x> <center_y> <width> <height>

The model training process was performed using the Ultralytics YOLOv8 framework in the Google Colab environment with GPU acceleration. Data augmentation techniques such as rotation, scaling, and brightness adjustment were applied to improve the generalization capability of the model. After training, the optimized model was deployed on the Raspberry Pi platform for real-time inference. The detection output generated by the YOLOv8 model is shown in Fig. 3, where plastic objects are detected with bounding boxes, class labels, and confidence scores.

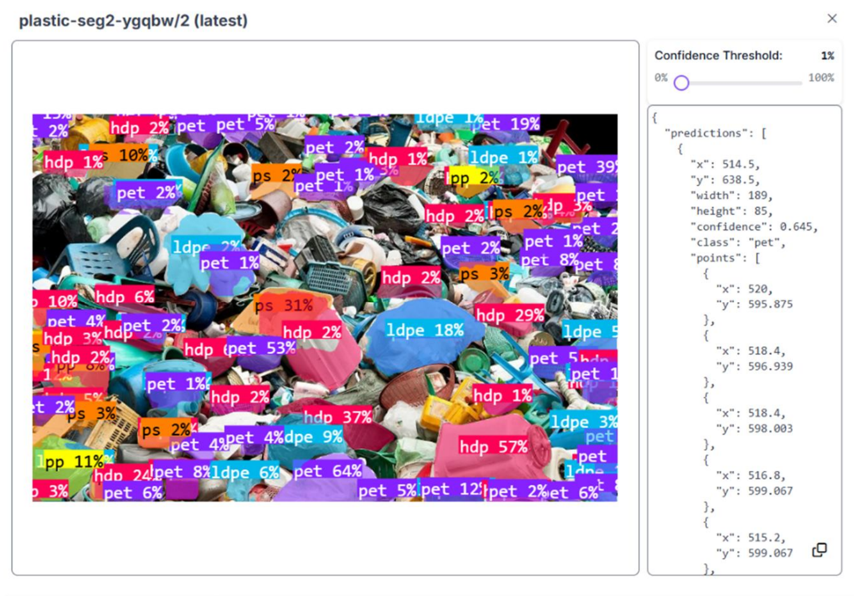

Fig. 3 Output Of Yolov8

The performance of the trained YOLOv8 model was evaluated using metrics such as mean Average Precision (mAP) and mAP@50:95. The training performance curve is illustrated in Fig. 4, which shows the improvement of detection accuracy over training epochs.

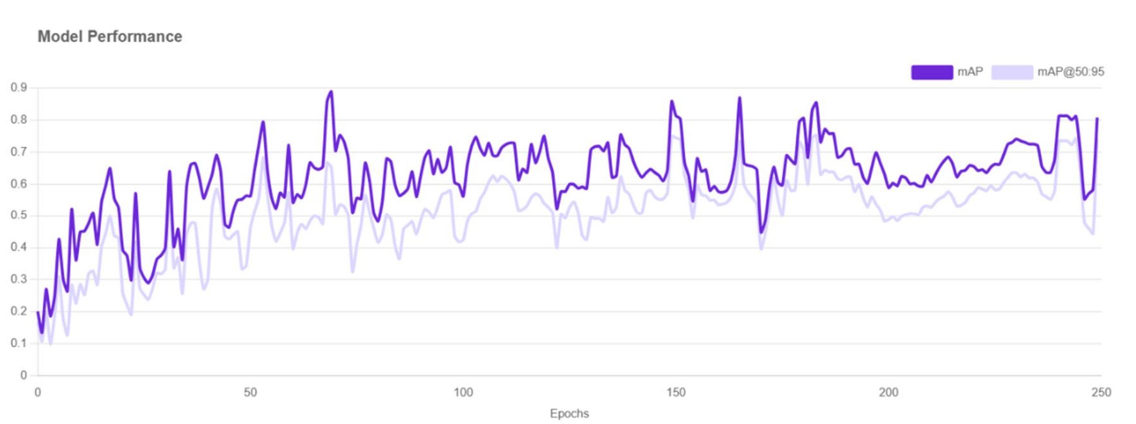

Fig. 4 Performance analysis of YOLO V8

C. Conveyor Belt and Sorting Mechanism

The conveyor belt system is responsible for transporting plastic waste materials from the input stage to the detection and sorting stages. The conveyor enables continuous movement of waste objects, allowing automated processing without manual intervention.

A 12 V DC motor is used to drive the conveyor belt at a controlled speed. The motor is operated through an L293D motor driver, which interfaces the motor with the Arduino UNO and enables safe current handling.

Once the YOLOv8 model detects and classifies a plastic object, the Raspberry Pi sends the classification result to the Arduino UNO. Based on this information, the Arduino generates control signals to operate the servo motor responsible for sorting.

The servo motor rotates to a predefined angle to divert the detected plastic object into the appropriate collection bin. For example, PET plastics are directed toward one bin, HDPE plastics toward another, and PVC plastics toward a separate bin. After completing the sorting operation, the servo motor returns to its original position, allowing the next plastic object to pass through the detection region.

D. Renewable Energy Power System

To enhance the sustainability of the proposed system, a renewable energy power module based on solar photovoltaic technology is integrated into the system design. The solar panel converts sunlight into electrical energy through the photovoltaic effect. The generated DC power from the solar panel is regulated using a solar charge controller to maintain stable voltage levels and prevent battery overcharging. The regulated energy is stored in a rechargeable battery, which acts as the primary power source for the system.

Since some components such as the Arduino UNO and control electronics require a stable 5 V supply, a buck converter is used to step down the battery voltage to 5 V. This regulated voltage ensures safe and reliable operation of the control circuitry.

The stored energy is supplied to the Raspberry Pi, camera module, conveyor motor, and servo motors during system operation. The integration of solar energy reduces the dependency on conventional grid electricity and improves the environmental sustainability of the automated plastic waste segregation system.

III.SIMULATION AND RESULTS

Simulation plays an important role in validating the functionality and operational behavior of the proposed automated plastic waste segregation system before hardware implementation. In this work, MATLAB/Simulink was used to model and analyze the dynamic behavior of the conveyor system and sorting mechanism of the system. The simulation helps in understanding the interaction between the classification signals generated by the object detection model and the electromechanical components responsible for sorting plastic waste materials. The objective of the simulation is to evaluate the system performance during the detection and sorting process, analyze the control logic used for servo motor actuation, and study the operational behavior of the conveyor belt system.

A. Simulation Model of the Sorting System

The complete simulation model of the automated plastic sorting system developed using MATLAB/Simulink is shown in Fig. 5.

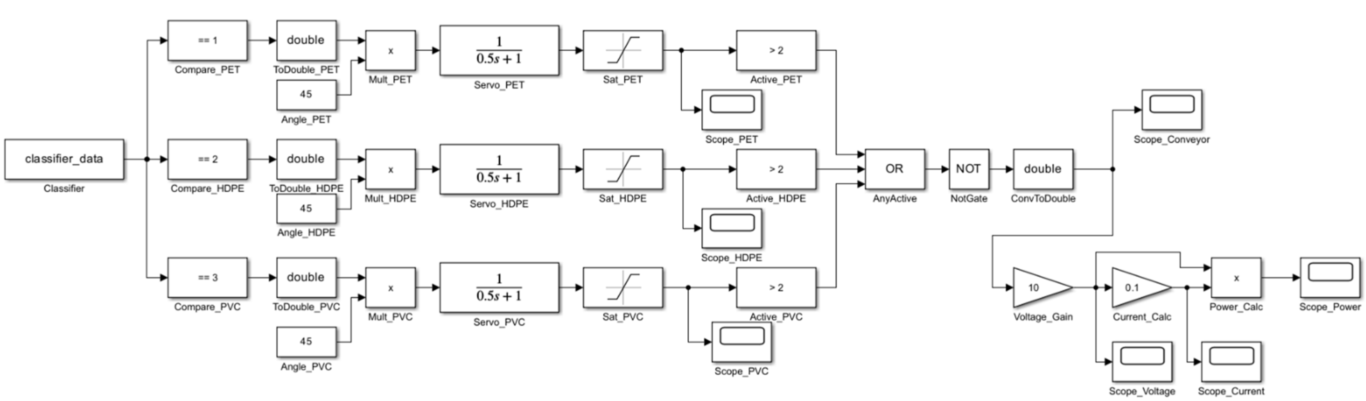

Fig. 5 Simulation model of automatic plastic sorting system

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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In the simulation model, a classifier signal is generated to represent the detection output of the YOLOv8 model. The classifier produces integer values corresponding to different plastic categories. For example, the value 1 represents PET plastic, 2 represents HDPE plastic, and 3 represents PVC plastic. A value of 0 indicates that no plastic object is detected at that moment. These classifier signals are fed into logical comparison blocks that determine which sorting mechanism should be activated. Based on the detected plastic type, the corresponding servo motor is triggered to rotate to a predefined angle, enabling the plastic object to be diverted into the correct output bin.

B. Servo Motor Control Simulation

Servo motors are responsible for actuating the sorting gates used to separate plastic waste materials. Each servo motor corresponds to a specific plastic category and is activated only when the corresponding plastic type is detected by the classifier signal. The servo control mechanism is modeled using logical comparison blocks, data type conversion blocks, and mathematical operations that generate the desired servo angle. When a plastic object is detected, the servo motor rotates to a predefined angle of 45 degrees in order to divert the object into the appropriate bin.

The dynamic response of the servo motor is represented using a first-order transfer function given by: $G(s) = \frac{1}{0.5s+1}$ where the time constant represents the response speed of the servo motor. The simulation output showing the servo motor angle response during plastic detection intervals is illustrated in Fig. 6.

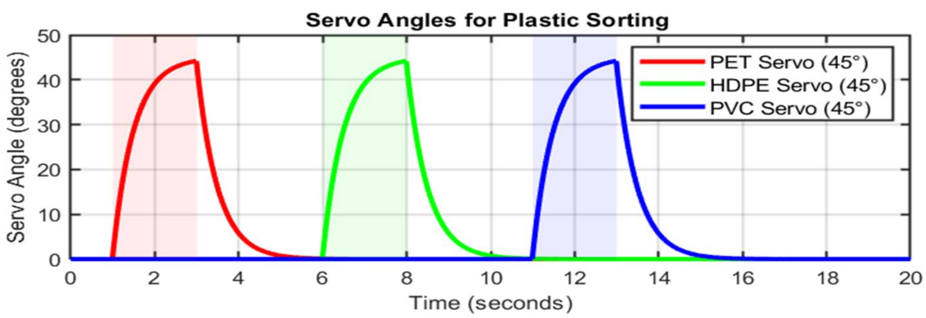

Fig. 6 Simulation result of servo angles for plastic sorting

The graph shows that the servo motor rotates from its initial position of 0 degrees to approximately 45 degrees when a plastic object is detected. Once the sorting operation is completed, the servo motor returns to its original position to prepare for the next detection event.

C. Conveyor Motor Control

The conveyor belt system plays a critical role in transporting plastic waste materials through the detection and sorting stages. In order to ensure accurate sorting, the conveyor must temporarily stop whenever a sorting operation is in progress. To achieve this functionality, the simulation includes a control logic that monitors the servo motor activity. A comparator block checks whether the servo angle exceeds a small threshold value, indicating that a sorting operation is currently taking place. If any servo motor is active, a logical OR operation generates a signal that temporarily stops the conveyor motor.

The simulation output of the conveyor motor operation is shown in Fig. 7. The graph illustrates that the conveyor motor pauses during sorting operations and resumes once the servo motors return to their idle positions. This coordinated operation ensures that plastic items are sorted accurately without overlapping or misclassification.

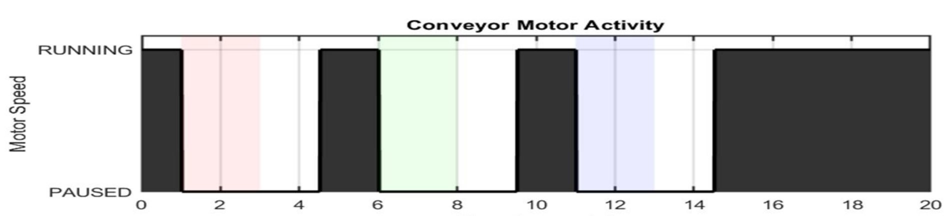

Fig. 7 Simulation result of conveyor motor activity

IV. SYSTEM OPERATION AND WORKING PRINCIPLE

After validating the operational logic and control strategy, the automated plastic waste segregation system was implemented using a hardware prototype. The hardware system integrates computer vision, embedded processing, mechanical automation, and power management components to perform real-time plastic waste detection and sorting. The objective of the hardware implementation is to demonstrate the practical feasibility of the proposed system and evaluate its performance under real-world conditions.

The system consists of several components including a Raspberry Pi processing unit, Pi Camera module, Arduino UNO controller, conveyor belt mechanism driven by a DC motor, servo motor-based sorting mechanism, motor driver circuit, and a solar-powered battery supply. These components operate together to detect plastic waste materials placed on a conveyor belt and automatically separate them into appropriate collection bins.

A. Hardware Architecture

The hardware architecture of the automated plastic waste segregation system integrates both electronic and mechanical components. The Raspberry Pi acts as the central controller responsible for executing the YOLOv8 detection model and controlling the sorting mechanism. A Pi Camera module is mounted above the conveyor belt to capture images of plastic waste materials moving through the detection region.

The captured images are processed by the Raspberry Pi, which performs real-time object detection using the trained YOLOv8 model. Based on the classification output generated by the model, the Raspberry Pi sends control signals through its GPIO pins to activate the corresponding servo motors. These servo motors rotate to specific angles to divert plastic waste items into designated bins. The conveyor belt system continuously transports plastic objects through the detection and sorting region, ensuring smooth and uninterrupted operation of the system.

B. Processing and Image Acquisition Unit

The Raspberry Pi 4 serves as the main processing unit of the system. It performs several important tasks including image acquisition, execution of the YOLOv8 detection model, generation of control signals, and communication with the electromechanical components of the system. The Raspberry Pi operates using Raspberry Pi OS and runs the object detection program developed using Python.

A Pi Camera Module is used for capturing real-time images of plastic waste materials placed on the conveyor belt. The camera is mounted above the conveyor belt at a fixed height and orientation to maintain consistent image capture conditions. The camera continuously captures frames of the moving plastic objects and transfers them to the Raspberry Pi for processing. The captured frames are analyzed by the YOLOv8 model to detect and classify plastic objects based on their type. This information is then used to control the sorting mechanism.

C. Conveyor and Sorting Mechanism

The conveyor belt system is responsible for transporting plastic waste materials from the input stage to the sorting stage. A 12 V DC motor is used to drive the conveyor belt, providing sufficient torque to move plastic waste materials smoothly along the belt surface. The motor operates at a controlled speed to allow sufficient time for image capture and object detection before the objects reach the sorting point.

The sorting mechanism is implemented using servo motors that control the direction of plastic waste materials after classification. Each servo motor corresponds to a specific plastic category such as PET, HDPE, or PVC. When the YOLOv8 model detects a plastic object and determines its category, the Raspberry Pi generates a control signal that rotates the appropriate servo motor to a predefined angle. This movement diverts the plastic object from the conveyor belt into the designated collection bin. After completing the sorting action, the servo motor returns to its initial position, allowing the next plastic object to pass through the system.

D. Solar Power Supply

To improve the sustainability of the system, a solar photovoltaic module is used as the primary power source for the hardware setup. The solar panel converts sunlight into electrical energy through the photovoltaic effect. The generated electrical energy is regulated using a solar charge controller and stored in a rechargeable battery. The stored energy is then supplied to the Raspberry Pi, camera module, DC motor, and servo motors used in the system. The use of solar energy reduces dependence on conventional grid electricity and allows the system to operate in locations where electrical infrastructure may not be readily available.

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E. Reactive Power Compensation and IoT Logging

The complete hardware prototype demonstrates the practical operation of the automated plastic waste segregation system. Plastic waste materials are placed on the conveyor belt and transported toward the detection region. As the objects move through the camera's field of view, images are captured and analyzed by the Raspberry Pi using the YOLOv8 detection model.

Once the plastic type is identified, the Raspberry Pi activates the corresponding servo motor to divert the plastic item into the appropriate collection bin. The conveyor belt continues transporting subsequent objects through the system, enabling continuous sorting operations. The working hardware prototype of the automated plastic waste segregation system is shown in Fig. 8

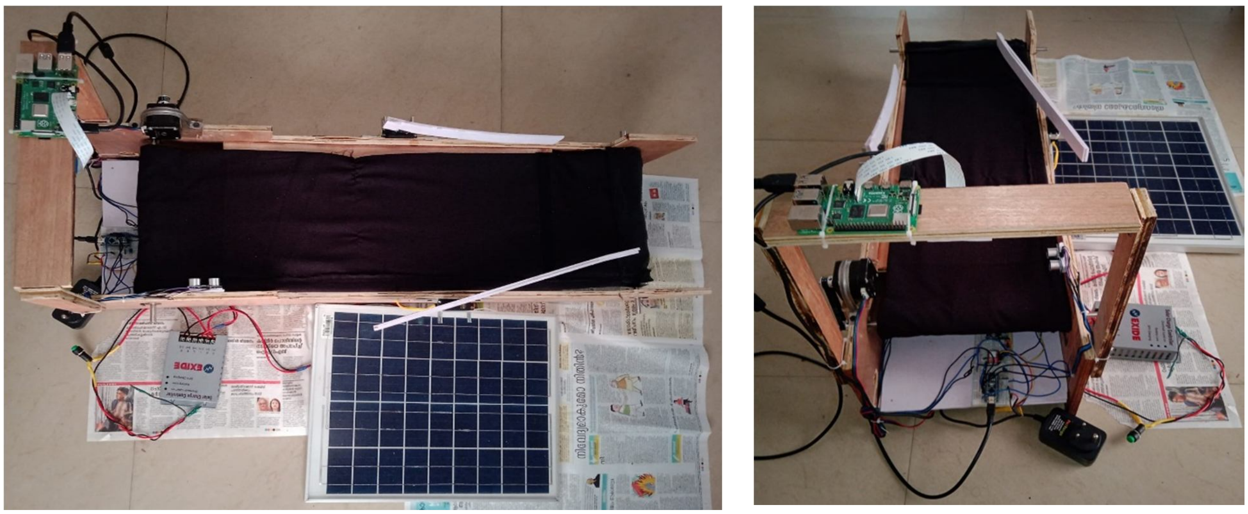

Fig. 8 Hardware Prototype of Automated Plastic Waste Segregation System

The hardware implementation confirms the feasibility of integrating deep learning-based object detection with embedded control systems for real-time waste segregation applications.

V. CONCLUSIONS

Automated plastic waste segregation using computer vision and embedded control techniques provides an effective approach for improving waste management efficiency. The developed system integrates a Raspberry Pi processing unit, Pi Camera module, Arduino UNO controller, and electromechanical sorting mechanism to automatically detect and separate plastic waste materials. The YOLOv8 deep learning model enables real-time object detection and classification of different plastic categories such as PET, HDPE, and PVC. Images captured from the conveyor belt are processed by the Raspberry Pi, and the classification results are transmitted to the Arduino UNO, which controls the servo motor and conveyor motor for the sorting operation. Continuous movement of waste materials through the conveyor mechanism allows efficient automated segregation without manual intervention. A renewable energy power system supported by a solar photovoltaic module and battery storage improves system sustainability, while a buck converter regulates the battery voltage to a stable 5 V supply required for the Arduino and other low-voltage electronic components. Reliable detection performance achieved by the YOLOv8 model demonstrates the suitability of deep learning–based approaches for real-time waste segregation applications. The overall system provides a compact, cost-effective, and scalable solution that can reduce manual labor, improve sorting accuracy, and contribute to environmentally sustainable plastic waste management.

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