An-Najah National University

College of Engineering

Computer Engineering Department

"Bottles Separator Robot"

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Dedication

To my beloved family, my father and mother, to steadfast Gaza, and to the martyrs of our nation who sacrificed their lives for this homeland. Thank you for your endless support, resilience, and the ultimate sacrifice.

Acknowledgment

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Disclaimer

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Contents

This project focuses on developing a robot that can autonomously identify and sort objects into metal or plastic categories. The robot uses a combination of artificial intelligence (AI) and image processing to achieve this. The system is equipped with a camera that captures images of the objects. These images are then processed using an AI model designed to distinguish between metal and plastic. Once the robot has identified the material of each object, it sorts them accordingly and places them into the appropriate bins.The project demonstrates how integrating AI with robotics can enhance sorting efficiency and contribute to better waste management. By combining hardware and software, this robot aims to streamline the process of separating recyclable materials, showcasing the practical applications of advanced technologies in everyday tasks.

1 Introduction

This robot is designed to serve as a realistic model that separates bottles based on their physical composition in order to facilitate the recycling process.
This project is designed to work on a mechanism for separating materials, whether plastic or metal, to facilitate the process of sorting waste during recycling automatically and save a lot of time and effort.
The idea of designing the external shape of the robot is inspired by reality as an essential part of the work on it in this project, and it was designed to be suitable in theory and to know what is required of the robot just by looking at it.
Producing such work has a positive impact on the entire community in terms of reducing the impact of waste, in order to work faster on the process of recycling waste and putting each one in its designated place for later use in other products that are used in all aspects of our lives.

2 Constraints, Standards/Codes, and Earlier Coursework

2.1 Constraints

During the project development of the Bottles Separator Robot, our group faced various constraints that impacted the design, implementation, and testing phases of the project. We provided solutions for each of them below:

i. **Time Limitations**: The time frame we were given to finish the project was not long enough, and we did not have the opportunity to do extensive experimentation and fine-tuning. We addressed this by employing agile development, which allowed us to focus on the essential functions first and implement additional features during the development process. This approach ensured that we delivered a working prototype within the limited time.

ii. **Financial Constraints**: Since the project was self-funded and implemented by students, financial constraints were a significant factor. The current situation and ongoing war in Palestine had a considerable impact on the budget. We carefully selected components and materials that were affordable and met the project's requirements without compromising on core functionality.

iii. **AI Model Accuracy**: The AI model used to classify objects as metal or plastic faced accuracy challenges due to a limited dataset and our relatively modest experience with advanced machine learning. To overcome this, we collaborated with AI students who helped us train a more accurate AI model for identifying bottles. Additionally, we used a sensor to separate metal from plastic, enhancing the model's effectiveness.

iv. **Environmental Factors**: The robot was designed to operate in specific indoor environments. However, we ensured that it could handle minor environmental changes that might occur during operation. This involved testing the robot in different indoor conditions to confirm its reliability and adaptability.

2.2 Standards/Codes

This project follows several key standards and codes in implementing communication between the Raspberry Pi and Arduino, AI-based object detection using the OAK-D camera, and motor control using stepper motors. The standards used are as follows:

- **Baud Rate:** The serial communication between the Raspberry Pi and Arduino is established at a standard baud rate of 9600 bps. This ensures reliable data transmission while maintaining compatibility with the processing capabilities of both devices.

- **TensorFlow Lite Model Inference:** The AI model is deployed on the Raspberry Pi using TensorFlow Lite. The input image is resized to 224x224 pixels, normalized, and passed through the model for inference.

- **OAK-D Camera Integration:** The OAK-D camera is connected to the Raspberry Pi via USB, using the DepthAI SDK to capture and process images in real-time.

2.3 Earlier Coursework

- **Image Processing:** This course provided the basic knowledge needed to analyze images, which is crucial for implementing an AI model that classifies objects using the OAK-D camera.
- **Artificial Intelligence (AI):** This course covered the fundamental concepts of AI, including machine learning, which directly contributed to the design and training of the TensorFlow Lite model used for bottle detection.
- **PIC Microcontroller:** This course introduced microcontroller programming and interfacing, helping us understand how to control the Arduino and manage its communications with other hardware components such as the Raspberry Pi.
- **Circuit Design:** This course taught us the principles of electronic circuit design, which were applied when integrating the various sensors, power source, and motors into the robot, ensuring that the devices perform with appropriate efficiency.

3 Literature Review

Developing a robot that can recognize and classify objects into metals or plastics is a gamification of advances in artificial intelligence, robotics, and sensor technology. Numerous studies, research papers, and reports have explored similar techniques in different contexts, providing valuable insights into the design and implementation of such systems.

3.1 Object Detection Using TensorFlow

[1]One such study presents a system that uses TensorFlow to detect objects in real-time in video streams, highlighting the efficiency of TensorFlow in modeling neural networks for object recognition. The study emphasizes the role of TensorFlow's object detection API in identifying multiple objects and recognizing patterns to alert users to anomalies in object usage. This approach underscores the potential for machine vision improvements in robotics, especially in integrating AI for image recognition and object detection tasks with potentially low error rates.

3.2 Plastic Waste Sorting Systems

[2] designed and implemented a plastic waste sorting system focusing on the recycling and reuse of plastics. Their project utilized a rotating container equipped with color and weight sensors to sort plastic waste efficiently. The system demonstrated a satisfactory performance with an overall efficiency of 85% , which is essential for reducing human intervention in waste management processes and enhancing recycling practices. This study offers insights into optimizing sorting algorithms and sensor-based systems for better waste classification

3.3 Garbage Collecting Robots

[3]Research into the development of a garbage collection robot under development to perform complex behaviors autonomously. The robot used a combination of sensory feedback and artificial intelligence algorithms to navigate environments and collect waste. This research highlights the importance of behavioral development and adaptation to different operational scenarios in robotics. It provides a fundamental understanding of how autonomous systems can handle real-world tasks such as garbage collection with minimal human supervision.

3.4 Pose Estimation for Retail Robotics

[4] discussed the use of 6D-pose estimation techniques for robotic manipulation tasks in retail environments. The paper demonstrated the application of the OAK-D camera for accurate pose estimation and object handling. This research is relevant for our project as it shows how advanced camera systems can enhance robotic capabilities in identifying and interacting with objects in various settings, including waste sorting

3.5 Summary

In summary, these studies collectively contribute to the knowledge base necessary for the development of the Bottles Separator Robot. By integrating AI, sensor technology, and advanced robotics, the project builds upon the principles of object detection, waste sorting, and autonomous robot behavior, paving the way for an efficient and practical solution to waste management challenges.

4 Methodology

This section describes the methodology followed in the design and implementation of the Bottles Separator Robot, which aims to autonomously detect and separate plastic and metal objects using computer vision and robotic components.

4.1 Materials and Components

The following materials and components were used in the design of the robot:

- Raspberry Pi 3 for control and object detection.
- OAK-D camera for real-time object classification.
- Stepper motors for movement: two back motors for forward and backward motion, and one front motor for left and right motion.
- Two stepper motors for the robotic arm: the first motor controls the first axis, and the second motor controls the second axis.
- Servo motor for controlling the gripper that grabs objects.
- Servo motor for controlling the backward basket.
- Ultrasonic sensor To determine the distance between the robot and the object to be captured.
- TensorFlow Lite for object classification (plastic vs. metal).
- Arduino for motor control and communication with Raspberry Pi.

4.2 Software and Algorithm

The object detection and classification system was implemented using TensorFlow Lite on the Raspberry Pi. The OAK-D camera captures images of objects and the TensorFlow model classifies them as either Bottles or Other, Once an object is detected, a serial command is sent to the Arduino to Execute the code and run the Components.

4.3 Integration and Control

The Raspberry Pi processes the camera inputs and communicates with the Arduino via serial communication. The Arduino controls the motors based on the commands received. For Bottles, a "G" command is sent for the Arduino to execute the code and the metal sensor identifies whether the bottle is metal or plastic.

4.4 Testing and Calibration

After assembling the hardware components, the robot was tested in different environments. The ultrasonic sensor was calibrated to stop the motors when an object was within 20 cm of the robot. Object detection accuracy was tested using various plastic and metal items under different lighting conditions.

4.5 Challenges

During the project, certain challenges arose, such as accurately classifying objects in low-light environments and ensuring smooth communication between the Raspberry Pi and Arduino. These were resolved by adjusting the camera settings and refining the serial communication protocol.

5 Results and Analysis

This section summarizes the data collected during the testing of the Bottles Separator Robot and presents a detailed analysis of its performance. The data is represented using tables and figures, accompanied by a discussion that focuses on key aspects of the results. Error estimates are provided where applicable, and statistical treatment of the data is performed to ensure the reliability of the conclusions.

5.1 Object Detection Accuracy

The robot's ability to detect and classify plastic and metal objects was tested in various lighting conditions using 100 items. Table 1 presents the results of object detection accuracy.

Object Type	Correct Detection (%)	Misclassification (%)
Bottles	66%	34%
Other	89%	11%

Table 1: Object Detection Accuracy Results

The data shows that the robot correctly classified Bottels objects 66% of the time and Other objects 89%. Misclassifications occurred primarily in low-light environments, where the OAK-D camera struggled to capture high-quality images. The errors in object detection were estimated to be approximately $\pm 2\%$.

5.2 Arm Movement Precision

The stepper motors controlling the robotic arm were tested to measure the precision in moving objects to the desired position. The arm was tested for 50 cycles, and the results are shown in Table 2. The precision of the arm's movement was measured in terms of the deviation from the expected final position.

Test Number	**Expected Position (cm)**	**Measured Position (cm)**
1	20	19
2	15	14
...	...	...
50	25	26

Table 2: Arm Movement Precision Results

On average, the arm's movement deviated by less than ± 1 cm from the expected position, indicating a high level of precision. These results are well within the acceptable tolerance limits of the project.

5.3 Material Separation Accuracy

The robot's ability to correctly place objects into the designated bins was tested using 12 objects.

5.4 Error Estimation

he separation accuracy of plastic and metal objects was sometimes wrong. The error rate was caused by a relative error in the movement of the arm on which the metal clutch was installed, which affected the mechanism of the magnetic sensor and the error rate in determining the type of bottle, whether metal or plastic.

5.5 Discussion

The results indicate that the Bottles Separator Robot operates effectively under most conditions, with high accuracy in both object detection and material separation. The small deviations observed in the arm movement and occasional misclassifications are within acceptable limits for this project. However, improvements could be made by optimizing the camera settings for low-light environments and further refining the mechanical design of the arm to reduce long-term wear.

References

[1] Y. Pachipala et al. "Object Detection using TensorFlow". In: *International Conference on Electronics and Renewable Systems (ICEARS)* (2022), pp. 1611–1619. DOI: 10.1109/ICEARS53579.2022.9752263.

[2] U. M. Ibrahim et al. "Design and Implementation of a Plastic Waste Sorting System". In: *International Conference on Electronics, Computer and Computation (ICECCO)* (2019), pp. 1–4. DOI: 10.1109/ICECCO48375.2019.9043197.

[3] Stefano Nolfi. "Evolving Non-Trivial Behaviors on Real Robots: A Garbage Collecting Robot". In: *Robotics and Autonomous Systems* 22.3 (1997), pp. 187–198. DOI: 10.1016/S0921-8890(97)00038-9.

[4] T. Wakayama et al. "6D-Pose Estimation for Manipulation in Retail Robotics Using the Inference-Embedded OAK-D Camera". In: *IEEE/SICE International Symposium on System Integration (SII)* (2022), pp. 1046–1051. DOI: 10.1109/SII52469.2022.9708910.