

AI-DRIVEN COLOUR/OBJECT SORTING ROBOTIC ARM

Shubham Phepade, Harsh Bhong, Ayyan Shaikh ,Prof.R.B.Nawale

Department of Electronics and Telecommunication
Sinhgad College Of Engineering Pune, India

Abstract – Automation in material handling and sorting has become a critical requirement for improving efficiency in manufacturing and packaging industries. This project presents the design and implementation of a low-cost robotic arm system capable of automatically detecting and sorting objects based on their colour and shape. The proposed system employs an ESP32-CAM module to capture real-time images of objects placed in the sorting area. The captured images are processed using Edge Impulse, which enables on-device machine learning for object classification. The system utilizes trained models to identify the dominant colour and geometric shape of objects through image preprocessing and feature extraction. The detection results are then transmitted to a microcontroller, which controls the robotic arm's servo motors to pick and place objects into the appropriate bins. Unlike conventional industrial solutions, this project focuses on developing a compact, energy-efficient, and cost-effective prototype suitable for small-scale industries, educational institutions, and research applications. The modular design of the system allows easy scalability and adaptation to different object categories, making it a flexible and accessible solution for intelligent automation.

Keywords - Artificial Intelligence (AI), Robotic Arm, Object Sorting, Edge Impulse, ESP32-CAM, Machine Learning, Automation

I. INTRODUCTION

In recent years, automation has become an essential requirement in industries such as manufacturing, packaging, and recycling to improve efficiency, accuracy, and productivity. Traditional manual sorting methods are time-consuming, inconsistent, and prone to human error, which reduces overall system performance and increases operational costs [1]. To overcome these limitations, intelligent automation systems integrating robotics and artificial intelligence (AI) are being widely adopted [2].

Robotic arms are widely used in industrial automation due to their precision, flexibility, and ability to perform repetitive tasks with high accuracy. When combined with AI techniques, these systems can identify and classify objects based on characteristics such as colour and shape, enabling smarter decision-making processes [3]. Several existing systems have demonstrated object sorting using sensors and image processing; however, many of them are either expensive or lack scalability for small-scale applications [4].

This project presents the design and implementation of an AI-driven robotic arm for automatic object sorting using a compact and cost-effective setup. The system utilizes an ESP32-CAM

module to capture real-time images of objects. These images are processed using Edge Impulse, which enables embedded machine learning and on-device inference for object classification. This approach reduces dependency on high-end computing systems and ensures faster response times [5].

Based on the classification results, the system controls servo motors to pick and place objects into appropriate bins. The proposed system focuses on developing a low-cost, energy-efficient, and modular solution suitable for small-scale industries, educational institutions, and research applications. The modular design also allows easy scalability and adaptability for different object categories [6].

In conclusion, this project demonstrates a practical implementation of embedded AI in robotics for intelligent automation. The system provides an efficient and accessible solution for object sorting, contributing to the advancement of smart manufacturing and Industry 4.0 technologies.

II. LITERATURE REVIEW

Automation in object sorting using robotic systems has been widely explored in recent years, especially with the integration of sensors, embedded systems, and artificial intelligence. Several researchers have proposed different approaches to improve the efficiency and accuracy of sorting systems.

A basic approach to automated sorting using robotic arms is presented in [1], where an ESP32-based system is used to sort objects based on colour and size. The study demonstrates the feasibility of low-cost embedded solutions but is limited in terms of advanced object recognition capabilities. Similarly, in [3], a microcontroller-based robotic arm is used for colour sorting using simple sensor inputs. Although the system achieves basic automation, it lacks flexibility and cannot handle complex object variations.

Research in [2] and [4] focuses on sorting objects based on both colour and shape. These systems utilize image processing techniques to improve classification accuracy. However, they often rely on conventional algorithms, which may not perform well under varying lighting conditions or with irregular objects. Additionally, such systems may require higher computational resources, making them less suitable for compact embedded applications.

More advanced approaches have incorporated computer vision and intelligent algorithms. In [8], a vision-based robotic arm system is developed for object detection using image processing techniques, improving detection accuracy compared to sensor-based methods. Similarly, [9] presents an AI-based object sorting system that uses machine learning techniques for better classification performance. These systems demonstrate improved accuracy but often depend on powerful hardware and complex software setups.

Recent developments in embedded AI have enabled more efficient solutions. The work in [6] introduces an autonomous sorting system using computer vision and lightweight models, highlighting the potential of real-time object detection. Additionally, [7] demonstrates a low-cost pick-and-place robotic arm controlled using embedded systems, emphasizing affordability and simplicity in design.

Despite these advancements, many existing systems face challenges such as high cost, lack of scalability, dependency on external processing units, and limited adaptability to different object types. To address these issues, the proposed system integrates embedded machine learning using Edge Impulse with a robotic arm, enabling efficient, real-time object classification on resource-constrained hardware.

In addition to the above studies, recent research trends focus on integrating embedded machine learning with robotic systems to achieve real-time and efficient object classification. Lightweight models deployed on edge devices have shown significant improvements in reducing latency and dependency on external computing systems. Platforms such as Edge Impulse enable on-device inference, making systems more compact and energy-efficient. These advancements highlight the shift toward scalable, low-cost, and intelligent automation solutions, which form the basis of the proposed system.

Thus, this project aims to combine the advantages of low-cost embedded systems and intelligent object recognition to develop a scalable, energy-efficient, and practical solution for automated object sorting.

III. PROPOSED METHODOLOGY

The proposed system follows a step-by-step methodology for automatic object detection and sorting using an ESP32-CAM, embedded processing, and a robotic arm. The working process is explained as follows:

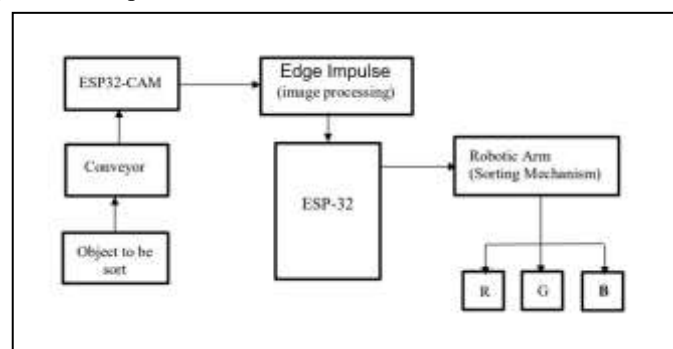


Fig 1: Block Diagram

1. Object Placement and Movement : The object to be sorted is placed on a conveyor belt. The conveyor system moves the object toward the detection area in a controlled manner, ensuring proper positioning in front of the camera.

2. Image Acquisition: The ESP32-CAM module captures real-time images of the object as it reaches the detection zone. This module acts as the vision system of the setup, continuously streaming images for processing.

3. Image Processing and Classification: Instead of traditional OpenCV processing, the captured images are processed using Edge Impulse. The image is analyzed using a trained machine learning model. Features such as colour (RGB) and shape are extracted. The object is classified into predefined categories (e.g., Red, Green, Blue).

4. Data Transmission to Controller: The classification result is sent to the ESP32 microcontroller. This acts as the central control unit, making decisions based on the detected object category.

5. Control of Robotic Arm: Based on the received data. The ESP32 generates control signals for servo motors. The robotic arm moves to the object location. It performs the pick-and-place operation.

6. Sorting Mechanism:The robotic arm places the object into the appropriate bin:Red objects → R bin . Green objects → G bin .Blue objects → B bin

7. Continuous Operation:The system repeats the above steps continuously, enabling real-time and automatic sorting of multiple objects without human intervention.

IV . RESULTS AND DISCUSSION

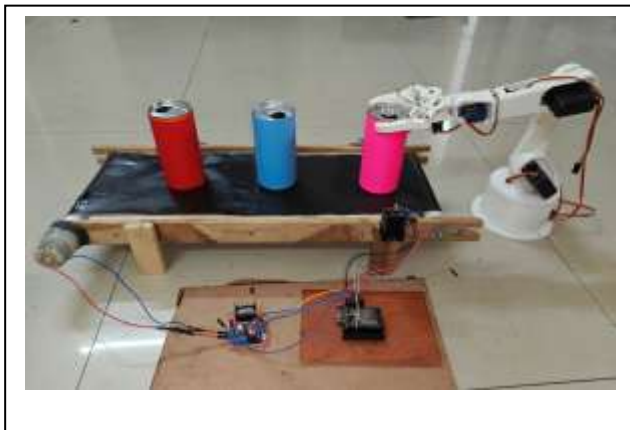


Fig 2: Hardware Setup

The hardware setup of the proposed system consists of a compact and cost-effective arrangement of components used for object detection, processing, and sorting. The system integrates a conveyor mechanism, vision module, controller, and a robotic arm to perform automatic colour-based sorting.

The conveyor belt is used to transport objects (cylindrical cans in this setup) from the input position to the detection area. It is driven by a DC motor, ensuring continuous and uniform movement of objects. The conveyor helps in maintaining a steady flow of items for real-time processing.

An ESP32-CAM module is positioned above or near the conveyor to capture real-time images of the objects. This module acts as the vision system, acquiring image data required for colour detection and classification using Edge Impulse.

The processing and control unit consists of an ESP32 microcontroller, which receives classification results and generates control signals for the actuators. It serves as the central unit coordinating between image detection and robotic movement.

The robotic arm is built using multiple servo motors, providing degrees of freedom for precise pick-and-place operations. The arm is equipped with a gripper mechanism to hold objects securely. Based on the detected colour, the arm moves to

predefined positions and places the object into the respective bin.

A motor driver module is used to control the conveyor motor, while a stable power supply unit provides the required voltage to all components, including the ESP32, servo motors, and sensors.

All components are mounted on a stable base platform, ensuring proper alignment between the conveyor, camera, and robotic arm. The overall setup is designed to be modular, allowing easy modification and expansion for different sorting applications.

Sr. No	Hue	Saturation	Value	Detected Colour
1.	5	210	220	Red
2.	18	200	230	Orange
3.	30	220	240	Yellow
4.	60	210	220	Green
5.	90	200	210	Cyan
6.	110	220	230	Blue
7.	135	210	220	Purple
8.	150	200	230	Pink
9.	0	10	240	White
10	0	200	30	Black

Table 1: HSV values and Output Colour

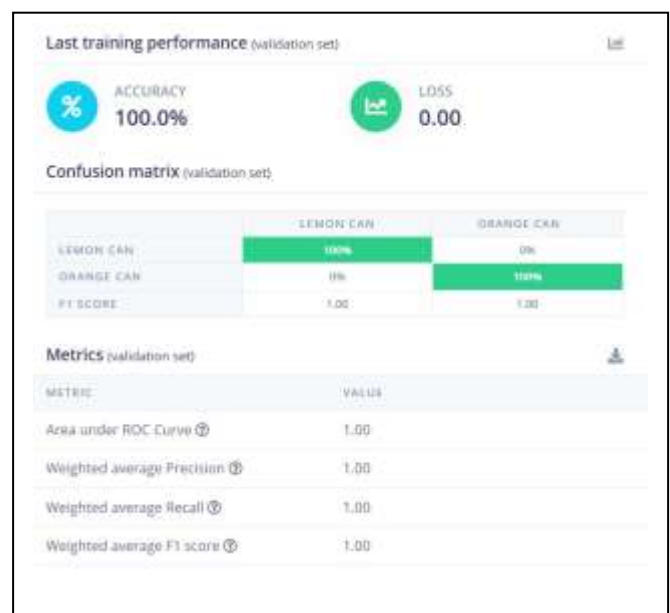


Fig 3: Edge Impulse Result

The above figure shows the training performance of the machine learning model developed using Edge Impulse for object classification. The model achieved an accuracy of 100% on the validation dataset, indicating that all test samples were correctly classified. The loss value is 0.00, which reflects that the model has minimal prediction error during validation. The confusion matrix further confirms the model's performance. It shows that objects belonging to both classes (Lemon Can and Orange Can) were classified correctly with 100% accuracy, with no misclassifications between the classes. This indicates excellent separation and learning capability of the model. Additionally, performance metrics such as Precision, Recall, and F1 Score are all equal to 1.00, which demonstrates perfect classification performance. The Area Under the ROC Curve (AUC) is also 1.00, indicating that the model has a strong ability to distinguish between different object classes. Overall, the results confirm that the trained model is highly accurate and reliable for real-time object detection and classification in the proposed robotic sorting system.



Fig 4. Distinguished Data

The above figure represents the Data Explorer visualization obtained from Edge Impulse during the training phase. This plot shows how the collected dataset is distributed across different classes. In the graph, each point corresponds to a sample image used for training. The two classes Lemon Can and Orange Can are represented by different colored clusters. It can be observed that the data points for each class are grouped closely together, forming distinct clusters with minimal overlap. This clear separation between clusters indicates that the extracted features from the images are highly distinguishable, allowing the machine learning model to effectively differentiate between the two object categories. The

compact clustering within each class also suggests consistency in the dataset, which contributes to improved model accuracy. Overall, the visualization confirms that the dataset is well-structured and suitable for training, leading to reliable and accurate classification performance in the object sorting system.

V. CONCLUSION

This paper presented an AI-driven robotic arm system for automatic colour and object sorting using an ESP32-CAM and Edge Impulse. The system successfully detects and classifies objects in real time and performs accurate pick-and-place operations using a servo-based robotic arm. The results show high classification accuracy and reliable performance, demonstrating the effectiveness of embedded machine learning in automation. Overall, the proposed system offers a low-cost, energy-efficient, and scalable solution suitable for small-scale industrial and educational applications.

VI. REFERENCE

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