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6 DOF 3D PRINTED ROBOT FOR VISION BASED SORTING

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ABSTRACT
This paper presents a low-cost and efficient object sorting system using a fully 3D-printed robotic arm with six degrees of freedom (6DOF). The system uses two types of sorting methods: sensor-based sorting and camera-based (vision-based) sorting. In the sensor-based method, sensors and servo-controlled deflectors on the conveyor belt help in allowing or blocking objects based on their physical properties like shape and color. In the vision-based method, a camera controlled by a servo captures images of the objects, and a Convolutional Neural Network (CNN) processes these images to identify the object's shape, color, and type. Only the correctly identified objects are sent to the robotic arm for picking and placing. The 3D-printed arm is cost-effective and offers flexibility in design. Tests show that the system works accurately and quickly in different conditions. This sorting system is useful for industrial automation, education, and research. The integration of both vision and sensor-based sorting increases reliability and reduces error rates. The modular nature of the system allows for easy upgrades and maintenance. The robotic arm's motion is precisely controlled based on real-time object data, improving the overall efficiency of sorting tasks. The use of 3D printing also allows quick customization for specific applications. This system demonstrates a strong potential for smart and automated manufacturing environments.

Keywords—*6DOF Robotic Arm, Vision-Based Object Sorting, Intelligent Sorting System*

1. INTRODUCTION

Automation in industrial processes is essential for enhancing productivity and accuracy. In the modern industrial landscape, efficiency and precision are critical for maintaining competitiveness and meeting increasing demands. Automation technologies, particularly robotic systems, have revolutionized how industries operate by performing repetitive and complex tasks with unmatched speed and accuracy. These technologies reduce human error, increase throughput, and improve overall product quality.

Robotic arms, equipped with advanced sensors and microcontrollers, have become crucial in automating tasks that require precision and reliability. These robotic systems are capable of executing intricate movements and handling delicate objects, which makes them indispensable in various sectors such as manufacturing, packaging, and material handling. The ability to automate such tasks not only boosts efficiency but also ensures consistency and reduces the physical strain on human workers.

One of the critical challenges in automation is the ability to sort objects accurately based on their attributes, such as size, shape, and colour. Sorting by colour, in particular, is essential in numerous industries, including food processing, recycling, and manufacturing. For instance, in the food industry, sorting fruits and vegetables by ripeness or quality based on colour can significantly enhance product quality and reduce waste. In recycling, differentiating materials by colour can streamline the sorting process, making it more efficient and cost-effective.

This research focuses on developing a robotic arm capable of sorting objects based on their colour attributes using a TCS colour sensor, Arduino microcontroller, and servo motors. The TCS colour sensor is a sophisticated device capable of detecting a wide range of colours with high accuracy. It functions by measuring the intensity of light in the red, green, and blue spectrum and converting this data into a digital format that the microcontroller can process.

The Arduino microcontroller serves as the brain of the system, interpreting the data from the colour sensor and sending commands to the servo motors to move the robotic arm accordingly. Arduino's flexibility and ease of programming make it an ideal choice for this application, allowing for quick prototyping and adjustments. The use of servo motors is crucial for achieving precise movements of the robotic arm. These motors provide accurate control over the position, speed, and torque, which is essential for handling objects delicately and positioning them correctly based on their colour classification.

The integration of these components forms a robust and efficient system capable of performing colour-based sorting tasks autonomously. The potential benefits of such a system are vast.

In industrial settings, it can lead to significant improvements in operational efficiency, reduce labor costs, and enhance the quality of sorted products. Furthermore, the system's adaptability allows it to be customized for various applications, making it a versatile solution for different industries.

The research aims to address the limitations of manual sorting by leveraging advanced technology to create an automated, precise, and reliable colour sorting robotic arm. By doing so, it contributes to the ongoing efforts to optimize industrial processes and meet the growing demands for efficiency and accuracy in automation.

2. Literature Review

2.1. Basic Principles of Machine Vision in Sorting:

The prime concept of using machine vision for object sorting is to provide robotic systems with vision so that they can "look" and perceive visual information so as to be able to carry out tasks that otherwise are handled by human sight. The most standard procedure usually involves visual capture of products, parts, or pictures by way of cameras and requisite illumination. Such captured images are processed through pre-set criteria-driven feature-detecting software, which is especially designed for that purpose. In object sorting, one popular method is to use pattern matching algorithms. Here, a template image of the object to sort is generated and saved in memory of the computer. When sorting software is run, the camera captures a live image of the object, and the vision program inspects the image, contrasting it with the saved template. If a match is established, an electrical signal is transmitted to the sorting mechanism to take the necessary action. In industrial use, the need for high-quality output requires careful analysis of product characteristics to provide qualified results. Machine Vision Inspection Systems do this by the fast capture of images at high frames per second, offering quick and precise input for decision-making.This is essential in sustaining production effectiveness and ensuring that goods manufactured are properly packed and sorted according to the time frame. Current vision-based sorting machines are expected to utilize advanced computer vision algorithms, typically supported by Convolutional Neural Networks (CNNs) or other machine learning models.These algorithms are set to study the visual data derived by cameras for accurately recognizing and classifying objects based on certain characteristics such as size, shape, color, texture, or even barcodes.

2.2. Essential Factors of Vision-Based Sortation Systems:

A typical vision-based sortation automated system has several important pieces of hardware that run side by side and offer the resulting effect. Cameras and sensors form the hardware foundation of an automated sortation system. Speed cameras are needed to photograph or film products as they move along a conveyor belt. Other sensors such as depth cameras, infrared cameras, or lasers can be included based on the specific requirements of the sorting task to provide more information about the items, i.e., their three-dimensional geometry or material properties. Natural light is also a key hardware requirement because light of predetermined intensity enhances contrast and object feature visibility, making subsequent image processing more effective. The software features are also crucial and consist of algorithms and models. The image processing algorithms enhance the quality of images captured and identify prominent features. Feature extraction methods identify and measure features like shape, texture, and color.

Object detection algorithms detect the target objects in the image frame, while classification models like CNNs classify these objects into classes depending on the features detected. Finally, software control logic decides the sorting mechanism's action from classification output. The sorting mechanism itself is the physical device that segregates the items into their respective groups. It is accomplished by using different mechanisms such as actuators, robotic arms, air jets, or diverters depending upon the analysis being performed by the vision system.

2.3. Feature Extraction Techniques in Image Processing:

Correct image processing is the most important aspect of correct object sorting in vision-based systems. Often the initial processing task is to convert color images, typically in RGB (Red, Green, and Blue) format, into grayscale or the HSV (Hue, Saturation, and Value) color space. This transformation enables intensity and color-based analysis to simplify the following processing steps. Thresholding is an important method utilized for segregating objects from their backgrounds according to their intensity levels within the image. Pixels of the object can be separated from the neighborhood pixels by imposing a suitable threshold value. For more intricate analysis, feature extraction algorithms are utilized to detect and measure different attributes of the objects. These algorithms are capable of examining geometric form, texture, and the position or angles of objects in an image. Sophisticated methods like edge detection are essential in separating objects by detecting the edges in an image. Template matching is another simple process where the system matches parts of the image with stored templates to identify objects that closely resemble known patterns. To improve feature recognition robustness, image normalization procedures are frequently used to normalize image features. Image segmentation methods are employed to emphasize the object of interest by isolating it from the remainder of the image, thus enhancing processing speed. In addition, transformation of normalized images into pyramidal form can facilitate feature recognition on different scales.

3. METHODOLOGY

In methodology for sorting objects we have used two main techniques:

1. By Using Colour Sensor
2. **2.** Vision Based Sorting

3.1 System Implementation:

3.1.1 By Using Colour Sensor:

FIGURE 3.1 System Design with Colour Sensor

The robotic arm sorting system is designed to automate the sorting of objects based on their colour attributes. The primary components of the system include a TCS colour sensor, an Arduino microcontroller, and servo motors. The TCS colour sensor is responsible for detecting the colour of objects, the Arduino microcontroller processes this data, and the servo motors execute the necessary movements to sort the objects.

The Colour Sorting Machines is used for sorting mainly RGB colours. This Colour sorting machine separates different coloured objects and classifies them in to respective containers/cups. The Colour Sorting machine is fully automated with the help of ArduinoUNO. This Electronics Project made up of Arduino UNO along with Arduino UNO BOB, RGB Colour Sensor, Two Servo Motors and some plastic funnels and tube parts.

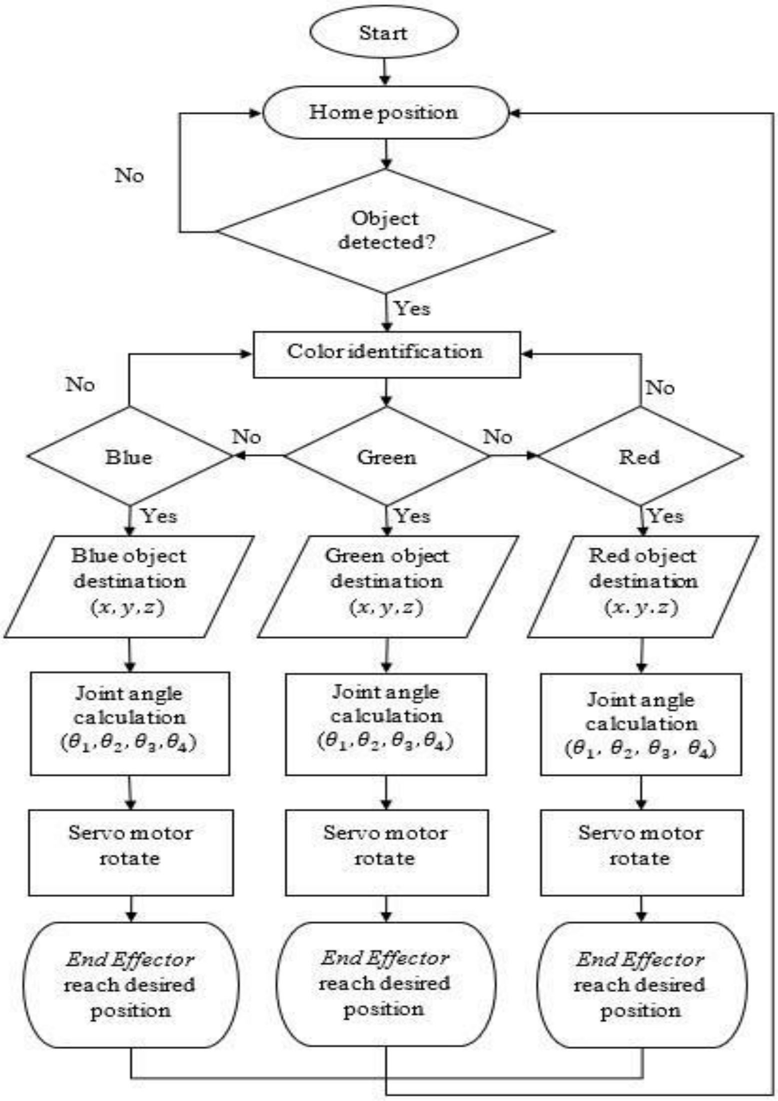


FIGURE 3.2 Colour sorting machine

Since the servo motor is used, so the servo library is essential part of the program. Here we are using two servo motors. The first servo will move the coloured balls from initial position to TCS3200 detector position and then move to the sorting position where the ball will be dropped. After moving to sorting position, the second servo will drop the ball using its arm to the desired colour bucket.

3.1.2 KEY COMPONENTS USED

The system of autonomous object sorting proposed here will employ the following key components:

ESP32: A microcontroller with in-built Wi-Fi and Bluetooth capabilities, which will be the system's primary control unit.

SG90 Servo Motors: Three tiny servo motors utilized for driving the camera module and potentially the deflectors.

MG995 Servo Motors: Two 180-degree high-torque servo motors and one 360-degree continuous rotation servo motor for the robot arm movements.

USB Camera: A camera to take pictures of the objects to be sorted.

Conveyor Mini: A mini conveyor belt system for moving objects.

Stepper Motor: A stepper motor for managing the movement and speed of the conveyor belt.

3.2 **Vision Based Sorting:** Vision based sorting very effectively working and implemented for sorting the object in industries. But for dynamic sorting it is very difficult to achieve Sensor less flaw detection on dynamic conveyor. But in our system we have implemented dynamic sorting by using camera module. In our Industry 4.0 lab we have FMS System and in that system we are having MITSUBISHI Electric Robot with big conveyor and small conveyor. We have implemented this system by removing sensor technique added Camera Module and implemented Vision Based Sorting. In Fig. 3.3 Vision Based Sorting did by Same 3D printed 6DOF Robot Arm

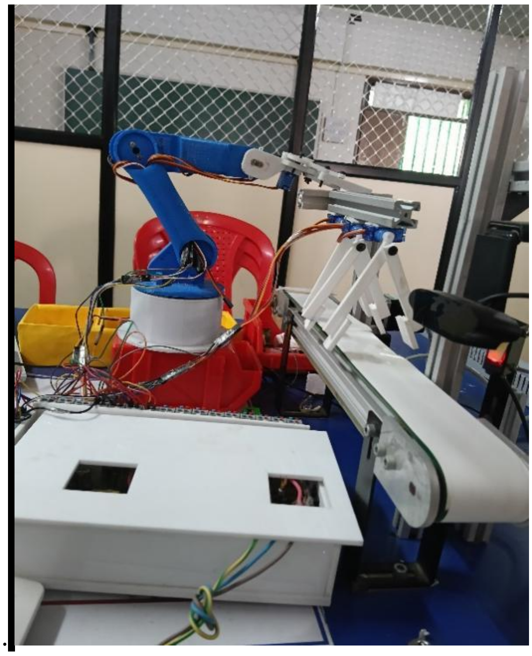


FIGURE 3.3 Vision Based Sorting System

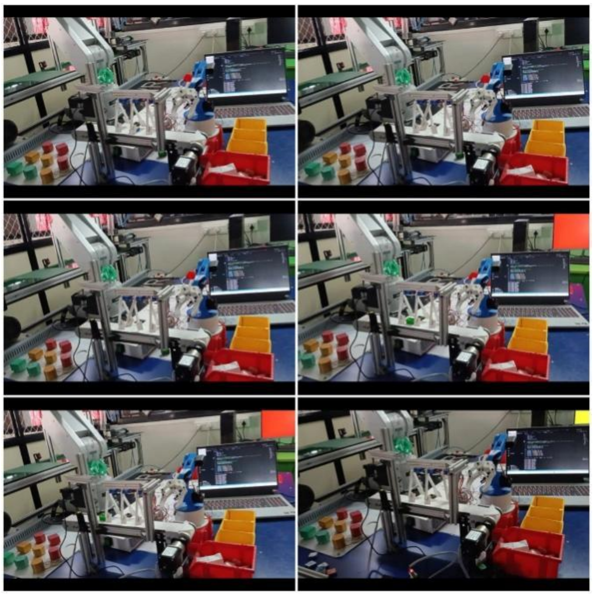


FIGURE 3.4 Stages of Sorting on Dynamic Conveyor

4. OBJECTIVES

1. Research existing low-cost autonomous sorting systems for objects.
2. Find information on the design and manufacturing of 6DOF robot arms using 3D printing techniques.
3. Explore computer vision systems utilizing servo motor-controlled cameras for real-time object recognition.
4. Investigate the application of Convolutional Neural Networks (CNNs) in object recognition for shape, color, and category detection.
5. Research the design and control of sorting devices that use servo-deflectors controlled by servo-motors.
6. Find methods and best practices for achieving seamless integration and synchronism among different robotic system units like robot arms, vision systems, and sorting devices.
7. Explore methodologies for evaluating the performance of autonomous sorting systems, specifically focusing on sorting precision, velocity, and dependability.
8. Search for case studies or research papers that discuss the development and evaluation of similar autonomous sorting systems.

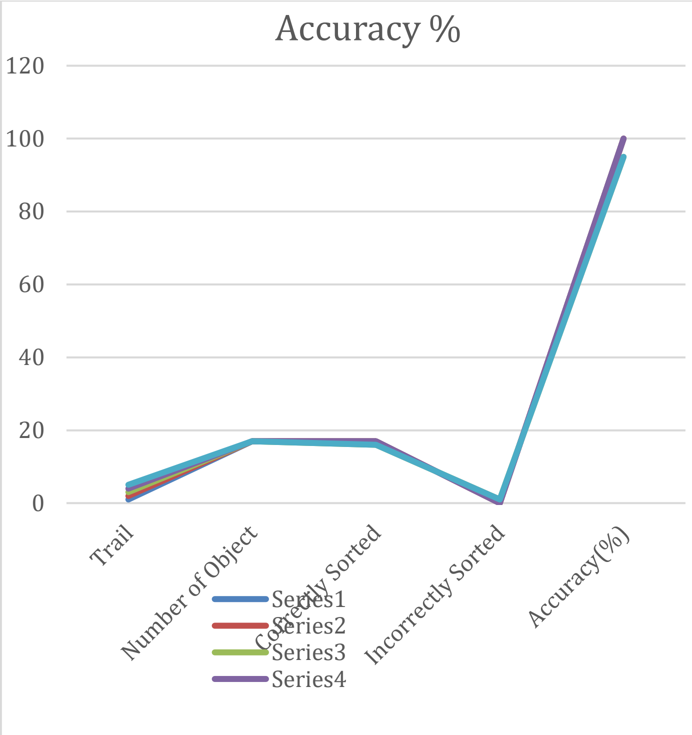
5. RESULTS AND DISCUSSION

a. Result

The results demonstrate the effectiveness of the robotic arm sorting system in accurately sorting objects by colour. The data collected from multiple trials shows consistent performance with high accuracy and efficiency.

Trail	Number of Object	Correctly Sorted	Incorrectly Sorted	Accuracy(%)
1	17	17	0	100
2	17	17	0	100
3	17	16	1	95
4	17	17	0	100
5	17	16	1	95

Table 1: Sensor Based Sorting Accuracy



Graph 3.1 Sensor Based **Sorting Accuracy**

b. Discussion

CONCLUSION

The fully automatic system outlined above provides cost effective, low time consuming and technically simple approach for sorting of objects. This system uses C programming which makes the model easy to use and more efficient. Generally, sensing the colour of the object is a big challenge as there is a chance of high uncertainty due to the external lighting conditions. Similarly, while collecting the objects from conveyor by using a linear actuator system. This project of automatic colour sorting is excellent one because of its working principle and wide implementation. Also the Vision-based systems enable the robot to identify and sort items accurately based on color, size, shape, and flaws or defects. In this the robot can make real-time decisions using camera input, improving sorting speed and efficiency. This is the big advantage that the robot can be reprogrammed for different sorting tasks, making it versatile for multiple applications

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