# COLOR BASED PRODUCT SORTING MACHINE USING EMBEDDED VISION AND IOT

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***Abstract :*** This project presents an automated color-based product sorting system that integrates embedded vision, Internet of Things (IoT) connectivity, and real-time web-based monitoring. The system employs an ESP32-CAM module to capture images of objects moving on a conveyor belt, where color classification is performed using HSV-based image processing techniques. An infrared sensor detects the presence of an object and triggers image acquisition, while servo-driven pushers guide the objects into designated bins based on their dominant color, namely red, green, or blue.

The entire sorting process is controlled by an ESP32 microcontroller, which interfaces with DC motors through an L298N driver for conveyor motion and servo actuators for selective sorting. For monitoring and data analysis, each detected object's image, classification result, and timestamp are uploaded in real time to a Firebase cloud database. A ReactJS-based web dashboard provides live visualization of sorting statistics, captured images, and system status. The proposed system demonstrates reliable real-time performance with minimal latency between detection and actuation, making it suitable for educational demonstrations, small-scale industrial packaging, and quality control applications.
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***IndexTerms* - Color-based sorting, ESP32-CAM, embedded vision, HSV color detection, conveyor automation, servo control, IoT monitoring, Firebase integration.**

## 1. INTRODUCTION

Automation has become an essential component of modern industrial and monitoring systems, enabling improved efficiency, accuracy, and operational reliability. With the rapid development of embedded systems and Internet of Things (IoT) technologies, industries are increasingly adopting automated solutions to replace manual processes that are slow, labor-intensive, and prone to errors [1], [2]. Applications such as monitoring, classification, and control benefit significantly from automation by reducing human dependency and improving system consistency. Manual inspection and handling of products or operational parameters often result in inconsistencies due to human fatigue, delayed response, and subjective judgment [3]. These limitations affect productivity and reliability, particularly in systems that require continuous operation and timely decision-making. Embedded controllers combined with sensors and real-time data processing offer an effective alternative by enabling accurate detection, classification, and actuation with minimal human intervention [1], [4].

Recent advancements in IoT-based embedded platforms have further enhanced the capability of automation systems by allowing real-time data acquisition, remote monitoring, and cloud-based storage [5]. Microcontroller-based systems equipped with sensors and actuators can perform real-time monitoring and control while transmitting operational data to cloud servers for visualization and analysis. Such architectures improve system transparency and support performance evaluation and optimization [2], [5].

In automated industrial applications, the integration of sensing, processing, and actuation enables systems to respond quickly to detected events. Data generated during operation can be logged and analyzed to assess system behavior and improve decision-making processes [3], [4]. These features are particularly beneficial in small-scale industrial setups and educational environments, where cost-effective and scalable solutions are required.

The proposed system utilizes an embedded controller-based architecture combined with sensing, actuation, and IoT connectivity to demonstrate an automated classification and control mechanism. By integrating real-time data processing with cloud-based monitoring, the system highlights the practical application of embedded IoT technologies for automation-oriented tasks. Such systems contribute toward improved reliability, reduced manual effort, and enhanced operational efficiency, supporting the transition toward smarter and more connected industrial solutions [1], [2], [5].

## 2. LITERATURE REVIEW

Automated embedded systems have gained significant attention in industrial applications due to their ability to reduce human intervention, improve efficiency, and enhance operational consistency. In recent years, researchers have explored various automation-oriented solutions that integrate sensors, embedded controllers, communication modules, and actuators to perform monitoring and control tasks in real time. Such systems are particularly effective in applications where manual operation leads to inefficiencies, inaccuracies, and increased labor costs.

P. Veeramani *et al.* proposed an IoT-based monitoring approach for detecting irregular activities in electrical distribution systems by comparing measurements obtained from multiple sensing points. The system enables real-time observation and immediate alert generation when abnormal patterns are detected. Although the application focuses on power systems, the study highlights the effectiveness of distributed sensing and embedded processing for real-time decision-making in automated environments.

Daniel Chowdary presented an automated sorting approach that replaces manual inspection with sensor-based detection and embedded control. The proposed system uses visual information obtained from sensors or cameras to classify products and actuates sorting mechanisms accordingly. The study demonstrates that automation improves sorting speed and consistency while reducing dependency on human labor. However, practical challenges such as lighting variations and processing limitations must be addressed for reliable deployment.

Visalatchi and Sandeep demonstrated the use of microcontroller-based automation systems for continuous monitoring and control applications. Their work emphasizes the integration of low-cost hardware components with sensors and actuators to achieve reliable automation. The study shows that embedded systems can effectively replace manual supervision while improving accuracy and system reliability, making them suitable for small-scale industrial and educational applications.

Khalid A. introduced an advanced classification model that utilizes computational techniques to analyze visual data and improve classification accuracy. The study shows improved performance compared to basic threshold-based methods, particularly in complex classification tasks. While such approaches provide higher accuracy, they require increased computational resources, which may limit their applicability in low-cost embedded platforms.

M. Y. Jamel proposed an automated control system that continuously monitors process parameters and responds to changes without human intervention. The integration of communication modules allows status monitoring and alert generation, improving transparency and operational control. The system demonstrates the benefits of automation in enhancing productivity and ensuring consistent performance in industrial environments.

Several studies have also compared manual and automated sorting methods, highlighting the advantages of intelligent automation systems. Automated approaches that combine sensing, processing, and actuation have shown significant improvements in sorting accuracy, speed, and consistency. Although challenges such as system calibration and processing speed remain, automated color-based sorting systems offer a reliable solution for reducing operational losses and improving efficiency in manufacturing applications.

## 3. METHODOLOGY

The proposed methodology focuses on automated color-based product sorting by continuously monitoring the visual characteristics of objects moving along a conveyor belt. In automated manufacturing environments, products are subjected to varying illumination conditions and surface reflections, which can significantly affect color perception. To ensure reliable color detection under such conditions, the system employs image processing techniques based on the Hue–Saturation–Value (HSV) color model.

Unlike raw RGB color values, which are highly sensitive to lighting variations and brightness changes, the HSV model separates color information from intensity and saturation components. This separation enables more stable and accurate representation of an object's actual color, thereby improving classification reliability. When an object reaches the detection zone, an infrared sensor triggers image acquisition using a camera module or USB webcam. The captured image is then processed to extract dominant HSV color values that represent the true visual characteristics of the product.

OpenCV is utilized to perform image processing and validate the color detection process under normal operating conditions. By analyzing the extracted HSV values and comparing them with predefined color thresholds, the system accurately identifies the dominant color of each product. This HSV-based approach provides a robust foundation for real-time color classification and serves as a reliable method for automated sorting applications.

**A**. Color Detection and Classification Process in the Sorting System

Fig: 1.1: Color Detection and Classification Process

The color detection and classification unit is positioned along the conveyor to detect products in real time. An infrared (IR) sensor triggers the camera module when an object enters the sorting zone. The captured image is converted from RGB to HSV color space to provide a stable and accurate representation of the product's color, as HSV separates hue information from brightness and saturation variations. The processed HSV values are compared against predefined thresholds to identify the dominant color of the product. A control unit, such as the ESP32, Raspberry Pi Pico, or Arduino Uno, generates control signals corresponding to the detected color, which are sent to the actuation unit to guide the product into the appropriate collection bin. This approach enables reliable, automated color-based sorting under varying operating conditions.

B. Flow of Product Movement and Sorting on Conveyor System


Fig: 1.2 : Flow of Product Movement and Sorting

Figure 1.2 illustrates the conveyor-based sorting setup designed to process multiple products sequentially. The conveyor belt transports products through the detection zone, where image capture and color analysis are performed. The embedded controller receives the color classification results and determines the appropriate timing required for sorting based on the product's position on the conveyor. Once the correct timing is calculated, the controller activates the corresponding servo motor to divert the product into the designated collection bin. By comparing the detected color values with predefined reference thresholds, the system accurately classifies each product. This coordinated control of conveyor motion and actuation ensures smooth sorting operation and reliable separation of products. Based on this timing, the controller activates the appropriate servo motor to divert the product into the correct collection bin. Differences between detected color values and predefined reference values allow the system to classify products accurately. This approach enables smooth sorting operations and ensures correct separation of products.

C. Communication from Embedded Controller to Cloud Platform

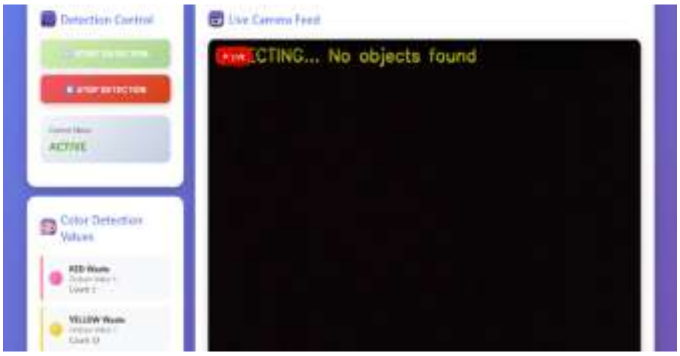

Fig: 1.3: Communication from Embedded Controller to Cloud Platform

This section describes the transmission of sorting data from the embedded controller to the cloud platform. The embedded controller sends processed information such as the detected color, timestamp, and captured image data to the cloud using Wi-Fi communication supported by the ESP-based module. The transmitted data is stored on a cloud server and made accessible through a web-based monitoring interface. This architecture enables remote monitoring and analysis of sorting performance in real time. By observing system behavior under different operating conditions, the cloud platform supports performance evaluation, fault detection, and overall system monitoring.

D. Overall Function of the Color-Based Product Sorting System

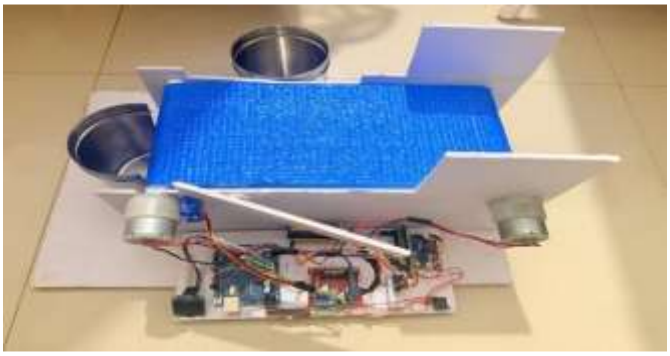

Fig: 1.4: Overall Function of the Color-Based Product Sorting System

The figure illustrates the complete operation of the color-based product sorting system. Products moving on the conveyor belt are first detected using an infrared sensor, which triggers image capture by the camera module. The embedded controller processes the captured image data and classifies the products based on their color. After classification, the corresponding servo motor is activated to guide each product into the appropriate collection bin. Simultaneously, the system transmits sorting results to the cloud platform through wireless communication. This integrated operation enables centralized monitoring while ensuring reliable, continuous, and fully automated sorting of products.

E. Image Acquisition and Processing Workflow Using Camera and Embedded Controller

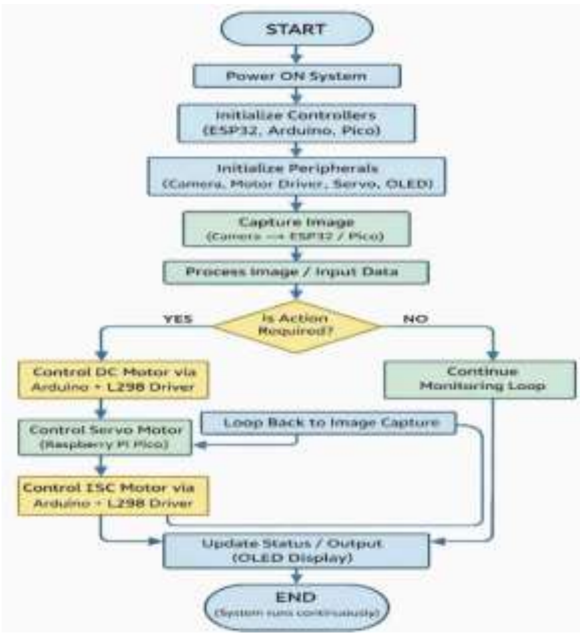


Fig: 1.5 Image Processing and Control Workflow

The automated product sorting system operates by capturing and processing images of products as they move along the conveyor belt, as illustrated in Fig. 1.5. When a product enters the camera's field of view, image capture is triggered at the detection point. The captured image is then transferred to the processing unit, where the dominant color of the product is identified.The extracted color information is compared with predefined reference thresholds to determine the appropriate product category, such as red, green, or blue. Based on this classification, the processing unit activates the corresponding actuator to direct the product into the correct collection bin. At the same time, the sorting information is transmitted to the monitoring system for record and analysis. This sequential operation enables accurate decision-making and ensures reliable real-time color-based product sorting..

## 4. FORMULAS USED

This section describes the logical expressions used for color classification and sorting decisions in the proposed automated product sorting system.

### A. Object Detection Model (Main Formula)

Let the IR sensor output be represented as a binary signal:

$$(t) = \begin{cases} 1, & \text{if object is detected at time } t \\ 0, & \text{otherwise} \end{cases}$$

**Image capture is triggered when:** $S(t) = 1$ **(1).**

### B. Feeder Image Representation Model

The captured RGB image is represented as:

$$IRGB(x, y) = [R(x, y), G(x, y), B(x, y)]$$

where $x$, $y$ denote pixel coordinates.

### C. RGB to HSV Conversion

The RGB image is transformed into HSV color space to improve robustness against lighting variations.

$$V = (R + G + B) / 3$$

Saturation (S):

$$S = 1 - [\, 3 \times \min(R, G, B) / (R + G + B) \,]$$

**Hue (H):**

**If $B \leq G$ :**

$$H = \cos^{-1} \{ [\, (R - G) + (R - B) \,] / [\, 2 \times \sqrt{(R - G)^2 + (R - B)(G - B)} \,] \}$$

**If $B > G$ :**

$$H = 360° - H$$

## 5. BLOCK DIAGRAM

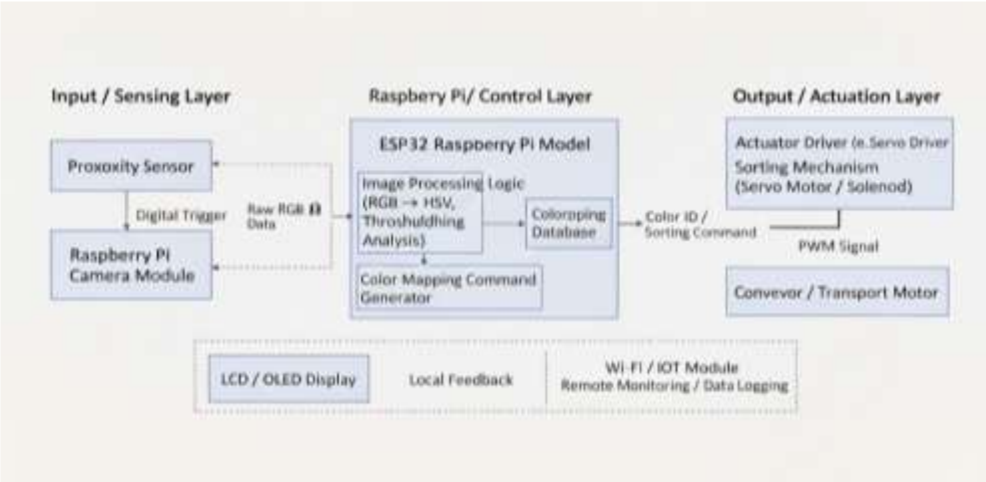


Fig: 2.1 Color-Based Product Sorting System

The block diagram shown in Fig. 2.1 illustrates the overall architecture of the color-based product sorting system, which is divided into sensing, processing, and actuation layers. The Raspberry Pi Pico serves as the central processing unit and performs real-time control and decision-making functions. It receives input signals from sensors and image-processing modules and evaluates color classification results based on predefined rules. The availability of programmable GPIO pins allows seamless interfacing with sensors, motors, and display units, enabling fully automated operation without manual intervention.

The sensing layer includes an infrared proximity sensor and a camera module. The infrared sensor detects the presence of a product on the conveyor belt and triggers image capture at the appropriate moment. Once triggered, the camera module or USB webcam captures images of the product and forwards them to the processing unit. This ensures accurate and consistent acquisition of visual data required for color classification.

The processing unit analyzes the received image data to identify the dominant color of the product. Based on the classification result, control signals are generated and transmitted to the actuation layer. The actuation layer consists of servo motors and a DC motor. Servo motors are used to divert products into the appropriate collection bins, providing precise angular control and fast response. The DC motor drives the conveyor belt and maintains synchronized movement to ensure stable positioning during detection and sorting.

For user interaction and system monitoring, a 16×2 LCD display is integrated into the system. The display presents real-time information such as detected color, system status, and sorting count, allowing quick verification of correct operation. In addition, a Wi-Fi communication module enables wireless data transmission between the embedded controller and the cloud platform. Sorting data, including color type and timestamps, are uploaded to the cloud for remote monitoring and logging. This connectivity supports real-time performance analysis and enhances system reliability.

**6. SOFTWARE REQUIRMENT**

The implementation of the color-based product sorting system requires software tools that support embedded control, image processing, cloud connectivity, and web-based monitoring. The primary development environment used for embedded programming is the Arduino Integrated Development Environment (IDE). It provides a unified platform for writing, compiling, and uploading firmware to ESP32 and ESP32-CAM modules using C/C++ programming. The Arduino IDE enables easy integration of libraries required for sensor interfacing, motor control, camera handling, and wireless communication, which are essential for real-time system operation.

Control logic for conveyor motion, servo actuation, and object detection is developed and tested within the Arduino IDE. Built-in libraries and board support packages simplify communication with hardware components such as infrared sensors, DC motors driven through the L298N motor driver, and servo motors. Timing control and interrupt-based processing are used to coordinate object detection, image capture, and sorting actions, ensuring accurate and synchronized system performance.

Image processing tasks are implemented using OpenCV functions adapted for embedded platforms. OpenCV is used for image preprocessing, color space conversion, and color feature extraction. Captured images are converted from the RGB color model to the HSV color model to improve robustness against lighting variations. The HSV-based representation allows reliable extraction of dominant color information, enabling accurate classification of products into predefined color categories. These image processing operations are executed locally on the embedded controller, reducing processing latency and enabling real-time decision-making.

For cloud connectivity and data storage, Firebase Realtime Database is used as the backend platform. The embedded system transmits sorting data such as detected color, timestamp, and image references to the cloud using secure Wi-Fi communication. This enables continuous data logging and supports remote monitoring and performance analysis.

Web-based monitoring is implemented using a ReactJS framework developed within the Visual Studio Code environment. The web application retrieves live data from Firebase and presents sorting statistics, captured images, and system status through an interactive dashboard. This allows users to monitor system performance remotely without direct access to the physical setup.

Overall, the integrated software architecture supports real-time data acquisition, processing, transmission, and visualization. The combination of embedded firmware, image processing algorithms, cloud services, and web-based monitoring ensures reliable system operation and makes the solution scalable for educational and small-scale industrial applications.

## 7. RESULTS AND DISSCUSSION

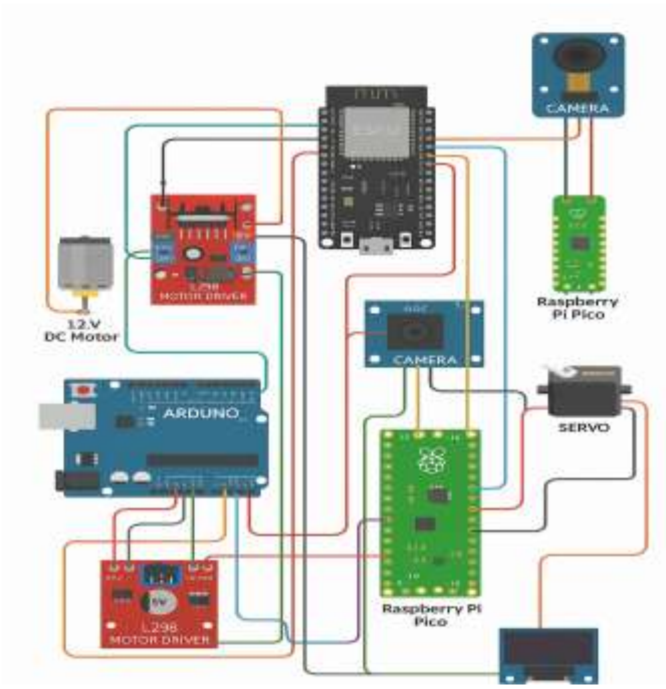


Fig: 3.1 Master side setup

Figure 3.1 shows the complete hardware implementation of the proposed color-based product sorting system. The setup demonstrates how different embedded controllers, sensors, cameras, motors, and actuators are interconnected to achieve automated sorting in real time. The ESP32 module functions as the central control and communication unit, while the Raspberry Pi Pico supports image processing and decision-making tasks.

As products move along the conveyor belt, camera modules capture images at the detection point. These images are processed by the embedded controller to identify the dominant color of each product. Based on the classification result, appropriate control signals are generated to activate the sorting mechanism. Servo motors are used to guide the products into their respective bins, ensuring precise and smooth diversion without interrupting the conveyor movement.

The conveyor belt is driven by a DC motor controlled through an L298 motor driver. This arrangement provides reliable speed control and maintains proper synchronization between image capture, processing, and actuation. The wiring layout shown in the figure highlights proper power distribution and signal connections between the controllers, motors, and sensors, ensuring stable system operation.

Experimental observations confirm that the system performs consistently under continuous operation. The coordinated interaction between sensing, processing, and actuation allows accurate color detection and timely sorting of products. Overall, the hardware implementation successfully validates the proposed system design and demonstrates its suitability for real-time automated color-based product sorting applications.

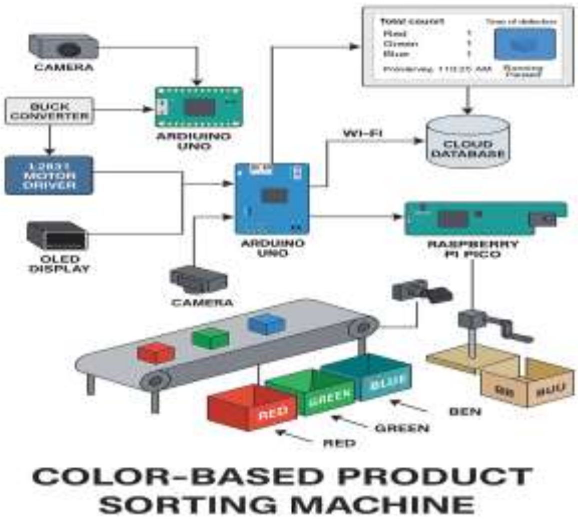


Fig:3.2 Assembly of Color -Based Product Sorting Machine

Figure 3.2 shows the complete setup of the color-based product sorting machine. Products move on a conveyor belt where a camera captures images for color detection. The Arduino Uno processes the image data and identifies the dominant color of each product. The conveyor belt is driven by a DC motor through an L298 motor driver to ensure smooth movement. Based on the detected color, servo motors are activated to guide products into the respective Red, Green, or Blue bins. An OLED display shows real-time information such as detected color and product count. The system also uses Wi-Fi communication to send sorting data to a cloud database for remote monitoring and analysis. This integrated setup enables accurate, continuous, and automated color-based product sorting.

A .Results in tabular

The table summarizes the sorting performance of the system for different colors. Out of 120 tested objects, 107 were sorted correctly, resulting in an overall accuracy of 89.2%**.** Red objects achieved the highest accuracy **(**92.5%**)** due to better contrast, while green objects showed slightly lower accuracy **(**85%**)** because of light reflection and surface variations. The system performed consistently during continuous operation, and minor lighting changes did not significantly affect accuracy due to HSV-based color processing. Overall, the system provides an efficient and low-cost solution for automated color-based product sorting with minimal human intervention.

Table 3.1: Color-wise Sorting Precision

| Color | No. of Objects Tested | No. of Objects Sorted Correctly | No. of Objects Sorted Incorrectly | Accuracy (%) |
|---|---|---|---|---|
| Red | 40 | 37 | 3 | 92.50 |
| Green | 40 | 34 | 6 | 85.00 |
| Yellow | 40 | 36 | 4 | 90.00 |
| TOTAL | 120 | 107 | 13 | 89.20 |

B. Color-wise Sorting Accuracy

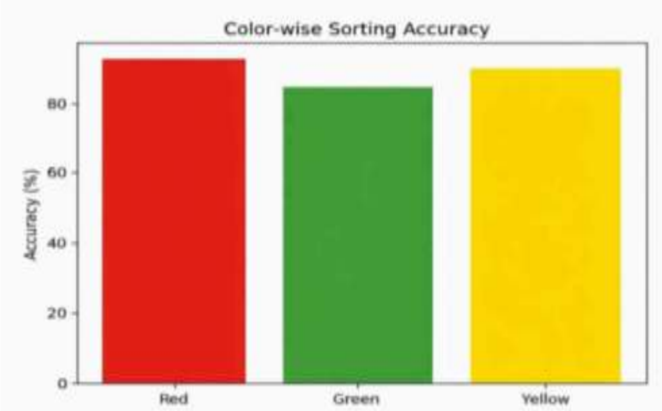


Fig 3.3 Graph Color-wise Sorting Accuracy

The bar chart presents the color-wise sorting accuracy of the proposed automated system. Among the tested categories, red-colored objects achieved the highest accuracy, followed by yellow and green objects. The higher accuracy observed for red objects is mainly due to their strong visual contrast with the background, which enables more reliable color detection during image processing. Green objects showed comparatively lower accuracy because surface reflections and lighting variations affected color discrimination.

Despite these variations, the system demonstrated stable and consistent performance during continuous operation. The graphical representation clearly validates the effectiveness of the color classification and sorting logic under real-time conditions. Overall, the results confirm that the proposed color-based product sorting system provides accurate, reliable, and efficient automated sorting with minimal human intervention.

## 8. ACKNOWLEDGEMENT

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## 9. CONCULSION & FUTURE SCOPE

The analysis confirms that the proposed color-based product sorting system operates with reliable performance and satisfactory accuracy. The system effectively integrates image processing, embedded control, and mechanical actuation to achieve fully automated sorting with minimal human intervention. Experimental results demonstrate accurate color detection, smooth conveyor operation, and precise actuation under continuous operating conditions. The developed color-based product sorting machine is well suited for small-scale industrial applications and educational laboratory demonstrations. The use of low-cost hardware components and open-source software tools ensures affordability while maintaining dependable system performance.

Future enhancements may include expanding the system to identify additional color categories and incorporating shape- or size-based classification for improved versatility. Machine learning techniques can be integrated to enhance detection accuracy under varying lighting and surface conditions. Cloud connectivity can be further utilized for advanced data analytics and remote performance monitoring. For large-scale industrial deployment, the system can be scaled by upgrading conveyor mechanisms, processing hardware, and control strategies. The inclusion of additional sensors and intelligent control methods can further improve system reliability, efficiency, and adaptability in real-world manufacturing environments.

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