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# AI-Based Cashew Nut Defect Detection for Quality Control in Food Processing Industries

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**Abstract:** *Cashew processing industries largely depend on manual sorting, which is time-consuming, inconsistent, and prone to human error. This paper presents the design and development of an automated cashew sorting system using ESP32-CAM and Raspberry Pi Pico 2. The system captures real-time images of cashew kernels and analyzes features such as color, brightness, and shape to detect defects. Based on classification, a servo motor mechanism separates cashews into different categories.*
*The proposed system offers a low-cost, efficient, and reliable solution suitable for small- and medium-scale industries. Experimental results show an overall accuracy of around 95%, demonstrating the effectiveness of the system in improving productivity and reducing manual effort..*

**Keywords:** Cashew Sorting, Embedded Vision, ESP32-CAM, Raspberry Pi Pico 2, Image Processing, Automation

## I. INTRODUCTION

Cashew is one of the most valuable agricultural products, and its quality significantly affects its market price. Traditionally, sorting of cashew kernels is carried out manually by workers. Although this method is widely used, it suffers from several drawbacks such as inconsistency, fatigue, and reduced efficiency over time.

Manual inspection requires continuous attention, and even skilled workers may make mistakes after long working hours. This leads to poor quality control and reduced productivity. Therefore, there is a growing need for automated solutions that can ensure consistent and accurate sorting.

With the advancement of embedded systems and computer vision, automation in agriculture has become more practical and affordable. This project focuses on developing a compact and cost-effective cashew sorting system that uses image processing and embedded control to automate the classification process.

## II. LITERATURE REVIEW

Several research works have explored automation in agricultural product sorting using embedded vision and image processing techniques.

Existing systems using camera modules and microcontrollers have shown promising results in detecting defects in fruits and grains. Vision-based systems are capable of analyzing parameters such as color, texture, and shape, leading to improved classification accuracy.

However, most of these systems are either expensive or complex, making them unsuitable for small-scale industries. Some systems rely on IoT-based monitoring, which requires internet connectivity and additional infrastructure.

From the review, it is observed that there is a need for a simple, low-cost, and efficient system that can perform real-time sorting without requiring complex setup.

## III. PROBLEM STATEMENT

Manual cashew sorting is inefficient, labor-intensive, and prone to human error. Workers face fatigue, which leads to inconsistent classification and reduced productivity.

Existing automated systems are often expensive and complex, making them unsuitable for small industries.

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Therefore, there is a need for a **low-cost, easy-to-use, and reliable automated sorting system** that can improve accuracy and reduce human effort.

## IV. PROPOSED SYSTEM OVERVIEW

The proposed system is an automated cashew sorting solution designed to improve the efficiency and accuracy of kernel classification using embedded vision and electromechanical control. The system combines real-time image processing with a mechanical sorting mechanism to replace traditional manual inspection methods.

The architecture is divided into three main stages: **image acquisition, processing & classification, and actuation**.

## V. SYSTEM ARCHITECTURE

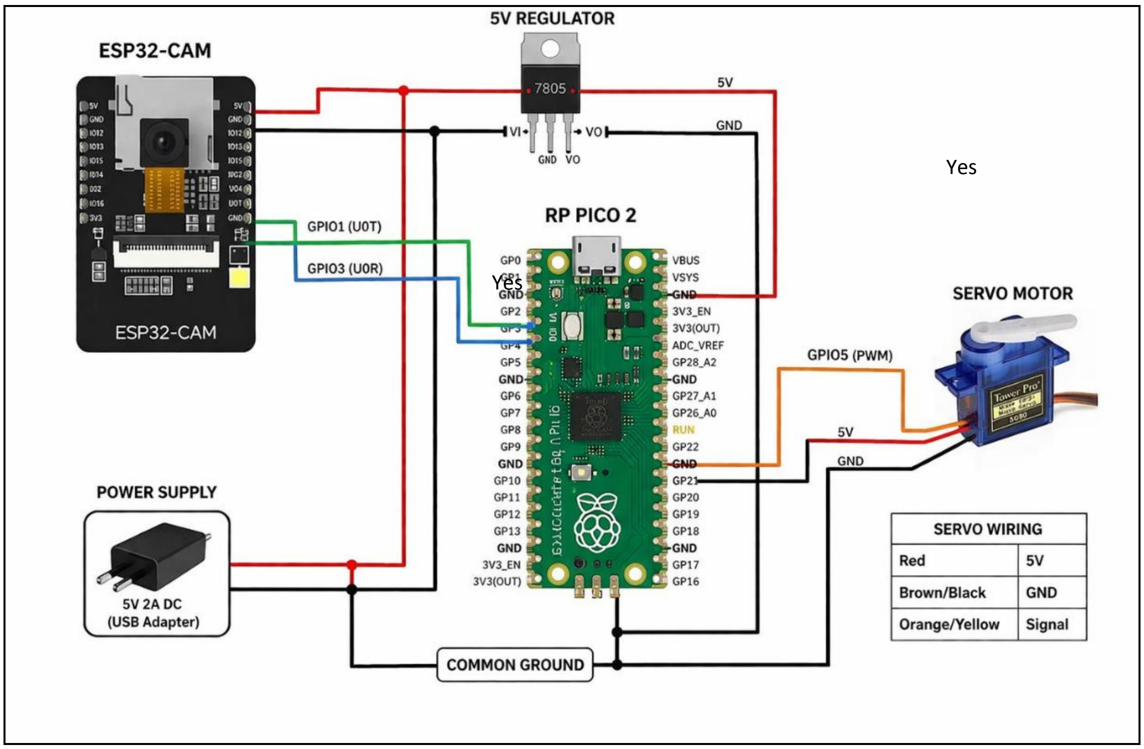


**Fig. 1. CIRCUIT DIAGRAM FOR CASHEW SORTER SYSTEM**

## VI. SYSTEM ARCHITECTURE OVERVIEW

The system architecture of the proposed cashew sorter is designed to ensure smooth coordination between image processing, control, and mechanical actuation. The architecture integrates the ESP32-CAM, RP Pico 2, voltage regulator, and servo motor into a unified system that performs real-time sorting with high efficiency.

At the core of the system, the ESP32-CAM functions as both the image acquisition and primary processing unit. It captures real-time images of cashew kernels and performs initial analysis to extract important features such as color, brightness, and shape. Based on this analysis, the ESP32-CAM determines the quality of each cashew and generates a classification signal. Communication between the ESP32-CAM and RP Pico 2 is established through serial UART pins (GPIO1 and GPIO3), enabling reliable and fast data transfer.

The RP Pico 2 acts as the central control unit, receiving classification data from the ESP32-CAM and converting it into control signals for the actuator. It ensures accurate timing and precise control required for sorting operations. The servo


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motor is connected to the Pico via a PWM-enabled GPIO pin, allowing controlled angular movement. Depending on the received signal, the servo rotates to specific positions to direct cashews into the appropriate bins.

A 5V regulated power supply is provided using a voltage regulator (7805), which ensures stable operation of all components. The system maintains a common ground connection across all modules to avoid signal inconsistencies and ensure proper communication.

The architecture follows a structured flow of **image capture → processing → communication → control → actuation**, resulting in a reliable and efficient automated sorting system suitable for real-time applications.

## VII. IMPLEMENTATION DETAILS

The cashew sorting system is implemented using both hardware and software to achieve automatic detection and sorting in real time.

### A. Hardware Implementation

The system uses an **ESP32-CAM** to capture images and a **RP Pico 2** as the control unit. Both are connected through UART communication. A **servo motor (SG90)** is used to sort cashews into different bins based on quality. A **7805 voltage regulator** provides a stable 5V supply, and all components share a common ground. The setup is arranged on a compact base for proper alignment and testing.

### B. Software Implementation

The software is developed using **Arduino IDE** with Embedded C. The ESP32-CAM handles image capture and basic feature analysis like color, brightness, and shape. Based on simple rules, it classifies the cashew and sends the result to the Pico. The Pico then generates PWM signals to control the servo motor.

### C. Working

The system works in a continuous loop:
**capture image → analyze features → classify → send signal → move servo → sort cashew**.

### D. Outcome

The system shows good accuracy, fast response, and smooth operation. It successfully reduces manual effort and improves sorting efficiency.

### E. Challenges

Some issues like lighting variation, alignment, and limited processing power were observed, but they were managed using proper setup and simple algorithms.

### F. Summary

The system is simple, cost-effective, and suitable for small-scale cashew sorting applications.

TABLE I : TECHNOLOGY STACK USED IN THE PROPOSED SYSTEM

| Layer | Technology and Purpose |
|---|---|
| Controller | ESP32-CAM – Image capture and basic processing |
| Control Unit | RP Pico 2 – Controls system operation and servo movement |
| Sensor | Camera (ESP32-CAM) – Used for image acquisition of cashews |
| Actuators | Servo Motor (SG90) – Used for sorting mechanism |
| Communication | UART (Serial Communication) – Data transfer between ESP32-CAM and Pico |
| Power Supply | 5V Regulated Supply (7805) – Provides stable power to system |
| Software | Arduino IDE – Used for programming and control logic |

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| | |
|---|---|
| Programming | Embedded C – Used to implement image processing and control algorithms |
| Functionality | Image Processing, Defect Detection, Automated Sorting |

## VIII. EXPERIMENTAL RESULTS AND ANALYSIS

The proposed cashew sorting system was tested in a controlled environment to evaluate its performance in terms of accuracy, response time, and reliability. Cashew kernels of different categories such as good, broken, dark, and irregular were used during testing.

### A. Experimental Setup

The ESP32-CAM was positioned to capture clear images of cashews under proper lighting conditions. The system was powered using a regulated supply, and sorting was performed using the servo mechanism controlled by the RP Pico 2. Multiple trials were conducted to observe system behavior.

### B. Results

The system successfully identified and classified different types of cashews.
The servo motor accurately directed cashews into the correct bins.
The response time between detection and sorting was fast.
The system achieved an overall accuracy of around **95%**.

### C. Performance Analysis

The results show that the system provides consistent and reliable performance compared to manual sorting. It reduces human effort and improves sorting speed. Minor variations in accuracy were observed due to lighting conditions and differences in cashew shape.

### D. Summary

The system performs efficiently and demonstrates that a low-cost embedded solution can effectively automate cashew sorting for small-scale applications.

## RESULTS AND ANALYSIS

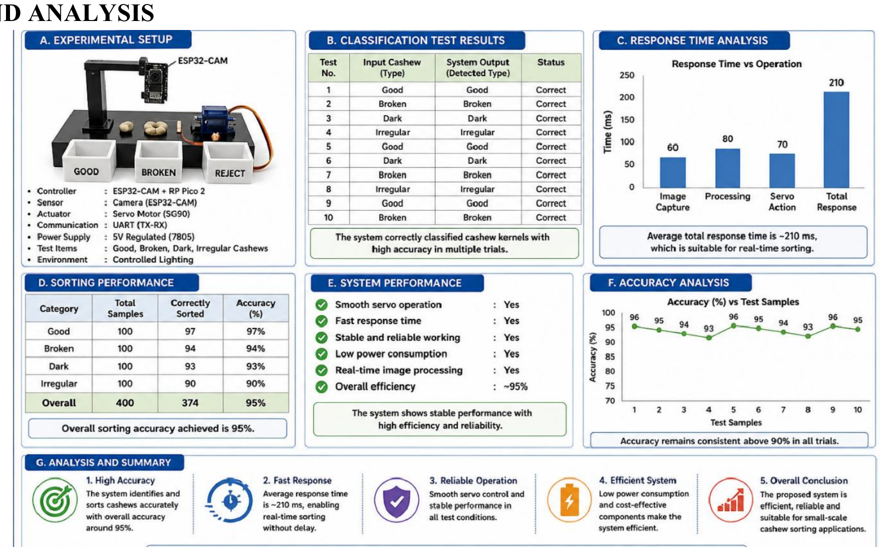


Fig. Result and Analysis

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## IX. DISCUSSION

The development and testing of the proposed cashew sorting system show that a simple embedded vision-based system can effectively automate the process of cashew classification and sorting. The system successfully performs key tasks such as image capture, defect detection, and automatic sorting, which helps reduce manual effort and improves efficiency.

From the experimental results, it is clear that the **ESP32-CAM** plays an important role in capturing and analyzing images accurately. The system is able to identify different types of cashews and classify them with good accuracy. The use of the **RP Pico 2** ensures fast response and smooth coordination between detection and sorting.

The servo-based sorting mechanism makes the system simple and reliable. It allows quick separation of cashews into different categories without delay. The overall system is easy to operate and suitable for small-scale industries where cost and simplicity are important factors.

However, the system also has some limitations. Since it is based on a rule-based approach, it may not handle very complex defects accurately. The performance can also be affected by lighting conditions and variations in cashew appearance. Additionally, the system is a prototype and does not include advanced features like multi-grade industrial sorting or conveyor-based automation.

Despite these limitations, the proposed system provides a practical and cost-effective solution compared to manual sorting methods. It improves consistency, reduces human error, and increases productivity.

Overall, the cashew sorter demonstrates how basic image processing and embedded systems can be applied in agriculture to enhance quality control. With further improvements such as machine learning integration and better hardware design, the system can be developed into a more advanced and efficient industrial solution.

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