Design and Implementation of a Conveyor based Automated Fruit Sorting Prototype using Multi-Sensor Integration

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Abstract-*Post-harvest remains a practical challenge, particularly for fruit sorting in small-scale operations where manual inspection can lead to an inconsistent result and slower the throughput. Workers are relying on subjective models, which varies consider between individuality. To address it we built and test a conveyor system that is based on fruit quality and can control system to integrate it with multiple sensors for automatic evaluation. Fruits are assessed on two criteria one is ripeness and other one is surface cleanliness. An IR sensor starts when a fruit enters the sensing zone and a TCS3200 color sensor then it can capture the RGB readings to gauge ripeness, and then a (GP2Y1010) dust sensor checks for the surface contamination. The conveyor system is 50 to 60 cm long and it runs at roughly for 0.07 to 0.08 m/s slow for enough to give the sensors 1 to 2 seconds per fruit. A 12 V DC geared motor drives the belt and it handles the typical fruit loads from 0.2 to 0.3 kg with a torque of almost 0.1 Nm. An Arduino/ESP32 has multiple average sensor readings and can compares them against a fixed threshold voltage. Defective fruits can be diverted and driven by servo arm. We can trial on 23 fruit samples like ripe, unripe, and dusty to work the system correctly and can be classified 21 of them, giving the accuracy of 91.3%. Contamination detection is more reliable and ripeness classification is based on fruit color values and sat it near threshold boundaries.Overall, the system works fully on small-scale agricultural for sorting tasks and it uses only low cost, off threshold values components.*

Keywords Fruit Sorting, Conveyor, ESP32, Arduino, Color Sensor, Ripeness Detection, Automated Sorting, Real-Time Processing, Agriculture, Automation

1. INTRODUCTION

Fruit quality directly affects both the selling price and also buyer satisfaction. Export markets and urban vendors can now set the specific grading standards, because most small farms and the processing units can still sort by the hand. Manual sorting is very slow, and the outcome also depends entirely upon the two workers looking at the same batch to disagree. For a large volume, this type of variability cannot acceptable simply.

A Conveyor based fruit sorting systems offer a practical way out. Moving fruits from fixed sensors and keep it at a position which is consistent and can makes it much easier to automate the step inspectional. Two parameters have most for basic grading such as one is ripeness which is visible through color and other one is surface cleanliness which can contaminated by dust. Measuring the both with sensors gives us objective like repeatable results without damaging the fruit physically.

Microcontrollers that are affordable can have to make this type of automation which is accessible and an Arduino/ESP32 for an instance which can coordinate through several sensors and the output can also control signal with the minimal wiring and its cost. Pairing with an IR detection module, a color sensor, and a dust sensor controlled a gives information which is enough to evaluate with two independent quality parameters simultaneously.

This paper describes us about such a system. Where, Fruits travel from a short conveyor and the sensors read each one as it passes from the microcontroller so it can decide whether it passes or fails, and a servo arm can physically reject the fruits. The goal was a design for any small operation that could build and run out without a specialized equipment or expertise in technical manner.

2. LITERATURE SURVEY

Prior work on automated based fruit sorting falls into three broad categories such as machine vision systems, sensor-based systems, and at last hybrids of the two.

Methods which are based on Camera can achieved a strong grading result. The work in [1] applied a deep learning so it can detect the surface defects with a higher accuracy, and [2] also used as color and shape features specially for citrus grading. Both can perform well in lab conditions, whereas they need some dedicated GPUs or higher end processors to be careful for lighting setups and its costs that can put them to reach out for small operations.

More recently a deep learning model has to push out the accuracy that is still higher. A Dense Net model [3] has been reported for nearly a perfect classification, and [4] then it can demonstrate for a real-time fruit detection which is directly on a moving conveyor system which has been used as an object detection framework. Impressively figures can be implemented and the hardware configuration can overhead to makes it deployment and difficult for outside well-funded research environments.

Lower the cost more the sensor approaches and can also have been explored. A good Load-cell sorting [6] gives us a reliable result but it can only measure the weight of one parameter which is often not enough for a reliable grading. Image processing system without a deep learning [9] can also manages a moderate accuracy but it is noticeably sensitive and can be change in ambient lighting.

The trend towards a multi-parameter is sensing a clear literature survey. A survey by [7] the system can be found that fusing and readings hits from different sensor types consistently it can improve a classification reliably.

Conveyor integrated designs are reviewed in [10], further it supports a continuous processing unit and better a throughput. IoT integration can monitor remote which appeared in recent work [8], though it adds a layer of configuration and the cost of that are not justified for a basic sorting technique.

In short, higher the accuracy systems can exist but can be expensive, and cheaper the alternatives are mostly evaluated only on one quality parameter. The gap of this work targets as a multi-sensor, and conveyor-based system design to keeps the cost low without any sacrificing and the ability to check the two independent quality that indicates simultaneously.

3. METHODOLOGY

Figure 1 shows the block diagram of the proposed system.

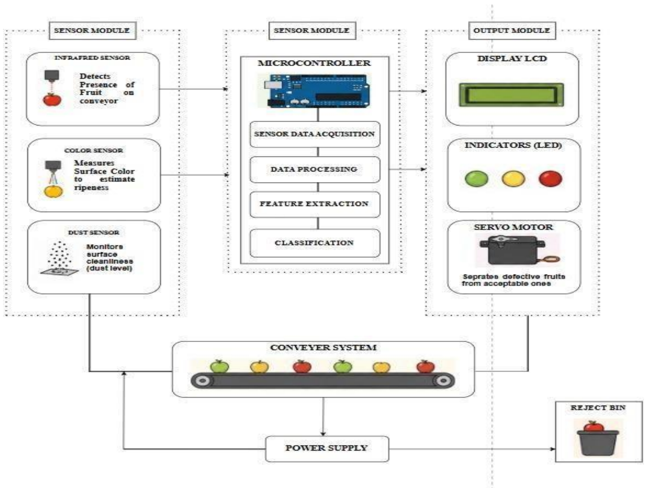

Fig.1. Proposed Automatic Fruit Sorting System

The hardware in this structure of the conveyor system of fruit sorting system. The ESP32 microcontroller acts as the main control unit and can also manages the sensing unit for supporting sorting operations. Infrared sensors can also detect the fruit presence on the conveyor system. Based on these inputs, the controller can operate servo motors which separates the fruits into different categories. A relay module can control the DC motor for a conveyor movement, display whereas a display unit provides us a system information. The system enables a real-time and automated fruit sorting system.

A. System Overview

The system can combine a mechanical conveyor system with an electronics stack and run fruit sorting continuously and without a human intervention. Fruits are loaded into the belt and then pass through the four sequential stages such as detection, sensing, classification, and physical sorting. A microcontroller of these stages together comes and ensures each step that happens in the right order and at a right time. Detection can come first, through the parameter measurement, and then at last through a binary pass/fail decision.

B The sequence of operations

The sequence of operations is as follows one is the belt that carries the fruits toward the sensor mount. When the IR sensor detects a fruit, it enters the sensing zone, and then triggers the measurement cycle. The color sensor takes out the several RGB readings from the surface of fruit; there are the averaged to filter out the noise. The averaged values are then checked against the present ripeness thresholds frequency. In parallel manner, the dust sensor can read the contamination level of the surface. Both results feed us a simple condition like the fruit passes only if it is ripe and then clean. A failure can be either criterion or it causes the servo to defect it off the belt

C. Conveyor Belt Design

1) Mechanical Structure

We kept the frame compact about 50 to 60 cm long and 10 to 12 cm wide. That is enough to fit out the sensor mount for sorting arm while it stays on a bench top. The belt material has been selected for the surface texture and it is enough grip and can prevent the fruits from sliding the sideways during a transit.

2) Belt Speed Selection

Belt speed was chosen to give sensors enough dwell time on each fruit. Linear belt speed is calculated from

the pulley diameter D and motor speed N. With a 25 mm pulley and 60 RPM motor, belt speed comes out to approximately 0.07 to 0.08 m/s. At this speed, each fruit spends around 1to 2 seconds under the sensors, which is sufficient for stable data collection.
The linear speed of the belt is determined using:

$$v = \frac{\pi DN}{60} \quad \ldots (1)$$

where Drepresents the pulley diameter and

60 Ndenotes motor

3) Load and Motor Torque Calculation

To determine the requirement of motor, the average weight of fruits can be considered between 0.2 and 0.3 kg. The force acting on the conveyor is given by:

$$F = m \times g \ldots (1)$$

$$F \approx 0.3 \times 9.81 = 2.94\,N \ldots (2)$$

The required torque at the pulley is:

$$T = F \ldots (3)$$

upper bound, the force on the belt is F = 0.3 × 9.81 ≈ 2.94 N. For a pulley radius of 15 mm, the raw torque needed is roughly 0.044 Nm. Adding a safety margin for friction and load variation, we selected a 12 V DC geared motor rated for at least 0.1 Nm.

D. Fruit Identification Mechanism

The system has been evaluating a fruit quality mechanism using a multiple sensing techniques to improve its classification reliability.

1) Fruit Detection

An IR sensor confirms that a fruit is present and can been properly positioned before any measurement begins. This prevents us a false reading between the fruits.

2) Ripeness Detection

The TCS3200 color sensor gives us a sample of fruit surface for multiple times. Readings are averaged and it can be able to reduce the effect of small lighting for fluctuations, and then it can compare with calibrated RGB ranges for the ripe and unripe fruit.

3) Cleanliness Detection

The GP2Y1010 dust sensor can measures the particulate density of nearby fruit surface. Fruits with a contamination and above preset the level that are flagged regardless for their color and readings.

4) Decision Process

A fruit is accepted only if both the conditions are met within the ripeness of color range and below the dust threshold frequency. This dual-check has been approaching and catches cases whether a visual ripe fruit is contaminated from which a color has only system would miss.

E. Sorting Mechanism

A servo motor can be mounted near the output and then end up the conveyor controls for a deflection arm. For a rejected fruit, the servo motor can rotate and the arm that can redirects it the separated bin. For an accepted fruit, the arm stays in the resting position and then the fruit moves forward, so the servo can response as fast enough and even not to disturb spacing between a successive fruit.

F. Electrical and Control Specifications

All components that can be widely used for an available and inexpensive. Table 1 lists us the key parts. The Arduino/ESP32UNO can handles both the sensing and control devices. The L298N motor can be drive and it should run through the DC conveyor motor via the relay switching model. A 12V DC supply powers gives us the motor a side and a 5V regulator feeds us the logical circuits.

Table 1. Components and Specification

Component	Specification
Microcontroller	Arduino/ESP32/ESP 32 controllers
Motor	12V DC geared motor
Motor Driver	L298N
Color Sensor	TCS3200
Dust Sensor	GP2Y1010
IR Sensor	Digital IR module
Servo Motor	SG90/MG90S
Power Supply	12V DC with 5V regulation

For a radius pulley of 0.015 m:

$$T \approx 0.044\,Nm \ldots (4)$$

Typical fruits weighed between 0.2 and 0.3 kg. Taking the

G. Design Justification

The proposed system integrates us the mechanical design with sensor-based evaluation to achieve it efficient fruit sorting tasks. The conveyor system design ensures us and can be controlled by movement, while the use of multiple sensors can improve the classification reliability. The selected components can provide us a balance between the cost, performance, and simplicity for, making the system suitable and for practical agricultural applications.

Flowchart

The block diagram mentioned in Fig. 1 has input from sensor module, processing at processor module and output at conveyor belt fig.2. Shows series of operation for checking ripeness and decision for accepting/ rejecting the fruit with conveyor belt mechanism.

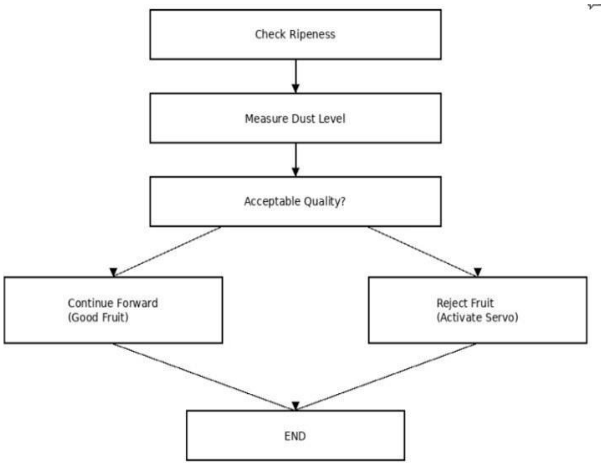

Fig.2: Fruit Quality Inspection Flowchart

4. RESULTS

The. The experimental setup is shown in Figures 3 and 4.

Fig 3 : Proposed Experimental setup

The setup is fabricated by 3D printing, and with calculations mentioned in the methodology section.

The setup working exhibits the following important observations:

1. Testing has been carried out under the fixed lighting Condition. As per Equation [2], The Dust Sensor calculate fruit distance.
2. Before the trials, the color sensor has been calibrated on a confirmed ripe sample; and resulting the RGB values were stored as the reference thresholds.
3. Twenty-three fruit samples consisting of 10 ripe, 8 unripe, and 5 dusty are used for testing.
4. Classification of results are summarized in Table 2. The system provides 21 fruits classification correctly out of 23, for the overall accuracy of 91.3%. The two errors have been occurred in both the ripeness category, and where the fruit color has been sat close to the threshold boundary.

Table 2. Fruit Classification Accuracy

Fruit Category	**No. of samples**	**Correct classified**	**Incorrect Classifie d**
Ripe Fruit	10	9	1
Unripe Fruit	8	7	1
Dusty Fruits	5	5	0
Total	23	21	2

Table 2 summarizes the classification of overall results. Among 23 tested samples, 21 fruits were correctly identified, whereas 2 samples were misclassified.

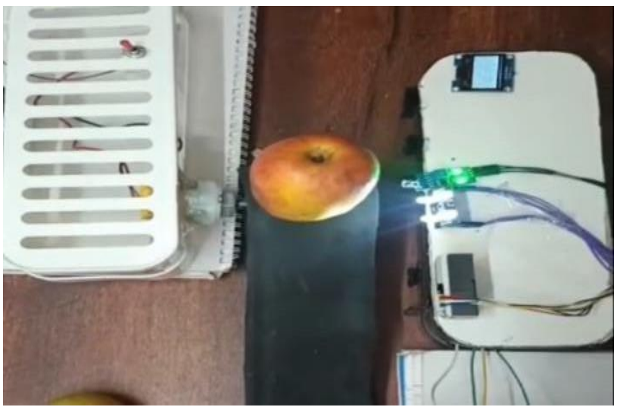

Fig 4: Closer look of the proposed experimental setup

4. DISCUSSION OF PERFORMANCE ANALYSIS

The following are important performance analysis parameters

1. Processing time

Processing time per fruit was 1.5–2 seconds, fast enough for the intended small-scale use case.

2. Accuracy

The graph in Figure 4 illustrates the classification accuracy achieved for different fruit categories in the proposed system. Dusty fruits achieved the highest accuracy at 100%, while ripe and unripe fruits achieved approximately 90% and 87.5%, respectively. The slight reduction in accuracy for ripe and unripe categories was mainly due to similarities in color values near the threshold range.

From the graph, it can be seen that the system performs best in identifying dusty fruits, where the accuracy reaches close to 100%. This indicates that the dust sensor is highly effective in detecting surface contamination.

For ripe fruits, the accuracy is around 90%, which shows that the system is able to correctly identify most of the ripe samples based on their color values. However, a few misclassifications occur when the fruit color is very close to the threshold values.

In the case of unripe fruits, the accuracy is slightly lower, around 87–88%. This is mainly due to variations in color that may overlap with partially ripe fruits, making classification more challenging.

Overall, the graph indicates that the system provides reliable performance across all categories, with better accuracy.

3. The overall accuracy

The overall accuracy of the system is calculated as:

Accuracy = Correct Classification / Total sample *100
Accuracy = 21/23*100 =91.3
Final Accuracy ≈ 91–92%

4. Performance Analysis of Sensors

Between the two sensors used, the dust sensor turned out to be more reliable. Surface contamination gives off a distinct signal that doesn't get confused across categories. The color-based ripeness detection worked fine for fruits that were clearly ripe or clearly unripe, but things got tricky at the margins – a partially ripe fruit can show RGB values that land right inside the ripe range. Taking multiple readings and averaging them helped bring those edge cases under control, though not completely. Each fruit took roughly 1.5 to 2 seconds, which is acceptable for the kind of small- scale application this system targets.

Figure 4 shows how well the system handles the three fruit categories: ripe, unripe, and dusty. Dusty fruits were classified with near perfect accuracy the dust sensor produces a clean, easy to distinguish output, so that result wasn't surprising. Ripe fruits came in around 90%: most samples were correctly identified, but a handful got misclassified when their color values sat too close to the threshold.

5. Category-wise Performance Analysis

Looking at the classification accuracy broken down by fruit type, a few things stand out.

Dusty fruit detection was the strongest, Ripe fruits also performed well errors only crept in when color readings hovered near the decision boundary.

Unripe fruits where the hardest to classify reliably, since their color profile can overlap with partially ripe samples.

Classifying unripe fruit was slightly less accurate because of how much their color characteristics overlap with partially ripe ones.

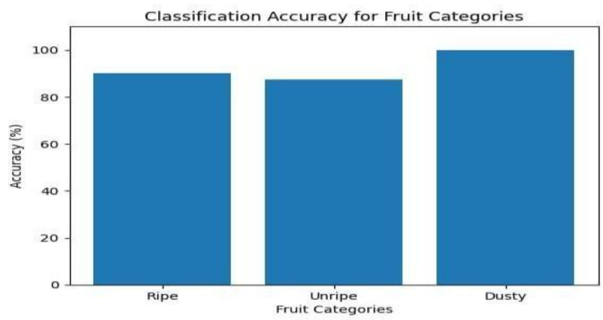

Fig.4. The classification of Accuracy for Ripe, unripe and dusty fruits.

System Behavior

Most of the misclassification came from borderlines cases fruits whose color values did not clearly on one side of the threshold.

Texture variation on the surface and minor inconsistencies in lighting also played a role. Calibration and averaging reduced these effects to a degree, but couldn't eliminate them entirely.

6. Validation of Design Approach

The test results back up the core design decisions made early on. The belt Speed gave the sensors enough time to take readings. The motor torque held steady throughout operation running two sensors in parallel improved classification decisions beyond what either could achieve alone, and the servo mechanism sorted fruits reliably without interrupting the flow on the conveyor.

7. Comparison with Existing Approaches

Against manual sorting, this system offers consistent and objective classification Compared to single-sensor setups, the dual parameter design catches problems that color or weight alone would miss. And while camera based or deep-learning systems can hit higher accuracy ceiling, they also come with significantly higher costs and more complicated setups this system trades some of that accuracy ceiling for a much simpler and cheaper build.

Future Scope

The system can be enhanced in several ways to improve performance and scalability:

- Bringing in camera-based image processing could improve accuracy on complex or edge-fruits.
- Machine learning could make the classification logic more adaptive over time.
- Adding weight and size sensors would allow for more through grading.
- IOT integration would enable remote monitoring and data logging.
- Optimizing the conveyor design

4. CONCLUSION

The Proposed fruit sorting system offers a practical, automated prototype using a combination of sensor inputs and a conveyor mechanism. We have successfully demonstrated Design and Implementation of a Conveyor based Automated Fruit Sorting Prototype using Multi-Sensor (Dust sensor, IR sensor, Color Sensor) Integration. The System shows impressive accuracy of 91.3% for testing of 23 fruits. System works on 12 V DC geared motor drives the belt and it handles the typical fruit loads from 0.2 to 0.3 kg with a torque of almost 0.1 Nm.

The system evaluates fruit quality on two axes: ripeness and surface cleanliness. Averaging readings and applying tolerance- b a s e d decision logic helped to reduce the influence of the sensor noise and environmental variation, keeping classification stable across different conditions.

However, the performance of the system can be influenced by external factors such as lighting conditions, sensor positioning, and variations in fruit surface texture. Addressing these factors can further improve accuracy and robustness.

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