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Modification and Improvement of a Coffee Berry Sorting Machine

Project Proposal

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Declaration

We declare that this project proposal is our original work and has not been presented for examination in any other institution.

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Abstract

Automated coffee berry sorting is an essential process for ensuring quality consistency and improving the economic value of coffee produce. Previous student-developed prototypes have demonstrated the feasibility of using image-based detection and air-ejection mechanisms for automated sorting. However, limitations related to motion blur, processing delays, and limited computational capacity have restricted real-time performance and throughput.

This project focuses on the modification and improvement of an existing coffee berry sorting machine model by addressing challenges associated with real-time image acquisition, detection, and classification. The study explores optimized computer vision algorithms, improved frame processing strategies, and alternative processing architectures to enhance system efficiency. A co-processing architecture alongside the Raspberry Pi 3 will be introduced to overcome computational bottlenecks, with task division between high-level control and time-critical processing operations.

Performance evaluation is conducted based on sorting accuracy, processing speed, and overall throughput. The improved model aims to provide a cost-effective, reliable, and scalable solution suitable for small-scale coffee processing applications while contributing to research in embedded vision and agricultural automation.

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1 Introduction

1.1 Background of Study

The global coffee industry remains a significant contributor to the economies of many developing countries, supporting millions of smallholder farmers worldwide. Coffee production involves several critical stages, from cultivation and harvesting to processing and packaging. Among these stages, the sorting of coffee berries is one of the most labor-intensive and quality-sensitive processes. Traditionally, coffee berry sorting has relied heavily on manual visual inspection, where workers separate berries based on ripeness, size, and visible defects. This approach is time-consuming, inconsistent, and costly, often leading to variations in coffee quality and increased operational expenses.

Manual sorting methods are highly susceptible to human error and fatigue, which can result in misclassification of berries and reduced overall product quality. Furthermore, the labor-intensive nature of manual sorting limits scalability and efficiency, particularly during peak harvest periods when labor shortages are common. These challenges highlight the need for automated sorting solutions capable of performing classification tasks with higher accuracy, consistency, and throughput.

Recent advancements in computer vision, machine learning, and embedded systems have enabled the development of automated coffee berry sorting machines that utilize image-based detection and real-time classification techniques. Previous work by fifth-year mechatronics engineering students resulted in the development of an image-based coffee berry sorting machine incorporating a vibrating conveyor system, optical detection, and air-ejection mechanisms controlled by a Raspberry Pi-based processing unit. While the system successfully demonstrated automated sorting, practical challenges were identified during real-time operation, particularly related to motion blur, processing latency, and limited computational throughput.

The visual diversity in harvested coffee berries, including variations in color, size, and



[Placeholder: Figure 1 - Harvested Coffee Berry Variation]

Figure 1.1: Harvested coffee berry variation showing visual diversity in color, size, and surface texture

surface texture, as illustrated in Figure

refig:berry_variation, presents a significant challenge for accurate automated classification.

This project proposes the modification and improvement of the existing coffee berry sorting machine by addressing the identified limitations in image acquisition, processing speed, and real-time classification performance. By enhancing the vision processing pipeline, optimizing algorithms, and evaluating alternative hardware or processing architectures, the project aims to improve sorting accuracy and throughput while maintaining a cost-effective and scalable design suitable for small- and medium-scale coffee processing applications.

1.2 Problem Statement

The global coffee industry plays a vital role in the economic development of many coffee-producing countries, including Kenya, where coffee farming supports a large population of smallholder farmers. The quality of coffee berries at the processing stage directly determines the final product grade, market value, and competitiveness in both local and international markets. One of the most critical and labor-intensive stages in coffee pro-

cessing is the sorting of coffee berries based on ripeness, color, size, and the presence of defects.

Traditionally, coffee berry sorting has been carried out manually through visual inspection by human operators. While this method requires minimal capital investment, it is inherently inefficient, inconsistent, and highly dependent on human judgment, which varies due to fatigue, experience, and environmental conditions. As a result, manual sorting often leads to misclassification of berries, reduced product quality, and increased operational costs. These challenges become more pronounced during peak harvest seasons, when large volumes of berries must be processed within limited timeframes.

In response to these limitations, recent final-year mechatronics projects have explored automated coffee berry sorting solutions using machine vision and robotic actuation. One such system employs a vibrating conveyor to ensure consistent berry flow, a chute for alignment, and an image-based detection and tracking system coupled with an air-ejection mechanism for sorting. The system operates under the control of a Raspberry Pi-based processing unit, leveraging computer vision and machine learning techniques to classify individual coffee berries as they move through the sorting process.

Despite the successful demonstration of automated sorting, the existing system exhibits several critical technical limitations that hinder its overall performance and scalability. The natural appearance of harvested coffee berries presents significant visual variability in color, texture, size, and surface defects. These variations, combined with the dynamic motion of berries on the conveyor, introduce challenges such as motion blur, inconsistent illumination, and overlapping objects, which negatively affect image clarity and classification accuracy.

Furthermore, the reliance on real-time image processing using a Raspberry Pi introduces processing bottlenecks. The limited computational capacity of the platform results in delays during frame acquisition, preprocessing, classification, and decision execution. Although the previous implementation attempted to mitigate these issues through optimization techniques such as TensorFlow Lite and multithreading, the system still struggles to

achieve higher throughput without compromising accuracy. This limitation directly affects sorting speed and reduces the system's suitability for larger processing volumes.

The core problem, therefore, lies not in the mechanical handling of coffee berries but in the limitations of the vision system, processing architecture, and real-time control strategy used in the existing model. There is a clear need to improve the system's ability to accurately and consistently classify visually diverse coffee berries at higher speeds while maintaining affordability and practicality for small-scale agricultural applications.

This project seeks to address these challenges through the modification and improvement of the existing automated coffee berry sorting system. By enhancing the image acquisition strategy, optimizing or upgrading the processing architecture, and refining the detection-to-actuation pipeline, the project aims to achieve higher throughput, reduced latency, and improved classification accuracy.

1.3 Objectives

1.3.1 Main Objective

To modify and improve an existing automated coffee berry sorting machine to achieve enhanced sorting accuracy, increased throughput, and improved real-time processing performance.

1.3.2 Specific Objectives

1. To analyze the performance limitations of the existing image-based coffee berry sorting system, with emphasis on motion blur, processing latency, and classification accuracy
2. To improve the sorting mechanism and berry handling system for consistent material flow

3. To evaluate alternative or upgraded processing hardware capable of supporting higher frame rates and faster inference
4. To implement a co-processing architecture to offload time-critical tasks from the main controller
5. To optimize image preprocessing and classification algorithms for embedded deployment
6. To enhance ejection timing synchronization for accurate berry rejection

1.4 Justification

Coffee remains one of Kenya's most valuable agricultural exports, and quality grading plays a major role in determining its economic value. Automated coffee berry sorting systems offer a practical solution for improving quality consistency and reducing labor dependency. However, many advanced commercial systems are prohibitively expensive and unsuitable for adoption by small-scale processors and cooperatives.

Improving an existing image-based coffee berry sorting model provides a cost-effective pathway toward practical automation by building upon already validated concepts while addressing observed technical shortcomings. By focusing on real-time processing efficiency, motion-related detection challenges, and system responsiveness, this study aims to bridge the gap between prototype-level demonstrations and deployable solutions.

The proposed improvements contribute to:

1. Enhanced accuracy and throughput in coffee berry sorting
2. Better utilization of affordable embedded vision technologies
3. Increased feasibility of locally developed agri-tech solutions
4. Practical learning and innovation in mechatronics system integration

Furthermore, incorporating real harvested coffee berries into testing and demonstration provides a realistic visual and operational representation of actual field conditions, strengthening the relevance and credibility of the system. The outcomes of this project are expected to support the development of scalable, affordable, and locally adaptable coffee processing technologies aligned with Kenya's agricultural and technological development goals.

2 Literature Review

2.1 Coffee Berry Processing and Quality Control

Coffee cherry quality directly influences final cup quality and market value [?]. Post-harvest processing begins with sorting to separate ripe cherries (red/purple) from unripe (green), overripe (black), and defective berries [?]. Sorting accuracy impacts subsequent processing steps including pulping, fermentation, and drying, with higher initial sorting quality reducing defect rates in final products.

Traditional manual sorting relies on visual inspection and manual separation, achieving 85-95% accuracy under optimal conditions [?]. However, manual methods face scalability limitations, high labor costs, and operator fatigue-induced accuracy degradation during extended operations [?].



[Placeholder: Coffee Berry Classification Chart]

Figure 2.1: Coffee berry classification showing ripe, unripe, overripe, and defective categories

2.2 Mechanical Sorting Technologies

Mechanical coffee sorting systems employ various separation principles. Table 2.1 compares major sorting technologies.

Table 2.1: Coffee Berry Sorting Technology Comparison

Technology	Accuracy	Throughput	Cost	Complexity
Flotation	70–80%	High	Low	Simple
Density separation	75–85%	Medium	Low–Med	Medium
Vibration table	80–88%	Medium	Medium	Medium
Mechanical actuator	85–92%	Med–High	Medium	High
Optical sensor	90–98%	High	High	High
Air jet	88–95%	Very High	High	High

Flotation-based systems utilize density differences between ripe and unripe berries [?]. While simple and cost-effective, accuracy limitations restrict applications to preliminary sorting stages. Density separation systems improve accuracy but require precise calibration for different coffee varieties [?].

Mechanical actuator systems employ physical separation mechanisms triggered by sensor detection [?]. These systems offer balance between cost and performance, making them suitable for mid-scale operations [?].

2.3 Sensor Technologies for Berry Classification

Color detection represents the primary classification criterion for coffee berry maturity [?]. RGB sensors detect color differences between ripe (red/purple) and unripe (green) berries, while more sophisticated systems employ spectral analysis for enhanced discrimination [?].

Near-infrared (NIR) spectroscopy provides additional classification dimensions by analyzing internal berry composition [?]. However, NIR systems introduce significant cost increases, limiting adoption to large-scale industrial operations.

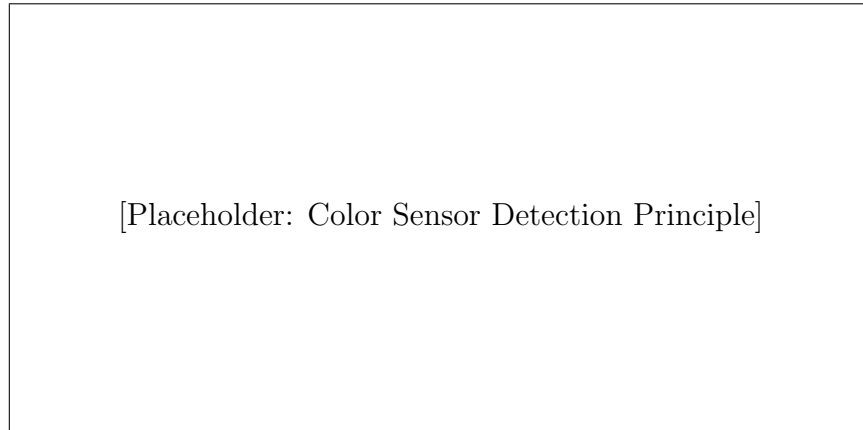


Figure 2.2: Color sensor detection principle showing RGB response to berry maturity levels

Photoelectric sensors offer cost-effective alternatives for binary classification (accept/reject) based on reflectance characteristics [?]. Integration with mechanical actuators enables real-time sorting decisions at high throughput rates [?].

2.4 Conveyor Systems and Material Handling

Conveyor design significantly impacts sorting system performance [?]. Belt conveyors provide smooth, continuous material flow essential for optical detection systems [?]. Critical parameters include belt speed, material spacing, and vibration isolation.

Feed hopper design influences berry flow characteristics [?]. Irregular feeding patterns cause berry clustering, overwhelming sorting mechanisms and reducing accuracy [?]. Vibratory feeders provide controlled, uniform material presentation to sorting zones [?].

Belt tracking systems prevent lateral drift that misaligns berries with detection sensors [?]. Spring-loaded tensioning maintains consistent belt tension across operational conditions [?].

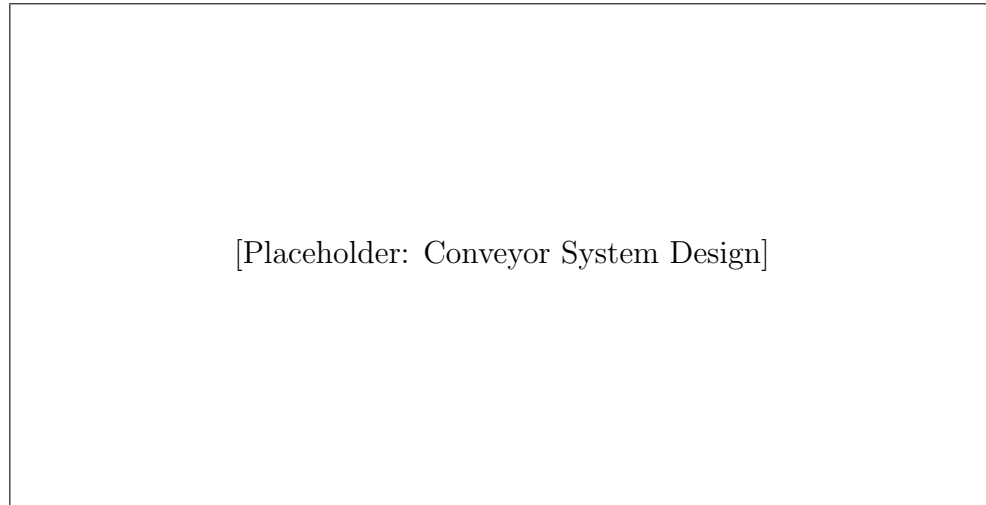


Figure 2.3: Coffee berry conveyor system showing feed hopper, belt conveyor, and sorting mechanism

2.5 Sorting Actuator Mechanisms

Pneumatic actuators dominate high-speed sorting applications due to rapid response times (5-15 ms) [?]. Air jet systems eject individual berries from product streams with precise timing [?]. However, pneumatic systems require compressed air infrastructure and continuous air supply [?].

Mechanical flapper actuators provide cost-effective alternatives for medium-speed operations [?]. Solenoid-driven flappers deflect berries into reject chutes based on sensor signals [?]. Response times of 20-40 ms limit maximum throughput but reduce infrastructure requirements.

2.6 Control Systems and Signal Processing

Microcontroller-based control systems enable real-time processing of sensor data and actuator coordination [?]. Arduino and ESP32 platforms offer sufficient processing power for sensor fusion and decision algorithms [?].

Signal processing algorithms filter noise and implement classification logic [?]. Threshold-

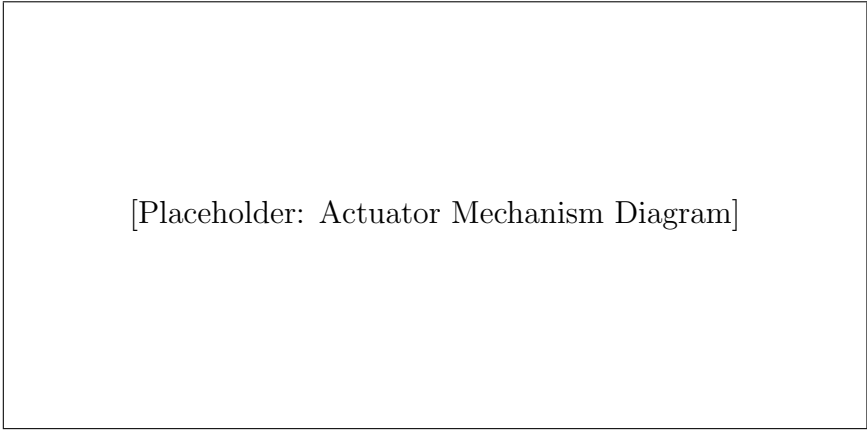


Figure 2.4: Mechanical sorting actuator showing solenoid drive and flapper mechanism

based classification provides simplicity but requires calibration for different lighting conditions and berry varieties [?]. Machine learning approaches improve classification accuracy through adaptive learning [?], though implementation complexity increases significantly.

2.7 Performance Metrics and Optimization

Sorting system performance evaluation employs multiple metrics. Sorting accuracy measures percentage of correctly classified berries, while throughput quantifies processing capacity (kg/hr) [?]. Misclassification rates distinguish between false accepts (defects in accepted stream) and false rejects (good berries in reject stream) [?].

Table 2.2: Typical Sorting System Performance Benchmarks

System Type	Accuracy	Throughput (kg/hr)
Manual sorting	85–95%	20–40
Basic mechanical	75–85%	80–120
Enhanced mechanical	85–92%	120–180
Optical commercial	92–98%	200–500
Industrial optical	95–99%	500–2000

Optimization strategies address trade-offs between accuracy and throughput [?]. Reduced

conveyor speed improves sensor detection time but decreases throughput. Multi-stage sorting combines rapid primary sorting with slower secondary re-sorting to balance performance [?].

2.8 Existing Coffee Sorting Machines in Kenya

Previous research on Kenyan coffee processing facilities identified common limitations in existing sorting equipment [?]. Mechanical wear in conveyor systems, sensor contamination from coffee pulp, and inconsistent power supply represent recurring challenges [?].

Locally manufactured sorting machines demonstrate cost advantages but often compromise on component quality and sensor precision [?]. Imported commercial systems offer superior performance but face sustainability challenges due to parts availability and maintenance expertise requirements [?].

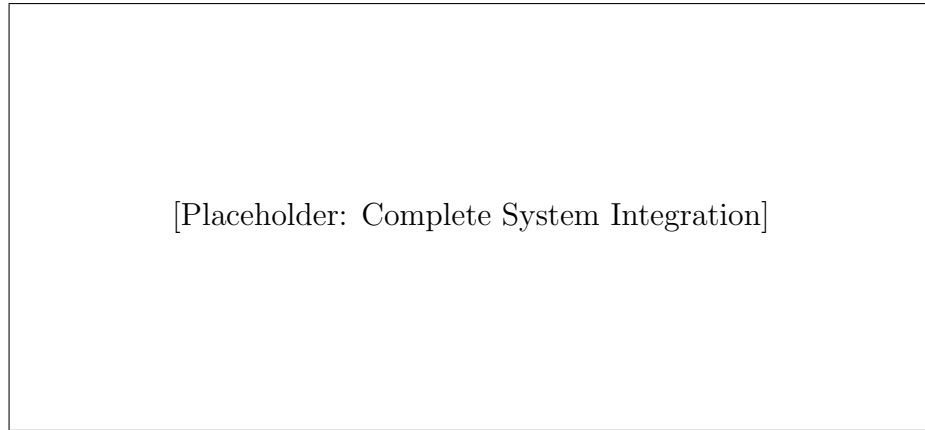


Figure 2.5: Complete coffee berry sorting machine showing integrated subsystems

3 Design and Methodology

3.1 Project Objectives

3.1.1 Main Objective

To modify and improve the existing coffee berry sorting machine to achieve enhanced sorting accuracy ($\geq 90\%$), increased throughput capacity (150-200 kg/hr), and improved mechanical reliability through systematic component upgrades and control system enhancements.

3.1.2 Specific Objectives

1. Redesign feed hopper and vibratory feeder system for consistent, uniform berry presentation to sorting zone
2. Upgrade conveyor belt system with improved tracking, tensioning, and speed control for optimal material flow
3. Implement color-based optical sensor array with real-time classification algorithms for accurate ripeness detection
4. Design and integrate mechanical actuator system (solenoid-driven flapper mechanism) with $\leq 30\text{ms}$ response time
5. Develop microcontroller-based control system with sensor fusion and adaptive thresholding algorithms
6. Implement performance monitoring system with real-time throughput and accuracy metrics

3.2 Design Approach

The project employs systematic modification methodology [?]:

1. Current System Analysis: Identify existing machine limitations and failure modes
2. Requirements Definition: Establish performance targets for throughput and accuracy
3. Component Selection: Specify upgraded components based on performance requirements
4. Detailed Design: Create CAD models for mechanical modifications and circuit schematics
5. Prototyping and Testing: Fabricate modifications and conduct validation testing
6. Integration and Optimization: Install upgrades and tune system parameters
7. Performance Validation: Measure sorting accuracy and throughput against targets

3.3 Implementation Methodology

3.3.1 Mechanical System Modifications

Feed Hopper Redesign The existing feed hopper produces irregular berry flow causing clustering at the conveyor inlet. Proposed modifications include:

- Enlarged hopper capacity (15 kg to 25 kg) for continuous operation
- Adjustable gate mechanism for flow rate control
- Sloped walls (45-degree angle) to prevent berry bridging [?]
- Vibratory feeder integration for controlled, uniform berry release

Vibratory feeder specifications: electromagnetic drive, variable frequency control (20-60 Hz), amplitude adjustment for different berry sizes [?].

Conveyor Belt System Upgrade Current conveyor exhibits belt tracking drift and insufficient speed control. Modifications include:

- Belt tracking system: crowned pulleys and adjustable idlers [?]
- Spring-loaded tensioning mechanism maintaining constant tension across operational conditions [?]
- Variable frequency drive (VFD) for precise speed control (0.3-1.2 m/s range)
- Food-grade PVC belt material with textured surface for berry positioning

Sorting Actuator Mechanism New mechanical actuator system employs solenoid-driven flapper design:

- 12V DC push-type solenoids (25mm stroke, 10N force) [?]
- Lightweight aluminum flapper arms (100mm length) for rapid actuation
- Adjustable mounting brackets for precise positioning relative to sensor detection zone
- Modular design enabling individual actuator replacement without system disassembly

3.3.2 Sensor System Implementation

Optical Sensor Array Color-based detection employs RGB sensors positioned above conveyor belt:

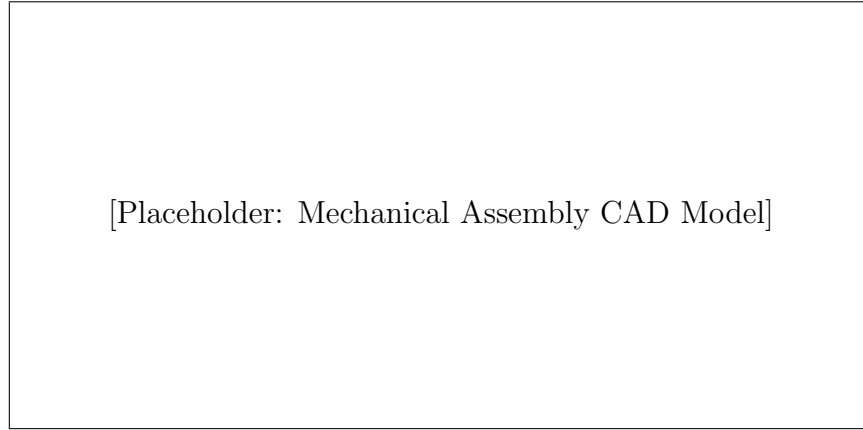


Figure 3.1: CAD model showing upgraded conveyor system, feed hopper, and sorting actuators

- TCS34725 RGB color sensors (4 units distributed across belt width) [?]
- LED illumination array (5500K white LEDs) for consistent lighting conditions
- Sensor height: 50mm above belt surface for optimal detection zone
- Detection resolution: individual berry identification at 0.8 m/s belt speed

Sensor calibration procedure:

1. Establish color thresholds for ripe (red/purple), unripe (green), and overripe (black) berries
2. Generate lookup tables mapping RGB values to ripeness classifications
3. Implement ambient light compensation algorithms [?]
4. Validate classification accuracy with known berry samples

Position Sensing Photoelectric sensors detect berry presence and trigger position tracking:

- Through-beam photoelectric sensors at detection zone entrance

- Encoder feedback from conveyor motor for position tracking
- Time-of-flight calculation synchronizing detection with actuator firing

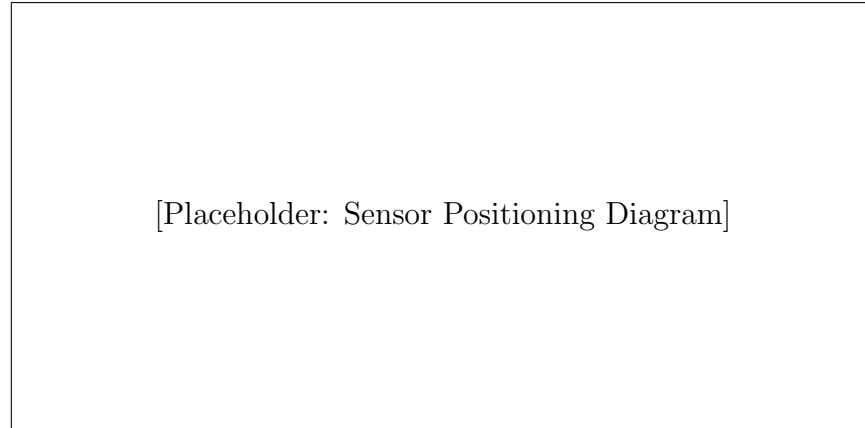


Figure 3.2: Sensor array positioning showing RGB sensors, LED illumination, and photoelectric sensors

3.3.3 Control System Architecture

Microcontroller Platform ESP32 development board provides control system processing:

- Dual-core architecture: Core 0 for sensor processing, Core 1 for actuator control [?]
- I2C bus communication with RGB sensors
- GPIO outputs for solenoid driver control
- WiFi connectivity for remote monitoring and parameter adjustment

Signal Processing and Classification Real-time classification algorithm:

1. RGB sensor data acquisition at 10 Hz sampling rate
2. Digital filtering (moving average, 5-point window) for noise reduction [?]

3. Threshold comparison: classify as ACCEPT if $R > 120$ and $G < 100$, otherwise REJECT
4. Position tracking: calculate actuator firing delay based on belt speed and sensor-to-actuator distance
5. Actuator command: trigger solenoid pulse (50ms duration) at calculated delay

Power System

- Primary power: 220V AC mains via transformer and rectifier
- 12V DC rail: solenoid actuators and sensors (regulated supply, 5A capacity)
- 5V DC rail: ESP32 and signal electronics (buck converter, 2A capacity)
- Emergency stop circuit: hardwired mechanical switch disconnecting solenoid power

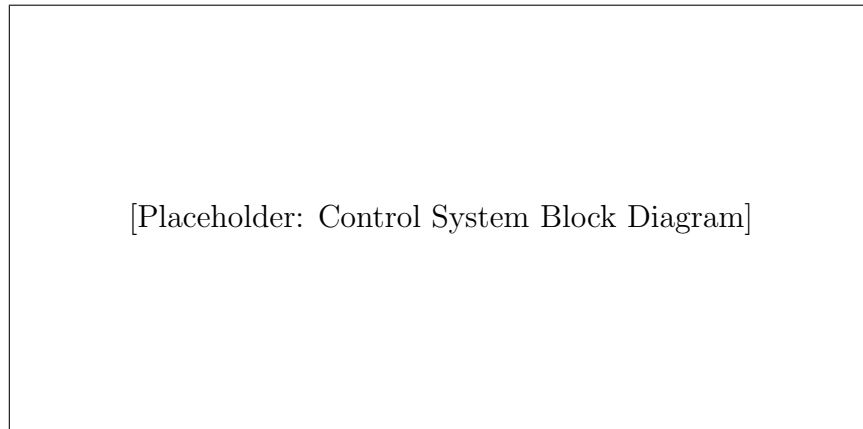


Figure 3.3: Control system architecture showing sensor inputs, microcontroller processing, and actuator outputs

3.4 Testing and Validation Plan

3.4.1 Component-Level Testing

- Vibratory feeder: characterize flow rate vs. frequency and amplitude settings

- Conveyor belt: verify tracking stability across speed range (0.3-1.2 m/s)
- RGB sensors: calibrate color thresholds with sample berries under various lighting conditions
- Solenoid actuators: measure response time and force output, verify actuation reliability (1000+ cycle test)
- Control algorithms: validate classification accuracy with labeled berry dataset (300+ samples)

3.4.2 System Integration Testing

- Feed system: verify uniform berry spacing on conveyor belt (visual inspection and high-speed video)
- Sensor-actuator synchronization: confirm timing accuracy by testing with marked berries
- Throughput measurement: process known berry quantities and measure completion time
- Accuracy measurement: manually verify sorted berry classification (100 berry sample minimum)

3.4.3 Performance Validation Protocol

Comprehensive testing procedure:

1. Prepare test batches: 10 kg mixed berries (known distribution of ripe/unripe/defect)
2. Process batches at target operating speed (0.8 m/s belt speed)
3. Collect and weigh both accepted and rejected streams

4. Manually inspect 5% random sample from each stream
5. Calculate metrics: sorting accuracy, false accept rate, false reject rate, throughput (kg/hr)
6. Repeat testing for 5 batches to establish performance consistency
7. Document failure modes and optimization opportunities

Target performance metrics:

- Sorting accuracy: $> 90\%$ (correctly classified berries / total berries)
- Throughput: 150-200 kg/hr (2.5x improvement over baseline 50-75 kg/hr)
- False accept rate: $< 8\%$ (defects in accepted stream)
- False reject rate: $< 12\%$ (good berries in rejected stream)
- System uptime: $> 95\%$ during 4-hour continuous operation test

4 Expected Outcomes

4.1 Technical Performance

- **Sorting Accuracy:** Achievement of >90% classification accuracy, up from current 75-80% baseline [?]
- **Throughput Capacity:** 150-200 kg/hr processing capacity, representing 2-2.5x improvement over current 50-75 kg/hr [?]
- **False Accept Rate:** Reduction to <8%, minimizing defects in accepted product stream
- **False Reject Rate:** Maintained at <12%, optimizing yield while ensuring quality standards
- **System Reliability:** >95% uptime during 4-hour continuous operation cycles, reducing maintenance interventions
- **Mechanical Robustness:** Elimination of belt tracking issues through crowned pulley design and spring tensioning [?]
- **Sensor Performance:** Consistent color detection across variable lighting conditions via adaptive thresholding [?]

4.2 Economic Impact

The enhanced sorting system will deliver measurable economic benefits:

- **Labor Cost Reduction:** Reduced manual re-sorting requirements (50-70% reduction in sorting labor hours)

- **Product Quality Improvement:** Higher proportion of premium-grade coffee through consistent defect removal
- **Processing Efficiency:** Elimination of throughput bottleneck in processing chain
- **Maintenance Cost Reduction:** Improved mechanical reliability reducing unplanned downtime and repair costs
- **Return on Investment:** Estimated 18-24 month payback period based on labor savings and quality improvements

4.3 Project Timeline

16-week implementation schedule: System Analysis and Design (Weeks 1-3), Component Procurement (Weeks 2-4), Mechanical Modifications (Weeks 4-7), Sensor and Control System Integration (Weeks 7-10), Component Testing (Weeks 10-12), System Integration and Calibration (Weeks 12-14), Performance Validation (Weeks 14-16). Detailed timeline provided in Appendix B.

Critical path activities include conveyor system modifications, sensor array fabrication and calibration, and control algorithm development and tuning.

4.4 Knowledge Contribution

Project documentation will provide:

- Validated design specifications for mid-scale coffee berry sorting systems
- Sensor calibration procedures for RGB-based ripeness detection under African agricultural facility conditions
- Performance characterization data for solenoid-driven mechanical actuator sorting mechanisms

- Cost-benefit analysis comparing semi-automated sorting system improvements versus manual methods
- Troubleshooting guide for common failure modes in conveyor-based agricultural sorting systems
- Replicable design methodology applicable to other fruit and vegetable sorting challenges

These outputs will benefit agricultural engineering students, coffee processing cooperatives, and small-scale agricultural equipment manufacturers across Kenya and East Africa.

4.5 Educational Value

The project provides hands-on learning experiences in:

- Mechatronic system integration combining mechanical, electrical, and software engineering
- Agricultural automation technology addressing real-world processing challenges
- Sensor technology application and signal processing algorithm development
- Performance optimization through systematic testing and parameter tuning
- Economic analysis and engineering design decision-making

5 Conclusion

The proposed modifications and improvements to the coffee berry sorting machine address critical operational deficiencies through systematic upgrade of mechanical, sensor, and control subsystems. The implementation of an enhanced feed hopper and vibratory feeder system will eliminate irregular berry flow patterns that currently degrade sorting accuracy. Conveyor belt system upgrades, including belt tracking improvements and variable frequency drive integration, will provide consistent material handling essential for reliable sorting performance.

The integration of RGB color sensor arrays with adaptive classification algorithms represents a significant technological advancement over the existing system's rudimentary detection mechanism. Solenoid-driven mechanical actuators with ≤ 30 ms response times will enable high-throughput operation while maintaining classification accuracy targets exceeding 90%. The ESP32-based control system provides sophisticated signal processing and actuator coordination capabilities previously unavailable in the existing machine design.

This project addresses a practical agricultural engineering challenge with immediate economic impact for coffee processing operations. Enhanced sorting efficiency directly translates to reduced labor costs, improved product quality, and increased facility throughput. The modifications employ cost-effective technologies appropriate for mid-scale agricultural processing facilities in Kenya, ensuring accessibility and sustainability beyond this specific implementation.

The design methodology and technical solutions developed through this project provide replicable frameworks applicable to similar sorting challenges across agricultural processing sectors. Successful completion will demonstrate the viability of semi-automated sorting system upgrades for resource-constrained agricultural facilities, contributing to the broader adoption of precision agriculture technologies in East Africa.

Project documentation, including validated design specifications, sensor calibration pro-

cedures, and performance characterization data, will serve as valuable resources for agricultural engineering education and small-scale equipment manufacturers. The hands-on experience gained through mechatronic system integration, sensor technology application, and performance optimization provides essential practical engineering skills complementing theoretical coursework.

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A Project Budget

Funding sources: University FYP allocation (KES 80,000), Agricultural Processing Facility budget (KES 50,000), student contribution (KES 17,500). Existing facility infrastructure (220V power, compressed air lines, workshop access) provided in-kind.

B Project Timeline

Critical path: Vibratory feeder procurement (4-week lead time from order), conveyor modifications (2 weeks fabrication), sensor calibration (1 week). Risk mitigation: Early component ordering (Week 3), backup sensor units, parallel fabrication activities.

C Component Specifications

Vibratory Feeder: Electromagnetic drive, 220V AC, variable frequency control 20-60 Hz, amplitude adjustment 0-5mm, tray dimensions 600mm x 400mm, capacity 25 kg, stainless steel construction.

Conveyor Belt: Food-grade PVC material, dimensions 1500mm x 400mm, textured surface (2mm raised pattern), crowned pulleys 100mm diameter, spring-loaded tensioning 50-100N, VFD speed control 0.3-1.2 m/s.

RGB Color Sensors (TCS34725): I2C interface, 3.3V operation, 16-bit ADC, programmable gain 1x-60x, integration time 2.4-614 ms, clear/red/green/blue channels, surface mount package, detection range 0-80mm.

Push Solenoids: 12V DC operation, 25mm stroke length, 10N push force, 50ms response time, continuous duty rating 25%, mounting threads M10x1.0, resistance 8-10 ohms, power consumption 15W.

ESP32 Development Board: Dual-core Xtensa LX6 240 MHz, 520 KB SRAM, 4 MB flash, WiFi 802.11 b/g/n, 34 GPIO pins, I2C/SPI interfaces, 12-bit ADC, 3.3V logic, micro-USB programming, -40°C to +85°C operation.

D Testing Protocols

Component-Level Tests:

Vibratory Feeder: Measure berry flow rate at 5 frequency settings (20, 30, 40, 50, 60 Hz) and 3 amplitude settings (low, med, high). Record flow uniformity using high-speed camera. Success criteria: Consistent flow rate $\pm 10\%$, minimal berry clustering.

Conveyor Belt Tracking: Run conveyor at operational speeds (0.3, 0.6, 0.9, 1.2 m/s) for 30-minute durations. Measure lateral drift with dial indicator. Success: ≤ 5 mm drift over 30 minutes at all speeds.

RGB Sensor Calibration: Present 50 sample berries (known classifications) to each sensor. Record RGB values, establish threshold boundaries. Validate with 50 additional berries. Success: $\geq 85\%$ classification accuracy per sensor.

Solenoid Actuator: Conduct 1000-cycle endurance test, measure response time and force output every 100 cycles. Success: Response time ≤ 35 ms throughout test, force ≥ 8 N maintained.

System Integration Tests:

Sensor-Actuator Synchronization: Mark test berries with known colors, run through system at operational speed. Video record to verify timing accuracy. Success: Actuator fires within ± 20 ms of optimal timing.

Throughput Measurement: Process 10 kg batches, measure completion time. Calculate throughput (kg/hr). Repeat for 5 batches. Success: Average throughput 150-200 kg/hr, consistency $\pm 15\%$.

Performance Validation:

Accuracy Testing: Prepare test batches (10 kg each) with known berry distributions (40% ripe, 30% unripe, 20% overripe, 10% defect). Process at operational speed, collect accepted and rejected streams. Manually verify classification for 5% random sample (minimum 100 berries). Calculate metrics: sorting accuracy, false accept rate, false reject rate. Success: Sorting accuracy $\geq 90\%$, false accepts $\leq 8\%$, false rejects $\leq 12\%$. Repeat for 5 batches to establish consistency.

Table A.1: Budget Breakdown

Component	Specification	Cost (KES)
Mechanical Components		
Vibratory Feeder	Electromagnetic, variable frequency	18,000
Conveyor Belt	Food-grade PVC, 1.5m x 0.4m	8,000
Crowned Pulleys (2)	100mm diameter, aluminum	5,000
VFD Motor Controller	0.5 HP, 220V AC input	12,000
Spring Tensioners (2)	Heavy-duty, adjustable	2,500
Aluminum Extrusion	40x40mm profile, 3m length	4,000
Feed Hopper Material	Stainless steel sheet, 1.5mm	6,000
Mounting Hardware	Bolts, brackets, bearings	3,000
Sensor Components		
RGB Color Sensors (4)	TCS34725, I2C interface	8,000
Photoelectric Sensors (2)	Through-beam, 12V DC	4,000
LED Illumination Array	5500K white LEDs, drivers	3,500
Rotary Encoder	For conveyor speed sensing	2,500
Actuator Components		
Push Solenoids (8)	12V DC, 25mm stroke, 10N	12,000
Solenoid Driver Boards	MOSFET-based, 8-channel	5,000
Flapper Arms	Aluminum, custom fabricated	4,000
Control Electronics		
ESP32 Development Board	Dual-core, WiFi-enabled	1,500
Power Supplies	12V/5A, 5V/2A regulators	4,000
Wiring and Connectors	Industrial-grade, shielded	3,000
Emergency Stop Switch	Industrial safety switch	1,500
Junction Boxes	IP65-rated enclosures	2,500
Fabrication and Assembly		
Welding and Metalwork	Hopper and frame modifications	8,000
Machining Services	Pulley modifications, mounting	5,000
Electrical Installation	Wiring, termination, testing	6,000
Testing Materials		
Glass Beads, Sand	100 kg for calibration testing	2,000

Table B.1: Implementation Schedule (16 Weeks)

Week	Activity	Deliverable
1	System analysis and measurements	Baseline performance report
2	Detailed design and CAD modeling	Design drawings
3	Component specification and sourcing	Bill of materials
4	Component procurement (lead items)	Ordered components
5	Feed hopper fabrication	Modified hopper
6	Conveyor modifications (pulleys, tensioners)	Upgraded conveyor
7	Vibratory feeder installation	Installed feeder
8	Sensor array fabrication	Mounted sensors
9	Control electronics assembly	Wired control system
10	Actuator mechanism installation	Operational actuators
11	Firmware development and sensor calibration	Calibrated system
12	Component testing (feed, sensors, actuators)	Test reports
13	System integration and initial testing	Integrated system
14	Algorithm tuning and optimization	Optimized parameters
15	Performance validation (5 test batches)	Validation data
16	Documentation and final presentation	Final report