

Performance Analysis of Microcontroller Based Tomato Fruit Separator Conveyor

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Abstract

The rapid development of automation technology in the agricultural sector has increased the demand for efficient and accurate fruit sorting systems. This study aims to analyze the performance of a microcontroller-based tomato sorting conveyor system that classifies tomatoes according to color and weight parameters. The system was designed using an Arduino Uno microcontroller as the main controller, a TCS3200 color sensor to detect fruit maturity, a load cell sensor to measure weight, and DC motors and servo motors as sorting actuators. A descriptive qualitative research method was employed, with data collected through direct observation and documentation during laboratory testing. The results indicate that the conveyor system operates automatically and consistently in detecting and separating tomatoes based on predefined criteria. The integration of color and weight sensors improves sorting accuracy compared to manual methods. Furthermore, the electrical power system and microcontroller control significantly influence the stability and reliability of conveyor operation. Therefore, the proposed system demonstrates strong potential as a practical solution to enhance post-harvest efficiency in agricultural applications.

Keywords: Conveyor System, Tomato Sorting, Microcontroller, Color Sensor, Load Cell

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Introduction

Industrial technology has progressed rapidly and has had a significant impact on increasing the efficiency of production processes in various sectors, including agriculture. Technological innovation has driven a shift from manual work systems to automated systems that are more efficient, accurate, and consistent. In the post-harvest stage, the process of sorting agricultural produce is a crucial aspect in maintaining product quality before distribution. However, manual sorting methods are still widely used and have various limitations, such as reliance on human subjectivity, low yield consistency, and high time and labor requirements [1]. Tomatoes (*Solanum lycopersicum*) are a horticultural commodity with high economic value and widespread consumption. Tomato plants grow optimally in loose, nutrient-rich soil and have both fibrous and taproot systems [2]. In trade practice, tomato quality is generally determined by the level of ripeness observed from the color of the fruit's skin. Fully ripe tomatoes on the vine are red, while tomatoes harvested at a semi-ripe state tend to appear orange after further ripening [3]. These differences in ripeness levels affect selling prices and consumer preferences, requiring a sorting system capable of objectively and consistently classifying tomatoes.

Agricultural product sorting aims to classify products based on specific criteria, such as color, size, and weight, to ensure uniform quality and increase sales value [4]. With the increasing need for efficiency, various studies have developed microcontroller-based automatic sorting systems. Kumar developed an Arduino-based automatic tomato sorting system that utilizes color and size sensors to improve efficiency in small-scale farming [5]. Samudra et al. designed a tomato sorting device based on color using the TCS3200 sensor, which allows for automatic tomato classifying through servo motor control [6]. A similar approach was also applied by Darminta et al. in simulating the separation of citrus ripeness levels using an ATmega328P microcontroller and a color sensor [7], and by Wibowo et al. in developing an Arduino Uno-based palm oil sorting machine with a TCS3200 sensor [8]. Further development was carried out by integrating a conveyor system to increase the capacity and continuity of the sorting process. Sari et al. analyzed the performance of an Arduino Uno-based tomato separating conveyor system using color and weight parameters and reported a sorting accuracy of 92% at a speed of 0.5 m/s. However, increasing the conveyor speed to 1 m/s caused a decrease in accuracy to 85% due to color sensor reading errors, making sensor calibration a critical factor [9]. Wibowo et al. further evaluated an ESP32 microcontroller-based conveyor system and achieved an accuracy of up to 95% at an optimal speed of 0.7 m/s with relatively low power consumption [10]. Meanwhile, Rahman et al. reported that a Raspberry Pi-based conveyor system had an accuracy of 88% and an overall efficiency of 90%, but still faced challenges related to sensor sensitivity to environmental lighting conditions [11].

Recent research by Putra et al. showed that a tomato separating conveyor system using an Arduino Mega and a load cell sensor achieved 94% accuracy at a speed of 0.8 m/s, despite relatively higher implementation costs [12]. Furthermore, Lestari et al. integrated Internet of Things (IoT) technology into an ATmega328-based tomato separating conveyor system and successfully increased sorting accuracy to 96% and energy efficiency to 92% [13]. However, most of these studies focused on a single primary parameter or did not specifically examine conveyor system performance in terms of power system integration and operational stability. Based on this review of previous research, a research gap was identified: the need for a tomato separating conveyor system that not only relies on a single parameter but also integrates two primary parameters, namely color and weight, and comprehensively analyzes them in terms of conveyor system performance and power system reliability. Therefore, this study aims to analyze the performance of a microcontroller-based tomato separating conveyor system combining a TCS3200 color sensor and a load cell sensor. This system is expected to improve sorting accuracy, operational efficiency, and support the implementation of sustainable automation technology in the agricultural sector.

Literature Review

Tomatoes (*Solanum lycopersicum*) are horticultural crops with two types of root systems: fibrous roots that spread laterally and taproots that penetrate the soil. Therefore, tomato plants are ideally planted in loose, nutrient-rich soil to support optimal growth. This plant has a relatively short life cycle and can grow to a height of between one and three meters [6]. Botanically, tomatoes are classified as fruits because they produce seeds, but in consumption and culinary practice, tomatoes are often categorized as vegetables due to their high water content and common use as a cooking ingredient. The ripeness of tomatoes is an important parameter in determining quality. Based on changes in skin color, tomatoes are generally classified into six stages of ripeness: mature green, breaker, turning, pink, light red, and red. These color changes reflect the physiological process of fruit ripening, which is related to the sugar content, texture, and flavor of the tomato [14]. Therefore, the color of the fruit surface is a primary visual indicator in the sorting process for ripeness.

The implementation of a microcontroller-based tomato fruit separating conveyor system is one example of automation technology implementation in agriculture, particularly in the postharvest stage. This system is designed to automatically separate tomatoes based on specific physical parameters, namely weight and color, which play a crucial role in determining the fruit's quality and ripeness [5], [16]. Several key components are integrated within the system, including a conveyor as the transport medium, a weight sensor, a color sensor, an actuator, and a microcontroller that serves as the central control for the entire process [17]. A conveyor or belt conveyor is a mechanical system used to continuously move objects from one point to another. In a tomato sorting system, the conveyor acts as a transport path, ensuring the fruit moves steadily and sequentially during the measuring and sorting process. The use of a conveyor allows for automation of the material transfer process, thereby increasing efficiency, production capacity, and the consistency of sorting results compared to manual methods [18]. Tomato weight detection is performed using a load cell sensor that operates on the principle of a strain gauge. This sensor converts the applied mechanical force or load into an electrical signal proportional to the object's weight. The electrical signal is then amplified and converted into digital data using an amplifier module such as the HX711. Tomato weight is used as an indicator of size and quality, allowing the fruit to be categorized as light, medium, and heavy [19].

In addition to weight, color is also a key factor in the tomato sorting process. Color sensors such as the TCS3200 or TCS34725 are used to detect the RGB (Red, Green, Blue) color composition of the fruit's surface. These sensors work by measuring the intensity of light reflected by an object and converting it into a frequency signal or digital data. This color information is used to determine the ripeness of the tomato, with green indicating unripe, orange indicating half-ripe, and red indicating full ripeness [20].

Research Methodology

This study uses a qualitative descriptive method to analyze the performance of a microcontroller-based tomato fruit separating conveyor system, with the aim of systematically describing the entire system's work process, starting from fruit transfer, reading the weight sensor (load cell) and the TCS3200 color sensor, to decision making by the microcontroller to direct the fruit to the sorting line according to grade, without conducting statistical hypothesis testing. The study was conducted in the Electrical Engineering laboratory of Panca Budi Development University, Medan in the even semester of the 2024/2025 academic year, including the stages of system design, hardware assembly, microcontroller programming, sensor and actuator function testing, system performance observation, and data analysis. The object of the study is an automatic tomato separating conveyor system consisting of a conveyor belt, a load cell sensor with an HX711 module, a TCS3200 color sensor, a proximity sensor, a DC motor for the conveyor drive, MG996R and SG90 servo motors as actuators, a DC-DC stepdown module, and an ESP8266 module for communication and data display. The study

population included all tomatoes used as test objects with variations in color (green and red) and weight (light, medium, heavy), while the sample was determined using purposive sampling to ensure representation of real sorting conditions. Data were collected through direct observation of the system's working process and documentation, including photos, videos, circuit diagrams, and tool test records. Analysis was carried out descriptively qualitatively by grouping data based on the performance of sensors, conveyors, microcontrollers, and actuators, then systematically describing the results to assess the effectiveness and reliability of the system. The system workflow is depicted in Figure 1 Flowchart, which shows the steps starting from microcontroller pin initialization, conveyor operation, weight and color sensor readings, data processing, fruit grade classification, to servo motor control to open and close the sorting line.

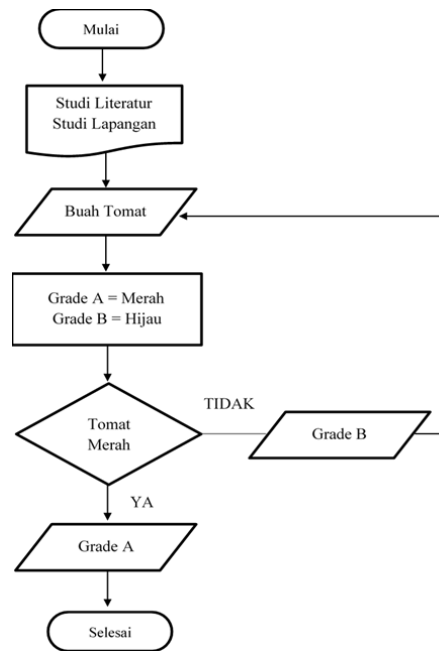


Figure 1. Flowchart

The overall structure of the system, including the relationship between sensor input, processing by the microcontroller, and output in the form of actuators and communication modules, is shown in Figure 2 Block Diagram. The system uses a DC-DC stepdown module to stabilize the voltage from 12V to 5V so that all components work optimally. With this approach, the study can provide a comprehensive picture of the performance of the microcontroller-based tomato separating conveyor system, both in terms of sorting accuracy, sensor response, and the effectiveness of the fruit grouping mechanism into predetermined grades.

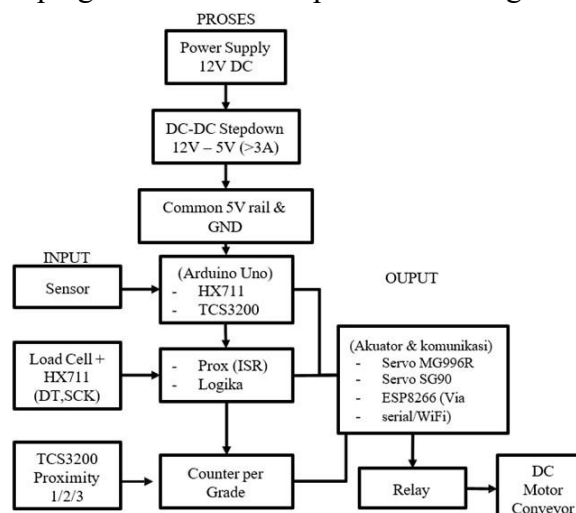


Figure 2. Block Diagram

Results and Discussion

The developed system is a microcontroller-based tomato fruit separating conveyor designed to perform automatic sorting based on weight and red color intensity. This system consists of an Arduino Uno as the main controller, a DC motor as a conveyor drive, a load cell sensor with an HX711 module for weight measurement, a TCS3200 color sensor for color detection, a servo motor as a sorting actuator, a relay, and a DC–DC stepdown module to maintain stable working voltage. The assembly results show that all components can be well integrated and work according to their functions. The conveyor is able to carry tomatoes continuously through the sensor, weight and color data can be read in real-time, and the classification results are translated into servo mechanical movements to separate the fruit into predetermined grades. The overall system configuration is shown in Figure 3.

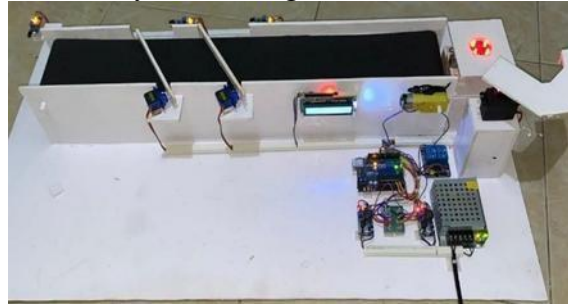


Figure 3. Results of tool design

Electrical testing is performed to ensure that each component receives the operating voltage required by its specifications.

1. Relay Operating Voltage

The voltage measurement results for the relay module are shown in Table 1. **Table**

1. Relay Voltage Measurement Results

Kondisi Pengukuran	Tegangan
ON	5,03 V
OFF	0 V

This voltage indicates that the relay is receiving a stable control signal from the microcontroller, ensuring proper switching.

2. 5 V Supply Voltage

The measurement results for the 5 V power supply output voltage are shown in Table 2. **Table**

2. Result of 5 V Supply Voltage Measurement

Kondisi	Tegangan
ON	5,03 V
OFF	0 V

This value indicates that the DC–DC stepdown module is capable of optimally stabilizing the voltage to support sensor and microcontroller performance.

3. Object Sensor Output Voltage

The results of the object sensor output voltage measurements are shown in Table 3. **Table**

3. Object Sensor Output Voltage

Kondisi Pengukuran	Tegangan
ON	±178 mV
OFF	0 V

This voltage is sufficient to detect the presence of tomatoes on the conveyor and serves as a trigger signal for the weight and color sensors.

4. DC Motor Voltage

The results of the DC motor voltage measurements are shown in Table 4. **Table**

4. DC Motor Voltage Measurement Results

Kondisi Pengukuran	Tegangan
ON	4,75 V
OFF	1 V

This operating voltage results in stable conveyor rotation and does not interfere with sensor readings.

5. Stepdown Module Input Voltage

The results of the stepdown module input voltage measurements are shown in Table 5. **Table**

5. Stepdown Input Voltage

Kondisi Pengukuran	Tegangan
ON	11,8 V
OFF	0 V

This value corresponds to the 12 V power source used and indicates the stability of the system power supply.

Sorting tests were conducted on ten tomato samples with varying weight and red color intensity. The test results are shown in Table 6.

Table 6. Results of Tool Performance Testing

No	Berat (gr)	Kadar Warna Merah	Grade
1	120	46	A
2	70	44	B
3	93	50	A
4	60	20	C
5	87	52	A
6	90	43	A
7	64	18	C
8	56	48	C
9	107	26	C
10	81	32	B

These results indicate that the system is able to consistently classify tomatoes based on a combination of weight and red color intensity. Tomatoes with high weight and red color intensity are categorized as Grade A, while tomatoes with medium and low values are classified as Grade B and C.

To evaluate the accuracy of the weight measurements, calibration was performed by comparing the load cell readings to a digital scale as a reference. The calibration results are shown in Table 7.

Table 7. Scale Calibration Results

No	Berat Terbaca (gr)	Berat Referensi (gr)	Selisih (gr)
1	120	122	2
2	70	71	1
3	93	94	1
4	60	60	0
5	87	88	1
6	90	91	1
7	64	64	0
8	56	56	0
9	107	108	1
10	81	81	0

The measurement difference is in the range of 0–2 grams, which indicates a good level of accuracy and is adequate for fruit sorting applications.

The test results show that the microcontroller-based tomato fruit separating conveyor system operates stably and according to the designed specifications. The voltage stability generated by the DC–DC stepdown module supports the performance of the sensors and actuators, allowing the system to operate without significant disruption. Modifications to the TCS3200 color sensor by replacing the built-in LED with a red LED have been shown to increase the sensitivity of red color readings, which is a key indicator of tomato ripeness. In addition, the use of two main parameters, namely weight and color, provides a more accurate and representative sorting approach compared to a single-parameter-based system. Overall, the results of this study indicate that the developed system has the potential to be applied to small- to medium-scale post-harvest processes, with advantages in yield consistency, time efficiency, and reduced reliance on manual labor.

Conclusion

This research successfully designed and analyzed the performance of a microcontroller-based tomato fruit separating conveyor system by integrating weight and red color intensity parameters. Test results showed that all system components, both mechanically and electrically, can operate stably and according to the designed specifications. Electrical performance evaluation showed that the use of a DC-DC stepdown module is able to maintain the stability of the working voltage in all components, thus supporting the overall system reliability. The load cell sensor calibrated using the HX711 module has a good level of accuracy with a measurement deviation in the range of 0–2 grams, making it suitable for use in the tomato fruit sorting process. In addition, modification of the TCS3200 color sensor with the addition of a red LED increases the sensitivity of the red color intensity reading which is the main indicator of fruit ripeness. The results of the sorting test showed that the system is able to classify tomatoes into Grade A, Grade B, and Grade C consistently based on a combination of weight and color parameters. This multi-parameter approach has been proven to improve classification accuracy compared to sorting methods that only rely on one parameter, and more objectively represents the assessment of fruit quality. Overall, the developed tomato fruit separating conveyor system has the potential to be applied to small- to medium-scale post-harvest processes as an efficient, consistent, and economical automation solution. This research also contributes to the development of a microcontroller-based agricultural product sorting system with an integrative approach between sensory, mechanical, and electrical aspects.

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