ISSN: 2754-6659

Journal of Artificial Intelligence & Cloud Computing

Research Article

Open Access

Intelligent Citrus Classification: An Automated System Using Weight Sensing and Image Processing with Arduino Microcontroller

Michael D Aliaga, Alan P Nebrida*, Rogie Mar Guiloy and Roxanne Mae Valera

College of Engineering, Computer Engineering Department, Nueva Vizcaya State University, Bambang Campus, Bambang, Nueva Vizcaya, Philippines

ABSTRACT

The citrus industry is a major player in the agricultural sector, and the preservation of citrus fruit quality and marketability depends on effective citrus fruit classification and sorting. The objective of this research was to create and assess an automated system for classifying and organizing citrus fruits according to their color, roundness, weight, and size. The system was developed with Arduino microcontrollers and image processing software to examine and classify fruits into discrete categories: extra small, small, medium, large, and extra-large. The evaluation of the automated system's performance included a comparison between its categorization outcomes and those obtained via manual approaches. The statistical study showed that there were no significant disparities between the average values acquired manually and those obtained by automation. This suggests that the automated system is capable of achieving the same level of accuracy as human classifiers. The system exhibited a notable level of uniformity in categorizing fruits according to the given characteristics, with average values for weight, diameter, roundness, and color % displaying a robust association with the predetermined size categories. The findings demonstrate that the automated system has the ability to precisely categorize citrus fruits with a significant level of uniformity, providing a practical solution to improve the effectiveness and excellence of fruit processing in the citrus sector. Implementing automated classification and sorting systems in the citrus industry has the capacity to greatly improve efficiency, leading to increased profitability and a more sustainable agricultural approach. Ultimately, this research effectively created and evaluated an automated system for classifying and sorting citrus fruits, which showed promising outcomes in terms of precision and uniformity. The deployment of this system provides a practical solution for improving the productivity and standard of fruit processing in the citrus sector, hence promoting a more lucrative and environmentally friendly agricultural approach.

***Corresponding author**

Alan P Nebrida, College of Engineering, Computer Engineering Department, Nueva Vizcaya State University, Bambang Campus, Bambang, Nueva Vizcaya, Philippines.

Received: May 28, 2025; **Accepted:** June 02, 2025; **Published:** June 12, 2025

Keywords: Automated Classification, Citrus Sorting, Image Processing, Arduino Microcontroller, Agricultural Automation, Quality Control

Introduction

The Philippines' agricultural economy greatly benefits from the citrus sector, with Nueva Vizcaya being known as the Citrus Capital of the nation. Despite its significance, the industry's dependence on antiquated techniques for classifying fruits causes production issues. Citrus fruit classification by hand is a labor-intensive, time-consuming method that is prone to human error, which causes inconsistent quality evaluation. The sector is also facing increased labor prices and a lack of competent workforce, which highlights the need for more effective manufacturing methods.

Automation lowers costs and increases manufacturing efficiency, making it a possible answer to these problems. Automated fruit categorization systems use image processing methods to evaluate fruits' visual quality attributes in an unbiased manner. These systems take pictures, process them, and then use image analysis to measure and categorize fruits according to how they look. Fruit chromatic qualities (such as color) and geometric qualities (such as form, size, texture, and weight) are combined to define visual quality. The existence of exterior flaws may also have an impact on the overall quality of fruit.

Since automated fruit grading offers a quick, affordable, reliable, and nondestructive method of categorization, it is essential for increasing the value of produce. Additionally, it lessens the subjectivity involved in human review, producing outcomes that are more trustworthy and accurate. Numerous scholars have investigated various methods for automating the categorization of fruits. For example, Changyong Li, Qixin Cao, and Feng Guo presented a dominant color histogram matching approach for fruit classification [1]. To separate the fruit from the backdrop, they used an RGB color space segmentation algorithm. Rasekhi et al. created a method to classify oranges into three size categories (small, medium, and large) by combining image processing and neural network approaches [2]. Hannan et al. developed a machine vision system for identifying oranges in varied lighting situations for automated harvesting, whereas Cavaco et al. suggested a nondestructive way to evaluate the interior quality of orange fruits [3,4]. A machine vision-based fruit recognition system for robotic Fuji apple harvesting was described by Bulanon & Kataoka [5].

The main difficulties in categorizing citrus fruits are precisely determining their color, weight, and size since the manual method mostly depends on human vision, which may cause errors. Furthermore, manual categorization is costly and ineffective, especially in busy seasons when manpower is scarce.

The objective of this system is to enhance manual operations by automating the sorting and categorization of goods. It efficiently categorizes fruits into consistent clusters based on certain characteristics, such as weight, size, shape, and quality. Automation is a crucial advantage in the agricultural industry because it not only reduces the amount of time and effort required but also has the capability to decrease costs in various processing steps.

Nevertheless, this research focused mostly on citrus fruits, namely, the Ponkan mandarin variety, and its scope is limited to indoor applications. Fruits are categorized based on their external characteristics, such as color, roundness, size, and weight. The duration of the system's processing is dictated by the computer's specifications. Due to its focus on the upper half of the fruit, the approach disregards any issues inside the fruit's interior and any external flaws on the bottom part of the fruit. Moreover, the attributes of the camera impact the quality of the photographs used for classification.

To summarize, a crucial measure for addressing the challenges faced by the citrus industry in the Philippines is the development of an automated system for sorting and categorizing fruits. This technology-based method, called "Intelligent Citrus Classification: An Automated System Using Weight Sensing and Image Processing with Arduino Microcontroller," has the capability to enhance the accuracy and efficiency of fruit categorization. It can also streamline production operations, reduce expenses, and ultimately contribute to the growth of the agricultural economy.

Methods

Process Block Diagram of the Citrus Classifier

Figure 1 depicts the process block diagram of the system, which visually illustrates the many processes involved in the automated citrus classification process. The process starts with unorganized "Ponkan" citrus fruits, which are incorporated into the system as the first raw material. The first stage of categorization is conducted using an image processing unit, which carefully examines the color, roundness, and size of each fruit. This step is critical because it employs advanced image processing methods to acquire and analyze visual data to precisely identify the qualitative characteristics of citrus fruits.

After the visual inspection, the fruits go to the next stage, where they are categorized based on their weight. An accurate weight sensor assesses each fruit and categorizes it based on its weight. This stage guarantees that the physical weight of the fruit is considered, which is a crucial trait for accurate categorization.

The sorting machine is the last component in the diagram where the combined data from image processing and weight classification come together. This equipment is responsible for physically sorting the fruits into their assigned groups. Fruits are categorized into several classes, such as tiny, extra small, medium, large, and extra-large, based on their evaluated qualities. If a fruit does not fulfill the stated requirements, it is considered a reject.

The last block in Figure 1 displays the system's output, which consists of a collection of categorized "Ponkan" fruits. The fruits have been sorted and are now prepared for further stages of the supply chain, such as packing for sale, delivery to retailers, or additional processing. The graphic demonstrates the automated system's effectiveness in improving the sorting process, showing a smooth transition from unprocessed, unsorted inputs to categorized, market-ready citrus products.

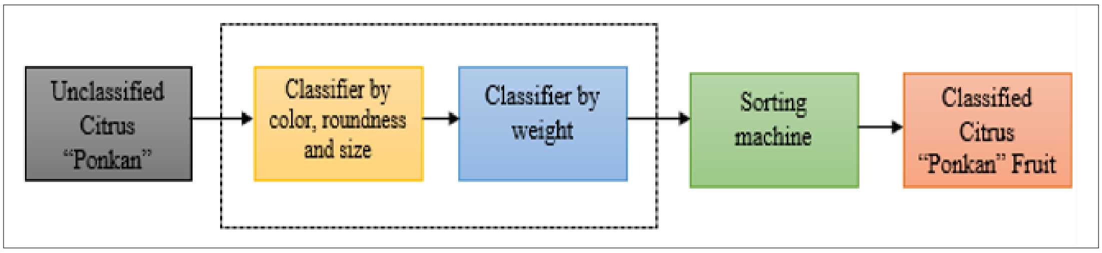


Figure 1: Process Block Diagram of the Citrus Classifier

Block Diagram of the Citrus Classifier

Figure 2 displays a schematic representation of the study plan for the citrus classifier. The AC power supply is the central component of the system, delivering the required power to the connected devices. This package consists of a personal computer (PC) and an AC-12 V DC converter. The converter's goal is to rectify the alternating current, converting it into direct current by eliminating its back-and-forth motion and ensuring a steady flow in one direction. A consistent 12 V direct current (DC) output is essential since it provides power to both the DC motor shield and the Arduino ATmega 2560 microcontroller.

The DC motor shield is responsible for controlling the functioning of the DC motors that power the conveyor belt, enabling the transportation of citrus fruits through the classifier. The Arduino microcontroller has many functions. It controls the weight sensor and the LCD display, delivering real-time data and status updates. Additionally, it directs the servo motors depending on the inputs it receives.

Servo motors, which need a 5 V DC power source, are essential components of the accurate motion and sorting process inside the classifier. Finally, when the personal computer (PC) is turned on, it initiates the camera, preparing it for capturing images. The PC also provides power to the Gizduino Atmega 644 microcontroller, which is presumably responsible for carrying out further processing and control chores associated with image analysis and classification logic. This integrated system guarantees smooth functioning of the citrus classifier, starting from the initial activation of the components to the ultimate categorization of the fruits.

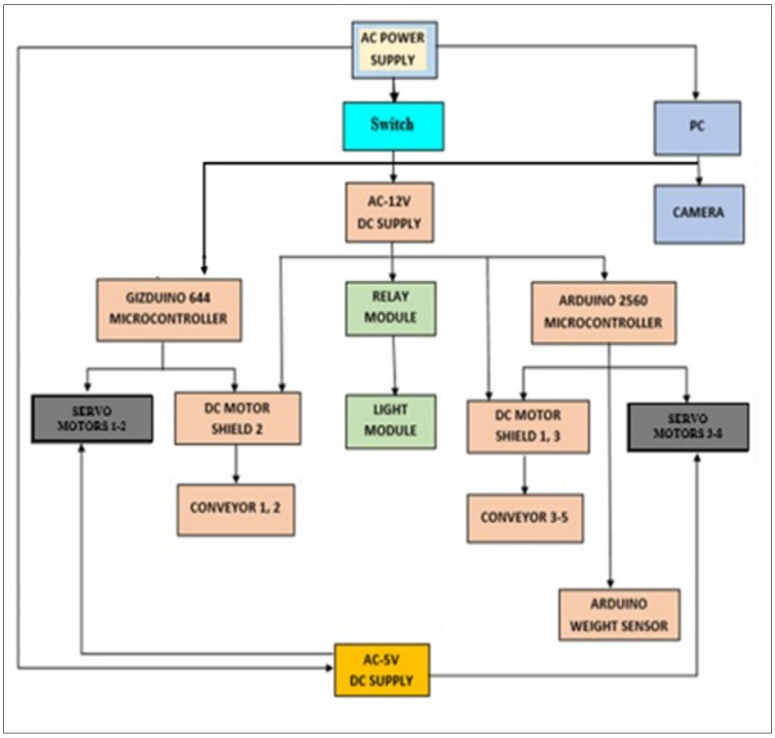


Figure 2: Block diagram of the Citrus Classifier

System Flowchart

Figure 3 provides a comprehensive flowchart illustrating the systematic process of an automated citrus classification system. This procedural map starts with the "Start" of the system, which then transitions into the first phase called the "Initialize System." This stage typically entails initiating the system's software, activating the hardware, and getting ready to receive the citrus fruits.

After being initialized, the system proceeded to the data collection phase. This phase begins with the task of "Determine radius," which indicates that the system measures the radius of each fruit. It is possible that the system uses image processing techniques to determine the radius based on acquired photos.

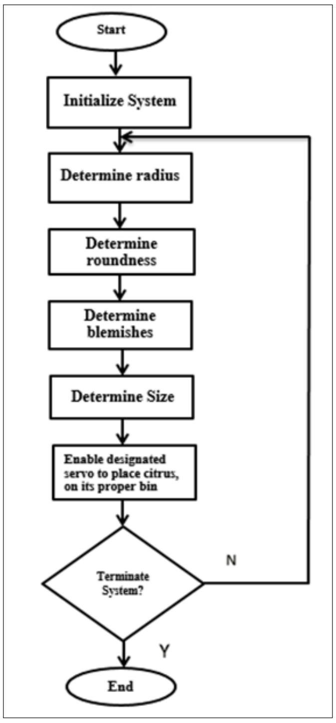


Figure 3: System Flowchart

The next step in the process is "Determine roundness," which means that the system evaluates the form of the fruit to ensure that it matches the roundness requirements for the particular citrus category. This phase may include examining the shape of the fruit photos to measure their circularity, which may serve as an indication of the fruit's level of ripeness and quality.

The next step in the process is "Determine blemishes," during which the machine carefully inspects the fruit for any surface faults or irregularities. Visible imperfections on the fruit's surface may provide information about its exterior condition and may impact how it is categorized.

Subsequently, the system evaluates the comprehensive "Determine Size" metric, which encompasses the fruit's diameter and volume. This metric is crucial for categorizing fruit size, as it frequently indicates fruit maturity and market categorization.

After evaluating all parameters, the flowchart proceeds to the action step: "Activate the specified servo to position the citrus fruit in its appropriate bin." This finding implies that the system utilizes servo motors to categorize the fruit into bins according to the gathered data points, which include radius, roundness, flaws, and size. The servo motors would activate as intended, physically relocating each piece of fruit to its assigned category.

The ultimate decision point in the flowchart, labeled "Terminate System? ", which allows the operation to be stopped. If the choice is negative, the system may return to receive and categorize the next fruit, proposing an ongoing process until a positive order is received to stop the procedure, at which point the flowchart ends with "End."

The flowchart shown in Figure 3 offers a comprehensive overview of the operational logic governing the citrus classification system. It particularly emphasizes the procedures involved in categorizing and arranging the fruit. The process involves a sequential and coherent series of actions that are executed to obtain the intended result—a well-arranged and categorized citrus product prepared for the subsequent phase in the distribution network.

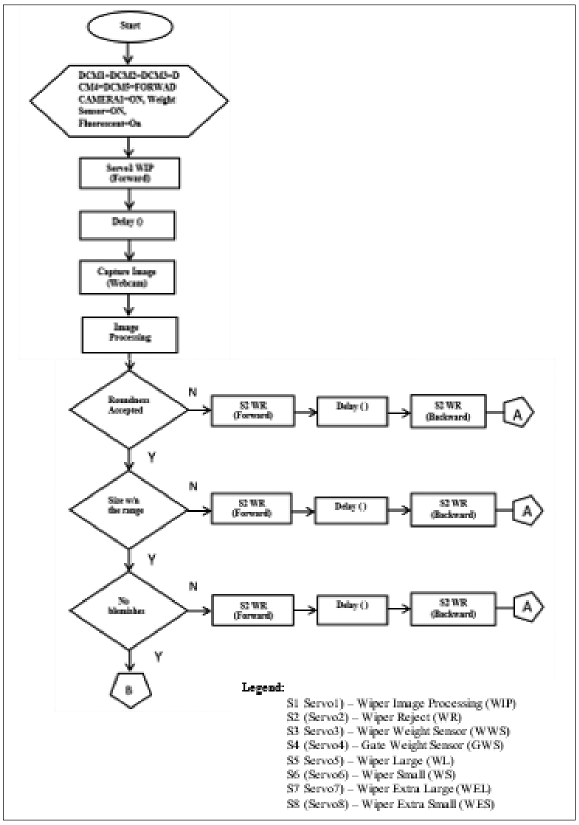
Process Flowchart

Figure 4 presents a process flowchart that illustrates the operational phases of the citrus classifier. This flowchart visually represents the step-by-step approach for classifying citrus fruits according to their quality and size. The method begins with obtaining a photograph of the citrus fruit, which is a vital step since it forms the foundation for further research.

After taking the picture, the system proceeded to analyze these visual data to determine whether the citrus fruit was devoid of any defects. This stage often involves a sequence of image processing algorithms specifically designed to identify any surface irregularities or flaws that would categorize the fruit as unsatisfactory. These may include imperfections, color variations, or unusual forms.

The fruits were weighed either at the same time or afterwards to determine their size. Size categorization is often determined by weight ranges that correlate to size categories such as small, medium, and large. The weight data, when paired with the picture analysis, provide a thorough comprehension of the overall quality and categorization of the fruit.

The flowchart outlines the process of sorting citrus fruits based on their size and quality. Nondetective fruits are subsequently allocated to the appropriate bins. Each bin corresponds to a distinct category of fruit quality or size, enabling systematic collection for subsequent distribution or packing.



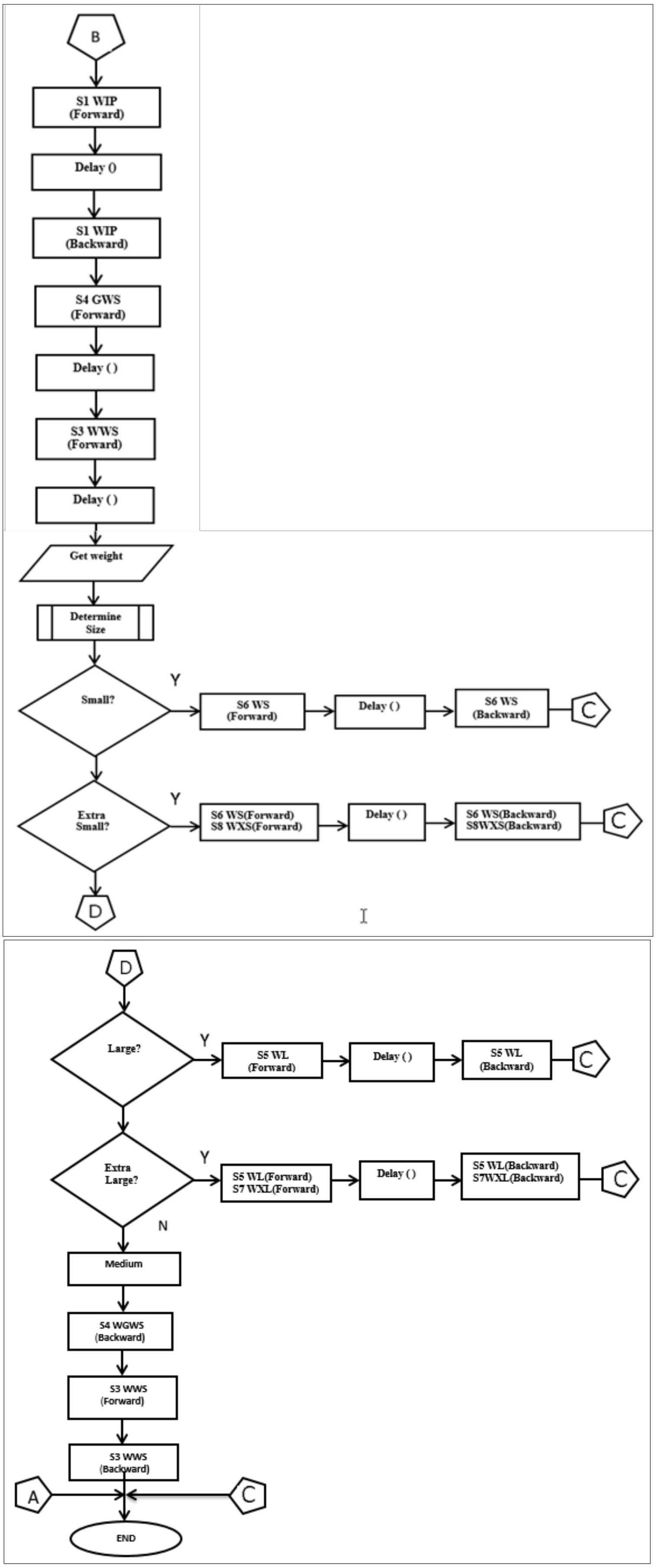
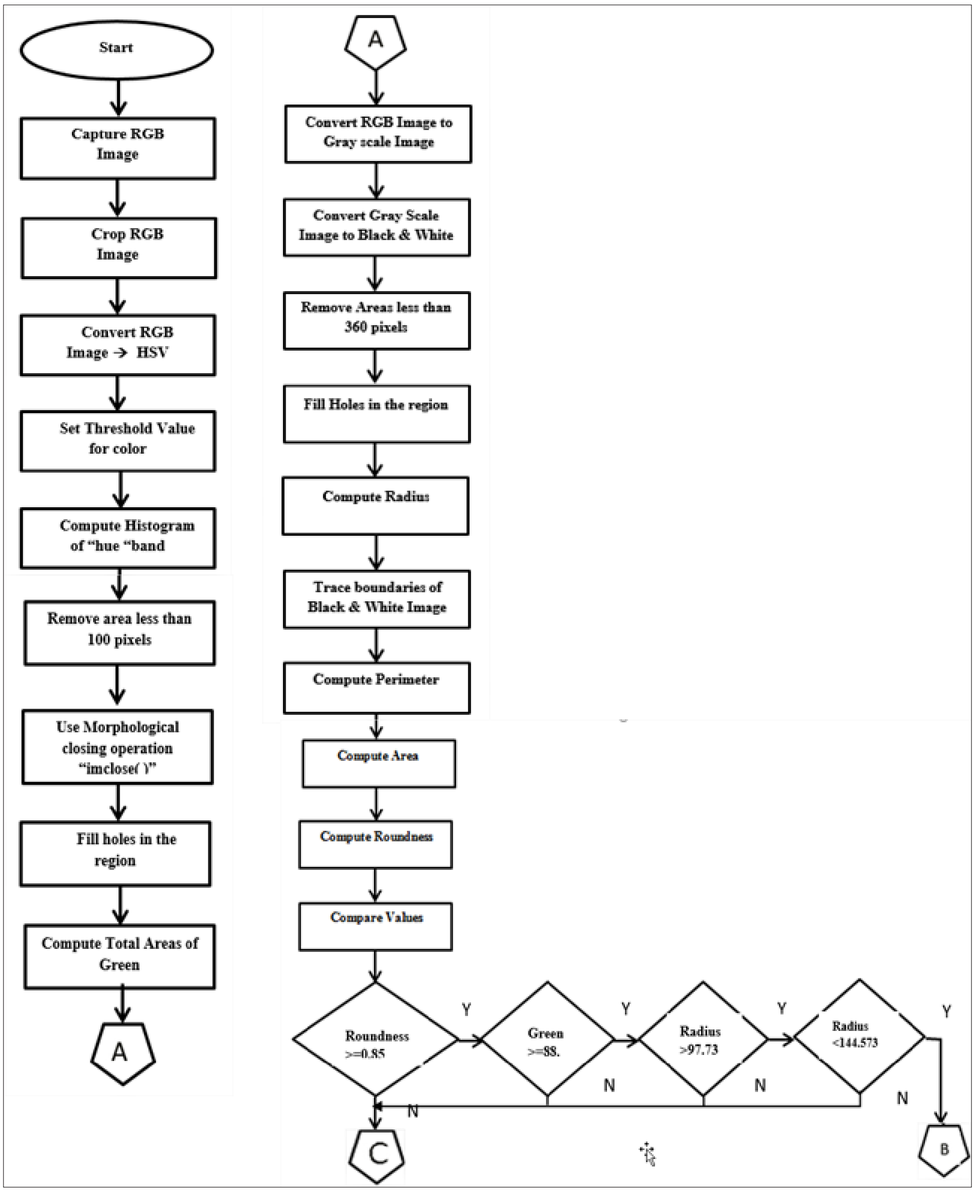


Figure 4: Process Flowchart

If the citrus is found to be faulty during the image processing step, the system will remove these fruits and place them in a specific bin that is designated for defective produce. This segregation guarantees that only the fruits that match the quality criteria are allowed to continue via the distribution channels, while those that do not meet the requirements are eliminated from the process.



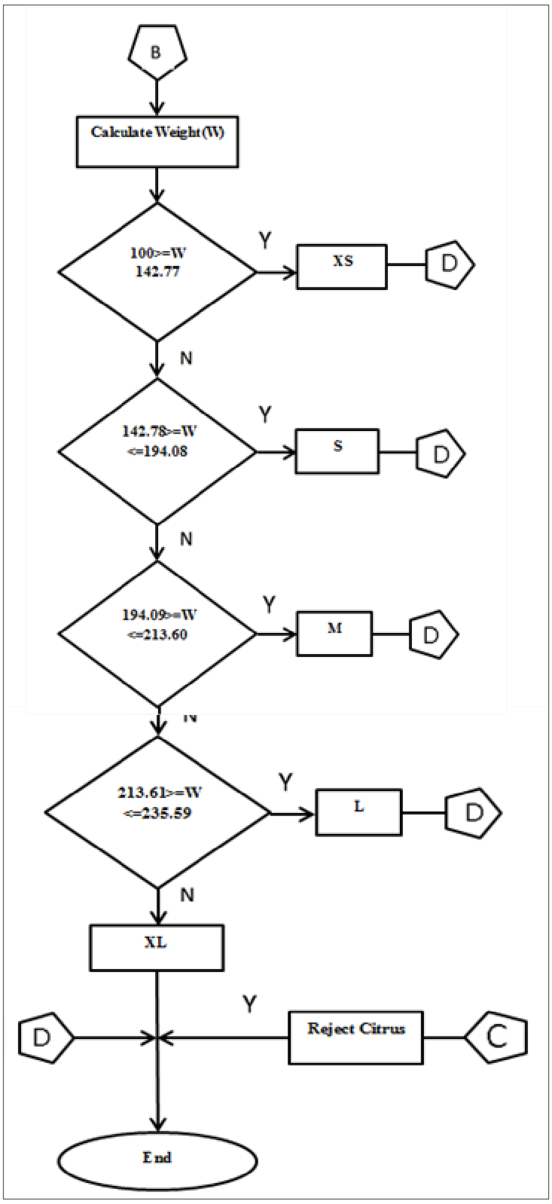


Figure 5: Program Flowchart

Figure 5 of the program flow chart for the citrus classifier system clearly depicts the software's sequence of actions, serving as a detailed reference for programming and debugging. The flow chart begins with the program's startup, which provides the framework for the series of automated tasks.

When fruits are introduced to the system, the software activates the image capture function, in which a camera takes pictures of the citrus fruits on the conveyor belt. Subsequently, these photos underwent meticulous scrutiny. The software uses advanced algorithms to analyze the acquired photos and determine the color, size, shape, and surface imperfections of the fruit. This is the main function of the system's quality control.

Once any faults are identified, the fruit is promptly marked as faulty in the system. Simultaneously, the weight of the fruit is determined using a sensor, and this information is carefully recorded. After the weighing process, the program is responsible for categorizing the fruit based on its size. This is accomplished by establishing a correlation between the measured weight and predetermined size categories, usually spanning from tiny to large. The program formulates the sorting choice. If a fruit is deemed faulty, it is designated as a reject bin. However, fruits that are free from defects are sorted into bins based on their size categorization. The decision-making process is crucial because it guarantees that the system's physical components, such as actuators or servos, receive precise instructions to move fruits to their assigned bins.

The software continuously verifies whether the categorization cycle is finished for all fruits that are now accessible. If there are more fruits that need to be processed, the cycle starts again with the step of capturing images, ensuring that the procedure continues without interruption. After the completion of fruit sorting or upon receiving a termination instruction, the software initiates a shutdown procedure, completing the batch operation and waiting for the next operational cycle or system maintenance.

The flow chart in Figure 5 is a crucial tool that supports the programming logic of the citrus classifier system. Its purpose is to guarantee the sequential execution of each operational function, leading to a synchronized coordination of software orders and hardware operations. Harmony is crucial for achieving efficient and accurate fruit categorization and sorting.

Materials Used

The automated citrus classifier system is built using a diverse range of materials and components, each of which has a crucial function. The Arduino Mega 2560 microcontroller is the central component of the system and functions as its main processor. This microcontroller is capable of controlling the complicated processes required for fruit categorization because of its extensive range of inputs and outputs, which include 54 digital input/output pins, 16 analog inputs, and 4 UARTs for serial connection. The Mega 2560 is equipped with a 16 MHz crystal oscillator for precise timing, a USB connector for computer interaction, and a power port for electrical communication. This device is specifically intended for easy and uncomplicated installation. It may be activated by connecting it to a computer using a USB cable or by using an AC-to-DC converter or battery.

The transportation of citrus fruits is aided by single and double conveyors, which are crucial for moving the fruits to different stations for inspection and sorting. These conveyors are designed to be durable, using fiberglass guiding systems that guarantee seamless and steady movement of the fruits to their intended destinations. These systems are very versatile and may be easily integrated into current manufacturing lines, improving their operational flexibility.

The c615 Logitech HD Webcam is used for the important purpose of capturing images. This camera is specifically designed to capture high-resolution photographs of citrus fruits. These images are then examined to detect any visible flaws or imperfections on the surface of the fruits. Additionally, the camera measures the diameter of each fruit, which is crucial for categorizing them based on their size.

Table 1: Materials for Automated Citrus Classifier Systems

Quantity	Unit	Description
4	pcs.	Single Conveyor
1	pc.	Double Conveyor
8	pcs.	MG995 Servo Motor
1	pc.	Hengfu Power, Supply (12 V-6A)
1	pc.	Arduino ATmega, 2560 Microcontroller
1	pc.	Gizduino Atmega 644
3	pcs.	Motor Driver Shield
1	pc.	Relay Module (5 V DC)
2	pcs.	Fan (12 V)
7	pcs.	Capacitor (10uf)
2	pcs.	Fluorescent Tube
1	pcs.	Logitech C615 HD Webcam
1	pc.	Weight Sensor, HX711 Amplifier
85	pcs.	1 pin male to male connector
342	pcs.	Bolts
496	pcs.	Knots
2	meters	Telephone Wire
63	pcs.	L-Frame (1x1 inches)
8	pcs.	Corner Brace
3/4	inch	Plywood
1/4	inch	Plywood
60x50	inches	Fiber Glass (Clear)
60x50	inches	Fiber Glass (Black)
2	pcs.	Bosy Paint (Black)
1	yard	Flat Cord
1	pc.	Socket
1	pc.	Switch
1	pc.	Personal Computer

Fluorescent tubes play a vital role in providing illumination throughout the picture-capturing process. They are essential for obtaining a clear and well-lit visual image of fruits, which enables accurate image analysis.

The system employs servo motors as its physical sorting mechanism. The motors are responsible for controlling the movement of the wipers, which act as barriers to guide the fruits into the correct containers, depending on the categorization findings.

A DC motor shield is used to regulate the movement of the conveyors. This component is crucial for determining the direction of the DC motors that power both the single and double conveyors. The 12 V DC power supply is responsible for providing power to all the different parts of the system, such as the microcontroller, conveyors, camera, weight sensor, and lights. This guarantees that all components of the system obtain the necessary electricity to operate efficiently.

A weight sensor was used to measure the weight of each citrus fruit. The data from this sensor are input into the system, providing information for the categorization of the fruit based on its size.

Fiberglasses, such as bracing, wipers, and supports for conveyors, are also used for structural purposes. It provides strength and support to the moving components.

The system utilizes one-pin male-to-male connections for internal communication. These connectors are crucial for establishing connections between components such as servo motors and the DC motor shield to the microcontroller, enabling effective communication and control across the system.

The structural integrity of the system is maintained by the use of bolts and nuts, which serve to fasten the fiberglass, servo motors, and other components to the conveyors. Furthermore, the camera and fluorescent tube are affixed to a wooden chamber using these fasteners.

The wooden chamber, made of ¾ plywood, is a crucial component of the picture collecting station. The setup is meticulously crafted to accommodate the camera and lights, ensuring a regulated atmosphere for capturing images.

To improve the clarity of the picture and minimize any reflections that may disrupt the image analysis, the inside of the wooden chamber was covered with a layer of black spray paint. This aids in minimizing glare, guaranteeing that the camera obtains the optimal picture of each fruit.

Finally, the electrical design incorporates electrolytic capacitors with a rating of 10 microfarads. These capacitors serve to stabilize the voltage provided to the system's components, thereby reducing the likelihood of any undesirable voltage fluctuations that may interfere with the functioning of the classifier.

An automated citrus classification system is composed of many materials and components that work together harmoniously to optimize the fruit sorting process. These parts include mechanical, electrical, and computational components.

Results and Discussion

Component Layout

Figure 7 is a schematic illustration that shows the detailed electrical and electronic connections of the citrus sorting mechanism. The blueprint provides a comprehensive plan outlining the researchers' conceptualization of the connections necessary for effective communication between different components of the device, resulting in the desired output.

A personal computer (PC) is essential to the system since it performs intricate picture processing operations. Once the camera collects photographs of the citrus fruits, the PC analyzes these images to ascertain the fruit's dimensions, form, hue, and any imperfections.

The device's control system is primarily composed of two robust microcontrollers: the Arduino Atmega 2560 and the Gizduino Atmega 328. These microcontrollers function as the central processing units responsible for coordinating the device's functions. The robots are designed to control a set of motors and sensors, which consist of five DC motors responsible for operating the conveyor belts and eight servo motors crucial for accurately placing and sorting items.

The system incorporates a relay module that fulfills a distinct purpose: toggling the activation and deactivation of the two fluorescent lights. These lights are essential for ensuring sufficient lighting throughout the picture-capturing process. The system has two fans specifically engineered to disperse heat produced by motor drivers. This design guarantees that the system remains at a safe working temperature, preventing overheating. By doing so, it effectively mitigates the risk of malfunctions or premature degradation of components.

The design incorporates a total of eight electrolytic capacitors to regulate the electrical current and reduce voltage spikes that may interfere with the precise functioning of the servo motors and the weight sensor. These capacitors guarantee seamless operation of the servo motors and precise readings from the weight sensor.

An adapter is used to fulfill the power needs of the system by providing the required voltage to the Arduino Atmega 2560. An alternating current (AC) power supply serves as the main source of energy for the whole system, while the main switch functions as the user's control point to activate or deactivate the system.

The depicted component structure, as shown in Figure 7, guarantees the proper power supply and synchronization of all system components. Researchers intend to create a dependable and effective sorting system by meticulously designing the structure. This system will allow for precise control over the sorting process, starting with the first picture capture and ending with accurate categorization of the fruits.

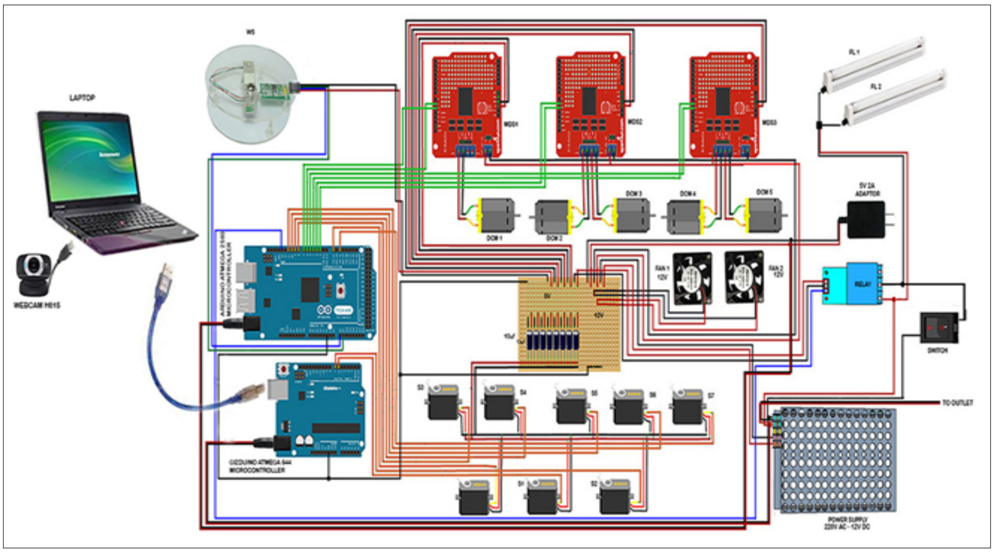


Figure 7: Component Layout

Schematic Wiring Diagram

Figure 8 displays a schematic diagram that shows the complex circuitry of the automated citrus sorting system. This comprehensive graphic delineates the precise electrical connections and the intricate interactions between each individual component inside the system.

The figure illustrates the pivotal functions of the Arduino ATmega 2560 and Gizduino Atmega 328 microcontrollers, which act as the primary command units for the gadget. Their associations with other components imply an intricate network of interactions necessary for accurate regulation and synchronization of the system's functions.

The DC motors, which are essential for the operation of conveyor belts, are shown with their corresponding driving circuits. The drivers are responsible for regulating the speed and direction of the motors, ensuring the controlled and seamless movement of citrus fruits through the system. The conveyor belts are divided into several zones, such as placement, imaging, and sorting, each equipped with a specialized motor for controlling movement.

There are a total of eight servo motors, as shown by the component count, which play a crucial role in the sorting system. These motors are most likely used to manipulate gates or platforms to guide fruits into the correct bins, depending on the classification data.

The relay module is shown for the purpose of toggling the operation of the fluorescent lights. These lights are necessary for the camera to collect high-quality photographs of the fruits, which will be analyzed later.

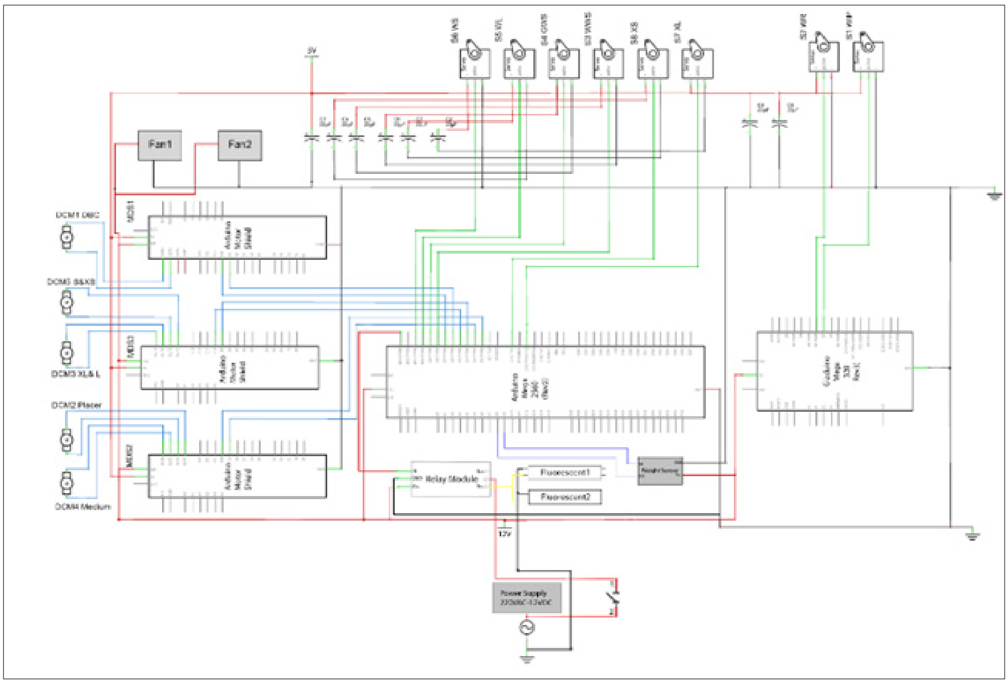


Figure 9: Schematic Diagram

The system incorporates cooling fans to remove the heat produced by motor drivers and other electrical components, therefore guaranteeing that the system functions within acceptable temperature limits.

Capacitors positioned strategically near servo motors and weight sensors play a crucial role in stabilizing voltage and minimizing electrical interference. This is essential for ensuring accurate sensor readings and precise motor control outputs.

The weight sensor is an essential component in the circuit and is connected to the microcontroller to assist in the sorting of fruits depending on their size.

The power supply connections illustrate the distribution of electrical power throughout the system, with the primary power supply supplying power to the whole system and a dedicated adapter delivering power to the microcontrollers.

Finally, the primary switch is shown as the user's central point of control for the whole system, enabling the device to be safely powered on and off.

Figure 8 acts as a technical guide for building the system, providing instructions for constructing the electrical framework to guarantee that all components are energized and connected properly for the best performance of the automated citrus sorting system.

The Designs

System Prototype Design

Figure 7 displays a comprehensive design plan for the automated citrus classification system. The system includes a selection of hardware components, each meticulously designed to perform certain functions within its functioning.

The procedure begins with "Single Conveyor 1," where the citrus fruits are individually deposited and thereafter transferred to a central imaging room. This chamber is constructed with durable ¾ inch plywood, which is coated in black to reduce reflection and provide ideal imaging conditions. The Logitech C615 HD Webcam is ideally positioned to take high-definition photographs of the fruit from different perspectives, which is crucial for precise categorization.

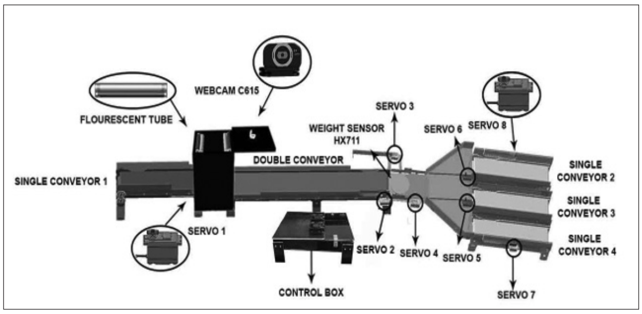


Figure 7: The System Prototype

As the fruits move forward, they come across the "Double Conveyor," which has two purposes: transporting the fruits and providing a platform for the weight sensor, most likely HX711, to measure the mass of the fruits. The information, in conjunction with the picture data, is used to ascertain the quality and size classification of every individual fruit item.

The chamber is illuminated by fluorescent tubes, which are necessary to provide constant illumination that is crucial for accurately capturing images. After the fruit's properties are identified, a series of servo motors (such as Servo 3, Servo 6, and Servo 8) become active. The motors are accountable for the actual sorting and manipulation of gates or diverters, which guarantees that each fruit is sent to its assigned bin along "Single Conveyors 2, 3, and 4."

The control box, containing the Arduino ATmega 2560 microprocessor, which serves as the orchestrator of this complex procedure, is the foundation of this activity. The control box serves as the medium via which instructions are sent, servo motors are engaged, and the sorting mechanism is accurately regulated.

Figure 7 depicts the fundamental nature of the system, illustrating a simplified arrangement created to enhance productivity and precision. Starting from the time a citrus fruit is introduced into the system until it is categorized, every element in the design plays a role in creating an advanced fruit sorting solution.

Table 2: Weight, Diameter, Roundness and Color of Citrus When Grouped According to Size

Sizes	Weight (grams)	Diameter (cm)	Roundness (%)	Color (%)
	122.57	6.066	90.33	94.10
Extra Small (XS)	137.15	6.437	90.28	92.20
	115.242	6.026	90.23	95.33
	161.324	6.892	90.77	93.24
	158.712	6.862	89.90	94.77
	151.04	6.63	90.20	94.57
Small (S)	185.266	7.176	90.04	94.12
	186.114	7.318	90.20	93.46
	175.896	7.1	90.02	94.78
	186.156	7.1696	90.12	95.72
	198.726	7.38	89.64	94.29
Medium (M)	204.658	7.486	89.64	97.25
	242.242	8.142	89.87	95.35
	267.884	8.396	89.69	97.52
	242.242	8.142	89.87	95.35
XL (Extra Large)	267.884	8.396	89.69	97.52
Mean Average	**187.69**	**7.23**	**90.03**	**94.97**

Table 2 compiles the characteristics of the citrus fruits classified by their size, including weight, diameter, roundness, and color %. The 'extra small (XS)' category typically has weights ranging from 122 to 137 grams, with diameters of approximately 6 cm. These balls consistently retain a roundness of more than 90%. The color uniformity remained consistently high, indicating a constant level of ripeness or skin quality within this specific size range. Within the 'small (S)' category, there was a significant increase in both weight and diameter, which suggested the growth stage. Moreover, the roundness and color percentages showed modest differences but remained generally similar to those of the XS fruits.

Fruits of medium size (M) exhibit a progressive increase in both weight and diameter, accompanied by a slight decrease in roundness. This observation may indicate the presence of several fruit forms within this category. The color percentages exhibit variability; however, they remain within a significant range, possibly indicating few disparities in exterior attributes or levels of maturity.

The fruits classified as 'extra large' (XL) display noticeably greater weights and diameters, as anticipated under this classification. Nevertheless, the roundness decreases slightly, perhaps because of the increase in size, which affects the uniformity of the fruit shape. The color percentage remains elevated, indicating that the fruits have a favorable exterior quality despite their size.

The mean values for weight, diameter, roundness, and color across all categories were 187.69 grams, 7.23 cm, 90.03%, and 94.97%, respectively. These values suggest that the citrus fruits being assessed exhibit a high level of quality and consistency. The consistent maintenance of roundness and color percentages over 90% indicates that the fruits possess a regular shape and look, which is essential for attracting consumers and meeting market criteria.

The results have substantial ramifications for the citrus sector. The research demonstrated that citrus fruits may be categorized into several groups based on recognizable traits, which helps simplify packaging and marketing methods. Uniformity in size and appearance may foster consumer confidence and contentment, as patrons can choose fruits based on their desired dimensions with the assurance that they will obtain a product that fulfills their standards of quality and visual appeal.

Growers and distributors may enhance the efficiency of their supply chain by accurately categorizing and forecasting the characteristics of their citrus fruits, which can be beneficial for various stages, such as harvesting, storage, and shipping. These data may be used to forecast the duration for which a product can be stored on a shelf, establish effective pricing tactics, and identify the most suitable markets to target. Ultimately, it aids in enhancing inventory management and minimizing waste. The color and roundness percentages show that the processes used for cultivating, harvesting, and handling the citrus fruits are efficient. This is crucial for maintaining the reputation and competitiveness of the citrus business.

Table 3: Comparative Analysis of Manual vs. Automated Citrus Fruit Weight Classification

Classification	Mean	SD	t computed	t tabulated
Manual	183.57	39.73	0.35	2.05
Automated	178.07	42.60		

Table 3 presents a statistical comparison between manual and automated citrus classification methods based on the weight of the fruit. The mean weight recorded for manual classification was 183.57 grams, while the automated system recorded a mean weight slightly lower at 178.07 grams. The closeness of these mean values indicates that both systems tend to classify the weight of citrus fruits with comparable accuracy.

The standard deviation, a measure of variability or spread in the data, is 39.73 grams for the manual method and slightly greater at 42.60 grams for the automated system. This suggests that the automated system has a slightly wider range of weight measurements, which may point to a marginally less consistent classification than the manual method. However, the difference is subtle and may not be significant in practical terms.

The key statistical metric here is the t-computed (t computed) value of 0.35, which is compared against the t-table (t tabulated) value of 2.05. Since the computed t value is much lower than the critical value obtained from the t-distribution table, there is no statistically significant difference in the weight classification accuracy between the two methods. In essence, any differences in the mean weights are likely due to random variation rather than a systematic error or inconsistency in the automated system.

From a practical standpoint, these findings imply that the automated classification system can match the performance of manual classification in terms of accuracy. The slightly greater variation in weight measurements with the automated system could be addressed through calibration and refinement of the system. Nevertheless, the absence of a significant difference between the two methods suggests that the automated system could be a viable replacement for the manual system, potentially offering the benefits of higher efficiency, lower labor costs, and the ability to operate continuously without fatigue. This finding positions the automated system as a promising tool for the citrus industry, with the potential to streamline operations while maintaining a high standard of quality control.

Table 4: Comparison of Manual and Automated Citrus Fruit Diameter Classification Results

Classification	Mean	SD	t computed	t tabulated
Manual	7.08	0.65	0.011	2.055
Automated	7.077	0.68		

Table 4 provides a brief summary of the test findings that evaluate the disparities in categorizing citrus fruit diameter using both human and automated techniques. The manual categorization revealed a mean diameter of 7.08 cm with a standard deviation (SD) of 0.65 cm, showing a considerable level of variation in the measurements from the mean. The automatic categorization nearly corresponded to this, with an average diameter of 7.077 cm and somewhat greater variability, as shown by a standard deviation of 0.68 cm. The t test comparison of these approaches results in a calculated t value of 0.011, which is much less than the tabulated critical t value of 2.055.

The substantial discrepancy observed between the calculated t value and the crucial t value indicates that the variations in diameter measurements between the human and automated classifications do not have statistical significance. To clarify, any inconsistencies noticed are most likely a result of random occurrences rather than inherent prejudices or mistakes in the automated system. This suggests that the automated categorization approach is almost as accurate as manual measurements, confirming the ability of automation technology to reproduce human precision in diameter evaluation.

The results have several ramifications. First, using an automated system has the potential to enhance operational efficiency by decreasing the time and personnel expenses involved in human categorization while maintaining a high level of accuracy. The somewhat higher standard deviation seen in the automated technique suggests that some calibration or tweaks may be necessary to achieve a level of consistency that is equal to or beyond that of human methods.

In addition, using an automatic categorization system will enable uninterrupted, 24/7 operation, removing the inconsistencies caused by human weariness, an unavoidable aspect of manual procedures. This approach might be especially beneficial during peak harvest seasons when it is crucial to maintain a constant standard of quality and size.

To summarize, the information shown in Table 4 provides evidence in favor of using automated categorization systems in citrus production. These systems have the ability to replace human approaches, leading to improved efficiency and reliable quality control.

Conclusion

Ultimately, the objective of this project was to create and assess a mechanized system for categorizing and organizing citrus fruits. The system was designed with Arduino microcontrollers and image processing software to evaluate crucial fruit characteristics such as color, circularity, weight, and dimensions. The technique aimed to enhance the efficiency and uniformity of fruit selection by classifying fruits into specific categories, such as extra small, small, medium, large, and extra-large, to simplify the sorting process.

The results suggest that the automated system can be used to categorize citrus fruits effectively according to the required criteria. The average results for weight, diameter, roundness, and color % in various size categories exhibited a significant level of uniformity, indicating that the system can consistently differentiate between fruit sizes and maintain a quality standard.

This statistical study, which compared human and automatic categorization techniques, provided more evidence of the system's effectiveness. The mean values acquired manually and by automation did not show any significant variations, indicating that the automated method may achieve the same level of accuracy as human classifiers while also providing the advantages of speed and impartiality.

These findings have significant and extensive effects on the citrus sector. Producers and distributors may enhance their efficiency in fruit handling and processing by using automated classification and sorting systems. These outcomes may result in financial savings, decreased workforce needs, and improved uniformity of products, all of which are crucial elements for sustaining competitiveness in the market.

Furthermore, the system's capacity to categorize fruits using various criteria concurrently might provide useful information for inventory management and quality control. Utilizing data to guide decision-making may have a positive impact on several aspects of the citrus sector, such as determining when to harvest and developing effective marketing strategies. This eventually leads to a more sustainable and financially successful citrus industry.

Overall, this research effectively accomplished its goal of creating and evaluating an automated system for classifying and sorting citrus fruits. The method exhibited favorable outcomes in terms of precision and uniformity, providing a feasible resolution for improving the effectiveness and excellence of fruit processing in the citrus sector [6-16].

List of Abbreviations
Not applicable

Declarations
Availability of Data and Material: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. The image processing algorithms and code used in this study are available in the supplementary materials.

Competing Interests: The authors declare that they have no competing interests.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' Contributions
Alan Nebrida and Michael Aliaga conceived and designed the study, developed the image processing algorithms, conducted the experiments, and wrote the manuscript. Rogie Mar Guiloy and Roxanne Mae Valera contributed to the development of the weight sensing system and data collection. Alan Nebrida assisted in the statistical analysis and interpretation of data. All authors read and approved the final manuscript.

Acknowledgements
The authors would like to express their sincere gratitude to their colleagues for their support and valuable insights throughout the research process. Special thanks are also extended to our families and friends for their encouragement and understanding during the course of this study.

References
1. Changyong Li, Qixin Cao, Feng Guo (2009) A method for color classification of fruits based on machine vision. WTOS 8: 312-321.
2. Rasekhi, R, Raoufat MH (2015) Design, development and evaluation of an orange sorter based on machine vision and artificial neural network techniques. Iran Agricultural Research 32: 21-38.
3. Hannan MW, Burks TF, Bulanon DM (2009) A machine vision algorithm combining adaptive segmentation and shape analysis for orange fruit detection. Agricultural Engineering International: the CIGR Ejournal 11.
4. Cavaco MA, Passos D, Pires M, Antunes M, Guerra R (2021) Nondestructive assessment of citrus fruit quality and ripening by visible–near infrared reflectance spectroscopy. IntechOpen.
5. Bulanon DM, Kataoka T (2010) Fruit detection system and an end effector for robotic harvesting of Fuji apples. Agric Eng Int: CIGR Journal 12: 203-210.
6. Ashok V, DS V (2016) A comparative study of feature extraction methods in defect classification of mangoes using neural network. 2016 Second International Conference on Cognitive Computing and Information Processing (CCIP) 1-6.
7. Bhole V, Kumar A, Bhatnagar D (2020) A texture-based analysis and classification of fruits using digital and thermal images. ICT Analysis and Applications. Lecture Notes in Networks and Systems 93.
8. Karakaya D, Ulucan O, Turkan M (2019) A Comparative Analysis on Fruit Freshness Classification. Innovations in Intelligent Systems and Applications Conference (ASYU), Izmir, Turkey 1-4.
9. Deepa PV, Geethalakshmi DS (2013) A comparative analysis of feature extraction methods for fruit grading classifications. Department of Computer Science, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore-641402, Tamil Nadu, India.
10. Fu Y, Nguyen M, Yan WQ (2022) Grading methods for fruit freshness based on deep learning. SN COMPUT SCI 3: 264.
11. Kim D, Burks TF, Ritenour MA, Qin JW (2014) Citrus black spot detection using hyperspectral imaging. International Journal of Agricultural & Biological Engineering 7: 20-27.
12. Abdullah MZ, Mohamad-Saleh J, Fathinul-Syahir AS, Mohd-Azemi BMN (2006) Discrimination and classification of fresh-cut starfruits (Averrhoa carambola L.) using automated machine vision system. Journal of Food Engineering 76: 506-523.
13. Nebrida AP, Amador CD, Madiam CM, Ranche GJ (2023) Development of Smart Meter to Monitor Real Time Energy Consumption for Sustainability. International Journal of Sustainable Construction Engineering and Technology 14: 28-39.
14. Sumaira Ghazal, Waqar S Qureshi, Umar S Khan, Javaid Iqbal, Nasir Rashid, et al. (2021) Analysis of visual features and classifiers for Fruit classification problem, Computers and Electronics in Agriculture 187: 106267.
15. Tho TP, Thinh NT, Bich NH (2016) Design and development of the vision sorting system. 3rd International Conference on Green Technology and Sustainable Development (GTSD), Kaohsiung, Taiwan 217-223.
16. Zeeshan S, Tauseef A, Fahid R (2023) The Design and Evaluation of an Orange-Fruit Detection Model in a Dynamic Environment Using a Convolutional Neural Network. Sustainability 15: 4329.