Prototype of Tomato Fruit Sorting Based on Color Based on Esp32-Cam with Fuzzy Logic Method

Rizka Nur Fitasari, Denny Irawan
Electrical Engineering Study Program, Faculty of Engineering, Muhammadiyah University of Gresik, Indonesia
E-mail:rizkafitasari02@gmail.com, den2mas@umg.ac.id

***Abstract*— The demand for fruits, especially tomatoes, continues to increase due to their widespread use in cooking, sauces, and juices. Before distribution, tomatoes must be sorted by weight, size, and color. The current sorting process is still done manually, making it less efficient and accurate. To overcome this, this study developed a prototype of an automatic sorting system using ESP32-CAM, HCSR04 distance sensor, and TCS34725 color sensor with fuzzy logic method. The HCSR04 sensor showed an average distance measurement error of 1.8%, indicating high accuracy in measuring tomato size. Color analysis with the TCS34725 sensor revealed different RGB value dominance patterns according to the ripeness of the tomatoes: green tomatoes are dominated by green values (G), yellow tomatoes are dominated by red values (R) that are close to green values, and ripe tomatoes have the most dominant red values compared to green and blue (B). With the application of fuzzy logic, the system is able to classify tomatoes into three categories: good, medium, and bad. Out of 12 trials, the system successfully classified correctly 11 times, resulting in an accuracy of 91.67% and an error rate of 8.33%. These results indicate that the fuzzy logic-based sorting system is effective in recognizing and classifying tomatoes based on color and size, although there is still room for further improvement to improve accuracy and reliability.**

***Key words*— Tomato sorting,fuzzy logic, TCS34725 color sensor, ESPCAM-32**

I. INTRODUCTION

Science and technology in the current era are increasingly developing, making the quality of human life increasingly developing and triggering people to look for alternatives. Especially when working, errors or mistakes often occur in work by several internal and external factors. [1]. In the Journal of Information Technology Development and Computer Science Internet Working Indonesia Vol.1/No.3 by Muhammad Fauzin Amin, Sabriansyah Rizqika Akbar, and Edita Rosana Widasari entitled Design and Construction of Apple Sorting System Using Color Sensor and Temperature Sensor. In this study which discusses the agricultural and plantation processing industry is also growing rapidly, one of the stages in the agricultural and plantation processing process is the selection of products based on their quality, for example at the level of fruit ripeness. [2]. The process of selecting agricultural and plantation products generally depends heavily on human perception of the color composition factor of the fruit. Some examples of agricultural and plantation products whose ripeness is determined by color are tomatoes. According to Ery Muchyar, Asniati and Wiwin in a journal entitled Automatic Control System for Sorting Tomatoes Using the Atmega 2560 Microcontroller [3]. Tomatoes are one of Indonesia's agricultural commodities, tomatoes have become a staple food requirement. Tomatoes are one type of cultivated garden fruit (Holticulture), with the characteristics of growth and development having distinctive color characteristics. To increase the economic value of tomatoes, sorting needs to be done based on physical characteristics. To overcome this, the author uses ordinary tomatoes or vegeTable tomatoes as objects, because this type of tomato is easy to find in local markets and the TCS34725 type color sensor because this sensor has high sensitivity, has a wide range and has infrared blocking which functions as a filter, so whatever the light conditions around the object, this sensor can still detect the color of the object well. This TCS 34725 sensor can detect the RGB color of an object. Can be connected to a microcontroller or ESP32-CAM. Therefore, a Tomato Fruit Sorting Prototype Based on Color Using the TCS35725 Color Sensor Based on ESP32-CAM was made with the fuzzy logic method which can increase the effectiveness and efficiency in the tomato sorting process.

II. MATERIALS AND METHODS

In this study, there are several main components of the tomato fruit system based on color based on esp32-cam with the fuzzy logic method in this study. Figure 1 is a block diagram in this study.

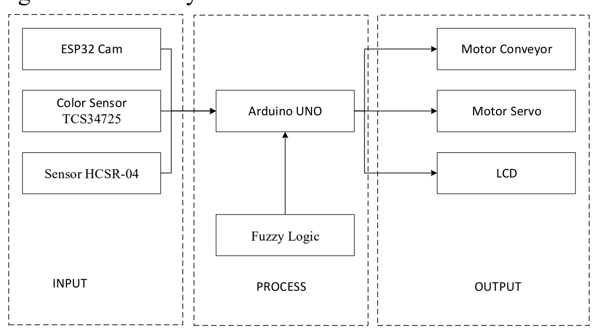

Figure 1. System Block Diagram

A. Arduino Uno

In this study, the main controller is Arduino UNO, Arduino Uno is a microcontroller board based on ATmega328 (datasheet). It has 14 digital input and output pins, of which 6 input pins can be used as pulse width modulation (PWM) output and 6 analog input pins, 16 MHz crystal oscillator, USB connection, power jack, ICSP header, and reset button. To support the microcontroller to be used, simply connect the Arduino Uno board to a computer using a USB cable or electricity with an AC-to-DC adapter or battery to run it [4] [5]. Each of the 14 digital pins on the Arduino Uno can be used as an input or output, using the pinMode(), digitalwrite(), and digitalRead() functions. These functions operate at 5 volts, each pin can provide or receive a maximum current of 40 mA and has a pull-up resistor (disconnected by default) of 20-50 kOhm. Figure 2 is the Arduino microcontroller used in this study.

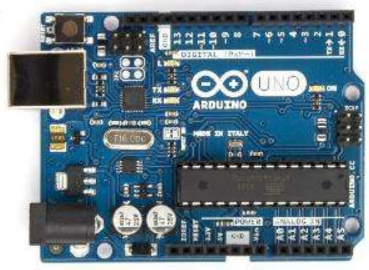

Figure 2. Arduino UNO

B. ESP32 CAM

In this study to detect the presence of objects using ESP32 CAM, ESP32-CAM is one of the microcontrollers equipped with an internal 2MP camera, microSD card and equipment to use an external antenna. The ESP32-CAM module is also equipped with library support to implement Image Processing capabilities. All of these features still have access to several GPIO pins, WiFi and Bluetooth capabilities. When compared to the previous ESP product, namely the ESP32 Wroom, the ESP32-CAM has less I / O with only access to 10 GPIO pins. This is because many pins are used internally for camera functions and microSD card slot functions [6]. Figure 3 is the ESP32CAM used in this study.

Figure 3. ESP32CAM

C. TCS34725 Color Sensor

To detect the color of tomatoes running on the conveyor, researchers used the TCS34725 Color sensor. This sensor can detect the RGB color of an object. It can be connected to a Microcontroller or to an Arduino using I2C. This sensor has high sensitivity, has a wide range and has Infra-Red Blocking which functions as a filter, so that even though the light conditions around the object, this sensor can still detect the color of the object well [7] [8]. Figure 4 is the TCS34725 Color sensor used in this study.

Figure 4. TCS34725 Color Sensor

D. Fuzzy Logic

Fuzzy logic is a precise way to map an input space into an output space. For very complex systems, the use of fuzzy logic is one solution. Traditional systems are designed to control a single output derived from several unrelated inputs. Because of this independence, the addition of new inputs will complicate the control process and require a recalculation process of all functions. In contrast, the addition of new inputs to a fuzzy system, a system that works based on the principles of fuzzy logic, only requires the addition of new membership functions and rules related to them. In general, fuzzy systems are very suiTable for approximation reasoning, especially for systems that deal with problems that are difficult to define using mathematical models. For example, the input values and parameters of a system are less accurate or less clear, making it difficult to define its mathematical model. [9] [10] [11].Fuzzy systems have several advantages when compared to traditional systems, for example in the number of rules used. The initial processing of a large number of values into a membership degree value in a fuzzy system reduces the number of values into a membership degree value in a fuzzy system reduces the number of values that must be used by the controller to make a decision. Another advantage is that fuzzy systems have reasoning capabilities that are similar to human reasoning capabilities. This is because fuzzy systems have the ability to provide responses based on qualitative, inaccurate, and ambiguous information. There are several reasons for using Fuzzy Logic

1. Fuzzy logic is very flexible.
2. Fuzzy logic has tolerance.
3. The concept of fuzzy logic is easy to understand. The mathematical concepts underlying fuzzy reasoning are very simple and easy to understand.
4. Fuzzy logic is capable of modeling very complex non-linear functions.
5. Fuzzy logic can build and apply the experiences of experts directly without having to go through a training process.
6. Fuzzy logic can work together with conventional control techniques.
7. Fuzzy logic is based on natural language

In general, there are 5 steps in the fuzzy system in carrying out reasoning, namely: [12] [13] [14] [15]:

1. Entering fuzzy input.
2. Applying the fuzzy operator.
3. Applying the implication method.

4. Composition of all outputs.
5. Defuzzification.

III. Results and Discussion

Figure 5 below is a system flow diagram in this study:

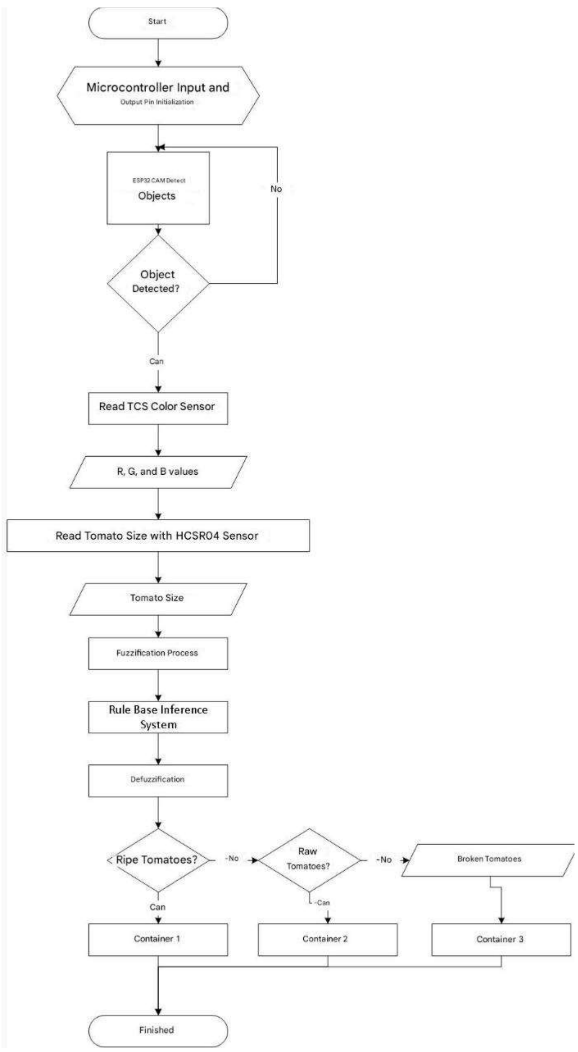

Figure 5. System Flowchart

This tomato sorting system uses ESP32-CAM as the main sensor to detect the presence of tomatoes in real-time, equipped with TCS34725 color sensor and ultrasonic size sensor to measure the color and dimensions of the fruit. The data obtained from these sensors is then processed using fuzzy logic methods, which convert numerical values into fuzzy membership degrees and apply inference rules to classify tomatoes into ripe, underripe, or rotten categories. This process allows the system to accommodate the natural variation in color and size of tomatoes, making the classification more adaptive and accurate. After classification, the system controls actuators such as servo motors and conveyors to automatically direct the tomatoes to the appropriate sorting bins, increasing efficiency and reducing errors that are common in manual sorting. The integration of ESP32-CAM provides advantages in visual analysis compared to ultrasonic sensors, allowing for more detailed recognition of tomato color and shape. This system also opens up opportunities for the development of additional features such as fruit defect detection. Overall, the system flow chart illustrates a well-integrated tomato sorting process, utilizing modern sensor technology and fuzzy logic to produce accurate classification and efficient automatic sorting process. This system is suiTable for application on an industrial scale or small and medium enterprises to improve the quality and productivity of tomato harvests. Figure 6 is a tomato sorting tool in this study.

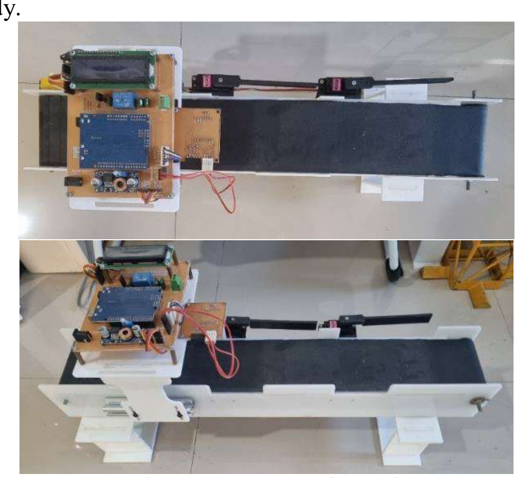

Figure 5. Prototype Sorting Tool

A. *Fuzzy Logic Design*

The following is the fuzzy system used in this study:

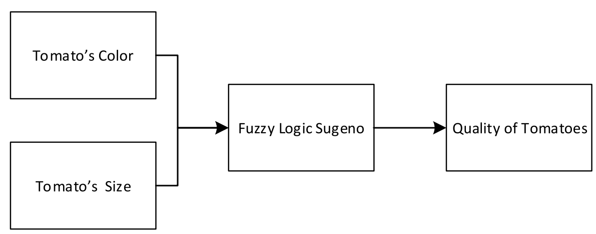

Figure 6. Fuzzy System

Table 1. Fuzzy Set

Function	Variable Name	Set	In Conversation	Domain
INPUT	Color	Green	[0-90]	[0 0 45]
		Yellow		[0 45 90]
		Red		[45 90 90]
	Size	Small	[0-130]	[0 0 65]
		Currently		[0 65 130]
		Big		[80 105 130]
OUTPUT	Quality	Bad	[0-10]	[0 0 5]
		Currently		[0 5 10]
		Good		[5 10 10]

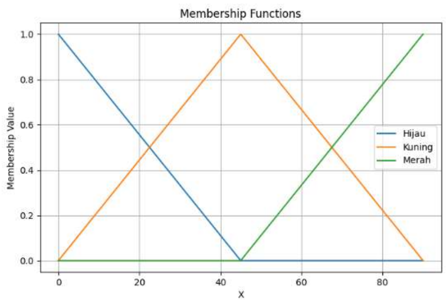

Figure 7. Membership Function Color

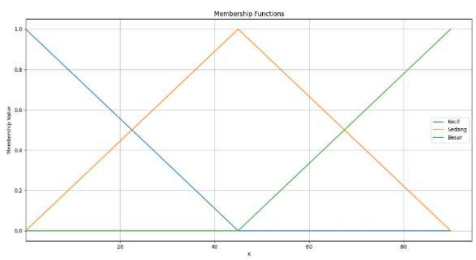

Figure 8. Membership Function Size

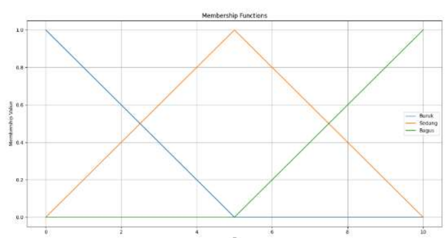

Figure 9. Membership Function Output

Fuzzy set Table is a fuzzy set Table for each variable. Input variables consist of 2, namely, color variables and size variables. The color variable has 3 sets, namely, the green set with domain [0 0 45], the yellow set with domain [0 45 90] and the red set with domain [45 90 90]. For the size variable also has 3 sets, namely, the small set with domain [0 0 65], the medium set with domain [0 65 130] and the large set with domain [80 105 130]. While the output variables consist of the bad set with domain [0 0 5], the medium set with domain [0 5 10] and the good set with domain [5 10 10]. And for the fuzzy rules used in this study are as follows:

Table 2. Rules base

NO	Rule	Decision
R1	If the color is Green and the size is Small	Bad
R2	If the color is Green and the size is Medium	Bad
R3	If the color is Green and the size is Large	Bad
R4	If the color is Yellow and the size is Small	Bad
R5	If the color is Yellow and the size is Medium	Currently
R6	If the color is Yellow and the size is Big	Currently
R7	If the color is Red and the size is Small	Currently
R8	If the color is Red and the size is Medium	Good
R9	If the color is Red and the size is Big	Good

B. Distance Sensor Calibration Results

To obtain accurate results, validation tests were carried out on each sensor, such as the HCSR-04 sensor used to determine the size of the tomatoes. In this test, six measurements of the object's distance were carried out using the HCSR04 sensor, then the results of the sensor readings were compared with the actual distance measured manually using a ruler. Each measurement produces a distance value from the sensor and the actual distance, and the percentage error is calculated as a measure of the sensor's accuracy in measuring distance. From the six-measurement data, it can be seen that the percentage error value varies at each measurement point, but overall, it remains in the low range. The average error obtained is around 1.8%, which shows that the HCSR04 sensor is able to provide measurement results that are very close to the actual value. In the context of distance measurement, an error of 1.8% means that if the actual distance is 100 cm, then the sensor only misses about 1.8 cm, which is a fairly small margin of error and is accepTable for tomato sorting applications.

Table 3. Distance Testing

NO	Sensor Reading Response	Object and Sensor Distance	Error
1	7.1	7	1.4%
2	6.3	6	5%
3	5.1	5	2%
4	4.1	4	2.5%
5	3	3	0%
6	2	2	0%
Average Error			1.8%

C. Distance Sensor Calibration Results

TCS34725 sensor data collection is carried out to obtain the required RGB values. The data required is the RGB (Red, Green, Blue) value with a range of 0 to 255. The data will then be converted into CMY (Cyan, Magenta, Yellow) form with a range of 0 to 100% so that it can be fed back to the system to be processed again by the microcontroller. The process of reading this sensor undergoes calculation or recalibration so that the RGB values read can be more precise. After automatically obtaining RGB values from the sensor, these values will be converted into CMY form using a mathematical formula, namely: [16]

$$Red = \frac{\text{Red Intensity} * 100}{255} \quad (1)$$

$$Green = \frac{\text{Green Intensity} * 100}{255} \quad (2)$$

$$Blue = \frac{\text{Blue Intensity} * 100}{255} \quad (3)$$

$$Cyan = 100 - \frac{Red \text{ Intensity} * 100}{255} \quad (4)$$

$$Magenta = 100 - \frac{Green \text{ Intensity} * 100}{255} \quad (5)$$

$$Yello = 100 - \frac{Blue \text{ Intensity} * 100}{255} \quad (6)$$

D. Fuzzy Testing and Systems

The following test aims to determine the response of the sorting system as a whole, the following is a trial of the sorting test.

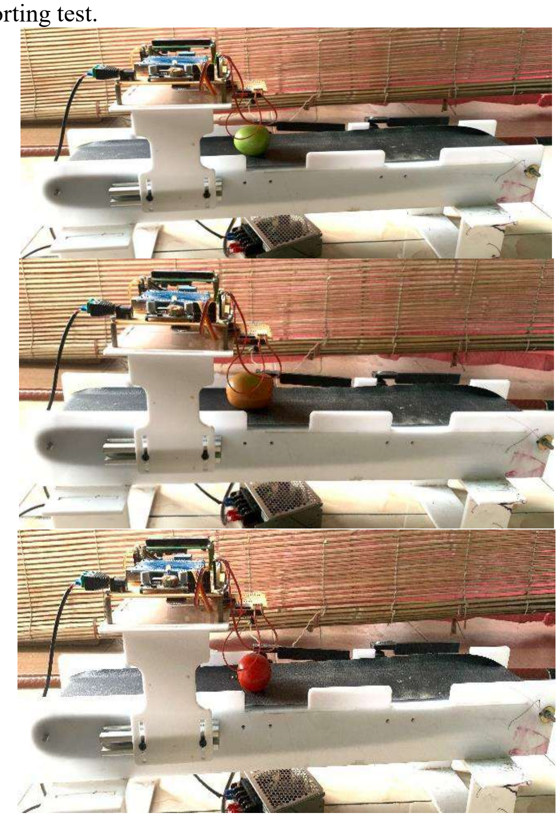

Figure 10. Sorting System Testing

Table 4. Fuzzy Testing and Systems

NO	Conditions Tomatoes Should Have	Color	Tomato Size	Fuzzy Classification Results
1	Good	Red	4.3	Good
2		Red	7	Good
3		Red	5	Good
4		Red	8	Good
5	Currently	Yellow	5	Currently
6		Yellow	7	Currently
7		Red	3	Currently
8		Yellow	4.3	Currently
9	Bad	Green	7	Bad
10		Green	4.3	Bad
11		Green	5	Bad
12		Yellow	4	Good

Based on the results of the experiments you conducted in the tomato sorting prototype research using the fuzzy logic method, data was obtained from 12 trials with various different tomato conditions, ranging from red, yellow, to green, and varying sizes. From all the trials, the system managed to classify correctly 11 times, while there was one reading error in the 12th trial. This error occurred when a yellow tomato with a size of 4 was classified as "Good", whereas in general yellow tomatoes usually indicate an underripe condition or are in the process of ripening, so the classification was incorrect.

When calculated in terms of accuracy, the system has a success rate of 11/12 x 100% = 91.67%. This means that out of 12 trials, about 91.67% of the classifications made by the system are correct and in accordance with the real conditions of the tomatoes. On the other hand, the error rate is about 8.33%, which comes from one misclassification. This accuracy figure shows that the fuzzy logic-based sorting system you developed is quite effective in recognizing and classifying tomatoes based on color and size, although there is still room for improvement.

IV. Conclusion

The test results show that the HCSR04 distance sensor has an average error of 1.8%, indicating good accuracy in measuring distance. For the TCS34725 color sensor, different RGB value patterns were found according to the color of the tomatoes: green tomatoes have the most dominant green (G) value compared to red (R) and blue (B); yellow tomatoes show the most dominant red (R) value with a green (G) value that is close, while the blue (B) value is very small; and ripe tomatoes have the most dominant red (R) value compared to green and blue. By using the fuzzy logic method, the system is able to classify the condition of tomatoes into three categories, namely good, medium, and bad. Out of 12 trials, the system managed to classify correctly 11 times, resulting in an accuracy of 91.67%. On the other hand, there was one misclassification so that the error rate reached 8.33%. This accuracy figure shows that the developed fuzzy logic-based sorting system is quite effective in recognizing and classifying tomatoes based on color and size. However, there is still room for improvement to increase the reliability and accuracy of the system in the future.

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