Implementation of Fuzzy Logic Algorithm on Robot Arm Sorting Goods Based on Weight and Color Using the Mamdani Method

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Abstract. The development of goods sorting technology has used automatic control systems and robotic that work more effectively and save energy. Therefore, this research aimed to design a robot arm for sorting goods based on weight and color by implementing a fuzzy logic algorithm with the Mamdani method to simplify human work. The robot arm uses the MG995 servo, while weight and color use the Load Cell and TCS3200 sensors. The results showed that the Load Cell sensor calibration has the lowest and highest accuracy of 97.64% and 100%, respectively. The TCS3200 had the smallest and largest standard error of 0.163 and 2.468, which indicated that both sensors had good accuracy. Decision-making using the fuzzy logic algorithm Mamdani method was successfully implemented with 100% accuracy. Therefore, the robot arm can move goods in the box based on the fuzzy decision quality output.

Keywords: *Arm robot, Fuzzy Mamdani, Calibration, sorting*

1 Introduction

The development of goods sorting technology has used control systems and robotic that work automatically. Investigations showed that robotic can make work more effective and save energy for improved quality of goods or packaging, maintenance, and safety. This technology is very important to be developed in sorting goods to increase productivity and save the cost of work compared to manual human labor.

Previous research on weight-based product sorting [1] has been carried out using robot arm technology. During the process, the weight of the goods to be sorted was initially determined and subsequently moved to their places with robots. The problem that is usually encountered using the method is when the weight of the goods is not determined. Therefore, in its development, a correct algorithm is needed to solve the sorting problem. Investigations on sorting goods based on color were conducted using the TCS3200 sensor as a color detector for objects [2]. Apples have also been successfully sorted using fuzzy logic in solving color and weight sorting problems [3].

ICSEDTI 2022, October 11-13, Tanjungpinang, Indonesia

DOI 10.4108/eai.11-10-2022.2326279

This research aims to develop an implementation of robot arm technology that can classify types of goods based on the quality with the input variables based on the weight and color using the fuzzy logic algorithm Mamdani method. Goods automatically arrive at the point of measuring weight using a conveyor. The weight was measured using a Load Cell sensor and the TCS3200 was used for color detection. Subsequently, the robot arm was used to lift the item and place each good in a box based on the output quality such as weight and color.

2 Relate Work

Previous research entitled “Design and Implementation of a Fuzzy Logic-based Joint Controller on a 6-DOF Robot Arm with Machine Vision Feedback”. This study discusses the design, simulation, and implementation of fuzzy logic (FLJC) for the control of a 6 DOF (Degrees of Freedom) robotic arm (4 DOF for the arm and 2-DOF for the gripper), which can move objects from one place to a specified position. The system design uses Arduino Uno as a microcontroller, Servo M100RAK as a robot driver, and MPU6050 sensor as a gyroscope and accelerometer to determine the degree of the robot arm. The implementation of fuzzy logic is successful, and this research shows that using fuzzy logic algorithms can refine and flexibly robotic leg movements. Furthermore, the comparison data between Inverse Kinematic and

Fuzzy against the ideal value proves that fuzzy is closer to the ideal [4]. Previous research entitled "Design of Sorting Goods Based on Weight with Microcontroller-Based Pick and Place System". This study discusses the sorting process. This research has used conveyors to move automatically to the weight measurement point. This arm robot uses an Arduino Uno microcontroller, Load Cell sensor for weight detection, Servo MG995 as a robot mover, an Infrared sensor for detecting goods, and a DC motor as a conveyor drive. This study explains that the sensor has a small measurement error of 2.7%. This study says that using a robotic arm can make work in the industrial sector easier because it can work automatically [1].

Previous research entitled "Computer Vision-Based Object Grasping 6DoF Robotic Arm Using Pi camera Vishal". This study discusses how the image recording process uses a Pi camera sensor, data processing, and robot movement. The robot is intended to perform the multifunctional task of detecting objects, identifying colours, and placing objects in their place. The robot arm with 6 DOF works starting from the Pi camera sensor detecting and identifying colours then processed using a raspberry pi microprocessor to be the object's centre point then sending a signal to the Arduino Mega 2560. The Arduino Mega 2560 microcontroller regulates the MG996R Servo as the robot arm from lifting, carrying, and putting the object in the appropriate place with the object that has been determined [5].

A previous study entitled "Design of a Robotic Arm Sorting Goods Based on Weight Using the Internet of Things (IoT) as Remote Control and Monitoring". This study discusses how a robotic arm can sort items by weight remotely. It uses a weight meter Load Cell sensor and an ESP32 Cam to record images. Arduino Uno as a data processor from the sensor is connected to the ESP8266, which is connected to the internet than through the Blynk platform on the cell phone, it can control the robot's motion using a slider widget and monitor the movement of the robot through the video streaming widget on the platform. This tool can see and control the robot's movement remotely [6].

A previous study entitled "Implementation of the Fuzzy Logic Controller Method in Controlling the Position of the Robot Arm 1 DOF". This study discusses how to apply fuzzy logic to the 1 DOF arm robot, namely determining the degree of membership error, delta-error, and PWM output, then the rules used to measure its control response graph with the specified set point. This tool uses a position sensor as input. This tool's control system uses a minimum microcontroller AVR ATmega8535 system, LCD as a monitor, L293D motor driver to adjust the direction of rotation of the DC motor. Fuzzy logic has been successfully implemented in the 1 DOF robot arm position control plant with a small error value of 3% [7].

3 Material and Methods

System design consisted of hardware and software. The hardware used several main components, namely a DC motor, Load Cell, TCS3200, Arduino Due, and Servo MG995 as conveyor drive, weight sensor, color sensor, control system microprocessor, and a driving force for the robot arm, respectively. The system architecture is shown in [2].

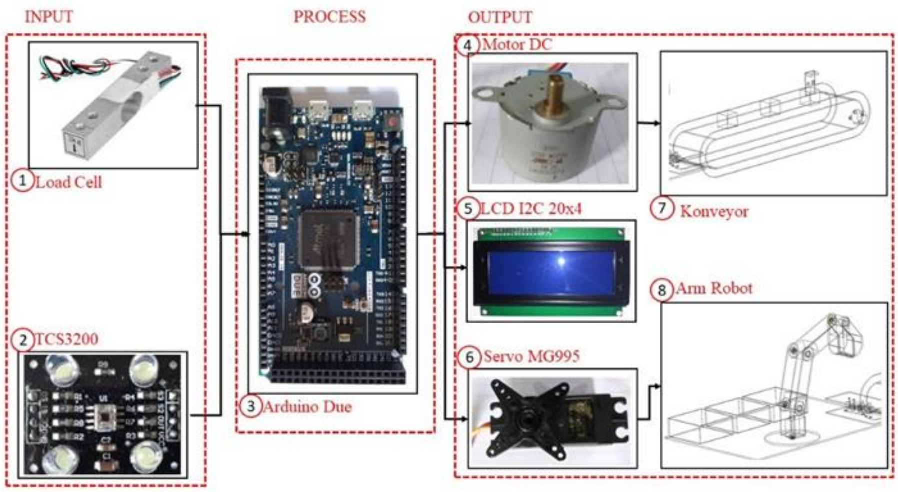


Figure 1. System architecture

The wiring cable was designed using fritzing version 0.9.10 (https://fritzing.org/) as shown in [5]. A load cell sensor is used to measure the pressure of a load, the force that occurs causes strain, and is converted into an electrical signal by a strain gauge (measurement of strain) attached to the sensor [8]. Furthermore, it is equipped with the HX711 module for converting the resistance into a voltage value to enhance the reading of the object's weight. According to a previous report, the TCS3200 color sensor can detect several types of colors based on the characteristic wavelength using an internal photodiode [9]. The TCS3200

sensor has 4 photodiode arrays with 4 different filters and requires a voltage of 2.7V-5V to operate. The light-to-frequency converter uses 8 × 8 of various photodiodes, where each 16 photodiodes have blue, green, and red filters, respectively, while the other 16 photodiodes have no filter. The robot arm moves using the MG995 servo, which uses the PCA9685 module by connecting to a 5VDC voltage source. LCD I2C 20x4 serves to display the readings of each sensor and fuzzy calculations. Arduino Due is a Microcontroller that used to carry out all the processing and driving of the servo with a 5VDC voltage source.
The device is designed to sort items by quality by weight, and colour. Decision-making of goods quality using fuzzy logic algorithm Mamdani method. The value of the Load Cell sensor reading as the weight input and the TCS3200 sensor reading value as the colour input, and the output in the form of the quality of the goods. The Mamdani method of the fuzzy logic algorithm for making quality decisions is designed first.

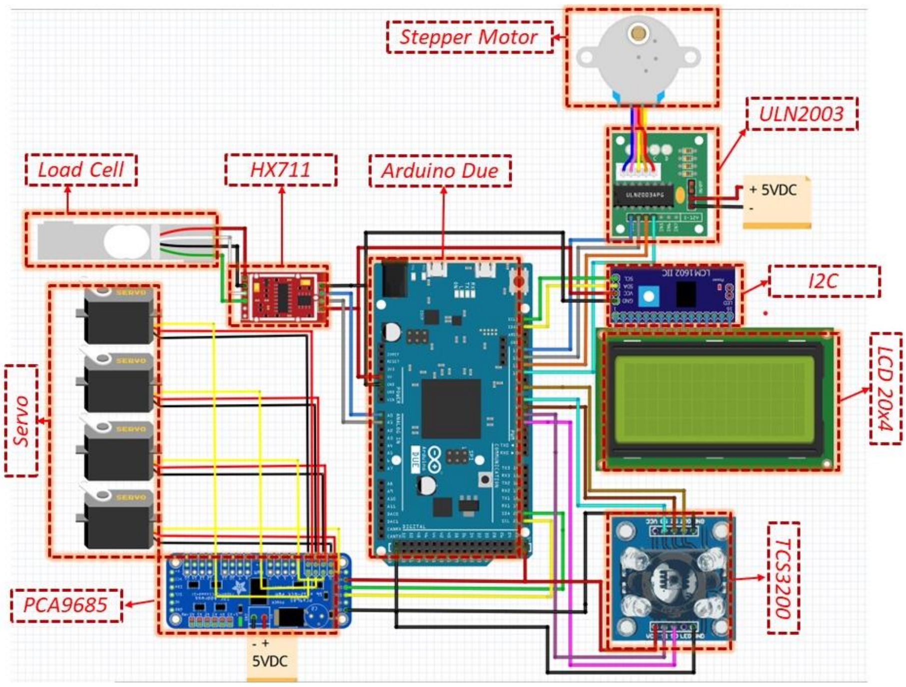
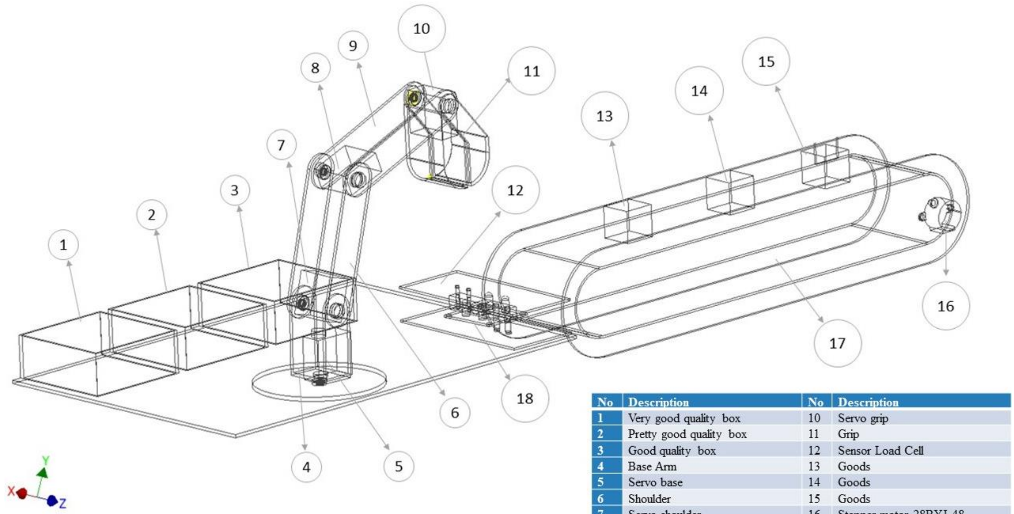


Figure 2. Cable wiring design

The robot arm is a device with a structure like a human hand that can imitate the motion of a human arm to help humans work [10]. The mechanical design of the arm robot using the Autodesk Inventor application can be seen in [14]. The robot arm has four main parts: base, shoulder, elbow, and grip. This arm robot drives using the MG995 servo.



No	Description	No	Description
1	Very good quality box	10	Servo grip
2	Pretty good quality box	11	Grip
3	Good quality box	12	Sensor Load Cell
4	Base Arm	13	Goods
5	Servo base	14	Goods
6	Shoulder	15	Goods
7	Servo shoulder	16	Stepper motor 28BYJ-48
8	Servo elbow	17	Conveyor
9	Elbow	18	Sensor TCS3200

Figure 3. Device design

Fuzzy logic describes a complex system by describing it into linguistic variables. The output of the fuzzy logic membership function is a real number. Basically, not all decisions are explained by 0 or 1, but there are conditions between 0 to 1, the area between the two is called fuzzy [4], [11],[12]. The fuzzy logic algorithm is a problem-solving method for mathematically making decisions based on linguistic variable inputs [13]. Formation of fuzzy membership set and knowledge base on fuzzy based on the author's knowledge and experience [14]. Linguistic variables based on subjective knowledge [15]. The input value from the sensor reading is formed by a fuzzy membership set by turning this value into a linguistic variable. This process is called fuzzification. The stages of decision-making using fuzzy Mamdani from the load cell and TC3200 sensor inputs can be seen in [10]. The knowledge base of the rules can be seen [12].

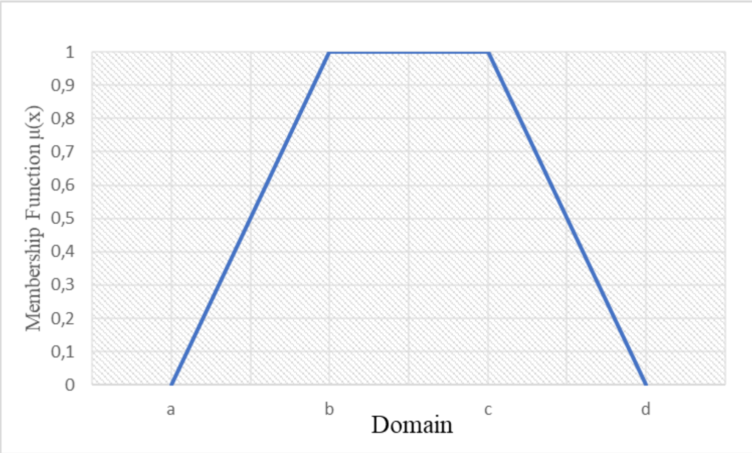


Figure 4. Membership Function

$$\mu\, x = \begin{cases} 0; x \leq a \;\; Or\; x \geq d \\ \dfrac{x-a}{b-a};\; a \leq x \leq b \\ 1; b \leq x \leq c \\ \dfrac{d-x}{d-c}; c \leq x \leq d \end{cases} \qquad (1)$$

Shows that the Load Cell and TCS3200 sensors as crisp inputs are formed into a fuzzy membership set called the fuzzification stage. If the Load Cell sensor reads the mass of an object is greater than 120grams, the degree of membership obtained is 1 with variable weight. Likewise, if TCS3200 gets a frequency value greater than 120, then the degree of membership is 1 in the Red variable and less than 40, then the membership degree is 1 in the Green variable because it uses a trapezoidal membership set. The inference stage is reasoning like humans do reasoning with their instincts by creating a knowledge base or fuzzy rules [4]. The greater the value of the frequency of the colour of the goods and the greater the value of the object's weight, the better the results of the quality of the goods obtained. The equation used in solving the degree of fuzzy membership at the fuzzification stage is shown in [11]. Equation 1 is the formula for getting the sensor input value's membership degree value.

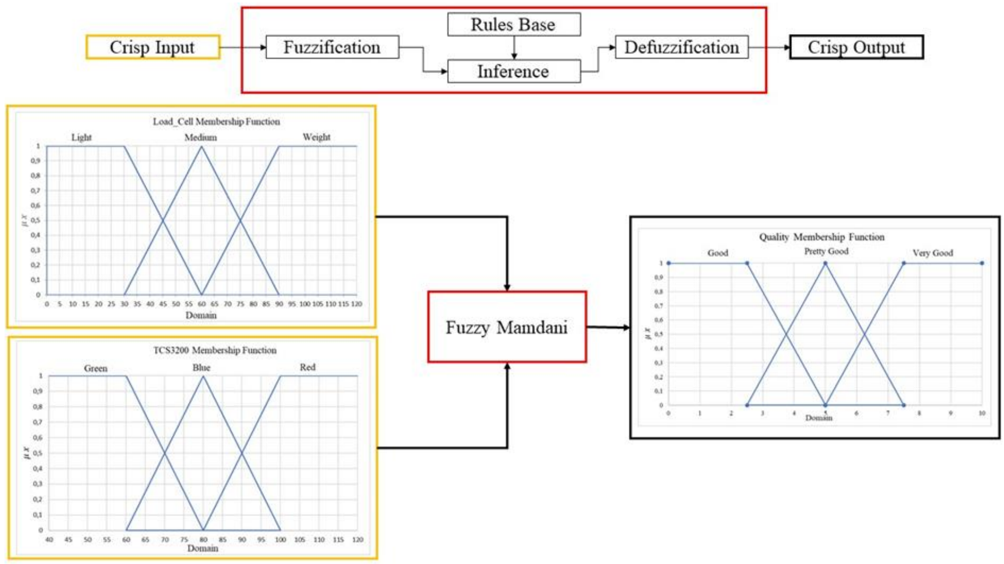


Figure 5. Mamdani Method and Fuzzy Set

Table 1

No	Inferences
1	If (Load Cell is Light) AND (TCS3200 is Green) Then (Quality is Good)
2	If (Load Cell is Light) AND (TCS3200 is Blue) Then (Quality is Good)
3	If (Load Cell is Light) AND (TCS3200 is Red) Then (Quality is Pretty Good)
4	If (Load Cell is Medium) AND (TCS3200 is Green) Then (Quality is Good)
5	If (Load Cell is Medium) AND (TCS3200 is Blue) Then (Quality is Pretty Good)
6	If (Load Cell is Medium) AND (TCS3200 is Red) Then (Quality is Very Good)
7	If (Load Cell is Weight) AND (TCS3200 is Green) Then (Quality is Pretty Good)
8	If (Load Cell is Weight) AND (TCS3200 is Blue) Then (Quality is Very Good)
9	If (Load Cell is Weight) AND (TCS3200 is Red) Then (Quality is Very Good)

$$Z^* = \frac{\int \mu(z)zdz}{\int \mu(z)dz} \rightarrow \frac{(\text{Moment})}{(\text{Area})} \qquad (2)$$

The final stage of the Mamdani fuzzy method is to perform defuzzification using the centroid method. Defuzzification is obtained by dividing the moment value by the area, as shown in equation 2. The moment value is obtained by integrating the membership degree values of all rule compositions. the area is obtained by calculating the area of the new fuzzy set. The workings of the device can be seen in Figure 6.

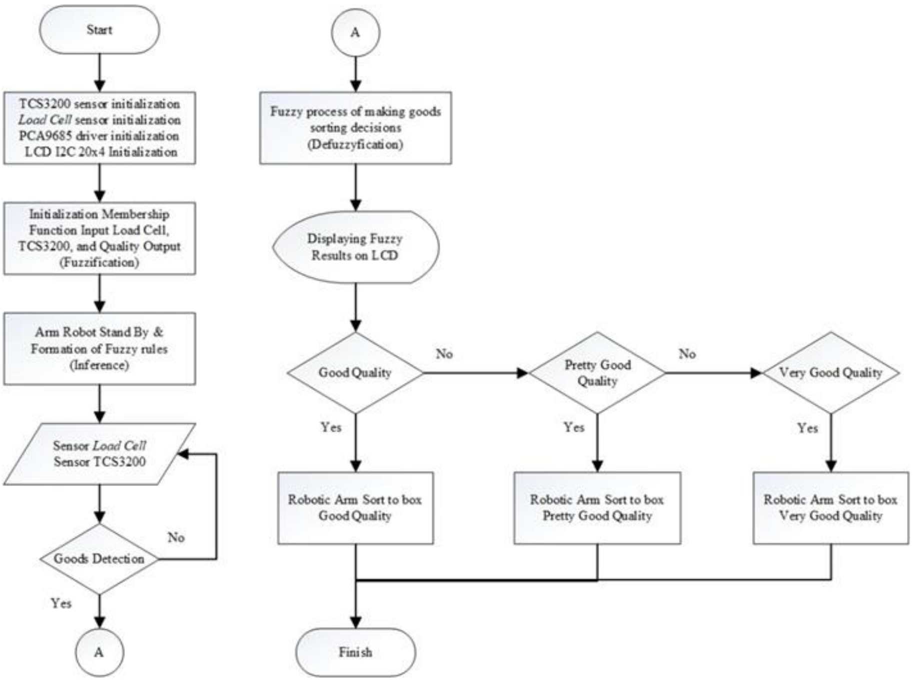


Figure 6. Program flow chart

The device starts by initializing each sensor and other components, creating a fuzzy set of Load Cell inputs, TCS3200, and Quality outputs. When the two sensors detect the goods and measure the value of weight and colour frequency, a decision is made using the fuzzy Mamdani method. After making a quality decision, the robotic arm sorts the goods in the quality box 11].

4 Result and Discussion

Load cell sensor calibration was carried out by comparing data of the same object placed on the sensor and digital scales.

Based on the measurement results in [6], the weight of the object produces the highest sensor accuracy values at 50 grams and 105 grams, with an average error of 0% and 100% accuracy. The lowest accuracy value of 97.64% and an error of 2.36% was obtained in the 38 gram, which showed that the sensor is good. This is because a smaller error value will yield a higher accuracy level to produce a better sensor. The RMSE value of the load cell sensor is 0.948 and in the range of 0-1. This indicated that the average value of measurement error is relatively small, therefore, the load cell sensor can be used for measuring object weight.

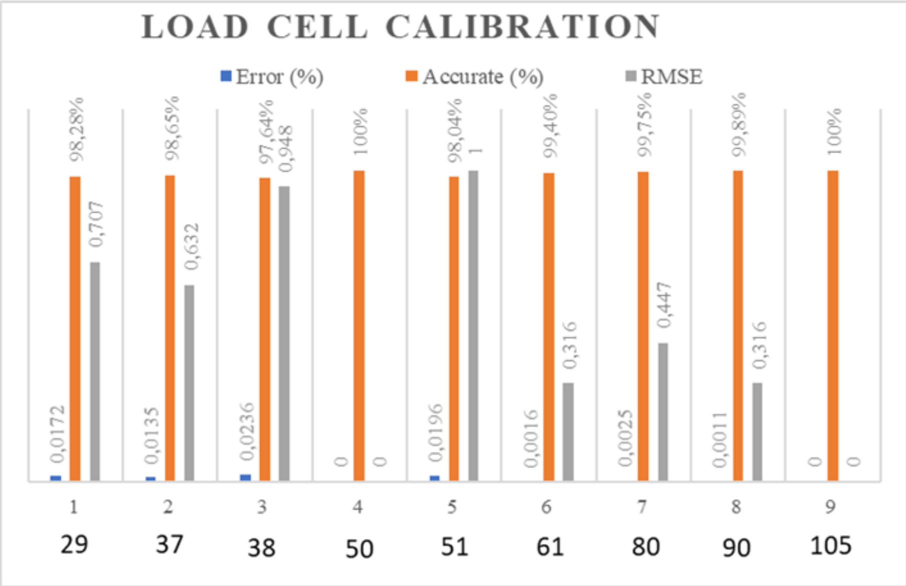


Figure 7. Load cell calibration

(a) (b)

Figure 8. light intensity measurement

Color sensor calibration was carried out by measuring the color frequency of objects 10 times. Meanwhile, the sensor calibration was conducted by calculating the Standard deviation value, and standard error of color frequency measurement. The color frequency was measured in the room light intensity range from 89.4 to 90.0, as shown in Figure 8. The light intensity measurement was carried out using the LX-1102 Light Meter measuring instrument.

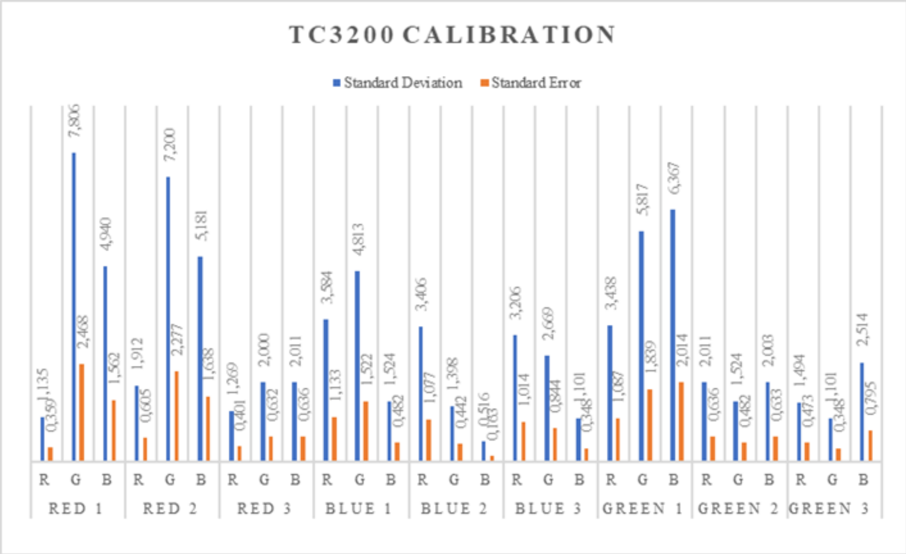


Figure 9. TCS3200 Calibration

Based on the graph shown in [5], it can be seen that the best measurement is shown in the measurement of the blue object 2 with the smallest standard deviation of measurement is 0.516 and the smallest standard error is 0.163. The measurement with the largest standard error is the measurement of the red object 1 which is 2.468 and the Standard deviation is 7.806. The standard deviation value obtained in all colour measurements does not exceed the average value of the measurements, which means that the average value is a good representation of the overall data obtained. The standard error values obtained from all colour measurements measure how precise the mean value obtained is, therefore the standard error value data obtained is correct because the smaller the standard error value, the more accurate it is.

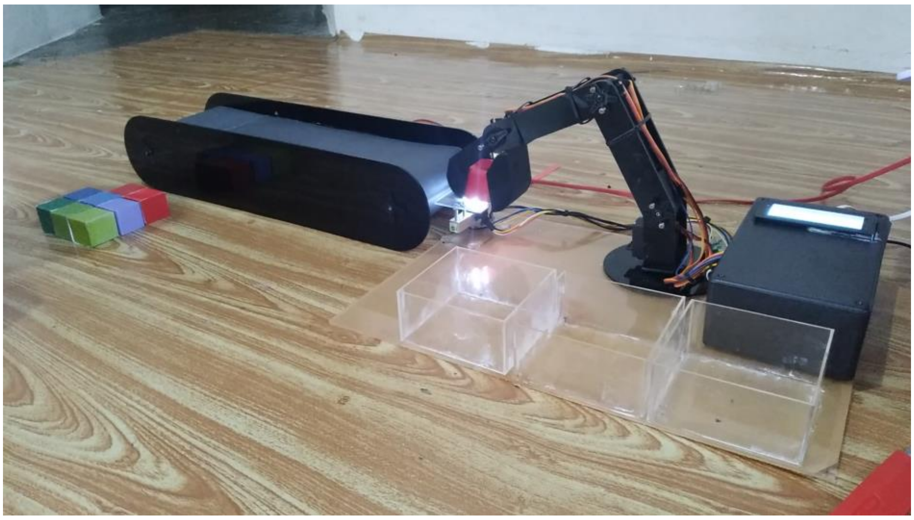


Figure 10. Goods sorting process

Field tests were conducted to determine the device's performance in reading the input value of the object's weight, the frequency of the object's colour, and output quality. The field test also tests the extent to which the robotic arm can sort. The process of sorting goods. First, the object moves to the place where the weight and frequency of the goods are measured using a conveyor. When the weight and frequency values have been measured, the fuzzy algorithm decides goods will be sorted in a quality box. After the decision is obtained, the robot moves the goods to the intended quality box. The results of the field test can be seen in [6].

Table 2. The result

No	**Mass (gram)**	**Colour**		**Quality**		**succeed**
		Colour	**Frequency**	**Value**	**Box**	
1	38.16	Blue	88,1	4,15	Pretty good	√
2	91.30	Blue	98,5	8.02	Very good	√
3	106.40	Red	139,0	8,06	Very good	√
4	80.99	Green	123,0	7,91	Very good	√
5	62.09	Red	149,0	8,01	Very good	√
6	29.91	Red	139,0	5,00	Pretty good	√
7	52.60	Blue	96,4	6,59	Very good	√
8	38.82	Green	67,30	2,95	Good	√
9	52.02	Green	95,4	6,33	Very good	√

The TCS3200 sensor input value is greater than the calibration time due to the influence of light intensity and the position of the item. See the colour frequency value in the 3rd to 6th tests (Table 2). It has a very large value and exceeds the TCS3200 fuzzy membership set that has been set. Values that exceed 120 have a membership degree of 1 and are in the domain 120 (Red) because the fuzzy set built in the form of a trapezoid can be seen in Figure 5. The quality results obtained based on sensor inputs have been set in fuzzy rules (Table 1). For example, field test results in No. 4 Table 2 are green, but the reading frequency is 123.0. This value is in the red domain, so the rule used is the 9th rule (If (Load Cell is Weight) AND (TCS3200 is Red) Then (Quality is Very Good)) with the resulting quality output is very good quality.

5 Conclusion

The results showed that the Mamdani method of the fuzzy logic algorithm can be implemented on a robot arm for sorting goods to make quality decisions based on weight and color. This system uses two sensors as gauges, calibrated with the lowest and highest load cell accuracy level of 97.64% and 100%, respectively. Furthermore, the TCS3200 sensor has the smallest and largest standard errors of 0.163 and 2.468, respectively, which indicates that both sensors have good accuracy. Although the system is 100% successful, it has not been able to move goods neatly into the box. This is because the box is not equipped with a system that can tidy up the sorting of goods.

Acknowledgment

The authors would like to thank the Department of Electrical Engineering, Faculty of Engineering, Universitas Maritim Raja Ali Haji, which has supported and facilitated this research.

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