Design and Implementation of Object Classifier based on Color and Shape

ECE 4600 Group Design Project

Group 16

Prepared By

Atif Muhammad
Chinmai Managoli
Bowen Shi
Milind Patel

Faculty Advisor

Dr. Sherif Sherif
Associate Professor

March 9th, 2018

Abstract

The goal of this project was to integrate shape and color detection capabilities and implement a working assembly line-type model that sorts objects. Objects are placed at the start of the conveyor belt and are automatically sorted when they reach the end of the belt. A color sensor and a camera are connected to a Raspberry Pi computer and are fed the computer color and image data from objects on the conveyor belt. The Raspberry Pi then processes this data and controls two motors which assist in the transportation of objects and their sorting process. The color sensor communicates with the Raspberry Pi using I^2C communication interface. The camera relays data to the computer over the dedicated CSI interface. The first motor is used to control the movement of the conveyor belt while the second motor is used to implement the sorting process.

The report details the three major components in the project which are hardware, electric circuitry and motors, and image processing. The hardware section describes the changes made to the conveyor belt to interface it with the Raspberry Pi computer by adding a rotational DC motor to turn the belt and a positional DC motor to sort the objects coming from conveyor belt. The section also covers the placement of the camera and color sensor to detect objects effectively. The circuitry and motors section explains the circuits designed to supply the appropriate voltage levels to control the motors from the Raspberry Pi. Finally, the image processing section explains the techniques used to determine the shape and color of different objects.

Contributions

The project was broken down into 5 sections: Hardware, Supporting Circuit, Image Processing, Color Sensor Programming, and Integration and Testing. The contributions of each member have been highlighted with bullet points in table 1.

Table 1: Contributions

	Atif Muhammad	Bowen Shi	Chinmai Managoli	Milind Patel
Hardware				
Prototype Design and Modification	●			●
Prototype Implementation	●			●
Supporting Circuit				
Motor Circuit Design	●			●
Motor Circuit Implementation	●	●		●
PCB Design and Implementation	●			●
Image Processing				
Shape Detection using PC			●	●
Shape Detection using Raspberry Pi Computer			●	●
Integration with Camera			●	
Color Sensor Programing				
Color Sensing		●		
Sensor Range Testing	●	●		
Integration and Testing				
Motors Integration with Raspberry Pi	●		●	●
Sensor Integration with Raspberry Pi		●	●	
Final Program Flow Design and Testing	●	●	●	●
Report Writing	●	●	●	●

Acknowledgements

A big thanks to our advisor, Dr. Sherif Sherif, for supporting us throughout the project, providing valuable guidance, educating us about image processing techniques and being patient with us all the way.

We would like to thank Mr. Daniel Card, for his invaluable advice and assistance he provided us in the electrical section of our project.

A huge thanks to Ms. Aidan Topping for reviewing all our documents, answering our endless questions and providing valuable feedback when it came to technical communications.

A big thanks to our colleague, Mr. Mujtaba Jalil, for his advice and technical guidance throughout the project.

We would like to thank Mr. Sinisa Janjic and the late Ken Biegun for handling all our orders.

A huge thanks to Mr. Zoran Trajkoski for playing a vital role in our hardware implementation.

We would like to thank Dr. Derek Oliver for his feedback on our logbooks.

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Nomenclature

CAD	Computer Aided Design
DC	Direct Current
EM	Electromagnetic
GHz	Giga Hertz
GPIO	General Purpose Input/Output
I^2C	Inter Integrated Circuit
k	Kilo
M	Mega
MHz	Mega Hertz
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RDP	Raemer Douglas Peuker
RGB	Red, Green, Blue
SCL	Serial Clock Line
SDA	Serial Data
SPI	Serial Peripheral Interface
ULP	User Language Program

Chapter 1 - Introduction

1.1 Background

Object sorting and shape detection are used in many industries, such as in the food production industry, where it is used to maintain quality standards by ensuring that all manufactured goods look exactly the same. For example, image processing is used to look for defects in processed foods as part of the quality control procedure [1]. Another example is the use of image processing to validate product specifications like date/time and expiry [2]. Image processing can also be used in sorting processes like waste sorting, which is often done manually in garbage processing and recycling plants [3].

Assembly lines are at the epicentre of the manufacturing industry and the industrial revolution [4]. Assembly lines ease the task of processing and packaging products in almost every industry. Many of today's assembly lines are automated to improve efficiency and productivity in industries. One of the early examples of assembly line automation is that of the Ford motor company [5].

RGB color sensors work on the principle that every color is composed of the three primary colors – red, blue and green. Color sensors are used in many sorting applications on assembly and production lines, along with image processing techniques. Image processing is the use of computer algorithms to process digital images for various applications [6]. Advanced image processing is used in traffic surveillance to monitor traffic patterns and traffic violations [7]. It is also used by self-driving autonomous cars to scan for traffic signs [8]. Image processing techniques can be applied on different objects to determine their contour. When an image of an object is captured, each pixel in the image has an RGB level associated with the color of that pixel. This information can be used to distinguish the object from its background and determine the object's contour.

1.2 Overview

The main goal of this project was to integrate color and shape sensing capabilities of an object on a single device. The device was implemented using a combination of color sensor, image processing with an external camera and a conveyor belt. The objects were classified based on their colors and shapes. A readily available conveyor belt was modified as an alternative to building the working model from raw materials. In order to control the sorting process, appropriate DC motors were selected. External circuits were designed to control the DC motors from the Raspberry Pi computer. The detection and sorting process are outlined in the flowchart shown in figure 1-1.

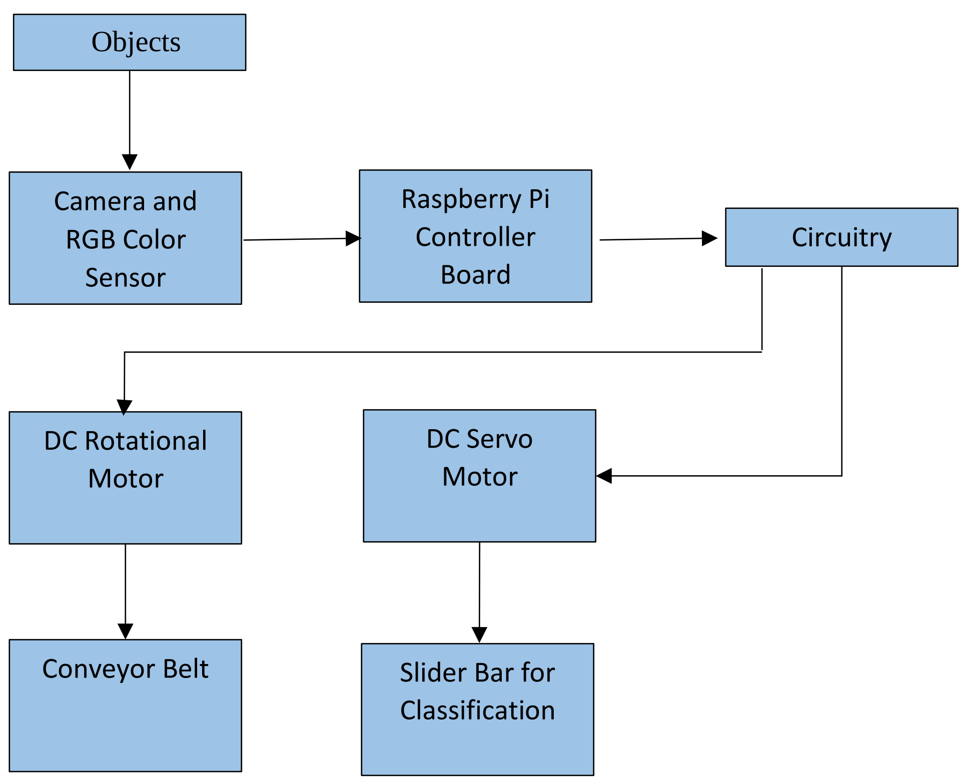


Figure 1-1 Project Flowchart

1.3 Scope

Shapes of simple, basic objects were determined so that they could be sorted using an assembly line-like prototype, as a proof of concept. A Raspberry Pi computer was used to carry out image capture, processing and control of the subsequent sorting mechanism. The assembly line was implemented on a modified conveyor belt with the help from the mechanical tech shop.

1.3.1 Parameters for Success

For the project to be considered a success, the following parameters were set:

1. The size of the entire working model was to be less than 80 inches in length by 20 inches in width by 30 inches in height.
2. The power consumption of all the components used was to be under 40 watts.
3. Each object would have to be sorted within 15 seconds from the time it landed on the conveyor belt.
4. The shape and color of the object was to be determined by the Raspberry Pi computer in under 7 seconds.
5. A total of 4 or more different colors and 3 or more different shapes had to be determined.

Chapter 2 - Design and Implementation

The aim of this project is to identify different objects based on shape and color and sort them. A conveyor system was implemented to achieve this task. The conveyor system relayed the objects to be sorted to their respective sorting piles. Conveyor systems are used in various industries for food processing, manufacturing, package processing, etc. [9].

2.1 Conveyor Belt Modification

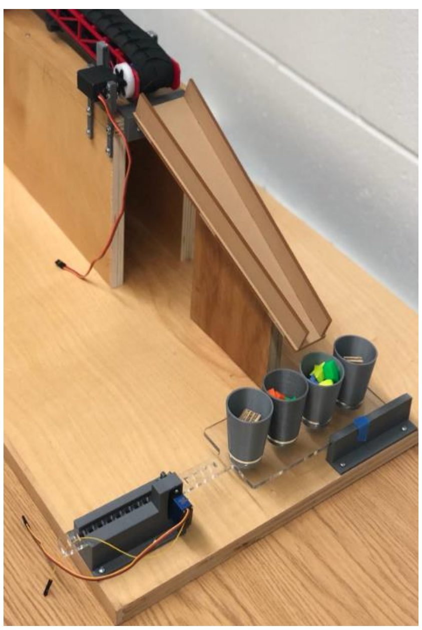
An off-the-shelf alternative shown in figure 2-1 (a) was used as an alternative to building the conveyor belt from raw materials. The belt was automated so that it could be controlled by the Raspberry Pi computer. The belt had an axle on each end, which aided in the belt's movement. A DC motor was attached to one of the axles as shown in figure 2-1 (b). The DC motor was controlled by the Raspberry Pi computer. The rotation of the motor was then automated using signals from the computer.

(a) (b)

Figure 2-1 : Conveyor Belt Modification

2.2 Sorting System

A slide was designed to move objects into their appropriate sorting container once they reached the end of the conveyor belt. The slide acted as a feed to four sorting containers, where objects were classified by color or shape. The movement of the four sorting containers was controlled by a rotating DC servo motor. The appropriate sorting container, in which the object was to be dropped, moved directly under the end of the slide so that the object landed right into the container. There were practical difficulties in maintaining the orientation of the containers with respect to the end of the slide over multiple trials. Consequently, the motor was designed to move to a fixed reference position after each object was classified. The reference position was determined by a push-button switch. When the motor moved the containers to one end, it resulted in the pushing of this button which signalled the Raspberry Pi computer. This point was taken as the reference position. The motor moved the containers to this reference position after each object was classified. The slide is shown in figure 2-2 (a) and the switch which was used to orient the containers with respect to the slide is shown in figure 2-2 (b).



(a)

(b)

Figure 2-2 Object Sorting

2.3 Camera and Sensor

The design uses an RGB color sensor and a camera to detect color and shapes of various objects. A wooden post was designed to house the Raspberry Pi computer, camera and RGB color sensor. The optimal distance between the conveyor belt and the camera for effective shape detection was determined to be roughly 8cm. A small hole was drilled on top of the wooden post so that the camera could have a direct line-of-sight with the conveyor belt and any object that went directly under the camera on the belt. Data from the color sensor was used in the shape detection process. Consequently, the color of the object was to be determined before the object's image was captured and processed. The color sensor also had to be very close to the objects on the conveyor belt for accurate readings. As the average height of the objects was about 1cm, the color sensor was designed to sit at a height of 1.5cm from the conveyor belt. This resulted in the objects being only 0.5cm away from the color sensor at the time of detection. The setup is shown in figure 2-3.

Figure 2-3 Camera and Sensor Placement

2.4 Prototype

When an object is placed on the moving conveyor belt, it first goes under the RGB color sensor. The color sensor detects the object, sends its RGB data to the Raspberry Pi computer and stops the conveyor belt after a certain fixed delay. This lands the object directly under the camera for image capture. The conveyor belt remains stopped until the shape of the image is successfully determined. Once the shape and color information of the object have been identified, Raspberry Pi computer resumes movement of the conveyor belt. At the same time, the second motor brings the appropriate sorting bin to the mouth of the slide. Once the objects lands in its designated bin, the sorting bins move back to their reference position. The conveyor belt continues to rotate so that the cycle can be repeated for the next object. The time taken per object to go to its respective sorting bin is under twelve seconds. See appendix B for additional images of the prototype.

Chapter 3 - DC Motors and Supporting Circuity

This chapter details the DC motors and the supporting electrical circuitry that was designed to interface them with the Raspberry Pi computer.

3.1 DC Motor

A rotational DC motor was used to move the conveyor belt. DC motors contain a stator and a rotor. DC motors are also referred to as permanent magnet direct current motors. This is due to the fact that the stator contains a fixed permanent magnet producing a uniform and stationary magnetic flux inside the motor. The armature consists of electrical coils wound around a metal which produce a North and South Pole. When current flows through these coils, it produces an electromagnetic field that generates a rotational movement [10].

To control the movement of the conveyor belt, a Pulse Width Modulation (PWM) controlled rotational motor was used. The PWM was used to control the speed and movement of the motor by regulating the amount of voltage across the motor terminals. To control the motor with a PWM, a series of on-off pulses of varying duty cycles were applied. The duty cycle was used to control the speed as well as the direction of rotation of the motor [11].

To operate the conveyor belt, a motor with slightly higher than normal torque rating was required. Operating voltage of the motor was 4.8 – 6 volts, with stall torque of 125.2 – 141.9 oz.in. The PWM pulses only serve the purpose of initiating the rotation of the motor. Stopping the PWM did not stop the rotation of the motor. As a result, the PWM signal could not be used to control the motor. The motor could be stopped by cutting off the power supply altogether. Hence, the control of the motor was achieved by controlling the power supply of the motor. At an operating voltage of 6 volts, the motor had a steady state current consumption of ~0.17 amperes. Therefore, an external motor controlling switch circuit was designed to turn the motor on and off. The switch circuit was designed to supply a steady state current of 0.17 amperes and voltage drop of about 6 volts.

3.2 Circuitry to Control DC Motor

As stated in section 3.1, a switch circuit was to be designed to control the motor. The motor operated at a voltage range of 4.8-6 volts. A 6 volt DC power supply was chosen to satisfy the voltage requirements. The switch was designed to be controlled by the GPIO pins on the Raspberry Pi computer which supplied ~3.3 volt signals. The switch was designed by using transistors as switches and amplifiers.

Transistors are three terminal active devices that can serve two purposes: switching and amplification. Bipolar transistors can operate in three different regions: [18]

1) Active region – The transistor operates as an amplifier. Emitter current I_C can be defined by

$$I_C = \beta * I_B \tag{3.1}$$

Where β = Current Gain and I_B = Base Current

2) Cut Off region – Transistor is OFF and $I_C \approx 0$
3) Saturation region – Transistor is ON I_C = Saturation current

A PNP transistor was used in series with a small 1 Ohm resistor with high power rating to control the supply voltage to the motor. In the simulation stage, the motor was modelled by a 33 ohm resistor. The motor resistance was calculated as follows:

Voltage Supply = 6V

Motor Current = 0.18 A

Let R_1 = Effective Resistance of Motor

$V = I R$

$R_1 = V/I = 6V/0.18A$

$$R_1 = 33.33\ \Omega \tag{3.2}$$

An NPN transistor circuit was used in parallel to account for any leakage currents from the current control circuit. Therefore, the maximum required current by using a small 1 Ohm resistor at the PNP transistor side could be pulled. On the NPN side, a 1K Ohm resistor (R_4) was connected at the emitter of the NPN transistor to limit the current drain from the source. This current drain at the NPN transistor could be controlled by changing the value of R_4.

From the Raspberry Pi, a 3.3 volt GPIO Pin was connected to the base of the NPN transistor. When a "High" signal i.e. 3.3 volts was supplied from the controller board, the transistor operated in its active region. Figure 3-1 shows the voltage drop at the collector terminal of about 2.64 volts. The drop from the base to the collector of the amplifier was 0.65 volts. Current at the emitter branch,

$$I_{e1} = 2.64V / 1000\ \Omega = 2.6mA \tag{3.3}$$

According to the bipolar transistor property, current at the emitter is equal to the sum of the base current and collector current i.e. $I_e = I_c + I_b$. As current in the base was very small, the approximation, $I_{b1} \cong 0$ amperes, was used. The current in the emitter is given by

$$I_{e1} = I_{c1} = 2.6mA \tag{3.4}$$

In the circuit, the base terminal of the PNP transistor was connected to the collector terminal of the NPN transistor. Therefore,

$$I_{b2} \cong I_{c1} = 2.6mA \tag{3.5}$$

Using $I_c = \beta * I_b$, Where $\beta = 60$ to 80 for PNP 2907, we get

$$I_c \cong 171mA$$
$$I_c \cong I_e \cong 171mA \tag{3.6}$$

The DC motor required 4.8 – 6 volts with ~0.17 amperes in the steady-state to operate smoothly. The voltage at the R_2 which represents the motor is equal to

$$V = 171\text{mA}*33.33\ \Omega = 5.62\text{V} \tag{3.7}$$

This satisfied this requirement.

Once the switch is opened, i.e. “Low” signal at the GPIO, the transistor goes into the cut-off region. Hence, $I_{c1} = 0$ since it is in cut-off mode. Also, $V_{b1} = 0$, therefore, with the voltage drop across the internal diode, $V_{e1} = \sim -0.65$ volts.

$$I_{e1} = -0.65\text{V}/1000\ \Omega = 0.65\text{mA} \tag{3.8}$$

I_{e1} was neglected as it was a very small value compared to the active region current.

$$I_{b2} = I_{c1} = 0.65\text{mA} \tag{3.9}$$

$$I_{c2} = \beta * I_{b2} = 43.75\text{mA} \tag{3.10}$$

This current was not enough to drive the motor. The PNP transistor acted as a switch for the input current of the motor. Controlling the high and low signal from the controller board gave full control of the rotation of the motor by controlling the amount of current that flowed through it. Hence, this circuit acted as a current controlling switch. Figure 3-2 shows the simulation design when 3.3 volt supply is disconnected.

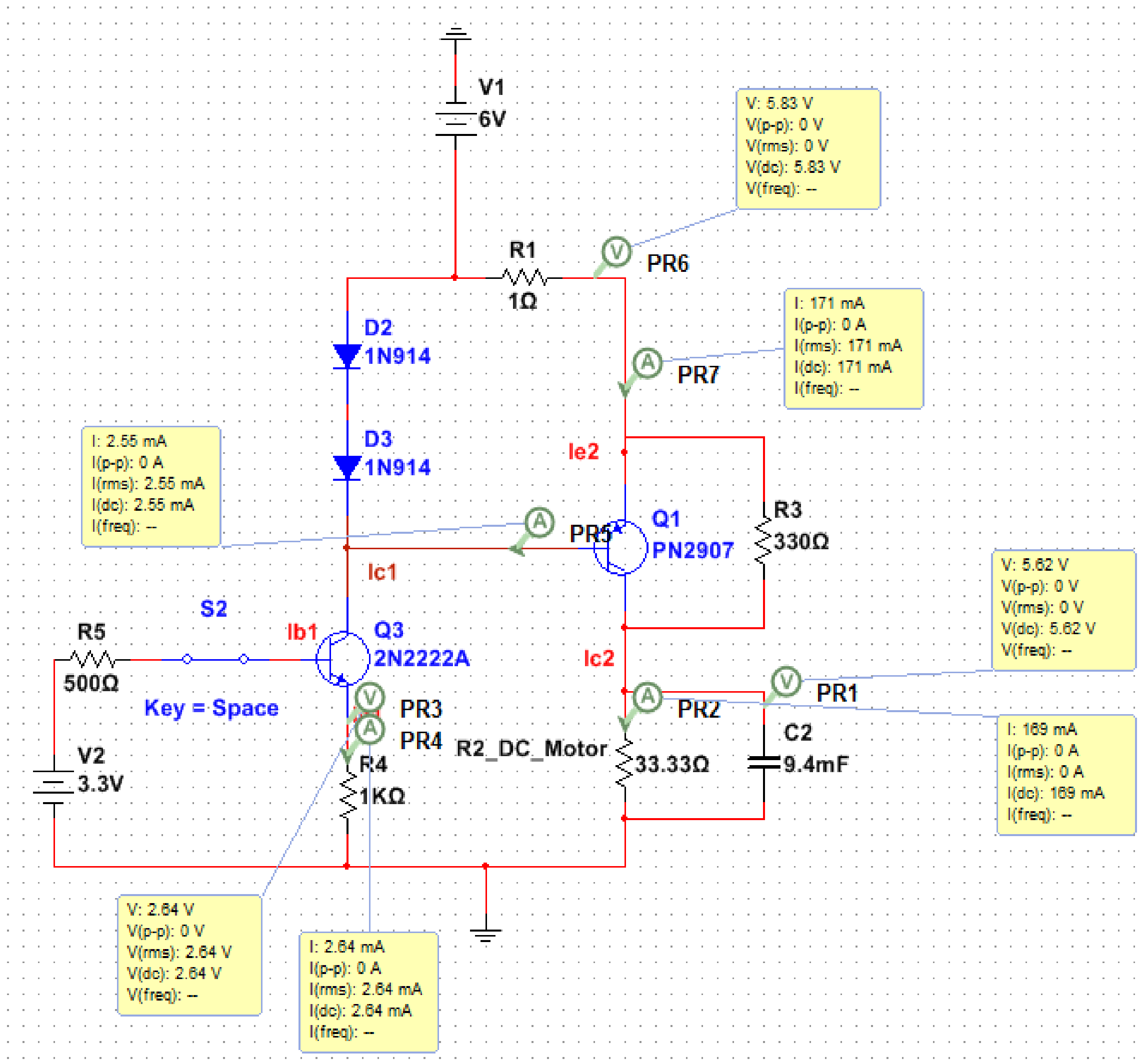


Figure 3-1 Current Controlling Switch Circuit (closed)

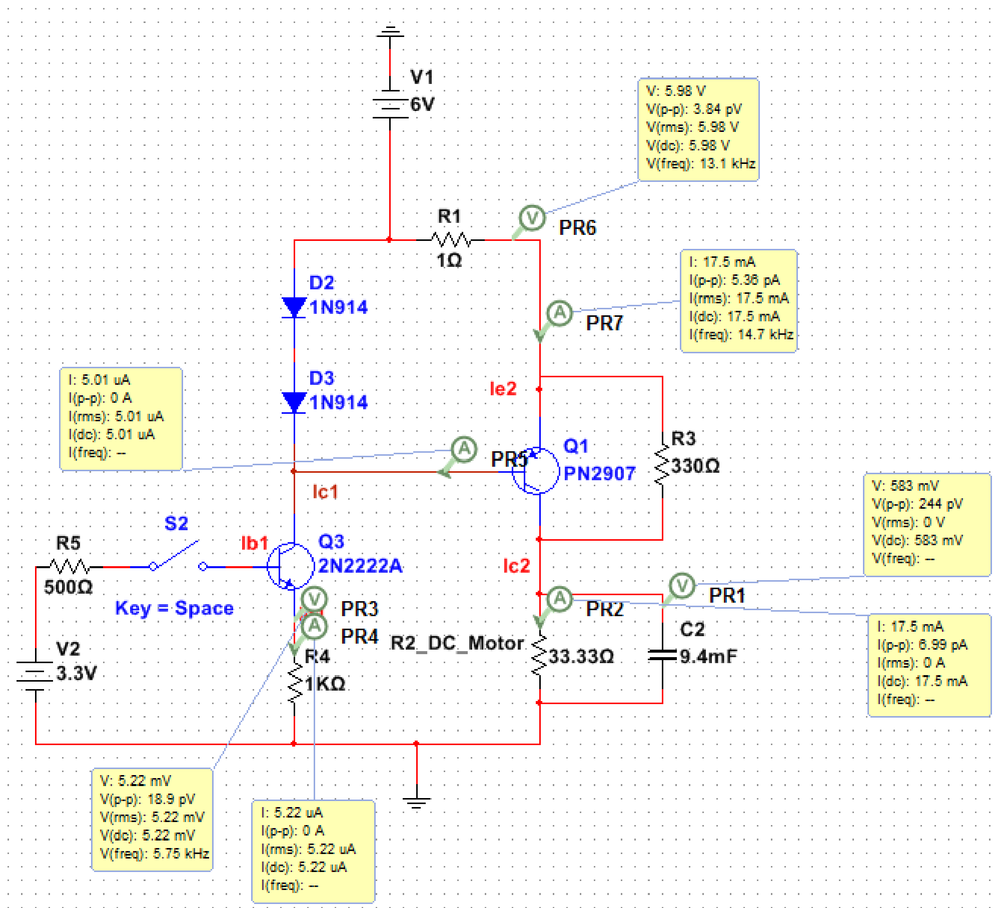


Figure 3-2 Current Controlling Switch Circuit (open)

The signal level of the PWM was to be the same as the voltage rating of the motor. The Raspberry Pi GPIO pin supplied 3.3 volt signals. Using the bipolar NPN transistor, an external Active Low Voltage control circuit was designed to provide ~6 volt signals to the DC motor.

A 3.3 volt GPIO pin from the Raspberry Pi was connected in series with a 500 Ohm resistor to the transistor base. A 6 volt source was supplied to the collector in series with a 5.6k Ohm resistor. The internal resistor at the PWM terminal of the motor was measured to be in the Mega Ohms range. Therefore, a 1M Ohm resistor was used to represent the PWM terminal of the motor in parallel with the NPN transistor for simulation. The 5.6k Ohm resistor acted as a voltage drop to control the voltage supply to the motor.

When a 3.3 volt signal was supplied to the base, the transistor operated in active mode. Approximately all the current flowed through the transistor and no current flowed towards the motor due to high resistance. This resulted in a very small voltage drop across the 1M ohm resistor, ~1.53 volt, which was not enough to initiate rotation of the motor. Once the 3.3 volt signal was disconnected, the voltage at the base of NPN transistor dropped to zero and the transistor operates in cut-off region. Therefore, the current at the collector was zero and all the current flowed to the PWM port. The PWM calculation is shown below:

Using voltage division,

Voltage at the 1M Ohm resistor,

$$V_{pwm} = 6V \text{ x } \frac{1M\Omega}{5.6k\Omega + 1M\Omega} = 5.96V \tag{3.11}$$

Therefore, a voltage drop of ~5.96 volts was achieved at the PWM terminal. The circuit was designed to be active-low, since it operated in the active region at a lower logic level, which resulted in the rotation of the DC motor. Figure 3-3 and figure 3-4 show the design and results of Active Low voltage circuit.

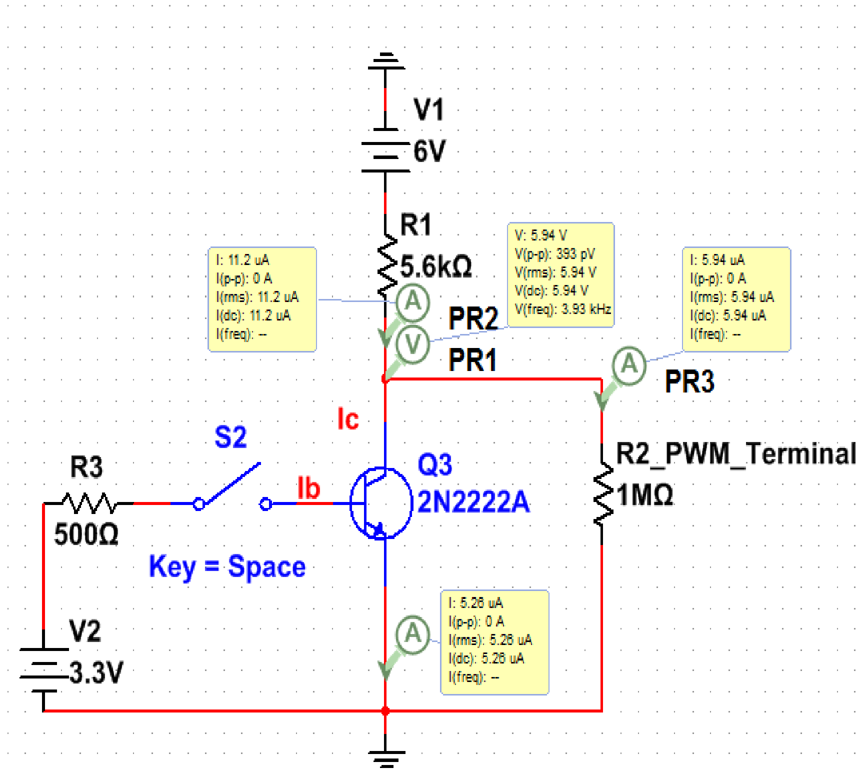


Figure 3-3 Active Low Voltage Circuit Open Switch

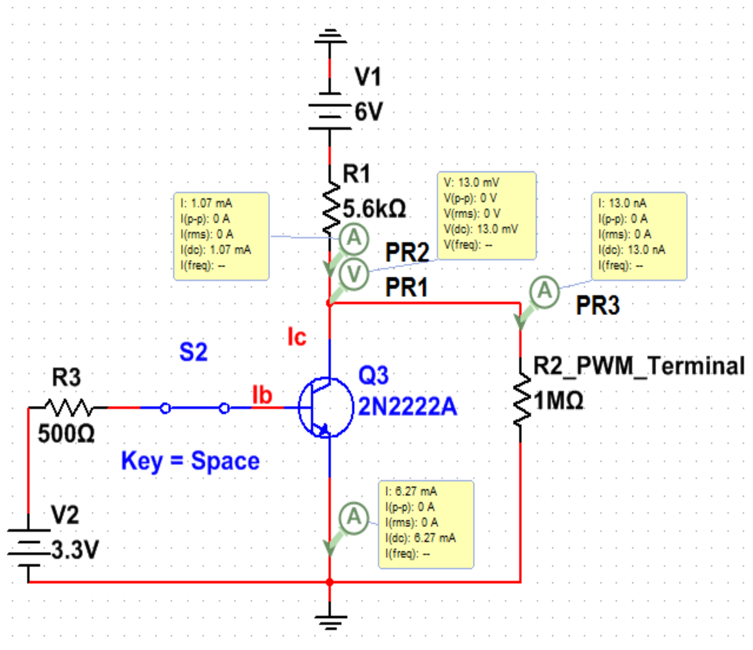


Figure 3-4 Active Low Voltage Circuit Closed Switch

The designed circuit was implemented on a prototype board and tested. Even though circuit provided 5.74 volts to the motor terminal, the motor did not operate. It was observed that there was indeed some power being supplied to the motor since the motor vibrated. However, the motor did not rotate. The voltage drop across the motor terminals was measured with an oscilloscope. At the same time, the current flowing into the motor was measured. It was observed that the motor pulled a surge current when it was turned on. A surge of current went through the inner capacitor to charge it and the resistor defined the charging time of the capacitor. After multiple trials, the peak voltage was measured to be ~800 milli volts and it took ~90 micro seconds to charge the capacitor. The lowest voltage was at ~400 milli volts with a charging time of ~50 micro seconds. Figure 3-5 shows the results for 400 milli volt peak represent the voltage across the capacitor and the resistor is 0.1Ohm.

$$I = V/R = 0.4V/0.1\ \Omega = 4A \tag{3.11}$$

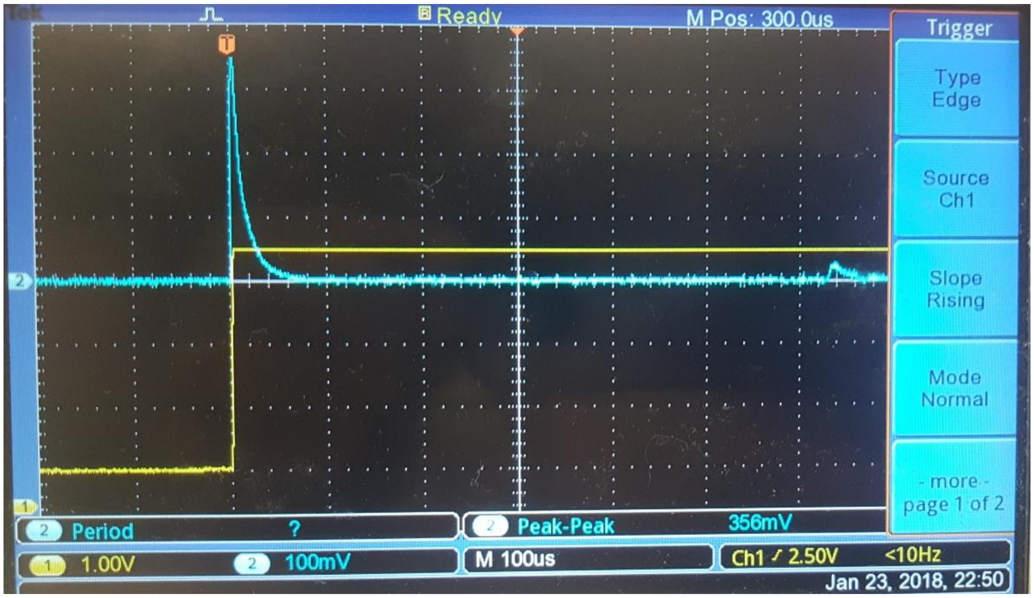


Figure 3-5 Motor's internal capacitor discharging

Time it took to charge the capacitor was about ~50 micro seconds. From this data, the approximate value of the inner capacitor of the motor was calculated using decaying exponential method. Below is the calculation for charge of the capacitor and the capacitance value of the motor.

$$Q = \int (I * e^{\wedge} ((-t/\tau))\, dt), \text{ integrate from } 0 < t < \infty$$

$$I = 4A,\ \tau = 50 \text{ us}$$

$$Q = 0.2x10\text{-}3 \text{ C}$$

Using capacitance $C = Q/V$

$$C_1 = \frac{(0.2x10-3)\ C}{6\ V}$$

$$C_1 = 30 \text{ x } 10^{-6} \text{ F} \tag{3.12}$$

Using the same approach, the highest approximate capacitance value was also calculated and found to be $C_1 = 0.13 \text{ x } 10^{-3}$ farad. To charge the inner capacitor C_1 of the motor, a larger capacitor C_2 was connected in parallel with the motor. The circuit first charged C_2 which in turn provided the surge current to C_1. A capacitance $C_2 = 9.4x10^{-3}$ farad was used in parallel with the motor. A resistor was also connected in series with C_2 to provide the required time constant. The time constant was necessary to immediately turn off the motor once the power was shut off.

The Current Controlling Switch, Active Low Voltage and RC_2 circuit, in parallel with the motor, were built on a breadboard and tested to operate and control the DC motor using PWM signals from the Raspberry Pi computer. Once a 3.3 volt signal was supplied to the base of the NPN transistor, the motor received its rated voltage and current, and started rotating. When the 3.3 volt signal was disconnected from the Raspberry Pi computer, the output voltage at the motor terminal dropped to ~0 volts and the motor became stationary. The motor could be successfully controlled using signals from the Raspberry Pi computer. Figure 3-6 shows the output 6 volt PWM signal with 3% duty cycle and 60 hertz frequency when logic low level signal was provided to the base of the active low voltage circuit. Figure 3-7 represents the output voltage of the motor when 3.3 volt signal was applied to the base of the current limiting circuit. This circuit was also implemented on the prototyping board and PCB designs were made. Details of the prototyping board and PCB design are explained in chapter 6 of this report.

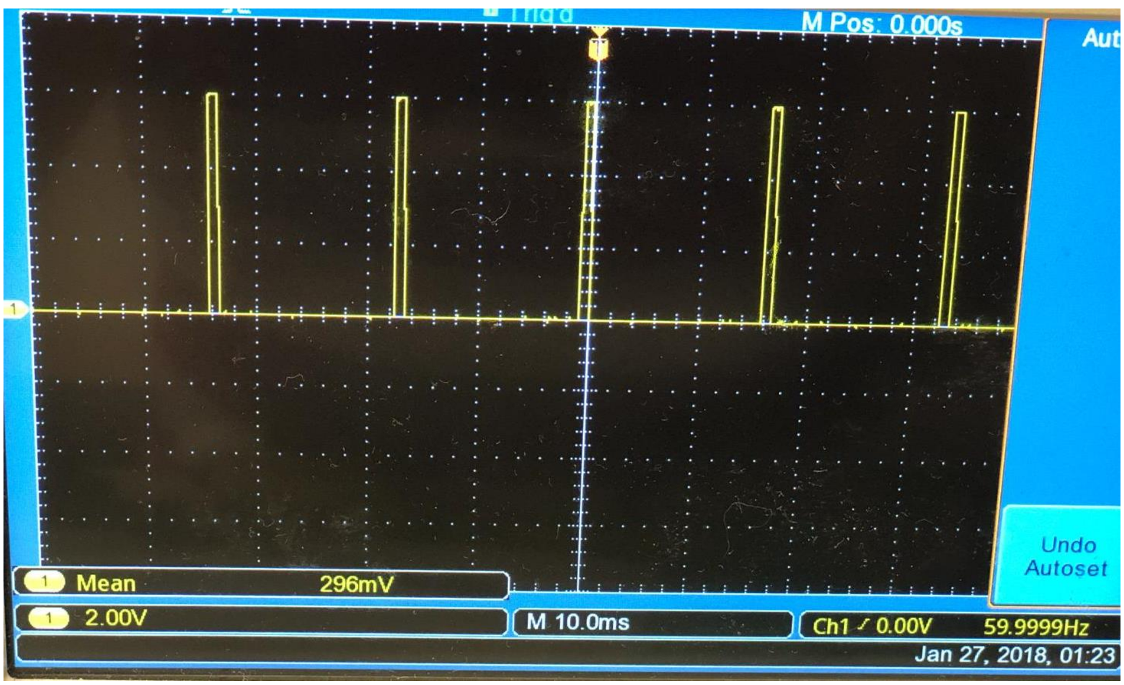


Figure 3-6 PWM: 6 Volts, 3% Duty Cycle

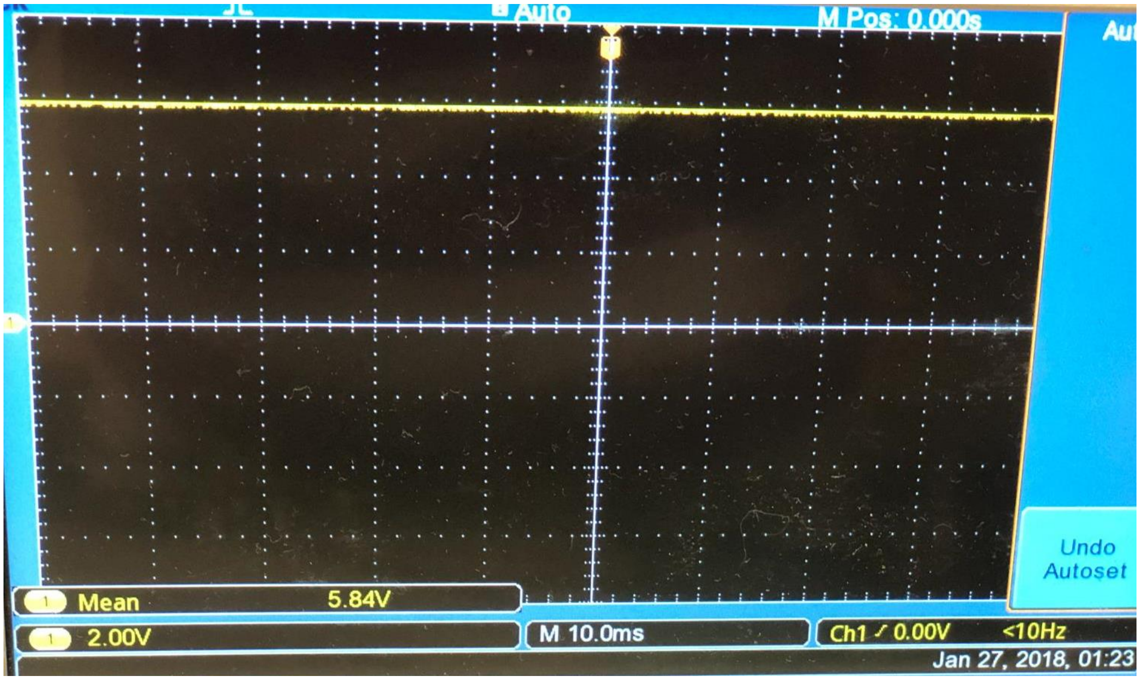


Figure 3-7 Output Voltage at Motor Terminal

3.3 Servo Motor

A 4.8 - 6 volt positional servo motor was used to operate the slider bar to control the positions of the sorting containers which sorted objects. The position of the motor could be changed by supplying pulses of varying duty cycle to the input pins of the motor. Positional servo motors consist of a DC motor, controller circuit and a potentiometer which works as a position sensor and provides feedback to the input port of the motor [12]. The servo motor used in the design was controlled by PWM signals and could turn 90 degree in either direction from its neutral position. When the servo motor received a signal from the controller while power was supplied, the internal shaft turned to the correct position, determined by the potentiometer. A neutral pulse value kept the servo shaft in the center position and increasing that pulse value made the servo turn clockwise, and a shorter pulse turned the shaft anticlockwise.

3.3.1 Modification of the Servo Motor

The design was improved to have a different sorting mechanism due to the limited rotation of the positional servo motor. As a result, the feedback path of the positional motor was removed to make it a fully rotational motor whose direction could be controlled with the help of two signals that controlled an internal H-bridge. The logic table 3-1 of the servo is shown below:

Table 2 H-Bridge Logic table

Signal A	**Signal B**	**Output**
High	Low	Clockwise rotation
Low	High	Anticlockwise rotation
Low	Low	No operation
High	High	No operation

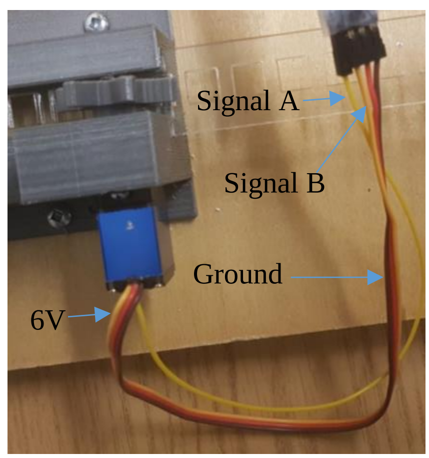


Figure 3-8 Modified Servo Motor

In table 3.1, high represents 6 volts and low represents 0 volts. The different logic level combinations supplied to pins A and B of the servo motor resulted in either clockwise or anti-clockwise rotation or no rotation at all as described in table 3.1. For example, when pin A was supplied with 6 volts and pin B was supplied 0 volts, the servo motor rotated clockwise. The modified servo motor is shown in figure 3-8. The signal levels used to control the new modified motor had to be the same as the input voltage level, which was 6 volts. Hence, a CE amplifier similar to the active low voltage in figure 3-3 was used to amplify the signals coming from the Raspberry Pi.

3.4 Power

The power consumption of each component in the model was measured. The motor that moved the conveyor belt and the motor that moved the sorting bins consumed 1.1 watts of power each. The Raspberry Pi computer powered the camera and color sensor. Hence, accounting for the computer's power consumption accounted for all other components. The Raspberry Pi's power was observed to peak at about 8 watts. The power never exceeded 8 watts.

When the motors were stationary, the circuitry still consumed some minimum power. The total power losses in the stationary mode was measured to be ~0.65 watts. This was a very small amount of power compared to the power consumption when the motors were being operated.

This resulted in a total power consumption to be less that 12 watts even in the worst case scenario assuming about a 20% margin for error.

Chapter 4 - Image Processing

The following flowchart in figure 4-1 outlines the process by which object shapes are determined:

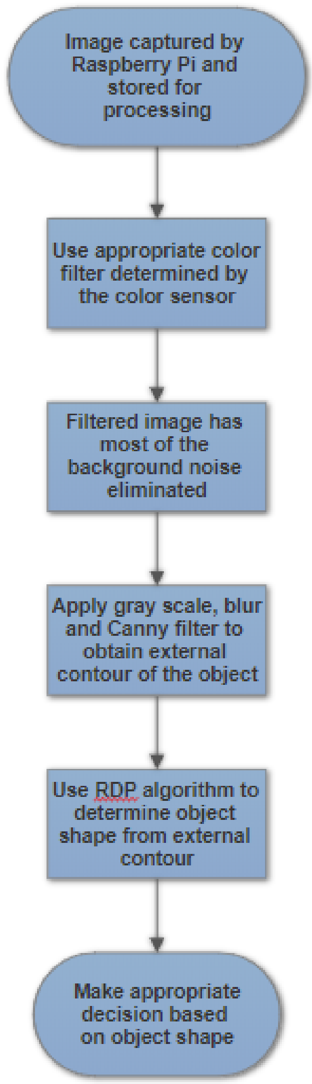


Figure 4-1 : Shape Detection Process

Each step in the shape detection process is described in the following sections.

4.1 Image Capture

The color sensor and camera had been set up in such a way that the color sensor first detected an object directly below it. The color sensor then paused the movement of the conveyor belt after an appropriate delay such that the object stopped right below the camera. This was done in order to get clear image capture and successful detection. Figure 4-2 shows the setup of the camera and sensor.

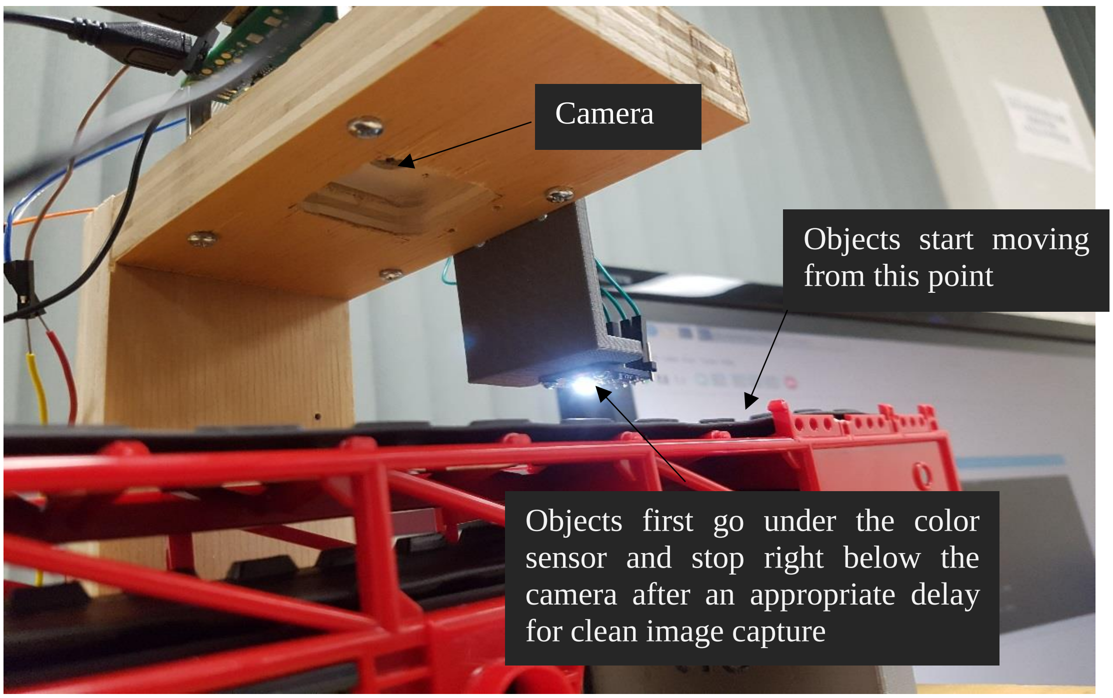


Figure 4-2 Camera and Sensor Setup

The color sensor had four 16-bit data fields that it sent to the Raspberry Pi using the I^2C communication protocol – clear, red, green and blue, each ranging from 0 to 65535. The clear field indicated how close an object was to the color sensor. In the case of the particular color sensor being used, when there was no object under the sensor, the typical value for the clear field was around 900 to 1000. The clear field jumped to a higher number ranging from 4000 to 35000 when there was an object under the color sensor, depending on color and shape of the object. The controller board stopped the movement of the conveyor belt 250 milli seconds after the color sensor had detected an object, hence landing the object right under the camera for successful image capture. Figure 4.3 shows sample images of objects captured by the camera.

4.2 Camera Parameters

The following camera parameters [13] were modified for optimal image capture:

4.2.1 ISO

ISO is a measure of the sensitivity of the image sensor. Generally, lower ISO values are used when the camera is required to be less sensitive to light. Higher ISO settings are used in darker conditions. The ISO can be set to any value between 0 and 1600. In our application, an ISO value of 800 was used.

4.2.2 Brightness

The brightness level of the camera can be set to any value from 0 to 100. It indicates how much white is mixed in the color. A brightness level of 70 was chosen for our application.

4.2.3 Contrast

Contrast in a camera is the scale of difference between black and white in images. The Raspberry Pi camera's contrast can be set to a value from -100 to +100. A contrast of +100 was chosen in our project to have maximum contrast and effective edge detection.

4.2.4 Exposure Mode

The exposure of the camera can be set to auto, night, backlight, antishake, etc., or can even be turned off. The exposure mode was set to 'night' to account for the dark color of the conveyor belt and low-light conditions.

4.2.5 Resolution

The resolution of the image captured affected the size of the image captured. Higher resolutions lead to better quality images but there was a trade-off with processing time. An optimal resolution of 512 x 512 was used.

4.2.6 Saturation

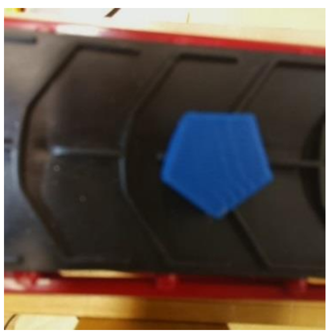
Saturation indicates the amount of grey in a color. It could be set to a value between -100 and +100 on the Pi Camera. It was set to 0 for optimal performance.

4.2.7 Sharpness

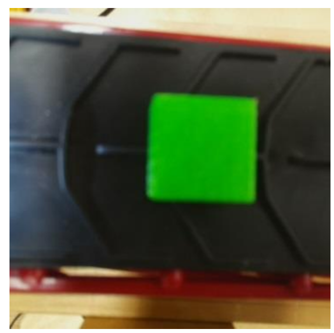
The sharpness in an image indicates the amount of edge contrast. Maximum edge contrast of +100 was chosen for our application.

4.2.8 Shutter Speed

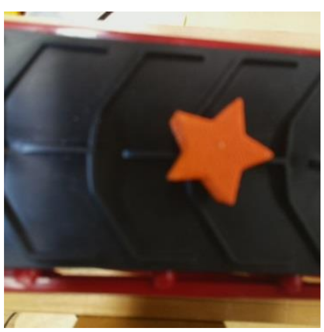
The shutter speed of the camera was automatically determined by the auto-exposure algorithm built into the Raspberry Pi camera.



(a)



(b)



(c)

(d)

Figure 4-3 (a) Blue (b) Green (c) Orange (d) Yellow Colored Objects Captured Automatically by the Camera Based on Signals from the Color Sensor

4.3 I²C Communication

The TCS3472-5 light-to-digital converter, shown in figure 4-4, was used as a color sensor in the design. It contained a 3x4 photodiode array. The Inter-Integrated Circuit (I^2C) protocol allows multiple digital integrated circuits or "slave" chips to communicate with one or more "master" chips. In this case, the "slave" chip being the color sensor and the "master" being the Raspberry Pi. It requires only 2 signal wires, SCL and SDA, and is only intended for short distance communications. I^2C is an asynchronous communication, meaning it does not need clock data to be transmitted. The main advantage of using I^2C over SPI and other synchronous communication protocols is that it requires less number of pins. It is not intended for simultaneous sending and receiving of data (full-duplex). [14]

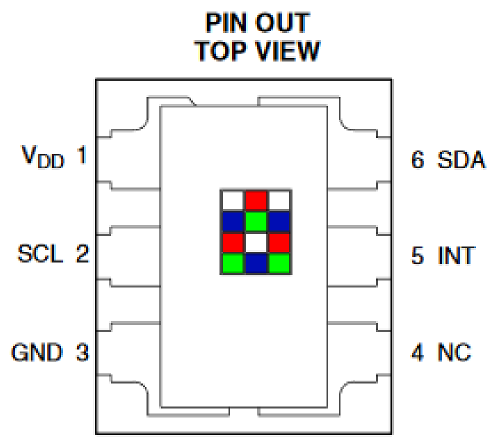
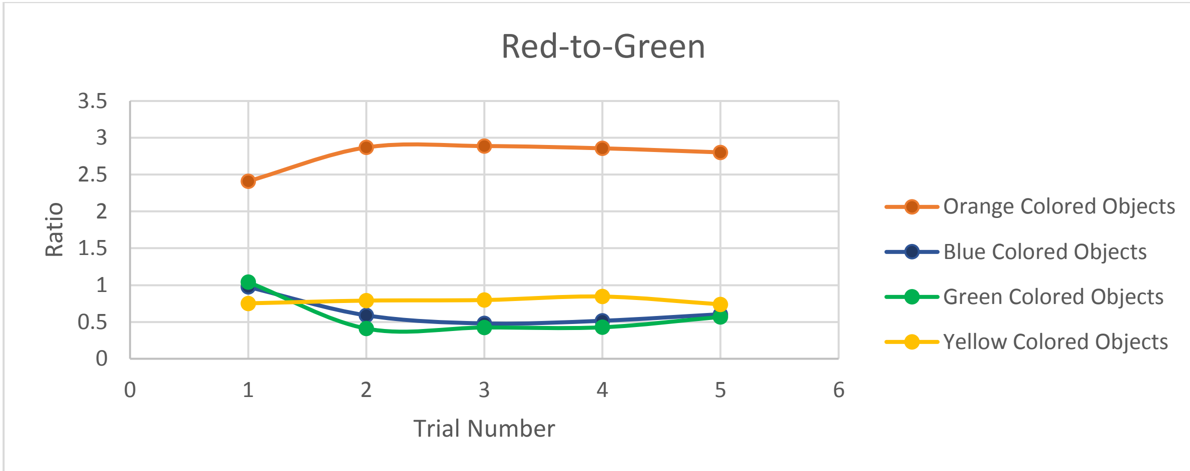


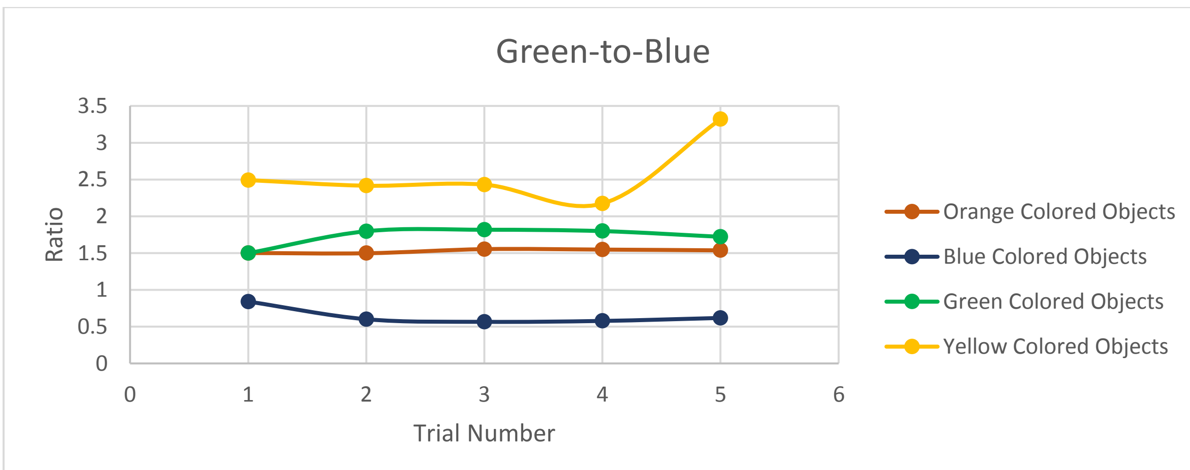
Figure 4-4 Pin Diagram for Color Sensor TCS3472

4.3.1 Using Color Filters to Remove Noise

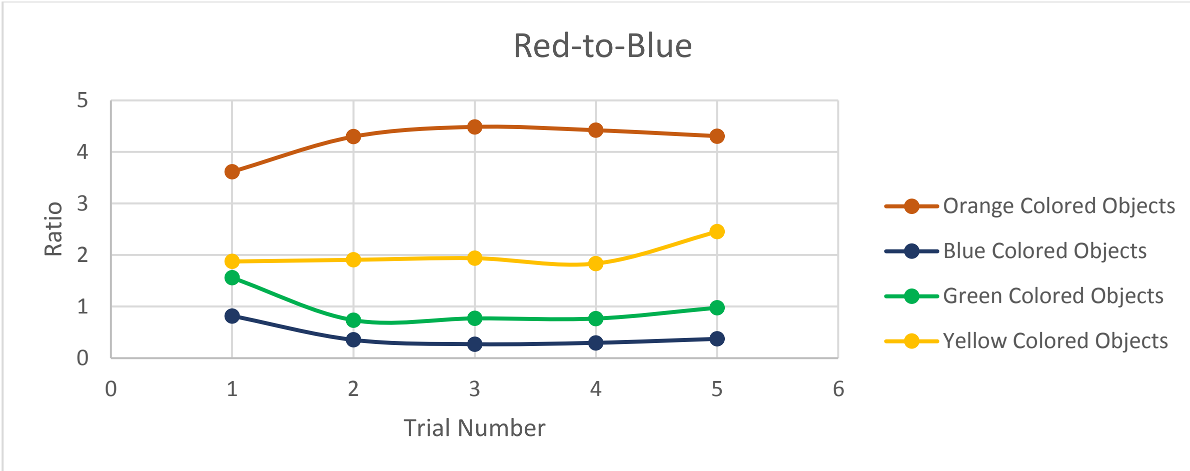
The object color was to be determined by using data from the red, green and blue (RGB) data fields of the color sensor. When the clear field was triggered, the clear along with the RGB values were recorded. It was observed that there was a direct correlation between the clear field and the RGB values. A higher clear value was accompanied by higher value readings of red, green and blue. Hence, the ratios of red-to-green, green-to-blue and red-to-blue were used to determine object color. Figure 4-5 below shows typical ratios for different colored objects.


Red-to-Green
Ratio
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
Trial Number
Orange Colored Objects
Blue Colored Objects
Green Colored Objects
Yellow Colored Objects

(a)


Green-to-Blue
Ratio
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
Trial Number
Orange Colored Objects
Blue Colored Objects
Green Colored Objects
Yellow Colored Objects

(b)



(c)

Figure 4-5 Color ratios for different colored objects

Using the clear distinction that we had in the ratios for different colored objects, the colors of the objects were determined. For the detailed recordings of the color sensor data for different trials, see Appendix A.

4.3.2 Removal of Background Noise

Once the color of the object had been determined, the data was used to apply bit-wise masking to the frame captured by the camera. This was done to filter out the background noise and get an accurate shape prediction. Every color has a unique range of RGB values which can be filtered from the rest of the image. Table 4-1 shows the RGB lower and upper limits for different color objects used in this project. The RGB values range from 0 to 255.

Table 3 RGB Ranges for Different Colored Objects

	Lower Limit [R, G, B]	**Upper Limit [R, G, B]**
Orange Color Object	185, 60, 0	220, 120, 55
Yellow Color Object	150, 150, 0	255, 255, 20
Blue Color Object	0, 0, 100	50, 100, 255
Green Color Object	0, 100, 0	90, 255, 100

Figure 4-6 shown below demonstrates an example of how the method described above can be used to perform shape recognition. The small amount of noise in the image left after bitwise masking can easily be eliminated.

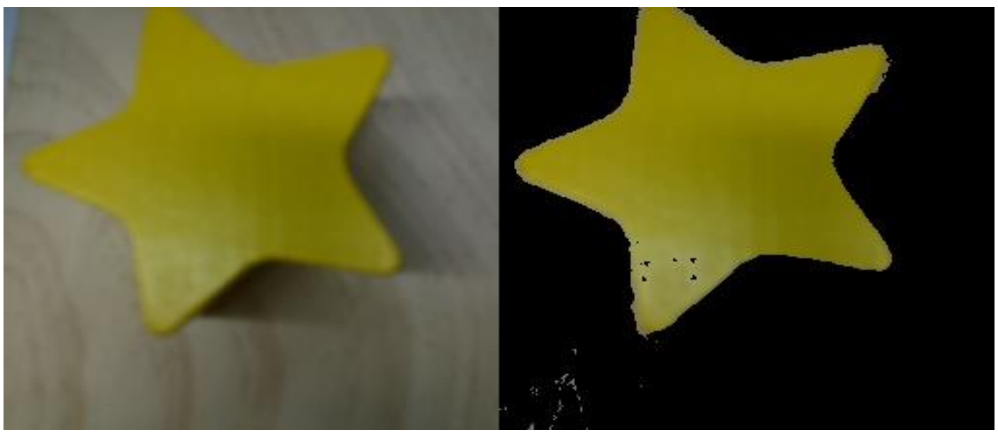


Figure 4-6 Color Filter Applied on Image to get rid of most of the Background Noise.

4.3.3 Grayscaling, Blurring and Edge Filter

In order to process an image for shape detection, it was first converted into a grayscale image. Then, a blur was applied on the image to get rid of the small amount of noise left over after implementing the color filter. After removing the noise, the Canny edge detection filter was applied to obtain the external contour of the object. Figure 4-7 shows the process described.

4.3.4 Canny Edge Detector [15] [16]

The Canny edge detector uses a multi-stage algorithm to detect edges in images. The Canny edge detector has a low error rate and has almost no false edges. The distance between the edge pixels detected and the real edge pixels is minimized and there is only one response per edge to reduce running time. The edge detector first filters out any noise, usually with a Gaussian noise filter. It then finds the intensity gradient of the image. It then removes pixels that are not considered to be part of an edge. This leaves behind only thin lines in the image. The process of removing these pixels is called non-maximum supression. The edge detector then uses a process called Hysteresis which compares pixel gradients to an upper and a lower threshold to determine edges.

An algorithm similar to the Canny filter is the Sobel edge detector which uses a similar methodology to detect edges in an image. Figure 4-8 shows the implementation of the Canny and Sobel filters in the early stages of this design project on Matlab.

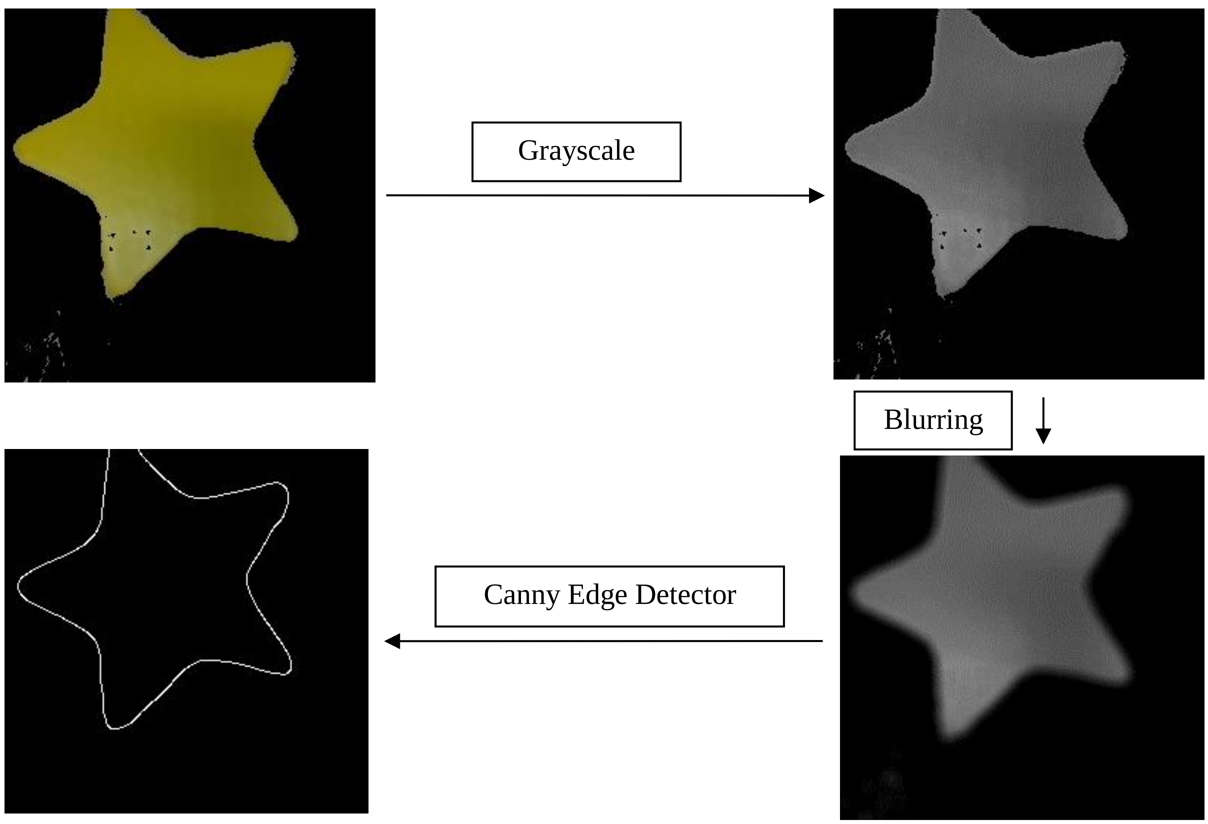
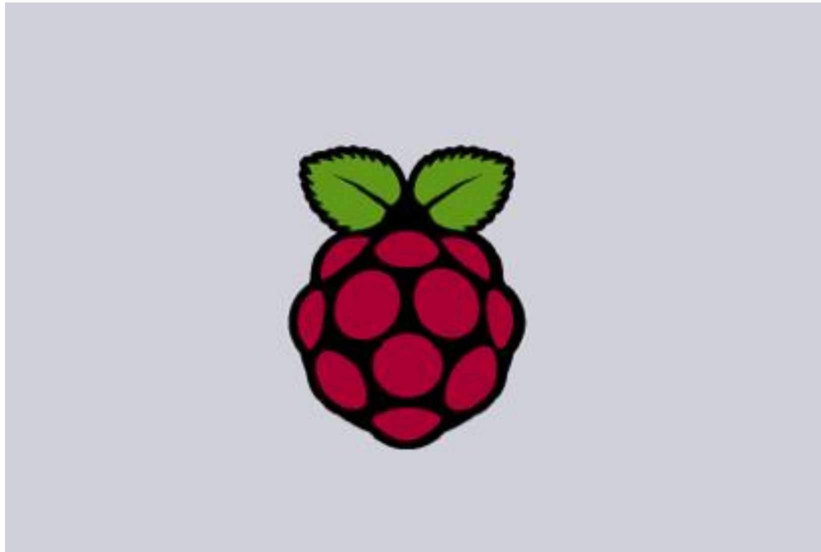
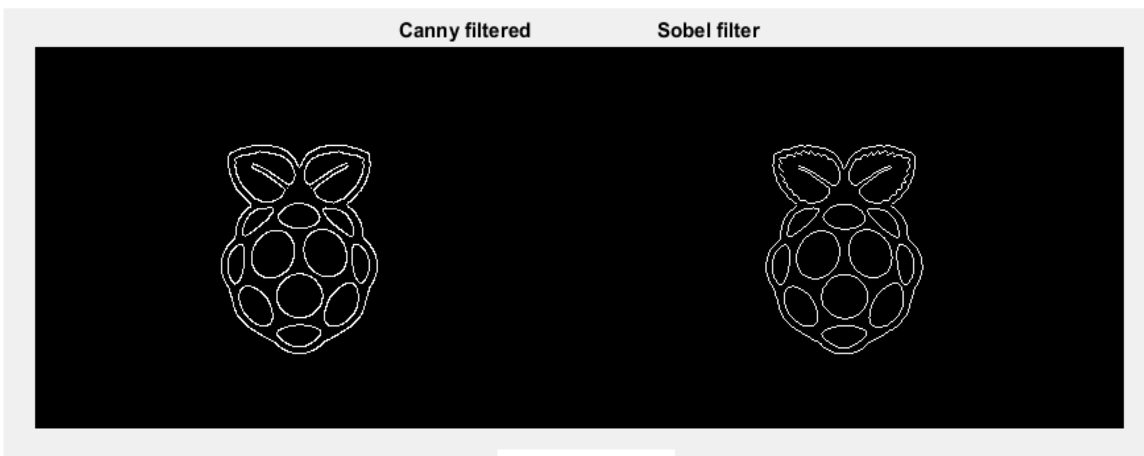


Figure 4-7 Obtaining the External Contour of the Object



(a)

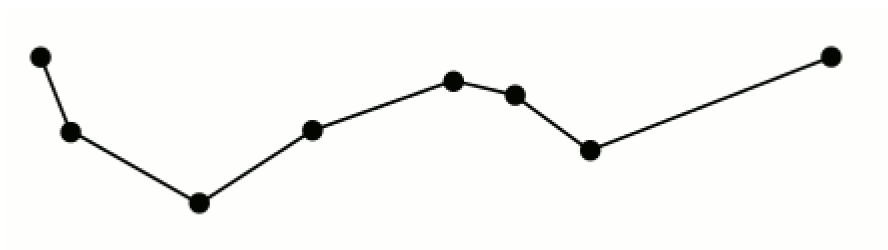


(b)

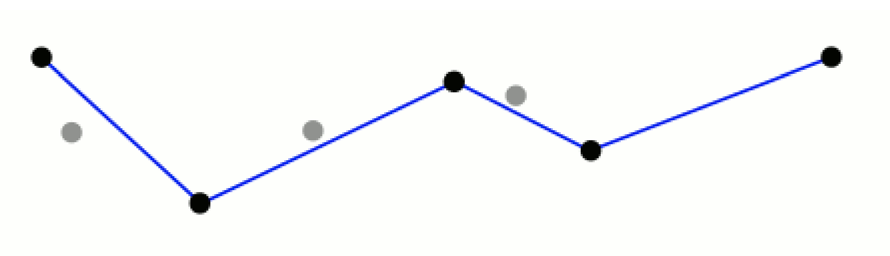
Figure 4-8 The Edge Detected Image of the Raspberry Pi Logo (a) Original (b) Canny and Sobel Edge Detection

4.3.5 Raemer-Douglas-Peuker (RDP) Algorithm to Detect Shape from External Contour

The RDP algorithm takes a curve which is composed of line segments and finds a similar curve with fewer points. The approxPolyDP function in the OpenCV library uses this algorithm. The approxPolyDP function approximates a curve or a polygon with another curve or polygon with less vertices so that the distance between them is less or equal to the specified precision. Figure 4-9 demonstrates the working of the RDP algorithm



(a)



(b)

.

Figure 4-9 The RDP algorithm has converted the original curve in (a) to a more simplified curve with less number of vertices as shown in (b) [17]

Chapter 5 - Program flow

The program that received data from the color sensor, captured images using the Raspberry Pi camera, processed images and controlled the conveyor belt and sorting bins has been described in this section.

5.1 Outline

The program described in figure 5-1 was written in python. The various libraries used in the program have been described briefly in the following section.

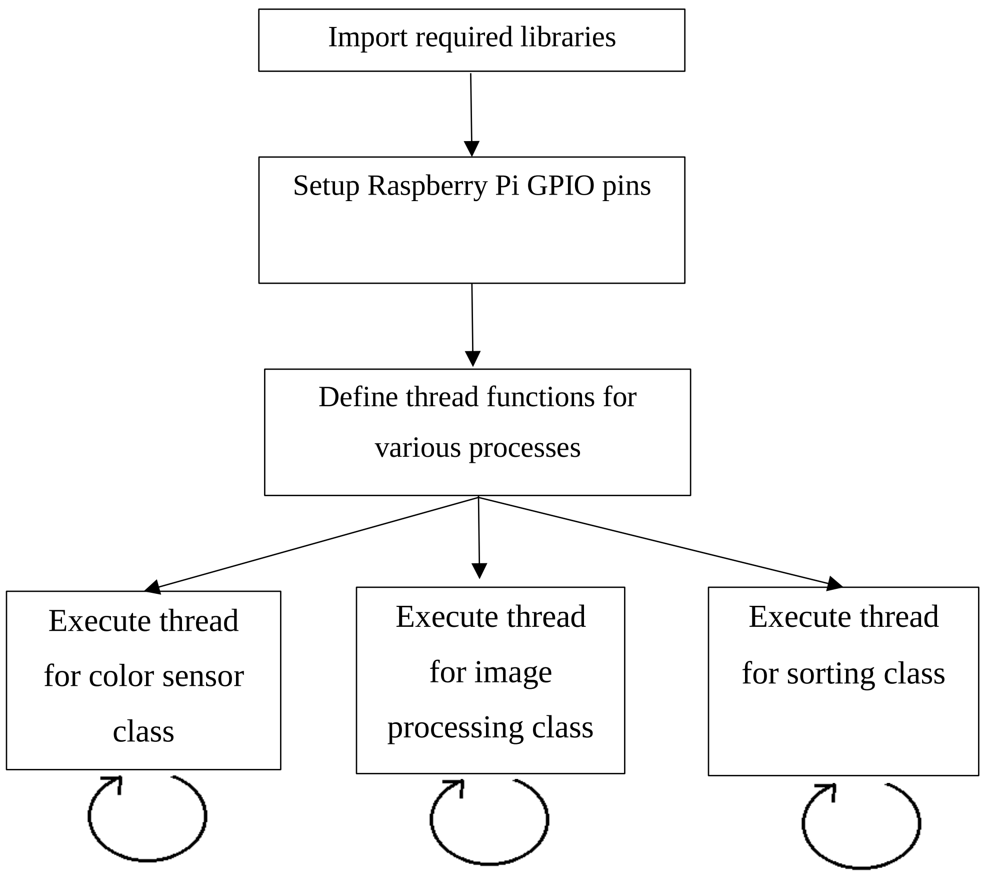


Figure 5-1 Program Flow Diagram

5.2 Libraries

Rpi Library was used to control the various GPIO pins on the Raspberry Pi computer. It was used to set pin modes to input or output and to generate PWM signals for the conveyor belt's DC motor. The input mode pin was used to read the signal coming in from the push-button switch which indicated the reference position of the sorting bins.

The smbus library was used to implement the I^2C interface to read data from the color sensor. The library accessed the I^2C/dev interface on the Raspberry Pi. To implement this library, the host kernel, which was the Raspberry Pi kernel, had to have I^2C support, I^2C device interface support and a bus drive adapter.

The time library was used to measure time between certain events in the detection and sorting process and set delays at various points in the program.

The PiCamera library provided a pure python interface to operate the Raspberry Pi camera module. This library enabled image capture, video capture, setting camera parameters like brightness, hue, saturation, and adding special effects to images like night, negative, snowy, spotlight, etc.

The OpenCV library was used to process the images captured by the camera. It was a very rich library with a variety of pre-defined methods that could be used for image and video processing. In the project, it was used to resize images, convert RGB color images to grayscale, apply blur to images to reduce noise, apply thresholding to binarize images, find contours in images and apply edge detection methods. The library is very capable of even higher end applications like face recognition and computer vision for artificial intelligence.

Large array operations necessary during image processing were carried out by the numpy library.

Chapter 6 - Circuit Implementation

This chapter describes the implementation of the circuit on a prototyping board as well as PCB design.

6.1 Prototyping board

After designing the circuit on a breadboard, it was implemented on a plane prototyping board. The circuit was developed for multiple functions i.e. current limiter for bidirectional DC motor and active low voltage control for all motors. Figure 6-1 provided below shows the setup for prototyping circuit.

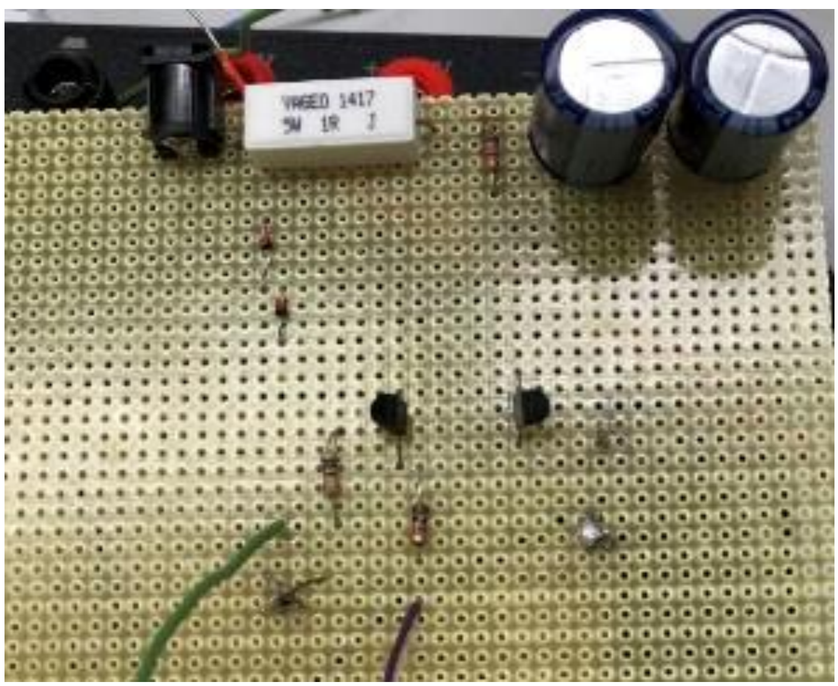


Figure 6-1 Circuit Implemented on Prototyping Board

6.2 PCB Fabrication

To provide an efficient interface between the peripherals and the Raspberry Pi, a PCB was fabricated. The goal was to minimize the extra space while maintaining the connection integrity of the circuit. It also added a robustness feature to the system. Figure 6-2 represents the fabricated PCB.

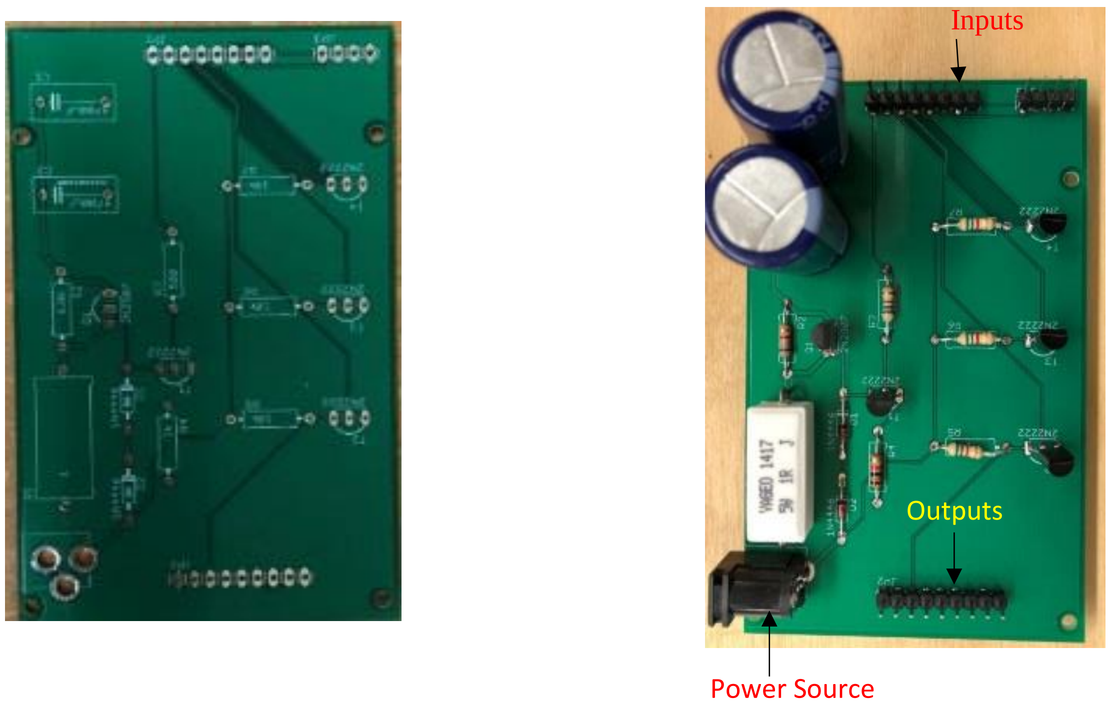


Figure 6-2 (a) Fabricated PCB (b) PCB with Components Soldered

6.3 Design Considerations.

The PCB was designed using Eagle CAD software. One major challenge was to ensure that the PCB copper traces were large enough to handle the current requirement. Eagle CAD offers a ULP script feature, which was used to calculate the required trace length and width for current required. Even though the project did not require any high frequency communication through the PCB, it was designed to operate with digital signals of frequencies as high as 1GHz. Figure 6-3 represents the measured data generated through Eagle.

Signal	f max. [MHz]	l [mm]	A [mm2]	R [mOhm]	w min [mm]	w max [mm]	Imax [A]
6V	2454.73	122.131	0.009	239.04	0.254	0.813	0.80
DC2A	5719.22	52.420	0.009	102.60	0.254	0.254	0.80
DC2A6	5395.88	55.561	0.009	108.75	0.254	0.254	0.80
DC2B	9415.22	31.842	0.009	62.32	0.254	0.254	0.80
DC2B6	77846.28	3.851	0.009	7.54	0.254	0.254	0.80
GND	1372.27	218.471	0.009	427.60	0.254	0.813	0.80
GPIO1	16525.18	18.142	0.009	35.51	0.254	0.254	0.80
GPIO2	16397.54	18.283	0.009	35.78	0.254	0.254	0.80
GPIO3	16525.18	18.142	0.009	35.51	0.254	0.254	0.80
N$1	58958.51	5.085	0.009	9.95	0.254	0.254	0.80
N$2	18395.11	16.298	0.009	31.90	0.254	0.254	0.80
N$4	22537.52	13.302	0.009	26.04	0.254	0.813	0.80
N$5	29134.72	10.290	0.009	20.14	0.254	0.254	0.80
N$6	3226.45	92.920	0.009	181.87	0.254	0.813	0.80
N$7	9894.60	30.299	0.009	59.30	0.254	0.254	0.80
N$8	37934.81	7.903	0.009	15.47	0.254	0.254	0.80
PWM6V	8010.88	37.424	0.009	73.25	0.254	0.254	0.80
PWMDC1	4128.58	72.616	0.009	142.13	0.254	0.254	0.80

Figure 6-3 Frequency and Current Parameters Generated by Eagle

The second most important consideration was to handle current spikes at the start-up for the DC motor. As discussed in chapter 3 the initial operation for DC motor required a current as high as 0.8 amperes. To absorb the heat generated from the current spike and analog noise generated from the surrounding electrical equipment along with thick power line traces, a ground plane was integrated in to the PCB as shown in Figure 6-4. It not only dissipated heat properly but also helped against the 60 hertz EM noise.

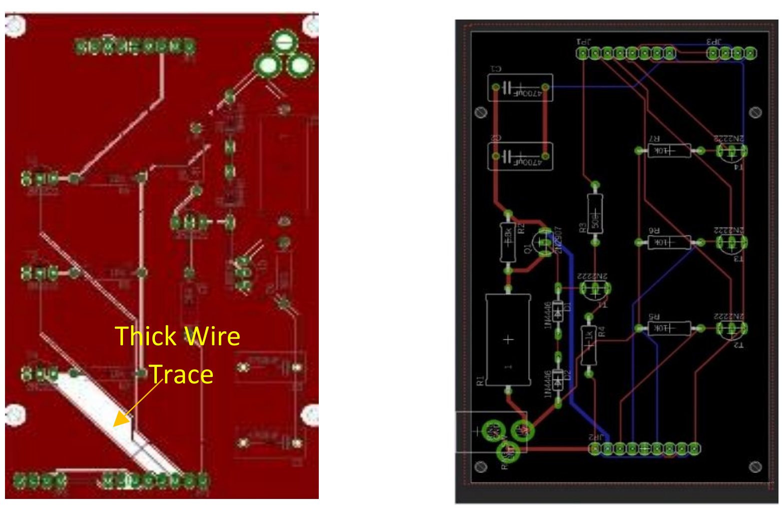


Figure 6-4 Thick Wire Trace

Chapter 7 - Conclusion

The goal of this project was to implement a device that integrated color and shape sorting capabilities on a single device. The project was broken down into hardware implementation, image acquisition and processing, and electrical circuitry to interface the Raspberry Pi computer with various peripheral devices. The hardware implementation relayed objects from one end of a conveyor belt to another in order for the objects to be sorted according to their shape and color.

Performance metrics were set at the start of the project to determine the success or failure of the project. The finished device could identify different object colors and shapes. It could sort the objects based on either of these. In case of failure to detect shapes, the object colors would still be identified. In the worst-case scenario, the conveyor belt would continued to relay the object and the object would be sorted into a sorting container designated specifically for indeterminate objects. The entire design had a power consumption of less than 12 watts. The prototype was capable of detecting up to 4 different shapes and 4 different colors accurately in less than 12 seconds.

The allotted budget for the project was $400. The estimated cost of this project was $241.03. The project was successfully implemented at a cost of $310.68. The project cost was slightly above the estimate. This was because a PCB was implemented to control the motors. This was over and above the performance goals set by the team at the start of the project.

7.1 Future Work

In future, the device can undergo more advanced development. One improvement it can have is the capability to detect more shapes of higher complexity. Also, the feature to detect multiple different shapes at the same time can be added. These features can put the device to some real practical use, since not all shapes are simple in nature. Another improvement it can have is the automation of the placing of objects on the conveyor belt. This will enable the device to be integrated into a real assembly line in a manufacturing industry. This reduces human labour costs since sorting tasks are often done manually by hand. Thirdly, material sensing capability can be added on to the device which will open the doors for application of the device to many other industries. The user-friendliness for all these aforementioned applications can be further enhanced by adding a wireless control option with a graphical user interface for users to operate easily.

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Appendix A

Color sensor data measurements

Table 4 Color Sensor Data BC

	Clear	Red	Green	Blue		R/G	G/B	R/B
Orange								
1	3450	2138	887	591		2.410372	1.500846	3.617597
2	14565	9320	3248	2169		2.869458	1.497464	4.296911
3	10868	7021	2431	1565		2.888112	1.553355	4.486262
4	10713	6906	2417	1562		2.857261	1.547375	4.421255
5	9447	6056	2161	1406		2.802406	1.536984	4.307255
Blue								
1	1655	536	550	654		0.974545	0.840979	0.819572
2	4789	888	1506	2507		0.589641	0.600718	0.354208
3	7783	1158	2415	4271		0.479503	0.565441	0.271131
4	6638	1068	2070	3584		0.515942	0.577567	0.297991
5	4164	806	1333	2157		0.604651	0.617988	0.373667
Green								
1	1198	491	472	315		1.040254	1.498413	1.55873
2	7086	1442	3514	1956		0.410359	1.796524	0.737219
3	5620	1192	2809	1546		0.42435	1.816947	0.771022
4	6061	1296	3034	1687		0.427159	1.798459	0.768228
5	2979	796	1401	814		0.568166	1.72113	0.977887
Yellow								
1	19459	6610	8785	3525		0.752419	2.492199	1.875177
2	23199	8083	10238	4238		0.78951	2.415762	1.907268
3	21903	7693	9646	3968		0.797533	2.430948	1.93876
4	5749	2075	2456	1130		0.84487	2.173451	1.836283
5	15779	5318	7198	2168		0.738816	3.320111	2.452952

Appendix B

Images of the hardware implementation

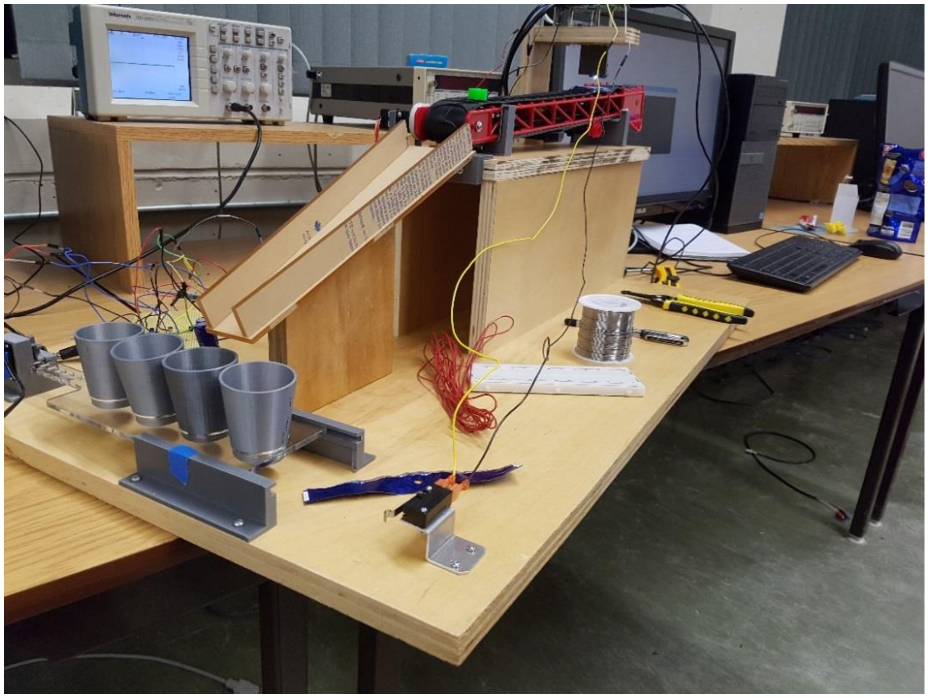

Figure 0-1 Overall Hardware Implementation

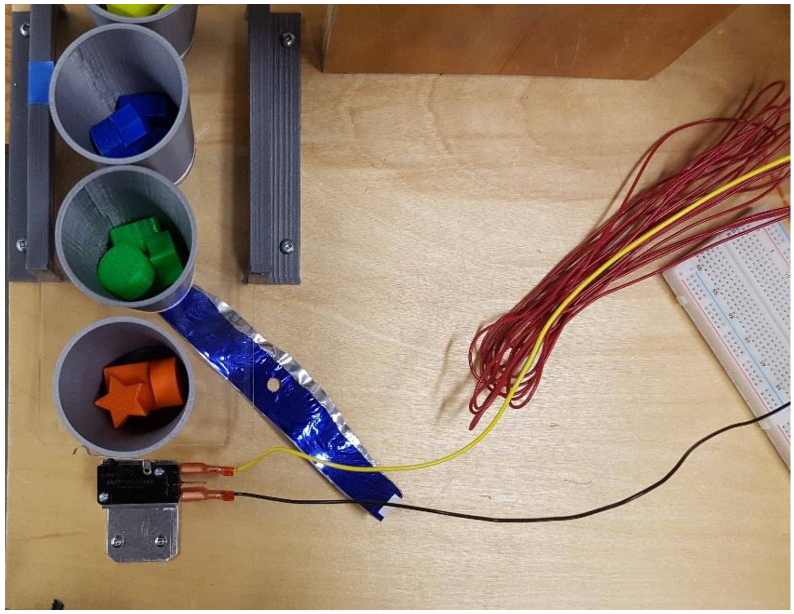

Figure 0-2 Sorting Bins and Switch

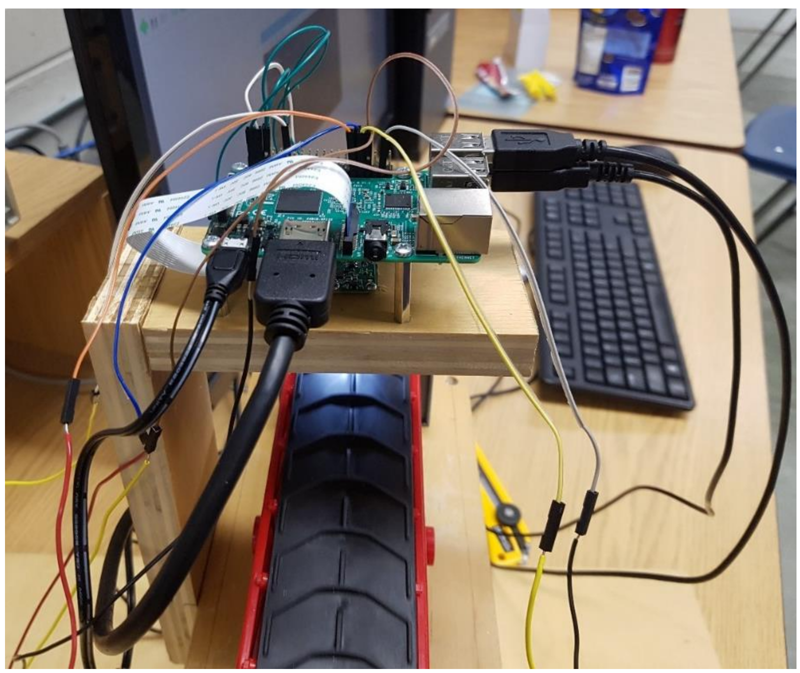

Figure 0-3 Raspberry Pi Mounted