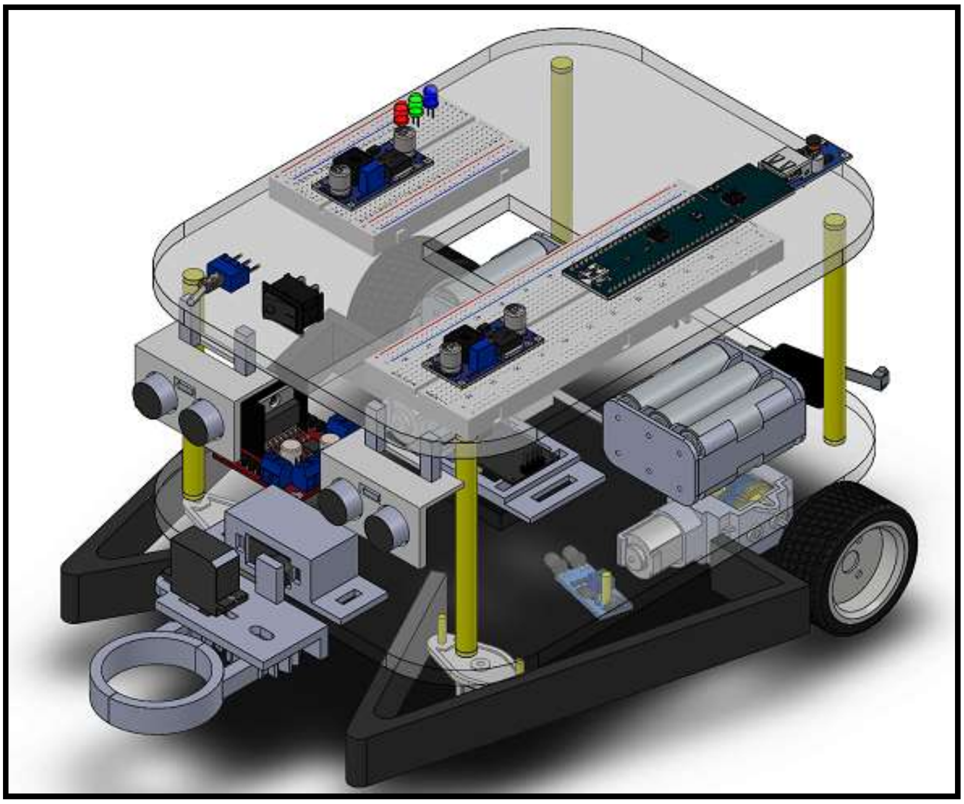
MONASH University
Engineering

ECE 3091 Engineering Design - S2 2020



Team 5
Project Report

Clifton Mak	29439701
Jolene Ong	29592038
Lim Wei Jun	29036348

Executive Summary

The goal of the project is to build an autonomous robot that is able to carry out a series of tasks on the competition arena. The robot has to collect one puck at a time from the puck collection zone at the center of the arena. Then it would need to transport the puck to the puck capture zone through certain zones in the arena. At the puck capture zone, the robot would need to deposit the puck depending on the colour assigned to it at the start. The robot also has to make sure that it will not collide with any obstacles in the arena. The robot is designed to autonomously repeat the tasks above within the time limit of 5 minutes. The robot should also perform all the tasks efficiently to collect more pucks because it will be competing with other teams in week 12.

In order for the robot to carry out the tasks described above, the robot has to have consistent navigation back to the desired section in the arena, identifying the colour of the puck, puck gripping and flipping mechanism and obstacles avoidance.

The tasks have also introduced problem statements to each mechanical, electrical and software engineering aspect. For mechanical, the body of the robot other than the gripper must be built sturdy in a dimension of 30cm x 30cm. The robot must also be able to navigate smoothly in the arena. For electronics , the choice of electronics components chosen for the robot must be reliable to perform the delicate tasks precisely. The robot must also have a good power management system that could allow all electronics components to work at their maximum potential. For software, an efficient code has to be written for the robot to maximise all the usage of the sensors and actuators placed on the robot. It is also responsible to allow the robot to autonomously perform all the tasks.

The key innovations included in the robot to solve the problems described above is that a light and sturdy material was used to build the chassis of the robot. Then there is also a lightweight 3D printed gripper powered by two servo motors to perform the gripping and flipping action to the puck. The robot also has a main supply of 15.6V from the Ni-mh rechargeable batteries which will be stepped down to 12V and 5V before supplying to the other electronics components. The extra voltages come from extra batteries included in the robot to make sure that the robot is able to last longer in the arena and also to further save on current the electronics components will be switched on only when they are in use.

According to the rules of the project the whole robot can only be controlled by the PsoC microcontroller. Therefore, the code written is well designed and arranged in a state diagram, such that it would simplify the debugging process of this complex algorithm. Besides, interrupts are also implemented to allow the important tasks such as colour sensing, obstacles detection and navigation system to be carried out without delay. For the navigation system, the XY coordinate system is also implemented to allow the robot to autonomously navigate in the arena safely.

The detailed CAD drawing of the final design of the robot is shown below.

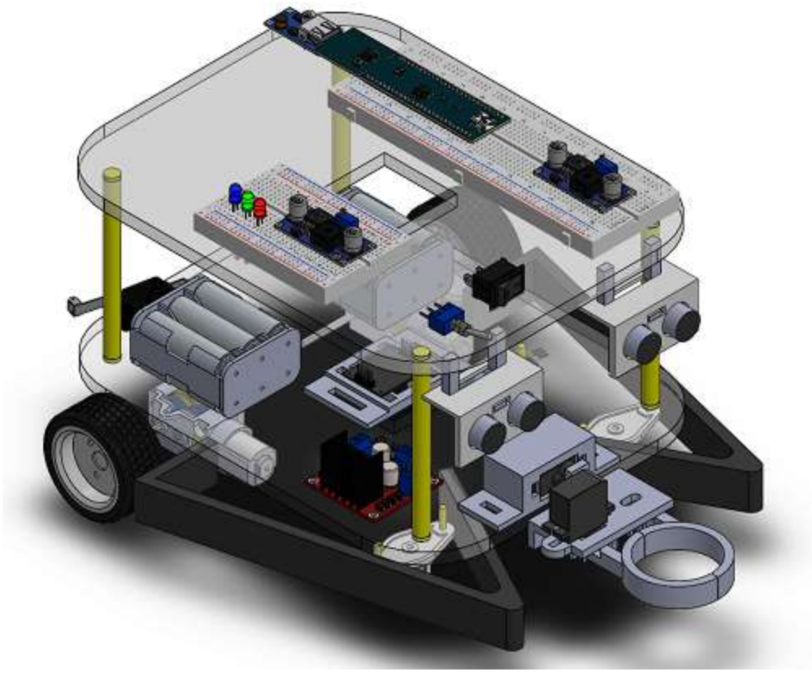


Figure 1: Isometric view of the robot design

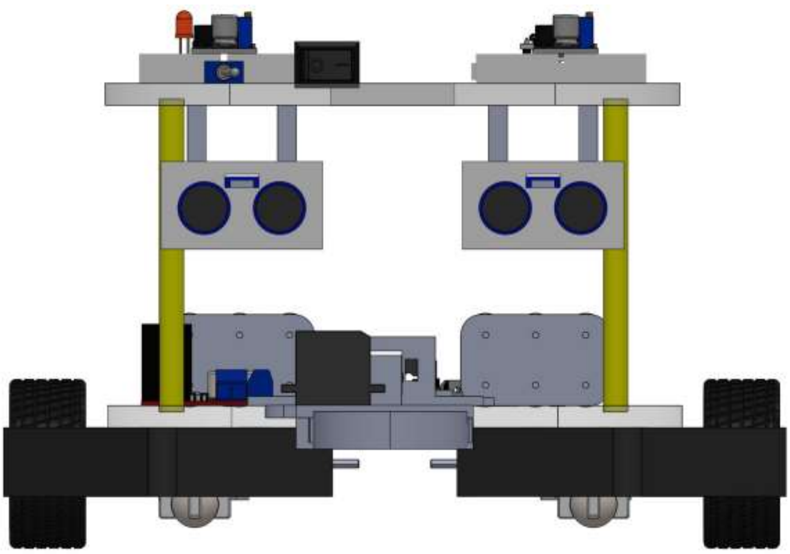


Figure 2: Front view of the robot design

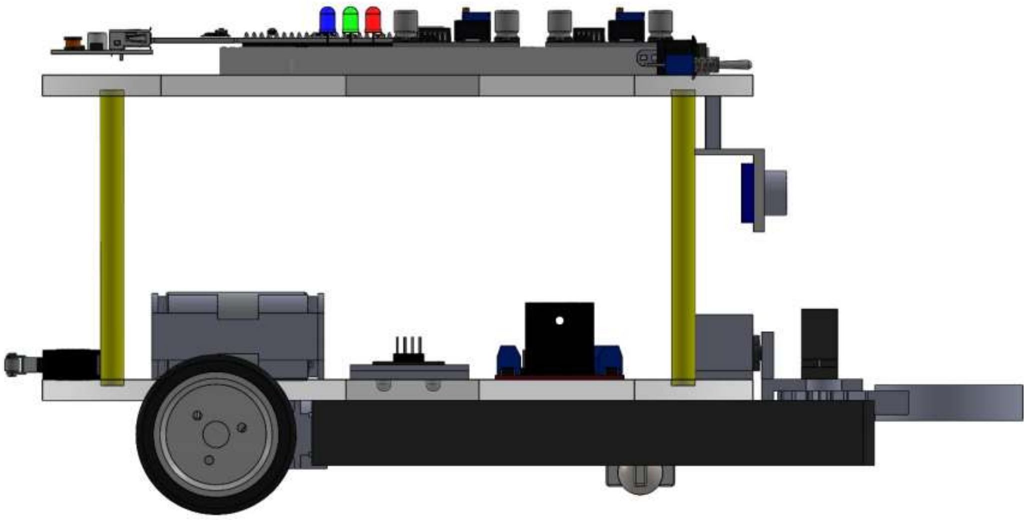


Figure 3: Left side view of the robot design

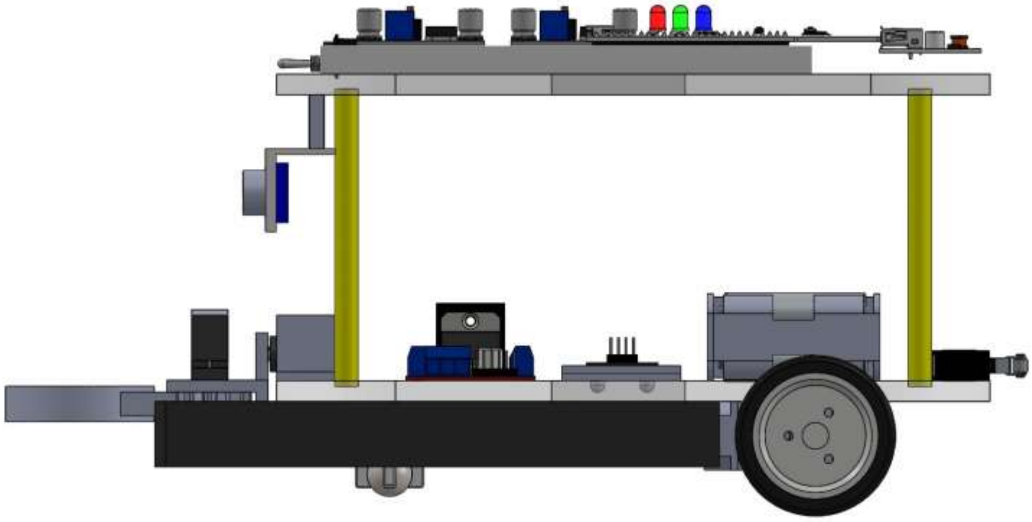


Figure 4: Right side view of the robot design

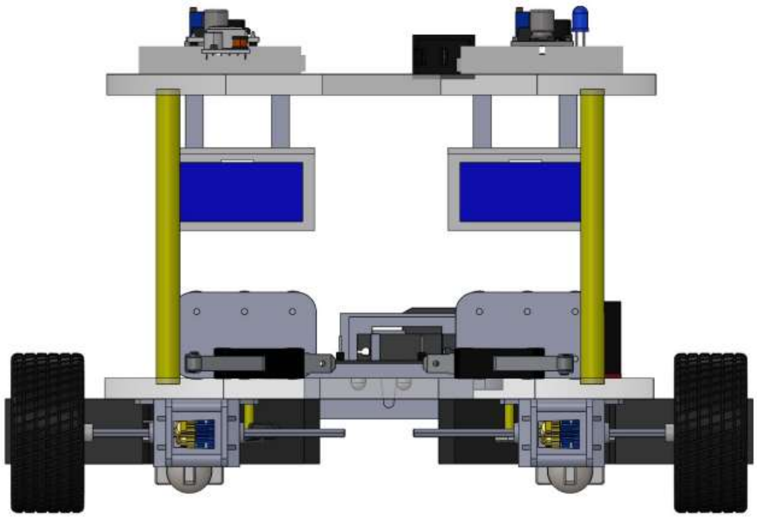


Figure 5: Back view of the robot design

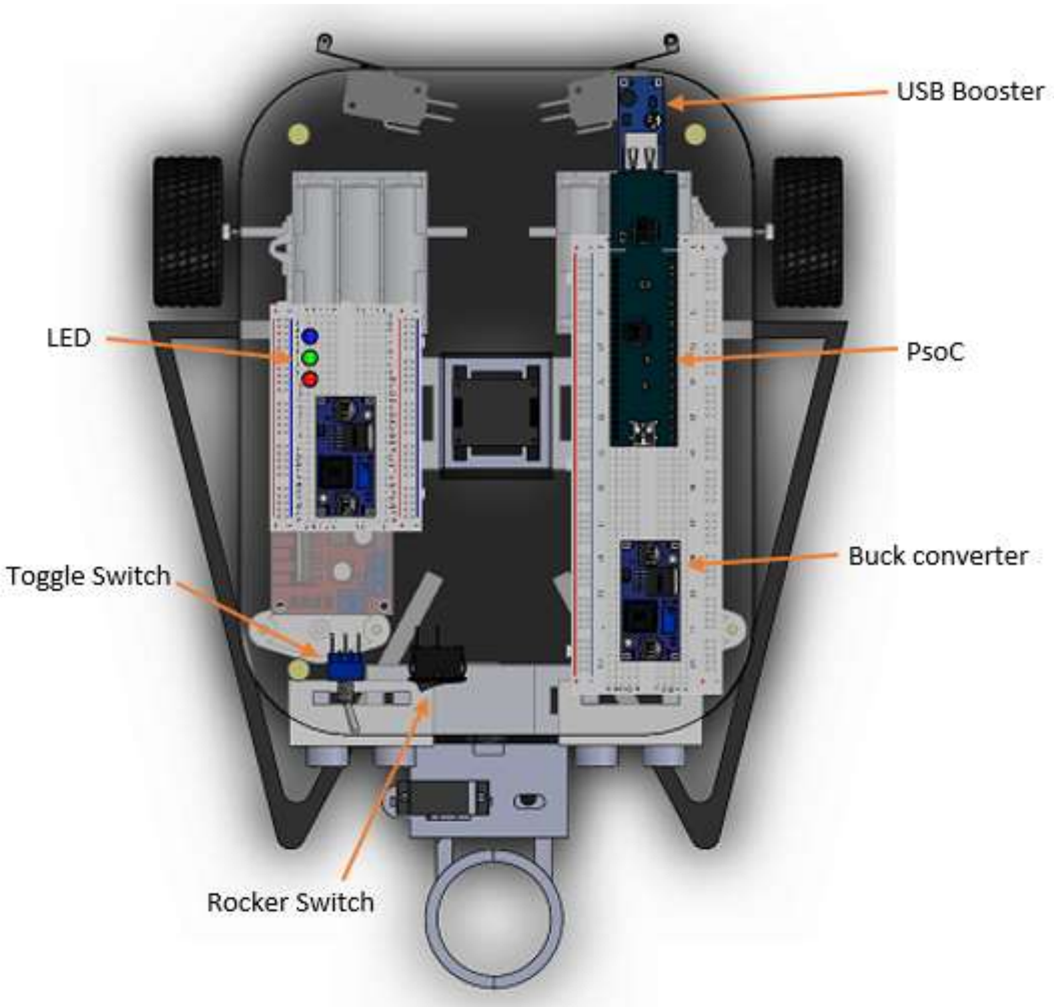


Figure 6: Top view of the robot design (top layer)

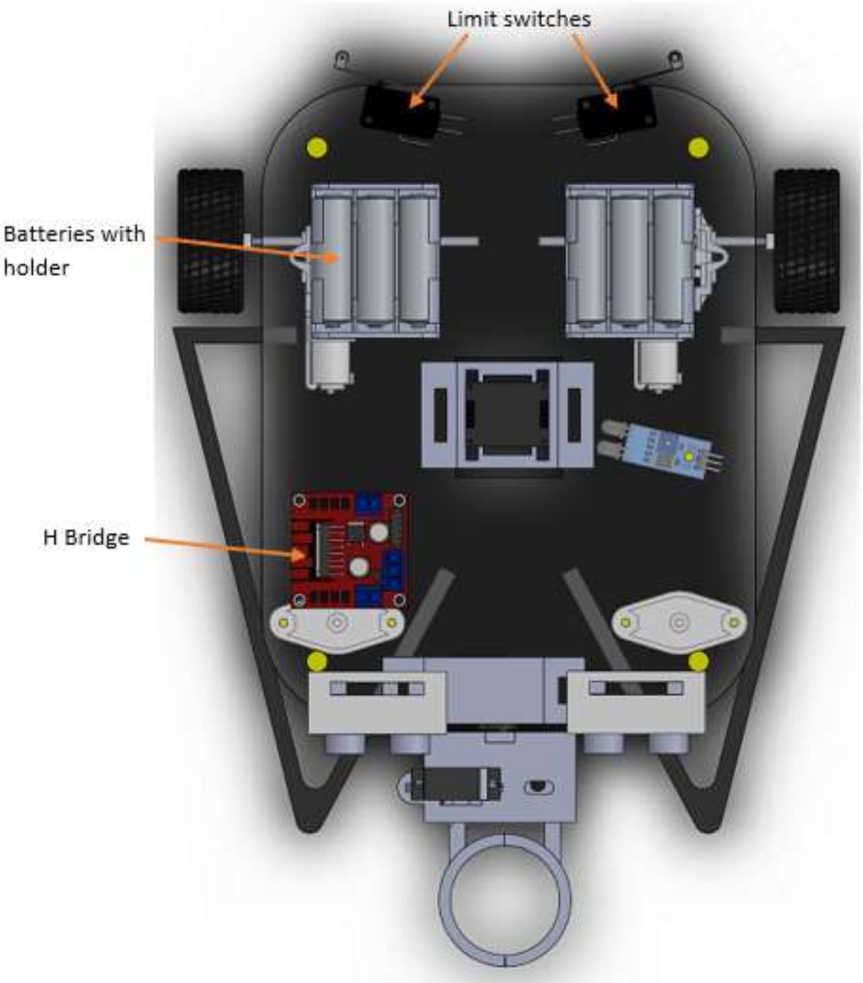


Figure 7: Top view of the robot design (bottom layer)

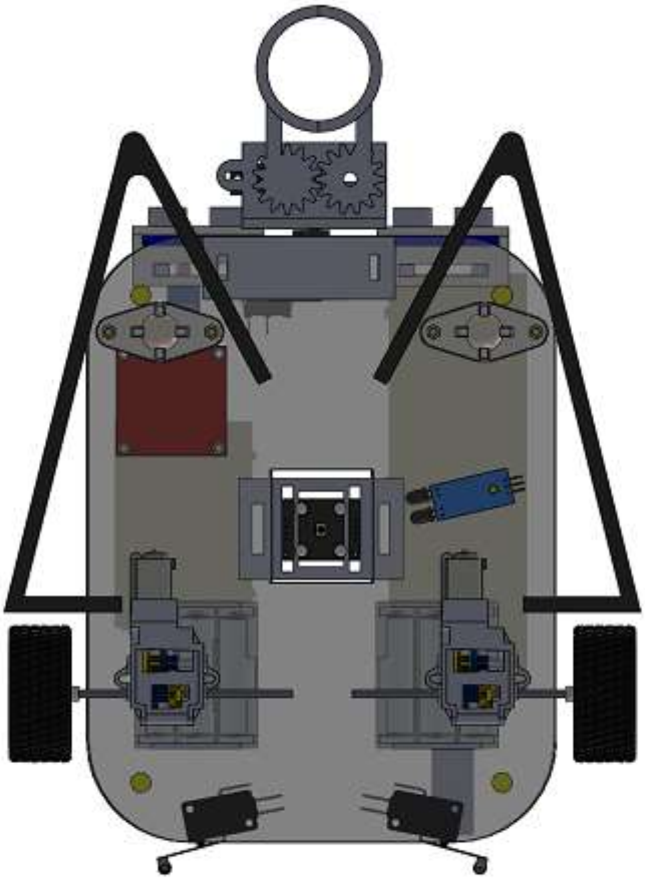


Figure 8: Bottom view of the robot design

Table of Contents

1.0 Mechanical Design

1.1 Chassis of the robot

Figure 9: Side view of the robot with chassis

According to the project requirements, the robot has to be sturdy and have no hanging wires showing outside of the robot. Therefore, a chassis was built to protect all the main components of the robot, such as sensors and the PsoC. The chassis of the robot as shown in Figure 9 is built from plastic corrugated cardboard because this material is rigid, lightweight and recyclable. Therefore, it is able to provide sufficient protection for the robot while keeping the robot lightweight. It is an important factor to keep the robot as light as possible because based on a few test runs with the robot, it was observed that the heavier the robot is, the slower it moves. This will then affect the numbers of pucks the robot can collect in a 5 minute round.

1.2 Placement of the Components

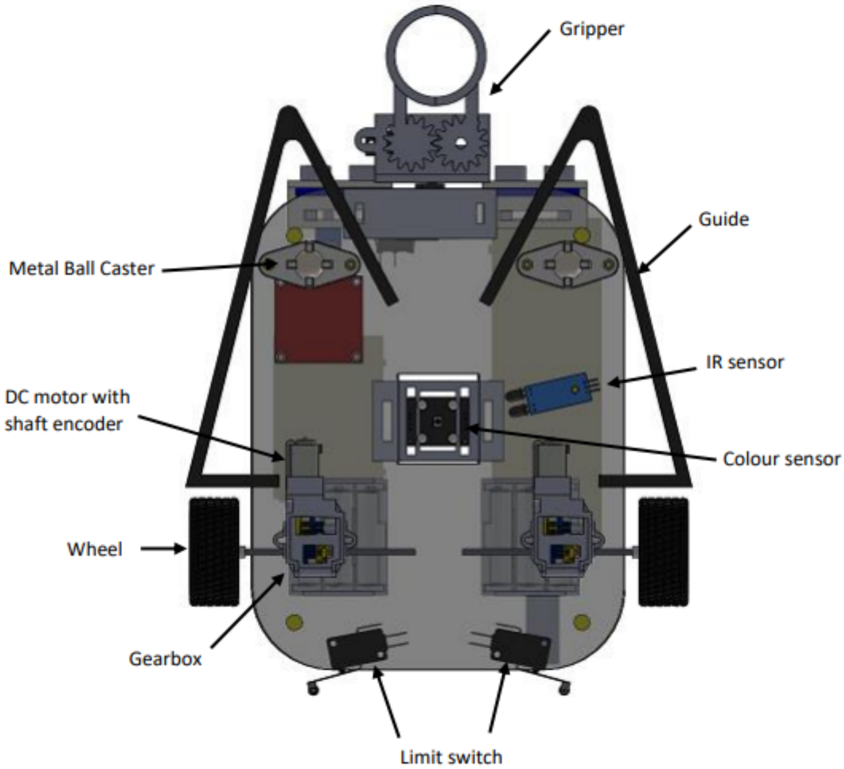


Figure 10: Bottom view of the robot with label

From Figure 10 above, it is shown that the robot has two wheels at the back of the robot that are powered by the DC motor with shaft encoder attached to the gearbox. The wheels are the main components for the locomotion of the robot and for the front part of the robot there are two metal ball casters that were used to provide support for the robot when the robot is moving, such that they are able to roll smoothly on the surface of the arena. The wheels and the caster are placed far apart to ensure that the robot is balanced properly with a center of gravity at the center of the robot so that the robot is able to make smooth and steady turns.

As for the gripper it will be placed at the very front of the robot whereas the colour sensor is placed at the bottom of the robot and directly behind the gripper. This is because the robot will move over the pucks in the arena and when there is a puck in front of the IR sensor, the robot will stop moving and then the colour sensor will start scanning for the colour of the puck. This is the reason why the IR sensor has to be placed at the side of the colour sensor and also pointing towards the center of the colour sensor, as shown in Figure 10.

The guide was built using plastic corrugated boards. It is used to ensure that only one puck at a time will be presented to the colour sensor by having a gap size between them that can only fit one puck. Besides, the guides will also prevent any pucks from getting stuck at the caster or the wheel of the robot. This is because having a puck stuck at the wheel would impede the wheel movement and hence affect the robot motion.

As for the limit switches, they were placed at the back of the robot as shown in Figure 10. They are used to align the robot with the wall of the arena. The reason why they are placed at an angle is to enable the robot to actuate them with only requiring a small force. This will ensure that the robot will not damage itself when pushing against the wall. The switches are also placed close to the end of each side of the robot such that the robot will be at a perfect perpendicular position with the wall behind it when both limit switches are triggered.

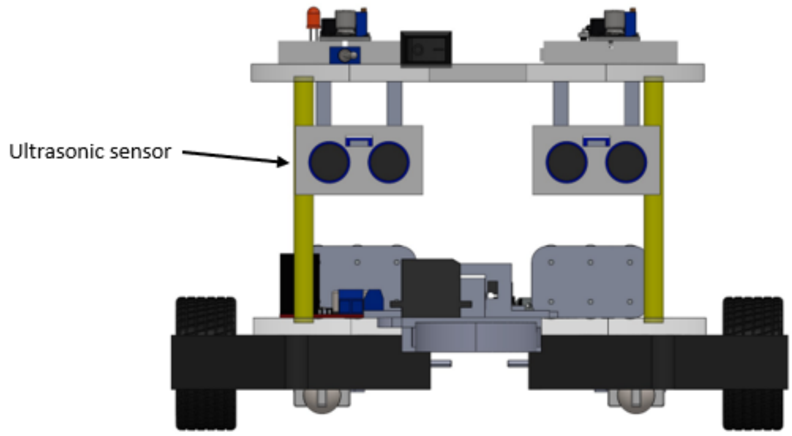


Figure 11: Front view of the robot with label

From Figure 11 it can be seen that there are two ultrasonic sensors placed at the front of the robot to avoid collision with the wall or any obstacles placed on the arena. The main reason for using two ultrasonic sensors far apart is to provide a wider view for the robot by having a wider sensing coverage.

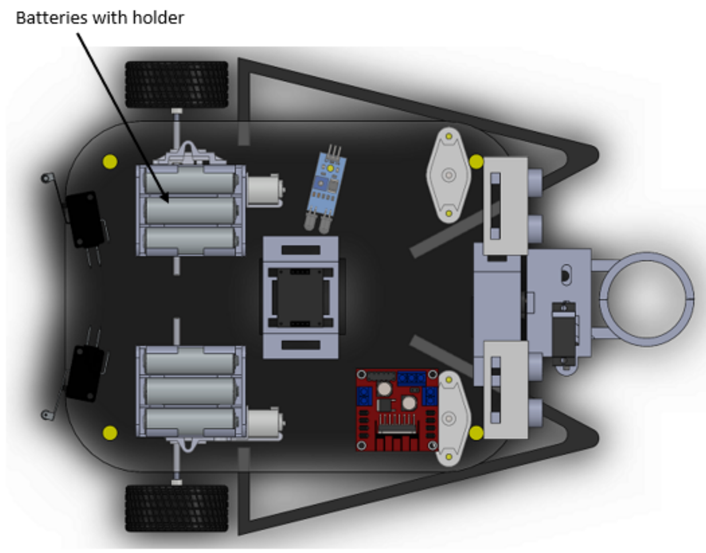


Figure 12: Bottom layer view of the robot with label

The 12 rechargeable batteries that are used to power the whole robot are the heaviest components on the robot base. Therefore, their weight must be distributed evenly on the robot so that it will not affect the center of gravity of the robot. From Figure 12, the 6 batteries with its holder are placed at each side of the robot supported by the two back wheels. They are placed at the bottom layer of the robot to make the center of gravity of the robot as low as possible.

1.3 Gearbox

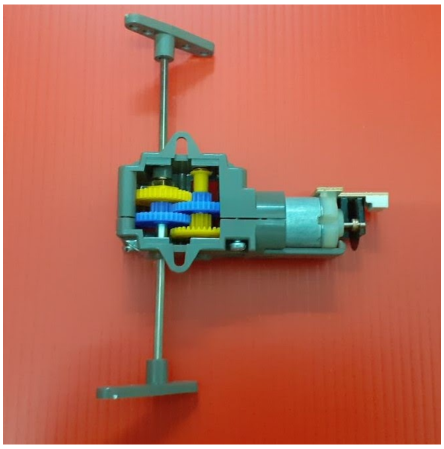


Figure 13: Tamiya gearbox

ギヤ比 Gear ratio	回転数 Rotations	回転トルク Torque
12.7:1	1039 rpm	94 gf-cm
38.2:1	345 rpm	278 gf-cm
114.7:1	115 rpm	809 gf-cm
344.2:1	38 rpm	2276 gf-cm

Figure 14: Configuration of the gearbox [1]

The tamiya single motor gearbox with 4 different configurations was used with the two DC motors with shaft encoder in the robot. It is used to reduce the shaft speed of the DC motor and increase the torque output of the motor. The gear ratio configuration that was used was 114.7:1 which can provide a torque of 809 gf.cm and rotational speed of 115 rpm as shown in Figure 14 above. In the case of a DC motor with constant voltage supply at around 10V, the relationship between the torque and speed is inversely proportional, and that means in order to move the robot, the gearbox would need to provide a sufficient amount of torque, but at the same time the speed will be reduced to compensate for that requirement.

1.4 Gripper design

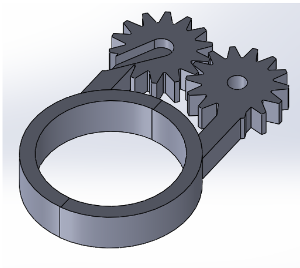


Figure 15: Gripper

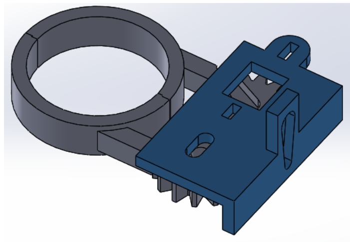


Figure 16: Base of the gripper

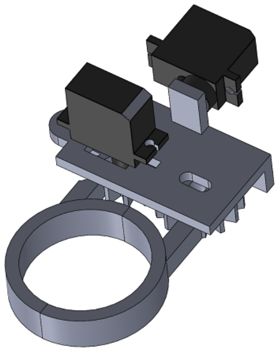


Figure 17: Gripper Design with servo motor

Figure 15 and Figure 16 above are 3D printed parts of the final design of the gripper used in the robot to perform actions such as picking up the puck and flipping the puck. The gripper is designed to be powered by two metal micro servos, MG90s as shown in Figure 17. The size and shape of the gripper is designed based on the dimensions of the puck, such that it is able to grip one puck at a time. From Figure 15, the gripper has two hands to it and the gears attached to both of them are meshed together, such that when one side is rotated by the servo motor, the other side will also be rotating at the same time. This design enables the gripper to open and close and hence gripping and depositing the puck. The base of the gripper is attached to the gripper and with the help of the servo turning 180 degrees, it is able to turn the whole gripper by 180 degrees. This base of the gripper is able to perform the flipping action to the puck when the gripper is holding a puck.

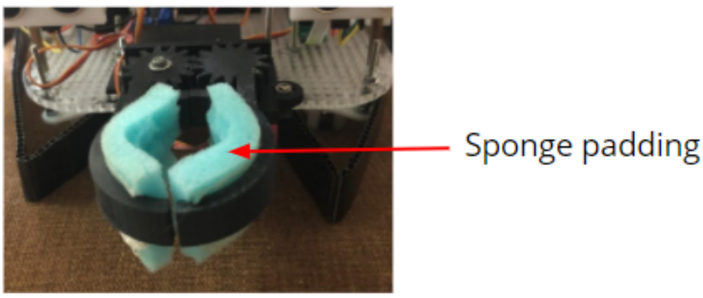


Figure 18: Gripper with sponge padding

There is a sponge padding added at the inner wall of the gripper to provide extra gripping friction to the puck, such that the puck will not drop off when the robot is transporting it to the puck capture zone. This sponge as shown in Figure 18, is taken from a recyclable dishwasher sponge.

1.5 Alternatives for Mechanical Design

1.5.1 Old Design of the Gripper

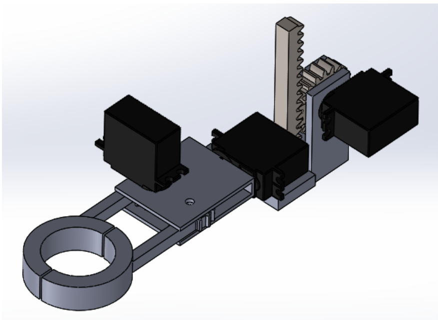


Figure 19: Alternative design of the gripper

The old design of the gripper as shown in Figure 19 are powered by 3 servo motors, two of them have the same usage as the current gripper design and the third servo motor is attached to a rack and pinion gear structure to raise the whole gripper structure up and down. The reason why it was not considered in the final design is because from a few test runs in the arena, when all 3 servo motors are powered at the same time, it would draw a large amount of current causing the other electrical components of the robot to not function properly. It would especially cause the whole robot to slow down by a significant amount.

1.5.2 Caster wheels

Figure 20: Metal caster wheel [2]

Figure 21: Plastic caster wheel [3]

At the very start of the project the metal caster wheel as shown in Figure 20 was used as the front wheel of the robot. The reason it was chosen over the plastic caster wheel at first is because it has small ball bearings in it that make it smoother than the plastic caster wheel. However, progressively, as all other components of the robots are assembled together, it was discovered that the plastic caster wheel is a better option because it is lighter and will also not affect the steadiness of the robot when travelling in the arena.

1.5.3 Chassis of the robot

Figure 22: MDF board [4]

Initially, the medium-density fiberboard (MDF) was decided to be used as the material for the chassis of the robot. It is made from wood residual that is combined using wax and resin, it is lighter and has the same density as a normal piece of wood. It can also be obtained easily from the market. Therefore, it would be a good material to craft the strong and sturdy casing for the robot. However, the chassis built from the MDF board is too heavy as compared to the chassis built from the corrugated board. If the robot is heavier, the amount of force required to move the robot will also be higher. Therefore, the DC motor will need to draw more current to move the robot in the arena and the batteries will get drained out much faster.

1.5.4 Use of rubber bands at the gripper

Since the gripper is built from two hands, and a servo is used to rotate the gears at one of the hands to either open and close the gripper. The initial idea is that rubber bands can be used to tie the hands together, such that the gripper will always be closed by the elastic force of the rubber bands tied on them. Then, when the robot wants to pick up the puck the servo motor will need to rotate at a bigger angle to open the gripper and at the same time try to overcome the elastic force of the rubber bands.

The benefit of this implementation is that after the gripper has picked up a puck, the servo motor can be switched off to save on the current. This is because the servo motor is not required to maintain its position to make sure that the gripper is close when holding the puck, but the rubber band would do the job. However, it was not implemented in the final gripper design because it has to be tight to perform the job correctly but if the rubber bands are too tight it would also require the servo to apply a larger force to overcome its elastic force when opening the gripper. Besides that, it is also vulnerable to wear and tear, and this inconsistency might cause the robot to drop the puck on the arena when transporting the puck to the puck capture zone.

1.5.5 Placement of the colour sensor and IR sensor

Initially the colour sensor was decided to be placed at the front of the second layer of the robot and the IR sensor will be placed directly under the gripper. So, when a puck is detected by the IR sensor, the gripper would capture and flip it up to let the colour sensor scan the colour of the puck. However, it was realised that it was stated in the rules that the robot should not manipulate the position of a green puck in the puck collection zone. Therefore, this placement method was not used to prevent any unforeseen error or accident occurred, such as error in the state of the robot or even obstacles detected in front of the robot that would cause the robot to move with the green puck. The current puck collecting algorithm is also much faster and more accurate such that the colour sensor at the bottom of the robot will not be affected by the surrounding light source and time saved on gripping the puck for colour sensing.

2.0 Electronic Design

2.1 Sensors

2.1.1 Ultrasonic Sensor

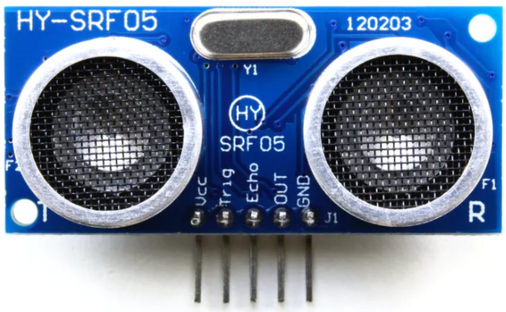


Figure 23: HY-SRF05 ultrasonic sensor [5]

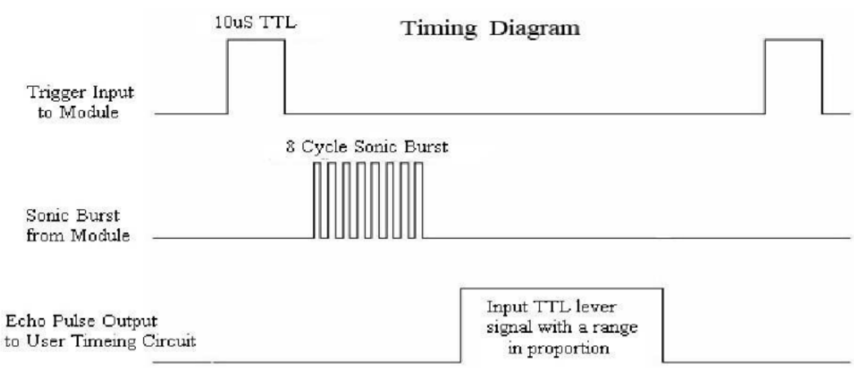


Figure 24: Timing diagram of the HY-SRF05 ultrasonic sensor [6]

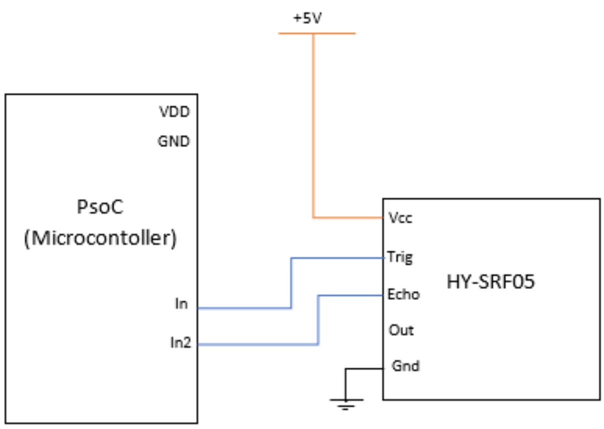


Figure 25: Wiring of ultrasonic sensor to PsoC

The HY-SRF05 ultrasonic sensor was used for the obstacle avoidance and collision detection feature. The HY-SRF05 ultrasonic sensor uses sonar to measure distance of an object with a working range of 2cm to 400cm. It has 5 pins namely; Vcc, Trig, Echo, Out and Gnd. When the Trigger(Trig) pin is set to high for 10μs, the 10μs pulse will transmit 8 cycles of sonic bursts of ultrasound at 40kHz. Immediately after, the echo pin will be triggered high and will stay high until the transmitted sonic burts is reflected back to the receiver of the ultrasonic, after which the echo pin will be pulled to low again. As seen in the timing diagram in Figure 24. The pulse width of the echo signal corresponds to the time taken by the transmitted signal to travel from the transmitter to the obstacle and then back to the receiver. Based on the component datasheet, 1μs corresponds to 58cm.[6] Therefore by using ratio, the distance can be calculated by the following formula:

$$Distance(cm) = \frac{Echo\ pulse\ width}{58(\mu s)}$$

Alternatively, the distance can also be calculated by relating the echo pulse width signal to the velocity of sound in air(340m/s). Since the echo pulse width includes the time for the transmitted signal to travel back and forth, the distance calculated must be divided by 2. The alternative formula is:

$$Distance = \frac{Echo\ pulse\ width\ x\ velocity\ of\ sound\ in\ air}{2}$$

2.1.2 Colour Sensor

Figure 26: TCS 3200 colour sensor [7]

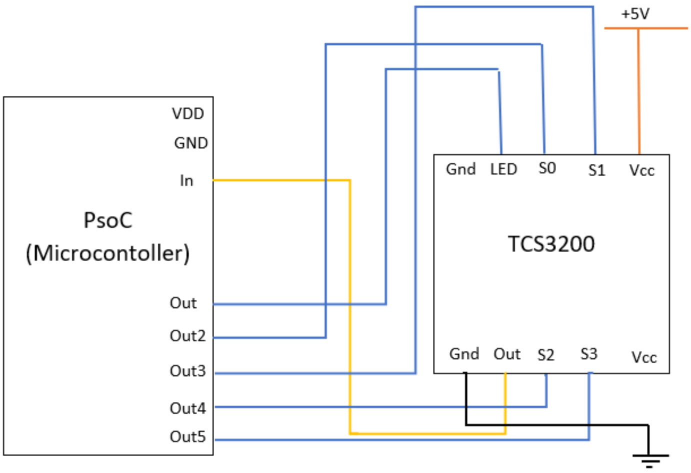


Figure 27: TCS3200 connections to PsoC

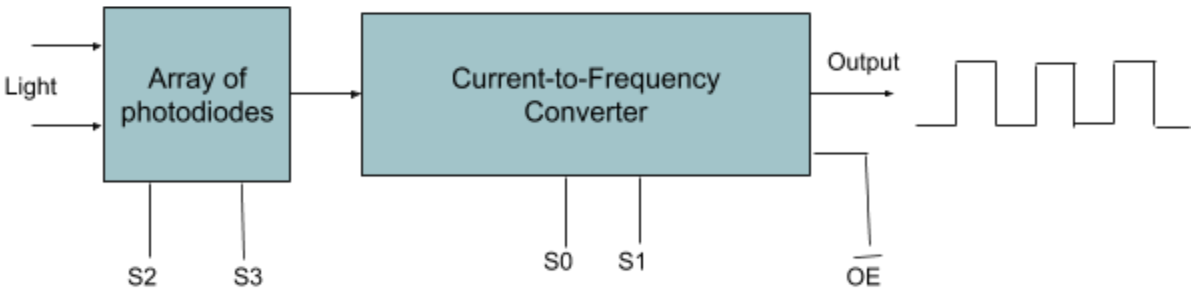


Figure 28: Colour sensing operation

The TCS 3200 was used to determine the colour of the pucks. It uses a TAOS TCS3200 RGB sensor chip to detect colour. It also contains 4 white LEDs that light up the object in front of it. [8]

The sensor consists of an 8x8 array of photodiodes with 4 different filters; 16 red filters, 16 blue filters, 16 green filters and 16 clear(No) filters. The S2 and S3 control pins are used to select which photodiode filter will be used whereas the S0 and S1 pins are used to scale the output frequency waveform. The control pin settings are summarised in tables x and x [9] below:

Table 1: Output frequency scaling settings

S0	S1	Output Frequency Scaling
Low	Low	Power down
Low	High	2%
High	Low	20%
High	High	100%

Table 2: Photodiode type settings

S2	S3	Photodiode type
Low	Low	Red
Low	High	Blue
High	Low	Clear(No filter)
High	High	Green

After configuring the pin settings, when the colour sensor is triggered by the detection of a puck, it will shine white light onto the puck when a high signal is fed to the LED pinout. The colour of the puck will determine what kind of wavelength and intensity of light is reflected back to the colour sensor. Depending on the photodiode filter type settings, the colour sensor will either be sensitive to red, blue or green wavelength of light. Referring to the colour sensing operation in Figure 28, the current-to-frequency converter will convert the photodiode readings to a square waveform with a frequency that is proportional to the chosen colour.[8] This waveform will then be fed to the PsoC.

2.1.3 Infrared (IR) Sensor

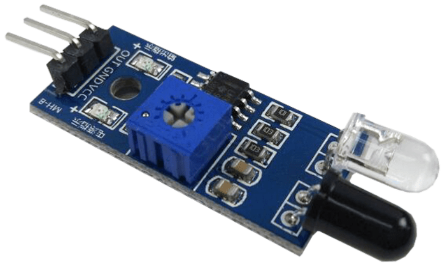


Figure 29: Infrared sensor module [10]

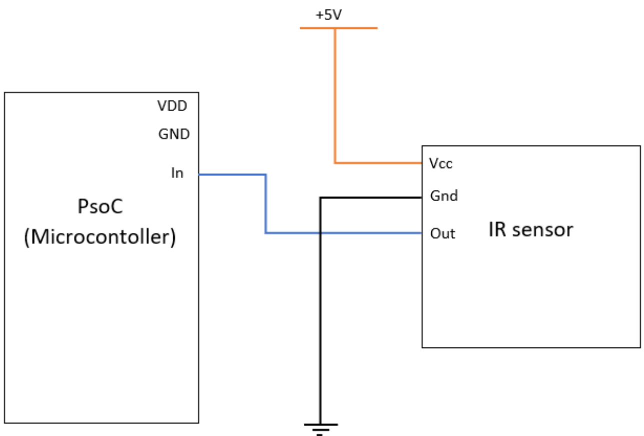


Figure 30: Connections of IR sensor to PsoC

The infrared sensor module was used to detect any pucks that are in close proximity to the colour sensor. It can detect obstacles in the range of 2-10 cm. The main components of the sensor module includes an IR diode transmitter, photodiode receiver, a comparator and a variable resistor. It also has 3 pins which are the VCC, OUT and GND pins. When the IR sensor is powered up, the IR diode will transmit IR light and if the light hits an obstacle/object, it will be reflected back to the black coloured photodiode receiver. The photoreceiver is black in colour as black surfaces absorb light better. When the receiver detects the reflected IR light, current will flow and the OUT pin will be pulled to low.

2.1.4 Limit Switches

Figure 31: Limit switch with roller [11]

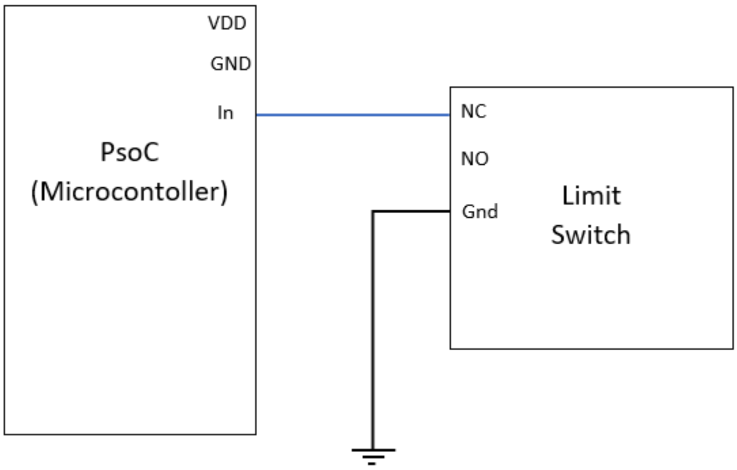


Figure 32: Connections of limit switch to PsoC

Limit switches are contact sensors and they are used to detect the presence of an object when the switch makes contact with the object. It consists of a mechanical actuator linked to a series of electrical contacts. When an object comes in physical contact with the actuator, this will result in either the opening or closing of the electrical contacts in the switch. [12] The roller on the lever of the contact switch is used to provide better physical contact with the object it comes in contact with. In the context of this project, the limit switches are used to align the robot with the walls of the arena.

The limit switch consists of 3 pins namely the Normally Closed (NC), Normally Open (NO) and GND pins. Either the NC or NO pin can be used and will be connected to the PsoC. If the NC pin is used, a resistive pull-up circuit must be set up in the PsoC software. Conversely, if the NO pin is used, a resistive pull-down circuit must be set up. For this robot, a NC pin was selected and therefore when the switch is actuated, the PsoC will read a low signal from the NC pin.

2.1.5 Shaft Encoder

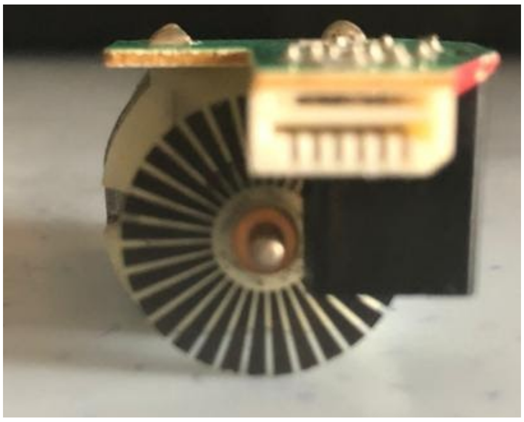


Figure 33: Shaft encoder connected to a DC motor

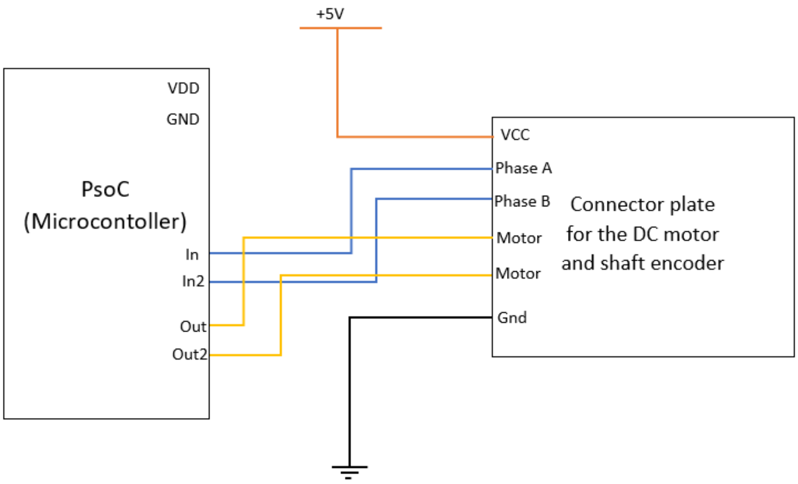


Figure 34: Connections of the connector plate of the DC motor + shaft encoder to the PsoC

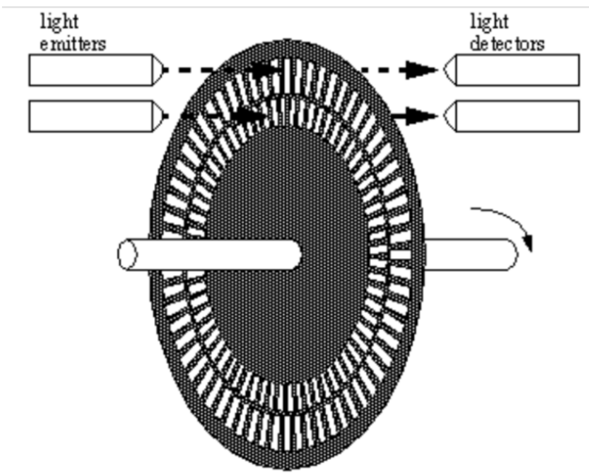


Figure 35: Structure of the quadrature encoder [13]

The 2 shaft encoders used for the robot are each attached to a DC motor. These shaft encoders are sensors that will assist in measuring the speed, direction of rotation and position of the shaft. The shafts are connected to the wheels of the robot and these encoders were mainly used to determine the direction of rotation. The encoders used are quadrature encoders that consist of a light chopping disc together with 2 photodiode transmitters and 2 photodiode receivers. The quadrature encoder structure can be seen in Figure 35.

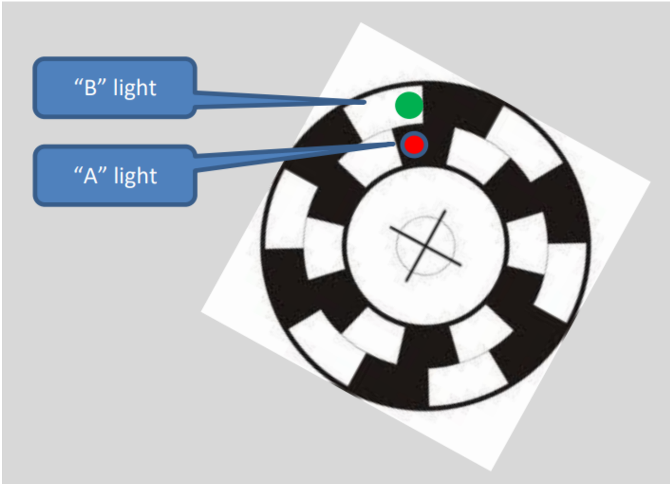


Figure 36: Perpendicular view of light chopping disc [13]

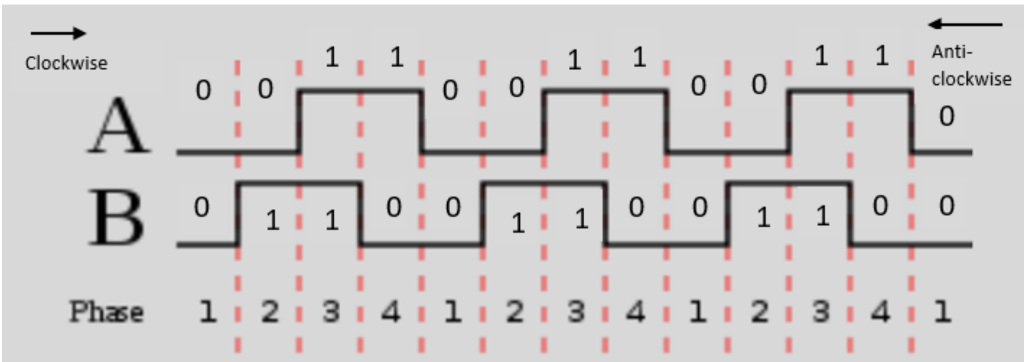


Figure 37: Timing diagram of the 2 output waveforms of A and B [13]

Referring to Figure 36, when the transmitted light falls on the shaded area, it will not be able to pass through. When it falls on the non-shaded area(holes), light will be able to pass through and will be detected by the photodiode receiver, resulting in the output signal going high. As seen in the figure, the top(A) and bottom(B) holes are actually separated by 90°. Hence, as the wheel rotates, 2 alternating waveforms(A and B) that are 90° out of phase from each other will be produced. To determine the direction of rotation, the sequence of binary outputs will be read. This is summarised in the tables below.

Table 3: Output sequences for clockwise direction

Phase	A	B
1	0	0
2	0	1
3	1	1
4	1	0

Table 4: Output sequences for anti-clockwise direction

Phase	A	B
1	1	0
2	1	1
3	0	1
4	0	0

2.1.6 Toggle Switch

Figure 38: 3 Pin Toggle Switch [14]

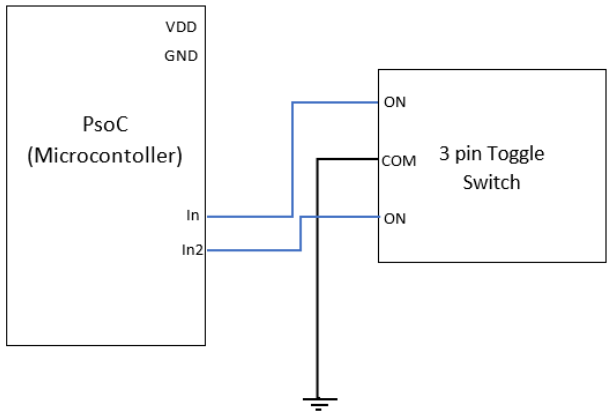


Figure 39: Toggle Switch Connection to PsoC

The toggle switch used in the project is an SPDT(single pole double throw) switch. This means that there are two options to be selected and they can be selected by toggling to either one of the two positions.The recommended maximum usage is at 2A and 24V.[15]

For the robot, the toggle switch was used to select between “Red robot” or “Blue robot”. “Red Robot” option means that a red puck must be deposited at the puck capture zone and vice versa. As shown in Figure 39, the COM pin of the toggle switch is connected to common ground and the other two ON pins are connected to input pins from the PsoC.

2.1.7 Rocker Switch

Figure 40: Rocker Switch [16]

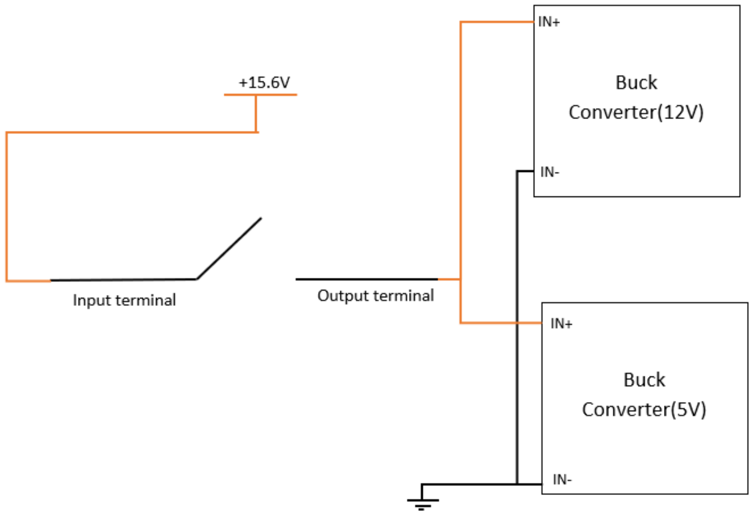


Figure 41: Rocker switch connection with batteries and buck converters

The rocker switch used in the project is a SPST (single pole single throw) switch. Flipping the switch to one side will complete the connection between input and output terminals and flipping it to the other will break the circuit. It is rated at 24V DC and 2A continuous.[16]

For the robot, the rocker switch was used to either break or allow voltage supply from the 12 AA NiMH batteries. As shown in Figure 41, the positive terminal of the battery supply is connected to the input terminal of the rocker switch. The IN+ pins of the 2 buck converters are connected to the output terminal of the rocker switch. The IN- pins of the buck converter on the other hand are connected to the common ground. Therefore, if the switch is not “ON”, no current or voltage can be supplied to the buck converters, and hence no other electronic components can be powered up.

2.2 Actuators

2.2.1 Metal Gear Servo

Figure 42: Metal gear servo(MG90s)

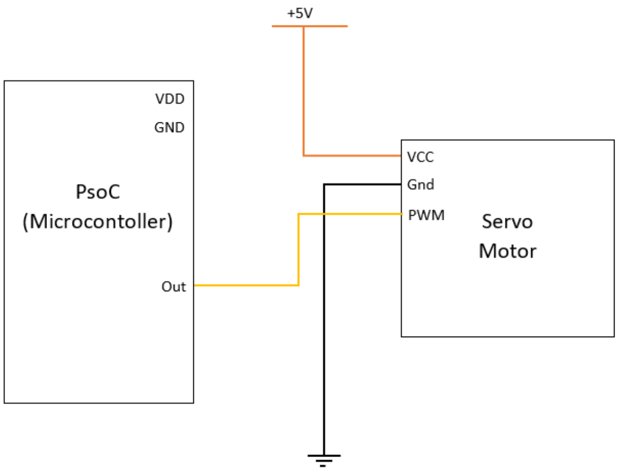
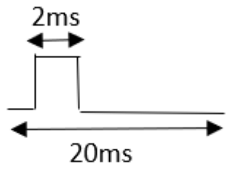
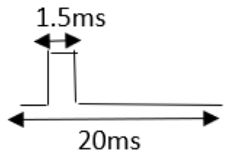
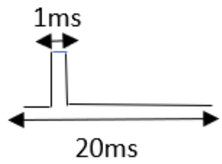


Figure 43: Connections of MG90s servo to PsoC

A servo motor is a DC motor that allows for precise control of the angular position. [17] In the case of the MG90S, it is a metal gear servo and because of the metal gears, it will reduce the chances of wear and tear. A metal geared servo can provide more stalling torque than the plastic geared servo (SG90), such that it is able to hold its position much better as compared to the plastic servo. The MG90s has 3 wires; red wire corresponds to +5V, brown wire corresponds to GND and orange wire corresponds to PWM signal fed to the motor. It has a typical stall torque of 1.8 kg/cm and a maximum stall torque of 2.2 kg/cm if 6V is supplied to it. It also has a rotation angle range from 0° to 180° with a typical operating speed of 0.1s/60°.[18] The angle of rotation can be controlled by adjusting the duty cycle of the pulse width modulation(pwm) that is being fed to the motor. This is summarised as shown in Table 5.

Table 5: Position of servo motor corresponding to the duty cycles of pwm

Servo Angle	0 degrees	90 degrees	180 degrees
PWM Duty Cycle	 2ms 20ms	 1.5ms 20ms	 1ms 20ms

In the implementation of servo motors in the robot, they were mainly used for the grippers. 1 servo motor was used to open and close the gripper fingers and another servo motor was used to flip the whole gripper 180°.

2.2.2 DC Motor

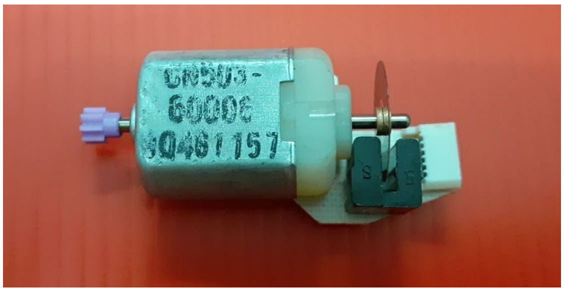


Figure 44: DC motor with shaft encoder

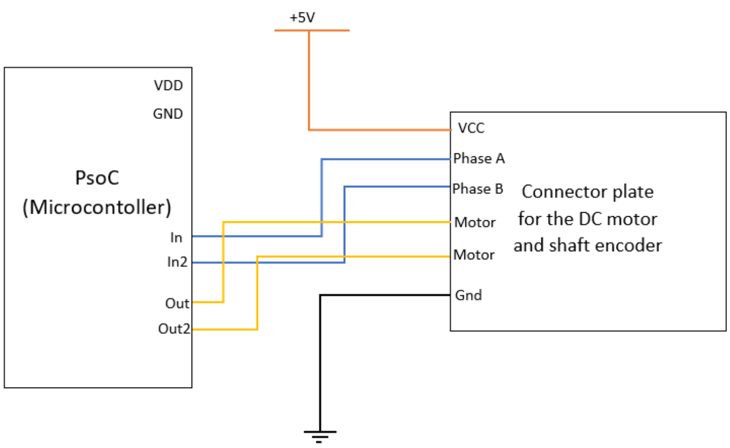


Figure 45: Connections of the connector plate of the DC motor + shaft encoder to the PsoC

The CN503-60006 DC motors were used as the main component for the motion of the robot. It will rotate the gears in the gearbox, which in turn rotates the wheels of the robot. It is also connected to a shaft encoder and its function was explained in Section 2.1.5.The DC motor has a maximum voltage rating of 12V. The connections of the DC motor with shaft encoder to the PsoC is shown in Figure 45.

2.3 Power Management

2.3.1 Connections of all electrical components

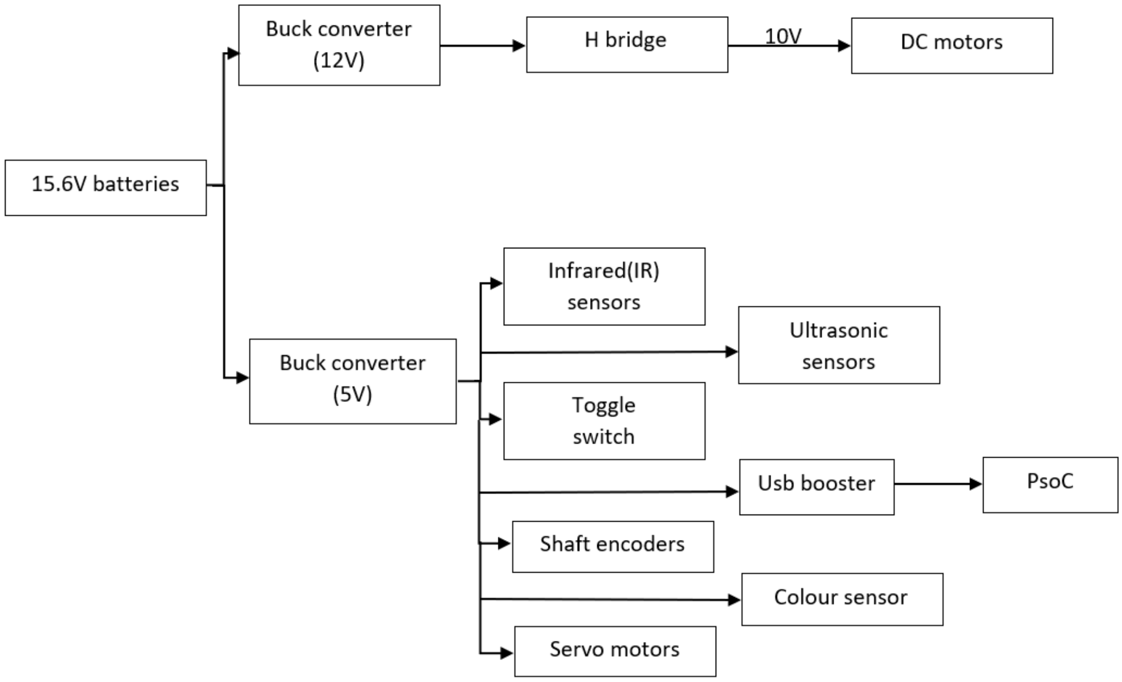


Figure 46: Overall Connection of all the electrical components

Figure 46 shows how all the electrical components are interconnected together. It can be seen that the main supplied voltage from the batteries is 15.6V, then the voltage will be step down by a DC to DC buck converter to 12V for the H bridge and due to the internal voltage drop at around 2V at the H Bridge, the DC motor will be supplied with 10V. Besides, there is also a second buck converter connected in parallel from the main supply to step down the voltage to 5V for other electronic components in the robot. The circuit is connected in parallel, if there is any chance that the DC motors draw lots of current, it will not damage the other components.

2.3.2 Rechargeable NiMH Batteries

Figure 47: Beston AA Rechargeable NiMH batteries

The Beston AA rechargeable batteries provide the main source of voltage and current supply to all the electrical components in the circuit. Each battery has a nominal voltage of 1.3V. 12 of these batteries were connected in series to provide 15.6V in total. The maximum voltage required is 12V to be supplied to the H bridge to power up the DC motors. The other electrical components only require 5V. Theoretically, 10 batteries would be enough to power up all the components, but more batteries were used to provide more voltage so that the robot can last longer on the arena, as a slight drop in voltage below 12V would greatly reduce the performance of the robot.

The batteries used also have a capacity of 3000mAh. This means that batteries can supply 3A of power at 1.3V for 1 hour. The total amount of current drawn by all the electrical components is less than 3A. Therefore, the batteries will be able to supply maximum power for more than an hour.

2.3.3 DC-DC Buck Converter

Figure 48: LM2596 Step-Down Converter [19]

The LM2596 is a DC-DC buck converter that steps down a DC input voltage to a lower output DC voltage. It also has an on-board potentiometer that helps to easily adjust the output voltage to the targeted voltage. This buck converter supports a wide range of input voltage from 3.2V to 40V DC and can also step down voltages to tha range of 1.25V to 35V. The maximum output current is 3A but standard output current is 2A. [19]

2 buck converters were used to step down the input voltage supply of 15.6V to 12V and 5V respectively. 12V is needed to be supplied to the H-bridge and 5V is needed to power up all the electrical components. By using a buck converter, rather than supplying straight from the batteries, a stable output voltage and current can be supplied, so long as the input voltage of the buck converter remains higher than the targeted output voltage.

2.3.4 H bridge

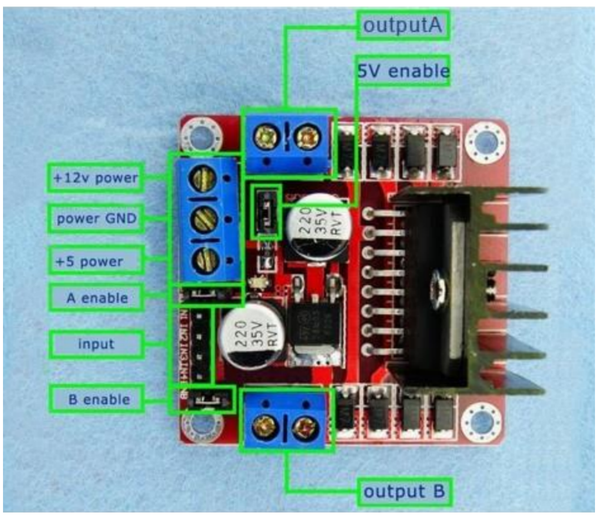


Figure 49: L298N Motor Driver(2 Drivers) [20]

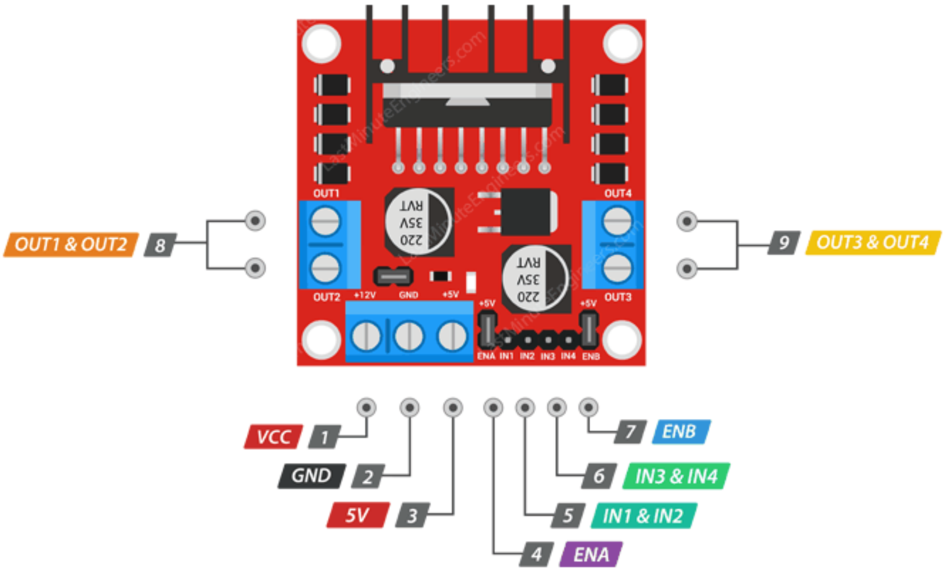


Figure 50: Pinout of the L298N motor driver module [21]

The L298N motor driver/H bridge was used to control the speed and direction of rotation of the DC motors that turns the wheels. To control the direction of rotation of the motors, the direction control input pins are connected to psoc output pins. IN1 and IN2 pins will control the motor(Motor A) connected to OUT1 and OUT2 pins whereas IN3 and IN4 pins will control the motor(Motor B) connected OUT3 and OUT4 pns. The direction of rotation of the motor will depend on whether a high or low signal is fed to the direction control input pins. To control the speed of the motors, PWM signals can be fed to the enable pins; ENA controls motor A and ENB controls motor B. If the jumpers on these enable pins are not removed, the speed cannot be controlled and the motors will move at maximum speed; 100% duty cycle. The VCC pin supplies power for the motor and can support inputs of 5 to 35V. If the 5V-EN jumper is in place, 2V of the supplied voltage would be lost due to internal voltage drop of the switching transistors in the H-bridge circuit. [21] The module also has an on-board 78M05 5V regulator that can be enabled or disabled through a jumper. When the jumper is on, the motor power supply is used to supply 5V and 0.5A through the 5V pin. If the jumper is removed, the 5V regulator gets disabled and 5V must now be supplied through the 5V input terminal. [21]

For this robot, 12V from the buck converter was supplied to the VCC pin of the H bridge. This means that the output pins will only output 10V to the DC motors. Although supplying 12V to the DC motors would enable the motors to move at maximum speed, this would mean that 14V would have to be supplied to the VCC pin. The main voltage supply is 15.6V and supplying 14V would drain the batteries faster. The calibrations of the robot varies greatly as the speed of the robot changes. As the supplied voltage drops below 14V, the motors would start rotating slower. Therefore, by only supplying 12V to VCC and getting 10V from the output, the robot can be calibrated at 10V and would also last far longer before the voltage supplied goes below 10V.

The 5V-EN jumper pin was also kept on so that an extra 5V would not have to be supplied to power up the H-bridge. This would also further help the battery supply voltage to last longer. A pwm signal with a 50% duty cycle is fed to both ENA and ENB pins. This means that the average voltage supplied to the motor is 5V.

2.4 Integration of Electronics

2.4.1 Navigation of robot

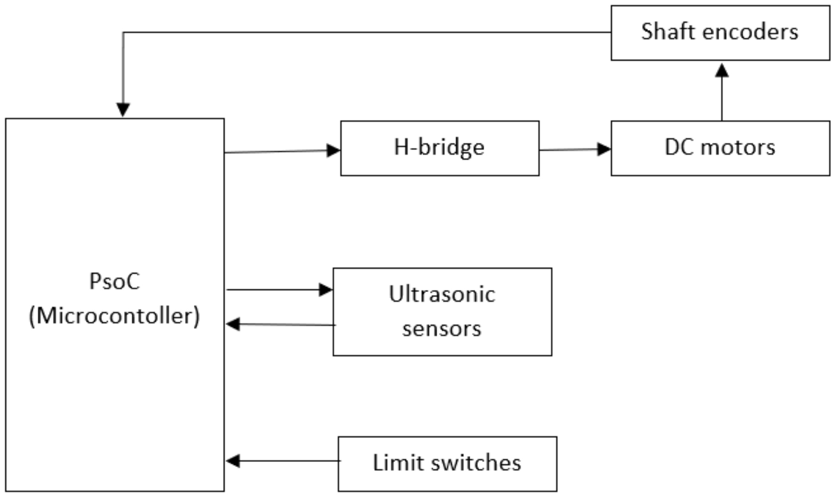


Figure 51: Integration of electronics for navigation process

In order for the robot to move from one zone to another, the DC motors with shaft encoders, H-bridge, ultrasonic sensor, PsoC and limit switches must work together. The PsoC will write either a high or low signal to the input pins of the H-bridge and also feed pwm signals to the enable pins of the H-bridge. These inputs will decide which direction the motors/wheels rotate and also the speed it rotates. As the motors rotate, the shaft encoder follows and will output a square waveform to the PsoC. From there, the PsoC will utilize the square waveform to decide how far the robot should move and also feedback suitable pwm signals to the slave motor to ensure it moves roughly the same speed as the master motor.

While the robot is moving, the PsoC will continuously trigger the ultrasonic sensor to transmit sonic bursts. As soon as the sonic waves get reflected back to the receiver of the ultrasonic sensor, the echo pin connected to PsoC will receive a low signal. The PsoC will use the echo signal to calculate the distance of the obstacle from the robot. If the obstacle is too close to the robot, the PsoC will send low signals to the input pins of the H-bridge to stop the DC motors.

For alignment of the robot on the arena, the PsoC will send the required input signals to the input pins of the H-bridge in order for the DC motor to move in a reverse direction. When both the limit switches get actuated, the PsoC will read a low signal and will then proceed to send low signals to the input pins of the H-bridge and stop the DC motors.

2.4.2 Colour sensing

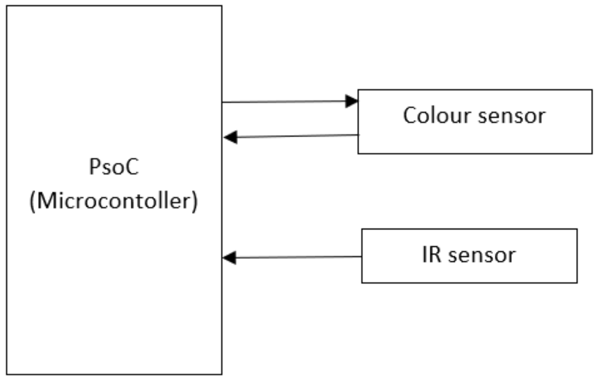


Figure 52:Integration of electronics for colour sensing process

To determine the colour of the pucks, the infrared(IR) sensor and TCS3200 colour sensor will both be needed. The transmitter of the IR sensor will continuously emit infrared ray and when the infrared ray hits a puck, it will be reflected back to the photodiode receiver of the IR sensor. Consequently, the PsoC will read a low signal from the OUT pin of the IR sensor and will send low signals to the input pins of the H-bridge to stop the DC motors and hence stop the robot. When the robot stops, the puck should be directly below the colour sensor. The PsoC will then start the colour sensor and depending on the colour of the puck and the filter of the sensor, the colour sensor will produce a square waveform with the corresponding frequency. This square waveform will then be fed to the PsoC through the OUT pin of the sensor. Based on the frequency of the square waveforms, the PsoC will be able to decide the colour of the puck.

2.4.3 Flipping and gripping of puck

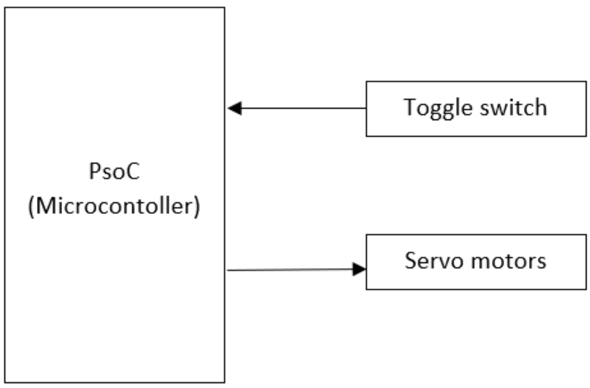


Figure 53: Integration of electronics for flipping, gripping and un-gripping process

In order to decide whether the puck must be flipped, gripped and ungripped, the toggle switch, servo motors and results from the colour sensing process must be utilized. After the puck colour is determined, the PsoC will write the required input signals to the H bridge in order for the motors to move the robot in a reverse direction and then stop. The PsoC will then start the servo motor that controls the flipping of the gripper to flip the gripper downwards. After a short delay, the servo motor controlling the gripper fingers.will then be started. Required signals are then sent by the PsoC to the H-bridge to move the DC motors such that the robot moves forward to cover up the distance it reversed. From there on, the PsoC then starts the servo motors to grip the puck and then flip the whole gripper up.

At the puck capture zone, based on which side the toggle switch is flipped to, the PsoC will either start the servo motors to flip the gripper down before un-gripping the puck if the puck does not need to be flipped or it will start the servo motor to straight away ungrip the puck if the puck needs to be flipped.

2.5 Alternatives for Electronics Design

2.5.1 SG90 Plastic Micro Servo

Figure 54: SG90 Micro Servo [22]

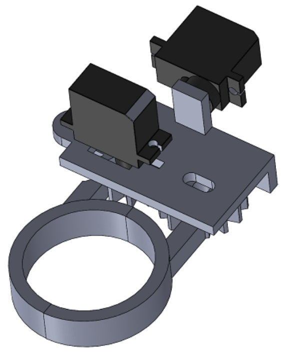


Figure 55: Gripper with servo motors

The SG90 plastic micro servo was suggested to be used in place of the MG90s metal servo motor to move the gripper fingers and also flip the gripper. The SG90 servo weighs only 9gm as compared to the metal servo that weighs 13.4gm. With a lesser weight, there would be less strain on the servo placed on the gripper holder to lift the whole gripper together with the servo that controls the gripper fingers. This is shown in Figure 55.

The SG90 was not used in the final prototype as the plastic gears are easily subjected to wear and tear. Since a lot of testing has to be done before the final competition, it was risky and unsuitable to be used. The servo on the gripper holder also has to rotate the whole gripper, which is quite heavy in weight, hence, the plastic servo cannot provide sufficient torque to lift the whole gripper.

2.5.2 3-axis Digital Compass (HMC5883L)

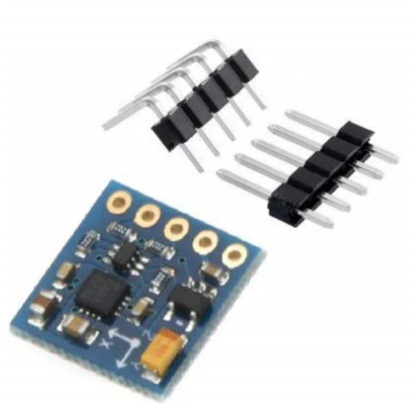


Figure 56: HMC5883L, 3-axis digital compass [23]

The HMC5883L is a triple axis magnetometer compass that senses Earth's magnetic fields. The IC has 3 magneto-resistive materials inside which are arranged in the direction x,y and z and by measuring the change in current flowing through these materials, the change in Earth's magnetic field can be measured. [24] It has 5 interface pins; VCC, GND, SCL, SDA and DRDY and uses I2C communication protocol with the microcontroller.

The digital compass was initially planned to be used to measure the orientation of the robot. By using the digital compass, the count values from the Quad decoder do not have to be relied on for the robot to turn at an angle.

This module was however not implemented in the final design as the readings given were inconsistent. This resulted in the robot not turning at the set desired angle consistently. The readings are also very sensitive to other magnetic interferences which would also cause very inconsistent readings.

2.5.3 Adjustable Long Range NPN Infrared Sensor Switch

Figure 57: Adjustable NPN Infrared Sensor Switch [25]

The adjustable NPN infrared sensor is a sensor that can detect distances in the range of 3cm to 80cm. It requires an input voltage of 5V DC and has a current consumption of 100mA. It also has an NPN output and a cable length of 45cm. To adjust the range of detection, there is a screw at the back of the sensor that can be manually adjusted.

This long range infrared sensor was initially supposed to be used for obstacle detection in place of the ultrasonic sensors. Two of these sensors were supposed to be used at the front of the robot. The IR sensors are good at detecting edges of an area, which would be helpful if the robot is heading to a corner of the arena. This is important as the robot sometimes moves at an angle in zones 3 and when going back to base, and so will approach a corner.

This idea was however discarded as the set detection distance cannot be altered by software. This was inconvenient as at different zones on the arena, different distance requirements are needed before the robot reacts to an obstacle. This could be easily done using an ultrasonic sensor. The IR sensor is also sensitive to variant light conditions. [26] This was inconvenient as getting a good and consistent bright light condition at home was difficult. This would therefore cause inconsistent distance detections.

2.5.4 Self-assembled Colour Sensor

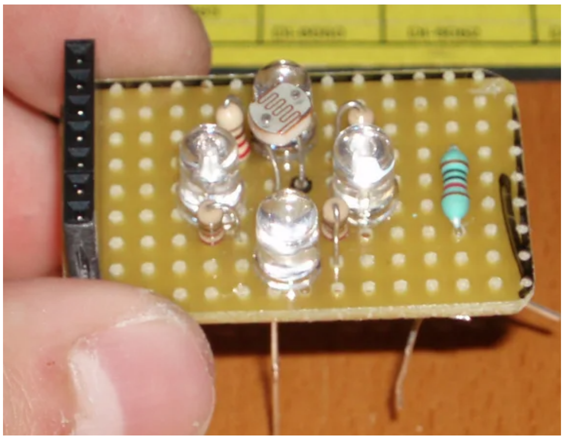


Figure 58:Self-assembled Colour sensor [27]

The components needed to build a homemade colour sensor are 4x RGB LEDs, 4x 220Ω resistors, 1x LDR, 1x 10kΩ resistor, female pins and a PCB. [27] Similar to the TCS3200 colour sensor, this homemade sensor will shine the different coloured lights (R,G or B) onto the object, and the light would be reflected back to the LDR. Since different colours reflect different amounts of light, the intensity of light absorbed by the LDR sensor will be different and will result in a different amount of current flowing in the voltage divider circuit. By calibrating the colour sensor with different colours, the homemade colour sensor will be able to determine colours. Since it is homemade, the sensor is much cheaper than the TCS3200 and can also be easily fixed and re-calibrated.

The homemade sensor however was not used as the readings were not as reliable as the TCS3200. The TCS3200 uses a current to frequency converter to output a square waveform of different frequencies depending on the filter used and the colour of the puck. This is more accurate than just measuring the output voltage in the divider circuit. Time was also a factor as to why this sensor was not used in the end.

2.5.5 Accelerometer

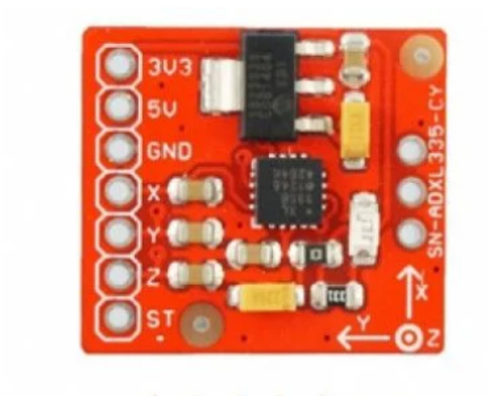


Figure 59: 3 axis ADXL335 Accelerometer [28]

An accelerometer sensor is a sensor that measures the changes in acceleration in the x,y and z directions. It has an operating voltage of 2.5V - 6V and a typical current of 300μA with an on-board 3.3V voltage regulator. [28]

The accelerometer can be used to determine tilt angle of the robot. By getting the acceleration from the accelerometer readings and using gravity as a reference, the tilt angle, θ can be obtained from the formula: [29]

$$\theta = sin^{-1} \text{ (Measured Acceleration / Gravity Acceleration)}$$

If the tilt angle is not 0°, this would mean that the robot is not flat on the ground. This can only happen if something, like a puck for instance, is stuck under any of the wheels of the robot. To overcome this, the robot was supposed to be programmed to reverse a little bit, so that the puck will no longer be under the wheel.

This method however gave inconsistent readings when the robot is not static. It was also much more convenient to solve this issue mechanically by extending the puck guide such that it encloses the sides of the robot. By doing this, no pucks will get in the way of the wheels when the robot is going forward. Using this method is much easier and more efficient, as no complex coding algorithms have to be implemented. The alternative method also does not guarantee a 100% success rate as sufficient torque sometimes cannot be generated for the wheel to roll off the stucked puck.

2.5.6 Usage of 4 ultrasonic sensors

4 ultrasonic sensors were initially planned to be used on the robot. 2 at the front and 2 on the sides; 1 on each side of the robot. The sensors on the sides of the robot were mainly used to detect opponent robots that are approaching the robot from the sides. If the ultrasonic distance measures a distance that decreases progressively, then this indicates that an opponent is coming towards the robot from the sides.

In the final prototype, only 2 ultrasonics were used at the front of the robot. The side ultrasonic sensors were discarded as the amended rules mean that there will be no opponent robots on the arena at the same time. This would make the side sensors redundant and so to simplify coding, the side sensors were removed.

3.0 Software Design

3.1 Overall system algorithm

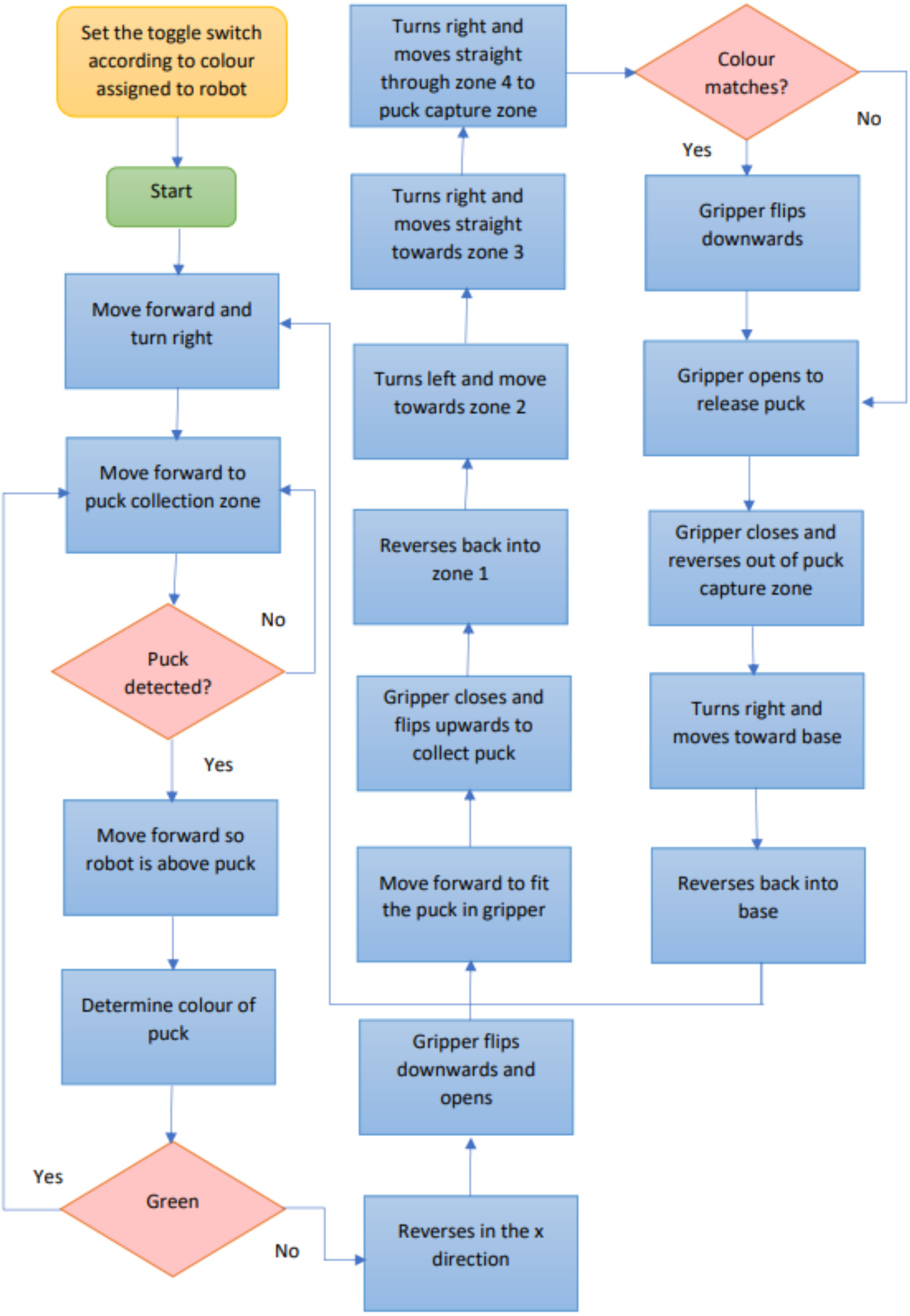


Figure 60: Overall Algorithm Flowchart

The robot is required to navigate through zones in the arena, collect pucks from the puck collection zone and accurately deposit them in the puck capture zone. The colour of the pucks deposited in the puck capture zone is set by the colour that is assigned to the robot before the competition starts. The robot is programmed to perform these tasks autonomously for a span of 5 minutes. Figure 60 shows the overall system algorithm and sequence of tasks performed by the robot. The various subsystems that have been used to achieve this are further detailed in the continuing sections.

3.2 Proportional Control

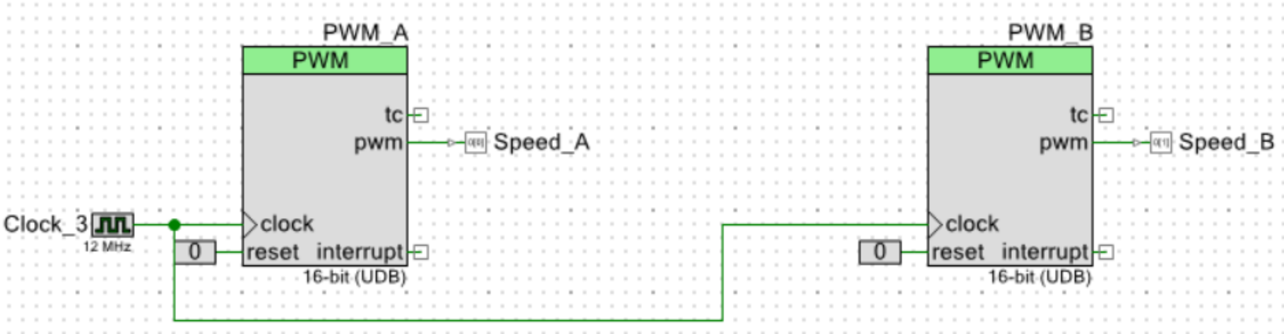


Figure 61: PWM blocks for each wheel

The two wheels of the robot are powered by DC motors. The speed of the wheels are controlled by outputting Pulse Width Modulator (PWM) signals to the DC motor for each wheel as shown in Figure 61. Pulse width modulation is used because it can be used to vary the width of each pulse without having to change the frequency of the signal.

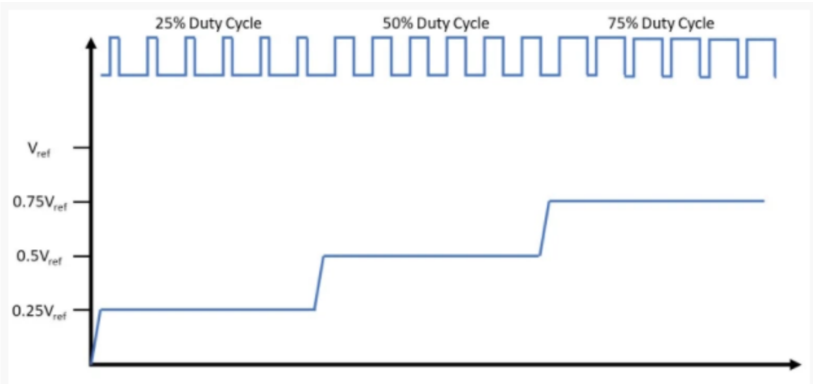


Figure 62: Duty cycles of PWM [30]

The speed of the motor is determined by the duty cycle of the PWM signal supplied to it. For example, with a 100% duty cycle, the motor would be running at its maximum speed and vice versa. By referring to Figure 62, changing the duty cycle of a signal results in a change in its average DC voltage.

In order to ensure both motors turn at the same speed, a proportional gain controller is used as a feedback system. This is because even when supplying the same PWM duty cycle, there will be discrepancies in regards to the amount of current drawn by both motors. This causes the wheels to rotate at different speeds, hence preventing the robot from moving in a straight line.

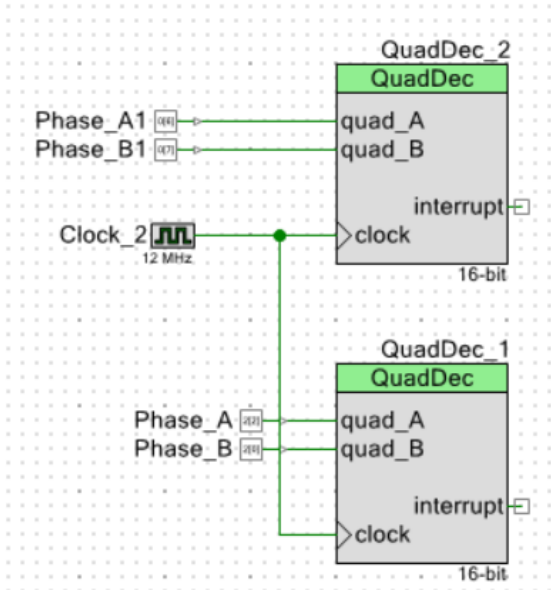


Figure 63: Quadrature Decoder (Quad Dec)

Referring to Figure 63, the Quad Dec counts the transitions on a pair of digital input signals. The output of phase A and phase B from each motor are connected respectively to two Quad Decs. These two input signals (Phase A and B) have a phase difference of 90 degrees, which is shown in Figure 64.

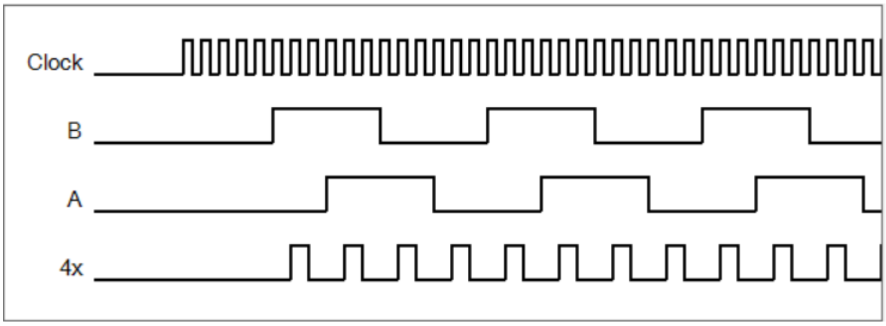


Figure 64: Output of phase A and B

The input of phase A and phase B signals into the Quad Dec provides a Gray code output, which is used to increment the count values on each one-bit change [31]. Hence, the Quad Dec provides output count values that are used to deduce the speed of the motors. The resolution of the counter is chosen to be 4x, in order to ensure greater accuracy when measuring the count values for each rotating wheel.

The counter size that is used for the Quad Decs are 16-bit, so the count value ranges from -32768 to +32767. As an example, when the robot is moving straight, the count values increase from 0 to 32767, then it resets from 0 and the process repeats. The output of the Quad Decs are fed into a proportional gain controller, which ensures that both motors will rotate at the same speed.

The purpose of a proportional gain controller is to compensate for the difference in speed between two motors. First, both wheels are classified as either the master or the slave. The goal of this system is to ensure that the speed of the slave wheel always matches that of the master. This is achieved by manually writing compare values to the slave pwm to adjust its speed. By doing this, the duty cycle of the pwm signal can be changed and hence the speed of the slave is adjusted accordingly.

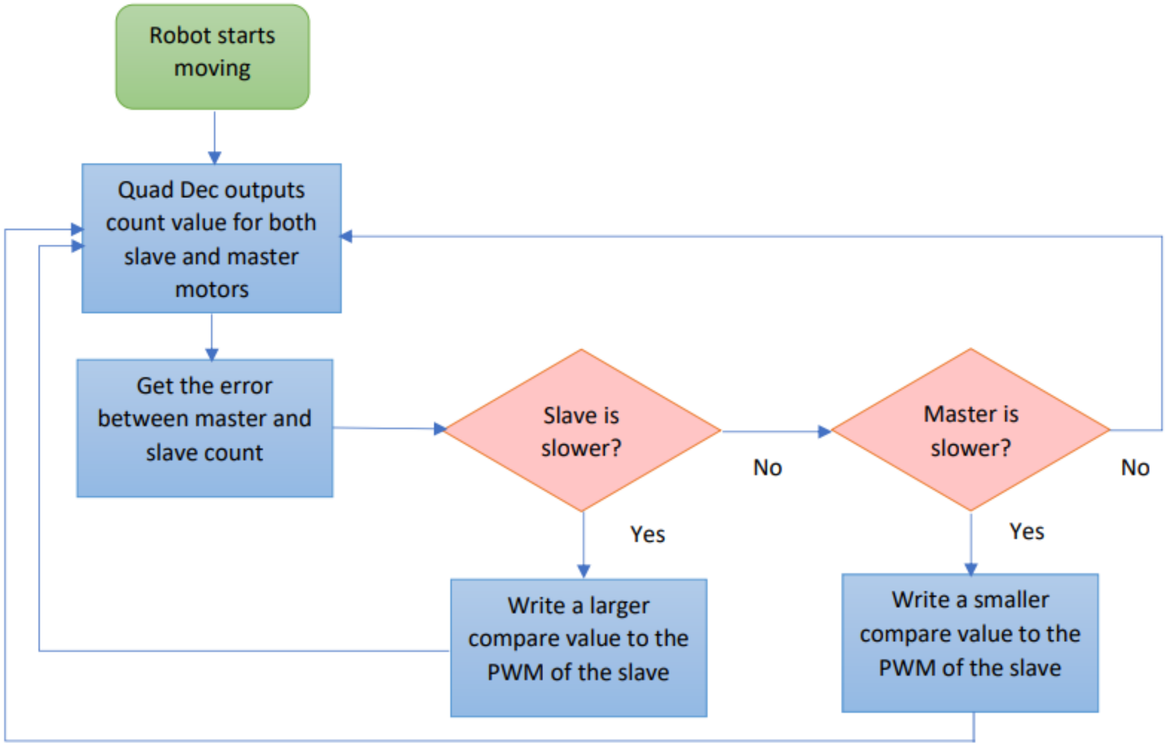


Figure 65: Proportional Control Flow Chart

Referring to Figure 65, the proportional gain controller is a continuous feedback loop system that runs during movement of the robot. The exact compare value to be written into the slave motor PWM is obtained by the equation,

slave = (kp*error) + original pwm value

The kp value is obtained through multiple testing and observing the response of the wheels.

With a larger kp, the slave wheel responds faster to the difference between the master and slave speed. However, this results in an overcompensation, where the slave's speed exceeds that of the master because a bigger value is being written into the slave's pwm signal each time. This causes the robot to have occasional jerks during movement. With a smaller kp, the slave might not be able to keep up with the speed of the master, which causes the robot to swerve to one side.

3.3 State diagram

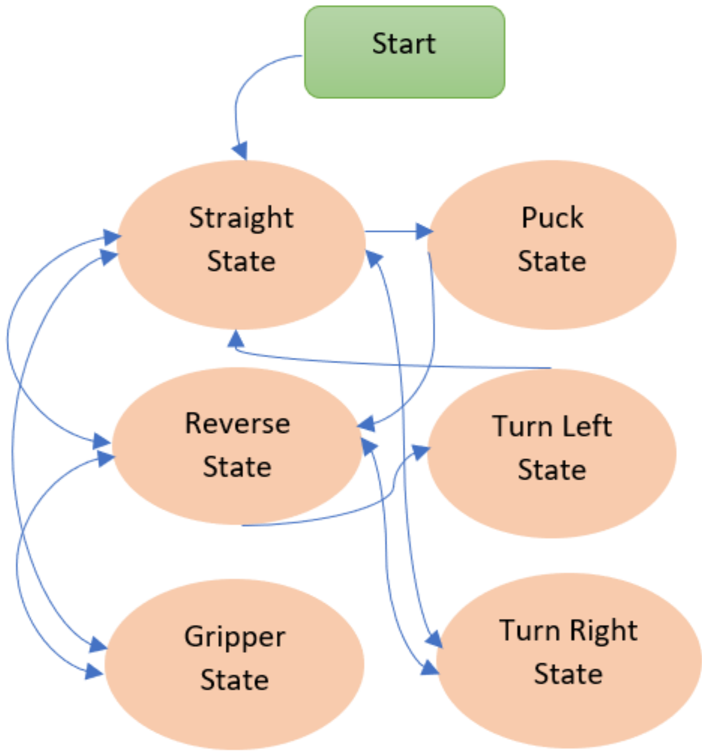


Figure 66: State diagram implemented in the code

To ensure that the robot can autonomously perform the tasks for five minutes, a state machine is constructed as per Figure 66. The robot switches through the multiple states as described in Figure 66 while completing the tasks throughout the time allocated. Case statements are used to code the states and the transitions between each one. This enables the robot to accurately change states according to its current location and the sequence of movement for each round.

Each state case statement contains a set of algorithms to be performed by the robot; along with if statements to check in order to enable smooth transitions between different states. By observing the movement and activities of the robot, the current state of the robot can easily be deduced. The transition between states is also an important factor used in our navigation system which is further described below.

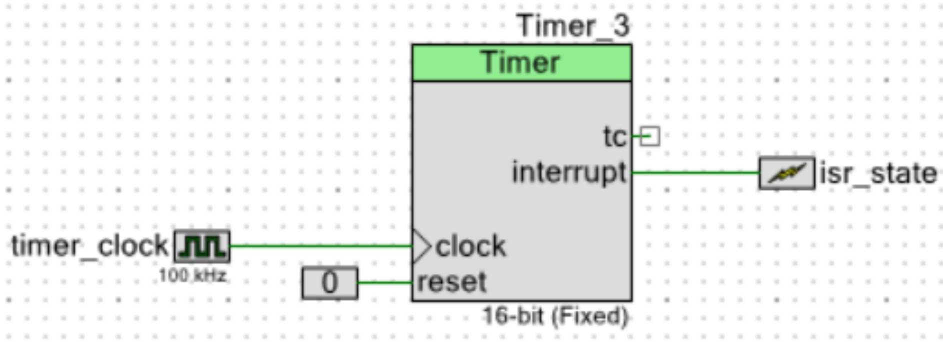


Figure 67: Timer block for State Machine

The state machine is implemented as an interrupt service routine (ISR) referring to Figure 67. By connecting the 100kHz clock to the timer block, the period is set as 100ms. This means that the state machine interrupt handler is triggered every 100ms to check for state transitions. The type of timer used to trigger the state machine ISR is selected as continuous to ensure that the timer continuously runs when it is enabled. This is important so that throughout the entire process, the state machine ISR will keep checking for state transitions periodically.

A total of four different interrupt service routines are used in the software design. The respective priorities are listed below:

Table 6: Priority of ISR

Interrupt Service Routine	Priority (0- Highest, 3- Lowest)
Colour Sensor	0
Trigger pin (Ultrasonic)	1
Echo pin (Ultrasonic)	2
State Machine	3

From Table 6, the priority of the state machine ISR is set to the lowest. The other ISRs require higher priority because they cannot be interrupted when they are working. The state machine ISR will only be triggered to check the state transitions after the other ISR have completed their tasks.

For example, the colour sensor counter ISR has the highest priority and would be called when a puck is sensed and the colour sensing activity has to be carried out. If another task assumes control within this period, the colour sensing would be halted and could result in inaccurate results.

The trigger pin of the ultrasonic sensor has the 2nd highest priority and is part of the collision detection system which would be further discussed in part 3.7. The trigger pin takes higher priority because it needs to continuously send out signals within a short period of time. The echo pin ISR also needs to be triggered frequently to check if a signal is received, indicating the presence of obstacles.

3.4 Motor Function

In order to move the wheels, the binary signals (either 1 or 0) have to be sent to the logic pins on the H bridge. Each motor is connected to two pins on the H bridge to control the motion of the robot. The pins that are connected to the H bridge are shown in Figure 68

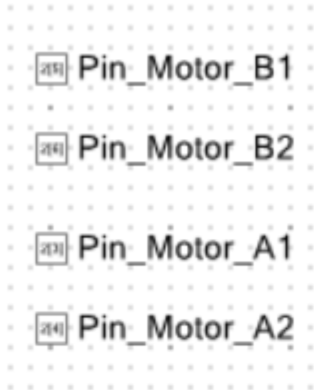


Figure 68: Motor pins

The motor function is used to write binary signals to these motor pins for the movement of the robot. The motor function also uses case statements to alternate between the different movement states, namely straight, reverse, turn left and turn right. The motor function also has a motor stop alternative which will be discussed further. Depending on the current state of the robot in the state machine as previously mentioned, the motor function is called with the state variable.

As an example, when motor(straight) is called in the straight state case statement, the binary values will be written to the motor pins so as to enable the robot to move straight. A table further detailing the binary numbers to be written into the H bridge pins for each type of motor movement is found in Table 7.

Table 7: Binary Values for H Bridge Pins

Motor Function	Pin_Motor_A1	Pin_Motor_A2	Pin_Motor_B1	Pin_Motor_B2
Straight	0	1	0	1
Stop	0	0	0	0
Turn Left	1	0	0	1
Turn Right	0	1	1	0
Reverse	1	0	1	0

As an example, in order to enable the robot to turn left, the motor function is called with Pin_Motor_A1_Write(1), Pin_Motor_A2_Write(0), Pin_Motor_B1_Write(0) and Pin_Motor_B1_Write(1). A flow chart detailing the sequence of this is shown in Figure 69

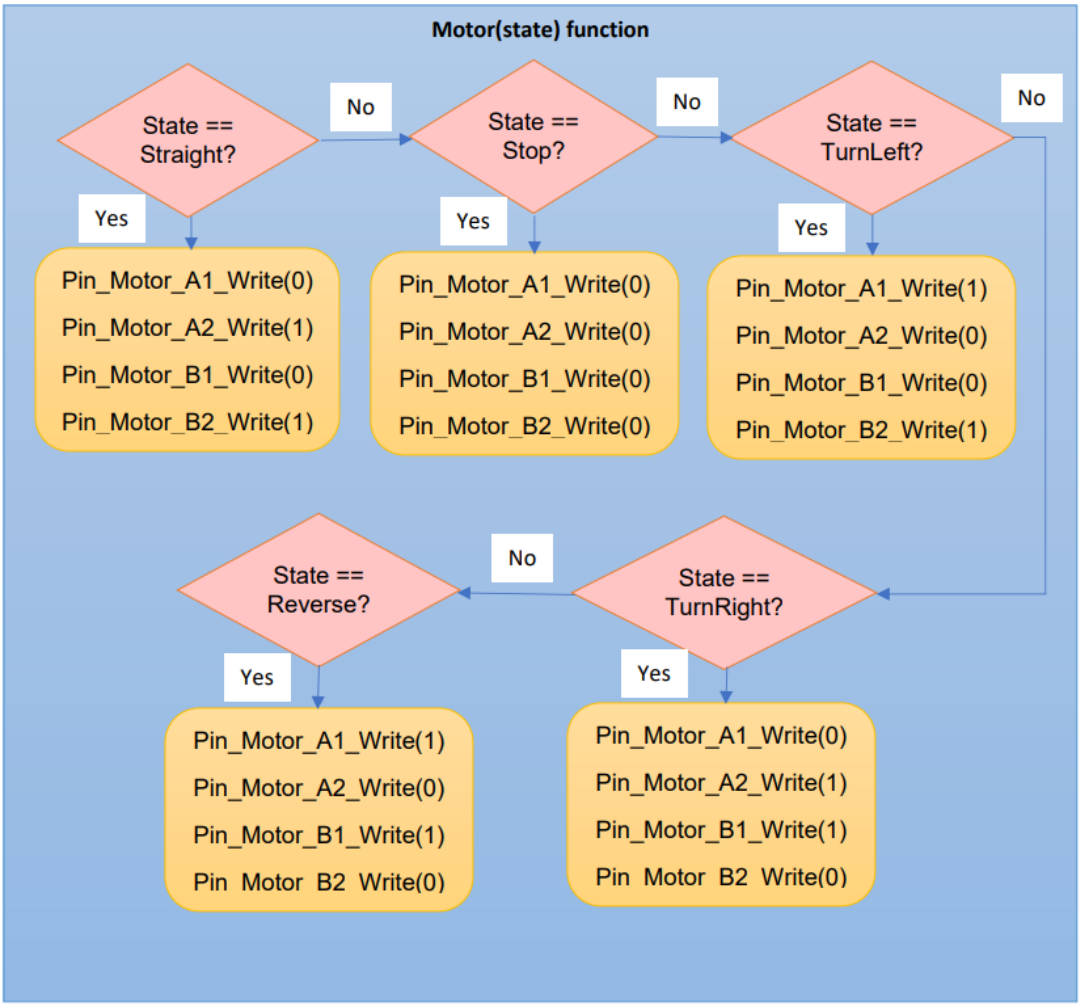


Figure 69: Motor function flow chart

In order for the robot to turn a certain angle, the turn right or turn left motor function is called and executed for a certain number of counts. The count value here is referring to the output value obtained from the Quad Dec. The average of the count values from both wheels, which is called "compare", are used to ensure that the turning is consistent. For the movement algorithm, the robot is required to turn at a different angle depending on the respective zones, hence this method enables customization of the turning angles.

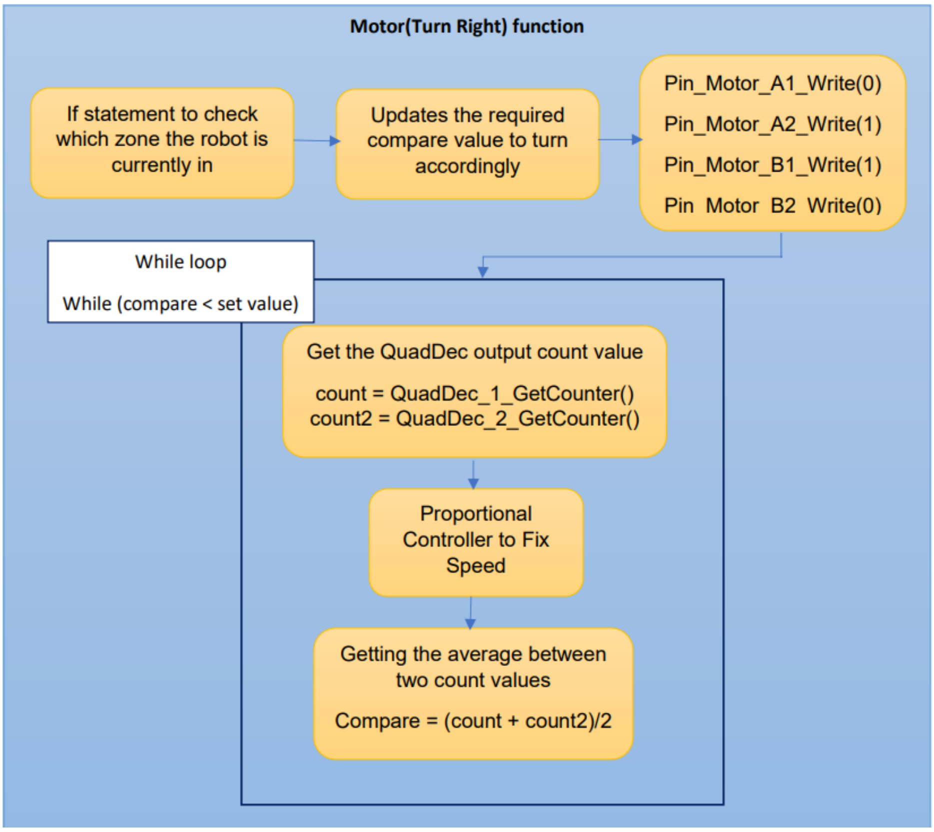


Figure 70: Motor function turn right flow chart

The motor function will enable the turning of the robot until the compare value exceeds a preset value, then the robot will stop turning. Within the motor function, the count value and hence the compare value is constantly updated by the QuadDec_GetCounter() function. Hence, the turning motion for each zone will be consistent for each round. A flow chart further detailing this is found in Figure 70.

3.5 Navigation with XY coordinates

In order to ensure the robot is able to accurately navigate through the arena, a XY coordinate system is implemented in the robot. This coordinate system makes use of the X and Y plane, hence when the robot travels in the arena, it updates the X and Y coordinates accordingly. Although the robot travels in a predetermined path, XY coordinates ensure that the robot will always be able to locate itself in the arena.

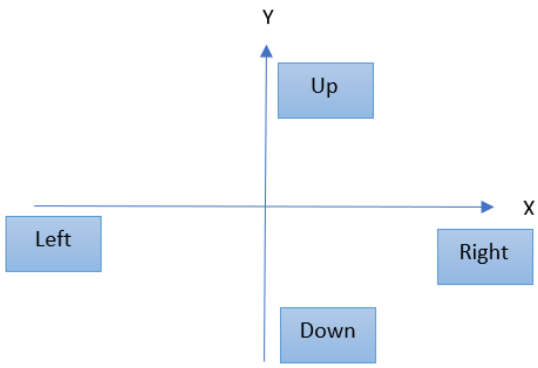


Figure 71: XY Plane and Direction Vectors

The working concepts behind the navigation system is determining the robot's current direction, and deducing the distance travelled to increment or decrement X and Y coordinates respectively.
Referring to Figure 71, the direction vector is determined according to the XY plane. In order to ensure that the XY coordinates are updated consistently when the robot is moving, the count value obtained from the Quad Dec is used. With every 5000 counts recorded by the Quad Dec, the XY coordinates are updated by one unit. Hence, this process repeats continuously throughout the movement of the robot.

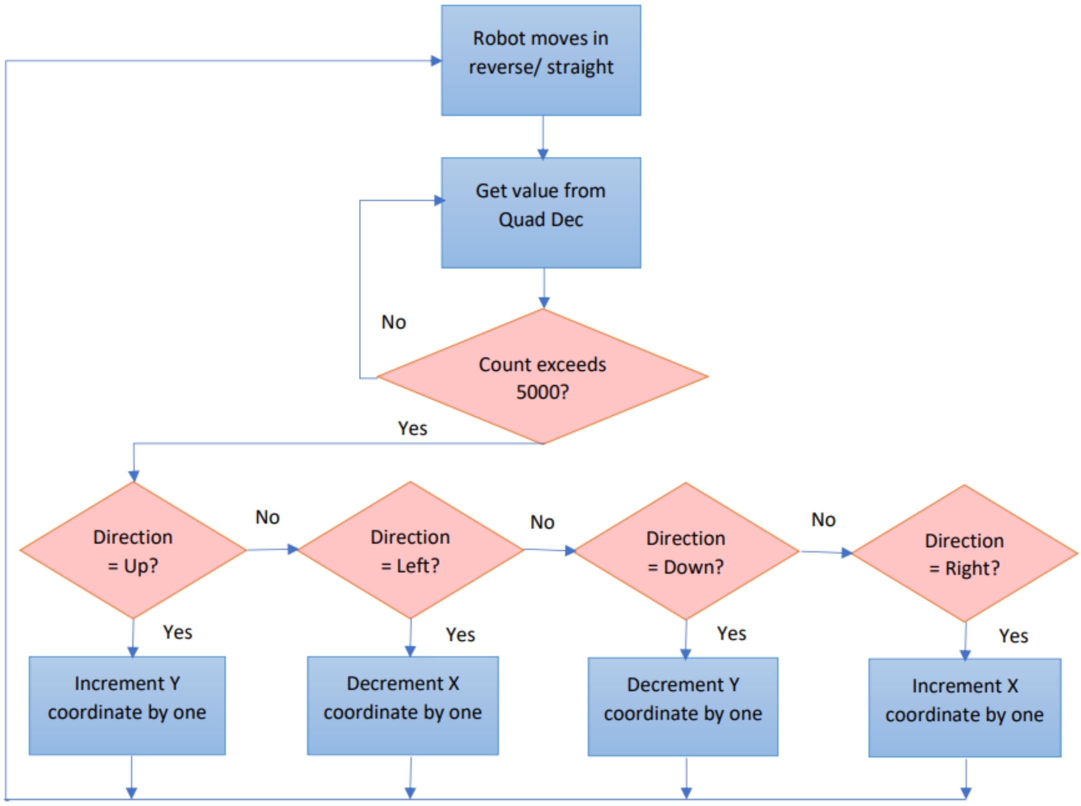


Figure 72: Flowchart of Updating XY Coordinates

The current direction of the robot depends on its current and previous state. For example, if the robot turns right after previously moving straight in the 'Up' direction, then the current direction of the robot will be updated to 'right'. After determining the direction of the robot, the X and Y coordinates are updated accordingly based on the flow chart in Figure 72.

3.6 Collision detection

The collision detection system consists of two main components, two ultrasonic sensors and two contact switches. The ultrasonic sensors are used to detect objects in front of the robot, while the contact switches are used to prevent collision when the robot is moving in the reverse direction.

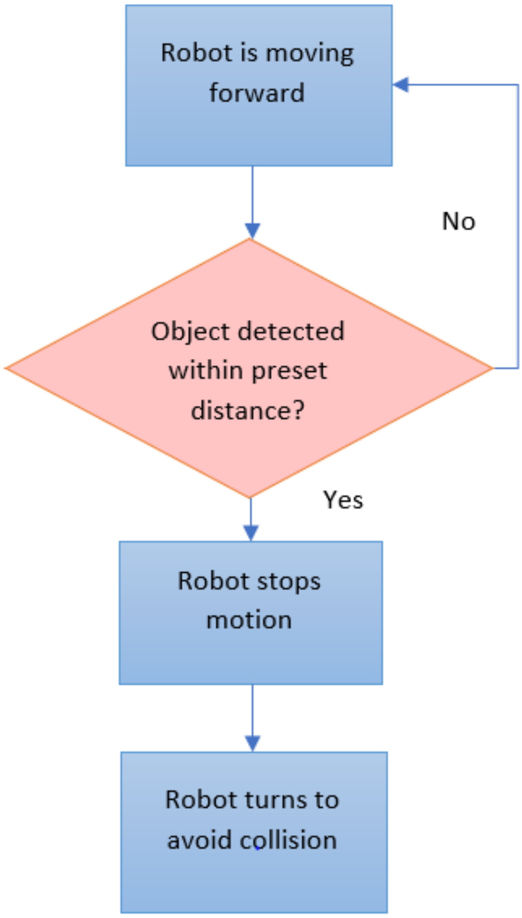


Figure 73: Flow Charts for Ultrasonic Sensor algorithm

Referring to Figure 73, the ultrasonic sensor is used to enable the robot to turn when there is an object or wall positioned in front of the object. This is important to ensure that the robot will consistently turn at the same position for each round. For each zone, the distance between the robot and the wall before it should turn is slightly different. This is to ensure that the robot is able to correctly navigate through the arena without entering prohibited areas, as well as to ensure the robot returns perfectly to base after each round.

As mentioned, two ultrasonic sensors are positioned at the front of the robot. The working principle of ultrasonic sensors are essentially the echo and trigger pins.

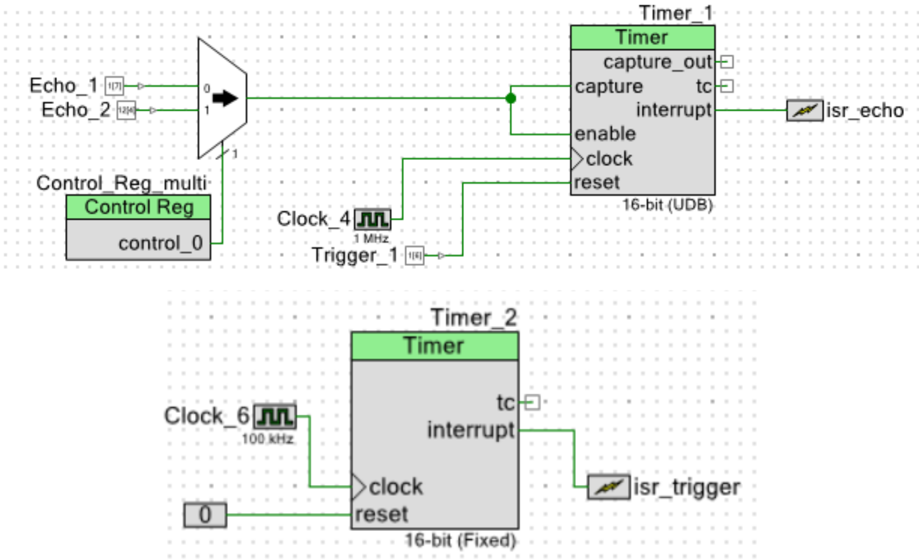


Figure 74: Echo and Trigger Timer

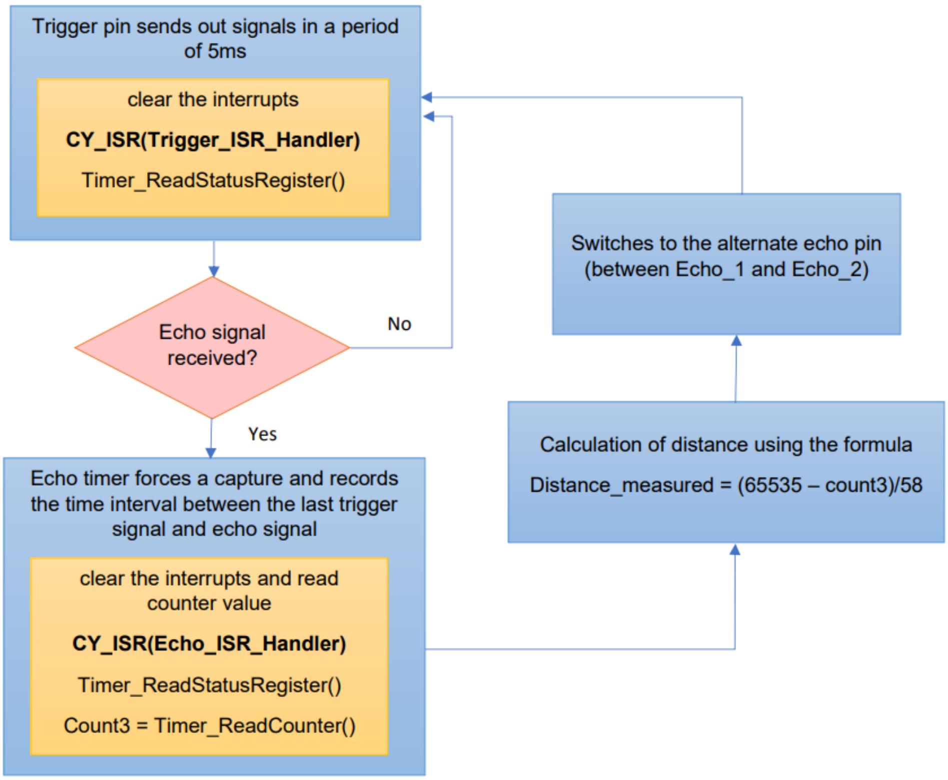


Figure 75: Flow Chart of Ultrasonic Sensor

For the ultrasonic sensors to work, a timer block is used each for the echo and trigger interrupt service routines. Timer_1 in Figure 74 corresponds to the echo pin timer, while Timer_2 in Figure 74 corresponds to the trigger pin timer. The trigger pin timer has a period of 5ms, which means it sends out trigger pulses every 5ms. The timer block is also chosen to be a continuous type to ensure that the process is able to repeat itself.

The echo pin timer gets enabled when the Echo_1 pin or Echo_2 pin is triggered. This happens when an ultrasonic signal sent out by the trigger pin gets reflected and is received by the echo pin.

The two echo pins correspond to the two ultrasonic sensors that are used, and the control register enables switching between the two signals. When an echo signal is received, the echo timer captures and records the time between the last trigger signal and the echo signal received.

Within the echo interrupt service routine, the distance between the object and the robot is calculated. If this distance exceeds the limit set for each zone, the robot will proceed to the movement sequence as per Figure 73. A flow chart detailing the coding process of the ultrasonic sensors is detailed in Figure 75.

Aside from collision detection, the contact switches are also used to realign the robot against the wall, enabling it to reposition itself and move straight forward. A flowchart detailing this process is found in Figure 76.

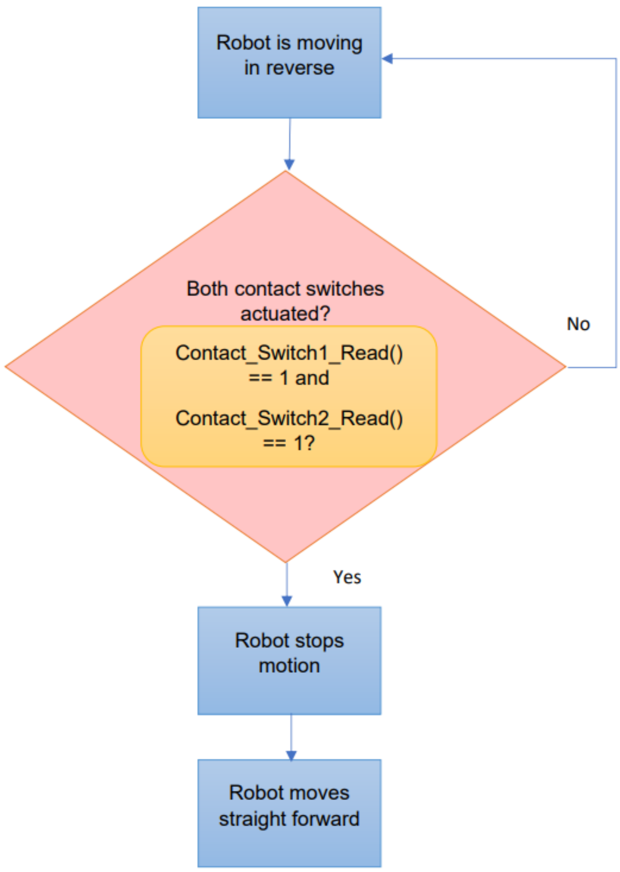


Figure 76: Flow chart for contact switches

Aside from collision detection, the contact switches are also crucial for the robot to perform realignment at the walls. This is done to correct the movement of the robot and ensure that it is able to proceed the round while moving in a straight line. As an example, if the turning angle at a previous zone was not a perfect 90°, this could cause the robot to be positioned at a wrong angle. This error could build up and cause the robot to move in the wrong direction and enter prohibited zones. Hence, aligning the robot at zones 3 and the starting base will ensure that this error can be avoided.

3.7 Puck Handling system

The IR sensor is used to determine the presence of a puck during the movement of the robot. When the IR sensor is triggered, the robot transitions into the puck state. In the puck state, the colour sensor is used to determine the color of the puck located beneath the robot.

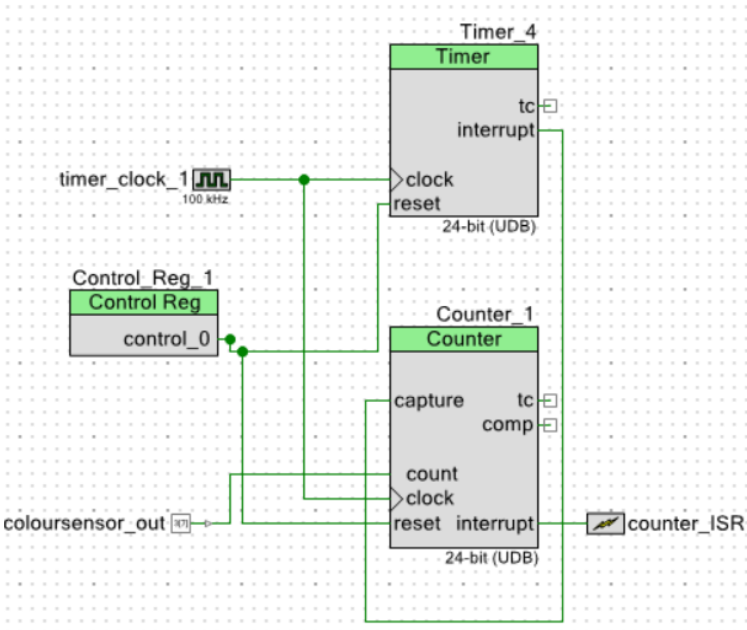


Figure 77: Colour Sensing Components

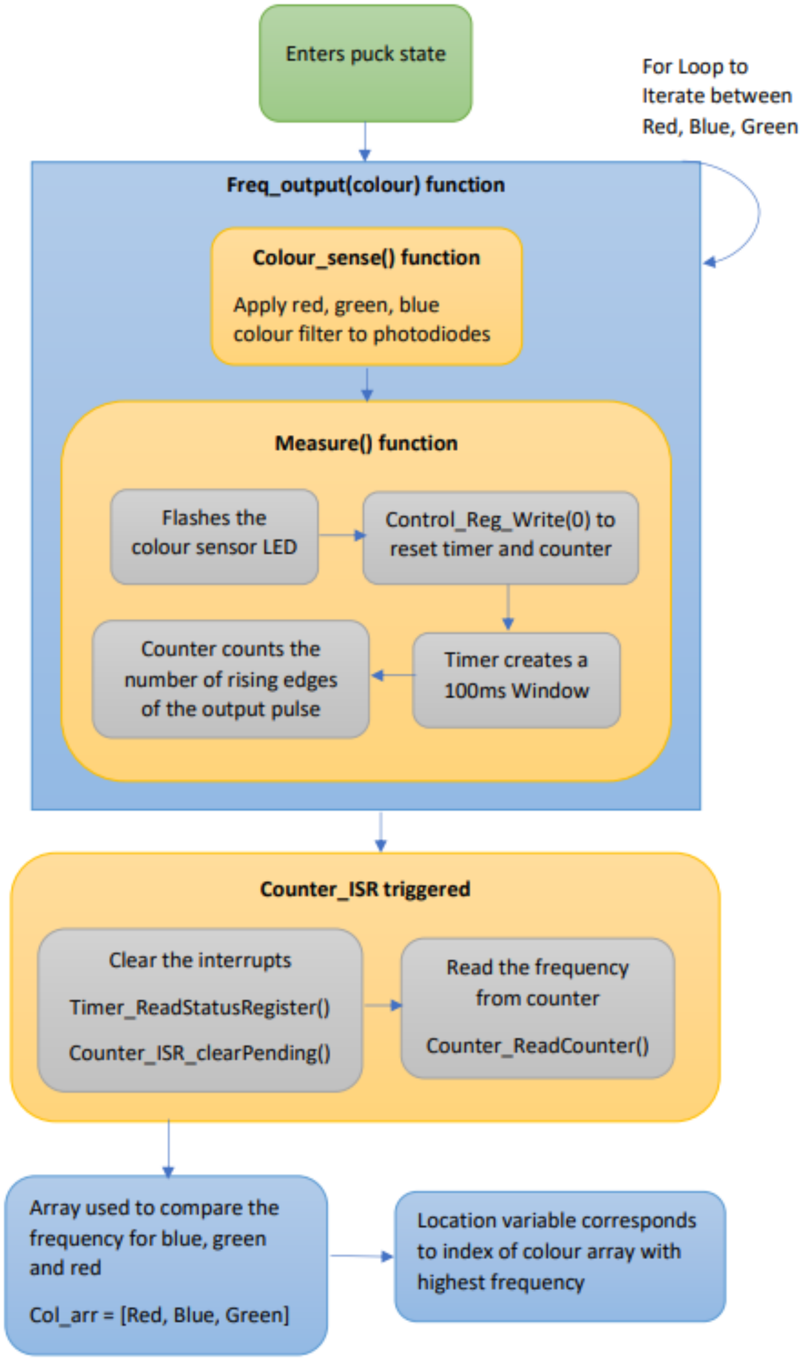


Figure 78: Flowchart of Color Sensor

The colour sensor outputs pulse waves that are fed into a counter block. Timer_4 from Figure 77 is a countdown timer that basically creates a time window in order for the counter to count the number of rising edges in the output pulse wave. This hence counts the frequency of the output pulse wave that comes from the colour sensor. Based on the filter applied to the photodiodes and the highest frequency counted, the correct colour is deduced. A one shot timer is used for the timer because the action of colour sensing only occurs when a puck is detected and can be manually reset by writing to the control register.

The counter interrupt service routine has the highest priority, this is because this task cannot be interrupted when it is being carried out. Since the robot will remain stationary during the colour sensing period, the ultrasonic ISRs and state machine ISR are not required to function. The counter_ISR will only be triggered when the robot is in the color sensor state. A flow chart further detailing the process of detecting and handling the puck is in Figure 78.

Servo motors are connected to the gripper in order to enable it to grip and drop the puck accordingly. In order to control the angle and position of the two servos, two pwm blocks are used.

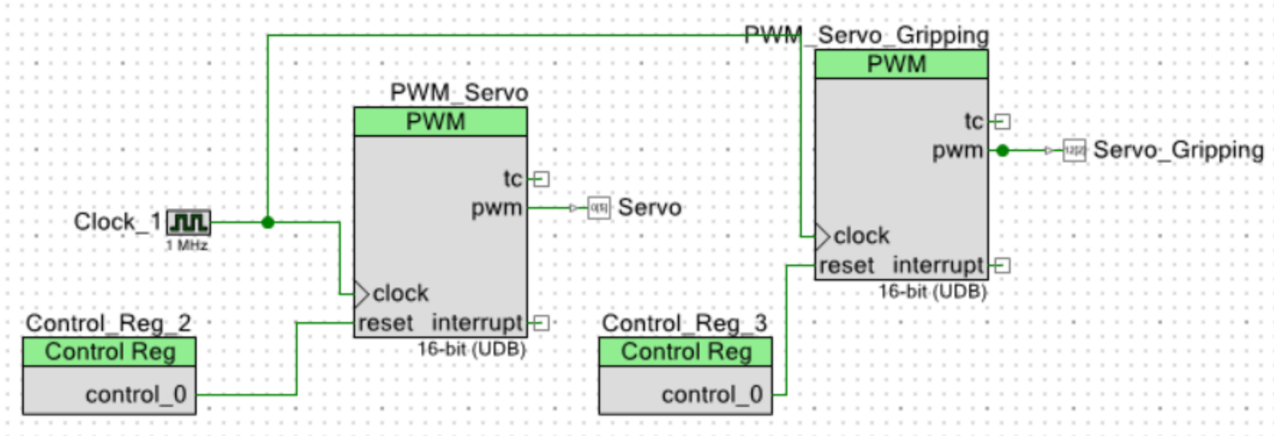


Figure 79: Servo Motor components

Referring to Figure 79, PWM_Servo refers to the servo motor that is used to flip the gripper upwards and downwards. Servo_Gripping refers to the servo motor that is used to grip and ungrip the puck. The angle and position of the servo motor is determined by the duty cycle of the PWM block, which can be changed based on the required actions. The control registers are connected to both PWM blocks in order to turn them on and off. This is crucial to prevent excess current drawn to the servo motors.

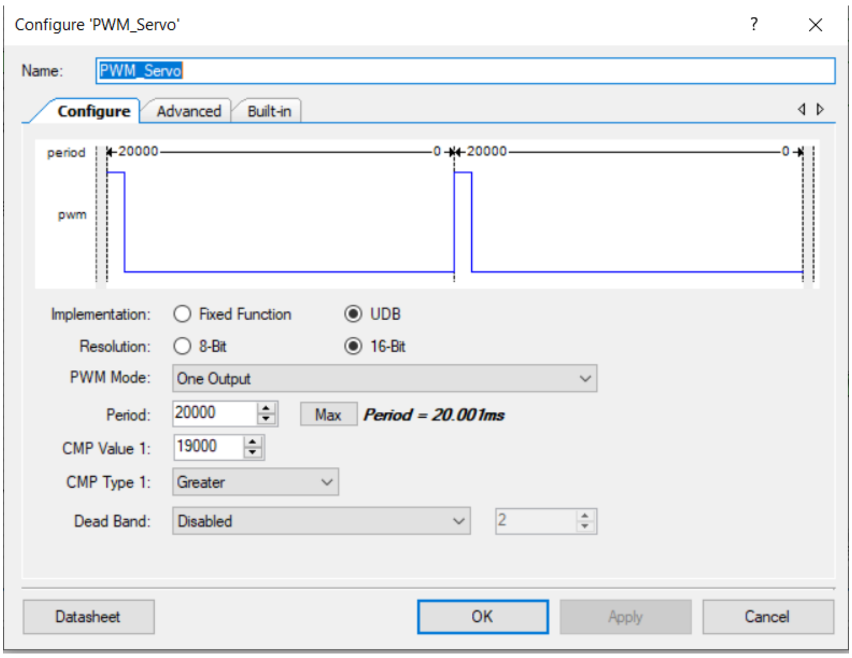


Figure 80: PWM setting for servos

The initial position of the gripper is set to be flipped up and closed.This is done by writing the compare value of (20000-450) to both servo PWMs in the main function. The reason why the compare values written to the PWMs are in this form is because in the TopDesign file, the compare value type of servo PWMs are set to ‘greater’. This is referring to Figure 80. It is found through testing that this configuration enables more accurate positioning and angles of the servo motor.

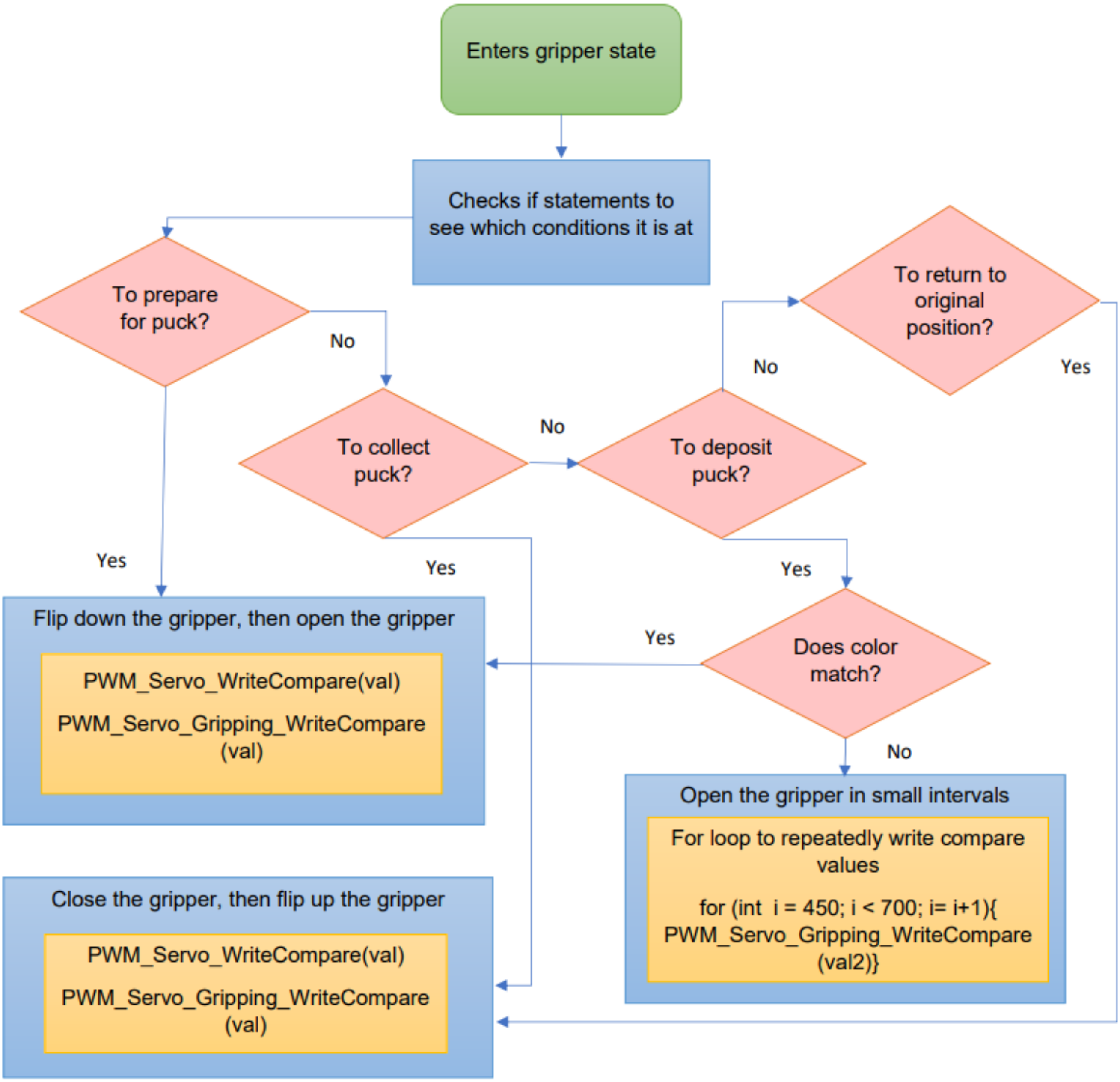


Figure 81: Gripper state flow chart

The gripper will remain in this position until a puck is encountered along the pathway of the robot. When the robot senses a puck, it will proceed to do colour sensing, then the robot reverses a set amount of distance in preparation to collect the puck. The gripper flips down, and opens before the robot moves forward a set amount of distance to fit the puck inside the gripper. Then, then gripper grips the puck and flips upwards. The robot proceeds to navigate across the arena before arriving at the puck capture zone, and depending on the colour of the puck and the colour assigned to the robot, decides whether or not to flip the puck before depositing it. A flow chart detailing the process of gripping and depositing a puck is found in Figure 81

3.8 Alternatives for Software Design

3.8.1 Use of Finite State Machine instead of Case Statements

Instead of using case statements to switch between the states of the robot, an alternative method would be to use a Finite State Machine (FSM). With the use of a FSM, the different states of the robot would be implemented using interrupt service routines instead of case statements. Hence, the robot alternates between the states accordingly and is able to reenter each state.

This alternative was not chosen because it requires an extensive use of interrupt service routines. This means that each state requires its own ISR, hence before transitioning between states, the individual ISRs will be called. Although this method could eliminate polling delays, the robot needs to handle each ISR priority to ensure this method works correctly. Using case statements for the switching between states would make the visualization of state transitions to be smoother and clearer. For the current implementation, each case statement represents a state for the robot. Within each case statement, the robot checks for 'if statements' and conditions that enable the transition to other states.

In order to minimize polling delays that could potentially occur in case statements, if else statements are used whenever possible, instead of multiple if statements. This helps to save time as the system checks through the multiple statements. As an example, if the robot meets the first condition in the 'if' component, the system does not need to waste time checking for the other 'else' components within the case.

3.8.2 Alternate Pathway for Robot

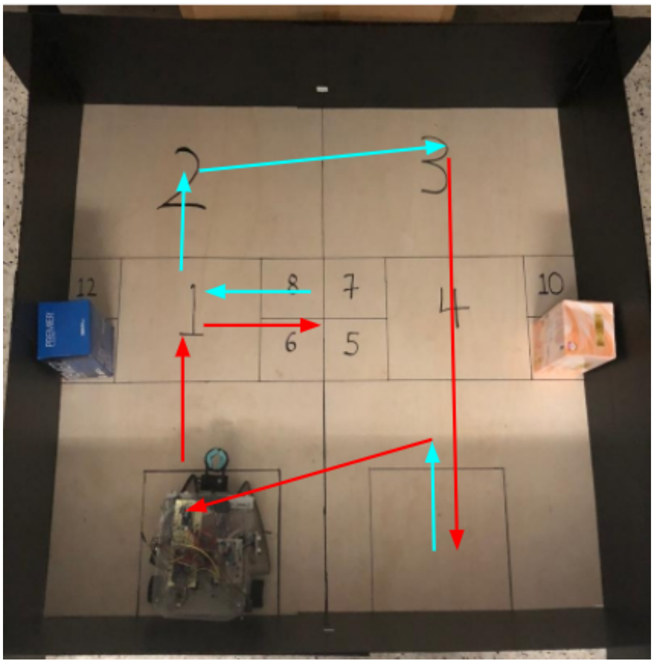


Figure 82: Alternate path for robot

Referring to Figure 82, the red arrows indicate where the robot will be moving in the forward direction, whereas the aqua arrows indicate where the robot will be travelling in the reverse motion.

Instead of the implemented pathway for the robot, an alternate pathway was proposed during the planning stage of the robot. The general route of the robot is similar, however, instead of moving straight, the robot would be moving in reverse in some areas as per Figure 82. Initially, this sequence of motion was proposed in order to prevent the gripper of the robot to crossover to prohibited zones. This method was also tested, but it was concluded that this alternate route came with several issues.

Firstly, the time taken for the robot to complete one round with this pathway is 1 minute 20 seconds. Comparatively, the time taken for the robot to complete one round with the currently implemented route is only 1 minute 5 seconds.

Besides, because the robot is reversing to move within zones, the movement of the robot is inconsistent. The motion of the robot is sometimes swayed to one direction, causing the robot to be unable to move consistently in a straight line.

Apart from that, because of the lack of ultrasonic sensors positioned at the back of the robot, it is unable to gauge the distance of obstacles from the direction it is moving in. Contact switches are positioned at the back of the robot as part of the collision avoidance system, however, contact switches require the robot to be pressed against the wall in order to work. Hence, this method would require heavy reliance on the XY coordinate system. If minor discrepancies or inconsistencies occur, then the robot would be prone to hitting obstacles or moving off course.

3.8.3 Use of count values to determine distance instead of XY coordinates

Instead of using XY coordinates, an alternative method to determine the distance travelled by the robot is to use the count values outputted from the Quad Dec. However, because a 16 bit Quad Dec was used in the design, the maximum count value that can be counted is +32767 and -32767. Hence, in order to ensure the count value can increment correctly after the Quad Dec resets, a separate variable is required to count the number of times this happens. Then, this value is multiplied by 32767 and added back to the current count value. This enables the count value to be correctly accumulated.

This method was not used because it brings several inconsistencies with the distance counted. This is because the count value from the Quad Dec changes at a very fast rate, hence the count values for each zone might contain minor discrepancies each time. The distance used would be in very large numbers, hence it would be harder to estimate the exact distance in count values that is required for the robot to move within each zone.

Besides, without the XY coordinate system, counting the distance independently would not provide any indication regarding the direction and positioning of the robot.

3.8.4 Using moving average filter

To filter out the fluctuations and noise readings obtained from the ultrasonic sensor, a moving average filter can be implemented. The ultrasonic readings will be continuously added to an array and when the array has 6 elements, the average of the 6 elements/readings will be taken. The average result will then be the final reading of the ultrasonic sensor. The array is then cleared and the process repeats. This method will help to smoothen out the readings if the fluctuations are small. As an example, an array consisting of [4,5,6,5,513] will give an average reading of 6.33cm, which is close to the true value of 6cm. If the outlier is too extreme however, the final average reading will be very far off from the true reading. As an example, an array consisting of [4,5,6,5,6,50] will give an average reading of 12.67cm, which is far off from the true value of 6cm.

The ultrasonic sensor that was used constantly gave very sharp outliers. The moving average filter idea was then changed to the median that was much better in dealing with extreme outliers. Using back the array example earlier consisting of [4,5,6,5,6,50], the elements are first bubble sorted so that the elements are arranged in ascending order and becomes [4,5,5,6,6,50]. The average of the 3rd and 4th element of this array;which are the 2 middle elements, is 5.5cm which is much closer to the true value of 6cm than what was obtained with the moving average filter.

3.8.5 Using different PWMs on master and slave wheels

In the efforts to increase the speed of rotation of the motor/wheels, the PWM duty cycles had to be increased. Through trial and error, it was noted that without error correction, the master wheel would be alot faster than the slave wheel. If both master and slave wheels receive the same amount of PWM duty cycles, since the wheels are now moving faster, it would be more difficult to control the error difference, especially the initial error. If the error difference is not controlled properly, the master wheel will stop while the slave wheel moves, and this will produce a jerking movement. To reduce the initial error difference between the count values(speed) of the master and slave wheels when performing error correction, the PWM block that is connected to the master wheel will be set with a duty cycle of 60% and the PWM block that is connected to the slave wheel will be set with a much faster duty cycle of 80%.

This method did help in making the initial error lower and hence making it easier to control the error. It was however sometimes inconsistent as the master wheel’s count value sometimes resets faster than the slave wheel’s count value. This would result in a negative error difference and an incorrect PWM correction value would be fed to the slave wheel, causing the slave wheel to move slower when it should not, and leading to a build up in error. This will then cause the robot to continuously jerk as it moves. This method was therefore scrapped in favour of using a lower PWM duty cycle of 50% for both the slave and master wheels. With a lower duty cycle, the error difference is easier to control as the count values do not increase so quickly.

4.0 Strategies and Innovations

4.1 Strategies adopted for each tasks

4.1.1 Navigation of the robot

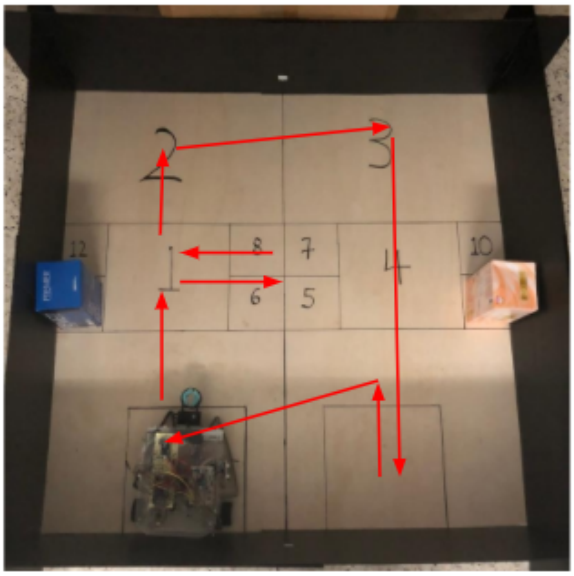


Figure 83: Path taken by the robot in the arena

The reason why the XY coordinate system was implemented into the navigation system of the robot is to ensure that the robot is able to accurately navigate in the arena itself. It will be used mainly as a limit that the robot should travel depending on the position of it in the arena. This will then help to solve any distance fluctuations collected by the ultrasonic sensors at the front.

Due to the extruding gripper at the front, the robot is unable to enter too far into zone 2 when coming from zone 1 before coming into the wall. Hence, if a 90° turn was made, the robot will overlap a lot into zones 7 and 8, which is against the rules. Therefore, to prevent the right wheel of the robot from crossing more than 20% into the puck collection zone (zones 8 and 7) the robot will be traveling at an angle from zone 2 to zone 3 as shown in Figure 83. When it is traveling at an angle upwards to the right, logically, the X and Y coordinates must both be incremented. The code logic however will only increment the X coordinate but not the Y coordinate. Hence, to solve this issue, the robot would also travel at the same angle after reversing from the puck capture zone and travelling back to the base. By doing this, any changes in the Y coordinate can be neglected.

Based on Figure 83, the robot was programmed to follow a predetermined path to navigate within the arena and complete tasks such as picking up and dropping the puck. This path is chosen after multiple testing and it was discovered that this was the most time efficient and reliable way to complete the tasks. To accomplish this, it must be ensured that the robot can autonomously follow this path consistently for five minutes consistently.

There are chances that the robot might travel off the predetermined path. Therefore, the robot was programmed to use the wall at zone 3 to realign itself after turning right to face zone 4. This is essential to ensure that the robot is able to move in a straight line to reach the puck capture zone after performing multiple turns prior to arriving at zone 3. After testing, it was discovered that without performing realignment at the wall using the limit switches behind the robot, the robot could be prone to these risks:

- The right wheel of the robot could cross over to zones 7 and 5
- The extruding gripper might exceed 20% of zone 10
- The robot might not be able to move in a straight line to the puck capture zone

These issues could potentially occur if a prior turn was not performed perfectly, or if the robot was not positioned straight towards the puck capture zone in zone 3. Although the realignment process takes up time, it ensures consistency and reliability of the algorithm.

The robot also performs realignment at the base before continuing the next iteration. This is to ensure consistency such that the robot will be able to start at the same position for the next iteration and the XY coordinates will also reset when the robot has successfully returned back to base. Therefore, any unforeseen error of increment and decrement of the X and Y value will be cleared for each iteration and the error in the system will not build up.

4.1.2 Identify colour of the pucks

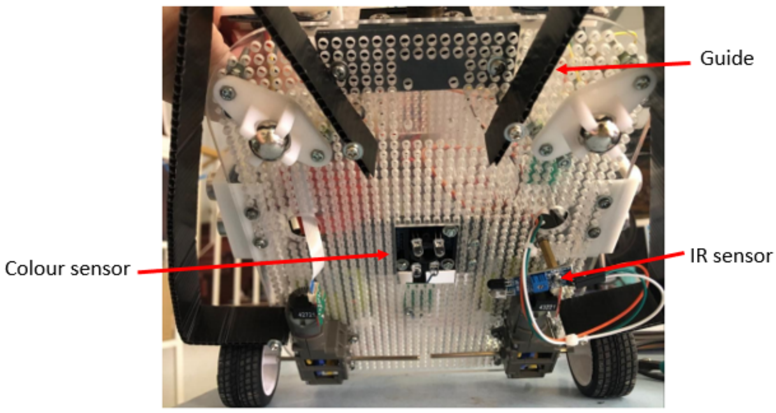


Figure 84: Placement of the colour sensing components at the bottom of the robot

The robot is designed to move over the pucks at the puck collection zone before scanning for the colour, which is why the colour sensor and IR sensor are both placed at the bottom of the robot. Scanning for the colour at the bottom of the robot will reduce the chances of any external light disturbances. The guide built for the robot will act as a funnel for the pucks, such that only one puck will be presented to the colour sensor at a time. When a puck is detected by the IR sensor, the robot would stop and the colour sensor will start sensing the colour of the puck. Then depending on the frequency of the reflected light, the filter with the highest frequency will be the colour of the puck and the corresponding coloured LED will light up at top of the robot to indicate the colour.

If the colour of the puck is green, the robot will continue moving forward until the next puck is detected. A slight delay is introduced to the IR sensing operation after scanning the green puck so that the IR sensor will not get triggered by the same puck. If the detected colour is either blue or red, the robot will enter the puck collection state to grip the puck.

4.1.3 Picking and Flipping of pucks

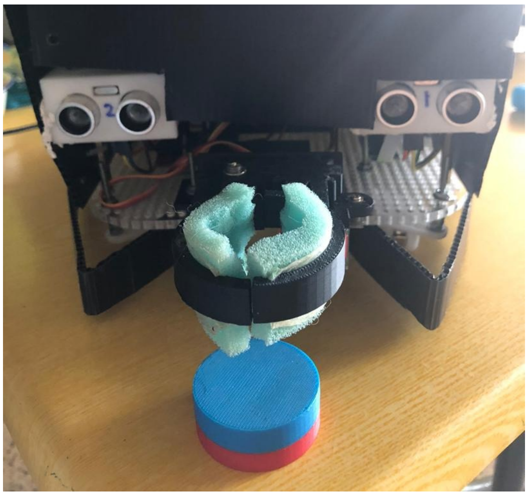


Figure 85: Initial position of the gripper

The gripper is designed to pick up any puck on the floor, that means the gripper would need to be close to the ground to pick up a puck. Since the colour sensing unit is placed directly behind the gripper unit, the gripper will first need to remain at the top position as shown in Figure 85 to allow pucks to pass through the gripper into the gap in between the guide. Therefore, when the robot is turned on at the base, the servo at the base of the gripper will be triggered to make sure that the gripper is initially flipped up.

At the puck collection zone, when a red-blue puck or blue-red puck is detected by the colour sensor, the robot will reverse to a predetermined distance from the puck (30 units of X coordinate away), so that the puck will be in front of the gripper. Then the gripper will flip downwards and open up to be ready to grip the puck. After that, the robot will move forward to let the puck enter between the hands of the opened up gripper. The gripper will then close and flip upwards before reversing back to zone 1, because according to the rule, the robot should pick up a puck to transport it to the puck collection and not bulldoze it. In the software aspect, it was coded in such a way where the IR sensor will not get triggered by any other puck until the robot realigned itself at the base after each iteration. This will therefore avoid any confusion in the state that the robot is in.

At the puck capture zone, because the puck will be flipped everytime it is picked up, the colour of the puck facing up should be the opposite colour detected by the colour sensor. Therefore, depending on the colour assigned to the robot at the very start it will either drop the puck straight away in mid air or the gripper will flip downwards to place the puck on the ground.

4.1.4 Obstacle avoidance

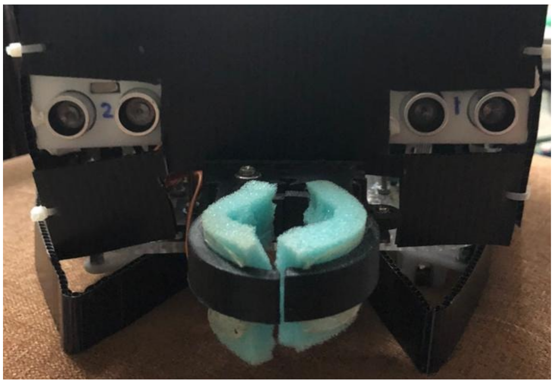


Figure 86: Ultrasonic sensors at the front of the robot

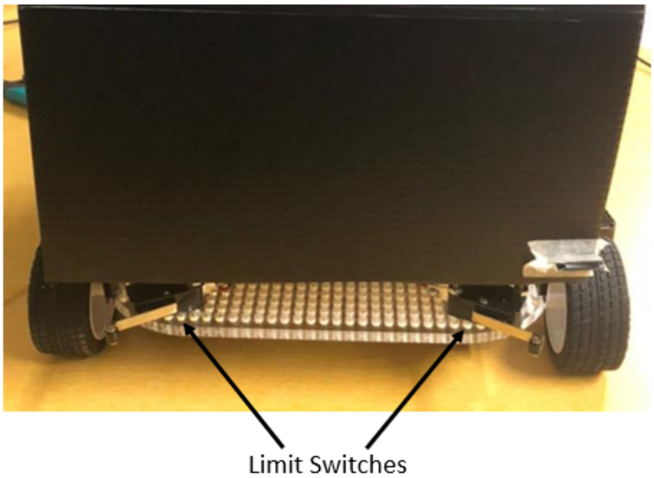


Figure 87: Limit switches at the back of the robot

The two ultrasonic sensors at the front of the robot as shown in Figure 86 will be used to avoid any obstacles 13 cm away especially when the robot is moving forward. This is to protect the 11cm extruding gripper from the base of the robot from hitting any wall or obstacles. The reason for using two ultrasonic sensors is to make sure the real distance of any obstacle in front of the robot will be more accurate. So if any obstacles are detected in front of the robot, it will turn right to avoid it.

Besides, when the robot is moving backward, the limit switches located at the back of the robot as shown in Figure 87, will be the main obstacle sensing unit. The reason why they are both placed at an angle is to make sure they get triggered slightly earlier before the ends of the robot really pushes onto the obstacle. So if the limit switches get triggered, the robot will stop reversing and then the robot will move straight.

4.2 Key Innovations

4.2.1 Mechanical

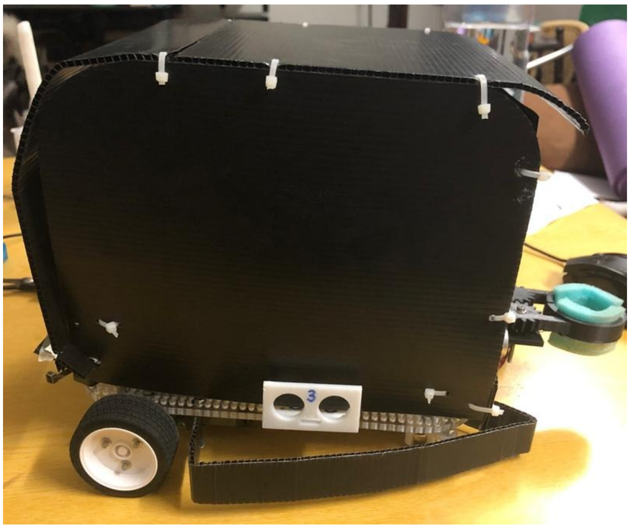


Figure 88: Side view of the robot

The key innovation for mechanical design is mainly at the design of the gripper. First the added sponge at the inner wall of the gripper provides a better gripping force to the puck without damaging the puck because the sponge is compressible.

According to the puck deposition algorithm discussed above, in order to flip the puck, it will be dropped at a certain height above the ground. Therefore, chances for the puck to flip itself after bouncing off the ground is relatively high (7 out of 10 times). To solve this problem the front wheel (caster wheels) of the robot is made to be as low as possible and the body of the robot will be slanting forward as shown in Figure 88. This can also ensure that the puck is landed at a slight angle, such that the chances of the puck bouncing off the ground will be reduced to none. This is because two ends of the puck will land on the ground at a different time interval. Therefore, the normal force on each end of the puck will tend to cancel each other.

Furthermore, the gear design at the end of each gripper hand is also one of the key innovations, because it allows the usage of only one servo to rotate the gears on one gipper hand and due to the mated gears, it is able to move both hands at the same time.

4.2.2 Electronics

A few key innovations were implemented in the electronics aspect. Firstly, a toggle switch was used to determine if the robot was a “Red” Robot or a “Blue” Robot. A “Red” Robot means that the robot will ensure that only a red puck is deposited at the puck capture zone and vice versa. With the toggle switch, this option can be selected quickly before the start of the competition round, rather than re-programming the robot. This would save time and provide more time for preparation in other aspects.

Furthermore, the usage of ultrasonic sensors to detect obstacles rather than using IR sensors is a key design. By using ultrasonic sensors to detect obstacles, the distance between the robot and the obstacle can be calculated. Therefore, different distance conditions can be set in the code algorithm to only react to obstacles at different zones, and with only using the same ultrasonic sensor. 2 ultrasonic sensors were also used at the front of the robot to improve sensing coverage. With a wider coverage, obstacles can be detected better to reduce the risk of collision.

Furthermore, DC motors with shaft encoders attached to it were also used. With the shaft encoders, the speed, direction of rotation and position of the motor/wheel can be determined. The shaft encoder also provides two output waveforms, Phase A and B that can both be connected to a Quad Dec in the software aspect to obtain count values. These count values can be used to ensure that both the master and slave wheel are moving at roughly the same speed, to ensure that the robot can travel in a straight line.

4.2.3 Software

There are a few key innovations for software design, such as the method used to reduce fluctuations of the measured distance value from the ultrasonic sensors and XY coordinate system.

The XY coordinate system uses the readings from the shaft encoder to determine the amount of distance traveled by the robot at each direction accurately. Therefore, it will allow the robot to navigate in the arena according to the predetermined route that will reduce the chances of colliding into any obstacles in the arena. Besides, it will also help to save time on walking on an unwanted route especially when the robot is searching for a puck in the puck collection zone.

Furthermore, XY coordinate system is also used to ensure that the robot moves the required distance across the arena before checking the distance recorded by the ultrasonic sensors. As another solution to the fluctuations in ultrasonic sensor readings, an array is used within the echo ISR to remove outliers. The distance values calculated using the readings of the ultrasonic sensor are put into an array with a length of 6 and sorted in ascending order. Then, by using the moving median method, the outliers will be removed and the average of the middle 2 values calculated are taken as the final distance.

5.0 System Integration and Testing

5.1 System Integration

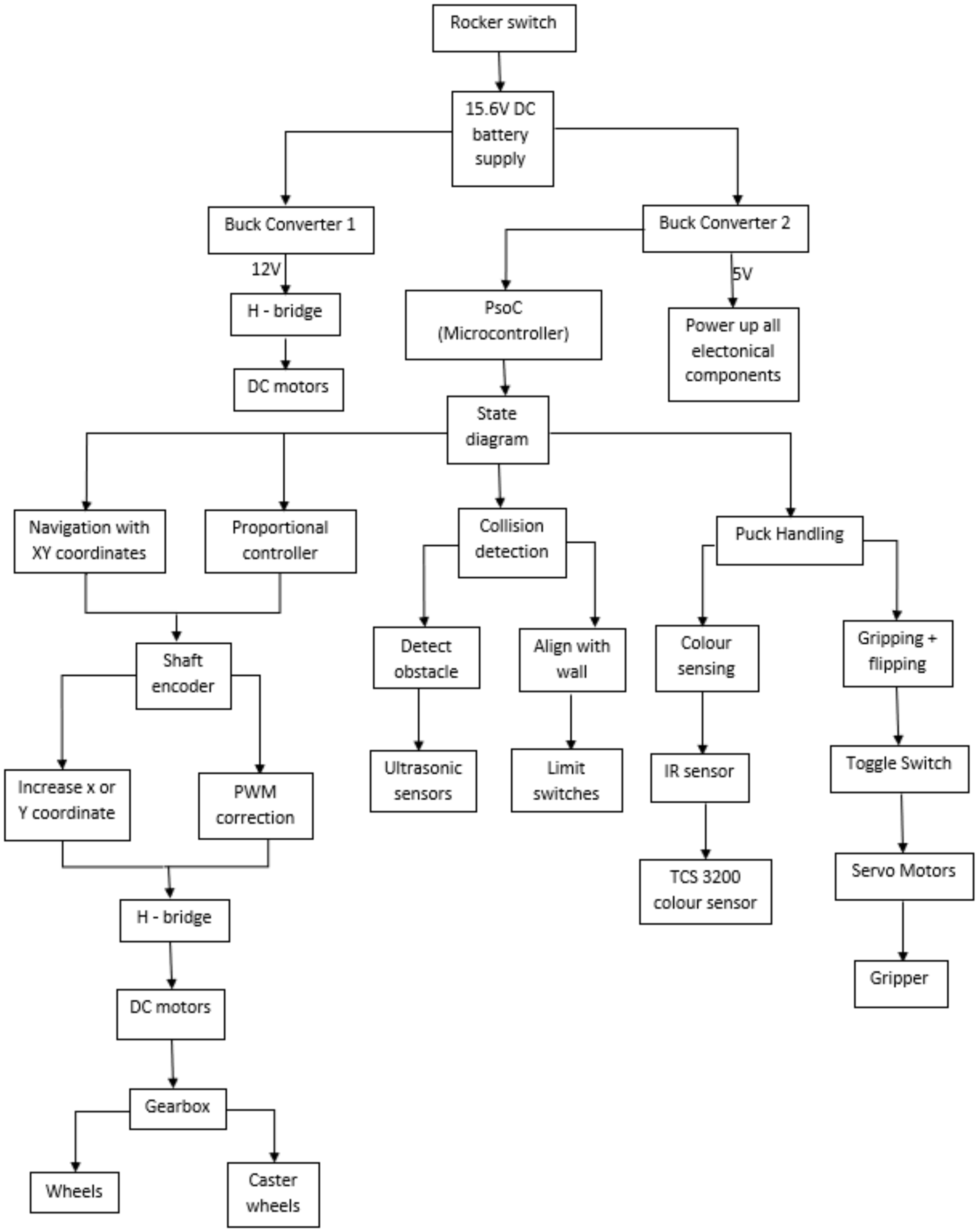


Figure 89: Integration of all subsystem in the robot

For the robot to perform a specific task autonomously, different subsystems from the software, mechanical and electrical aspects have to work together. Figure 89 outlines integrated subsystems of the robot to complete different tasks.

In order to power up the PsoC and the other electrical components, the rocker switch must first be flipped to the “ON” position to allow current and voltage to be supplied to the 2 buck converters. Buck converter 1 will provide 12V to the H-bridge to be provided to the DC motors whereas buck converter 2 will provide 5V to power up the PsoC and all the other electronic components.

The PsoC microcontroller is the main control unit of all the subsystems and is where the software subsystem is implemented. It will decide which state in the state diagram that robot will enter; be it the “straight” state, “puck” state, “turn left” state, “turn right” state, “reverse” state or “gripper” state. Within the state diagram, different tasks must be carried out to ensure autonomous functionality.

In order for the robot to navigate around the arena with the use of XY coordinates while also implementing the proportional controller, the shaft encoder must be utilized. As the DC motor rotates, gears in the gearbox also rotates. With the gearbox, a higher torque can be produced to move the wheels and the whole weight of the robot. As the DC motor rotates, the shaft encoder also rotates and will give 2 square waveform outputs; Phase A and B to the input pins of the PsoC, which are connected to Quad decoders. These Quad Decoders would produce count values by counting the transitions of the Phase A and B waveforms. The count values will then be used to increment or decrement the X or Y coordinates and also perform PWM correction on the slave wheel. While the robot is travelling, the PsoC will continuously feed different PWM signals(in terms of duty cycle) to the H-bridge and then to the slave motor that is controlling the slave wheel. This is to ensure that the slave wheel moves at about the same speed as the master wheel. If the robot has travelled the specified X or Y coordinate, the PsoC will feed signals to the H-bridge that connects the DC motors and the wheels for the next required movement. As the robot moves, the caster wheels also move together to act as the front two wheels.

As for collision detection, the PsoC will continuously trigger the ultrasonic sensor to send sonic pulses and calculate the distance of the robot from the obstacle by measuring the time it takes for the emitted signal to be reflected back to the echo pin of the sensor. If the distance from the obstacle meets a specified condition in the software subsystem, the PsoC will immediately output signals to the DC motors through the H-bridge for the required wheel movement. In terms of wall alignment, when both contact switches are actuated, only then will the PsoC send signals to stop the DC motors and change the state to “straight” state.

To handle the pucks, when the IR sensor detects a puck, a low signal is read by the input pin of the PsoC. From there, the PsoC will change the state to “puck” state and start scanning for the colour of the puck using the TCS3200 colour sensor. If the puck is not green, PsoC will send signals to the DC motor to enable the wheels and hence the robot to reverse and then go forward to grip the puck(using the XY navigation). The PsoC is also responsible for sending signals to the servo motors to flip the gripper and also open and close the gripper hands. At the puck capture zone, the PsoC will read the 2 pins connected to the toggle switch. Depending on which option is toggled, the PsoC will decide whether or not to send a signal to servo to flip the gripper down before triggering the servo to ungrip the puck.

5.2 Testing Environments

5.2.1 Gripper mechanism

In order to rotate the servo motors to the accurate position, trial and error was carried out in order to get the compare value to be written into the servo motor PWMs. The maximum period count for both the servo PWMs are 20000.

Table 8: Duty cycle of the PWM signal required for each action

Gripper Position	Compare Value for PWM	Duty Cycle
Flipped Up	450	2.25%
Flipped Down	2320	11.6%
Ungrip	800	4%
Grip	470	2.35%

5.2.2 Speed of the DC motor

The maximum speed of the DC motor would mean 100% of its duty cycle. Since 16-bit PWMs were used for the motor, the maximum period count is 65535. For the purposes of this project, 50% duty cycles were used for both wheels, hence writing 32767 to both motor PWM. It is also tested with 60% duty cycle for both wheels but the outcome of it is the slave wheels could not catch up to the master wheel and causes the robot to be unable to move straight.

5.2.3 IR sensor and Ultrasonic sensor

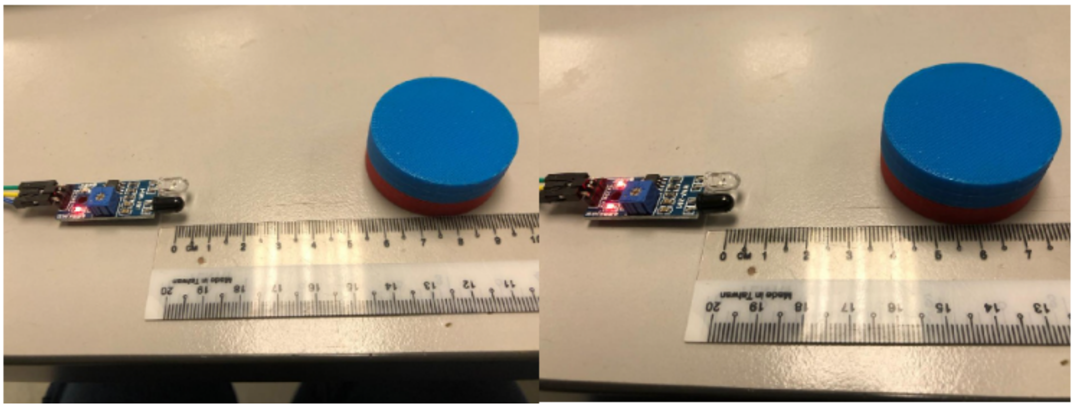


Figure 90: Adjusting the Distance of IR Sensor

The IR sensor is adjusted to sense an object within the distance of 2cm. This was done by fixing the position of the IR sensor and manipulating the puck position and sensing range of the IR sensor by adjusting the potentiometer of the IR sensor to manipulate the sensing range until the LED that indicates an obstacle has detected lights up. This is set so that given the position of the IR sensor underneath the robot, the robot will have enough time to stop and proceed with the colour sensing algorithm.

The ultrasonic sensors are used to sense distances for different ranges depending on the current zone of the robot. The reason why different distances are required is because the turning and movement of the robot are specific to the zones in order for the robot to accurately navigate through the arena. As an example, the robot needs to stop and turn when it is 18cm away from the wall in order to accurately reverse back to base. Data was collected by placing the robot at different positions on the arena where the distance is required and getting the distances from UART.

Table 9: Ultrasonic distance and different location in the arena

Zones	Ultrasonic Distance Sensed (cm)
2	11
3	14
Puck Capture Zone	15
Base	18

5.2.4 Navigation algorithm

Algorithm 1 - The current implemented algorithm
Algorithm 2 - The reversing algorithm
Algorithm 3 - The current algorithm, but instead of performing realignment at the wall at zone 3, the Robot skips realignment and turns right to proceed to Zone 4 straightaway

Table 10: Time taken for each navigation algorithm tested

Algorithm	Time taken for 1 round	Justification
1	1 min 5 secs	This algorithm was chosen because it provides the highest consistency
2	1 min 20 secs	Movement of robot is inconsistent and takes a long time
3	58 secs	Robot is unable to accurately return to base due to inconsistencies

5.2.5 Puck Handling

Depending on the color of the puck and the color assigned to the robot, the robot might be required to either flip the puck once or twice. In the event where the robot is only required to flip the puck once, the puck will be dropped from a high position. This creates risk where the puck will flip itself before landing on the ground, hence causing an inaccurate outcome. To solve this issue, further testing has been carried out to find the optimal gripper height from the ground to prevent auto flipping. This is done by adjusting the height of the steel castors at the front of the robot.

Table 11: Tabulation of the number of times puck flicks itself

Height of the Gripper from Ground (cm)	Average number of times the puck flips itself (out of ten trials)
5.5	1
5.0	5
6.4	7

Hence, the first option is implemented because it provides the most consistent outcome.

5.2.6 XY coordinates

Based on the distance required for the robot to travel in each zone, the X and Y coordinates are determined. The values of X and Y are used to ensure that the robot travels for that amount of distance before checking the ultrasonic sensor readings

Table 12: XY Coordinate Values for Each Zone

Zone	X / Y Coordinate
Starting base to Zone 1	Y = 133
Zone 1 to Zone 2	Y = 140
Zone 2 to Zone 3	X = 65
Zone 3 to Puck Capture Zone	Y = 8

The X and Y coordinate displayed in Table 12 does not mean the robot turns at that coordinate. Instead, the X and Y coordinate just helps the robot to travel a certain amount of distance before relying on the ultrasonic sensors for accurate distance to turn. This is important to minimize errors due to inconsistencies in ultrasonic reading.

5.2.7 Kp Value

The kp value used for the proportional gain controller is determined based on the results collected from the UART. In order for the robot to move straight, the error between the count values for both motors obtained from the QuadDec has to be a small and consistent value. To perform testing, the kitProg was connected to the PSoC on the robot while holding the robot in mid air and allowing the wheels to rotate. The data was collected as follows in Figure 91 and Figure 92 along with testing several other values of Kp. Aside from that, the robot was also put onto the ground in order to visually compare the movement.

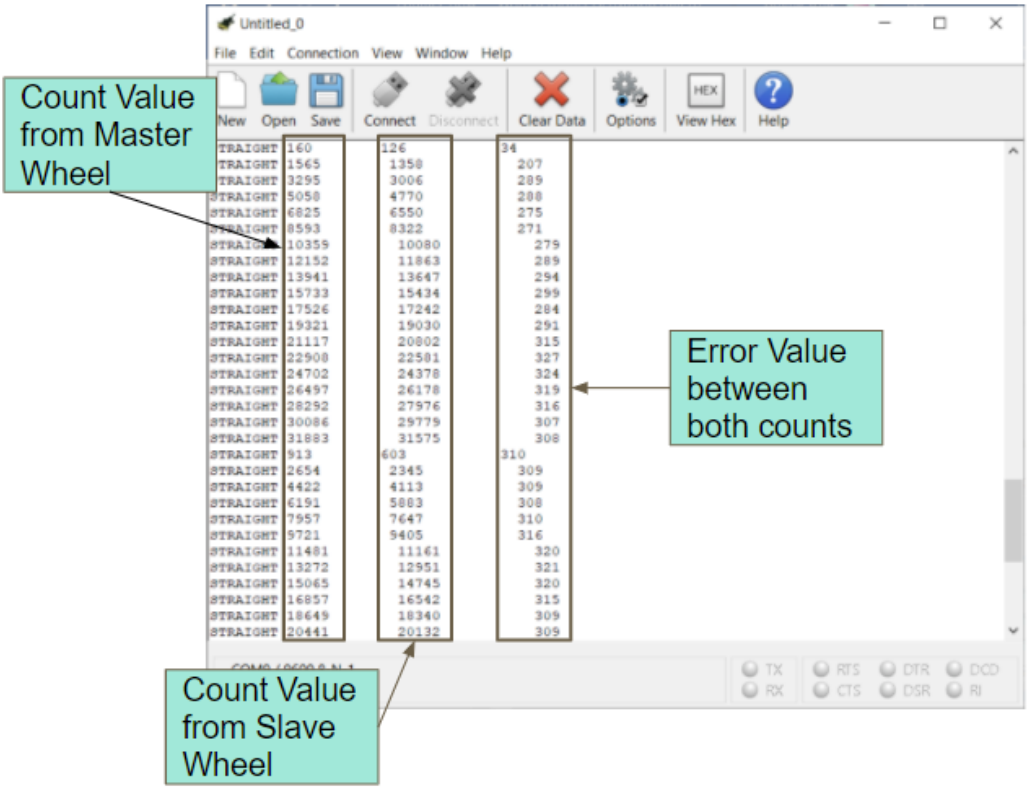


Figure 91: Coolterm Window for Kp = 55

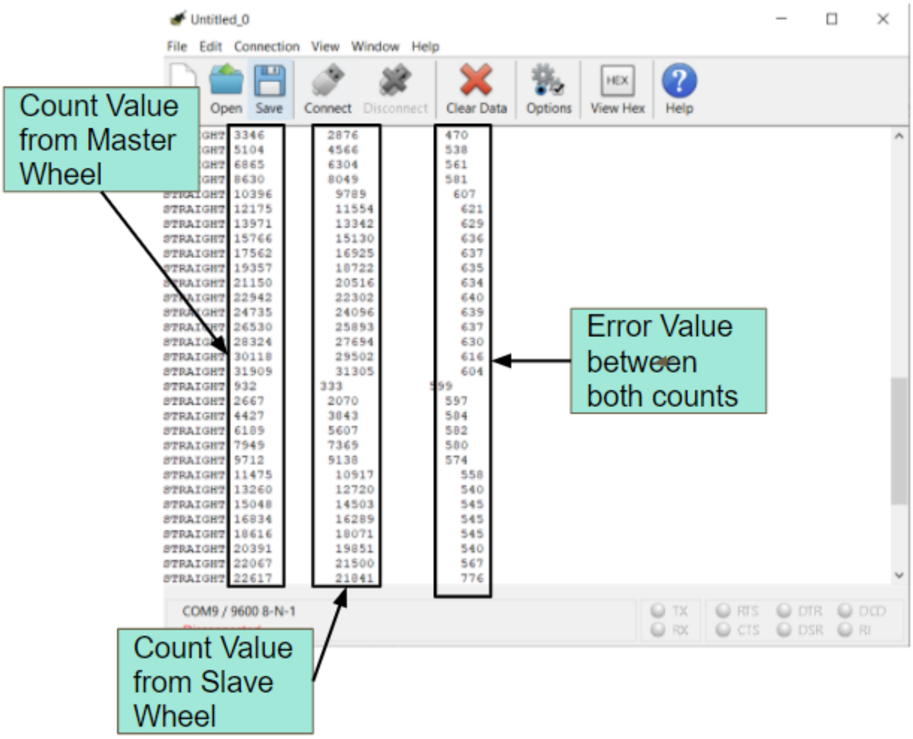


Figure 92: Coolterm Window for Kp = 30

From Figure 91, the magnitude of error is small and remains consistent around the 300 range. On the other hand, from Figure 92, the magnitude of error is quite large and is inconsistent from the 400 to 700 range. Hence this will cause the robot to be unable to move straight because of a large difference in speed for both motors.

6.0 Project Management

6.1 Team roles

Table 13: Description of each team roles

Role	Description
Project Manager	● Ensures that the project progress is kept on track ● Plan achievable weekly goals for the team ● Manages team members and delegates work ● Resolves conflict that arise between team members
Mechanical Designer	● Design the components required for 3D printing on SolidWorks ● Design the prototype of the robot ● Perform testing on the mechanical mechanism of the robot ● Assembling the hardware of the robot ● Troubleshooting mechanical related problems ● Build the chassis of the robot
Electrical Designer	● Design the electrical system that provide enough powers for the robot to perform the required tasks ● Choose the best available electronics components used in the robot ● Perform testing on the electrical components of the robot ● Ensure that wiring and circuitry are arranged neatly ● Troubleshooting electrical related problems
Software Designer	● Design and write codes for the robot to perform the required tasks accurately ● Integrates the software into the hardware subsystems of the robot through programming ● Debugging and troubleshooting software related problems

Table 14: Team member and respective roles

Team Member	Team Roles	Belbin's Team Roles
Clifton Mak	Project Manager, Electrical Designer, Software Designer	Completer Finisher, Shaper, Monitor Evaluator
Jolene Ong	Software Designer, Mechanical Designer	Completer Finisher, Shaper, Implementer
Lim Wei Jun	Mechanical Designer, Electrical Designer	Completer Finisher, Resource Investigator, Coordinator

The team roles are assigned according to each team member's speciality and preferences. This is to ensure that the team will be able to work under maximum efficiency.

Based on Table 14, all members in our team are of the Completer Finisher (CF) trait, this indicates that we pursue perfection in our work and are meticulous in every detail. Our team consists of 2 members that are Shapers (SH) that will constantly be able to keep the team on track and ensure that progress is made within the given time frame. Our team leader is a Monitor Evaluator (ME), which means that he is able to look at problems critically and strategically to make good decisions.

Our team also consists of an Implementer (I), this role is important as it ensures that the work actually gets done. The implementer will be able to turn ideas and plans into practical actions. The Resource Investigator (RI) in our team will be responsible for motivating the team and gathering useful information for the project. Lastly, our team's Coordinator (CO) will be able to define our goals as a team and effectively delegate tasks amongst team members.

In terms of project and time management, the delegation of tasks was mainly done through Whatsapp and Zoom Meetings. The scheduling and time allocated for each task was also done according to the Gantt Chart. Hence, task deadlines were also constantly reminded through Whatsapp to ensure that the progress is kept on track. Besides, the updated codes are always timely uploaded in the shared Google Drive, so this ensures consistency among all team members.

6.2 Gantt Chart

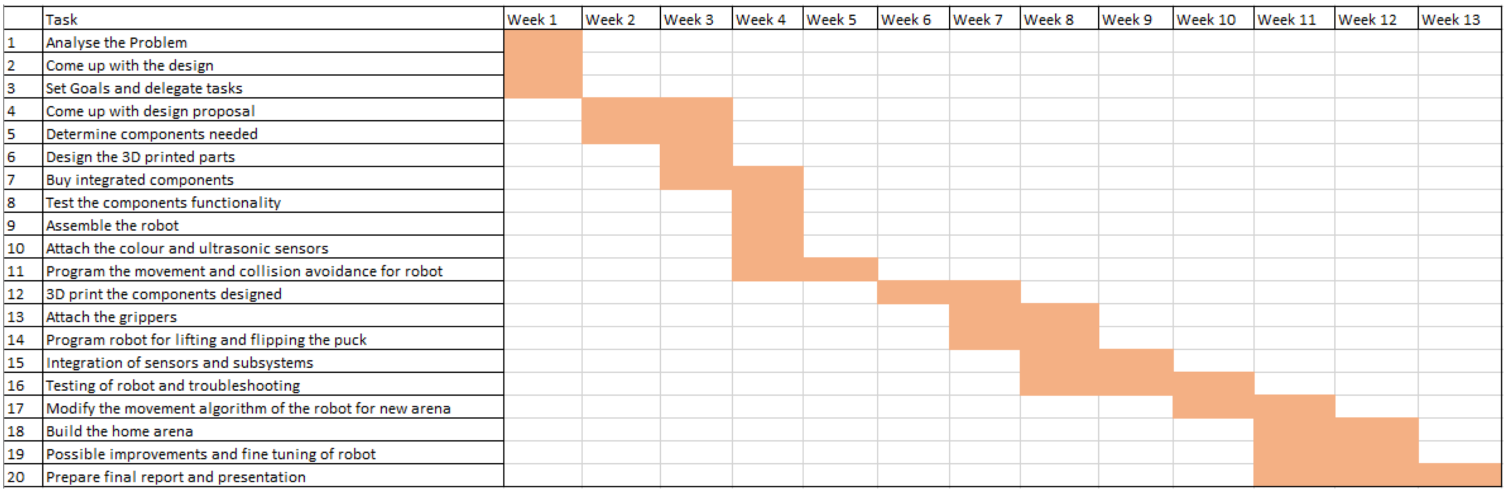


Figure 93: Gantt Chart of the project

Table 15: Description of the tasks

Task	Description
Analyse the problem	Analyse the tasks required to be carried out by the robot in the arena. For example, the robot needs to be able to colour sense, grip and flip the puck and also autonomously navigate itself in the arena for 5 minutes.
Come up with the design	Based on the problem statement, possible design ideas from mechanical, electrical and software aspects were brainstormed to approach the problem.
Set goals and delegate tasks	Decide on the best design available and start to work on them. The required tasks are then further divided and allocated to members based on their strengths in terms of software, mechanical and electronics aspect.
Come up with design proposal	The initial design of the robot is documented and the budget for the components needed to build the robot is prepared.
Determine the components needed	Finalise on all the required components such as sensors, batteries and building materials for the chassis of the robot.
Design the 3D printed parts	Start drawing the CAD drawing that is required to perform 3D printing. For example, holders for the electronics components and the gripper.

Buy integrated components	Place order on the components required such as integrated sensors, caster wheels and switches.
3D print the components designed	Start 3D printing the required components and test the suitability of its dimension. After which, minor adjustments are made to the design before reprinting the materials.
Test the components functionality	Test the functionality of the purchased components by studying and programming them using the PSoC board. Also ensure that each of them is able to carry out the required tasks and meet the design requirements.
Assemble the robot	Attach the DC motor with shaft encoder, gearbox, wheels and caster on to the base of the robot. Then a second layer is built to place the breadboard for the PsoC and buck converters.
Attach the colour and ultrasonic sensors	Allocate a suitable location on the robot to attach the colour sensor and ultrasonic sensor. Test to make sure that the location allocated allows the sensors to perform their delegated task efficiently.
Attach the grippers	Place the final design of the gripper onto the robot and test out its functionality and performance on the robot. Adjust the mechanical aspects of the robot to help the gripper perform at its best.
Program the movement and collision algorithm	Allow the robot to move in the arena by only being powered by batteries to test the navigation and collision detection algorithm. Fine tune and test for consistency on the best navigation algorithm available.
Program the robot for lifting and flipping the puck	Perform intensive testing on the gripper mechanism with the puck and look for the best way to handle the pucks.
Integration of sensors and subsystems	Allow a combination of all the subsystems and sensors to work together as a single whole system. Run a few test runs for the functionality of the robot in the arena.
Testing of robot and troubleshooting	Perform some final testing for consistency and troubleshooting any problems that occurred in each subsystem.

Modify the movement algorithm of the robot for new arena	Change the navigation algorithm of the robot for the new home based arena and the new rules. Perform tests with the new algorithm in the new arena.
Build the home arena	Construct the home arena at one of the members house according to the dimensions given.
Possible improvements and fine tuning of robot	Enable the robot to perform at its best performance by fine tuning each subsystem and the navigation algorithm to save on the time for each iteration.
Prepare final report and presentation	Start documenting the final design of the robot and prepare a presentation on the design of the robot and strategies implemented to solve the problems.

6.3 Critical Path Identification

The arrows in red indicate the critical path.

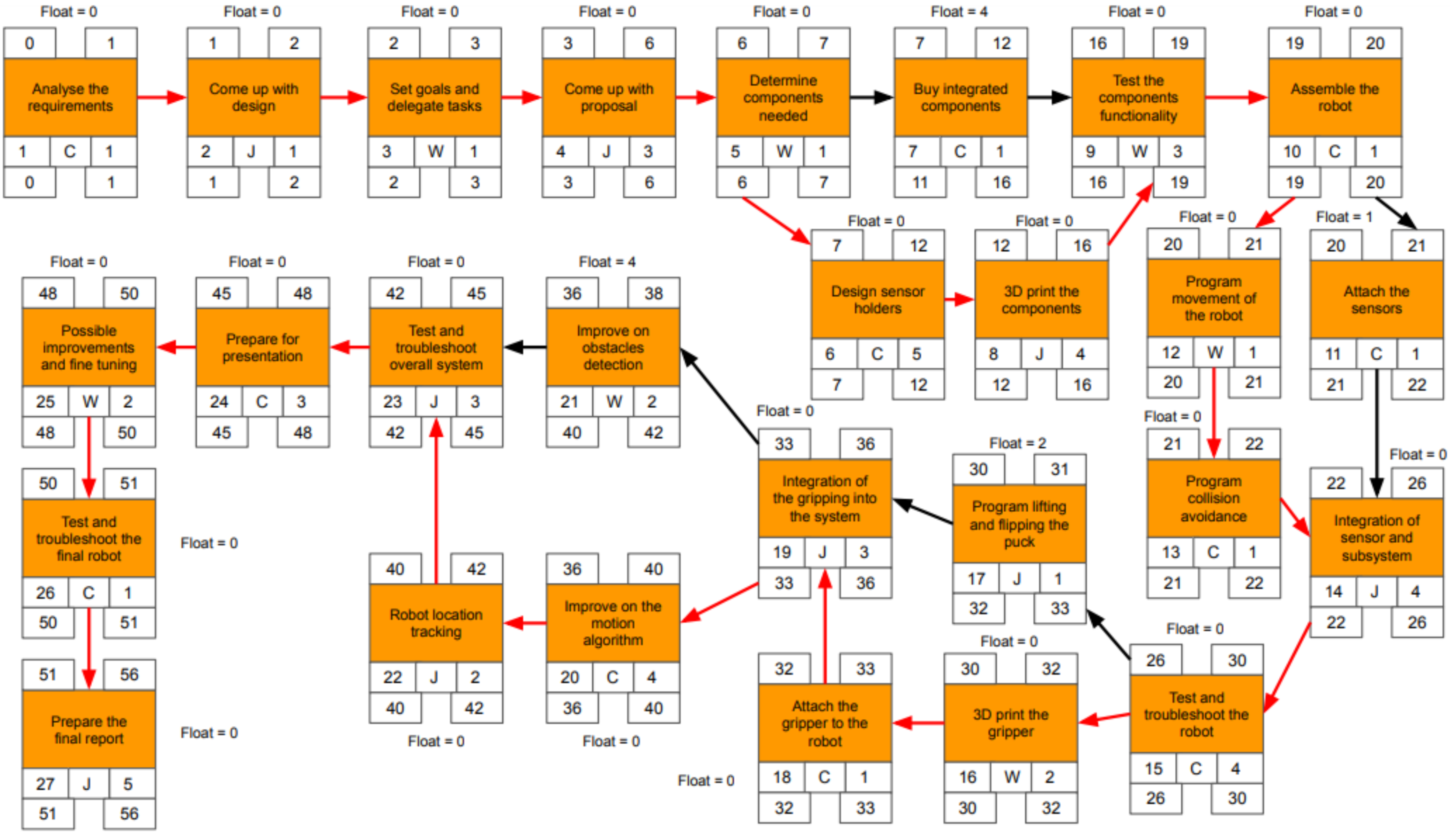


Figure 94: Critical path diagram of the project

6.4 Project Budget

The project budget allocated to purchase additional materials that are not available in the project kit is RM380. Table 16 shows the total actual cost of materials purchased throughout the project. Some of the components were not used on the final prototype but were important for testing purposes. Table 17 on the other hand outlines the estimated budget at the proposal stage.

Table 16: Total cost of materials

No	Item name	Supplier	Quantity	Price per unit (RM)	Shipping fee (RM)	Total price (RM)
1	Infrared Sensor Module	Cytron Technologies	1	0.95	-	0.95
2	TCS3200 Colour Sensor Module	Cytron Technologies	1	12.50	-	12.50
3	Omron Limit Switch (No roller)	Cytron Technologies	2	1.75	-	3.50
4	PKCELL NiMH Rechargeable AA 2000mAh Battery(4pcs)	Cytron Technologies	3	12.50	-	37.50
5	Beston 4pcs AA 3000mAh Ni-MH Rechargeable Batteries	Beston Electronics	3	21.00	4.00	67.00
6	W420 Steel Ball Universal Wheel (Castor)	Cytron Technologies	2	3.00	-	6.00
7	Metal ball caster(53mm)	Mybotic	2	7.90	4.66	20.45
8	Metal ball caster(53mm)	Mybotic	2	7.90	5.50	21.30
9	6xAA Battery holder	Cytron Technologies	2	1.50	-	3.00
10	4xAA Battery holder	Cytron Technologies	2	1.00	-	2.00
11	LM2596 3A Step-Down Converter	Cytron Technologies	1	1.50	-	1.50
12	LM2596 3A Step-Down Converter	SG Robot Technology Enterprise	1	3.50	1.16	4.65

13	Omron Limit Switch (with roller)	Cytron Technologies	2	3.50	-	7.00
14	0.9 to 5V DC Usb Booster Module	Cytron Technologies	1	3.00	-	3.00
15	Rocker Switch with Wire-20cm	Cytron Technologies	1	2.50	-	2.50
16	3 Pins Toggle Switch	Cytron Technologies	2	2.30	-	4.60
17	M3 X 70mm PH M/Screw Zinc	Yew Siong Industrial Supplies	20	0.30	-	6.00
18	M3 MS Flat Washer Zinc	Yew Siong Industrial Supplies	10	0.02	-	0.20
19	M3 X 0.50P Hex Nut Zinc	Yew Siong Industrial Supplies	30	0.05	-	1.50
20	M3 X 0.50P Hex Nut Zinc	Yew Siong Industrial Supplies	25	0.04	-	1.00
21	M3 X 1meter MS Stud Rod Zinc	Yew Siong Industrial Supplies	1	5.00	-	5.00
22	Double Sided Mounting Tape 18/24mm	UBiz Stationery by Traders Site	1	3.00	-	3.00
23	Cloth Binding Tape(36mm-48mm)	UBiz Stationery by Traders Site	1	2.00	-	2.00
24	Artline Permanent Marker 100	UBiz Stationery by Traders Site	1	6.20	4.66	10.85
25	Corrugated board	KH Stationery	4	8.50	4.66	38.65
26	Corrugated board	KH Stationery	1	8.50	4.66	13.15
	Total					278.80

Table 17: Estimated Budget at Proposal stage

No	Item name	Supplier	Quantity	Price per unit (RM)	Total price (RM)
1	Colour Sensor TCS 3200	Cytron Technologies	1	12.50	12.50
2	Caster wheels	Cytron Technologies	2	9.90	19.80
3	Infrared Sensor Module	Cytron Technologies	1	0.95	0.95
4	PKCELL NiMH Rechargeable AA 2000mAh Battery(4pcs)	Cytron Technologies	3	12.50	37.50
5	Battery holder	Cytron Technologies	2	1.50	3.00
6	Omron Limit Switch	Cytron Technologies	2	1.75	3.50
7	Step-Down Converter LM2596	Cytron Technologies	1	1.50	1.50
8	Corrugated fiberboard	Popular bookstore	1	7.00	7.00
	Total				85.75

The total actual cost spent and the estimated budget have a very big discrepancy of about RM193.05. This discrepancy is a result of unexpected additional components that were required and also the additional shipping fee.

Shipping fee

The shipping cost was previously not considered in the estimated budget. It was assumed that all components could be purchased from Cytron Technologies whereby no shipping fee would be charged for members. Some components like the batteries and caster wheels however were not available on Cytron.

NiMH Rechargeable Batteries

Initially, the PKCELL NiMH Rechargeable AA 2000mAh batteries were thought to be sufficient to be used throughout the whole project. It was discovered however that 2000mAh battery capacity was not lasting enough for the robot to run smoothly on the arena for 10 minutes. A slight decrease in voltage after a certain level would greatly reduce the performance of the robot; speed and calibration. Having only 1 set of batteries (12) was also inconvenient as the robot cannot be tested when the batteries are being charged. Furthermore, prolonged testing of the robot using the same batteries also decreased the performance of the batteries. It was decided later on that getting the Beston batteries with 3000mAh capacity was the best option, although the total cost was RM29.50 more expensive than the PKCELL brand.

Omron Limit Switch

Initial plan was to get the limit switches with a long lever but with no rollers. Since the walls of the arena were made from corrugated board and were only secured together by tape, it was not as sturdy as the walls of the arena in the lab. This made it difficult for the contact switches to be actuated against the wall. Therefore, to overcome this issue, a new pair of limit switches with rollers was purchased. The rollers helped to improve surface contact of the limit switches with the walls, making it easier to actuate the contact switches.

Caster Wheels

2 large caster wheels with ball bearings from Mybotic were initially used at the bottom front of the robot to act as the 2 front wheels. These ball bearings rusted very quickly and this affected the movement of the robot on the arena as the caster wheels were unable to rotate smoothly. These caster wheels were also inefficient when the robot makes an angled turn due to the ball bearings in the casters causing the robot to skid a little from the desired turning angle.

A different pair of caster wheels from Cytron was then obtained to replace the old and rusted caster wheels. These caster wheels are smaller and also do not rust as easily as the old ones.They are also more stable when the robot makes angled turns. Another set of caster wheels from Mybotic were also purchased at the same time, in case the Cytron casters did not work out, as project competition day was approaching.

LM2596 3A Step-Down Converter

The initial idea was to only use 10 batteries of 1.2V each, totalling to 12V. This 12V was to be connected directly to the H-bridge to be fed to the DC motors. The 12V supply was also supposed to be connected to the step down converter in parallel to the H-bridge, to be stepped down to 5V to power up all the other components.

Due to power management purposes, for the robot to last longer on the arena with optimal performance, a higher voltage supply of 15.6V was used. Therefore, an extra step-down converter was needed to step down the voltage to 12V.

Screws, Washer, Nuts and Stud Rod

While making the estimated budget in the proposal, it was assumed that the screws, washer, nuts and stud rods could be obtained from the lab at no charge. All these components however were not enough for all the teams and were therefore purchased later on. These screws, washers and nuts were used to fix and lock other components onto the base of the robot. The stud rod was initially used to support the levelled base before switching to spacers due to greater stability of the spacers. These spacers were obtained at no charge from the lab.

Double Sided Mounting Tape, Cloth Binding Tape, Artline Permanent Marker and Corrugated board

Due to the imposed CMCO, teams were unable to use the arena in the lab and were required to build their own arenas at home using corrugated board as the walls and an MDF board as the arena floor. The double sided and cloth tape were used to attach the walls together and also the MDF board to the floor. The Artline permanent marker was used to outline the zones on the arena. With the exception of the MDF board, all these extra components had to be purchased in Week 9.

7.0 Recommendations and Conclusion

7.1 Recommendations

Table 18: List of improvements in the project

Recommendations	Comment and Reason
Use of mecanum wheels	The mecanum wheels are omnidirectional wheels that allow the robot to travel in any direction and usually it will be a four wheel configuration design. The force of the wheel is at 45 degrees to the axis of the robot, thus by varying the amount of force and direction of rotation for each wheel, it allows the robot to travel in any possible direction. This implementation might be expensive and harder to control but the benefit of it is that it could save up the time required to do point turning and the shortest distance can be taken because it can be moving at any angle.
Use of lidar sensor	The lidar sensor will emit laser pulse to the surrounding environment and depending on the time for the reflected light beam, it is able to tell the distance of the object precisely. Therefore, it can be used as the obstacles detection unit and because it allows the robot to map the whole arena, the robot is able to avoid going near to them. Besides, as compared to ultrasonic sensors it will be much more reliable because it depends on light beams instead of soundwaves and the maximum reachable distance is also further.
Solder all the wires on veroboard	Currently, all the electronic components are wired onto 2 breadboards. There is a risk of loose connections as the robot is moved frequently from one place to another. This may cause some subsystems to fail and troubleshooting the connections would be time consuming. However, if the wiring was soldered to a veroboard, such a problem can be avoided and the circuit will be more robust. Besides, breadboards should be used in the prototyping stage and not at the final stage.
Protect the gripper in the body of the robot	The gripper is currently extruding at the base at the font of the robot. This is because the base at the bottom layer is not cut to allocate space for the gripper to be placed inside the body of the robot. The extruding gripper strongly relies on the obstacles detection system to protect it from any damage. Therefore, if the gripper is able to be kept within the body robot, it would reduce the chances of the gripper hitting any obstacles especially when the robot is turning.

Implement a PID controller to control the speed of the wheels	For the current design, the left wheel of the robot is set as the master wheel, another wheel is the slave wheel. The speed of the slave wheel is mainly controlled by a proportional controller, which will multiply the difference in count for both the wheels to make the error difference between them small and consistent. However, based on a few test runs, it is realised that the master wheel is actually much faster than the slave wheel, hence at higher PWM value the speed of both wheels is hard to control. In order to improve on the maximum speed that the robot can travel, a PID controller should be implemented to control both the wheels as a system. This is because a PID controller has 3 different variables that are able to be fine tuned to reduce the steady state error to zero and make the system reach stability much faster. The main difficulty of this is that a large number of data has to be collected to model the speed of the wheels into one system.

7.2 Conclusion

In conclusion, the construction of the robot required the integration of the three main aspects, namely electrical, mechanical and software. This is important to ensure that the robot is able to complete all the tasks autonomously and accurately for a time span of 5 minutes.

The ultrasonic sensors that are positioned in front of the robot enable for accurate distance measurement and turning, as well as act as a collision detection mechanism. The colour sensor and IR sensor is placed under the robot to sense the presence of a puck and its colour. The contact switches are positioned behind the robot as a realignment and collision avoidance mechanism. These electrical components require the use of software programming in order to ensure they work correctly in the system.

In terms of software aspects, aside from integrating the various electrical components, a navigation system was implemented in the robot. This enables the robot to map its movements across the arena using X and Y coordinates. Hence, this allows for more accurate movement and positioning. The microcontroller that is used to program the robot to complete the tasks is the PSoC board. The movement algorithm along with configurations for all the electrical components are programmed through the use of the PSoC.

The mechanical aspects such as the gripper design is also crucial to ensure that the puck can be gripped and flipped accurately. In order to customize the gripper design, a 3D model was designed and printed to be included in the final construction.

Throughout this project, the team has come up with innovations and strategies to be implemented onto the robot in order to maximize its efficiency. Troubleshooting and repeated testing has been carried out to ensure that the best solution is approached to tackle the problem statements.

Team work has been a key factor throughout the execution of this project. Project management skills are also crucial to ensure that the work can be completed on time. Overall, the project provided a very valuable learning experience that is both challenging and rewarding.

Reference

[1] Tamiya.com*. 2020. Single Gearbox (4-Speed).* [online] Available at: https://www.tamiya.com/english/products/70167gearbox/index.htm [Accessed 10 November 2020].

[2] *Metal Ball Castor (53mm) - Castors - Wheels And Castors*. [online] Mybotic.com.my. Available at: https://www.mybotic.com.my/products/Metal-Ball-Castor-(53mm)/630 [Accessed 8 November 2020].

[3] *W420 Steel Ball Universal Wheel (Castor)*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-w420-steel-ball-universal-wheel-castor?r=1&gclid=CjwKCAiAqJn9BRB0EiwAJ1SztcFeWMocNNkB6PUsSdYuM2yWaq0CcSlEhtg4WyQ__QunxQCf7RqyaBoCrW0QAvD_BwE [Accessed 8 November 2020].

[4] *MDF board*. [online] Lazada.com.my. Available at: https://www.lazada.com.my/products/mdf-board-3mm-x-600mm-x-1200mm-art-sculpture-model-making-decorative-panel-i518678428-s1002380593.html?exlaz=d_1:mm_150050845_51350205_2010350205::12:9574256127!98208390363!!!pla-368231893610!c!368231893610!1002380593!167649774&gclid=Cj0KCQiAy579BRCPARIsAB6QoIYhzaCRkwc-POYICIGDoKXxpAG93-kMqWbqfkIMuUu9NtZUIF6v1pAaAu_3EALw_wcB [Accessed 8 November 2020].

[5] Arduino Project Hub. 2020. *Distance Measurement With An Ultrasonic Sensor HY-SRF05*. [online] Available at: https://create.arduino.cc/projecthub/Nicholas_N/distance-measurement-with-an-ultrasonic-sensor-hy-srf05-64554e [Accessed 4 November 2020].

[6] Cdn.sparkfun.com. 2020. [online] Available at: https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf [Accessed 4 November 2020].

[7] Ecosystem, A. and Pi, R., 2020. *Colour Sensor Module*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-colour-sensor-module?r=1&gclid=CjwKCAiA-f78BRBbEiwATKRRBLuA_vKacglv2iNiC9jPdLHY_E_LfqD0q1xSR95XTLmaNEailytoURoCmzsQAvD_BwE [Accessed 5 November 2020].

[8] Santos, R., Garcia, D., Santos, S., Santos, S. and Santos, S., 2020. *Arduino Color Sensor TCS230 TCS3200 | Random Nerd Tutorials*. [online] Random Nerd Tutorials. Available at: https://randomnerdtutorials.com/arduino-color-sensor-tcs230-tcs3200/ [Accessed 8 November 2020].

[9] HowToMechatronics. 2020. *Arduino Color Sensing Tutorial - TCS230 TCS3200 Color Sensor - Howtomechatronics*. [online] Available at: https://howtomechatronics.com/tutorials/arduino/arduino-color-sensing-tutorial-tcs230-tcs3200-color-sensor/ [Accessed 8 November 2020].

[10] *Infrared Sensor Module*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-infrared-sensor-module?search=ir%20sensor&description=1&src=search.list [Accessed 8 November 2020].

[11] *Omron Limit Switch*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-omron-limit-switch-1946?search=limit%20switch&description=1&src=search.list [Accessed 8 November 2020].

[12] Thomasnet.com. 2020. *What Are Limit Switches And How Do They Work?*. [online] Available at: https://www.thomasnet.com/articles/instruments-controls/limit-switches/#:~:text=Limit%20switches%20use%20the%20mechanical,the%20electrical%20switch's%20state.&text=Hence%2C%20limit%20switches%20are%20contact,types%20of%20proximity%20sensing%20devices. [Accessed 9 November 2020].

[13] *Shaft encoders.* Monash University, Melbourne, Australia, 2018. [Accessed 7 November 2020].

[14] *SPDT Toggle Switch 3 Pin (2 Ways) - Switches > Toggle Switch - Switches*. [online] Mybotic.com.my. Available at: https://www.mybotic.com.my/webshaper/store/viewProd.asp?pkProductItem=72 [Accessed 10 November 2020].

[15] *3 Pins Toggle Switch*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-3-pins-toggle-switch?r=1&gclid=Cj0KCQiA7qP9BRCLARIsABDaZzhqKItlw6VLeFF45ldTewGD5_6N0QxEapJKVUt3jhfYluMAmb_c29MaAm7wEALw_wcB [Accessed 8 November 2020].

[16] *Rocker Switch With Wire-20CM*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-rocker-switch-with-wire-20cm?search=rocker%20switch&description=1&src=search.list [Accessed 8 November 2020].

[17] ElProCus - Electronic Projects for Engineering Students. 2020. *Servo Motors - Working Principle, Controlling And Applications*. [online] Available at: https://www.elprocus.com/servo-motor/ [Accessed 6 November 2020].

[18] Components 101. 2020. *MG90S – Metal Gear Micro Servo Motor*. [online] Available at: https://components101.com/motors/mg90s-metal-gear-servo-motor [Accessed 6 November 2020].

[19] *LM2596 3A Step-Down Converter*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-lm2596-3a-step-down-converter?r=1 [Accessed 5 November 2020].

[20] *Robot Design and Construction Guide*. Monash University Malaysia [Accessed 7 November 2020].

[21] Last Minute Engineers. 2020. *In-Depth: Interface L298N DC Motor Driver Module With Arduino*. [online] Available at: https://lastminuteengineers.com/l298n-dc-stepper-driver-arduino-tutorial/ [Accessed 2 November 2020].

[22] *SG90 Micro Servo*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-sg90-micro-servo?search=sg90&description=1&src=search.list [Accessed 3 November 2020].

[23] Ecosystem, A. and Pi, R., 2020. *3-Axis Digital Compass Breakout Board*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-3-axis-digital-compass-breakout-board?search=HMC&description=1&src=search.list [Accessed 8 November 2020].

[24] Circuit Digest. 2020. *Digital Compass Using Arduino And HMC5883L Magnetometer*. [online] Available at: https://circuitdigest.com/microcontroller-projects/digital-compass-with-arduino-and-hmc5883l-magnetometer [Accessed 8 November 2020].

[25] *Adjustable Infrared Sensor Switch*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-adjustable-infrared-sensor-switch?r=1 [Accessed 7 November 2020].

[26] MaxBotix Inc. 2020. *Ultrasonic Vs Infrared (IR) Sensors - Which Is Better? | Maxbotix Inc.*. [online] Available at: https://www.maxbotix.com/articles/ultrasonic-or-infrared-sensors.htm#sensorhelp [Accessed 7 November 2020].

[27] M., 2020. *DIY Arduino Color Sensor*. [online] Instructables. Available at: https://www.instructables.com/DIY-Arduino-Color-Sensor/ [Accessed 9 November 2020].

[28] *3-Axis Accelerometer*. [online] Cytron Technologies Malaysia. Available at: https://my.cytron.io/p-3-axis-accelerometer?search=accelerometer&description=1&src=search.list [Accessed 10 November 2020].

[29] Tutorials of Cytron Technologies. 2020. *Measuring Tilt Angle With Gyro And Accelerometer | Tutorials Of Cytron Technologies*. [online] Available at: https://tutorial.cytron.io/2012/01/10/measuring-tilt-angle-with-gyro-and-accelerometer/ [Accessed 10 November 2020].

[30] Upverter Blog. 2020. *Using PWM For DC Motor Control*. [online] Available at: https://blog.upverter.com/2019/11/21/using-pwm-for-dc-motor-control/ [Accessed 10 November 2020].

[31] Cypress, 2017. Quadrature Decoder (QuadDec). [Accessed 7 November 2020]

Appendix

Receipts

Infrared sensor module, Colour Sensor Module and Omron Limit Switch(No roller)

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1, TAMAN INDUSTRI IMPIAN, 14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: RM0.00

Invoice No. : CI1483137
Invoice Date : 19 August 2020

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
137685	Touch & Go eWallet	GDEX	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	Infrared Sensor Module Model: SN-IR-MOD	1	RM0.95	RM0.95
2.	Colour Sensor Module Model: SN-COLOUR-MOD	1	RM12.50	RM12.50
3.	Omron Limit Switch Model: SW-LI-V153-IC25	2	RM1.75	RM3.50

For Cytron Technologies Sdn Bhd

Sub-Total :	RM16.95
GDEX :	RM0.00
CytronCash :	RM-1.02
GRAND TOTAL :	RM15.93

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

PKCELL NiMH Rechargeable AA 2000mAh Battery(4pcs)

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1, TAMAN INDUSTRI IMPIAN, 14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: RM0.00

Invoice No. : CI1483362
Invoice Date : 19 August 2020

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
138411	Maybank2U	GDEX	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	PKCELL NiMH Rechargeable AA 2000mAh Battery (4 Pcs) Model: BA-PKC-4AA-2000	2	RM12.50	RM25.00

For Cytron Technologies Sdn Bhd

Sub-Total :	RM25.00
GDEX :	RM0.00
GRAND TOTAL :	RM25.00

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

Cytron Technologies

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1, TAMAN INDUSTRI IMPIAN, 14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: **RM0.00**

Invoice No. : CI1483682
Invoice Date : 19 August 2020

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	Thank You!
139159	Touch & Go eWallet	GDEX	

No.	Product	Quantity	Unit Price	Total
1.	PKCELL NiMH Rechargeable AA 2000mAh Battery (4 Pcs) Model: BA-PKC-4AA-2000	1	RM12.50	RM12.50

Sub-Total :	**RM12.50**
GDEX :	**RM0.00**
GRAND TOTAL :	**RM12.50**

For Cytron Technologies Sdn Bhd

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

Beston 4pcs AA 3000mAh Ni-MH Rechargeable Batteries

Package 1 *Delivered*
Sold by Beston Electronics >
Delivered on 24 Sep 2020, Standard Delivery

Buy more save more

Beston 4pcs AA 3000mAh Ni-MH Rechargeable Batteries For Digital Camera
No Warranty
RM21.00
x 3
until 08 Oct 2020

WRITE A REVIEW

RETURN/REFUND

Track Package Chat Now

Order #262472225007250
Placed on 22 Sep 2020 21:09:48
Paid on 22 Sep 2020 21:10:37

Subtotal	RM63.00
Shipping Fee	RM4.00
Order Discount	-RM6.00

3 Items, 1 Package
Total(0% GST): RM61.00
Paid by Touch 'n Go eWallet

W420 Steel Ball Universal Wheel (Castor)

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: **RM0.00**

Invoice No. : CI1492464
Invoice Date : 09 October 2020

PRIORITY SHIPPING FOR PROMAKER
Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
152580	Touch & Go eWallet	J&T Express	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	W420 Steel Ball Universal Wheel (Castor) Model: WL-BTU-W420	2	RM3.00	RM6.00

For Cytron Technologies Sdn Bhd

Sub-Total :	RM6.00
J&T Express :	RM0.00
CytronCash :	RM-0.14
GRAND TOTAL :	RM5.86

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

Metal ball Caster

kailling Visit Shop >

Parcel 1 Delivered

Metal Ball Castor (53mm)
x 2
RM 7.90

Merchandise Subtotal	RM 15.80
Shipping	RM 4.66
Shipping discount subtotal	-RM 4.66
Redeemed 164 Shopee Coins	-RM 1.64
Total	RM 14.16
Parcels Total Payment	RM 14.16
Order Total	RM 14.16

Payment Method
Online Banking

Shopee Coins earned	158 Coins
Shopee Voucher Applied	158 Coins

Order ID	2008289DX5XC1F COPY
Order Time	28-08-2020 22:30
Payment Time	28-08-2020 22:31
Ship Time	29-08-2020 13:20
Completed Time	31-08-2020 18:10

Package 1 Shipped

Sold by MYBOTIC >

Get by Wed 14 Oct - Sat 17 Oct, Standard Delivery

Metal Ball Castor (53mm)

No Warranty

RM7.90

x 2

CANCEL

Track Package | Chat Now

Order #264800356207250

Placed on 13 Oct 2020 18:47:46

Paid on 13 Oct 2020 18:48:24

Subtotal	RM15.80
Shipping Fee	RM5.50

2 Items, 1 Package

Total(0% GST): RM21.30

Paid by Touch 'n Go eWallet

6xAA Battery holder

Cytron Technologies™

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: RM0.00

Invoice No. : CI1483991

Invoice Date : 19 August 2020

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia

Attn : Clifton Mak Ren Ming

Tel : +60 123747881

Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
139791	Touch & Go eWallet	GDEX	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	6xAA Battery Holder (Compact) Model: CN-BA-UM3-06	2	RM1.50	RM3.00

Sub-Total :	RM3.00
GDEX :	RM0.00
GRAND TOTAL :	RM3.00

For Cytron Technologies Sdn Bhd

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

4xAA Battery holder

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: **RM0.00**

Invoice No. : CI1483866
Invoice Date : 19 August 2020

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
139587	Touch & Go eWallet	GDEX	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	4xAA Battery Holder Model: CN-BA-UM3-04-A	2	RM1.00	RM2.00

For Cytron Technologies Sdn Bhd

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Sub-Total :	**RM2.00**
GDEX :	**RM0.00**
GRAND TOTAL :	**RM2.00**

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

LM2596 3A Step-Down Converter

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: **RM0.00**

Invoice No. : CI1483908
Invoice Date : 19 August 2020

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
139695	Touch & Go eWallet	GDEX	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	LM2596 3A Step-Down Converter Model: DC-LM2596-WOD	1	RM1.50	RM1.50

For Cytron Technologies Sdn Bhd

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Sub-Total :	**RM1.50**
GDEX :	**RM0.00**
GRAND TOTAL :	**RM1.50**

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

Package 1

Delivered

Sold by SG ROBOT TECHNOLOGY ENTERPRISE >

Delivered on 07 Sep 2020, Standard Delivery

Arduino LM2596 DC-DC Adjustable Step Down Voltage Converter Module

No Warranty Available

RM3.50

x 6

WRITE A REVIEW

Track Package

Chat Now

Order #261367507338380

Placed on 03 Sep 2020 15:03:39

Paid on 03 Sep 2020 15:04:53

Subtotal	RM21.00
Shipping Fee	RM3.50
Order Discount	-RM0.50

6 Items, 1 Package

Total: RM24.00

Paid by Credit/Debit Card

Omron Limit Switch (with roller)

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: RM0.00

Invoice No. : CI1489239

Invoice Date : 14 September 2020

PRIORITY SHIPPING FOR PROMAKER

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia

Attn : Clifton Mak Ren Ming

Tel : +60 123747881

Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
147653	Touch & Go eWallet	J&T Express	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	Omron Limit Switch Model: SW-LI-V156-IC25	2	RM3.50	RM7.00

Sub-Total :	RM7.00
J&T Express :	RM0.00
CytronCash :	RM-3.02
GRAND TOTAL :	RM3.98

For Cytron Technologies Sdn Bhd

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

0.9 to 5V DC Usb Booster Module

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: **RM3.05**

Invoice No. : CI1487166
Invoice Date : 28 August 2020

Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
144447	Free Checkout	GDEX	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	0.9 to 5VDC USB Booster Module - Green Model: DC-B5V-GREEN	1	RM3.00	RM3.00

For Cytron Technologies Sdn Bhd

Sub-Total :	RM3.00
GDEX :	RM0.00
CytronCash :	RM-3.00
GRAND TOTAL :	RM0.00

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

Rocker Switch with Wire-20cm

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: **RM2.94**

Invoice No. : CI1488481
Invoice Date : 09 September 2020

PRIORITY SHIPPING FOR PROMAKER
Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	
146544	Free Checkout	J&T Express	Thank You!

No.	Product	Quantity	Unit Price	Total
1.	Rocker Switch with Wire-20CM Model: SW-ROC-B-W	1	RM2.50	RM2.50
2.	Personalized Badge for Makers (Free Gift) Model: MAKER-BADGE - Printed Name: Clif	1	RM0.00	RM0.00

For Cytron Technologies Sdn Bhd

Sub-Total :	RM2.50
J&T Express :	RM0.00
CytronCash :	RM-2.50
GRAND TOTAL :	RM0.00

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

3 Pins Toggle Switch

Cytron Technologies

CYTRON TECHNOLOGIES SDN BHD
755563-V
1, LORONG INDUSTRI IMPIAN 1,TAMAN INDUSTRI IMPIAN,
14000 BUKIT MERTAJAM, PULAU PINANG, MALAYSIA.
TEL: +604-548 0668 FAX: +604-548 0669
sales@cytron.com.io support@cytron.io

INVOICE / RECEIPT

CYTRONCASH balance: **RM-1.01**

Invoice No. : CI1491451
Invoice Date : 01 October 2020

PRIORITY SHIPPING FOR PROMAKER
Bill To: No22, Jalan USJ 17/3C
47630 Subang Jaya
Selangor Malaysia
Attn : Clifton Mak Ren Ming
Tel : +60 123747881
Email : cliftonmak1998@gmail.com

Order ID:	Payment Method:	Shipping:	Thank You!
151073	Touch & Go eWallet	J&T Express	

No.	Product	Quantity	Unit Price	Total
1.	3 pins Toggle Switch Model: SW-TO-MTS-102-A2	2	RM2.30	RM4.60

Sub-Total :	**RM4.60**
J&T Express :	**RM0.00**
CytronCash :	**RM-1.01**
GRAND TOTAL :	**RM3.59**

For Cytron Technologies Sdn Bhd

CYTRON TECHNOLOGIES SDN BHD (755563-V)

Authorized Signature

Largest Digital Maker Marketplace In Southeast Asia www.cytron.io

Screws, Nuts and Stud rods

YEW SIONG INDUSTRIAL
SUPPLIES SDN BHD 178306-U
NO 24, JALAN PJS 11/22,BANDAR SUNWAY,
46150 PETALING JAYA, SELANGOR.
TEL : 03-5634 5419 FAX : 03-5634 5626

SALES RECEIPT

RECEIPT#:SUN_IV-21590 PIC : IMAMUL
DATE:2020-09-14 10:23 TERM: CASH
CUST: CASH

==

ITEM	AMT
M3 X 70MM PH M/SCREW ZINC 20.00 PC x RM 0.300000	6.00
M3 MS FLAT WASHER ZINC 10.00 PC x RM 0.020000	0.20
M3 X 0.50P HEX NUT ZINC 30.00 PC x RM 0.050000	1.50

==

ITEM COUNT : 60

SUBTOTAL:	7.70
DISC:	-0.00
ROUNDING:	0.00
TOTAL:	7.70
CASH:	7.70
[]	
CHANGE:	0.00

GOODS SOLD ARE NOT RETURNABLE, THANK YOU

YEW SIONG INDUSTRIAL
SUPPLIES SDN BHD 178306-U
NO 24, JALAN PJS 11/22,BANDAR SUNWAY,
46150 PETALING JAYA, SELANGOR.
TEL : 03-5634 5419 FAX : 03-5634 5626

SALES RECEIPT

RECEIPT#:SUN_IV-20979 PIC : MOSHIUR
DATE:2020-09-03 11:28 TERM: CASH
CUST: CASH

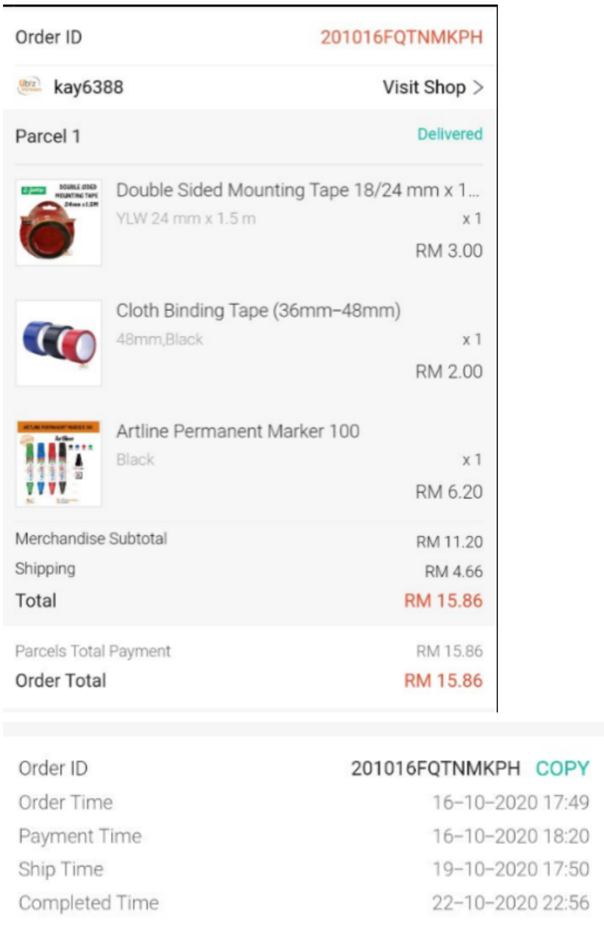
ITEM	AMT
M3 X 1METER MS STUD ROD ZINC 1.00 LGT x RM 5.00000	5.00
M3 X 0.50P HEX NUT ZINC 25.00 PC x RM 0.040000	1.00

ITEM COUNT : 26

SUBTOTAL:	6.00
DISC:	-0.00
ROUNDING:	0.00
TOTAL:	
CASH:	6.00
[]	
CHANGE:	0.00

GOODS SOLD ARE NOT RETURNABLE, THANK YOU

Double Sided Mounting Tape 18/24mm, Cloth Binding Tape(36-48mm), Artline Permanent Marker



Order ID 201016FQTNMKPH

kay6388 Visit Shop >

Parcel 1 Delivered

Double Sided Mounting Tape 18/24 mm x 1...	YLW 24 mm x 1.5 m	x 1	RM 3.00
Cloth Binding Tape (36mm-48mm)	48mm,Black	x 1	RM 2.00
Artline Permanent Marker 100	Black	x 1	RM 6.20

Merchandise Subtotal	RM 11.20
Shipping	RM 4.66
Total	RM 15.86
Parcels Total Payment	RM 15.86
Order Total	RM 15.86

Order ID	201016FQTNMKPH COPY
Order Time	16-10-2020 17:49
Payment Time	16-10-2020 18:20
Ship Time	19-10-2020 17:50
Completed Time	22-10-2020 22:56

Corrugated board

Shipping Information COPY
J&T Express

Payment Information

Merchandise Subtotal	RM 34.00
Shipping - J&T Express	RM 4.66
Order Total	RM 38.66

Payment Method
Cash Payment at 7-Eleven

funfunmee Visit Shop >

Impra Board/ Corrugated Board/ Plastic Bo...
Black x 4
RM 8.50

Order ID	201016FQTNMKPJ COPY
Order Time	16-10-2020 17:49
Payment Time	16-10-2020 18:20

funfunmee Visit Shop >

Parcel 1 Delivered

Impra Board/ Corrugated Board/ Plastic Bo...
Black x 1
RM 8.50

Merchandise Subtotal	RM 8.50
Shipping	RM 4.66
Redeemed 171 Shopee Coins	-RM 1.71
Total	RM 11.45
Parcels Total Payment	RM 11.45
Order Total	RM 11.45

Payment Method
Credit / Debit Card

Shopee Coins earned 7 Coins

Order ID	201027DQBRCYCM COPY
Order Time	27-10-2020 12:22
Payment Time	27-10-2020 12:30
Ship Time	27-10-2020 15:41
Completed Time	28-10-2020 19:37