ECE4191: Engineering Integrated Design
Final Report

MONASH University

Group 14

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1. Executive Summary

1.1. General Project Overview

The objective of the competition is to engineer a self-sufficient (autonomous) robot that can detect and move coloured pucks, utilizing them to displace bowling pins by a flicking mechanism, all determined by the specified color signals given (level 1 and level 2) or by detecting the position of the bowling pins placed in their respective zone (level 3 and level 4). This operation must take place within a designated playing field. The challenges involve not just the technicalities of puck detection and movement but also the precise execution of the flicking action to ensure the bowling pins are successfully knocked down. The intricate details of the competition's requirements and design constraints will be further broken down into specific sections.

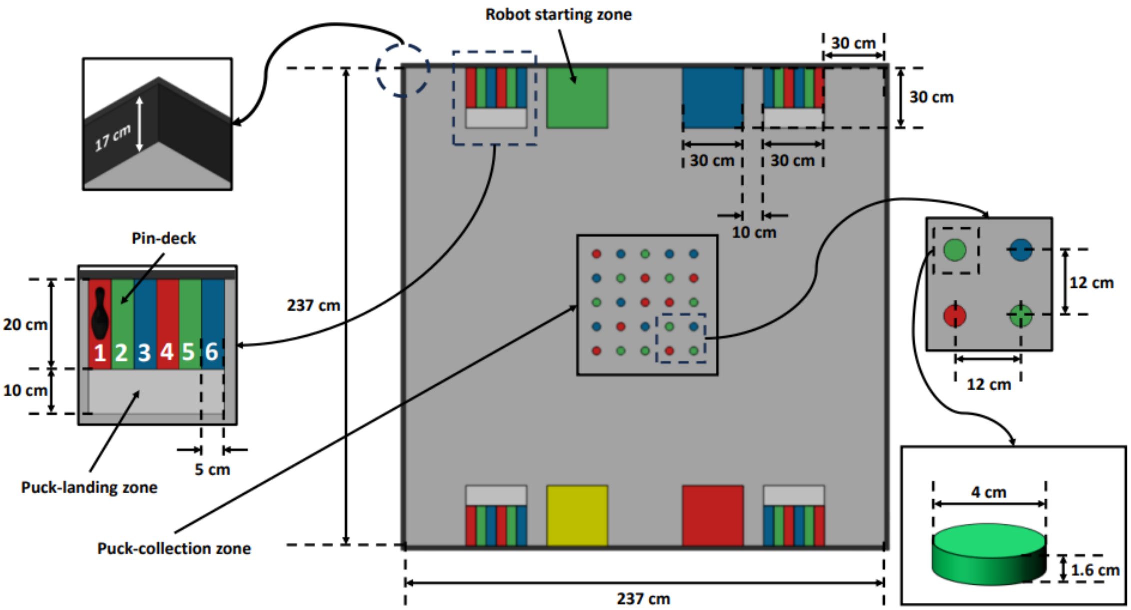


Figure 1: Top View of the Arena [1]

Objective

Teams are required to design and construct an autonomous robot capable of transporting coloured pucks to knock down bowling pins through a flicking action based on color coding within a specified arena.

Arena Description

The competition arena consists of:
a) Robot starting bases
b) Puck-collection zone with 25 pucks in 3 distinct colours (red, blue, and green)
c) Puck-landing zone
d) Pin-deck labelled from zones 1 to 6

Competition Format

a) Two rounds, each comprising four levels.
b) Each round has a duration of 10 minutes.
c) Robots will begin from any of the four robot starting bases.

Levels

1. Known-Zone Pin

Robot transports a puck matching the communicated pin-deck zone number and knocks down the nearby bowling-pin.

2. Known-Color Pin
Robot identifies which of the two possible pin-deck zones contains the bowling-pin based on the communicated color and performs actions like Level 1.

3. & 4. Unknown-Pins
Robots detect the zone of the bowling-pin, identify the correct coloured puck and execute the knocking down process.

Wireless Communication
a) A Bluetooth-enabled communication will be established between the robot and a host.
b) The host communicates tasks to the robot using a predefined text format.
c) The robot acknowledges receipt and awaits a start command to begin its tasks.

Winning Criteria
a) The quickest team to complete all four levels wins.
b) If no team finishes within the allotted time, the one that has progressed the most wins.
c) Top 4 teams proceed to the final round.

Project Rules
a) Competitions will occur in a designated laboratory and area.
b) Robots that require human assistance post-start will incur a "touch penalty."
c) Intervening with the robot's activities without judge approval results in disqualification.
d) Robots must demonstrate "normal progress" or face disqualification.
e) The robot should only use the provided PSoC board.
f) A budget of RM 320 is allocated for additional parts, with penalties for exceeding.
g) 3D printing of robot parts is allowed but limited.
h) Use of mechatronics project lab is encouraged over 3D printing for some structures.
i) Robots should operate as a single unit, manipulating only one puck at a time and must remain within the starting base's dimensions.
j) Robots must function autonomously post-start.
k) Only specified battery types (Ni-MH rechargeable batteries) are allowed, and they should be visible on the robot.
l) Poorly constructed robots with hanging wires, breadboards, or using adhesives will be disqualified.

1.2. Problem Statement

The complexities of automation and robotics, especially in a competitive scenario, encompass a myriad of challenges, from the intricate design of the robot to the rapid decision-making capabilities required of the robot. As we navigate through this section of the report, we will delve deep into the issues presented by the nature of this project and how these challenges could potentially influence the realization of our objectives. To provide clarity and coherence, the problem statements detailed in the subsequent sections have been formulated based on the requirements of the project.

Problem Statement 1: Localization and Navigation
i) Identifying its starting position in a competition arena.
ii) Navigating efficiently to specific zones within the arena, namely the puck-collection zone, puck-landing zone, and pin-decks.

Problem Statement 2: Object Recognition and Manipulation
i) Recognizing pucks based on their colour and transporting them without allowing them to touch the floor.
ii) Identifying bowling-pins placed in specific zones, either based on pre-communicated information or autonomously detecting the pin's location and associated zone colour depending on the current level.
iii) Using the transported puck to knock down the identified bowling-pin through a flicking motion.

Problem Statement 3: Communication
i) Establishing a Bluetooth connection with a host.
ii) Receiving and acknowledging specific texts from the host regarding game rules and progress.
iii) Communicating readiness and task reception back to the host.

Problem Statement 4: Game Strategy
i) Efficiently sequencing the tasks across four levels, each with varying levels of information available about the pin location and colour.
ii) Ensuring quick and precise actions to complete all levels within the shortest possible time.
iii) Strategically returning to the starting position after the completion of each level, anticipating the next round.

Problem Statement 5: Competition Adherence
i) Adhering to the time constraints and other rules specified for the competition, including the specifics for each of the four levels, waiting times and communication protocols.
ii) Ensuring the robot's design adheres to the stipulations, such as preventing the puck from touching the floor during transportation.

Problem Statement 6: Structural Integrity and Durability
i) Is constructed with materials that ensure longevity and can withstand the rigours of the competitive environment, including possible collisions, abrupt movements or any unforeseen challenges.
ii) Features a design that minimises wear and tear over repeated rounds of competition.

Problem Statement 7: Functional Design
i) Has specialised compartments or mechanisms for securely holding and transporting pucks without letting them touch the ground.
ii) Incorporates an efficient mechanism for the flicking action to knock down bowling pins.
iii) Is agile enough to navigate the arena quickly, avoid obstacles, and possibly outmanoeuvre competing robots.

Problem Statement 8: Adaptability
i) Features a modular design, allowing for easy adjustments or replacements to adapt to different game scenarios or to replace worn-out parts.
ii) Offers flexibility to integrate advanced sensors or modules for object (puck and pin) recognition, communication, and navigation without compromising its structural stability.

Problem Statement 9: Weight and Balance

i) Maintains a balanced weight distribution to ensure stability during high-speed manoeuvres and when executing the flicking action.

ii) Is optimized in weight to ensure swift movements without compromising on strength or stability.

Problem Statement 10: Integration with Technology

i) Provides seamless integration points for technologies like sensors, ultrasonic modules and communication modules, ensuring that the physical design supports the robot's technical functionalities.

ii) Ensures that the robot's structure protects sensitive components from potential damage during the competition.

Overall Objective

The goal is to design a robot that efficiently completes all tasks across the four levels, not just within the 10-minute time limit, but in the shortest time possible among all competing teams, with an aim to qualify for and win the final round of the competition.

1.3. Crucial Aspects of the Design

In the realm of robotics, innovations in design are paramount to achieving superior performance. This becomes even more crucial when the robotic challenge requires a multifaceted approach to complex problem statements. Our design strategies are not just driven by the need for functionality but also by the aspiration to push the boundaries of conventional robotics, adopting innovations that set our robot apart from its competitors. In this section, we will unravel the crucial design elements and innovations we've integrated to navigate the myriad challenges presented by the problem statements.

1. Enhanced Localization System

Using a combination of sensors and shaft encoders, our robot efficiently determines its starting position, ensuring rapid commencement of task sequences.

2. Adaptive Pathfinding and Backtracking Algorithm

Employs a dynamic navigation mechanism, allowing the robot to calculate the shortest and most efficient route to its target zones, be it for puck collection or pin striking.

3. Advanced Puck and Color Detection

Our robot uses an effective puck and color detection system, ensuring that both the puck and color identification is quick, effective and error-free.

4. Precision Flicking Mechanism

Through careful design and testing, we've developed a flicking mechanism that offers both strength and precision, maximizing the chances of pin knockdown.

5. Robust Bluetooth Module

Ensures quick and stable communication with the host, minimizing lag and ensuring that commands are received and executed properly after receiving the correct information.

6. Algorithmic Game Strategizing

The robot will not just follow instructions, it analyses the game field and autonomously decides on the best sequence of actions for maximum efficiency.

7. Durable & Lightweight Construction

Using composite materials, we've achieved a balance between durability and weight, ensuring that the robot remains agile yet resilient to challenges on the field.

8. Modular Component System

The design permits swift component replacement and adaptability, ensuring that changing game scenarios or wear and tear do not impact performance.

9. Low Centre of Gravity Design

Ensures the robot remains stable during high-speed manoeuvres and pin-flicking actions.

10. Holistic Technology Integration

Every piece of tech, from sensors to communication modules, has been meticulously integrated into the design. This ensures smooth operation, protection of components, and the synergy of form and function.

In summary, our design philosophy is rooted in the belief that each problem statement represents an opportunity for innovation. As such, we have strived to develop a robot that is not only efficient and effective but also exemplifies the pinnacle of robotic design and innovation.

1.4. Overview of the Robot Design

In this section, we delve into the intricate design of our robot, presenting a comprehensive visual representation that captures its structural and functional dimensions. Through meticulous design considerations, we've ensured that our robot addresses all aspects stipulated in the problem statement.

Presented here are six distinct views of our robot: front, back, left, right, top and bottom view. Each view offers a unique perspective that highlights the robot's components and features, giving a clear understanding of how the robot's design aligns with its intended functions. These drawings serve as a testament to the thoughtful engineering and design prowess that went into creating this machine.

By studying these visuals, an insight into how each element of the robot was conceptualized and implemented can be obtained, ensuring that every challenge posed by the problem statement was adeptly tackled.

Overview of the Final Robot

Figure 2: Front View of the Robot (With Casing)

Figure 3: Back View of the Robot (With Casing)

Figure 4: Top View of the Robot (With Casing)

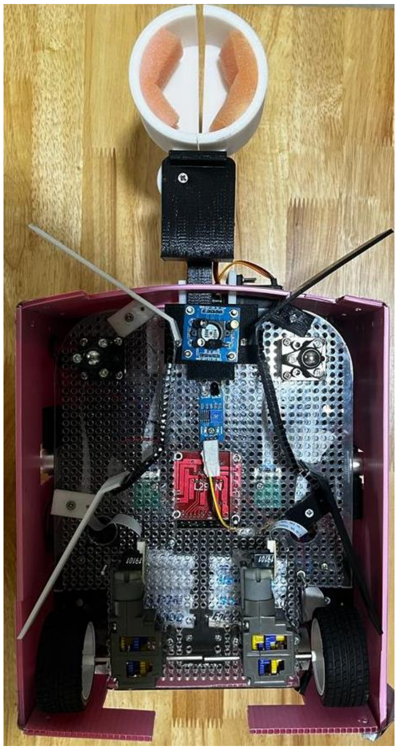


Figure 5: Bottom View of the Robot (With Casing)

Without Corrugated Sheet
i) The Front View of the Robot

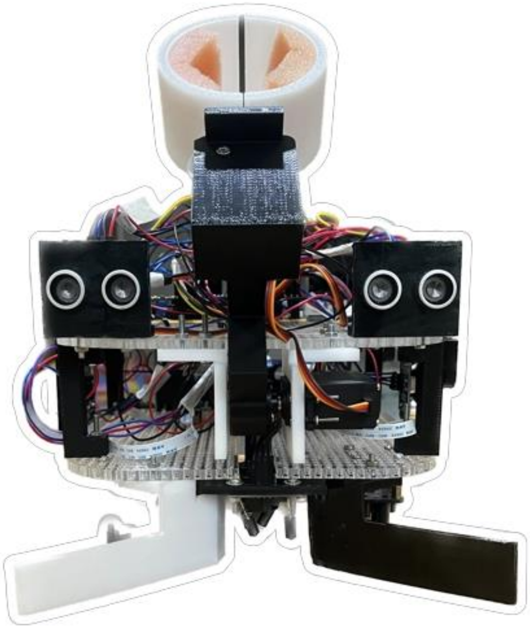


Figure 6: Front View of the Robot (Without Casing)

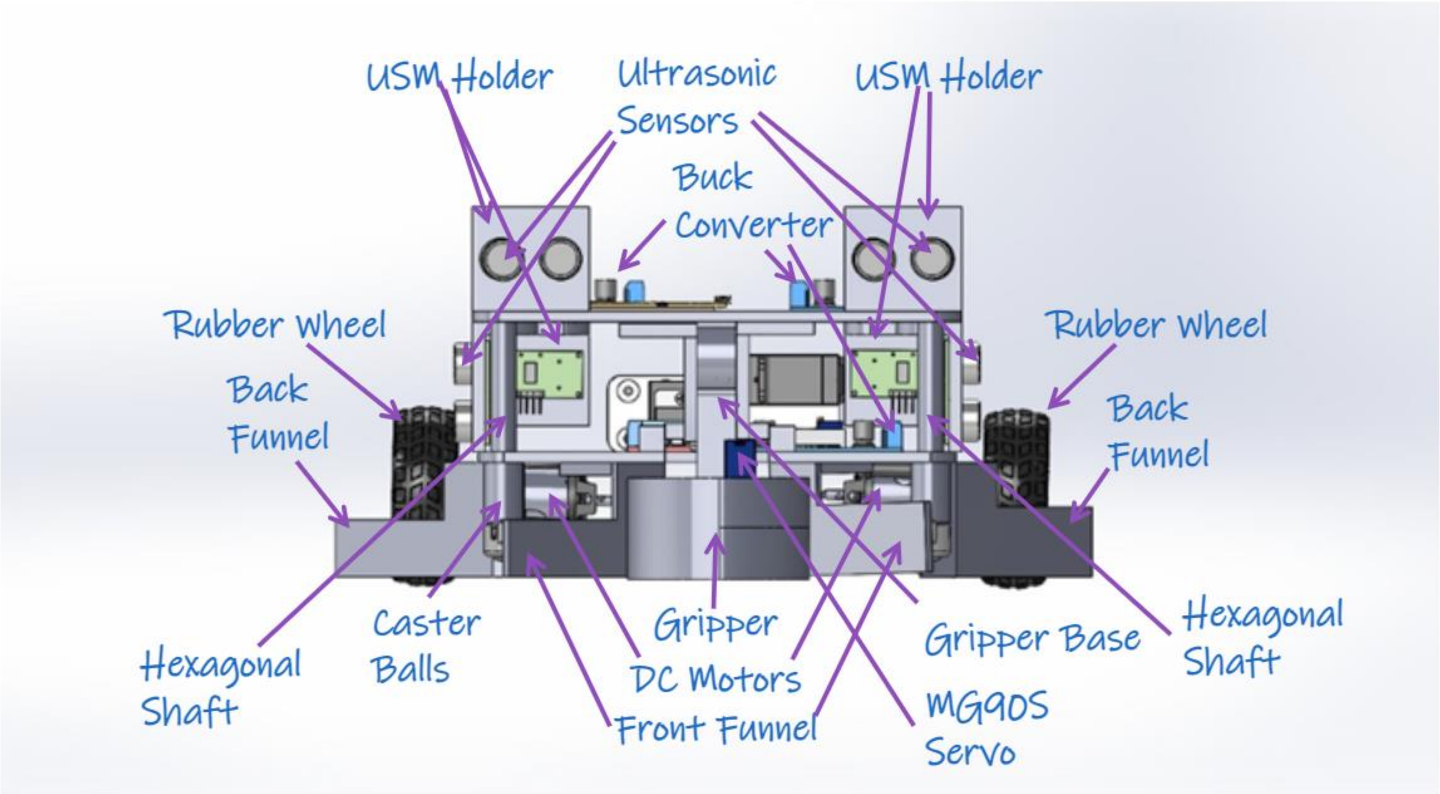


Figure 7: Front View of the 3D Model Robot

ii) The Back View of the Robot

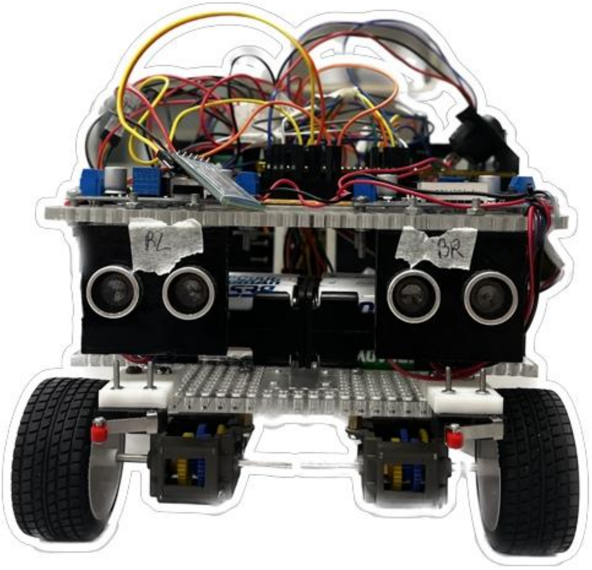


Figure 8: Back View of the Robot (Without Casing)

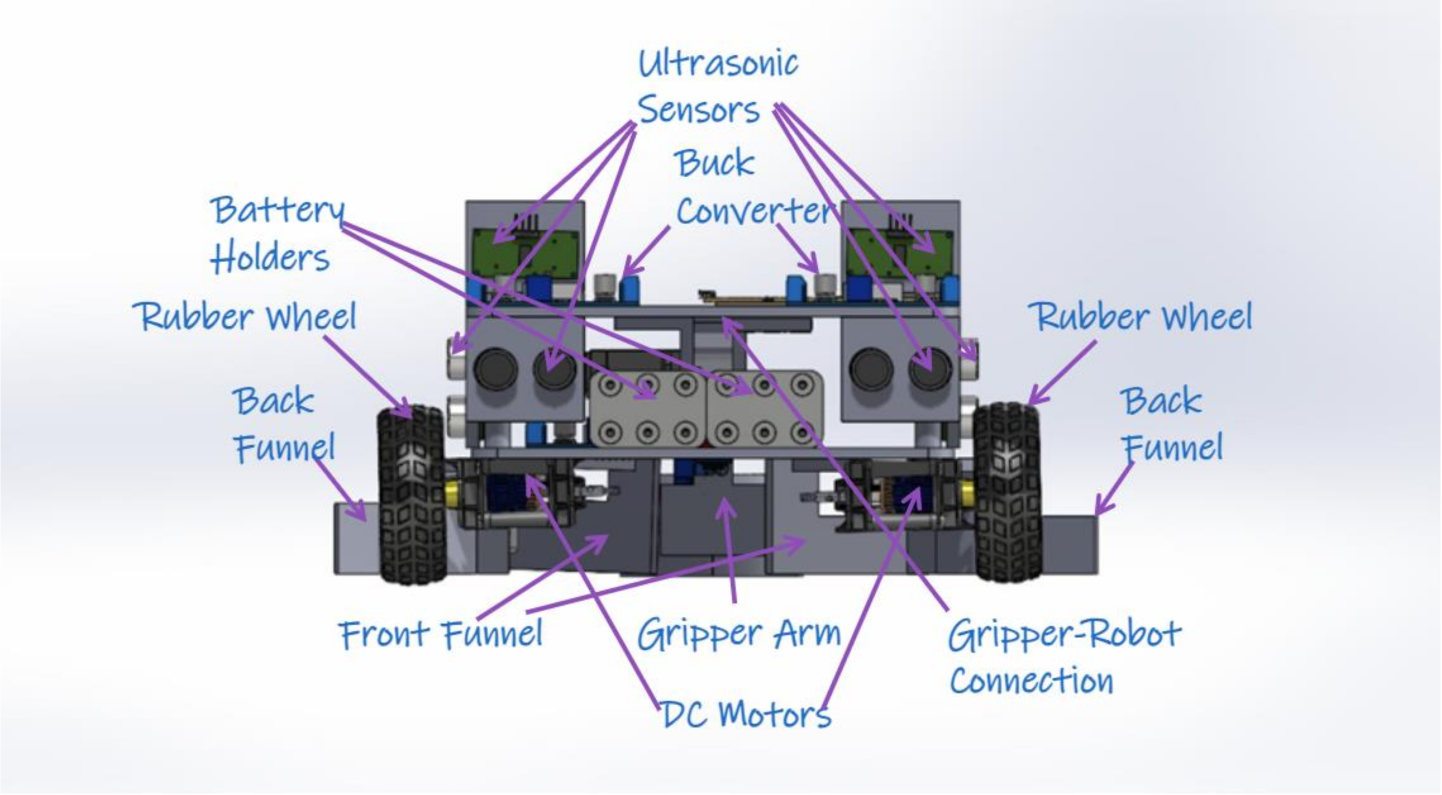


Figure 9: Back View of the 3D Model Robot with Labels

iii) The Left View of the Robot

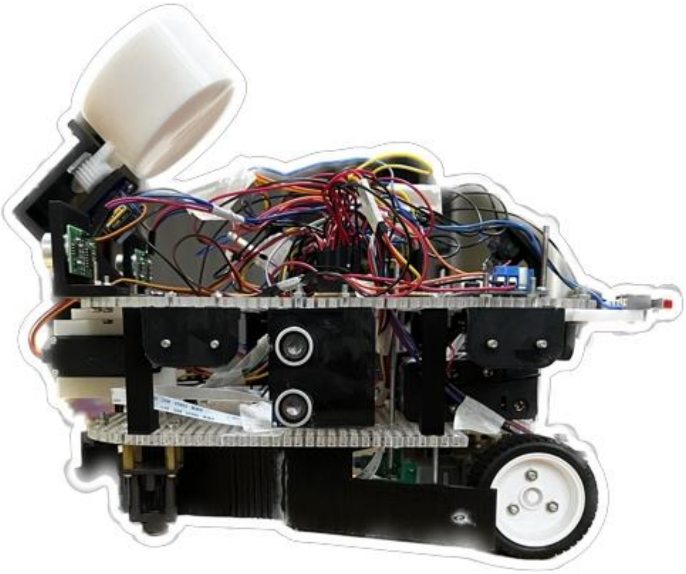


Figure 10: Left View of the Robot (Without Casing)

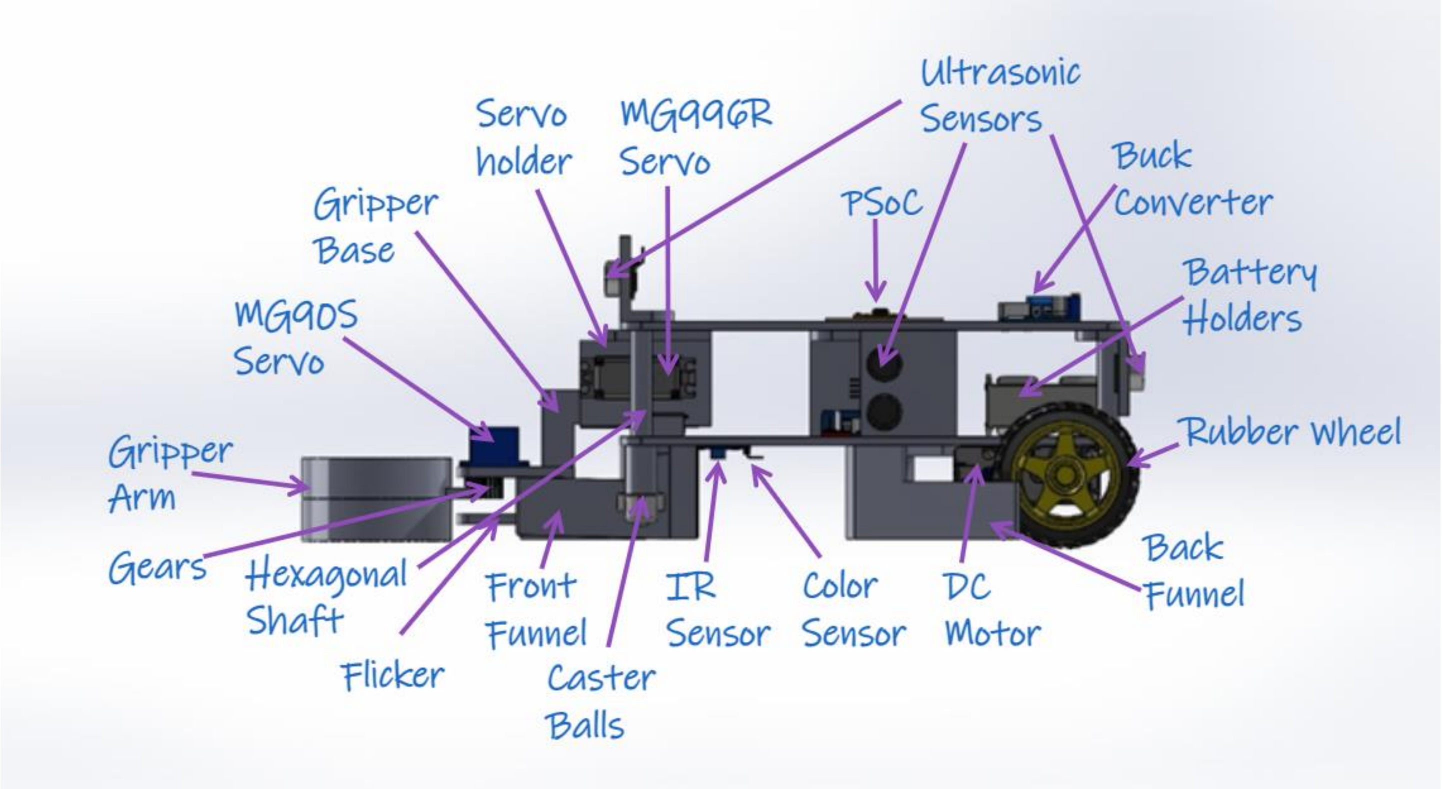


Figure 11: Left View of the 3D Model Robot (Without Casing)

iv) The Right View of the Robot

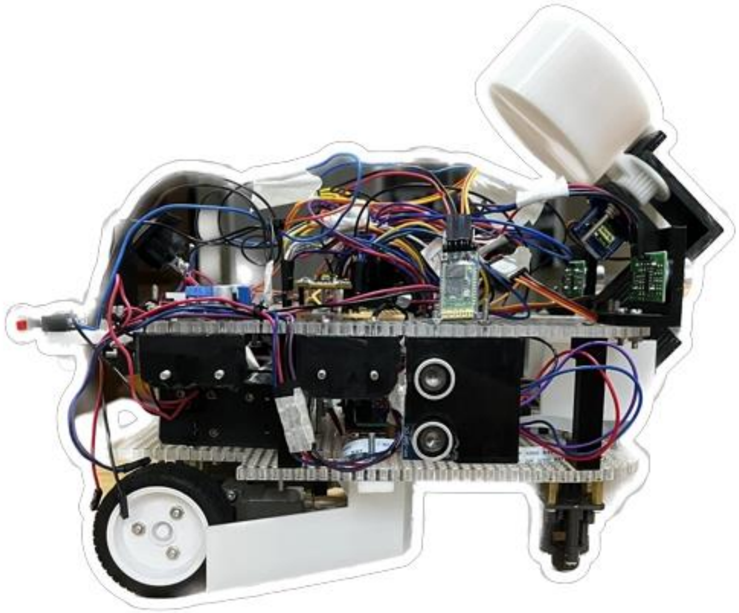


Figure 12: Right View of the Robot (Without Casing)

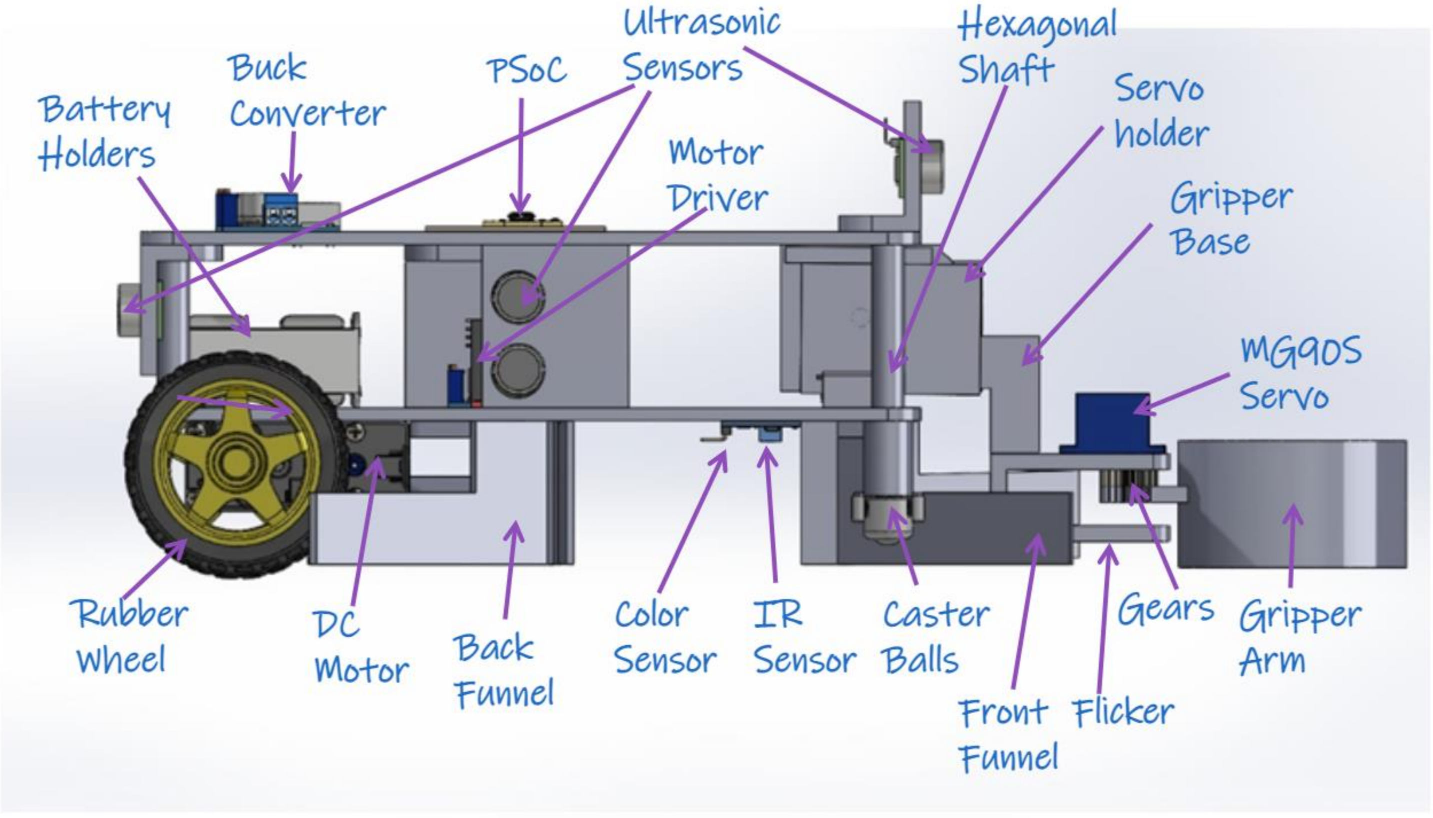


Figure 13: Right Side of the 3D Model Robot with Labels

v) The Top View of the Robot

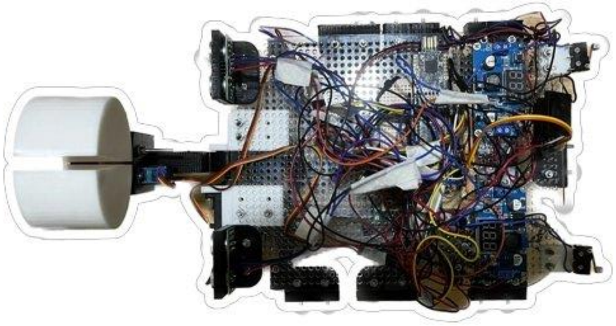


Figure 14: Top View of the Robot (Without Casing)

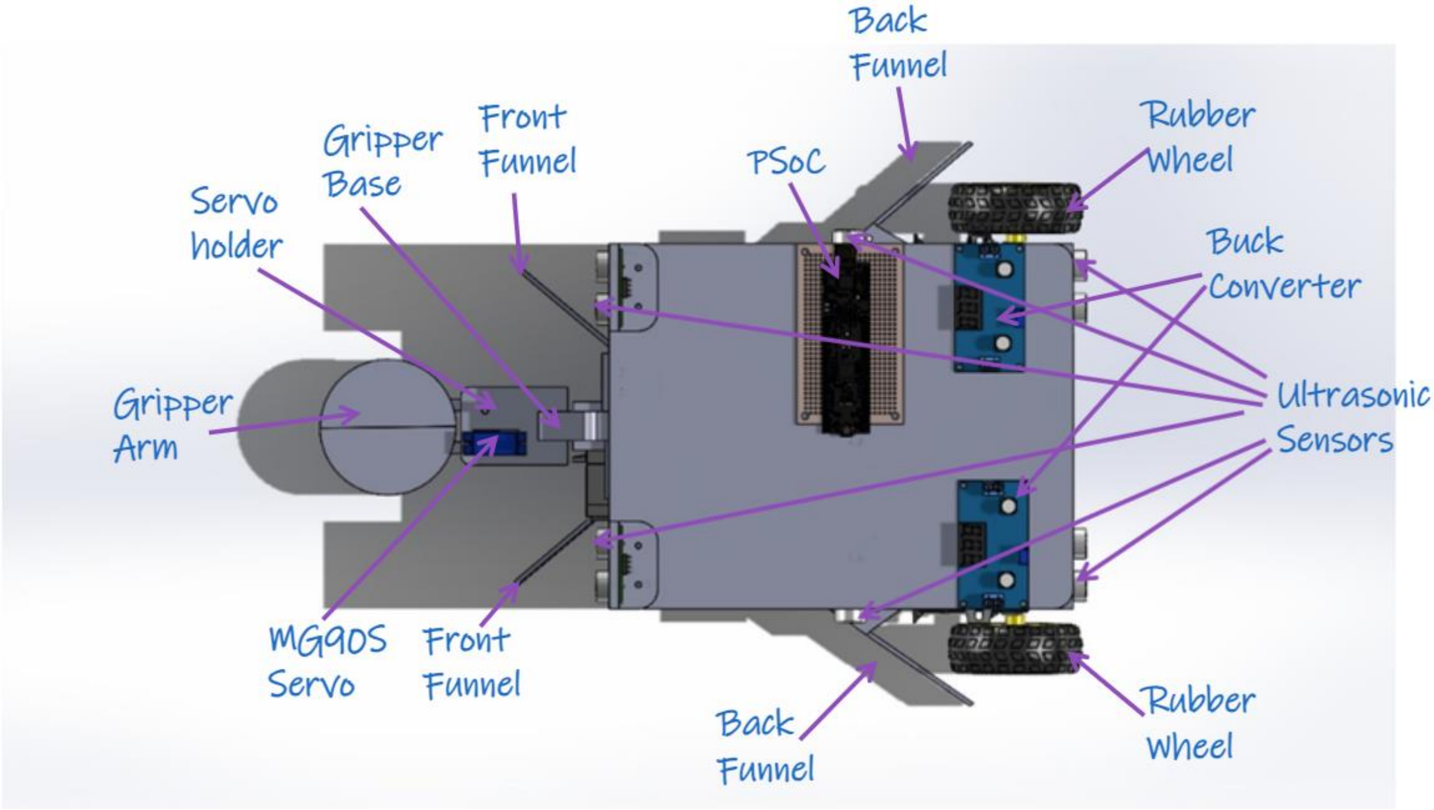


Figure 15: Top View of the 3D Model Robot with Labels

vi) The Bottom View of the Robot

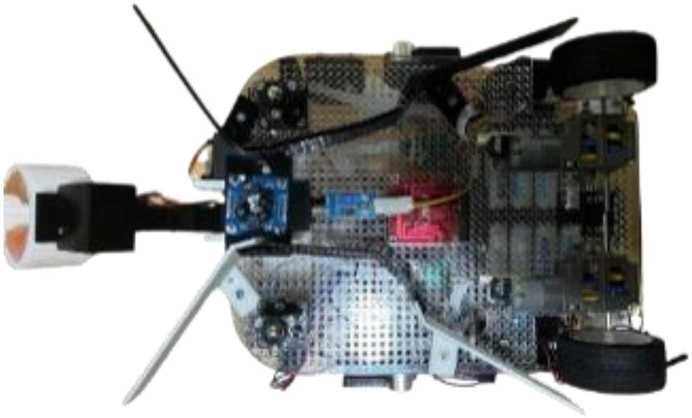


Figure 16: Bottom View of the Robot (Without Casing)

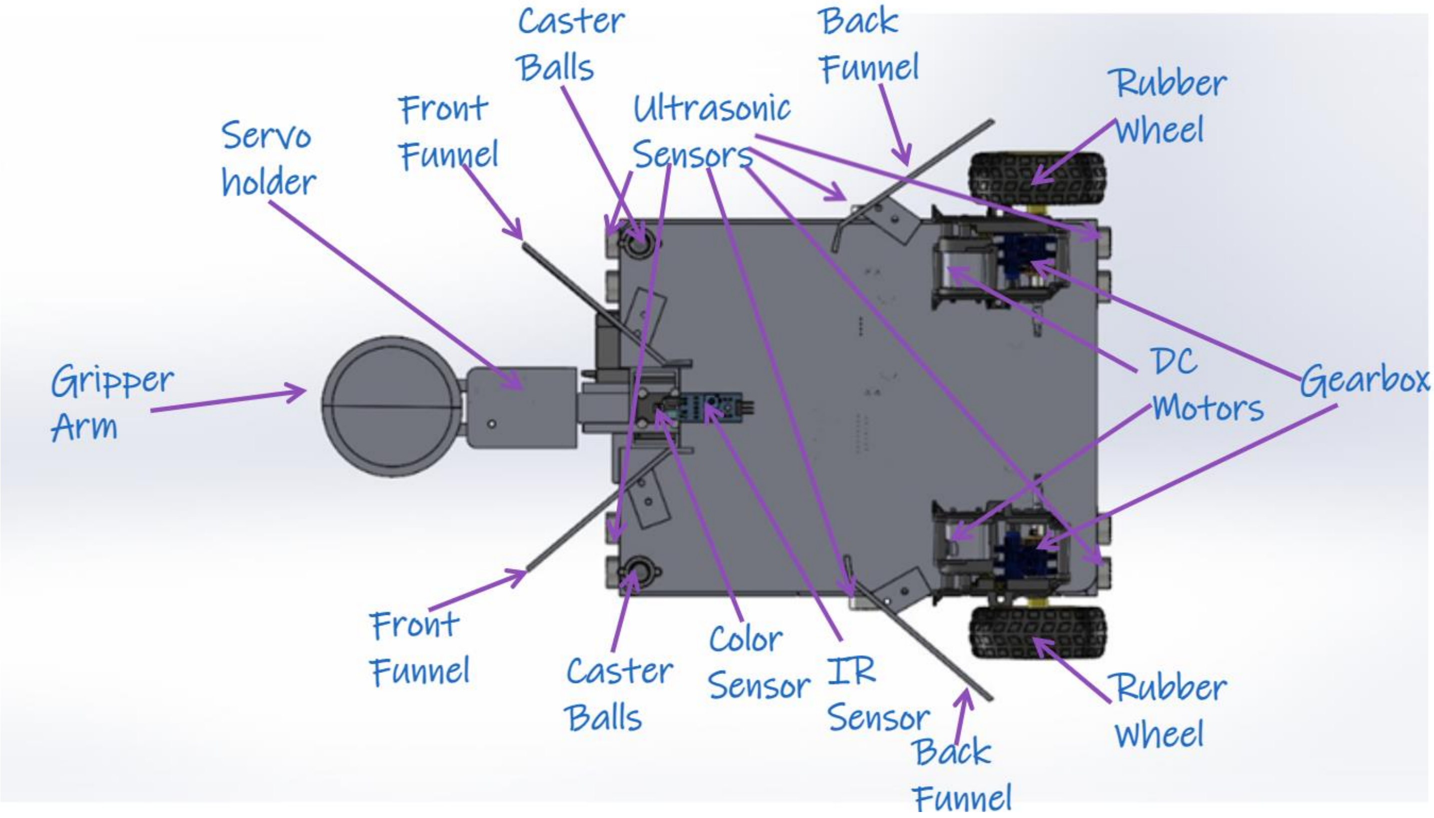


Figure 17: Bottom View of the 3D Model Robot with Label

The components labelled in the figures above, their functionalities and the problem statements they address is summarised in the table below:

Table I: Components of the Robot and Their Associated Functionalities

<table>
<tr><th>Number</th><th>Part</th><th>Features</th><th>Quantity</th><th>Role</th></tr>
<tr><td colspan="5">**System 1: Locomotion**
Problems Addressed
PS1: *Localization & Navigation*
PS4: *Game Strategy*
PS5: *Competition Adherence*
PS7: *Functional Design*
PS9: *Weight and Balance*</td></tr>
<tr><td>1</td><td>Driver Wheels</td><td>Tamiya 70111 Sports Tire Set</td><td>2</td><td>Provide traction and are responsible for propelling the robot forward or backward. Transfer the motor's rotational motion to linear motion for movement.</td></tr>
<tr><td>2</td><td>Motors</td><td>DC motor powered with 12V supply. Has in-built rotary shaft encoder.</td><td>2</td><td>Primary power source to rotate wheels. Rotary encoders provides distance travelled information.</td></tr>
<tr><td>3</td><td>Gearbox</td><td>Tamiya Single-Gearbox (4-speed)</td><td>2</td><td>Responsible for controlling the speed and torque of the motor output.</td></tr>
<tr><td>4</td><td>Motor Driver</td><td>L298N H-Bridge rated at 3A</td><td>1</td><td>Acts as an interface between the motors & the microcontroller.
Controls the direction and speed of the motors.</td></tr>
<tr><td>5</td><td>Transfer Plate</td><td>Flexible Fat Cable (FFC) with a bending radius as small as 1-2 mm</td><td>2</td><td>Carries the feedback data from the rotary encoders to the control and monitoring systems.</td></tr>
<tr><td>6</td><td>Castor Wheels</td><td>Tamiya Castor Wheels</td><td>2</td><td>Provide omnidirectional mobility, stability and front weight support for smooth motion</td></tr>
<tr><td colspan="5">**System 2: Puck Detection & Handling**
Problems Addressed
PS2: *Object Recognition and Manipulation*
PS4: *Game Strategy*
PS5: *Competition Adherence*
PS7: *Functional Design*
PS8: *Adaptability*
PS10: *Integration with Technology*</td></tr>
<tr><td>7</td><td>IR sensor</td><td>FC51 Proximity Sensor with detection range of 2-10cm</td><td>1</td><td>Detect presence of puck to activate color sensor</td></tr>
<tr><td>8</td><td>Color sensor</td><td>TCS3200 Color Sensing Module</td><td>1</td><td>Detect puck color</td></tr>
</table>

9	LEDs	Red, Green, Blue	3	To display the detected puck color to the user
10	Gripper Arm	PLA 3D Printed	1	To grip the puck
11	Gears	Interlocking gears for bidirectional motion. PLA 3D Printed.	1	To open and close the gripper arm.
12	Servo	MG90S Servo MG996R Servo	2	MG90S for gripper arm opening & closing motion. MG996R for gripper base upward & downward motion.
13	Servo Holder	PLA 3D Printed	2	Hold the servos in place.
14	Gripper Base	PLA 3D Printed	1	Connects the gripper and the MG996R servo motor.
15	Flicker	PLA 3D Printed	1	Flick the puck to knock the pin down.
16	Funnels	PLA 3D Printed. 2 front funnels. 2 back funnels.	4	Front funnels serve to align the puck directly under IR & color sensor. Back funnels prevents the pucks from interfering with the driver wheels.
System 3: Robot Obstacle Detection & Alignment Problems Addressed PS1: *Localization & Navigation* PS4: *Game Strategy* PS8: *Adaptability* PS10: *Integration with Technology*				
17	Ultrasonic Sensor Modules	US015. Range 2cm-4m. Resolution 0.5mm. 2 at the front. 2 at the back. 1 each on the left and right.	6	Front and back USMs to align robot for linear motion and detect obstacles. Side USMs mainly for pin detection.
18	USM Holders	PLA 3D Printed	6	To connect the USMs to the upper robot deck (horizontally or vertically)
19	Limit Switches	DM1-Series (1A 125V)	2	For precise alignment
System 4: Power Supply, Control & Interfacing Problems Addressed PS3: *Communication* PS5: *Competition Adherence* PS6: *Structural Integrity and Durability* PS8: *Adaptability* PS9: *Weight and Balance* PS10: *Integration with Technology*				
20	Batteries	Beston Rechargeable Ni-MH batteries. 12V 1300mAh.	16	Supplies DC power for the whole robot
21	Battery Holders	4-battery capacity	4	To hold the batteries in place

22	Buck Converter	LM2596 DC-DC Adjustable Step-Down Module with 7 Segment Display	3	Step down 12V power supply to 5V
23	Microcontroller	PSoC® 5LP	1	Overall data processing & instruction execution unit
24	Vero Board	$15cm^2$ Stripboard	1	Ground for mounting the microcontroller and the male header pins/jumper wires
25	Header Pins	Male-Male	A lot	To connect female-male jumper wires with the Vero Board
26	Jumper wires	Male-Male, Female-Male	A lot	To interface electronic components with the PSoC
27	Bluetooth Module	HC-05 Wireless Communication	1	To transmit instruction and receive sensor data wirelessly
28	Robot Base	Transparent Acrylic Base with M3 holes	2	Houses all the components. Body of the robot.
29	Hexagonal Shafts	32mm hollow shaft	4	To connect the top deck with the bottom deck
30	Screws, Bolts & Nuts	M3 x 10 mm pan head bolts, M3 Nuts, M3 shake proof washers	A lot	To lock all the components into place

2. Mechanical Design

2.1 Mechanical Aspects Description & How the Design Solves Robot's Problems

In this section, we delve into the model and distinctive attributes of each mechanical component carefully chosen for our robot. The design decisions that effectively address and resolve specific challenges in the robot's design are emphasized in **BOLD**, and we provide in-depth justifications to underscore their significance.

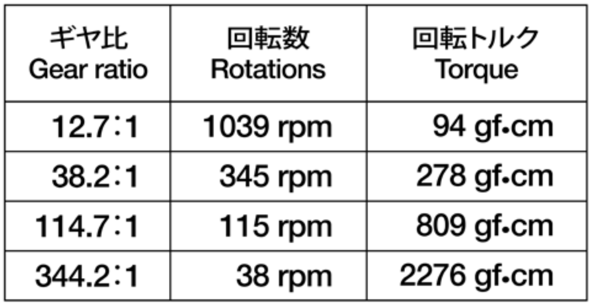
Mobility

Gearbox

Figure 18: Motor-Driven Gearbox Assembly with Dual-End Actuators [2]

The gearbox that we utilised is the Tamiya single gearbox. This gearbox allows you to choose from different gear ratios by changing the included gears and their orientation. You can adjust the speed and torque output by changing the gears.

Table II: Gear Ratio vs. Rotational Speed and Torque Characteristics [2]



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

As seen in the table above, elevating the gear ratio enhances torque but sacrifices speed. Extensive testing led us to the 114.7:1 ratio. It strikes the perfect balance, **robustly supporting the robot's weight during movement** while facilitating precise control, especially during point turns. Despite a somewhat reduced speed, it **sustains stable robot motion**. The high gear ratio can also improve the overall efficiency of the system. Reducing the speed and increasing the torque allows us to optimize energy usage and **reduce wear and tear** on the components.

Wheel Selection & Arrangement

The selected wheel configuration for our robot is the "two-wheeled turtle geometry." This design is reminiscent of the educational Logo Turtles, which use a similar layout for their movement. These turtles execute commands that involve straightforward drawing movements and on-the-spot point turns. Our robot is equipped to perform these movements effectively.

Figure 19: Wheels and Tamiya Caster Balls [3]

Our robot's configuration features two driver wheels positioned side by side at the rear, allowing for precise control and motion. The driver wheels are generic rubber tires that **provide enough traction** for a flat and even surface like the arena. To enhance the stability of our robot, we've also integrated a third and fourth point of contact in the form of Tamiya caster balls situated at the front. These caster balls provide several advantages for our robot.

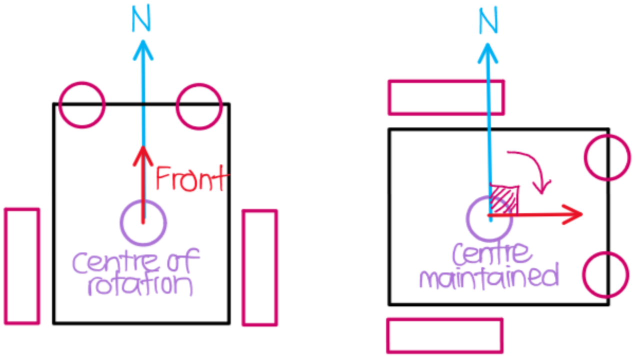


Figure 20: Centre of Rotation for the Robot

Firstly, the centre of the robot is maintained during point rotations. Furthermore, as the tires are omnidirectional and made up of steel, the friction is reduced. This translates to smoother and more efficient movement, as less energy is wasted in overcoming resistance. The reduced friction also extends the lifespan of the robot's components and tires. Thirdly, the metal caster balls offer high load-bearing capacity and durability.

Component Placement

Figure 21: Robot Plastic Base

2 transparent robot base is used to house all the components. Since the robot configuration is limited to the base size (30 by 30 cm) we have utilised a double-decker configuration. These robot bases are connected to each other by using 4 hexagonal shafts. All the components are connected to the base by using bolts, nuts & screws (strictly no adhesives).

The bottom deck mainly contains heavyweight components such as 16 Ni-MH Rechargeable Batteries, 4 battery holders, 1 buck converter, 1 H-bridge, 2 limit switches, 1 infrared sensor, 1 colour sensor, 2 motor drivers (which are connected to the gearbox and rubber tires), 2 caster balls and the funnel. Placing heavy components in the lower deck of the robot's chassis reduces its centre of gravity. This improves the robot's overall stability, which is essential for precise control and preventing unwanted tilting or rolling during manoeuvres. It also provides greater traction for the wheels.

The top deck has the PSoC microcontroller, 2 buck converters, 6 ultrasonic sensors, 1 switch and the gripper-flicker mechanism. The PSoC microcontroller, being a central component for controlling the robot, is placed on the top deck for easy access during programming, debugging, and testing. This placement also allows for real-time monitoring of the microcontroller's status. The placement of the six ultrasonic sensors on the top deck allows them to have a clear line of sight and reduces potential interferences such as the sound waves reflecting off the arena floor. This positioning enhances the accuracy of sensor data, especially when they are used for obstacle detection, pin detection, alignment and navigation. The gripper-flicker mechanism had to be attached to the top deck of the robot. Due to its larger size, even if we consider the bottom deck as the centre of rotation, it won't fit in the space between the first and second decks and will collide with the top deck.

After deciding on which deck to put the components in, the exact placement of the components had to be determined. The guidelines followed were:

1) Limit switches which employ contact sensing and ultrasonic sensors which employ non-contact sensing are placed on edges

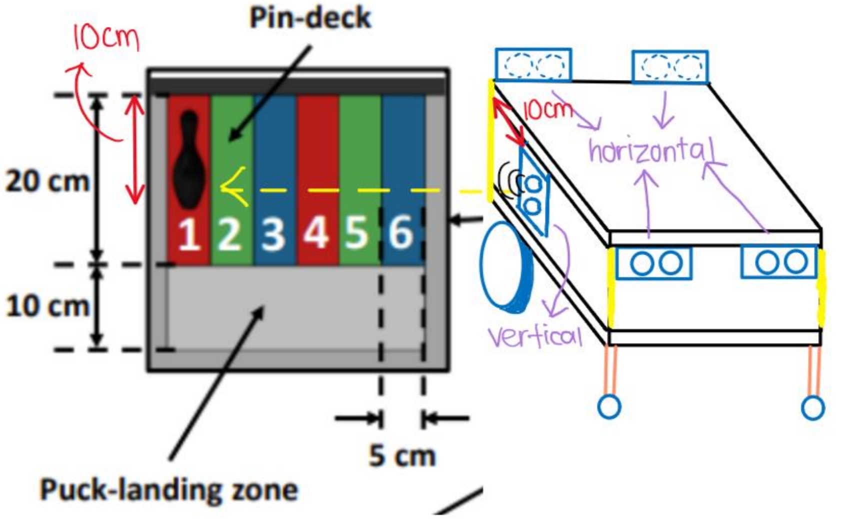


Figure 22: Drawing of using USM for pin detection

2) Front-back ultrasonic sensor pairs are placed horizontally whereas single ultrasonic sensors at each side are placed vertically to facilitate pin detection.

3) The vertical ultrasonic sensors should be placed ~10cm from the back end of the robot as the pin will be placed at the flicking zone approximately in the middle which is 10cm from the wall too.

4) Similar components should be placed in symmetry to the robot’s centre of mass (e.g., multiple buck converters, batteries, ultrasonic sensors)

To validate the effectiveness of our component placement strategy, we employed SolidWorks for comprehensive simulations. Our iterative simulation process allowed us to fine-tune the component placement until it achieved a state of perfect centre of mass balance.

Structural Form

Upon soldering all the wirings and locking all the components into place, the robot needed a protective shell to prevent all its' components from taking damage. Corrugated sheets were perfect for this purpose.

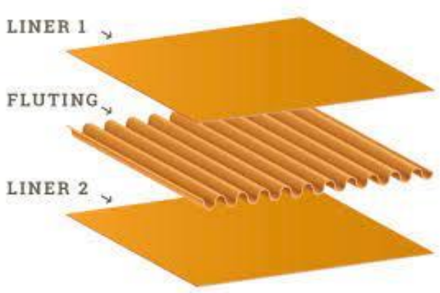


Figure 23: Corrugated Sheet [4]

The following are the characteristics of plastic corrugated sheets which are useful to protect our robot:

1) Rigid: Seen as liners 1 & 2 above, this twin wall structure provides rigidity and strength

2) Stiff: The fluted sections in plastic corrugated board are typically square, U-shaped, or V-shaped, and they run perpendicular to the flat sheets. These flutes enhance the material's stiffness and impact resistance.

3) Shock Absorption: The corrugated structure of the sheets can provide some degree of shock absorption, reducing the impact force on the internal components during accidental collisions.

4) Lightweight: Corrugated sheets are lightweight, which is essential for maintaining the robot's overall weight and balance. Excessive weight can affect a robot's mobility and energy efficiency.

5) Durable: Despite their lightweight nature, corrugated sheets are relatively durable and can withstand mild impacts and environmental conditions. They provide protection against minor bumps and scratches, preventing damage to the robot's internal components.

6) Customizability: Corrugated sheets are easy to cut and shape, allowing you to create a custom-fitted shell that precisely matches the robot's dimensions and design.

7) Cost-Effective: Corrugated sheets are cost-effective compared to many other materials used for protective shells, making them a budget-friendly choice for DIY robot projects.

8) Electrical Insulation: Corrugated sheets, being non-conductive, can help insulate the robot's components from electrical interference and static discharge.

Integrated Grip-Flick Mechanism

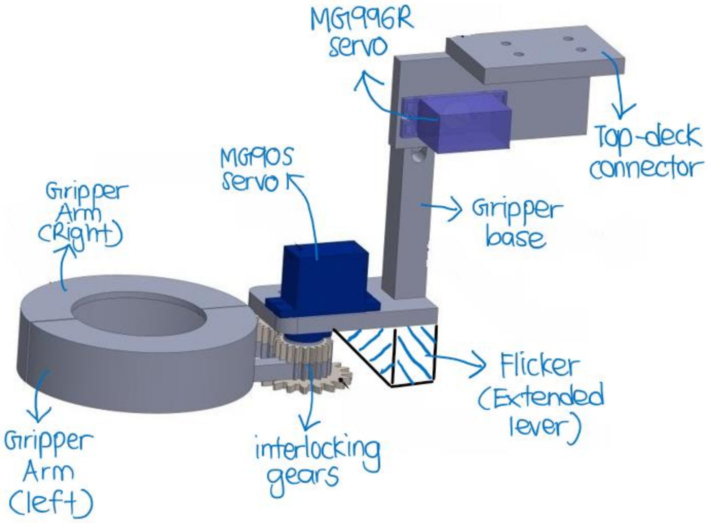


Figure 24: Labelled Gripper and Gripper Arm

i) Gripper Arm

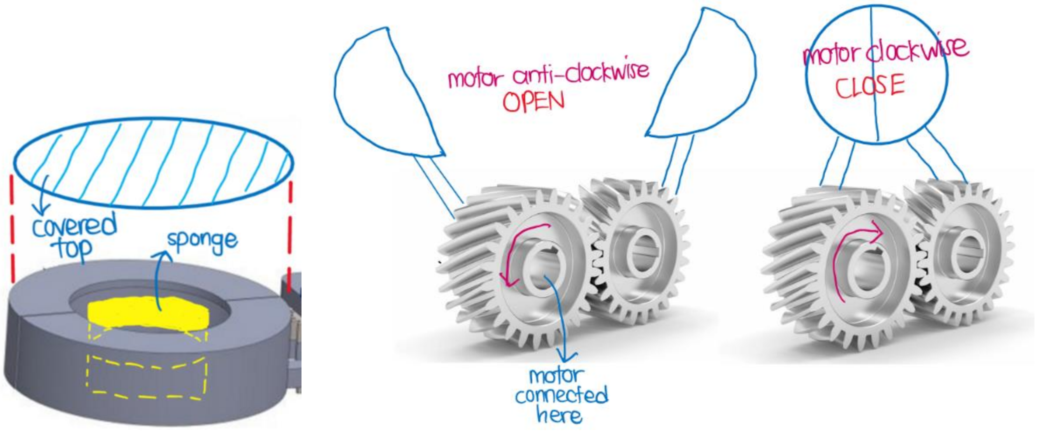


Figure 25: Labelled Gear

The gripper arm serves the crucial role of collecting pucks from the centre of the arena and securely holding them until they reach the designated puck landing zone. To achieve this, it's equipped with an innovative mechanism controlled by two interlocking gears, which are efficiently powered by the robust MG90S servo motor. The gripper arm executes an open-close motion.

The unique feature of these interlocking gears is their ability to move in opposite directions simultaneously. This intelligent design allows the gripper arm to execute **bi-directional movements using only one servo** motor's rotation. This efficiency not only simplifies the control system but also conserves energy.

The MG90S servo motor was chosen for this task due to its remarkable torque capacity of 2kg/cm. This torque ensures that the motor can confidently manage the weight of the gripper arm, the puck, and the interlocking gears, ensuring smooth and reliable puck handling.

To further enhance its gripping capability, the gripper arm incorporates a sponge element that allows for compression. This feature provides a superior grip on the puck, ensuring that it remains securely held during transport.

ii) Gripper Base

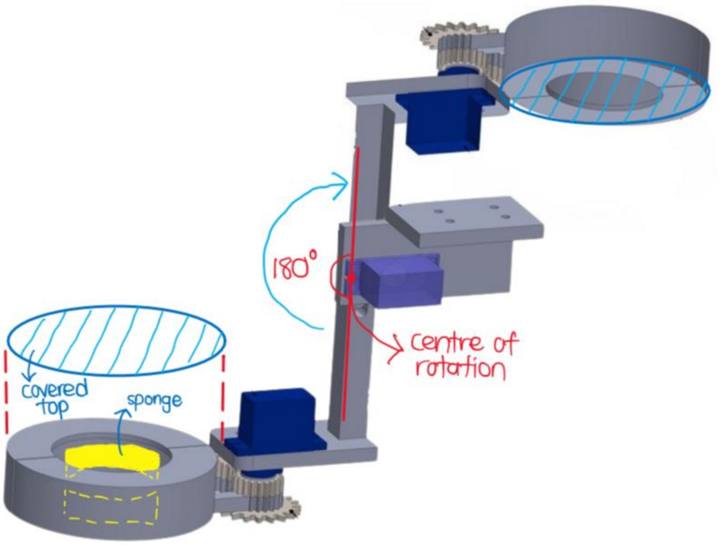


Figure 26: Rotation of Gripper Arm by 180 degrees

The gripper base on the other hand ensures that the puck does not touch the ground from the time it was picked up until it has been landed. It executes a top-down motion. Since it only moves in 1 direction at a given time, the use of gears was redundant. It was directly connected to the servo axle for better mechanical power transfer.

Notably, the gripper base faces additional challenges. It must support the entire gripper arm mechanism along with an extra motor, which introduces added weight and complexity. Moreover, its top-down motion involves working against the force of gravity, requiring a servo with significant torque capacity to perform this task effectively. For this demanding role, the MG996R servo has been chosen, offering an impressive torque of 13kg/cm while maintaining compact dimensions.

To further enhance functionality, the gripper base features a covered top. This feature proves invaluable when retracting the gripper base, as it prevents the puck from falling downward from the gripper arm. This thoughtful addition ensures that the puck remains securely held during all stages of the robot's operation.

iii) Flicker

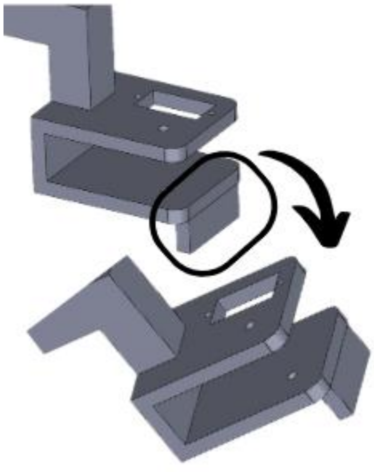


Figure 27: Base Flicking Mechanism

The flicker mechanism acts as an extended lever positioned underneath the interlocking gears, with a primary purpose of executing precise and efficient flicking actions. This design's cleverness lies in its practical use of locus knowledge, taking advantage of the natural gap formed when the gripper base follows a circular path. This gap aligns the extended lever perfectly with the puck.

The selected servo for controlling the vertical movement of the gripper base is the stronger, enhanced MG996R servo, making it an excellent choice for the flicking action as well. Using the same powerful servo for both lifting the gripper base and executing flicking simplifies the design and reduces the need for extra components.

Notably, the system features a natural alignment mechanism pre-flicking. As the gripper releases the puck in the landing zone, the design ensures that the puck aligns itself linearly with flicker without requiring manual adjustments or dedicated alignment devices. This not only simplifies the overall design but also eliminates the need for an additional power source, reducing overall energy consumption.

Additionally, the flicker's placement is efficient, guided by ergonomic considerations to ensure seamless practical functionality. This approach enhances the flicker's performance while minimizing the use of extra materials, contributing to the overall efficiency and practicality of the robot's design.

2.2 Use of Recyclable Materials

Table III: Component Materials and Its Recyclability Factor

Component Name	**Material Name**	**Recyclability**	**Benefit/Drawback**
Robot Deck	Transparent Acrylic	Often referred to as polymethyl methacrylate (PMMA), acrylic glass is completely **recyclable**.	PMMA has a relatively high melting point, which can make the recycling process more energy intensive.
Gripper Arm, Gripper Base, Flicker, Interlocking Gears, USM holders, Gripper-Robot Connection, Funnel	Polylactic Acid	PLA is a biodegradable thermoplastic derived from renewable resources such as corn starch or sugarcane. It is **recyclable**.	Multiple methods to break down & recycle: i) mechanical (heat melting) ii) chemical (lactic acid) iii) composting (turns into water and carbon dioxide)
Robot Shield	Corrugated Sheet	Typically made from a material known as polypropylene (PP). Our corrugated sheet is designated with the recycling symbol "5", hence **recyclable**.	The recyclability of plastic corrugated sheets made from polypropylene can be influenced by factors such as additives, coatings, and the overall composition of the sheets.

2.3 Alternative Designs

Design 1: Pinball Flicker-Funnel

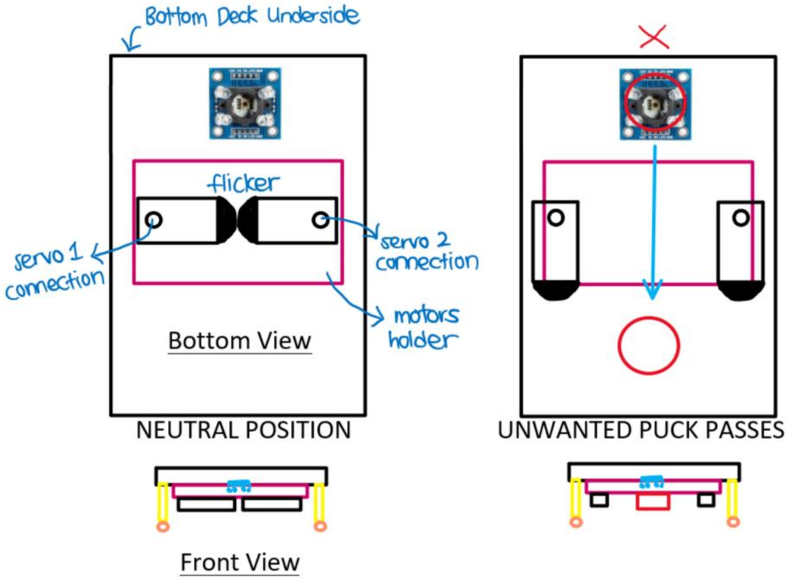


Figure 28: Pinball Flicker-Funnel Mechanism (Incorrect Puck)

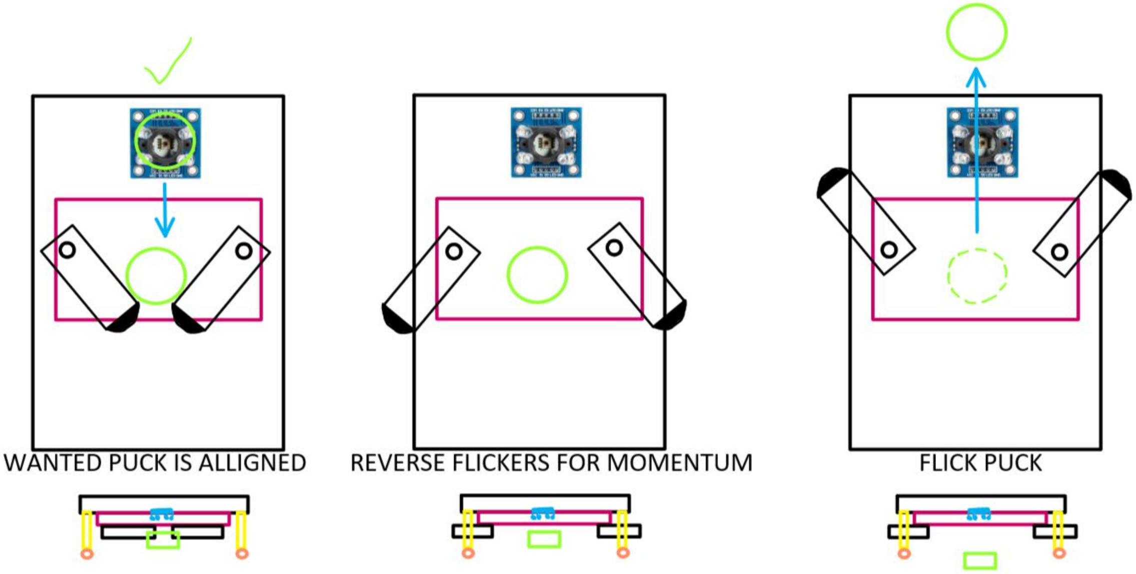


Figure 29: Pinball Flicker-Funnel Mechanism (Correct Puck)

Taking inspiration from the pinball game, we decided to design our flicker like the pinball flippers. The flicker is not only used to flick the puck but is also a barrier mechanism which selectively allows and blocks pucks. It also aligns the pucks like a funnel before striking it. These steps are illustrated in the figure above. The reasons why this flicking method wasn't selected were:

1) Usage of 2 servo motors

Having two motors increases the weight of the robot, which can reduce its speed. Double servos consume double current, rapidly draining the power supply from the batteries.

2) Synchronous motion expected

Attaining precise synchronization of two servo motors for achieving a straight, non-angled flicking motion presents a notable technical challenge. The reason for this challenge lies in the nature of servo motor control. Independent PWM (Pulse Width Modulation) signals must be supplied to each motor as they travel in opposite directions to execute the flicking motion. Due to this inherent separation, a single PWM signal cannot be readily shared between the two motors. Even when signals are triggered simultaneously, there appears to be a latency between the initiation of motion in the two motors. This inherent delay necessitates the implementation of a sophisticated control system to ensure that both motors strike the puck in perfect synchrony.

3) Heightens robot

As depicted in the front view sketches provided, the robot's design necessitates accommodating servo motor holders, servo motors, and flickers beneath its chassis. To create adequate room for these essential components, the lower deck must be elevated further from the ground. While this adjustment is imperative for component placement, it comes with certain consequences. Specifically, it contributes to an overall increase in the robot's height, which, unfortunately, has implications for the robot's stability.

This heightened profile can impact the robot's ability to maintain balance and stability, particularly during dynamic movements or in scenarios where a lower centre of gravity is advantageous. Furthermore, the elevation of the lower deck also leads to an increased vertical separation between the color sensor and the puck during interactions. This spatial discrepancy can introduce inaccuracies in the color sensing process, as the increased distance may affect the sensor's ability to precisely detect and identify the puck's color. Therefore, the trade-off between accommodating components and preserving the robot's stability and sensor accuracy warrants careful consideration in the design process.

4) Precise alignment is essential

Ensuring precise alignment of the puck with the flicker is vital for accurate puck striking. If the alignment is not in the middle, the puck may not be flicked straight, resulting in not hitting the pin.

Design 2: Rack & Pinion Flicker

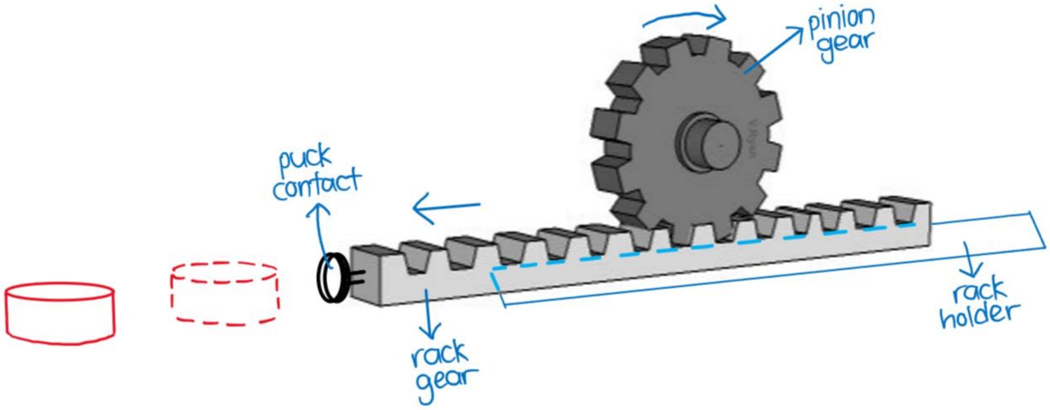


Figure 30: Rack and Pinion Gear Mechanism

The rack and pinion mechanism is a fundamental mechanical system used to convert rotational motion into controlled linear motion. It comprises three essential components: the rack, the pinion and the rack holder.

Rack: The rack gear is a straight bar or rod featuring evenly spaced teeth, which are typically straight ridges along its length. It moves dynamically with the teeth of the pinion gear.

Pinion: The pinion is a small gear that meshes with the rack's teeth. It's directly linked to the servo motor, providing the rotational force necessary for the mechanism's operation. As the pinion rotates, it engages with the rack's teeth, translating its rotary motion into precise linear movement.

Rack Holder: The rack holder is a critical component that supports the rack gear’s linear movement. The rack holder is typically designed to be rigid and stable, providing a fixed mounting point for the rack. It helps maintain the proper alignment of the rack with the rotating pinion, which is essential for the reliable and precise conversion of rotational motion into linear motion.

A notable feature of the rack gear is the placement of a contact point at its end. This contact point plays a crucial role in transferring maximum force and momentum to the puck, essentially creating a flicking motion. For this mechanism, our rack gear is 3D-printed with a 100% infill to maximize its mass for higher flicking momentum. In contrast, the pinion, or gear, is often printed with a 50% infill to strike a balance between weight and functionality. The rack and pinion flicker were installed beneath the lower deck of our robot. Unfortunately, it was not implemented due to the disadvantages below:

1) Limited Range of Motion
Due to the limitation of the rack gear and holder, the mechanism can extend or retract up to a certain length.

2) Wear & Tear
The interaction between the rack and pinion can generate friction and wear over time. Regular maintenance is often required to ensure smooth operation and prevent premature wear and tear of components.

3) Power Consumption
The sliding motion in a rack and pinion system requires more power compared to some other mechanisms, especially since there's a need to overcome friction.

4) Interference with other components
The dynamic rack gear, which is long, could interfere with other components underneath the robot base such as the infrared sensor, colour sensor, funnel and motor drivers.

Design 3: Lower Deck Connected Puck Gripper

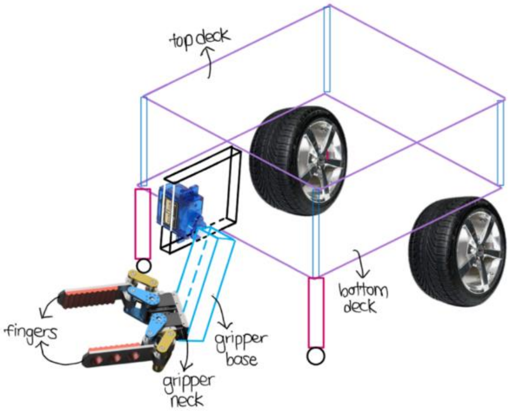


Figure 31: Lower Deck Connected Puck Gripper

In this gripper design, the gripper base rotates around a servo attached to the robot's top side of the bottom deck. Consequently, during puck retraction, the whole gripper mechanism resides within the space between the top and bottom decks. This design offers several advantages. Firstly, thanks to the small radius of the gripper base (axle), the motor requires less torque for rotational movement. Secondly, the sharp interior of the gripper fingers establishes contact points with the puck, promoting a secure grip through increased traction. Despite these benefits, the design presents the following drawbacks that have made it less appealing:

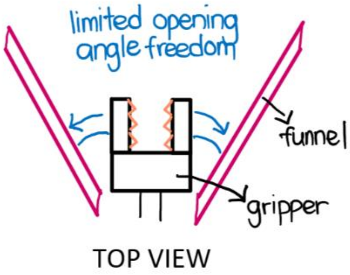


Figure 32: Lower Deck Connected Puck Gripper (Top View)

1) Restricted range of motion:
Due to the limited space between the top and bottom decks, the gripper base and neck MUST be short to avoid collision with the top deck. As the funnels are also present in front of the robot, this results in a shorter angle of freedom for puck capture. Consequently, if the puck is slightly out of alignment, the gripper may not be able to grip it as it may slip out.

2) Space Consumption:
This gripper design occupies valuable space on the bottom deck, which is used for accommodating heavier objects such as the buck converter and batteries. This space occupied becomes a critical concern.

3) Continuous Power Drain:
To prevent the puck from falling on the arena floor during puck retraction, the servo motor of the gripper arm must remain activated. This constant power consumption places an unnecessary drain on the rechargeable batteries.

4) Puck Retention Challenges:
Since the gripper arm features open top and bottom sides, there is a risk of the puck falling out if a collision occurs. This configuration may not provide sufficient puck retention in certain situations.

3. Electronic Design

3.1 Working Principle of Circuits Used for Sensors and Actuators

In the field of robotics, a strong synergy between hardware and software is essential. This principle is exemplified in our project's robot design. At the core of its electronic system is the Programmable System on Chip (PSoC), a versatile platform that seamlessly integrates programmable analog and digital components. This section provides a detailed examination of the electronic architecture of our robot, explaining how sensors, actuators, and the PSoC work together to bring the robot to life.

Electronics play a crucial role in our robot, not merely for its basic functions but as the central system that controls its movements, responses, and decision-making. A color sensor allows the robot to recognize and interact with objects by discerning color. An ultrasonic sensor serves as its "eyes," helping it navigate and avoid obstacles. Motors act as the "muscles," propelling the robot and translating commands into motion. To fully understand these components, it's essential to explore their electronic workings, how they integrate to create a cohesive system, and the power management considerations.

Throughout this section, we will delve into the circuitry of each component, examine their integration into a unified system, discuss alternative component choices that were considered during the design phase and address the critical aspect of power management. These elements collectively contribute to the creation of an intelligent robot capable of intricate interactions with its environment.

The below image is the circuit diagram of the entire robot that we have designed.

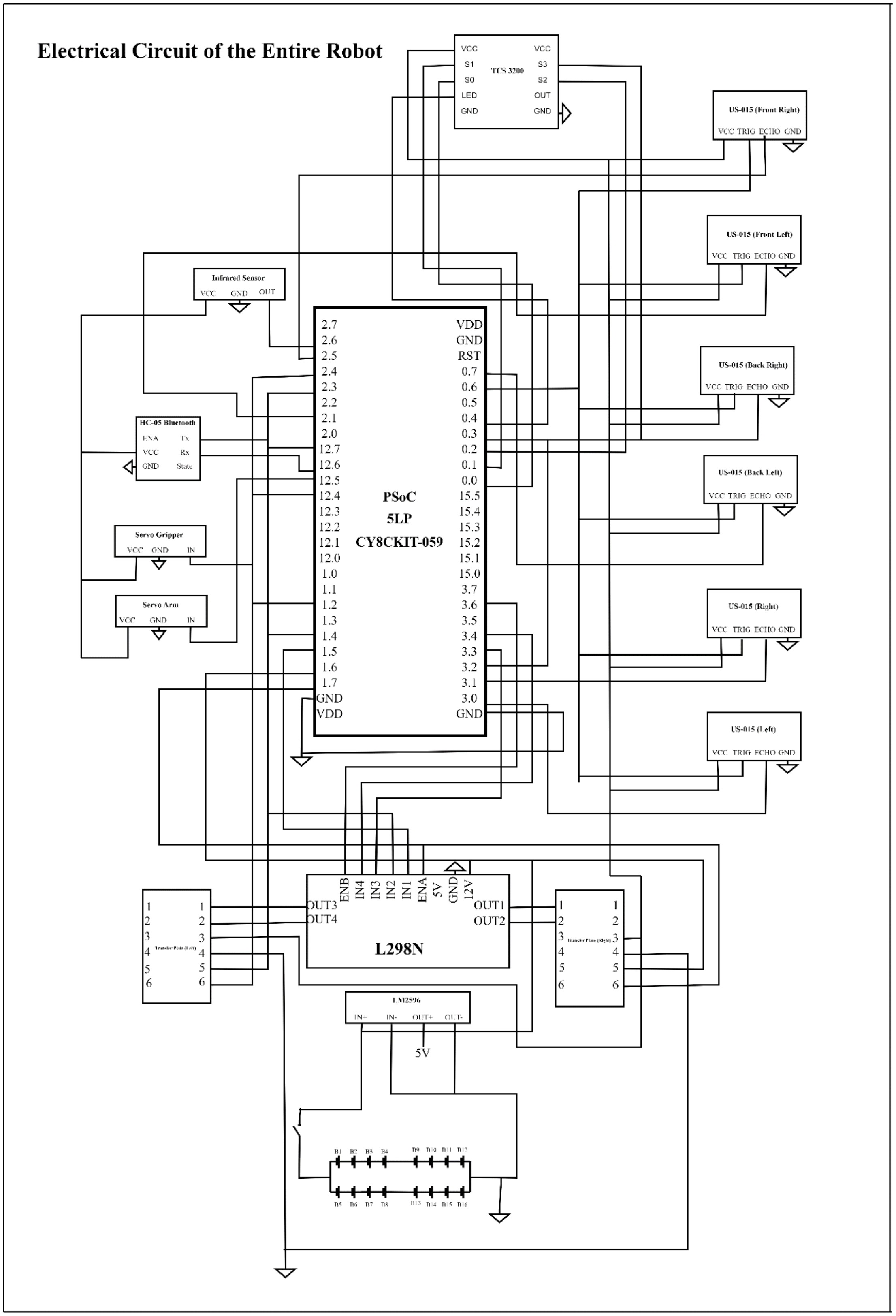


Figure 33: Electrical Connection of the Entire Robot

Working Principles of The Circuits Used for Components

Microcontroller

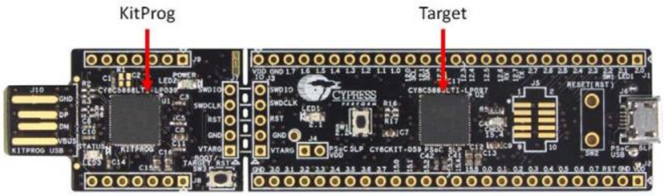


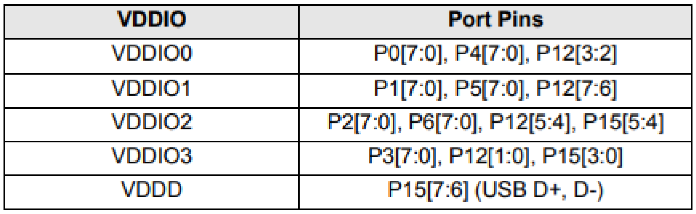
Figure 34: Cypress Development Board with KitProg and Target Sections Highlighted [5]

The PSoC® 5LP acts as a comprehensive embedded system-on-chip, combining memory, a microcontroller, and adjustable analog and digital peripherals all within a single unit. This architecture enhances its capabilities through:

1) Utilizing a 32-bit Arm Cortex-M3 core, supplemented with a Direct Memory Access (DMA) controller and digital filter processor, running at speeds up to 80 MHz.
2) Offering extremely low power consumption while supporting the industry's broadest voltage spectrum.
3) Its adaptable digital and analog peripherals allow for tailored functions.
4) A versatile pin assignment system, enabling any analog or digital peripheral function to be mapped to any desired pin.

The electronic components that are involved in the entire robot system have been connected to the 4 segments of pins found on the microcontroller.

Table IV: VDDIO Voltage Domains and Corresponding Port Pins Mapping [6]



VDDIO	Port Pins
VDDIO0	P0[7:0], P4[7:0], P12[3:2]
VDDIO1	P1[7:0], P5[7:0], P12[7:6]
VDDIO2	P2[7:0], P6[7:0], P12[5:4], P15[5:4]
VDDIO3	P3[7:0], P12[1:0], P15[3:0]
VDDD	P15[7:6] (USB D+, D-)

The pins that are connected to VDDIO0 is as stated below:
USM (Ultrasonic Sensor Module)
0.7 – Echo (Back Left Sensor)
0.6 – Trigger

Colour Sensor
0.5 – Count (Out)
0.4 – S4
0.3 – S3
0.2 – S2
0.1 – S1
0.0 – S0

Start Switch

The pins that are connected to VDDIO1 is as stated below:

Left Motor
1.7 - Motor_1_Phase_B
1.6 - Motor_1_Phase_A
1.5 - Motor_1_IN_1
1.2 - Motor_1_ENA

Bluetooth
12.7 - Tx_1
12.6 – Rx_1

The pins that are connected to VDDIO2 is as stated below:
Right Motor
2.6 – IR Sensor
2.5 – Echo Front Right Sensor
2.3 – Motor_2_Phase_B
2.2 – Motor_2_Phase_A

Servo Motors
12.5 – Gripper Arm
12.4 – Gripper

The pins that are connected to VDDIO3 is as stated below:
3.6 - Motor_2_ENA
3.4 – Motor_2_IN_4
3.3 – Motor_2_IN_3
3.2 – Echo Back Left Sensor
3.1 – Echo Right Sensor
3.0 – Echo Left Sensor

Color Sensor

The color sensor that we have used for our robot is the TCS3200 Color Sensor Model.

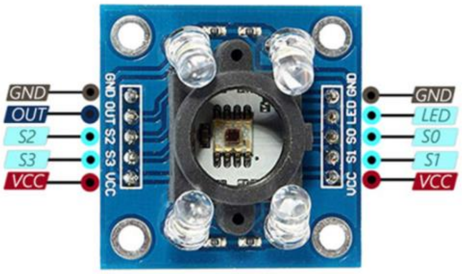


Figure 35: TCS3200 Color Sensor [7]

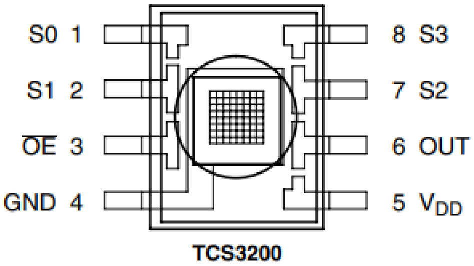


Figure 36: TCS3200 Color Sensor Circuit Diagram [7]

The TCS3200 color sensor is an adaptable color light-to-frequency converter. These devices seamlessly integrate configurable silicon photodiodes with a current-to-frequency converter into one unified CMOS integrated circuit. Their output manifests as a square wave, maintaining a 50% duty cycle, where the frequency correlates directly with the light's intensity (irradiance).

Pin Assignments

Table V: Pin Assignments for TCS 3200 Color Sensor [8]

Pin Name	Pin Number	Description
S0, S1	1, 2	Output frequency Scaling
OE	3	Enable for FO (Active Low)
GND	4	Ground
VCC	5	Supply Voltage
OUT	6	Output Frequency
S2, S3	7,8	Photodiode Type

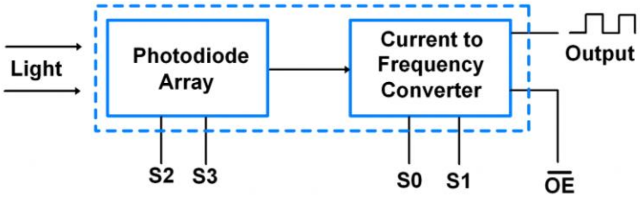


Figure 37: Functional Block Diagram for the TCS3200 Color Sensor [9]

TCS3200 Color Sensor Working Principle

The TCS3200 has an array of photodiodes, selectable to be either red, blue, green or clear filters. When you shine a light on the sensor, some amount of that light will be absorbed by each photodiode, depending on the color of the light. The sensor then converts this light into a square wave with a frequency proportional to the intensity of the light for each color as shown in the functional block diagram above. By reading this frequency with a microcontroller or another device, you can determine the color of the light. After the photodiode, light beams are channelled through a converter that translates current to frequency, creating a square wave. This wave's frequency mirrors the strength of the incoming light. By adjusting the S0 and S1 pins, these square wave frequencies can be modulated. This modulation affects the precision of color detection. The table below showcases the logic patterns for each frequency scale. Should a particular color filter detect a strong light reflection, the square wave's frequency rises, yielding a higher pulse count over a specific time span.

1. Powering the TCS3200

Connect VDD pin to 3.3V or 5V (depending on your microcontroller).
Connect GND pin to the ground.

2. Output

Connect the OUT pin to a digital input on your microcontroller. This is where the square wave output will be read.

3. LEDs

If you want to use the onboard LEDs to illuminate the object, connect OE (Output Enable) pin to the ground. To turn them off, connect the OE pin to VDD.

4. Filter Selection

The sensor has pins to select the color filter: S2 and S3. By setting these pins HIGH or LOW, you can select the color.

Table VI: Filter Logic Patterns by TCS 3200 Color Sensor [8]

S2	S3	Color Filter
L	L	Red
H	H	Green
L	H	Blue
H	L	Clear (No Filter)

5. Frequency Scaling

The sensor can output different frequency scales which can be useful to adjust for different microcontroller speeds. This is set using the S0 and S1 pins.

Table VII: Frequency Scaling Logic Patterns for TCS 3200 Color Sensor [8]

S0	S1	Output Frequency Scaling
L	L	Power Down
L	H	2%
H	L	20%
H	H	100%

Ultrasonic Sensor Module (USM)

The Ultrasonic Sensor Module that we have chosen is the US-015 Sensor Module.

Figure 38: US-015 Ultrasonic Sensor Module (USM) [10]

The US-015 Ultrasonic Distance-Measurement Module is designed for distance detection, ranging between 2cm to 4m, with a stable resolution of up to 0.5mm. Compatible with the PSoC microcontroller, it comes with 4 pins: two designated for 5V power supply (VCC - GND) and the remaining two for data transmission. Ideal for various projects, including robotics and automation, it's also favoured in educational settings due to its user-friendly interface. It bears similarities to the HC-SR04 module but differs in aspects like range, resolution, and frequency.

Pin Assignment

Table VIII: Pin Assignments for US-015 USM [11]

Pin Symbol	**Pin Function Description**
VCC (Voltage Common Collector)	5V Power Supply
Trigger	Trigger Input Pin
Echo	Receiver Output Pin
GND (Ground)	Power Ground

Ultrasonic Sensor Module Working Principle

Ultrasonic sensors, commonly termed as transducers or transceivers when they both transmit and receive, operate on a methodology echoing radar or sonar systems. These sensors emit high-frequency sound waves and subsequently measure the reflected echo. By gauging the time span between the emission of the sound wave and the reception of its echo, the sensor can accurately deduce the distance to an object or obstacle.

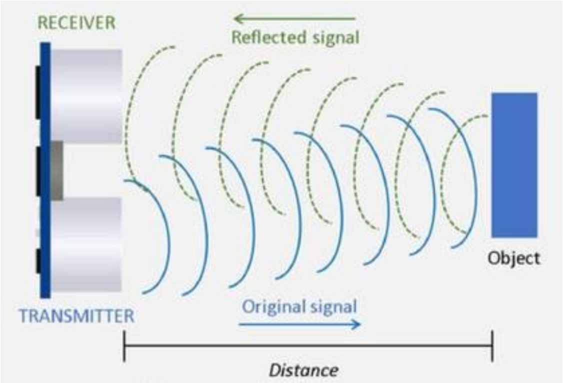


Figure 39: Working Principle of Ultrasonic Sensor [12]

Here's a breakdown of the process:

1. Emission of Sound Waves

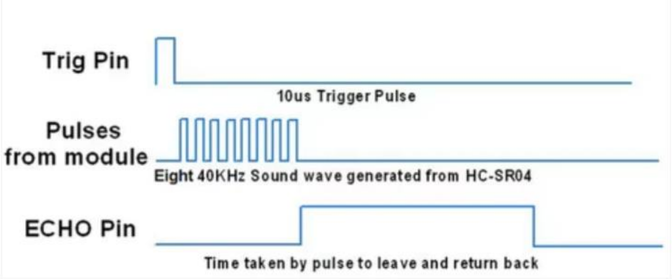


Figure 40: Ultrasonic Sensor Module Timing Diagram [13]

The USM sensor receives a $10\mu s$ trigger pulse, causing the USM to produce a burst of 8 sound pulses in the ultrasonic range, typically $40kHz$.

2. Echo Reception

Once these sound waves hit an object, they reflect as an echo which the sensor detects.

3. Distance Calculation

The sensor computes the time difference between the wave's transmission and the reception of its echo. Using this time interval, it calculates the distance of the object.

4. Conversion and Display

The received echo, in the form of sound waves, is converted back into electrical energy. This data can then be interpreted and displayed for various applications.

It's crucial to note that the efficiency of this USM can be affected by the surface shape and the material's density or consistency. For instance, materials like foam can lead to inaccuracies in surface level measurements. But for our use case, since the puck/pin are made from 3D printed PLA and the walls are rigid, the USMs works as intended.

Circuit Diagram for Ultrasonic Sensor Module

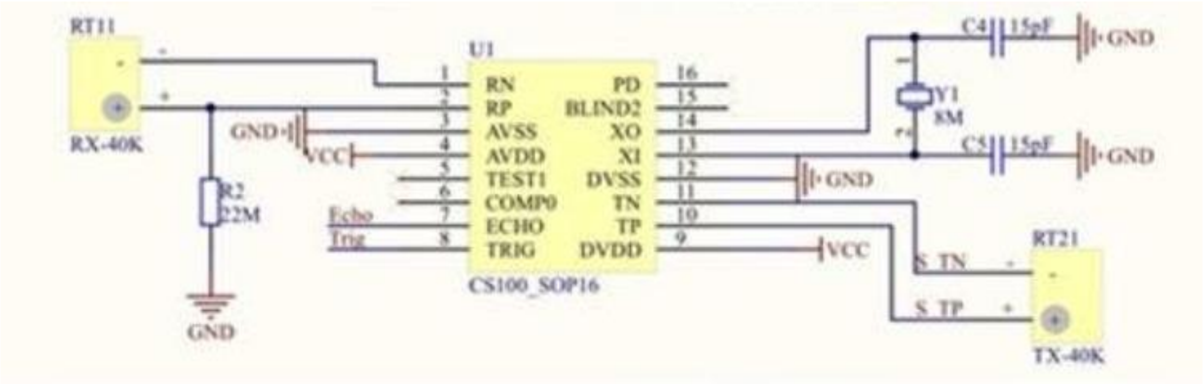


Figure 41: Ultrasonic Sensor Module Circuit Diagram [14]

Rocker Switch (2 Pin On-Off Round Rocker Switch)

Figure 42: Round Rocker Switch

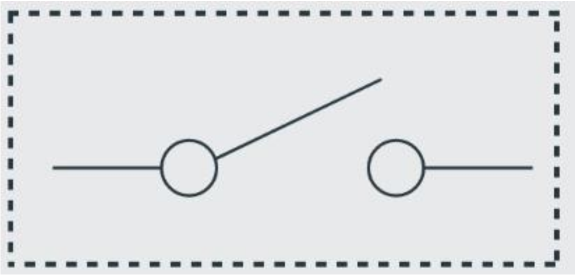


Figure 43: Circuit Diagram for the Round Rocker Switch

Working Principle of a 2-Pin Round Rocker Switch

A 2-pin round rocker switch operates as a simple binary switch. It is designed to open or close an electrical circuit, providing a means to control the flow of electrical current through a device or system.

1. Mechanical Action

The rocker switch employs a "rocking" mechanical action. When pressed, the actuator of the switch (the part that moves) pivots or "rocks" from one side to the other. This rocking action either makes or breaks the connection between the two pins, depending on the switch's position.

2. Electrical Connection

Internally, the switch consists of a movable contact and a stationary contact. The two pins correspond to these contacts. When the switch is in the "ON" position, the movable contact bridges the gap between the two contacts, completing the circuit and allowing electrical current to flow. When the switch is in the "OFF" position, the movable contact is away from the stationary one, breaking the circuit and stopping the flow of current.

3. Binary Operation

Due to its design, a 2-pin rocker switch operates in a binary manner: it's either in the "ON" or "OFF" position. There's no intermediate state. Therefore, devices controlled by such a switch have two basic states corresponding to these positions.

4. Installation

The round design of the switch typically allows for easy installation into a circular panel cutout. The two pins are usually soldered or connected to wires, which in turn connect to the device or system being controlled.

In essence, a 2-pin round rocker switch is a straightforward and efficient manual interface for controlling electrical circuits. It's widely used in various applications due to its simplicity, reliability, and ease of use.

Bluetooth Module

The Bluetooth module that we have used in this project is the HC-05 Bluetooth Module.

Figure 44: HC-05 Bluetooth Module [15]

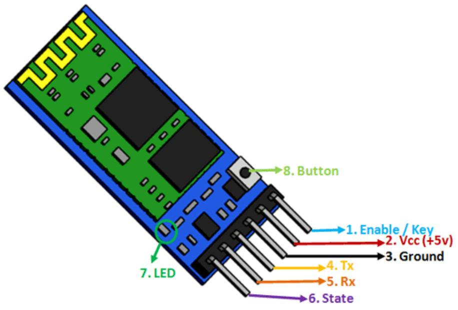


Figure 45: HC-05 Bluetooth Module Pinout [15]

Table IX: Pin Assignment for HC-05 Bluetooth Module [15]

Pin Name	**Pin Function Description**
Enable / Key	Used to toggle between Data Mode ()
VCC (Voltage Common Collector)	Powers the module, Connect to +5V Supply Voltage
Ground (GND)	Ground Pin of Module, Connect to System Ground
TX - Transmitter	Transmits Serial Data. Everything received via Bluetooth will be given out by this pin as serial data.
RX - Receiver	Receive Serial Data. Every serial data given to this pin will be broadcasted via Bluetooth
State	The state pin is connected to on board LED, it can be used as feedback to check if Bluetooth is working properly.
LED	Indicates the status of Module. Blink once in 2 sec: Module has entered Command Mode Repeated Blinking: Waiting for connection in Data Mode Blink twice in 1 sec: Connection successful in Data Mode
Button	Used to control the Key/Enable pin to toggle between Data and command Mode

Working Principle of HC-05 Bluetooth Module

The HC-05 Bluetooth module is a versatile wireless component designed for two-way communication or full-duplex communication. At its core, this module operates based on the Serial Port Protocol (SPP), making it compatible with devices that have Bluetooth functionalities, such as computers, mobile phones, and microcontrollers like Arduino.

The HC-05 module has dual operating modes:

1. Data Mode

This is the default mode when the module is powered up. In this mode, the HC-05 can establish connections with other Bluetooth devices to exchange data.

2. AT Command Mode

By grounding the key pin during power up, the module enters the AT Command mode. This mode allows users to modify the default settings of the HC-05, including its name, password, and other parameters. Once powered, the module can be detected by other devices as "HC-05." Connections can be established using the default password "1234." Post-connection, the module facilitates data transfer between the paired devices. To set up communication between the HC-05 module and a microcontroller, one must connect the Rx pin of the HC-05 to the microcontroller's Tx pin, and vice versa. This setup allows for a seamless exchange of data between the devices. While the HC-05 is proficient in handling textual data exchange, it's not suitable for transferring multimedia content like images or songs.

In essence, the HC-05 Bluetooth module serves as a bridge, enabling wireless communication between devices in various applications, from home automation and wireless robots to data logging and consumer applications.

Pin/Circuit Diagram of HC-05 Bluetooth Module

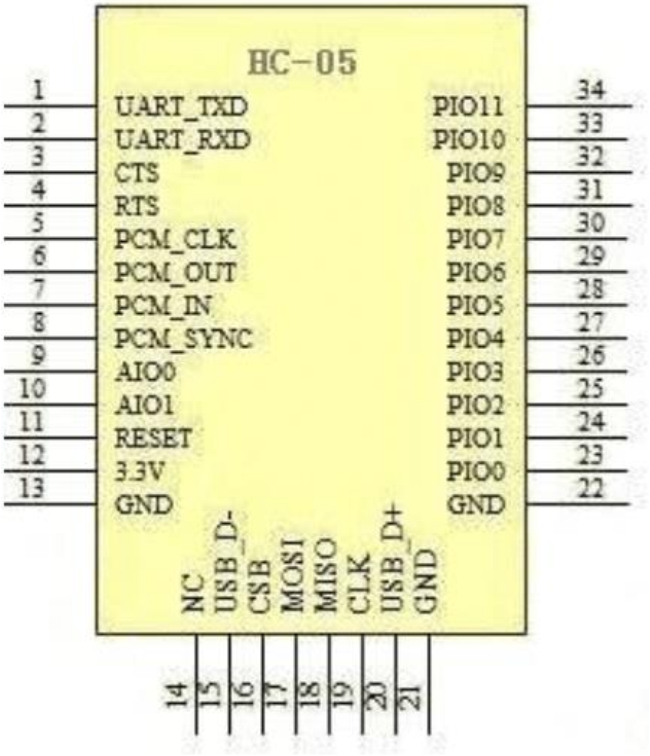


Figure 46: HC-05 Bluetooth Module Pin Diagram [16]

Shaft Encoder

Figure 47: Shaft Encoder [17]

Working Principles for the Shaft Encoder

The shaft encoder utilised for the robot, which is an optical encoder, operates based on the principle of detecting interruptions in a light beam. Let's break down its working:

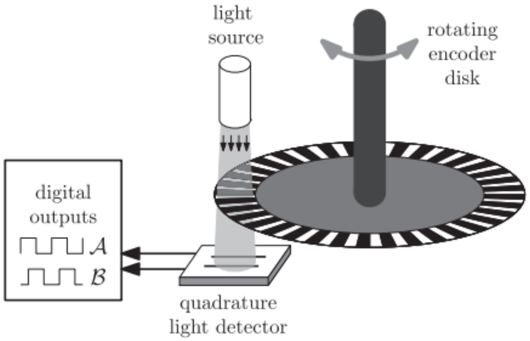


Figure 48: Working Principle of a Shaft Encoder [18]

1. Light Emission

The encoder has an internal LED (Light Emitting Diode) that emits a continuous beam of light. This light is aimed to pass through a code disk that's attached to the encoder's shaft. This is illustrated in the figure above.

2. Code Disk Rotation

The code disk, which is a crucial component of this system, is a transparent disk with opaque lines or patterns on it. These opaque lines are spaced out at regular intervals and are akin to spokes on a bicycle wheel. As the shaft of the encoder rotates, this code disk also rotates, causing the opaque lines to move with it.

3. Light Interruption

Due to the opaque lines on the rotating code disk, the continuous light beam from the LED gets interrupted periodically. This means as the disk rotates, the light beam will be blocked by the opaque lines and allowed to pass through the transparent spaces between them.

4. Photodetector Assembly

Positioned opposite the LED, the photodetector (or a set of them) continuously senses the presence or absence of the light beam. When the light beam is uninterrupted (i.e., passing through a transparent portion of the code disk), the photodetector reads this as an "on" state. When the light beam is blocked by an opaque line on the code disk, the photodetector reads this as an "off" state.

5. Signal Generation
This continuous change between the "on" and "off" states as the disk rotates produces a pulse signal. The frequency of the pulse is directly related to the speed of rotation of the shaft.

6. Signal Processing
This pulse signal is then sent to a counter or controller. The counter can determine the number of pulses over a time period to calculate speed or can count the total number of pulses to determine position. The controller processes the pulse signals and translates them into actionable data or commands, which can be used to monitor the rotation or control other connected devices.

In summary, an optical shaft encoder leverages the principle of light interruption by a rotating code disk to generate pulse signals that correspond to the rotation of the shaft, providing valuable information about position, speed, or direction of rotation.

DC Motor (Motor Driver)
The motor driver that we have used is the L298N for our robot design.

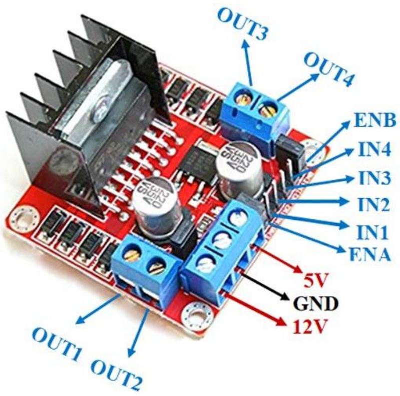


Figure 49: L298N Pinout [19]

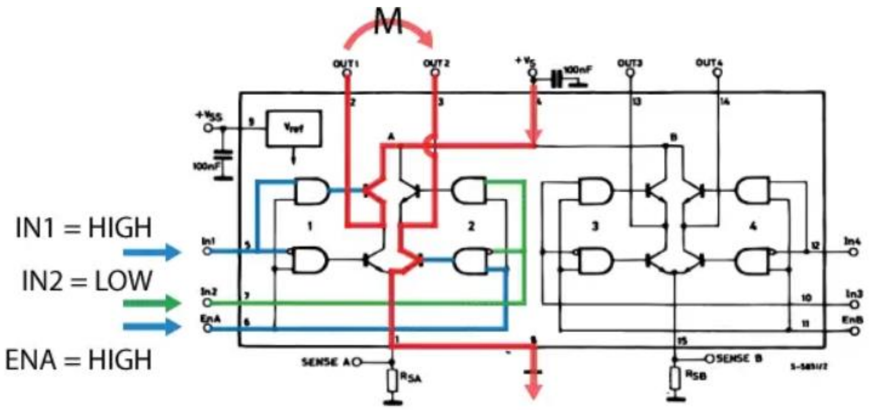


Figure 50: L298N Circuit Diagram [20]

The L298N Motor Driver Module is a potent module designed to drive both DC and Stepper Motors. It's equipped with the L298N motor driver IC and a 78M05 5V regulator. The module has the capability to manage four DC motors or two DC motors, offering both direction and speed control.

L298N Pin Configuration

Table X: Pin Assignment for L298N Motor Driver [19]

Pin Name	Description
IN1 & IN2	Motor A Input Pins. Control Direction of Spin for Motor A
IN3 & IN4	Motor B Input Pins. Control Direction of Spin for Motor B
ENA	Enables PWM Signal for Motor A
ENB	Enables PWM Signal for Motor B
OUT1 & OUT2	Output Pins of Motor A
OUT3 & OUT4	Output Pins of Motor B
12V	DC Power Source (12 V)
5V	Supply Power for Switching Logic Circuitry Inside L298N IC
GND	Ground Pin

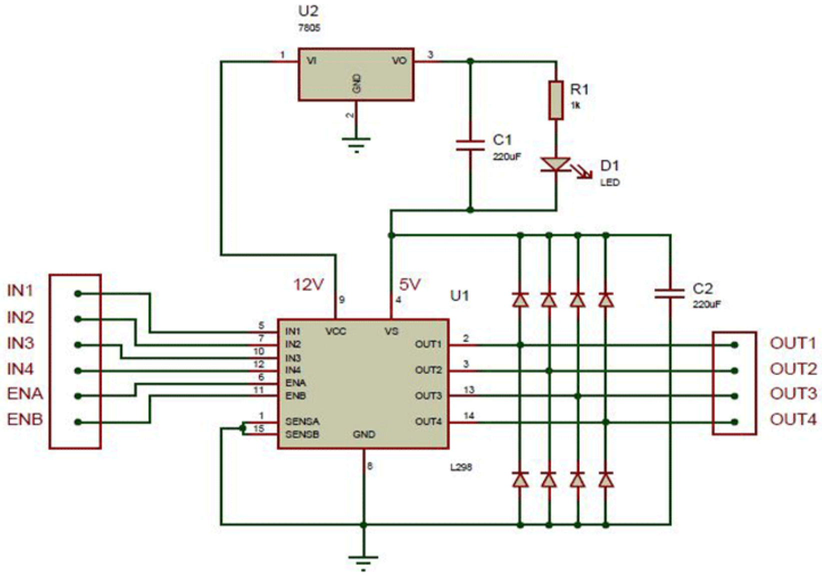


Figure 51: L298N Internal Circuit Diagram [19]

L298N Working Principle

The L298N Motor Driver module is a versatile device designed to control both small and large motors. Let's break down how it works step-by-step:

1. Components of the L298N Motor Driver Module

i) L298 Motor Driver IC

This is the heart of the module. It's responsible for controlling and driving motors.

ii) 78M05 Voltage Regulator

This ensures a steady 5V output, protecting the IC and other components from voltage fluctuations.

iii) Resistors & Capacitors

These are passive components that support the functioning of the IC and regulator.

iv) Power LED

Indicates when the module is powered on.

v) 5V Jumper

It's a bridge or connector that decides how the 5V regulator is used.

2. Power Management

When the power supply to the module is 12V or less, we can enable the 78M05 voltage regulator by placing the jumper. This action allows the internal components of the module to draw power from the regulator. Moreover, the 5V pin can act as an output, potentially powering other devices or microcontrollers.

If the power supply exceeds 12V, it's crucial to remove the jumper to prevent potential damage. In this case, the module's internal components need a separate 5V input, provided through the designated 5V terminal.

3. Motor Control

Speed Control (ENA & ENB pins)

These pins control the speed of Motor A and Motor B, respectively. By adjusting the voltage level or providing a PWM (Pulse Width Modulation) signal, you can regulate the speed of the motors.

Direction Control (IN1, IN2, IN3, & IN4 pins)
These pins determine the rotation direction of the motors. For Motor A, IN1 & IN2 decide its direction, and for Motor B, IN3 & IN4 take on this role. By setting these pins HIGH or LOW, you can make the motor rotate forward, backward, or stop.

In essence, the L298N Motor Driver module acts as an interface between the motors and a microcontroller, allowing for precise control over motor speed and direction.

Infrared Sensors

The Infrared Sensor that we have used is the Infrared Sensor Model that was given to us in the Project Kit.

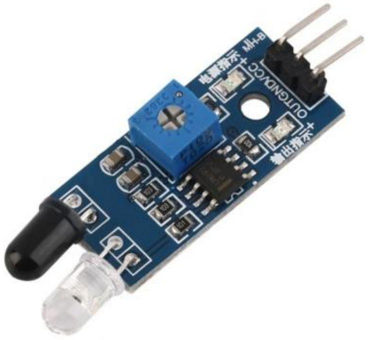


Figure 52: Infrared Sensor (IR) Module [21]

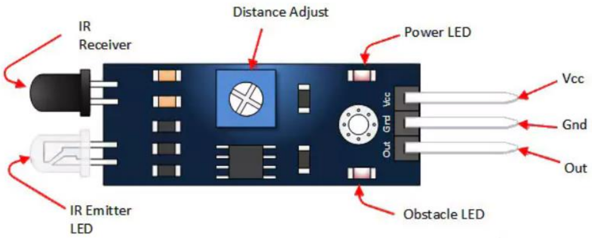


Figure 53: The Pin Arrangement of the IR Sensor [21]

Pin Arrangement

Table XI: Pin Assignment for Infrared Sensor Module [21]

Pin Name	Description
VCC	3.3 to 5V Input
GND	Ground
Out	Output

Working Principle of the IR Sensor Model

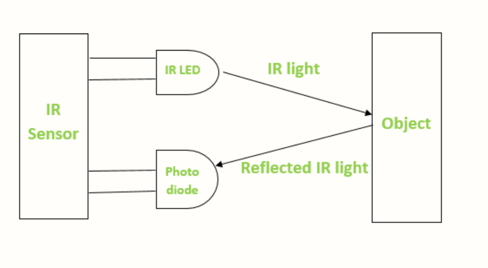


Figure 54: Working Principle of IR Sensor Model [21]

1. Components of an IR Sensor

IR LED (Infrared Light Emitting Diode): This is essentially the source of infrared radiation in most IR sensor setups.
IR Photodiode (Receiver): This acts as the detector, responsible for receiving or detecting the infrared radiation.

2. IR LED

Figure 55: IR LED [21]

An IR LED, while resembling an ordinary LED, emits light in the infrared spectrum. This infrared light is invisible to the human eye. When powered, the IR LED emits this radiation, which can then be directed at a specific object or area.

3. IR Photodiode

Figure 56: IR Photodiode [21]

This is the counterpart to the IR LED. It's specifically designed to detect infrared radiation. Photodiodes, in general, are semiconductors that generate a voltage or change their electrical resistance when exposed to light. Infrared Photodiodes, however, are tailored to be sensitive only to infrared radiation. They don’t respond to visible light in the way standard photodiodes might. When the IR radiation from the LED reaches a target, it reflects off it. The IR photodiode then detects this reflected radiation.

4. Operational Principle

When the IR LED emits its radiation, it may strike an object and then get reflected. The degree or intensity of this reflection varies based on the object's color, material, distance, and angle. The IR photodiode detects this reflected radiation. Depending on the intensity of the received radiation, the resistance and output voltage of the photodiode change. The output can then be processed to determine various aspects such as the presence of an object, its distance, or even its relative color (since different colours reflect IR differently).

5. Matching Wavelengths

It’s crucial that the wavelengths of both the transmitter (IR LED) and the receiver (IR Photodiode) match. This ensures optimal sensitivity and performance. For example, if an IR LED emits at a specific wavelength, the photodiode should be particularly sensitive to that same wavelength to ensure maximum detection capability.

Infrared Sensor Module Circuit Diagram

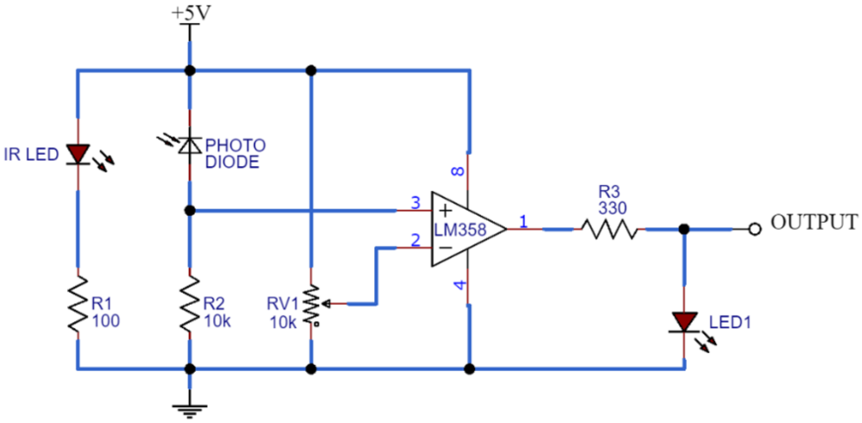


Figure 57: IR Sensor Module Circuit Diagram [22]

Servo Motors (Gripper Arm & Gripper)

There are 2 types of servo motor that we are using which is the SG90S motor and the MG996R servo motor. We are using the SG90S servo motor for the puck gripper and the MG996R servo motor for the arm of the gripper.

Working Principle of the Servo Motor

Figure 58: SG50 Servo Motor [23]

Servo Motor Pin Arrangement

Table XII: Pin Assignment for Servo Motor [23]

Wire Colour	Description
Brown	Ground Wire Connected to the Ground of the System
Red	Powers the Motor (Typically +5V)
Orange	PWM Signal

Working Principle of Servo Motor

A servo motor is designed to rotate and position its shaft at specific angles based on the input it receives. The foundational mechanism behind a servo motor's operation hinges on a simple but effective control system: the Pulse Width Modulation (PWM) signal.

1. Connection and Powering

The servo motor typically has three wires:
Red Wire: This provides power, usually +5V.
Brown/Black Wire: This is the ground connection.
Orange/Yellow/White Wire: This wire carries the PWM signal, which commands the servo to move to a particular position.

2. Controlling the Servo

The servo's movement is governed by the PWM signal sent to its control wire. This PWM signal dictates two things: its frequency and its duty cycle (or the duration for which it's high during each cycle).

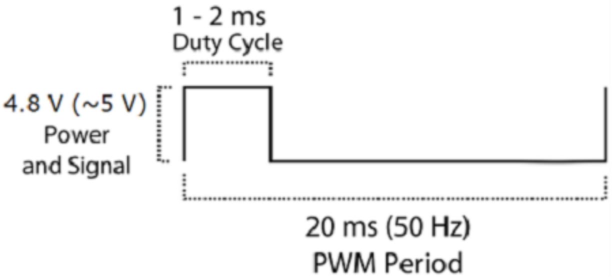


Figure 59: PWM Control of a Servo Motor [23]

3. Interpreting PWM for Position

The PWM signal's frequency is 50Hz, translating to a 20ms period.
The 'on' duration or pulse width of the PWM signal within this 20ms period determines the servo's position:
i) 1ms Pulse Width: The servo positions itself at 0°.
ii) 1.5ms Pulse Width: The servo is at its midpoint, usually 90°.
iii) 2ms Pulse Width: The servo turns to its maximum position, often 180°.

By varying the PWM pulse width between 1ms and 2ms, you can achieve precise control, positioning the servo motor anywhere between 0° to 180°.

4. Commanding the Servo

Various electronic components can generate the necessary PWM signals. This includes dedicated ICs like the 555 Timer or microcontroller platforms like Arduino, PIC, and ARM. When the PWM signal is fed to the servo's control wire, the internal circuitry and mechanics of the servo translate this signal into a specific position of the motor's shaft.

In summary, a servo motor moves based on the pulse width of the incoming PWM signal. This allows for precise control over the position of the motor's shaft, making servo motors indispensable in numerous robotic and control applications.

SG90S Circuit Diagram

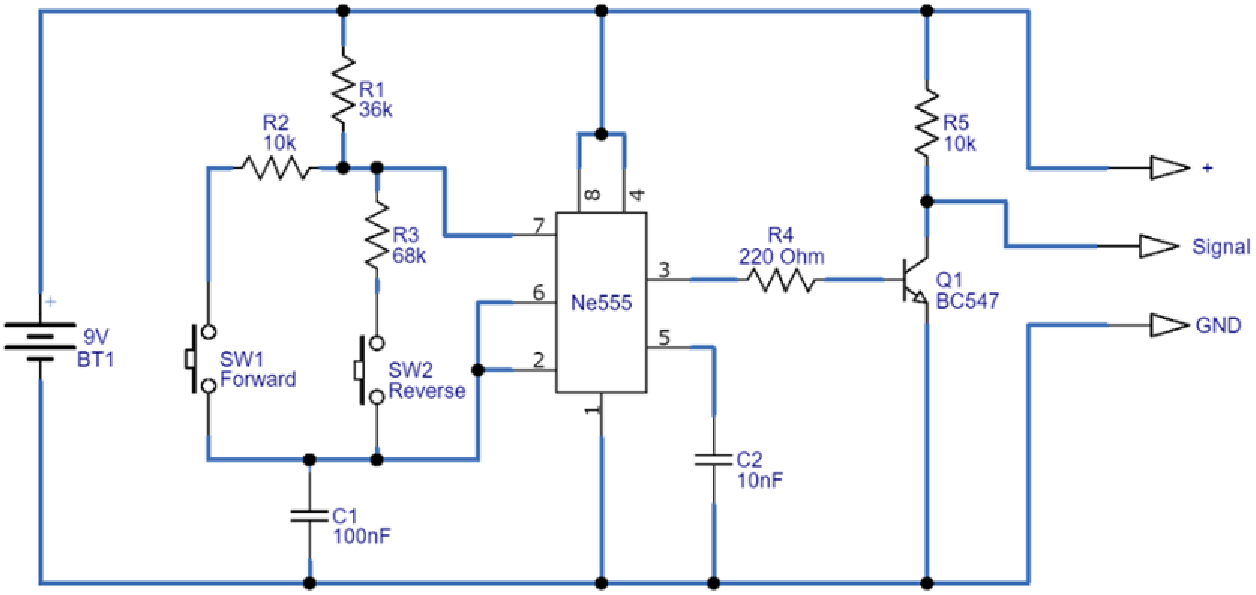


Figure 60: Circuit Diagram for SG90 Servo Motor [24]

MG996R Servo Motor

Figure 61: MG996R Servo Motor [25]

Pin Arrangement for the Servo Motor

Table XIII: Pin Arrangement for MG996R Servo Motor [25]

Wire Colour	Description
Brown	Ground Wire Connected to the Ground of the System
Red	Powers the motor (Typically +5V)
Orange	PWM Signal

1. Basic Components

Motor: Provides the movement.
Potentiometer (Position Sensor): Detects the motor's current position.
Control Circuit: Processes the input (desired position) and compares it with the potentiometer's value (current position) to drive the motor in the correct direction and by the right amount.
Gear System: Amplifies the motor's torque and gives precise control over its position. The MG996R, for instance, has metal gears for increased durability.

2. Pulse Width Modulation (PWM)

The MG996R, like many RC servos, operates based on PWM signals. This means it determines its position based on the duration (width) of a pulse in the input signal. A typical servo recognizes a pulse width of about 1 millisecond as its extreme counterclockwise position, a pulse width of about 1.5 milliseconds as its centre position, and a pulse width of about 2 milliseconds as its extreme clockwise position. The MG996R moves between 0 and 180 degrees based on the duty cycle of the PWM wave.

3. Feedback Loop

As the servo motor turns, the potentiometer's resistance changes, which in turn adjusts the control circuit's voltage. When the voltage reaches a specific value (corresponding to the desired position), the control circuit stops the motor.

4. Torque

The torque of a servo motor like the MG996R refers to the force exerted by the motor to move an object. The MG996R has a maximum stall torque of 11 kg/cm, meaning it can handle a force of up to 11 kilograms at a radial distance of 1 cm from the motor's axis before stalling (or stopping due to overload).

5. Operation

When a PWM signal is sent to the servo with a specific duty cycle (pulse width), the control circuit compares the desired position (from the PWM) to the current position (from the potentiometer).

If there's a difference, the control circuit drives the motor in the needed direction until the potentiometer's value matches the desired position. This constant comparison and adjustment create a feedback loop, allowing the servo to maintain its position even when external forces try to move it.

In essence, the MG996R, like other servo motors, uses a feedback loop to provide precise control of its rotational position. The PWM signal dictates where the motor should go, and the potentiometer provides feedback on where the motor currently is, with the control circuit making the necessary adjustments.

3.2 Integration of Electronic Circuit towards Solving the Problem Statement

To address the intricate engineering challenge in the project, a holistic integration of various electronic components was adopted, resulting in a robot that can seamlessly navigate, detect, and interact with its environment.

1. User Communication

Enhancing the robot's interactivity is its Bluetooth Communications Module (HC-05). This vital component bridges the gap between user intent and robotic action, allowing directives to be sent from an Android phone using the Serial Bluetooth Terminal Application, ensuring the robot remains in perfect alignment with user objectives.

2. Robot Locomotion

At the heart of the robot's movement mechanism is the PSoC microcontroller, which dictates speed by modulating the PWM duty cycle directed at the motor driver's Enable pins. Simultaneously, motor directions are influenced using digital logic to actuate the driver's direction pins. This harmonized orchestration is then channelled through a transfer plate to the DC motor and shaft encoder, ensuring precise and intentional movement within the arena. Importantly, to keep tabs on its trajectory, signals from the shaft encoders (phase A and B) are interpreted by the microcontroller, furnishing critical motion data.

3. Obstacle Management

For real-time obstacle navigation, the robot employs multiple ultrasonic modules (US-015). Triggered periodically by the PSoC, this module dispatches ultrasonic waves and awaits their reflection. These reflected signals, transformed into square pulses, carry information about proximate obstacles. A crucial metric – the distance to the obstacle – is derived from these pulses. In scenarios where this distance drops below a certain preset threshold, the robot will wisely pause its movement, moving on to the next path with the smart backtracking algorithm that has been implemented.

4. Puck Detection

Key to the robot's interaction mechanism is the IR sensor. Continuously sending out IR waves, it monitors the intensity of reflections. A significant reflection – indicating a puck's presence – compels the sensor to signal a halt in the robot's movement, pivoting its attention to the impending color-sensing phase.

5. Color Sensing

Upon detecting a puck in which the IR Sensor is triggered, the color sensor (TCS3200 Color Sensor) will jump into action. Activated by the PSoC, it throws light on the puck while sequentially cycling through color filters. As light reflects, it's translated into frequency pulses, which are then counted and analyzed. This data-rich feedback loop allows for the precise discernment of the puck's color.

6. Puck Handling

Once the robot identifies a target puck, its intricate gripping mechanism, orchestrated by the servo motors (MG996R and MG90S), springs to life. By fine-tuning the PWMs values feeding the two gripper servos (gripper arm and gripper itself), the robot can dexterously handle pucks - from the delicate act of reaching out to them, to adjusting its grip for secure handling.

7. Pin Detection

Central to the robot's navigation and interaction within the arena is the ability to detect pins, which denote specific zones. For this essential task, the Ultrasonic Sensor Module (USM) is employed. As the robot traverses the environment, the USM continuously emits ultrasonic waves. Upon encountering a pin, these waves are reflected back to the sensor. By measuring the time taken for the ultrasonic waves to return, the distance to the pin is accurately calculated. This distance, when matched with predefined thresholds, enables the robot to determine the color zone associated with the pin. This information is vital as it dictates subsequent robot actions, ensuring accurate and efficient completion of its tasks within the arena.

In this restructured approach, the integration and flow of each component are clearly articulated, ensuring a comprehensive understanding of the robot's electronics integration to meet the project's complex engineering challenges.

3.3 Alternatives Considered for Sensors and Actuators

1. SR-04 USM vs. US-015 USM: Ultrasonic Sensors

Specifications Comparison

Figure 62: Comparison of US-015 and SR-04 [26]

Table XIV: Comparison of US-015 and SR-04 USM [26]

Specifications	**US-015 Ultrasonic Sensors**	**SR-04 Ultrasonic Sensors**
Resolution	0.5 mm	0.3 cm
Ranging Function	2cm to 400 cm	2cm to 400cm
Detection Angle	Less than 15 degrees	15 degrees
Detecting Precision	0.1cm / 1%	1%
Size	45mm*20mm*12mm	45mm*20mm*15mm

Based on the specifications above, there is clear advantage of using the US-015 Ultrasonic Sensors compared with the SR-04 Ultrasonic Sensors.

1. Resolution

The US-015 has a finer resolution of 0.5 mm compared to the SR-04's 0.3 cm. This implies that the US-015 can detect changes in distance with greater precision. For applications where minute changes in distance matter, the US-015 would be preferable.

2. Detection Angle

The US-015 has a slightly narrower detection angle (less than 15 degrees) compared to the SR-04's 15 degrees. A narrower detection angle can be advantageous in scenarios where you need to avoid unwanted reflections or reduce the likelihood of sensing unintended objects, especially in cluttered environments.

3. Detecting Precision

While both sensors have a 1% precision, the US-015 specifies an additional precision measure of 0.1 cm. This might indicate a better performance in certain conditions.

4. Size

The US-015 is slightly slimmer in one dimension (12mm vs. 15mm). Depending on the design constraints of your robot or project, this smaller size could be advantageous for tighter spaces or sleeker designs.

Conclusion

Choosing the US-015 Ultrasonic Sensor over the SR-04 would be primarily motivated by its superior resolution and slightly narrower detection angle. The enhanced resolution provides more accurate and refined distance measurements, which could be crucial in specific applications. Additionally, its smaller form factor can be beneficial for design considerations.

2. Servo Motors: MG996R vs. MG90S vs. SG90S

Figure 63: Comparison of MG996R Servo Motor, MG90S Servo Motor and SG90S Servo Motor [27]

Table XV: Specifications of MG996R, MG90S and SG90S Servo Motors [27]

Specifications	**MG996R**	**MG90S**	**SG90S**
Torque	(9.4 - 11)kg/cm	(1.8 – 2.2) kg/cm	2.5 kg/cm
Weight	55 grams	13.4 grams	9 grams
Operating Voltage	4.8 – 6 V DC	4.8V – 6 V DC	5 V DC
Speed	(0.2 – 0.16)sec/60 degrees	0.1s/60 degree	0.1s/60 degree

Based on the specifications above, there is clear advantage of using the MG996R for the Gripper Arm and SG90S for the gripper itself.

1. MG996R
Torque: It has the highest torque among the three, ranging between 9.4 to 11 kg/cm. This means that it can handle heavier loads and exert a greater force.
Weight: It is the heaviest servo, weighing 55 grams. While this can be seen as a disadvantage in terms of overall robot weight, it can also be indicative of more robust internal components that can handle the increased torque.
Operating Voltage: Compatible with a range from 4.8 to 6 V DC, offering flexibility in power source selection.
Speed: Its speed, measured as time taken to rotate 60 degrees, is slightly slower than the other two.

2. MG90S
Torque: The torque is significantly less than the MG996R but higher than the SG90S, falling between 1.8 to 2.2 kg/cm.
Weight: This servo is much lighter than the MG996R at 13.4 grams. This suggests it may not have as robust components as the MG996R, but it's ideal for applications requiring less weight.
Operating Voltage and Speed: Has a similar range to the MG996R in terms of operating voltage and boasts a fast rotation speed of 0.1s/60 degrees.

Given the specifications stated above:

Gripper Arm
The arm of a gripper is responsible for movements that require significant strength, especially if it's lifting objects. The MG996R with its higher torque is better suited for this task. The higher torque ensures the gripper arm can lift and manoeuvre objects without stalling or straining the motor. Its weight, indicative of sturdier construction, can also support the stress and wear and tear of repeated lifting and moving.

Gripper Itself

The actual gripping mechanism requires precision rather than brute strength. The MG90S, with its lighter weight and reasonably high torque, is apt for this role. It's fast, ensuring the gripper can quickly grip or release objects. Its torque is sufficient for holding objects securely but without the excess force that could damage them. Additionally, its lighter weight won't add unnecessary strain to the gripper arm.

In conclusion, for applications like a gripper arm and gripper, the choice of the MG996R for the arm and the MG90S for the gripper mechanism makes sense, optimizing the robot's performance while ensuring durability and efficiency.

3. TCS3200 vs. TCS34725: Color Sensor Modules

Figure 64: Comparison of TCS3200 Color Sensor and TCS34725 Color Sensor [28]

Table XVI: Specifications of TCS3200 Color Sensor and TCS34725 Color Sensor [28]

Specifications	**TCS3200**	**TCS34725**
Supply Voltage	2.7 V – 5.5 V	3.3 V – 3.8 V
Color Sensor Channels	RGBC	RGBC
IR Blocking Filters	Yes	Yes
High- Resolution Conversion of Light Intensity to Frequency	Yes	Yes
Communication	PWM	I²C Interface

Based on the specifications above, there is clear advantage of using the TCS3200 Color Sensor as compared to using TCS34725 Color Sensor.

1. Supply Voltage
TCS3200: This module offers a broader range of supply voltage from 2.7 V up to 5.5 V. This flexibility can be beneficial when integrating with other systems or components that might have varied voltage requirements.

TCS34725: This module's range is more restrictive, as it operates between 3.3 V and 3.8 V. This limited range might require more precise voltage regulation, depending on the overall system design.

2. Color Sensor Channels
Both sensors have RGBC (Red, Green, Blue, Clear) channels, so there's no differentiation in terms of color sensing capabilities based on this specification.

3. IR Blocking Filters
Both sensors come with IR blocking filters. This ensures that infrared light doesn't interfere with the visible light measurements, improving the accuracy of color readings.

4. Familiarity and Curriculum Support
Familiarity plays a significant role. The TCS3200 is what's taught and supported by the lecturers which provides a clear advantage. This means better support in terms of troubleshooting, availability of resources and a smoother learning curve. The TCS3200 color sensor also integrates much more easily with the overall system of the robot itself.

Conclusion
Given the information provided and the additional factor of curriculum support, the TCS3200 seems like the logical choice the project. Its broader supply voltage range offers more flexibility, and its teaching by lecturers indicates a strong foundation of resources and knowledge to tap into.

3.4 Power Management

The power management of the robot has been meticulously designed to ensure optimal power consumption without compromising the robot's performance.

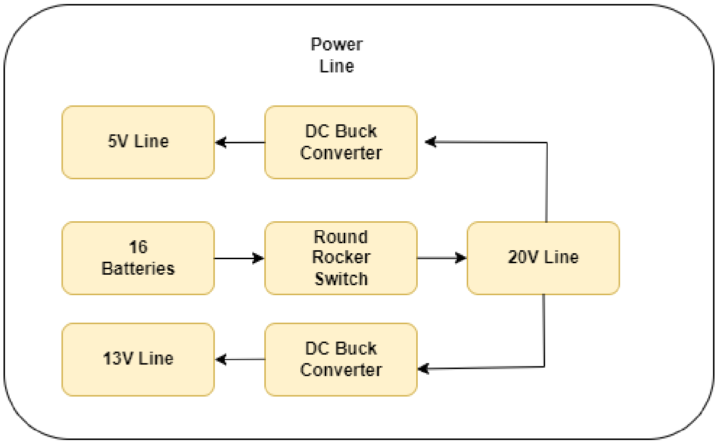


Figure 65: Block Diagram of Power Line of Robot

Starting with a 20V supply, the voltage is converted to a safe operating level of 5V for most of the robot's sensors and actuators using a DC Buck Convertor and 13V for the L298N Motor using another DC Buck Converter.

Power Supply

Batteries

We used Beston Rechargeable Ni-MH batteries for the robot's power supply, boasting a capacity of approximately 1300mAh. The batteries' used is shown in the figure below.

Figure 66: Beston Ni-MH Rechargeable Battery [29]

Our measurements consistently showed a supply voltage range of 20V, emphasizing the consistency and reliability of the batteries. The choice of rechargeable batteries proved economical, supporting continuous testing without additional costs.

Buck Converters

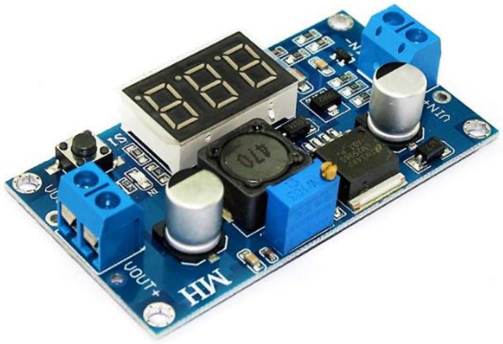


Figure 67: DC Buck Converter [30]

The Buck Converter that we have used is the LM2596 DC-DC Buck Converters.
A buck converter is a DC-DC power converter which steps down voltage (while potentially stepping up current) from its input (supply) to its output (load). The key components in a buck converter include a switch (usually a transistor), a diode, an inductor, and a capacitor.

DC Buck Converter

This module efficiently steps down voltage with minimal power loss, thanks to its well-designed functional block diagram depicted in the figure below.

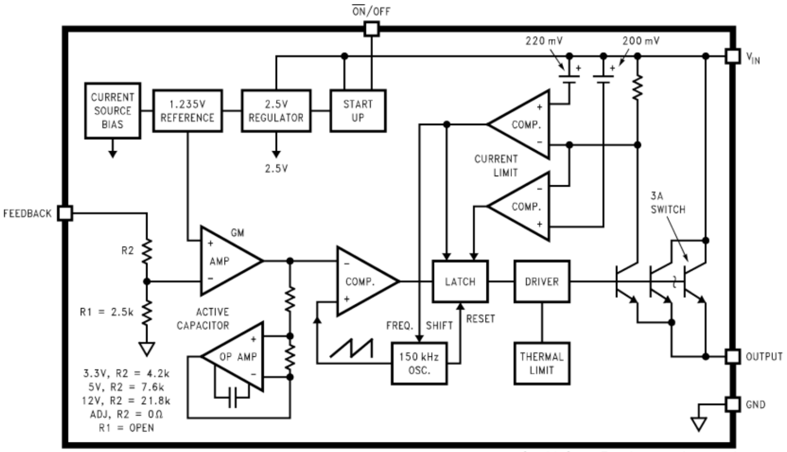


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Figure 68: DC Buck Converter Schematics [31]

The built-in potentiometer ensures customizable output, allowing us to obtain the precise voltage levels required by various components.

Power Consumption

Empirical testing revealed the robot's power consumption patterns:
Idle: 0.11A
Motor Actuation/Puck Detection: 0.25A
Gripper Engagement: Peaks at 0.4A, especially when gripping a puck.

The substantial current draw during gripping results from the servos' stress when trying to maintain their position, evident in both the metal and plastic gear servos.

Power Conservation Strategies

The design and operational strategies were employed to curtail excessive power use in 6 main parts of the robot:

1. Motors

The robot has been programmed to be optimized and precise in its movement using a smart backtracking algorithm. Instead of taking a longer and tedious path which will consume a lot of energy, the robot will take 5 main straightforward paths as outlined in the smart backtracking method section of the report. To conserve more power, the gear of the robot’s wheel has been constantly lubricated to reduce friction.

2. IR Sensors

The robot's software ensures that once a correct color of puck is detected, the sensors will remain inactive until the puck's release, conserving energy for the robot.

3. Color Sensors

LEDs on the color sensor, which demand more power, are only activated when detecting a puck which is triggered by the IR Sensors.

4. Servo Motor

A structural modification to the gripper allows for power conservation. Once the puck is gripped and retracted upwards, the gripper's PWM signal is deactivated (in code) and the puck rests on a covering, reducing continuous power use.

5. Robot Structure

The use of corrugated sheets for protection serves a dual purpose in power conservation: Corrugated sheets, by nature, are lightweight yet robust. By fitting the robot with such sheets, you ensure minimal addition to its overall weight. A lighter robot requires less energy to move, thus consuming less power during its operations and it also provides protection against external harm which means fewer instances of damage. A robot that runs without frequently needing repairs or adjustments is more energy-efficient, as interruptions and restarts can consume additional power.

6. Extended Lever as Flicker

This flicker is realised by adding a small lever to the gripper mechanism. Hence, this gripper-flicker component of ours provides unified control in a shared interface. When compared to other flicking options explored such as solenoid flicker, pinball flicker, rack and pinion flicker which all needed an independent electric supply to power the mechanism, this lever does not need any dedicated power source but can flick the pin down. With the smart and strategic flicker placement ergonomics, the power usage has been drastically reduced, effectively enhancing power conservation.

Very few screws have also been used which means a reduction in the robot's overall weight. Even if screws might seem small individually, collectively, they can add a considerable amount of weight. A lightweight robot can move more efficiently, ensuring less power consumption. The robot is also designed with simplicity in mind which means the robot tends to have fewer components. Fewer components can lead to reduced weight, less complex movements or operations and less that can go wrong which in turn requires less power and fewer stops, starts and adjustments, all of which can be power intensive.

In essence, by integrating these design choices, the robot's power management strategy prioritizes efficient movement and operation. Every decision, from the materials used to the overall design, contributes to a robot that can do more with less, ultimately saving power and extending its operational time.

4. Software Design

In the realm of robotics, while the hardware forms the body, it is the software that truly breathes life into it. Software stands as the fulcrum that transforms a collection of mechanical and electronic components into a dynamic, autonomous entity. It's the software that empowers our robot to interpret its surroundings, make informed decisions, and actuate its components in a seamless choreography of tasks. Drawing parallels to a sentient being, if the hardware represents the physical senses and limbs, the software would undeniably be the cognitive brain. This brain, intricately designed and refined, ensures the robot can make sense of its sensory inputs, determine the most apt responses, and marshal its hardware capabilities towards fulfilling the project's overarching goals. As we delve deeper into this section, we will unveil the layers of code, algorithms, and logic that form this essential cognitive layer, steering our robot towards autonomous excellence.

4.1 Software Design Organization

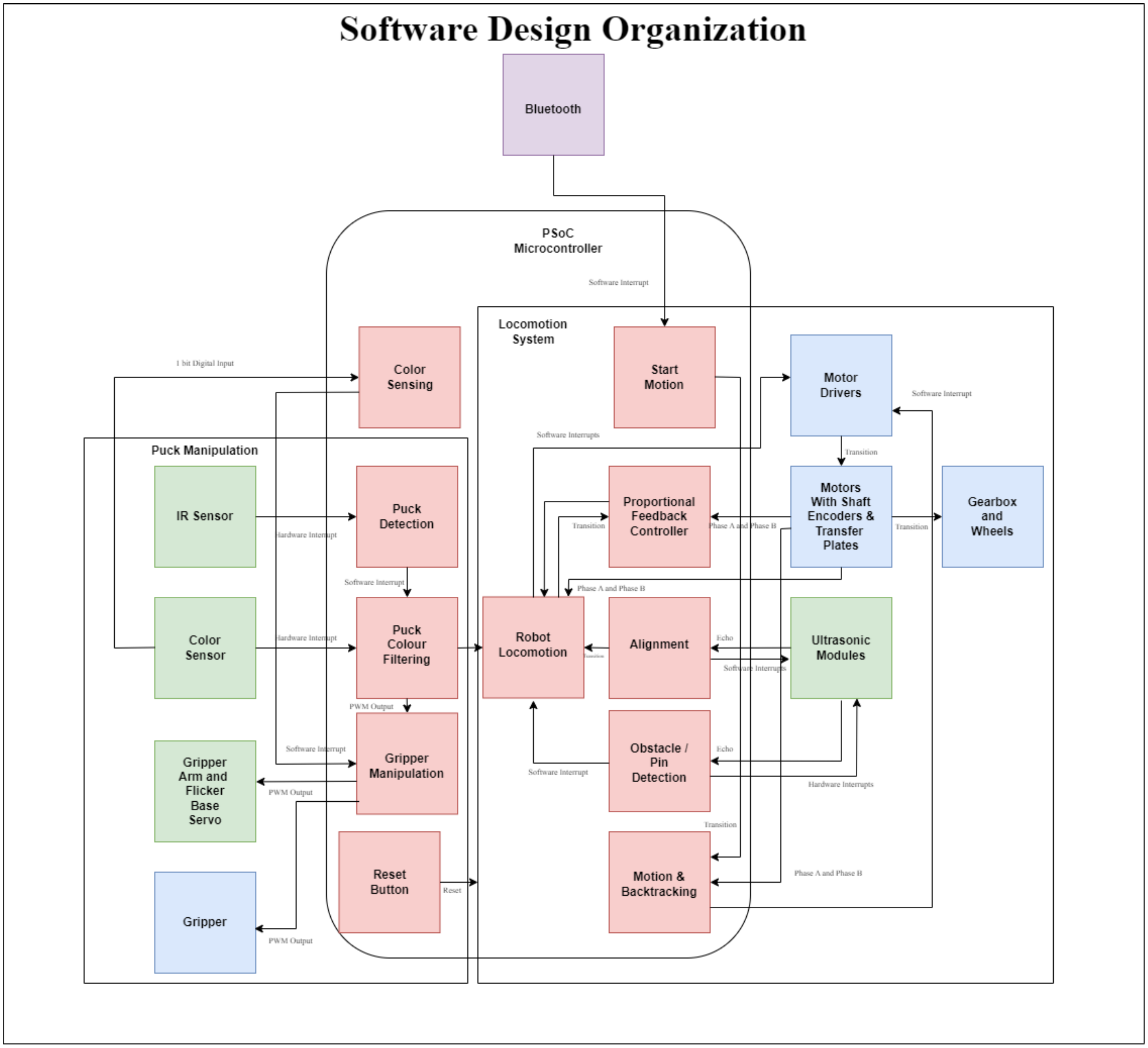


Figure 69: Block Diagram of the Entire Software Design Organization

The essence of a robot lies in its ability to autonomously interact with its environment, respond aptly to external stimuli and carry out tasks seamlessly. The embodiment of this essence is captured within our robot's software design.

Before embarking on its autonomous journey, our robot relies on a series of command messages relayed via Bluetooth using the HC-05 module. Once these initial instructions are received, the robot becomes a self-sustaining unit, navigating the environment without necessitating further user interventions.

Our robot's decision-making process hinges on the Finite State Machine (FSM). This design paradigm, by encapsulating distinct operational states, offers a snapshot of the robot's multifaceted functionalities. With sensor inputs serving as the catalyst, the FSM seamlessly transitions between states, allowing the robot to adeptly adapt to its environment's ever-evolving dynamics.

The robot's locomotion is facilitated by a set of intricately designed algorithms, pivotal for navigation. Foremost among these are the motion algorithms. Each movement state culminates with the robot pausing momentarily, a product of the stop algorithm, before diving into its next move. To maintain consistent motion and ensure directional stability, the robot employs a proportional gain speed controller. The robot's journey, its distance traversed, and its pause-and-proceed manoeuvres are all orchestrated by the shaft encoders. Additionally, the integration of the Ultrasonic Sensor Module plays a dual role: it apprises the robot of its position and sets the stage for obstacle detection.

Navigating a dynamic environment demands acute obstacle detection capabilities. Equipped with Ultrasonic Modules (USMs) on all its four sides, our robot continuously gauges its surroundings. If the frontal USMs detect an imminent obstacle within a set distance, the robot swiftly halts, backtracks and adopts a new path dictated by its smart backtracking algorithm.

Puck detection showcases the seamless marriage of hardware and software within our robot. Encountering a puck result in the microcontroller registering a logic “1”. This detection triggers a cascade of events: an immediate halt in movement, followed by the initiation of the color-sensing routine.

The color discernment process is both systematic and precise. Under the microcontroller's guidance, LED control logic, frequency scaling, and color filter selections are relayed to the color sensor. Each color filter's frequency readings materialize as square pulse inputs fed into a counter. Upon processing all filters, the dominant frequency pinpoints the puck's color.

Should the identified color resonate with preset criteria, the robot seamlessly transitions to the puck gripping phase. A choreographed set of motions ensures the puck is securely gripped. Subsequent steps involve transporting the puck to a designated puck flicking zone and executing a puck flick. The robot's journey culminates as it returns to its base, poised and ready for the next user-command.

In essence, our robot's software architecture is a testament to precision, adaptability, and efficiency, enabling it to effortlessly navigate and interact within its environment.

4.2 Software Algorithms

Bluetooth Receiving Commands Algorithm

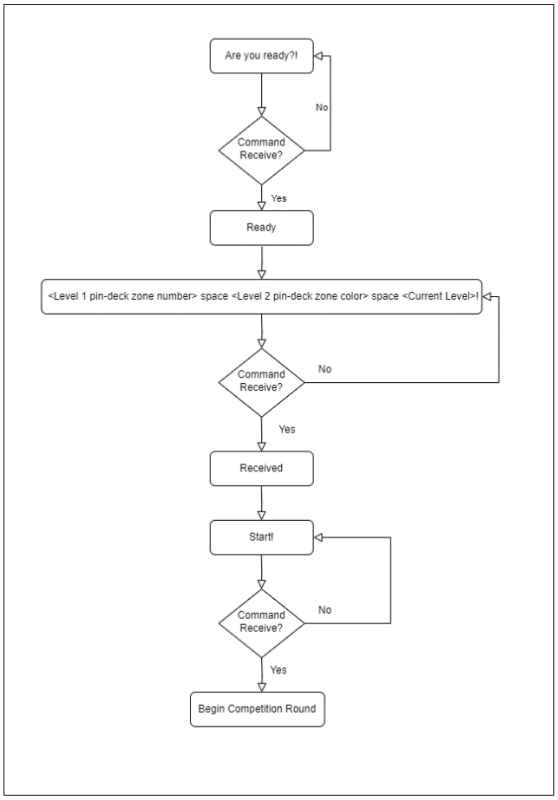


Figure 70: Bluetooth Algorithm Flow Chart

1. Listening Mode
The robot continually listens for incoming Bluetooth messages.

2. Check for Activation
If the robot is in a ready state and no tasks are currently being processed, it checks for specific command messages.

3. Response to Commands
When the robot receives a "Are you ready?" message, it responds with "Ready".
If it receives a "Start" message, it sends an acknowledgment "Okay to Start" and then start the robot movement.

4. Task Processing
Upon receiving a task-related message, the robot parses the information to determine the zone number, zone color, and current level.
Depending on the zone color in the message, it sets a flag to identify the color (red, blue, or green).
After processing the message, the robot sends a "Received" acknowledgment.

5. Resetting for Next Command
After processing a command or task, the robot resets certain variables, preparing to process the next incoming message.

6. Continuous Listening
The robot continually loops back, listening for the next command or task message.
This general overview summarizes the key stages and responses of the robot based on the provided Bluetooth algorithm. The loop will continuously run, always waiting for new commands or data.

Linear Trajectory Algorithm

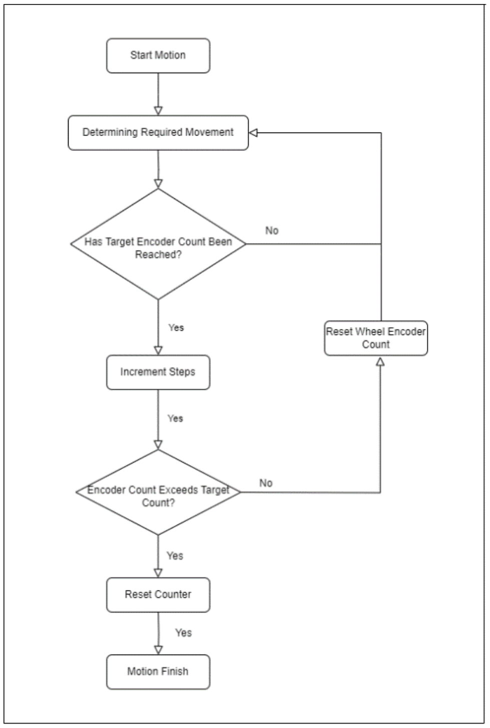


Figure 71: Linear Trajectory Algorithm

1. Initialization
The robot signals the commencement of a linear motion, indicative of its basis in raster scanning. The current shaft counts for both the left and right motors are fetched. This provides a real-time reference for the robot's progression.

2. Determining Required Movement
Using the input values – number of steps for the state, the distance for each step, and the desired direction – the algorithm calculates the target shaft encoder count that the robot aims to achieve for each movement. This target is derived through a formula which translates the required distance into encoder ticks, representing the motion's granularity.

$$Desired\ Tick\ Count = Distance * \frac{Ticks\ Per\ Full\ Wheel\ Cycle}{Distance\ Covered\ Per\ Cycle}$$

3. Evaluate and Execute Movement
Continuously checking the shaft encoder count, the robot evaluates its progress towards the target. Based on the specified direction and distance yet to be covered, it either propels forward or reverses.

4. Path Transition Mechanism
When the target shaft encoder count is reached, the robot increments its steps, resetting the encoder count simultaneously. Upon achieving the specified number of steps, a flag is raised, indicating that the motion is complete. Consequently, the robot transitions to its subsequent motion state.

5. Stopping Condition and Obstacle Handling
If the encoder count exceeds the target, and no obstructions are detected in its vicinity, the robot ceases movement. After halting, the path state undergoes adjustment to guide the robot's next set of actions or the direction of movement. This algorithm establishes a framework allowing the robot to travel with precision over specified distances and in given directions, adapting its actions based on dynamic conditions.

Proportional Control

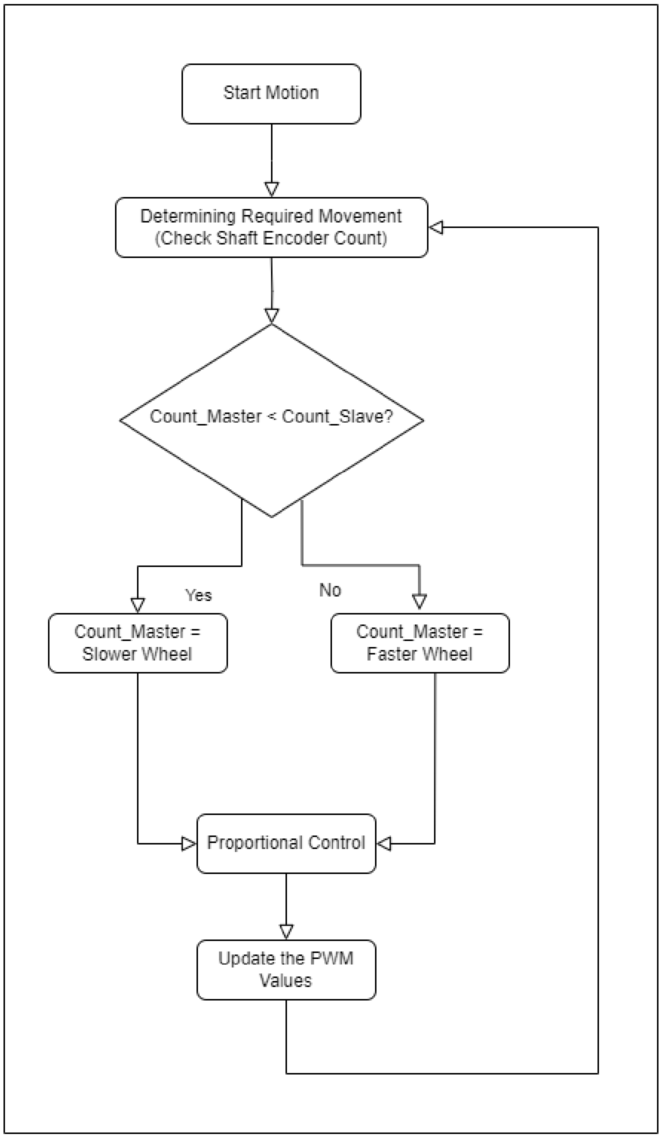


Figure 72: Proportional Control Algorithm

To address discrepancies between the robot's wheels arising from uneven wheel rotations, a proportional controller was employed. Within each control loop, the wheel exhibiting a slower speed, denoted by its shaft encoder count, is designated as the master. The feedback mechanism operates by leveraging the difference between the master and slave shaft encoder counts, dynamically modulating the Pulse Width Modulation (PWM) of the motors. The speed adjustment can be represented by the equation:

$$PWM_{master} = PWM_{slave} - K_p * (Count_{master} - Count_{slave})$$

Within the robot's microcontroller, there's a built-in capacity to discern which wheel is lagging by identifying the wheel with the reduced shaft encoder count. To ensure a consistent application of this control, enabling the robot to maintain a straight trajectory, the proportional adjustment is managed by a separate timer interrupt, distinct from the Motion Shaft Encoder timer.

Rotation Algorithm

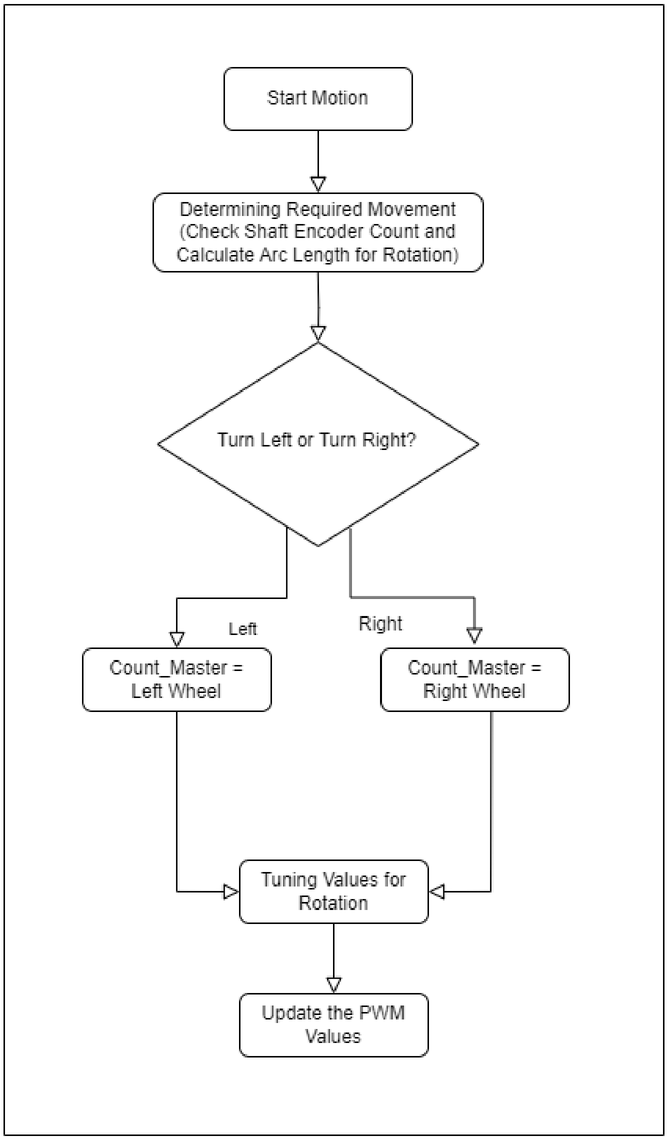


Figure 73: Rotation Algorithm Flowchart

The rotation function is designed to facilitate precise turns of the robot. It takes two primary inputs: the desired angle of rotation and the intended direction of that rotation. Unlike the linear motion function, the rotation function doesn't utilize steps since it typically conducts point turns of 90 degrees at a time.

To achieve this, the algorithm first establishes the current shaft encoder counts for the left and right motors. The robot's radius is factored into the calculations to deduce the arc length the robot needs to traverse for the specified angle of rotation. This arc length is then converted into a target shaft encoder count, which acts as a reference for the rotation.

For the actual rotation, the algorithm checks the shaft encoder counts to determine if the robot has rotated to the required angle. Depending on the specified direction, the robot will either turn left or right. Basically, the algorithm can be summed up into the stated equation below:

$$Desired\ Tick\ Count = Arc\ Length * \frac{Ticks\ Per\ Full\ Wheel\ Cycle}{Distance\ Covered\ Per\ Cycle}$$

Alignment Algorithm

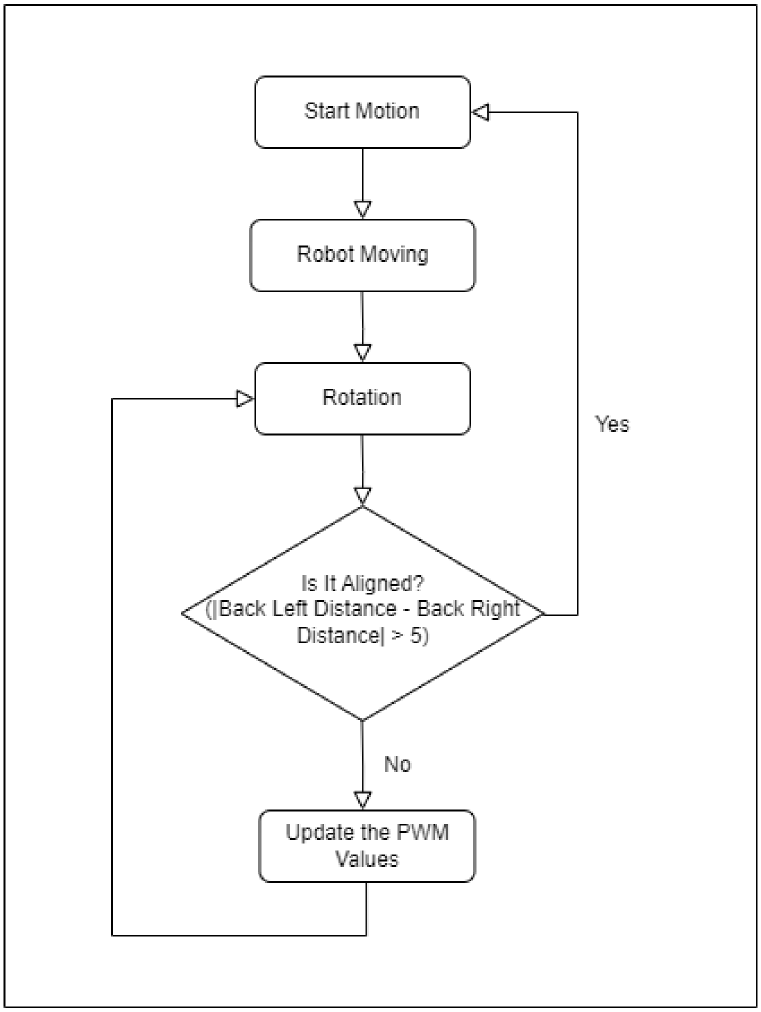


Figure 74: Alignment Algorithm Flowchart

The alignment procedure is intricately woven into the raster scan algorithm, ensuring the robot is perfectly oriented for optimal operation. This alignment process is initiated after the robot completes two 90-degree point turns, positioning it to face the puck collection zone. Instead of using limit switches, as traditionally done, the robot employs ultrasonic sensor modules positioned at the back to ensure precise alignment.

Once entering the alignment phase, the robot begins to reverse. The ultrasonic sensors measure the distances from the back-left and back-right to the arena walls. The differences between these measurements determine the robot's alignment. If the discrepancy between the two measurements surpasses a certain threshold – in this case, 5 units – the robot identifies that it's misaligned. Depending on its current orientation, the robot will make slight left or right adjustments, with brief pauses in between to ensure precision.

After the alignment process, which is confirmed when the distance differences fall within the accepted range, the robot halts. It then progresses to its next operation state, which might involve moving forward or proceeding with another segment of the raster scan, depending on its current state and additional sensors, like the color sensor.

This alignment procedure, in conjunction with the raster scan algorithm, ensures the robot operates seamlessly and efficiently within the arena. A visual representation of this alignment process is provided in the figure.

Smart Raster Scan Algorithm

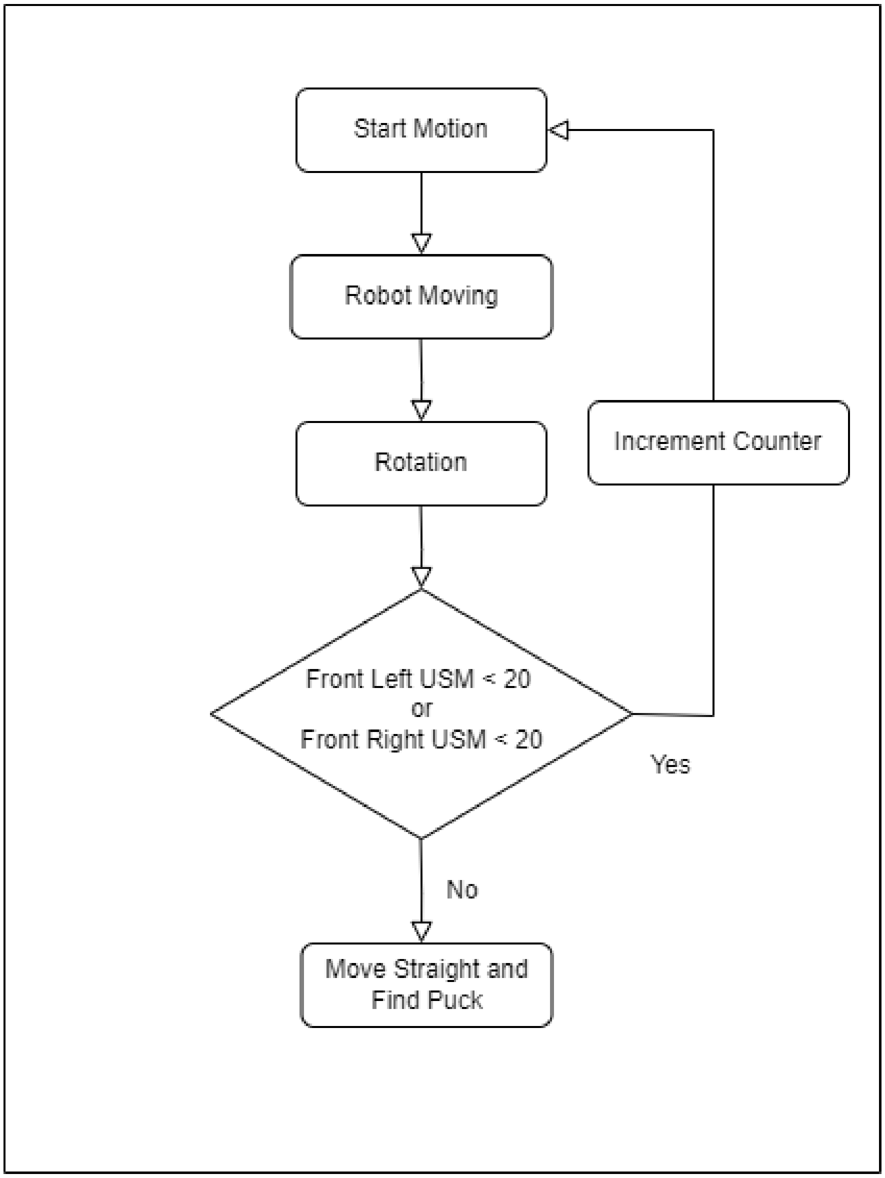


Figure 75: Smart Raster Scan Algorithm Flowchart

The raster scan algorithm employed here deviates from the traditional approach. Instead of navigating the solution space (puck collection zone) using a standard zigzag pattern, we've delineated five specific paths for the robot. This strategy is adopted to enhance the control over the robot's movements, thereby minimizing potential errors. By defining these paths, we can introduce more controlled variables, ensuring a reliable and consistent performance from the robot within its operational environment. The additional heuristics given to the robot will help the robot to avoid exploring paths that will unlikely lead to a solution early in the process of searching the solution space.

Obstacle Detection

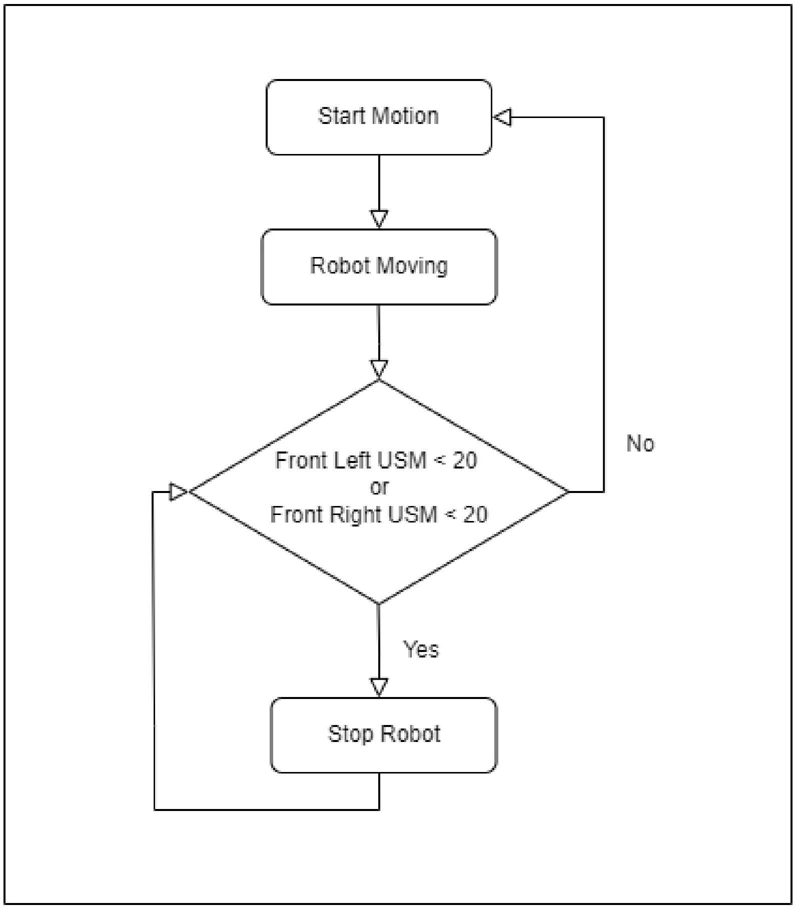


Figure 76: Obstacle Detection Algorithm Flowchart

The primary objective of our obstacle detection algorithm is to safeguard the robot against potential collisions within the arena. This safeguard mechanism is primarily active when the robot is executing its linear movements, either advancing forward or retracing backward, during the raster scan process or while backtracking.

Upon encountering an obstacle, the robot will halt immediately and wait. Despite this halt, certain operational variables such as the shaft count remain unaffected. This intentional design choice ensures that, once the obstruction is cleared or no longer poses a threat, the robot can seamlessly resume its predefined motion.

In situations where an obstacle interrupts the robot's path during its raster scan, the robot adopts an evasive manoeuvre. It halts, then shifts backward out of the said path. Subsequently, an internal counter advances, prompting the robot to transition to the next closest path among the predefined five. This adaptability ensures not only the robot's safety but also the efficient continuation of its tasks, even in dynamic environments.

The proximity to the detected obstacle is gauged through a formula that translates the timer counter value into a measurable distance.

$$distance = \frac{65536 - USM\ Obtained\ Count}{58}$$

where 65536 is the maximum count a 16-bit timer can reach. USM Obtained Count is the reading from the timer when the sensor detects an object. It tells us how long the sound wave took to bounce back from the obstacle and 58 is a number that helps convert the timer's count into a distance in centimetres.

So, we subtract the timer reading from the maximum count to get the time taken for the sound to travel. Then, by dividing by 58, we convert this time into the actual distance in centimetres from the sensor to the obstacle.

The resultant "distance" from this formula is the distance from the sensor to the obstacle.

Puck Detection Algorithm

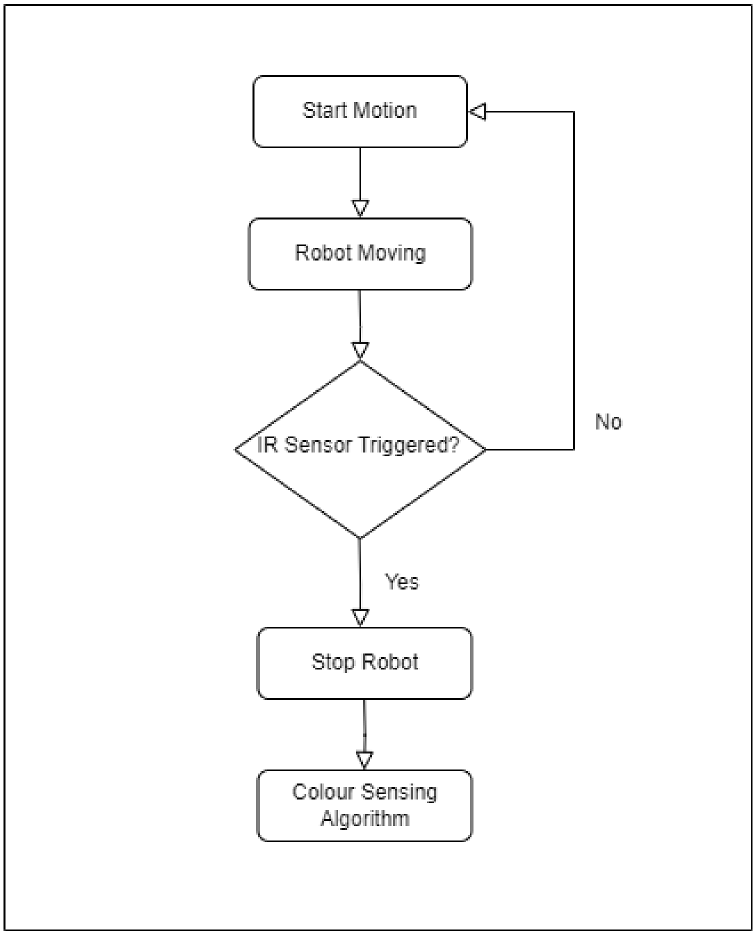


Figure 77: Puck Detection Algorithm Flowchart

The puck identification process is integral for the robot as it navigates the arena. To accomplish this, an IR sensor, positioned under the robot, scans for pucks as the robot moves forward. By manually adjusting a screw on the IR sensor, we set a minimal threshold ensuring it's activated only when an object is directly below the color sensor. Once the IR sensor has been triggered, the color sensor will then be activated.

Color Sensing Algorithm

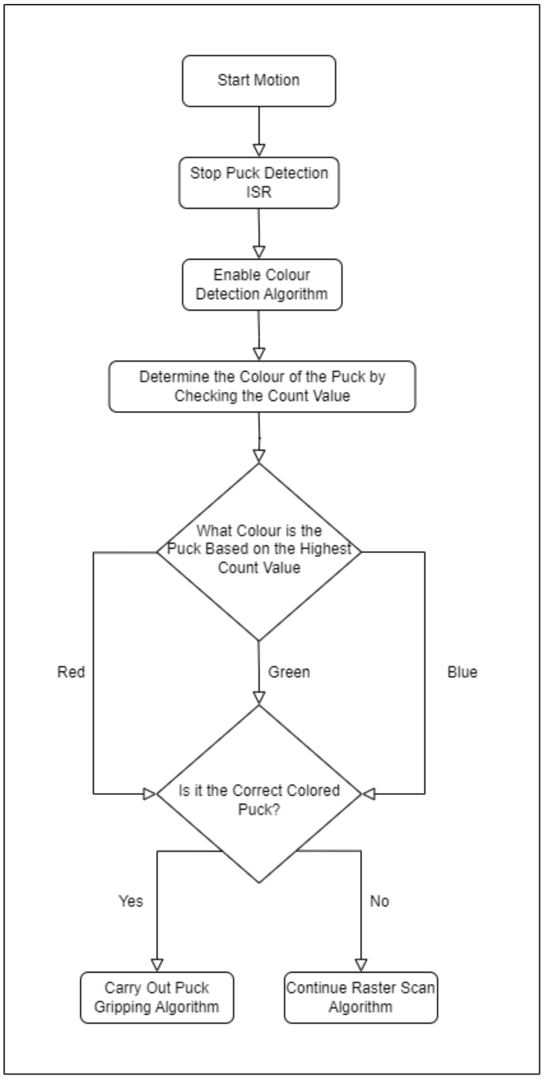


Figure 78: Color Sensing Algorithm Flowchart

After a puck's presence is discerned via the puck detection algorithm, the system delves into the nuances of its color through a meticulously designed color-sensing algorithm. This procedure starts when the robot perceives a puck and immediately commences the color discernment routine.

The primary role of this algorithm is to deploy an Interrupt Service Routine (ISR) for the color sensor, which signals when it is primed to compare colours. Following the trigger, a sequence of actions is initiated: first, the system adapts the frequency scale suitable for color distinction. Sequentially, the algorithm captures color values by cycling through red, green and blue filters, accumulating counts for each color.

Upon acquiring the counts, the algorithm then assesses which color holds the maximum count, effectively determining the puck's color. If the identified color aligns with the robot's search criterion – be it red, green, or blue – the robot shifts its operational mode, prepping it for the subsequent stages, such as puck gripping. If the color doesn't match the sought-after criterion, the robot seamlessly reverts to its scanning phase, disregarding the detected puck. Throughout this process, a real-time feedback loop keeps the user updated on the color detected and the subsequent robot actions, bolstered by the UART's string updates.

Puck Gripping / Releasing and Flicking Algorithm

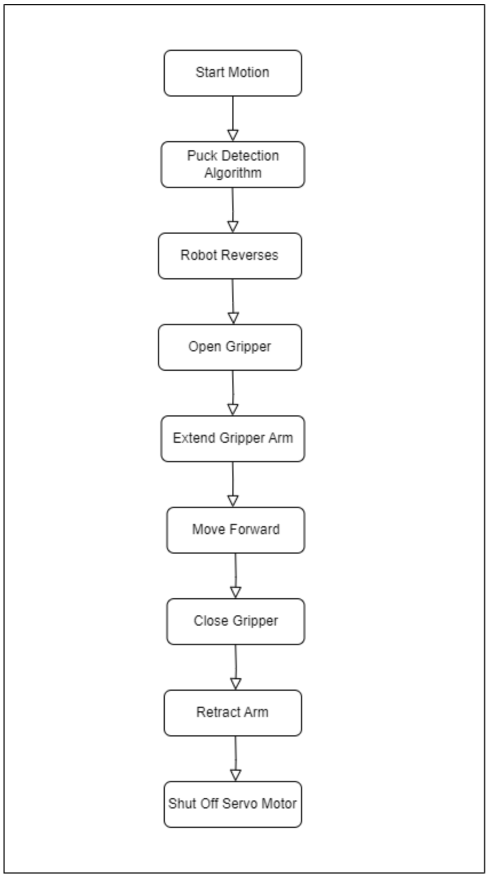


Figure 79: Puck Gripping Algorithm Flowchart

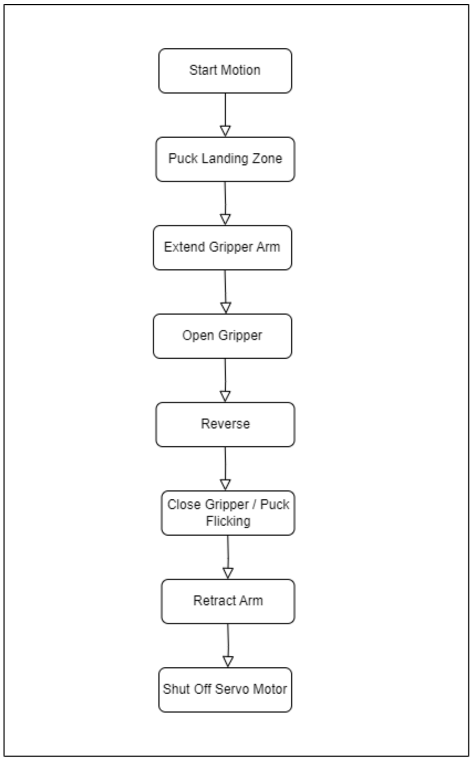


Figure 80: Puck Releasing and Flicking Algorithm Flowchart

Upon successfully identifying the desired puck color, the robot initiates the puck gripping routine. This process is a series of meticulously sequenced actions ensuring the puck's secure grip.

1. Initiating the Gripper State

The robot, after ensuring that the color sensing phase is complete, broadcasts the commencement of the gripper state. A short delay ensures smooth transitioning between operations.

2. Opening the Gripper

The gripping mechanism is activated using the “PWM_GRIPPER_Start()” function. Once active, the gripper is set to an open position, preparing it to hold the puck, by writing a compare value of 130 to the PWM of the gripper.

3. Arm Extension

Simultaneously, the robot's arm is ready. After another short interval, the “PWM_ARM_Start()” function is called. The robot arm then extends forward by setting its PWM compare value to 89, ensuring it is well-positioned above the puck.

4. Positioning over the Puck

A delay ensures the arm reaches its desired extended position. Following this, the robot inches forward for a short duration, ensuring precise placement of the gripper above the puck.

5. Gripping the Puck

After the robot halts, it then proceeds to close the gripper to secure the puck. This is achieved by adjusting the PWM gripper's compare value to 240, effectively clenching the puck.

6. Retracting the Arm with the Puck

Once the puck is securely held, the robot initiates the arm retraction process. The PWM for the arm is set to a compare value of 199, pulling the arm back and ensuring the puck is safely away from the ground.

7. Final Steps

With the puck now safely in its grip, the robot acknowledges its successful grip by setting the “puck_obtained” variable to 1. Additionally, the puck detection is disabled to prevent redundant operations using the “ENA_DIS_puck_detection()” function. The system then prepares for the next course of action by incrementing the “path_state”.

In essence, this algorithm ensures a synchronized and sequenced approach to grip the puck successfully and securely once its desired color is confirmed.

Puck Flicking Algorithm

The puck flicking algorithm governs the robot's actions when it reaches the puck landing zone to effectively release and subsequently flick the puck. The process is straightforward, yet crucial for the robot's task completion. Here's how it operates:

1. Arm Positioning

Upon reaching the puck landing zone, the first action the robot undertakes is to position its arm. The robot's arm is designed to interact directly with the puck, so ensuring it's in the right position is imperative.

2. Puck Release

With its arm correctly positioned, the robot gently drops the puck onto the designated landing zone. The precision of this action is crucial to ensure the puck lands correctly for the subsequent step.

3. Flicking Action

Once the puck is securely in place, the robot initiates its base flicking mechanism. By reversing and closing the gripper, the robot engages this mechanism which then strikes the puck, propelling it forward. This flicking action ensures the puck is moved to its intended final position within the landing zone.

4. Completion

After the flicking process, the robot's arm will be raised from its position, indicating the successful completion of the puck landing task and the servo motor will be turned off.

In summary, the puck flicking algorithm is a concise sequence of actions centred around the robot's arm movement and its base flicking mechanism. Though simple in its steps, its execution is pivotal for the accurate placement and movement of the puck within the landing zone.

Smart Backtracking Algorithm

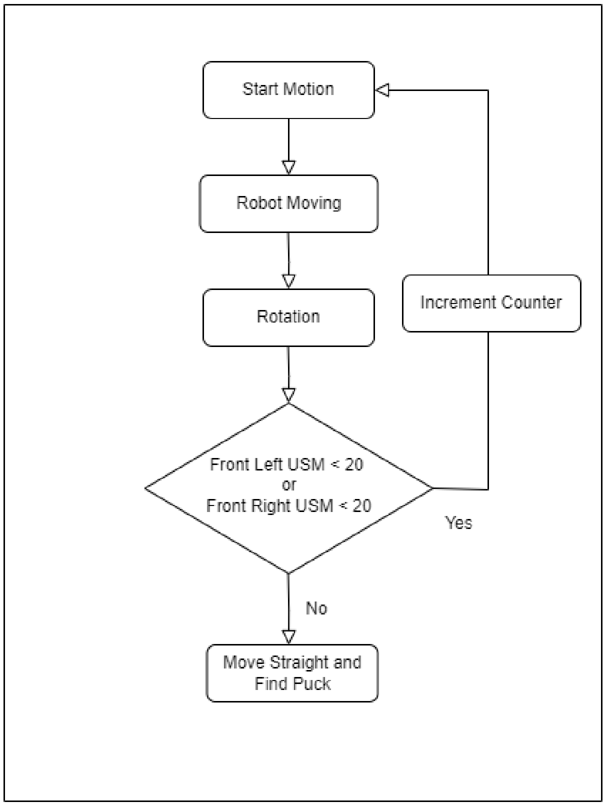


Figure 81: Smart Backtracking Algorithm Flowchart

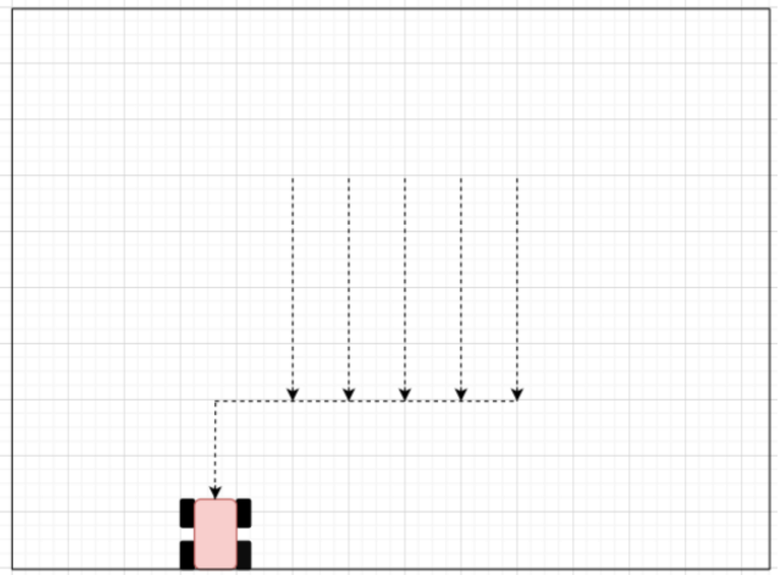


Figure 82: Smart Backtracking Paths

After successfully securing the puck, the robot employs a smart backtracking algorithm to efficiently return to the puck landing zone. This algorithm leverages a counter that keeps track of the current path the robot is navigating. By referencing this counter, the robot can make informed decisions about its optimal return route.

1. Path Reference

The counter serves as a dynamic reference point, indicating the robot's current position within its designated paths. By referencing this counter, the robot can determine which one of the five paths that it is currently in and the most direct route back to the landing zone.

2. Reversing Direction

To initiate the backtracking process, the robot first reverses its direction. This action ensures the robot retraces its steps, moving backward along the same path it used to approach the puck.

3. Point Turn Execution

The robot's initial journey out of the base set certain flags, denoting the turns and manoeuvres it executed. As the robot backtracks, it refers to these flags to determine the exact point turns required to redirect itself toward the puck landing zone.

4. Smart Navigation

The essence of this smart backtracking algorithm lies in its ability to utilize prior navigational data (from the flags set and the counter's value) to avoid redundant or unnecessary manoeuvrers. By doing so, the robot ensures a swift and efficient return, minimizing the time taken to deposit the puck in the puck landing zone.

In summary, the smart backtracking algorithm is a strategic approach that capitalizes on previously recorded navigation data to guide the robot back to the puck landing zone with precision and efficiency.

Pin Detection Algorithm

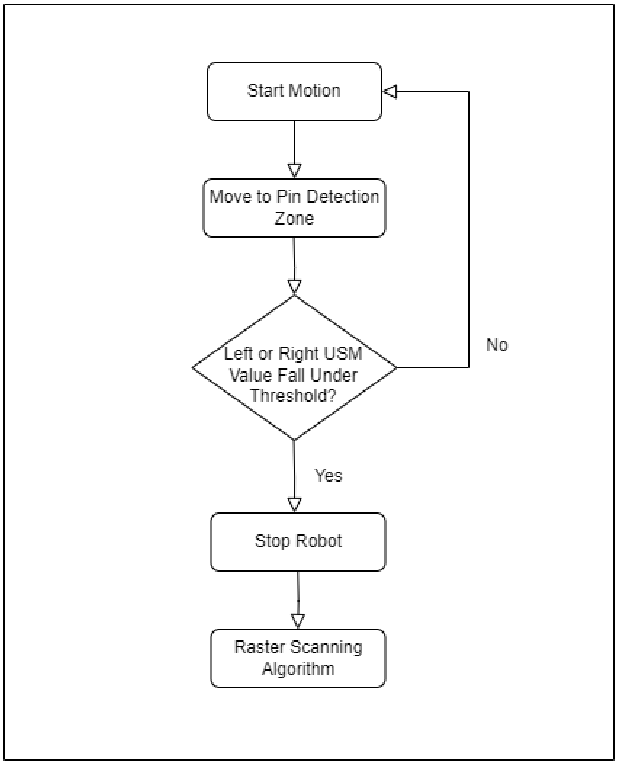


Figure 83: Pin Detection Algorithm Flowchart

The pin detection algorithm is engineered to use ultrasonic sensor modules (USM) to detect the presence of a pin in the robot's vicinity. This process is primarily achieved by monitoring significant changes in the distance readings from the USM. Here's a breakdown of the algorithm:

1. Initial Detection
The algorithm continuously reads the left or right USM values. A significant deviation from the norm, such as a jump from a reading of 40 to a sudden dip of 30, signifies the detection of a pin.

2. Pin Location Determination
Once a pin is identified, its exact location relative to the robot is crucial. This determination is done using the front USM. By gauging the distance of the robot from the wall, the algorithm can pinpoint the pin's precise location.

3. Zone Classification
The area in which the robot operates is segmented into zones, labelled from 1 to 6. These zones are internally represented by counters ranging from 1 to 6. Depending on the distance read by the front USM, the algorithm classifies the detected pin into one of these zones. For instance, if the front USM reads a specific range, it might conclude that the pin is in Zone 3, translating to an internal counter value of 2.

At the culmination of this algorithm, the robot not only identifies the presence of a pin but also discerns its exact location in terms of zones. This zonal information, represented by the counter value, is crucial for subsequent tasks or decisions the robot might undertake. In essence, the pin detection algorithm is a two-tiered process – initial detection using the side USM and precise location determination using the front USM. This layered approach ensures both accuracy and specificity in pin detection tasks.

4.3 Alternatives for Software Design

Conventional Backtracking Algorithm

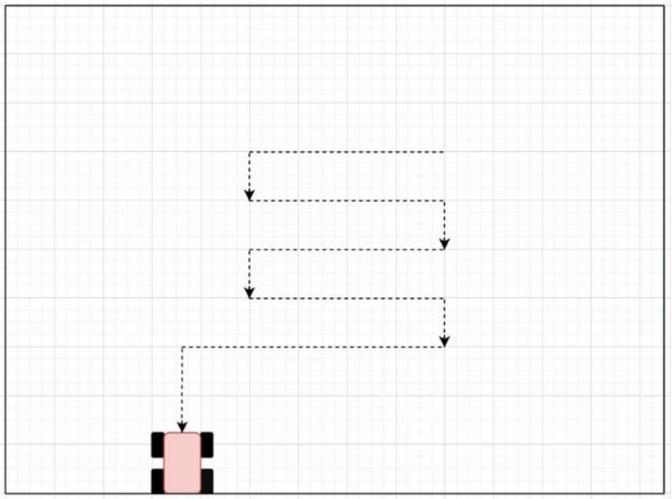


Figure 84: Conventional Backtracking Algorithm

Description

This method employs a linked-list structure to record the robot's path as it navigates the arena during the scanning phase. To backtrack, the robot retraces its steps by following the linked list in reverse order.

Advantages

This approach provides a reliable method for the robot to return to its base. Since it retraces its exact path, the robot can always find its way back, no matter the complexity or length of its initial journey.

Drawbacks

The major limitation is its inefficiency, especially in scenarios where the robot has taken an extended period to locate the desired puck. In such cases, the linked list becomes significantly long, causing the robot to spend a disproportionate amount of time merely retracing its steps.

In summary, while the conventional backtracking algorithm offers assured reliability in guiding the robot back to its base, its lack of efficiency in longer routes can be its Achilles heel. The smart backtracking algorithm presents a more efficient alternative while still maintaining its step, allowing it to be able to backtrack to its original position.

Localization of the Robot

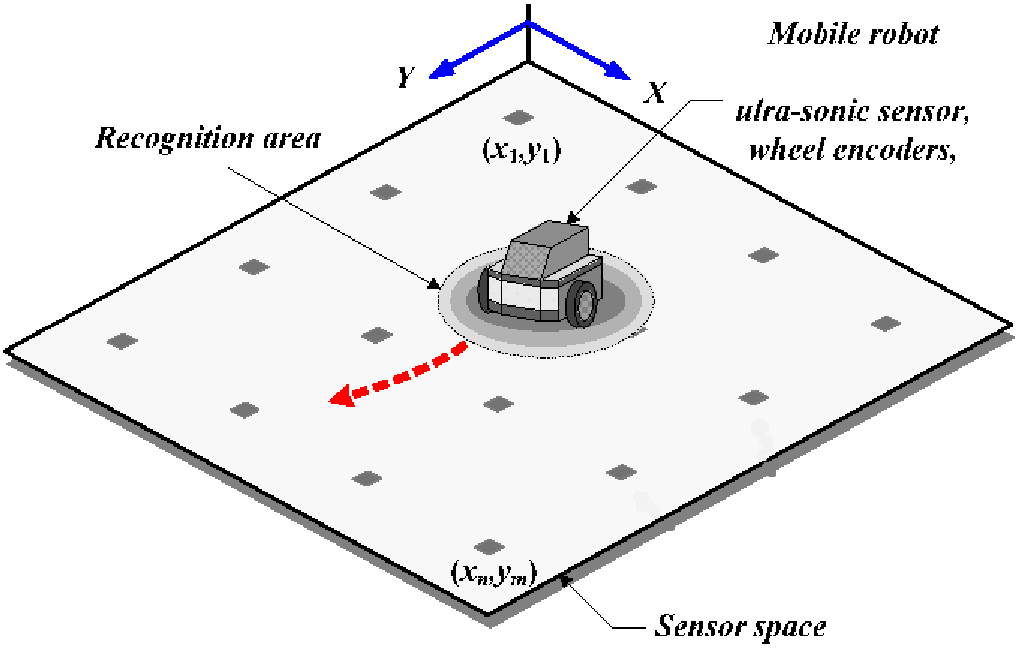


Figure 85: Localization of the Robot [32]

1. Hard Coded Navigation

Description

This method is based on pre-specifying the distances and headings that the robot should adhere to while navigating. By strictly defining these parameters, the robot has a clear-cut path to follow.

Advantages

Simplified Implementation: Hard coding the navigation is straightforward, making it relatively easy to put into action.
Ease of Testing & Debugging: Since the robot's path is pre-defined, identifying and rectifying errors becomes a more streamlined process.
Memory Efficiency: This approach demands significantly less memory compared to more complex algorithms like the navigation stack.

Drawbacks

The primary limitation stems from the unpredictability of the environment. Given that puck positions can change randomly, it's challenging to predefine how far or in what direction the robot should move. Hard coding lacks the flexibility to adapt to dynamic environments.

To summarize, while hard-coded navigation offers a straightforward solution with lower computational demands, its lack of adaptability can be a major constraint in dynamic environments.

Behaviour Tree (BT)

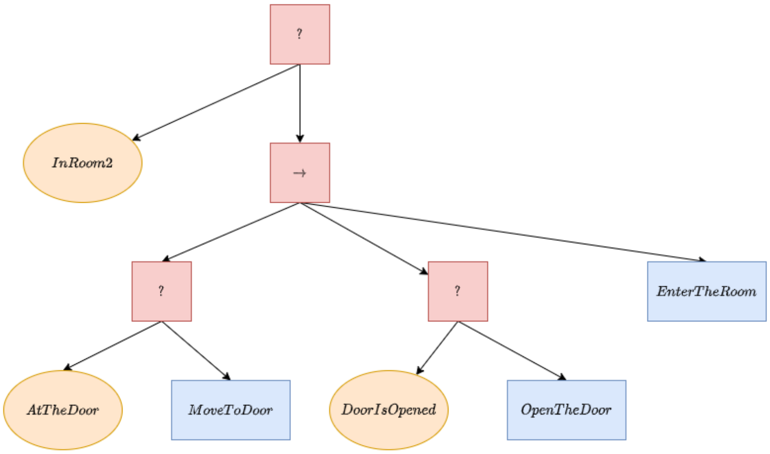


Figure 86: Behaviour Tree Example [33]

Description

A Behaviour Tree (BT) is a graphical modelling language primarily used in game development and robotics for building complex, hierarchically organized sets of tasks. BTs can be thought of as an upgrade from Finite State Machines, providing a more intuitive, modular, and scalable way to design logic.

Behaviour Trees decompose robot behaviour into tasks or "nodes". These nodes can be actions (doing something), conditions (checking something), or composites (which organize and determine the order in which children are executed). This hierarchical and modular structure makes BTs especially versatile and reusable.

Advantages

Modularity

Individual behaviour nodes are designed to be self-contained, allowing them to be easily reused across different parts of a tree or even different trees altogether.

Flexibility

You can easily insert, remove, or modify parts of the tree without having to redesign the entire behaviour.

Intuitive Design

The graphical nature of BTs makes them easier to understand and visualize, especially for complex tasks.

Dynamic Decision Making

BTs continuously evaluate the state of the robot and its environment, allowing for real-time decision-making.

Drawbacks

Complexity

For very simple tasks, BTs can be overkill. They shine in more complex environments.

Learning Curve

While they are powerful, BTs do require an understanding of their structure and philosophy.

In summary, Behaviour Trees present a certain level of complexity and require dedicated time to grasp fully. While their structured and clear-cut design offers advantages for intricate robotic operations, their implementation necessitates a deep understanding and commitment to the learning process. The decision to integrate BT largely hinges on the intricacy of the robotic tasks at hand and the readiness to delve into the nuances of this methodology which is unnecessary for this design competition.

5. Strategies and Innovation

5.1 Strategies for Robot Activities

Transmission of Commands from Bluetooth

The robot will continually “listen” for incoming Bluetooth messages with the HC-05 Bluetooth Serial Transceiver. It will then continually check for a specific command message.

When the robot receives a "Are you ready?!" message, it responds with "Ready". The robot will then wait for the subsequent message in the following format: <Level 1 pin-deck zone number> space <Level 2 pin-deck zone color> space <Current Level>! For example, 2 blue 1! The command means that the robot will be placed within Zone 2 of the pin deck during Level 1, a blue-coloured zone within the pin-deck (3 or 6) during Level 2. After processing the message, the robot will send a “Received” text indicating acknowledgement. When the robot receives a "Start" message, it sends an acknowledgment "Okay to Start" and then the robot will leave the base and do its preset routine.

Obstacle Detection and Collision Avoidance Strategy

In the vast expanse of the competition arena, obstacles pose a significant threat to the robot's consistent performance. Our strategy to counter this challenge lies at the heart of our Obstacle Detection mechanism.

The paramount objective of this algorithm is to act as a protective shield, ensuring our robot doesn't fall prey to unexpected collisions. This algorithm springs to action primarily when the robot is in the midst of its linear movements. These movements often arise during two distinct operations: the raster scan process, wherein the robot methodically combs the arena, and during backtracking, when the robot navigates back after accomplishing specific tasks.

On detecting a potential obstacle, the robot's immediate response is to cease all forward or backward motion. However, a noteworthy feature of our design is the robot's retention of certain operational variables, such as the shaft count, even during the standstill. This retention ensures that once the obstruction is out of the equation, the robot can pick up from where it left off, without any hiccups.

In more intricate scenarios, particularly during the raster scan, if an obstacle hinders the robot's trajectory, our strategy introduces an evasive manoeuvre. The robot halts, then reverts backward, effectively distancing itself from the obstacle. An integral internal counter then increments, signalling the robot to adjust its course and transition to the subsequent path from its set of five predetermined paths. This approach guarantees the robot's safety and ensures its tasks proceed unhindered, even amidst unforeseen challenges.

This rigorous strategy, woven with precision and adaptability, equips our robot to navigate with confidence, dodging any obstacles that dare to come its way.

Puck Detection Strategy

In the labyrinth of the competition arena, accurately identifying and interacting with pucks is crucial for the robot's success. As the robot forges ahead, a strategically positioned IR sensor, nestled beneath the robot, vigilantly scouts for pucks. A manually calibrated screw on this sensor establishes a sensitivity threshold, ensuring it's activated only when a puck is in direct alignment below the color sensor. Thus, false activations are minimized. Once this IR sensor identifies a puck, the color-sensing module is prompted into action.

Puck Color Identification Strategy

One of the primary design considerations is operational efficiency. To augment this, the color sensor is astutely placed, ensuring that when a puck is detected, it aligns directly below the sensor. This strategic positioning negates the need to engage the gripper for every puck detection, resulting in both time and energy conservation. Additionally, with the sensor's underside placement, it remains shielded from ambient light interferences, enhancing the accuracy of color readings. By incorporating these strategies, we ensure our robot not only detects pucks efficiently but also identifies their color with unmatched precision, all the while maximizing operational efficiency and minimizing energy consumption.

Flicking and Transportation of the Puck Strategy

The robot's puck transportation is seamlessly orchestrated by its dual-servo gripper, pivotal for adept puck handling. Activated solely during key instances, such as securing a correctly identified puck or positioning it at designated zones, the gripper employs a meticulous procedure to ensure accuracy. Initiated by a slight reverse motion, the robot carves out space for the gripper's descent. Subsequently, the gripper's claw will open, setting the stage for the robot's forward movement to adeptly seize the puck. Once in possession, the claw and arm retract in unison, ensuring the puck is well kept within the vicinity of the robot. Once the robot has reached the puck landing zone, the robot will first lower its arm, open the gripper, move forward a bit and lift its arm up, essentially flicking the puck as well to knock down the bowling pin. During the transportation of the puck, the servo motor will be deactivated in order to save energy.

Alignment and Navigation Strategy

The robot employs a linked-list structured navigation stack to accurately record its coordinates and directional orientation within the competition arena. Utilizing a systematic smart raster scan search pattern, it divides its movements into "long stride" and "short stride" phases. The "long stride" phase ensures the robot moves set distances, maintaining a buffer from the arena boundaries, thus avoiding unintended collision mechanisms triggered by Ultrasonic Sensors. Conversely, the "short stride" aids in directional shifts, predominantly through U-turns. By analyzing the feedback from the shaft encoder, the robot discerns its movement's completion. Given the arena's grid-like structure, it updates its coordinates based on its travelled distance and orientation. This data is then stored in the navigation stack, assisting in localization and potential backtracking. An integrated flag also monitors the robot's relative position within the arena, pivotal for its return journey.

After capturing a correctly coloured puck, the robot checks its position relative to its base using the flag. If on the same side, it streamlines its return by aligning using the difference between the readings of the two rear Ultrasonic Sensors, advancing a set distance, rotating to aim at its base, and then reversing into position. If positioned on the opposite side, it retraces its steps using the navigation stack to the correct side before implementing the mentioned shortcut. This approach optimizes efficiency, especially when the robot's extensive search doesn't yield the desired puck, eliminating the need to retrace a lengthy initial path.

Pin Detection Strategy

The robot employs ultrasonic sensor modules (USM) for pin detection. It first uses side USMs to spot significant changes in distance, signalling a pin's presence. Once detected, the front USM gauges the distance to the arena wall, determining the pin's exact position. The robot segments its operational field into six zones, each represented by internal counters. Depending on the front USM's reading, the detected pin is assigned to a specific zone. This dual USM approach facilitates broad pin detection followed by precise localization within set zones.

5.2 Key Innovations

Mechanical

Puck Flicking Innovation

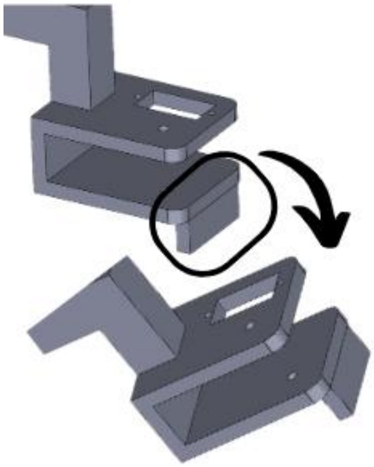


Figure 87: Puck Base Flicking Mechanism

An essential hallmark of our robot's design lies in its commitment to the principles of simplicity and integration. At the core of this commitment is the puck flicking mechanism. The design philosophy behind this mechanism is rooted in its user-friendly nature. With an emphasis on seamless integration, the puck flicking system is intrinsically tied to the robot's broader puck handling and detection framework. Our vision is not just about individual parts but optimizing them collectively for a cohesive performance. All elements, including puck handling and flicking, are governed through a singular, unified interface.

Gripper System Innovations:

1. Gripper

Figure 88: Gripper

The Gripper Arm epitomizes both form and function. Architecturally, it offers an expansive puck capture zone, ensuring a significant capture rate. Comprising a shorter arm length leading to a circular capture field, it guarantees ease in capturing pucks. This design ensures the puck centres itself, which aids in precise drop-offs. Enhancements, like the inclusion of Styrofoam attached to the side of the gripper prevent the puck from slipping during movements. Moreover, the puck-retaining ledge ensures its safe retention, enabling energy conservation by turning off the gripper servos when not required.

2. Gripper Arm Structure with Support Mechanism

Figure 89: Gripper Arm Structure with Support Mechanism

Our iterative design process led to the development of a gripper gear structure that significantly curtails wear and tear. To counteract this, a compound gear system was introduced. It includes two vertically aligned gears on each gripper arm. The upper gear finds support in the lower one during the interlocking phase, preventing momentary forces from inducing misalignment. A third compound gear reinforces the connection between both gripper arms, ensuring a snug fit. This tight connection permits the powering off of the gripper, a strategy that not only conserves energy but also extends the gripper's lifecycle.

3. Gripper Arm Retraction/Extension Mechanism

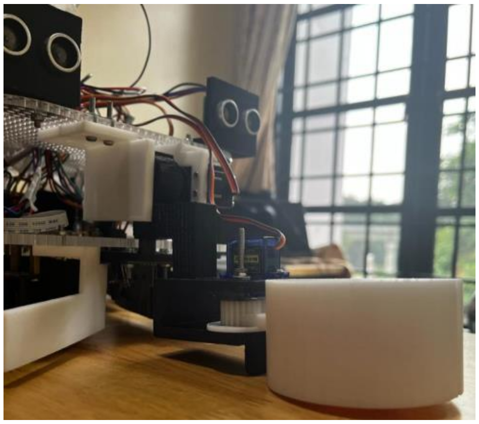


Figure 90: Gripper Arm Retraction/Extension Mechanism

The ingenuity of the gripper extension and retraction system stems from its secure connection to the robot base via a servo. Facilitating a full motion arc of 180 degrees, it ensures both complete retraction and extension. This retractable design aims to protect the puck and vital components of the puck handling system, safeguarding them even during potential collisions. By minimizing the length of the rotary pole, power consumption is reduced, as it exerts less moments on the servo motor. When the gripper is retracted to a vertical position of approximately 180 degrees, the power to the servo can be switched off, resulting in energy savings. This stability, without external force, highlights the meticulous mechanical engineering behind our robot.

Electronics

Powering of PSoC

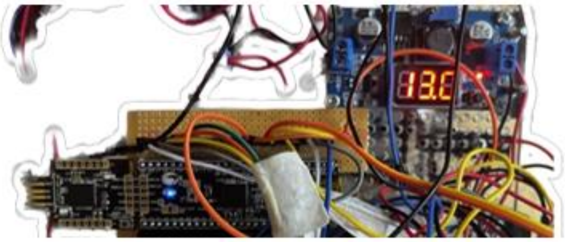


Figure 91: Powering of PSoC without Connecting to USB

A hallmark of our project's electronic ingenuity is the autonomous power management of the PSoC. Once programmed, the PSoC no longer remains tethered to a continuous USB power source. The integration of a rocker on-off switch offers a seamless operational experience, enabling the robot's activation without the necessity of plugging in a USB cable to the PSoC. This advancement not only enhances the portability of our robot but also augments its ease of use.

Ultrasonic Modules (Alignment)

Furthermore, in our pursuit of precision and efficiency, the robot employs Ultrasonic Sensor Modules (USMs) for its alignment. This eliminates the traditional reliance on mechanical limit switches for orientation, ensuring remote and more accurate alignment capabilities.

Color Sensor

Figure 92: Black Tape Applied to the LED of the Color Sensor

In the realm of color detection, meticulous attention to detail has been exercised. To optimize the performance of the TCS3200 color sensor module, we've sheathed the LED tips with black tape. This strategic modification acts as a shield, mitigating external light interferences. As a result, we've fortified the sensor's accuracy, ensuring it delivers consistently reliable readings irrespective of the ambient lighting conditions.

Software

Smart Backtracking Algorithm

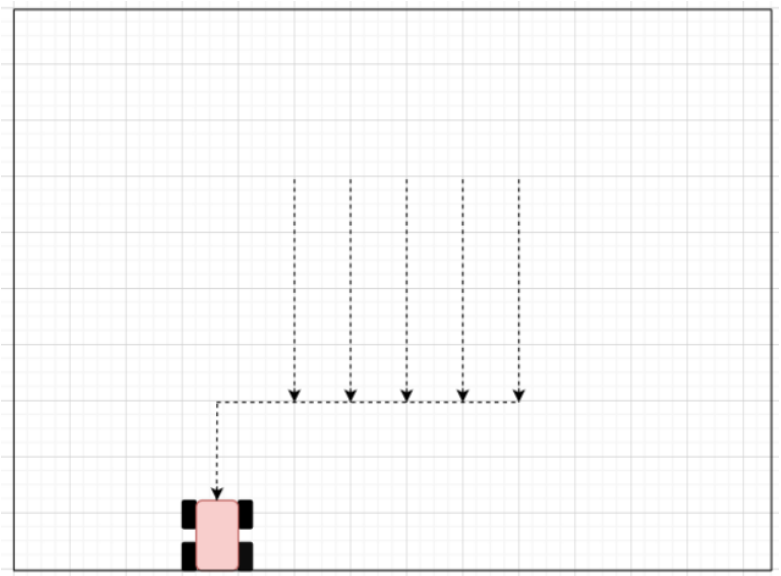


Figure 93: Smart Backtracking Algorithm

A pivotal software advancement realized in this undertaking is the strategic utilization of the path counter for adept navigation and backtracking. This innovation hinges on an intuitive counter system, termed as the "path counter", which continually updates to signify the robot's current path. When an exit scenario arises, the counter offers insights into the robot's movement and its relative position. As the robot navigates, it interprets its location and discerns its proximity to the starting base. Upon reaching the vicinity of its commencement point, the robot adjusts its orientation, aligns itself in the right trajectory towards the base, executes a precise point turn, and smoothly reverses into its original stance. This methodology dramatically minimizes the time duration for the robot to revert to its base post a successful puck identification. This inventive strategy is notable as it empowers the robot to harness its location data, efficiently deducing its position in the arena, and facilitating a rapid return to the base, bypassing the exhaustive route tracing that might otherwise consume significant time, especially if the puck remains undetected after extensive searches.

6. System Integration and Testing

6.1 System Integration

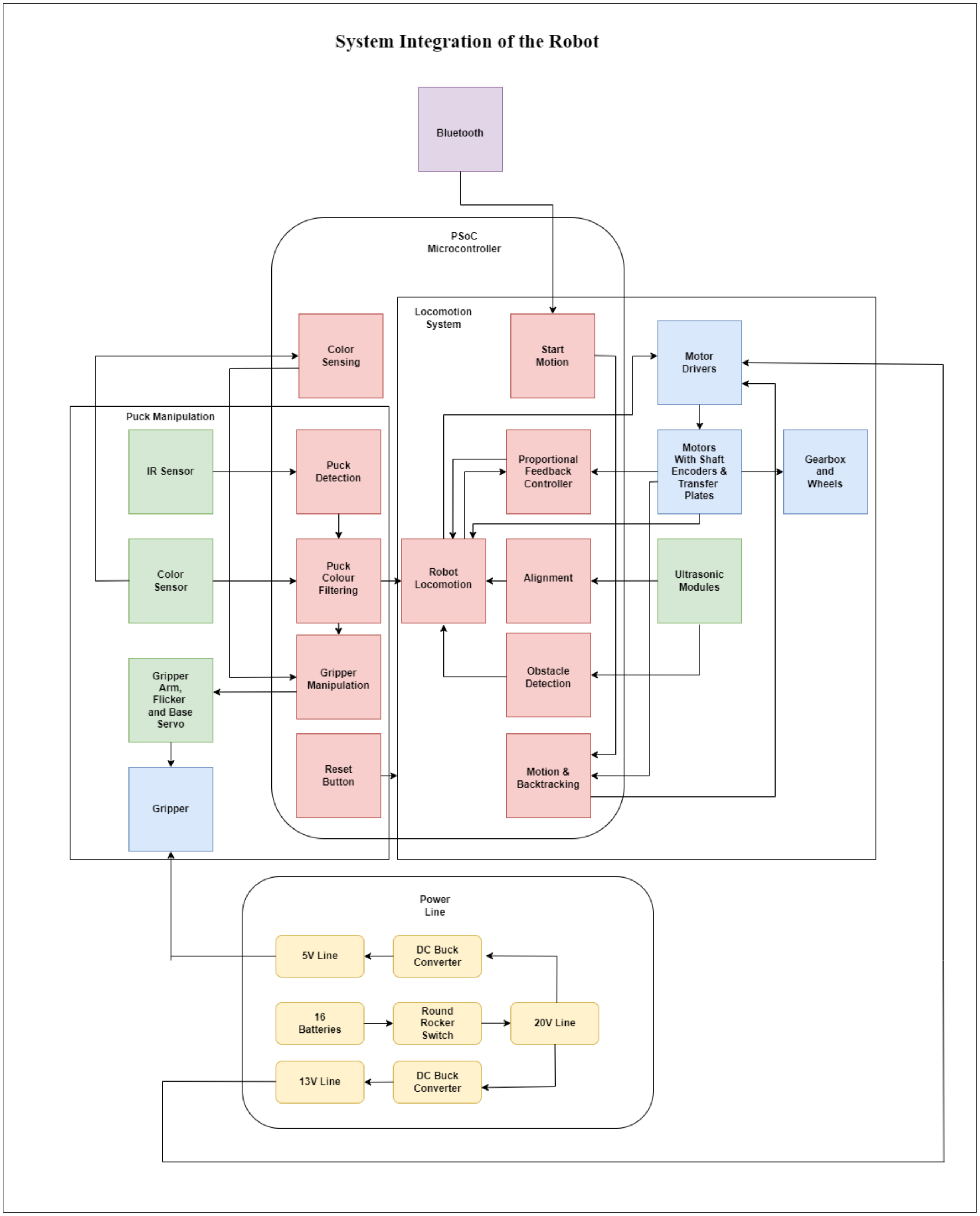


Figure 94: Overview of the System Integration

The comprehensive system of the robot is illustrated in the attached figure above. This representation captures a holistic view of the robot's functionalities, synergistically combining power management, electronic components, mechanical structures and embedded software to perform seamlessly.

Power Management (Highlighted in Yellow)

The power infrastructure comprises a set of 16 batteries, channelling energy through a Round Rocker Switch. 2 DC Buck Converter play a pivotal role, converting the high 20V output into a manageable 5V (Sensor and Actuators) and 13V (Motor Driver). This regulation ensures that all components, including the pivotal PSoC Microcontroller, sensors and actuators, receive the appropriate power levels for efficient operations.

Electronics & Actuators (Highlighted Green)

The robot's nerve centre is the PSoC Microcontroller, facilitating interactions across modules. It integrates inputs from the Color Sensor and IR Sensor under the Puck Manipulation domain, while also coordinating with the Locomotion System and Ultrasonic Modules for navigation and obstacle detection.

Mechanical Structure (Highlighted in Blue)

The mechanical infrastructure comprises Motor Drivers that power the Motors with Shaft Encoders & Transfer Plates, facilitating movement. The robot's precise movement is achieved using the Gearbox and Wheels. Additionally, the Gripper, enhanced with a flicker arm and base servo, is pivotal for puck manipulation.

Software & Algorithms (Highlighted in Red)

Upon initialization, the robot receives instructions via the Bluetooth Module (Highlighted Purple), setting the stage for subsequent operations. Based on this input, the robot employs various algorithms, such as puck detection, color sensing, and navigation, to execute its tasks. Key features include IR-based puck identification, Color Sensor-based puck validation and precise Gripper actions to pick up the puck. The robot's journey involves sophisticated raster scanning of the arena, backtracking, and employing shortcuts to efficiently reach the base. An inbuilt alignment state ensures the robot maintains appropriate orientation throughout its tasks.

The Navigation System synergistically works with the Obstacle Detection System. Using Ultrasonic Modules, the robot can identify opponent robots, avoiding potential collisions by halting its movement until the path is clear. The diagram encapsulates the intricate interplay of hardware and software, portraying a robot designed to execute a complex task with precision and efficiency.

6.2 Testing

Test 1: Ultrasonic Sensor Module (USM) Testing

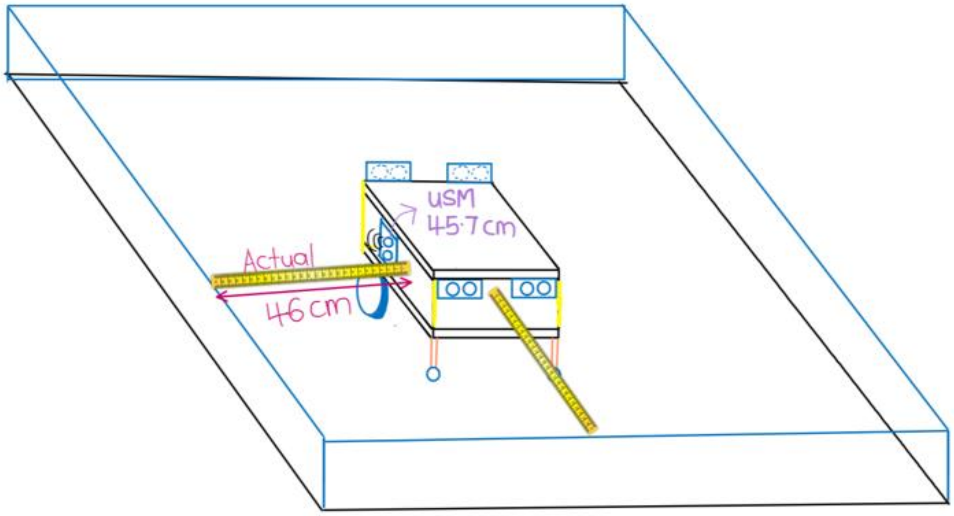


Figure 95: Testing of Ultrasonic Sensor Module in the Arena

For this test, we focused on examining the performance of the US-015 Ultrasonic Sensor Modules (USM). Two primary methodologies were employed:

1. Static Surface Testing
The robot was positioned in front of a flat surface, and the USM readings were observed as the robot was moved progressively closer and farther from the surface.

2. Arena Distance Verification
The robot was placed within an arena. USM readings were then captured and juxtaposed against actual distances measured using a conventional measuring tape.
For instance, in one of the test scenarios, the USM reported a distance of 45.7 cm, which, when cross-verified with the measuring tape, showed an actual distance of 46 cm. Such tests verified the accuracy and precision of the US-015 USM within acceptable limits.
Upon evaluation, the USM exhibited measurements within a tolerance of ±1cm during static tests. However, during dynamic movement tests, due to the interplay between the USM's latency and the robot's motion algorithm, a discrepancy of about ±5cm was observed.

Refinements Post Testing:
To compensate for the observed latency and achieve more accurate stopping, two critical changes were made:

1. When the robot was navigating the central parts of the arena, the stopping threshold was increased to account for the additional distance covered due to latency.
2. For finer alignments, the robot's motion was broken down into smaller incremental steps. A delay was introduced post each step, providing the system more time to obtain accurate distance measurements.

This assessment not only validated the accuracy of the USMs but also provided insights that led to improvements in the robot's motion algorithms, ensuring better alignment and obstacle detection.

Test 2: Funnel and IR Sensor Testing

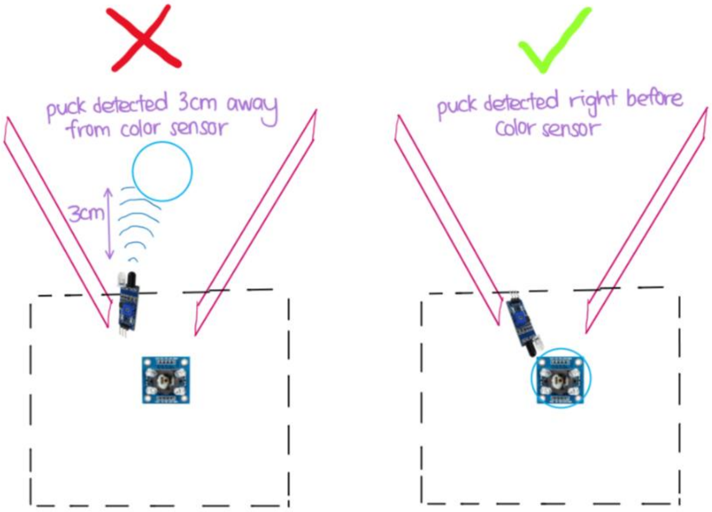


Figure 96: Testing of Funnel and IR Sensor

The funnel's performance, designed to direct pucks towards the IR Sensor, was assessed. When the robot moved straight, any puck within the funnel's range was expected to be redirected towards the IR Sensor. Once the IR Sensor detected a puck, it signalled this by outputting "Puck Detected" via UART.

Initial Observations:

Initially, the infrared (IR) sensor was found to be too sensitive, detecting pucks when they were approximately 3 cm away from the color sensing region. The challenge was that the IR waves travelled in a linear path, causing premature detection.

Adjustment and Calibration

To counteract this, the angle of the IR LEDs on the proximity sensor was repositioned to face directly towards the color sensing zone. This ensured that the IR sensor was only activated when the puck was correctly positioned in the color sensing region.

Testing Procedure

The robot was set in motion, and as it moved, the mechanism was observed. Ideally, upon puck detection, the robot should come to an immediate halt, positioning the puck directly beneath the color sensor. The alignment of the puck was indicative of the system's success.

Experimental Setups

Two distinct placements for the IR sensor were trailed:

1. Setup A

Here, the IR sensor functioned as a funnel, designed to guide the puck centrally towards the color sensor.

2. Setup B

In this configuration, the IR sensor was placed directly behind the color sensor.

Results

Setup A, while effective, yielded inconsistent results Given the robot's requirement for precision, these results weren't satisfactory. On the other hand, Setup B demonstrated a marked improvement in performance, precisely detecting and positioning the puck 100% of the time.

Setup B emerged as the superior configuration. It ensured the puck was positioned directly beneath the color sensor with high accuracy, thereby enhancing the reliability of color readings. By optimizing the puck's positioning, the system significantly reduced the likelihood of color sensing errors, ensuring the robot operated with maximum efficiency.

Test 3: In-depth Color Sensor Testing

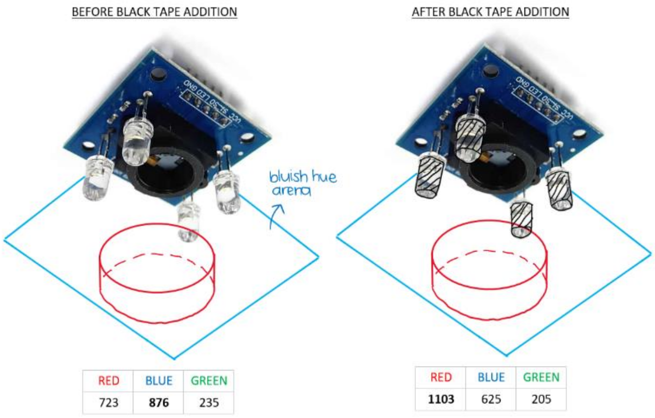


Figure 97: Testing of TCS3200 Color Sensor

The core aim of this test was to evaluate the accuracy and precision of the color sensor in detecting and differentiating the colours of pucks within the arena. Given the critical role the color sensor plays in the robot's operations, ensuring its accuracy is paramount. The color sensor reads the Red, Green, and Blue (RGB) values of the detected object and determines the predominant color.

Initial Observations

In preliminary tests, when a red puck was placed under the sensor, the 'R' value consistently registered significantly higher than the 'G' and 'B' values. This was a promising indication of the sensor's capability to correctly identify the puck's color.

Challenges Encountered

However, some inconsistencies were observed during subsequent tests. The arena floor's bluish hue interfered with accurate readings, especially when the robot was in motion. In some instances, the 'B' value spiked, leading to incorrect puck color identifications.

Solution and Calibration

To counter this, a two-fold solution was employed:

1. Shielding with Black Tape

A specialized black tape was applied around the LED of the color sensor, leaving the central tip exposed. Black, being a non-reflective color, served to isolate the sensor from external light interferences, particularly from the bluish arena floor.

2. Software Adjustments

On the software front, a calibration mechanism was introduced. This allowed the robot to differentiate between the floor's blue and the puck's blue by setting a threshold value. Any 'B' reading above this threshold, while in the presence of a puck, would correctly identify it as a blue puck, while readings below the threshold, despite being high, would be disregarded as the arena floor's interference.

Post-Calibration Results

After these modifications, the color sensor's performance improved markedly. The interference from the arena floor was minimized, and the sensor consistently detected puck colors with a high degree of accuracy.

Through a combination of physical modifications and software calibrations, the color sensor's efficiency was optimized, ensuring the robot's operations remained seamless and error-free in diverse conditions. This detailed analysis underscores the iterative nature of robotic testing and the importance of calibration to achieve operational excellence.

Test 4: Puck Gripping Mechanism

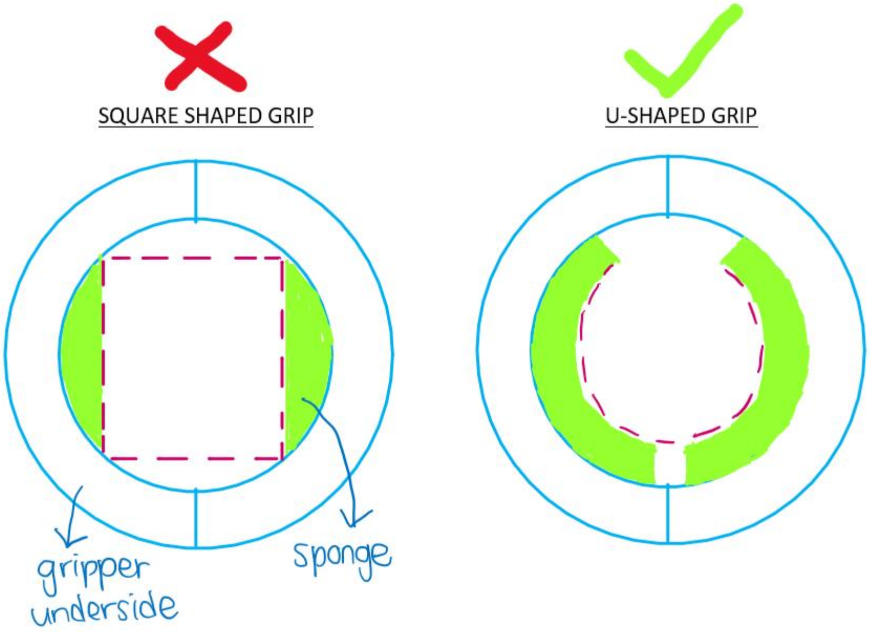


Figure 98: Testing of Puck Gripping Mechanism

The primary goal of this test was to evaluate and optimize the efficiency of the robot's puck gripping mechanism, particularly focusing on the design modifications and the use of sponge for better grip. The robot's success in the arena largely depends on its ability to effectively grip and transport pucks. Over the course of development, while the gripping mechanism itself was largely efficient, issues were observed with the material and design of the sponge that facilitated this grip.

Initial Observations

In earlier tests, the robot employed a square-shaped sponge. While it was somewhat effective, there were instances where the puck slipped or wasn't gripped tightly. This prompted the need to reconsider the design and material aspects of the sponge.

Modifications Made

1. Shape Alteration

After several design considerations, it was determined that a U-shaped sponge was optimal. The U-shape provided a better contouring grip, accommodating the puck's circumference better than the square design. This ensured a snug fit, reducing the chances of slippage.

2. Thickness Calibration

The thickness of the sponge also came under scrutiny. While a thicker sponge ensured a firmer grip, making it excessively thick led to challenges in puck release. After various trials, an optimal thickness was identified that balanced grip strength and release efficiency.

Post-Modification Tests

With the newly designed U-shaped sponge of optimal thickness, the robot's grip on the pucks was re-evaluated. The results were promising: the robot was able to consistently grip the puck 100% of the time without any slippage or release issues. The new design clearly outperformed the earlier square-shaped sponges in both grip and release efficiency.

This iterative testing process emphasized the importance of even the minutest details, like the shape and thickness of a sponge, in the overall efficiency of a robotic system. By continually refining and re-evaluating the design, the team was able to significantly enhance the robot's puck gripping capability, ensuring optimal performance in the arena.

Test 5: Base Flicking Mechanism

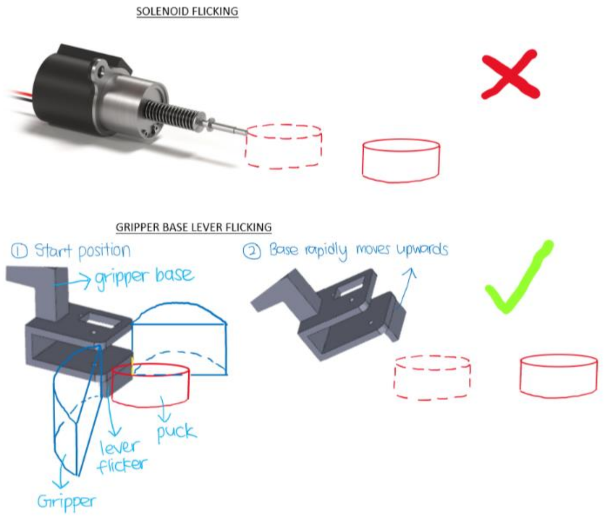


Figure 99: Testing of Base Flicking Mechanism

The purpose of this test was to assess the effectiveness of the robot's newly implemented base flicking mechanism in comparison to the earlier solenoid-based design, focusing on power consumption, risk factors, and accuracy. The robot's capability to accurately flick a puck is a crucial element of its overall performance. The primary mechanism initially chosen for this task was a solenoid, owing to its direct linear motion that seemed ideal for a flicking action.

Initial Observations with Solenoid:

1. High Power Consumption

One of the first challenges encountered was the unusually high energy consumption. To achieve a strong enough flick, the solenoid had to be driven harder, draining the battery at a faster rate.

2. Risk of Overdrive

To generate a more forceful flick, overdriving the solenoid became a necessity. This not only further increased power consumption but also introduced the risk of equipment failure.

3. Equipment Damage

As feared, consistently overdriving led to the shorting of the solenoid during one of the test runs, emphasizing the need for an alternative solution.

Switch to Base Flicking Mechanism

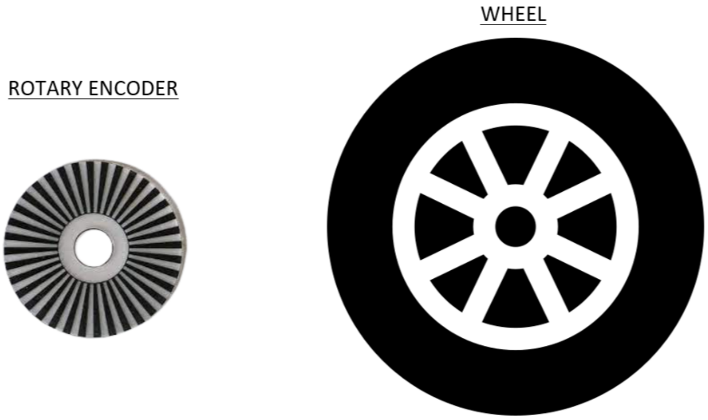
Given the risks and inefficiencies of the solenoid-based design, a new base flicking mechanism was conceptualized and implemented. This mechanism was designed to replicate the flicking action without the pitfalls associated with the solenoid.

Performance Assessment of Base Flicking Mechanism

When tested, the base flicking mechanism showed promising results. It not only matched the solenoid's accuracy but also consumed significantly less power. The added advantage was the elimination of any risks associated with overdriving, ensuring longer operational life and safer usage.

The shift from a solenoid-based flicking mechanism to a base flicking design proved beneficial in multiple ways. While achieving the desired flicking accuracy, it also addressed the issues of high-power consumption and equipment risk. The entire testing process underscored the importance of flexibility and adaptability in design, with a readiness to pivot when faced with challenges.

Test 6: Robot's Movement and Speed Control



	ENCODER RPM	WHEEL ROTATION ANGLE	DISTANCE TRAVELLED
INITIAL	12000	332°	32.3 cm
ADJUSTED	13000	360°	35.0 cm

Figure 100: Comparison of Initial and Adjusted Encoder RPMs and Their Effects on Wheel Movement

1. Distance Accuracy of Motor

The fundamental aspect of the robot's movement is tied to the shaft encoder count necessary for one complete wheel rotation and the robot's radius. Initial measurements showed the shaft encoder count for one revolution to be approximately 12000. However, after subsequent calibrations, the count was adjusted to 13000 for an accurate 35cm movement.

2. Speed Control Gain

Ensuring the robot moves in a straight line, especially during the scanning of the solution space was vital. By altering the gain values in the proportional controller, the optimal movement was determined. Multiple gain values were tested. At a gain value of 4.9, the robot demonstrated the straightest and most consistent motion. Any deviation from this gain led to undesirable steering or oscillatory movement. Further adjustments to the speed control algorithm showcased improvements, but a gain parameter of 4.9 consistently delivered the best outcomes. These tests ensured the robot's efficient functioning in various aspects, guaranteeing accuracy, speed, and reliability in its operations.

7. Project Management

7.1 Team Roles

Tan Jin Chun – Project Manager, Main Firmware, and Electronics Engineer

Jin Chun will be the person in charge of keeping everyone in the team on track by frequently updating the Gantt charts specified in Section 6. He will also oversee meetings to solve the issues faced by the team members as well as coordinating meetups with the unit coordinator for general advice and feedback.

Jin Chun will also code out the algorithms and interface of the sensors attached to the robot to ensure the sensors control the robot as illustrated by the block flow diagram. He will also be responsible for interfacing the communications module from the user to the robot. Together with Agill, Jin Chun will integrate the sensors and circuitry with the firmware to ensure that the robot functionalities are accurate and structurally sound.

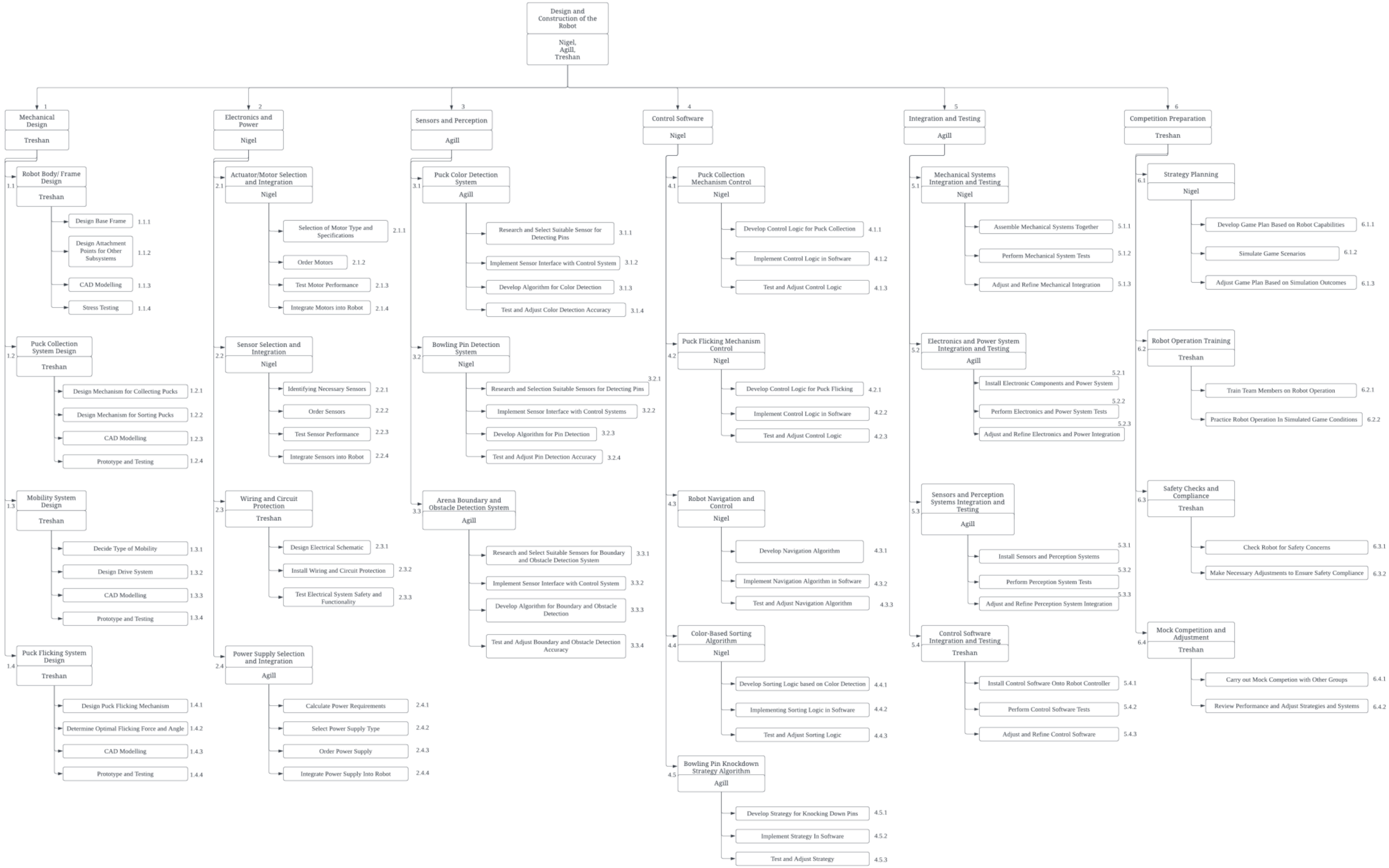
K Appuhamilage Don Treshan Rajinda Appuhamy – Main Mechanical Design and Secondary Electronics Engineer

Treshan will be the person in charge of designing the base structure and the mechanical aspects of the robot. He will also evaluate the structural integrity of the robot when the circuitries are connected, and the firmware is utilized to control the robot. He will also be responsible for designing SOLIDWORKS drawings to model the robot and facilitate the 3D printing services provided by the university. Together with Jin Chun, Treshan will integrate the mechanical and electrical subsystem of the robot with the firmware to ensure the robot's structural integrity is maintained.

Agill Kumar Saravanan – Secondary M&E Engineers, Main Documenter & Spokesperson

Agill is the primary individual responsible for overseeing the documentation involving the construction of the robot and updating the progress reports weekly. Agill will also be the main coordinator for presenting the robot to the stakeholders. Agill will assist Treshan in his duties as the M&E Engineer to ensure the robot's structural integrity is maintained during the competition.

7.2 Work Breakdown Structure



7.3 Responsibility Matrix

Table XVII: Responsibility Matrix

WBS Item	Work Item	Nigel Tan Jin Chun	Agill Kumar Saravanan	K Appuhamilage Don Treshan Rajinda Appuhamy
	Design and Construction of the Robot	P	P	P
1	Mechanical Design	P	S	S
1.1	Robot Body / Frame Design	P	S	S
1.1.1	Design Base Frame	P	S	S
1.1.2	Design Attachment Points for Other Subsystem	P	S	S
1.1.3	CAD Modelling	P	S	S
1.1.4	Stress testing	P	S	S
1.2	Puck Collection System Design	S	S	P
1.2.1	Design Mechanism for Collecting Pucks	S	S	P
1.2.2	Design Mechanism for Sorting Pucks	S	S	P
1.2.3	CAD Modelling	S	S	P
1.2.4	Prototype and Testing	S	S	P
1.3	Mobility System Design	S	S	P
1.3.1	Decide Type of Mobility	S	S	P
1.3.2	Design Drive System	S	S	P
1.3.3	CAD Modelling	S	S	P
1.3.4	Prototype and testing	S	S	P
1.4	Puck Flicking System Design	S	S	P
1.4.1	Design Puck Flicking Mechanism	S	S	P
1.4.2	Determine Optimal Flicking Force and Angle	S	S	P
1.4.3	CAD Modelling	S	S	P
1.4.4	Prototype and Testing	S	S	P
2	Electronics and Power	P	S	S
2.1	Actuator/ Motor Selection and Integration	P	S	S
2.1.1	Selection of Motor Type and Specifications	P	S	S
2.1.2	Order Motors	P	S	S
2.1.3	Test Motor Performance	P	S	S
2.1.4	Integrate Motors into Robot	P	S	S
2.2	Sensor Selection and Integration	P	S	S
2.2.1	Identifying Necessary Sensors	P	S	S
2.2.2	Order Sensors	P	S	S
2.2.3	Test Sensor Performance	P	S	S
2.2.4	Integrate Sensors into Robot	P	S	S

2.3	Wiring and Circuit Protection	S	S	P
2.3.1	Design Electrical Schematic	S	S	P
2.3.2	Install Wiring and Circuit Protection	S	S	P
2.3.3	Test Electrical System Safety and Functionality	S	S	P
2.4	Power Supply Selection and Integration	S	P	S
2.4.1	Calculate Power Requirements	S	P	S
2.4.2	Select Power Supply Type	S	P	S
2.4.3	Order Power Supply	S	P	S
2.4.4	Integrate Power Supply into Robot	S	P	S
3	Sensors and Perception	S	P	S
3.1	Puck Color Detection System	S	P	S
3.1.1	Research and Select Suitable Sensor for Detecting Pins	S	P	S
3.1.2	Implement Sensor Interface with Control System	S	P	S
3.1.3	Develop Algorithm for Color Detection	S	P	S
3.1.4	Test and Adjust Color Detection Accuracy	S	P	S
3.2	Bowling Pin Detection System	p	S	S
3.2.1	Research and Selection Suitable Sensors for Detecting Pins	P	S	S
3.2.2	Implement Sensor Interface with Control Systems	P	S	S
3.2.3	Develop Algorithm for Pin Detection	P	S	S
3.2.4	Test and Adjust Pin Detection Accuracy	P	S	S
3.3	Arena Boundary and Obstacle Detection System	S	P	S
3.3.1	Research and Select Suitable Sensors for Boundary and Obstacle Detection System	S	P	S
3.3.2	Implement Sensor Interface with Control System	S	P	S
3.3.3	Develop Algorithm for Boundary and Obstacle Detection	S	P	S
3.3.4	Test and Adjust Boundary and Obstacle Detection Accuracy	S	P	S
4	Control Software	P	S	S
4.1	Puck Collection Mechanism Control	P	S	S
4.1.1	Develop Control Logic for Puck Collection	P	S	S
4.1.2	Implement Control Logic in Software	P	S	S
4.1.3	Test and Adjust Control Logic	P	S	S
4.2	Puck Flicking Mechanism Control	P	S	S
4.2.1	Develop Control Logic for Puck Flicking	P	S	S
4.2.2	Implement Control Logic in Software	P	S	S
4.2.3	Test and Adjust Control Logic	P	S	S

4.3	Robot Navigation and Control	P	S	S
4.3.1	Develop Navigation Algorithm	P	S	S
4.3.2	Implement Navigation Algorithm in Software	P	S	S
4.3.3	Test and Adjust Navigation Algorithm	P	S	S
4.4	Color-Based Sorting Algorithm	P	S	S
4.4.1	Develop Sorting Logic based on Color Detection	P	S	S
4.4.2	Implementing Sorting Logic in Software	P	S	S
4.4.3	Test and Adjust Sorting Logic	P	S	S
4.5	Bowling Pin Knockdown Strategy Algorithm	S	P	S
4.5.1	Develop Strategy for Knocking Down Pins	S	P	S
4.5.2	Implement Strategy in Software	S	P	S
4.5.3	Test and Adjust Strategy	S	P	S
5	Integration and Testing	S	P	S
5.1	Mechanical Systems Integration and Testing	P	S	S
5.1.1	Assemble Mechanical Systems Together	P	S	S
5.1.2	Perform Mechanical System Tests	P	S	S
5.1.3	Adjust and Refine Mechanical Integration	P	S	S
5.2	Electronics and Power System Integration and Testing	S	P	S
5.2.1	Install Electronic Components and Power System	S	P	S
5.2.2	Perform Electronics and Power System Tests	S	P	S
5.2.3	Adjust and Refine Electronics and Power Integration	S	P	S
5.3	Sensors and Perception Systems Integration and Testing	S	P	S
5.3.1	Install Sensors and Perception Systems	S	P	S
5.3.2	Perform Perception System Tests	S	P	S
5.3.3	Adjust and Refine Perception System Integration	S	P	S
5.4	Control Software Integration and Testing	S	S	P
5.4.1	Install Control Software onto Robot Controller	S	S	P
5.4.2	Perform Control Software Tests	S	S	P
5.4.3	Adjust and Refine Control Software	S	S	P
6	Competition Preparation	S	S	P
6.1	Strategy Planning	P	S	S
6.1.1	Develop Game Plan Based on Robot Capabilities	P	S	S
6.1.2	Simulate Game Scenarios	P	S	S
6.1.3	Adjust Game Plan Based on Simulation Outcomes	P	S	S
6.2	Robot Operation Training	S	S	P
6.2.1	Train Team Members on Robot Operation	S	S	P
6.2.2	Practice Robot Operation in Simulated Game	S	S	P

	Conditions			
6.3	Safety Checks and Compliance	S	S	P
6.3.1	Check Robot for Safety Concerns	S	S	P
6.3.2	Make Necessary Adjustments to Ensure Safety Compliance	S	S	P
6.4	Mock Competition and Adjustment	S	S	P
6.4.1	Carry out Mock Competition with Other Groups	S	S	P
6.4.2	Review Performance and Adjust Strategies and Systems	S	S	P

Remarks:
P = Primary Responsibility
S = Support Responsibility

7.4 Preliminary Activity Breakdown

Table XVIII: Preliminary Activity Breakdown

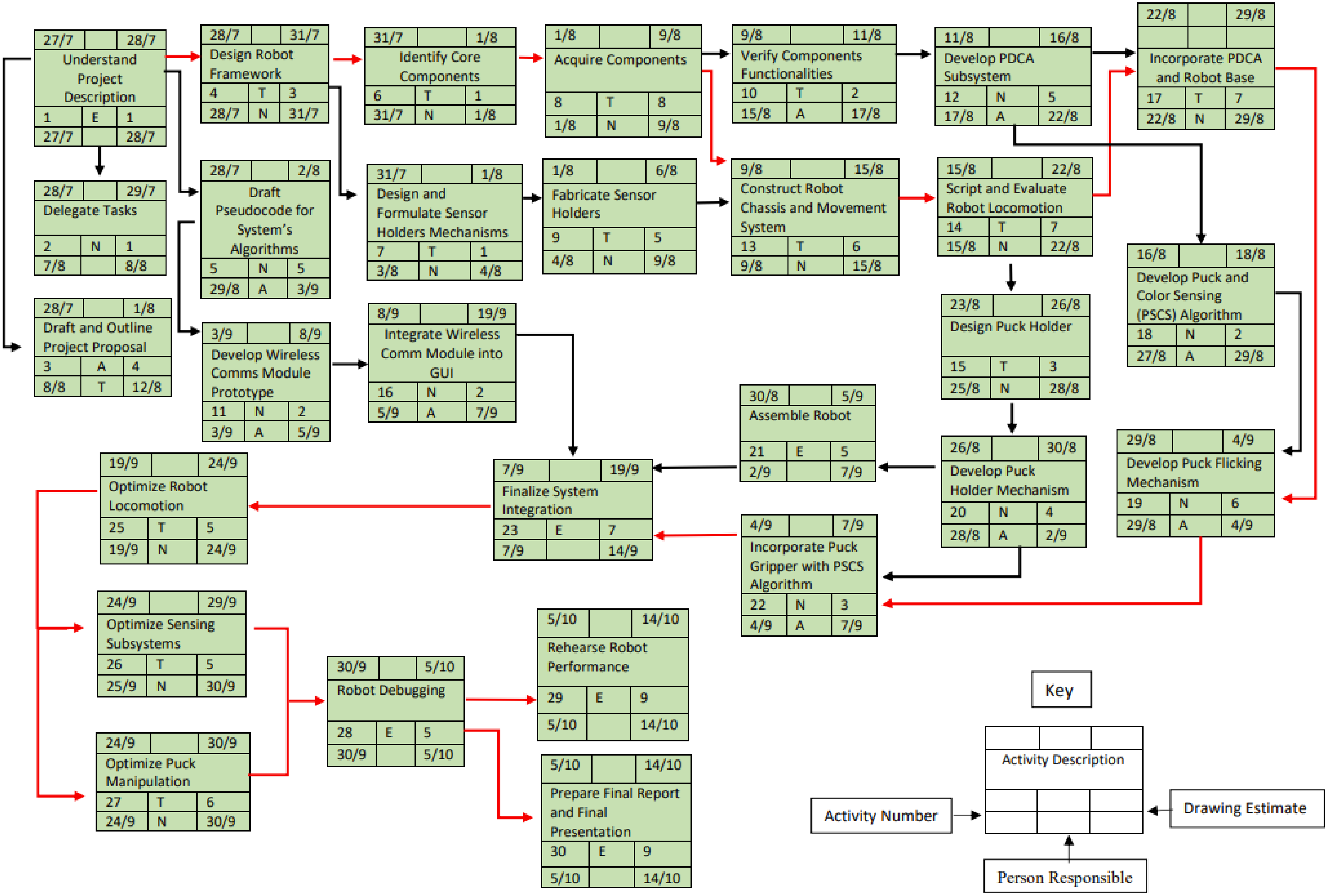
No.	Activity Description	Responsibility	Immediate Predecessors	Duration (Days)
1.	Understanding Project Description, Requirements and Rules	E	-	1
2.	Delegate Tasks	N	1	1
3.	Draft and Outline Project Proposal	A, T	1	4
4.	Design Robot Framework	T, N	1	3
5.	Draft Pseudocode for System's Algorithm	N, A	1	5
6.	Identify Core Components	T, N	4	1
Completion Target: Week 3 Friday (11/8/2023)				
7.	Design and Formulate Sensor Holders Mechanisms	T, N	4	1
8.	Acquire Components	T, N	6	8
9.	Fabricate Sensor Holders	T, N	7	5
10.	Verify Components Functionalities	T, A	8	2
11.	Develop Wireless Communication Module Prototype	N, A	5	2
12.	Develop Proximity Detection Prototype and Collision Avoidance Subsystem Prototype	N, A	5	5
13.	Construct Robot Chassis and Movement System	T, N	8	6
14.	Script and Evaluate Robot Locomotion	T, N	13	7
15.	Design Puck Holder	T, N	14	3
16.	Incorporate Wireless Communication Module into GUI	N, A	11	2
17.	Incorporate Collision Avoidance Subsystem into Robot Base	T, N	14	7
18.	Develop Puck and Color Sensing (PSCS) Algorithm	N, A	16	2
19.	Develop Patterning Algorithm	N, A	17, 18	6
20.	Develop Puck Holder Mechanism	N, A	15	4
21.	Assemble Robot	E	20	5
22.	Incorporate Puck Holder with PCSC Algorithm	N, A	21	3
23.	Finalize System Integration	E	22	12
24.	Optimize Robot Locomotion	T, N	25	5
25.	Optimize Sensing Subsystems	T, N	25	5
26.	Optimize Puck Manipulation (Flicking)	T, N	26	6
27.	Robot Debugging	E	26, 27	5

Completion Target: Week 11				
28.	Rehearse Robot Performance	E	28	9
29.	Prepare Final Report and Final Presentation	E	28	10
Completion Target: Week 12				

Remarks:
N – Nigel Tan Jin Chun (Main Programmer + Secondary System Integrator)
A – Agill Kumar Saravanan (Main Documenter + Secondary Programmer)
T – K Appuhamilage Don Treshan Rajinda Appuhamy (Main System Integrator + Secondary Documenter)
E – Everyone

No further tasks will be added since all current activities are in line with the unit content and match our critical path network.

7.5 Critical Path Network Diagram



7.6 Final Project Budget

Table XIX: Real Project Budget

Components	**Price Per Unit (MYR)**	**Number of Components**	**Total Price (MYR)**	**Product URL**
LM2956 3A Buck Module with Display	13.50	2	27.00	https://my.cytron.io/p-lm2596-3a-buck-module-with-display
Round Rocker Switch	15.00	1	15.00	https://my.cytron.io/p-rocker-switch-small-2-pins-red?search=on-off%20switch
8x Double A Battery Holders	1.90	2	3.80	Autobotic
US-015 Ultrasonic Sensor Modules	8.90	6	53.40	FabGear (Shopee)
Double A Rechargeable 1.2V NiMH Dry Cells (4 Batteries in a Pack)	25.00	4	100.00	https://my.cytron.io/p-pkcell-nimh-rechargeable-aa-2000mah-battery-4-pcs
Tamiya Ball Caster (Set)	23.00	1	23.00	https://www.mybotic.com.my/hardware/wheel-and-castor/tamiya-ball-caster-kit-2-casters
IR Sensor	1.80	4	7.20	https://my.cytron.io/p-infrared-sensor-module
MG996S Servo Motor	21.99	1	21.99	Robotronik
Corrugated Board (Black and Pink)	4.50	4	18	Mydin
Total (MYR): 269.39				

7.7 Comparison of the Project Budget with the Estimated Budget

Table XX: Estimated Project Budget

Components	**Price Per Unit (MYR)**	**Number of Components**	**Total Price (MYR)**	**Product URL**
LM2956 3A Buck Module with Display	13.90	2	27.80	https://my.cytron.io/p-lm2596-3a-buck-module-with-display
Rocker Switch	1.60	5	8.00	https://my.cytron.io/p-rocker-switch-small-2-pins-red?search=on-off%20switch
6x Double A Battery Holders	3.00	1	3.00	https://my.cytron.io/p-6xaa-battery-holder-compact
Double A Rechargeable 1.2V NiMH Dry Cells (4 Batteries in a Pack)	25.00	3	75.00	https://my.cytron.io/p-pkcell-nimh-rechargeable-aa-2000mah-battery-4-pcs
Tamiya Ball Caster (Set)	28.50	1	28.50	https://www.mybotic.com.my/hardware/wheel-and-castor/tamiya-ball-caster-kit-2-casters
IR Sensor	1.90	4	7.60	https://my.cytron.io/p-infrared-sensor-module
3-Axis Digital Compass Breakout Board	20.00	2	40.00	https://my.cytron.io/p-3-axis-digital-compass-breakout-board
Bracket for Ultrasonic SR-04 Module	1.50	2	3.00	https://my.cytron.io/p-bracket-for-ultrasonic-hc-sr04?gclid=EAIaIQobChMIjoOMqZG3-QIVA4LpBR3mIAQLEAEYASABEgK8m_D_BwE
LM2596 DC-DC Step Down Converter	15.60	2	31.20	https://www.mybotic.com.my/dc-dc-adjustable-step-down-converter-power-module-with-7-segment-display?search=lm2596
4x Double A Battery Holder	2.00	1	2.00	https://my.cytron.io/p-4xaa-battery-holder-compact
Analog Distance Sensor	29.00	2	58.00	https://my.cytron.io/p-analog-distance-sensor-10-80cm
Long Push-Pull Solenoid	9.43	1	9.43	Diymore Official Store (Shopee)
Total (MYR): 290.41				

Our final project expenditure amounted to MYR 269.39, which was significantly lower than our initial estimated budget of MYR 290.41. This favourable variance arose from a series of strategic economic decisions and adaptive measures our team employed:

1. Component Optimization:
Initially, we procured extra ultrasonic sensor modules due to concerns over potential defects. This was a precautionary economic choice to prevent future costs of replacements. As the project progressed, we discovered that many of these components such as the analog distance sensor, digital compass and the long push-pull solenoid weren't necessary, leading to direct cost savings.

2. Resource Utilization
Demonstrating ingenuity and adaptability, our team capitalized on resources readily available to us. Materials like copper stands and screws were generously provided by the lab technician, preventing unnecessary expenditures and reducing overhead costs. Moreover, we printed out components like brackets for the ultrasonic sensor module, casing holders, the gripper, and base holders. This resourceful approach not only minimized wastage but also resulted in considerable financial savings.

3. Opportunistic Savings
Fortunately, we managed to acquire some additional components during the project's course. These unplanned acquisitions further reduced our budgetary requirements.

In summary, our team's meticulous planning, combined with resource optimization and a keen sense of economic decision-making, allowed us to deliver efficiently without compromising on quality. The end result was a project executed below the anticipated budget, underscoring our capability to achieve cost savings through prudent management and strategic thinking.

8. Recommendations and Conclusion

8.1 Recommendations

Our puck flicking robot, while demonstrating commendable performance in the final design competition, is by no means at the pinnacle of its potential. Every design, no matter how refined, has room for improvement. Reflecting upon the robot's operation, interactions, and any challenges faced during the competition, we've identified several areas where enhancements could be made. These recommendations not only aim to fine-tune the robot's current capabilities but also envision a more adaptive, efficient, and resilient machine for future iterations. The following section elucidates these proposed improvements, providing a roadmap for the robot's evolution.

Recommendation 1: Self-Diagnostic Capabilities

Current Issue

The efficiency and performance of our robot may be compromised over time due to factors such as wear and tear or subtle damage that may go unnoticed.

Recommendation

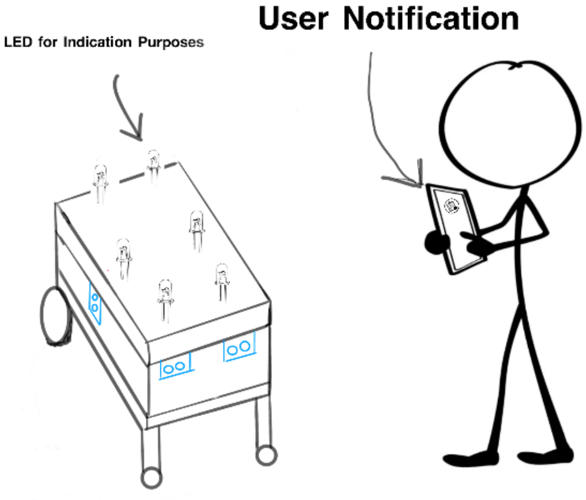
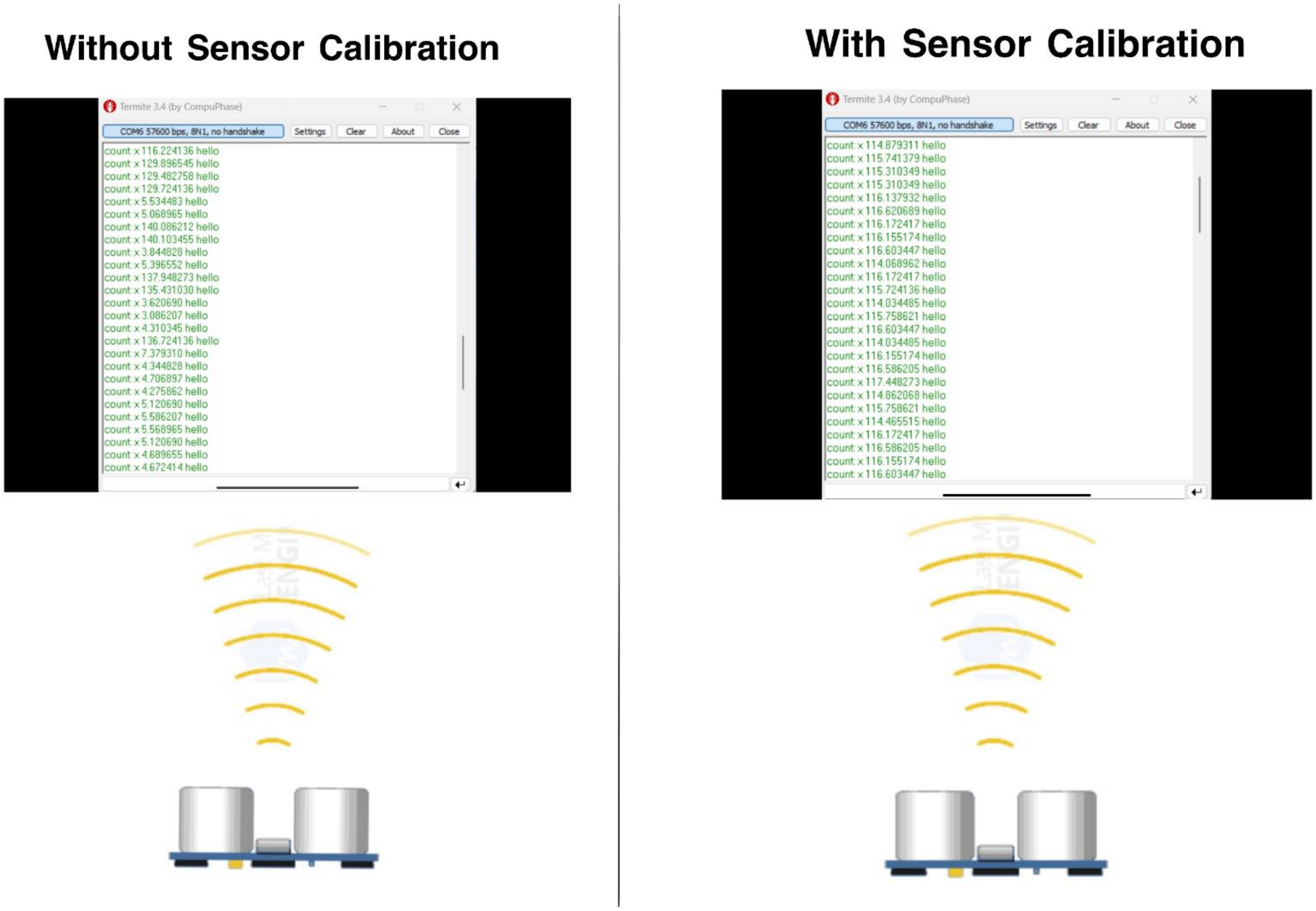


Figure 101: Robot LED Indicators and User Notification System

Introducing a self-diagnostic system would be invaluable. This system would conduct routine checks on the robot's functions and components. Upon detecting any abnormalities or malfunctions, the system could undertake corrective actions autonomously. If the issue requires human intervention, the system will promptly alert the user through a notification, mitigating prolonged downtimes and ensuring optimal performance. The robot could also have LEDs attached to each of the 6 sensors, lighting up when the Ultrasonic Sensor Module is not working properly.

Recommendation 2: Advanced Sensor Calibration


Without Sensor Calibration

With Sensor Calibration

```
count: x 116.224136 hello
count: x 129.896545 hello
count: x 129.482758 hello
count: x 129.724136 hello
count: x 5.534483 hello
count: x 5.068965 hello
count: x 140.086212 hello
count: x 140.103455 hello
count: x 3.844828 hello
count: x 5.396552 hello
count: x 137.948273 hello
count: x 135.431030 hello
count: x 3.620690 hello
count: x 3.086207 hello
count: x 4.310345 hello
count: x 136.724136 hello
count: x 7.379310 hello
count: x 4.344828 hello
count: x 4.706897 hello
count: x 4.275862 hello
count: x 5.120690 hello
count: x 5.586207 hello
count: x 5.568965 hello
count: x 5.120690 hello
count: x 4.689655 hello
count: x 4.672414 hello
```

```
count: x 114.879311 hello
count: x 115.741379 hello
count: x 115.310349 hello
count: x 115.310349 hello
count: x 116.137932 hello
count: x 116.620689 hello
count: x 116.172417 hello
count: x 116.155174 hello
count: x 116.603447 hello
count: x 114.068962 hello
count: x 116.172417 hello
count: x 115.724136 hello
count: x 114.034485 hello
count: x 115.758621 hello
count: x 116.603447 hello
count: x 114.034485 hello
count: x 116.155174 hello
count: x 116.586205 hello
count: x 117.448273 hello
count: x 114.862068 hello
count: x 115.758621 hello
count: x 114.465515 hello
count: x 116.172417 hello
count: x 116.586205 hello
count: x 116.155174 hello
count: x 116.603447 hello
```

Figure 102: Comparison of Sensor Readings: Uncalibrated vs. Calibrated

Current Issue

Sensors, being delicate instruments, might drift from their original calibration over extended periods, which can lead to inaccurate readings or false triggers. Sensors, as sophisticated and intricate instruments, are prone to calibration drift over time due to wear and tear, environmental factors, or other unforeseen variables. This drift may result in inaccurate readings, which in turn can lead to the robot misinterpreting its environment or even malfunctioning.

Recommendation

It's crucial to equip the robot with self-calibrating sensors. These sensors would frequently recalibrate themselves, ensuring that the readings remain consistent and reliable. Incorporating mechanisms to reduce unwanted reflections or filter sensor readings can further enhance their accuracy. Sensor drift is a common issue faced in robotics and automation. The reasons can range from simple physical wear to more complex causes such as temperature fluctuations, humidity changes, or electromagnetic interference. When sensors lose their calibration, even slightly, the robot might perceive an environment differently than it is, leading to inefficiencies, or worse, errors that could be hazardous.

1. Self-calibrating Sensors

Equip the robot with the latest sensors that have built-in self-calibration capabilities. These sensors can:
- Periodically check their own readings against known benchmarks.
- Make necessary adjustments autonomously to align with the reference values.

2. Environmental Compensation

Integrate sensors with capabilities to compensate for environmental variables. For instance:
- Temperature-compensated sensors that adjust readings based on ambient temperature.

- Humidity sensors that consider moisture levels to ensure reading accuracy.

3. Anti-reflection Mechanisms

Reflections can often interfere with sensor readings, especially in optical or infrared sensors. Implementing anti-reflective coatings or designing the sensor placement to minimize direct exposure to unwanted light sources can alleviate these challenges.

4. Digital Filtering

Incorporate digital filters in the sensor's data processing chain. These filters can:
- Smooth out noisy readings, especially useful in environments with electromagnetic interference.
- Eliminate outliers that could be a result of transient disturbances.

5. Calibration Alerts

Introduce a system where, if a sensor drifts beyond an acceptable limit and cannot self-calibrate, it sends an alert to the maintenance team or logs it for review. This ensures that potential problems are addressed promptly.

Recommendation 3: Dynamic Performance Analysis & Strategy Modification

Current Issue

Our robot operates on pre-defined parameters and follows a static sequence of actions. This lacks flexibility in dynamic scenarios.

Recommendation

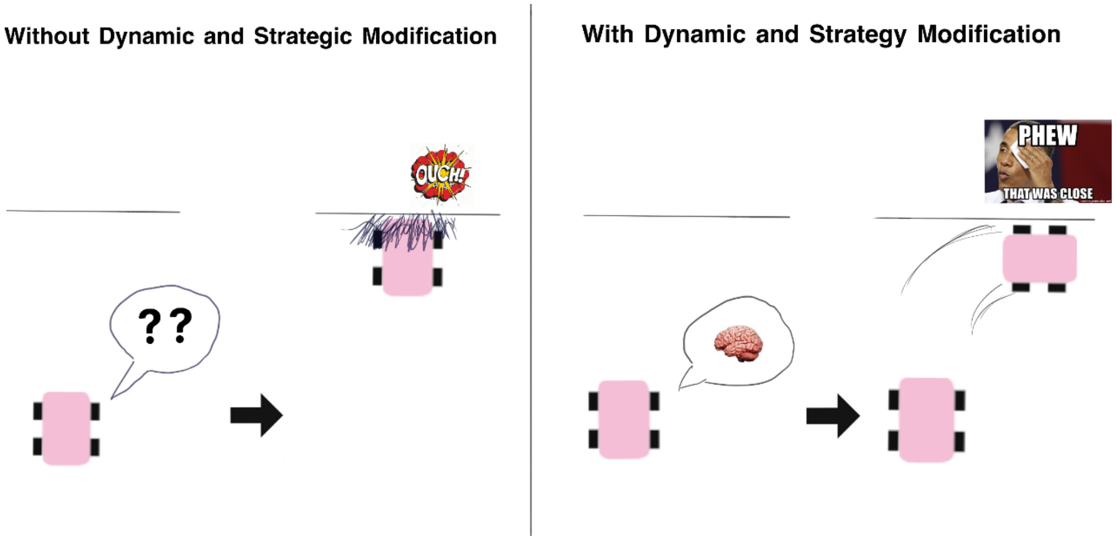


Figure 103: Example of Adaptive Intelligence for the Robot

By integrating real-time data analytics, the robot can continuously assess its performance against set benchmarks. This immediate feedback loop allows the robot to make instant operational adjustments. Furthermore, if the robot identifies an inefficiency in its puck handling or any other task, it can autonomously adapt its strategy, ensuring consistent optimum performance. Traditional robotic systems often rely on pre-programmed sequences to execute tasks. While this approach guarantees consistency, it does not provide the adaptability needed to address unforeseen challenges or changes in the environment. For instance, if a new obstacle appears or the dynamics of the task change, the robot might not respond efficiently.

1. Real-time Data Integration

Implement sensors and cameras that constantly feed real-time data into the robot's central processing unit. This could include information about the robot's environment, its internal state, and the status of the task it's executing.

2. Advanced Analytics and Machine Learning

Leverage machine learning algorithms that can process this data on-the-fly. These algorithms can:
- Predict possible changes or challenges in the robot's environment.
- Recognize patterns and make decisions based on historical and real-time data.
- Learn from previous experiences to optimize future actions.

3. Dynamic Feedback Loops

Establish feedback mechanisms that allow the robot to adjust its actions based on real-time analytics. For instance, if the robot is missing a puck repeatedly, it can recalibrate its sensors or change its approach angle.

4. Modular Strategy Implementation

Develop a modular approach where the robot can choose from a suite of strategies based on the situation. For example, in puck handling, if one technique fails, the robot can quickly switch to another.

Recommendation 4: Enhanced Precision and Movement of the Robot

Current Issue

The robot's current pace, while steady, isn't particularly swift. Additionally, its calibration and alignment, though adequate, don't always ensure precision in its movements.

Recommendation

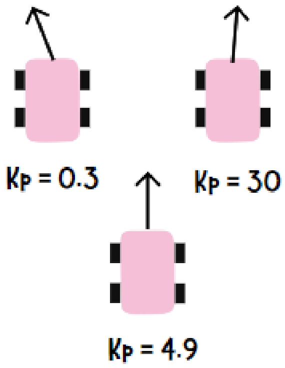


Figure 104: Proportional Gain (Kp) Effects on System Response of the Robot

Reworking the robot's design and control algorithms can boost its operational speed without compromising stability. Meanwhile, refining the calibration processes and algorithms will result in movements that are not just precise but also highly robust, allowing the robot to handle a wider array of challenges with finesse.

Recommendation 5: Adaptive Battery Management

Current Issue

Prolonged and consistent operation can strain the robot's battery, risking premature depletion and potentially reducing its overall lifespan.

Recommendation

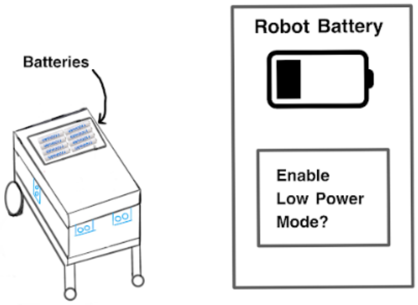


Figure 105: Robot Battery Management and Low Power Mode Interface

Incorporating an adaptive battery management system is pivotal. This system would continually monitor the battery's charge level and modulate the robot's operations accordingly. During lower battery levels, the system can prioritize essential tasks and minimize non-critical functions, ensuring that the robot's operation remains unhindered, and its components are always adequately powered.

Recommendation 6: Implementation of a Colour Sensor Holder

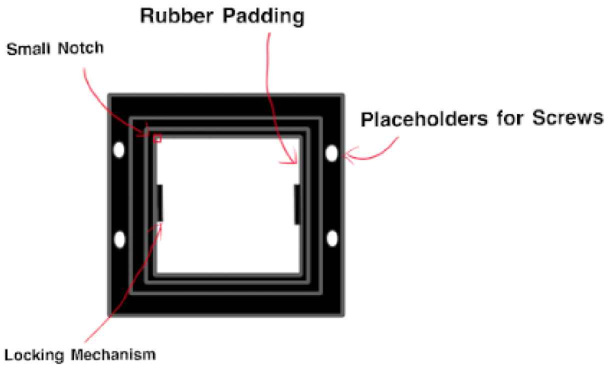


Figure 106: Colour Sensor Holder

Current Issue

While the current color sensor holder design is functional, there are areas of potential refinement to improve its utility and durability, ensuring that the color sensor remains stable and unobstructed during operations.

Recommendation

1. Enhanced Locking Mechanism

The existing locking mechanism can be strengthened by using a more durable material or by implementing a dual-lock system. This would ensure that the color sensor stays securely in place even during high-intensity robot operations.

2. Rubber Padding for Protection

The rubber padding is a great addition for cushioning and preventing any damages to the color sensor. Consider using a higher-density rubber or silicone padding that can absorb more impact and resist wear and tear over time.

3. Streamlined Design

The small notch in the holder can be slightly enlarged or rounded off to allow for easier and quicker placement or removal of the color sensor. This can speed up maintenance times and ensure the sensor is always perfectly aligned.

4. Reinforced Screw Holders

To further secure the holder to the robot, consider using screws with deeper threads or adding an additional washer. This enhancement would provide added stability, ensuring the holder remains firmly attached even under strenuous conditions.

5. Material Selection

Evaluate the current material used for the holder. If it's made of plastic, consider upgrading to a more robust material like aluminum or reinforced polycarbonate to ensure longevity and resistance to environmental factors.

Implementing these recommendations would result in a color sensor holder that's not just secure and durable, but also user-friendly for routine maintenance and adjustments.

8.2 Conclusion

This project stands as a testament to the synergy of mechanical, electronic, and software domains. Through collaborative efforts, we were able to create a puck-flicking robot that not only meets the prescribed project goals but does so with efficiency, precision and cost-effectiveness. Our robot's ability to execute tasks—such as precise movement, puck identification and handling, and accurate color sensing—is a demonstration of the seamless integration of its various subsystems.

Furthermore, our implementation of the obstacle detection feature and the smart backtracking algorithm ensures the robot's longevity by minimizing potential damages from external collisions. Coupled with the Bluetooth communication module, our robot exemplifies modern-day technological innovations, offering a wireless interface that elevates user interaction and convenience.

While the current robot design showcases significant accomplishments, the recommendations detailed in the preceding section underline our commitment to continuous improvement. Embracing innovations like a durable ultrasonic sensor module cover, self-diagnostic capabilities and enhanced precision of our design will ensure that our robot remains at the forefront of design and functionality.

In a nutshell, it is evident that the combined dedication and expertise of our team were instrumental in achieving the commendable results seen in the final design competition. This endeavour is a clear reflection of each member's commitment, underscoring the importance of collaboration in the engineering world and reflection of what is to come as being a competent engineer in the working world.

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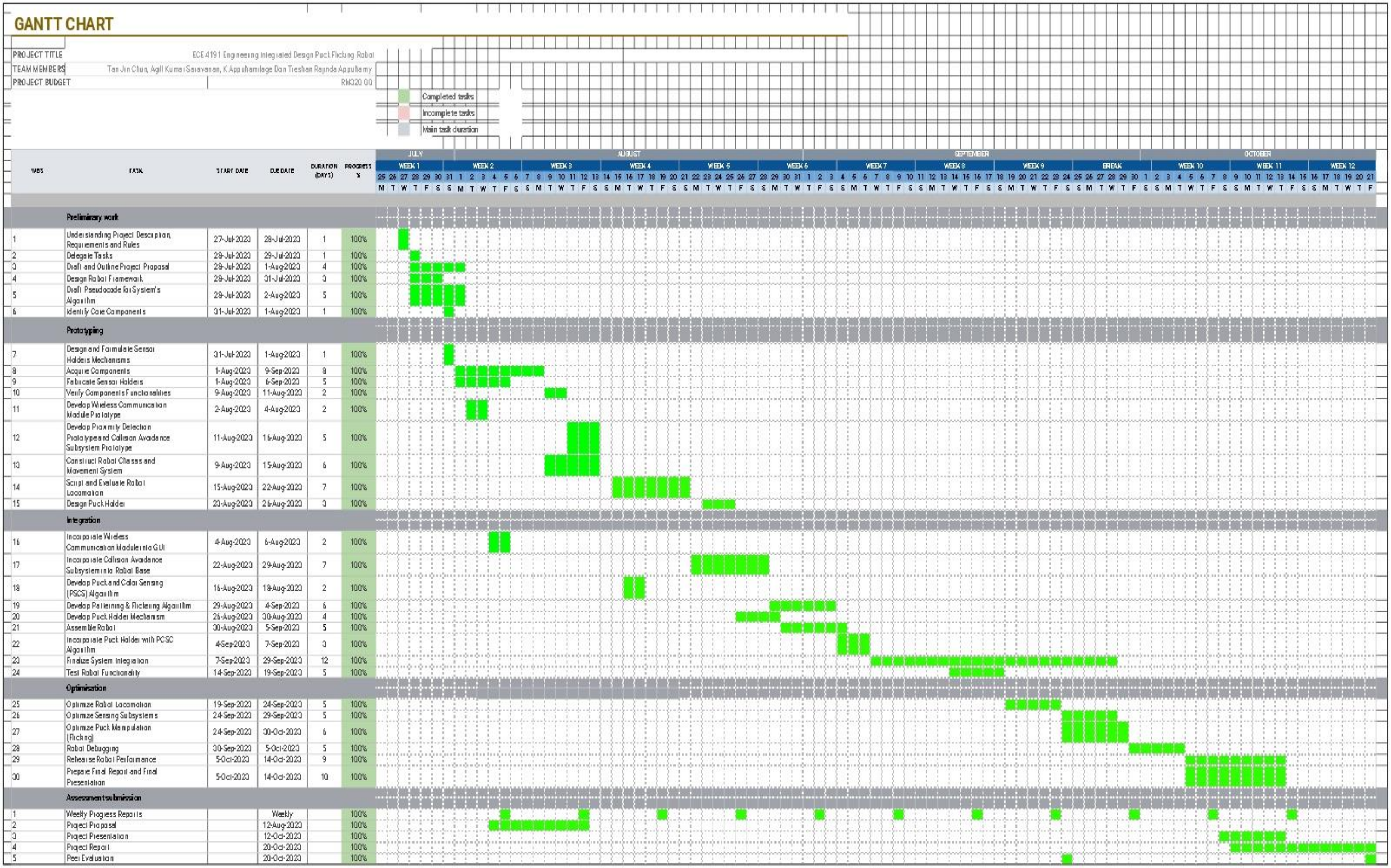
10. Appendix



GANTT CHART

PROJECT TITLE	ECE 4191 Engineering Integrated Design Puck Flicking Robot
TEAM MEMBERS	Tan Jin Chun, Agil Kumar Saravanan, K Appuhamilage Don Tieshan Rajinda Appuhamy
PROJECT BUDGET	RM020.00

- 🟩 Completed tasks
- 🟥 Incomplete tasks
- ▨ Main task duration

WBS	TASK	START DATE	DUE DATE	DURATION (DAYS)	PROGRESS %
	Preliminary work				
1	Understanding Project Description, Requirements and Rules	27-Jul-2023	28-Jul-2023	1	100%
2	Delegate Tasks	28-Jul-2023	29-Jul-2023	1	100%
3	Draft and Outline Project Proposal	28-Jul-2023	1-Aug-2023	4	100%
4	Design Robot Framework	28-Jul-2023	31-Jul-2023	3	100%
5	Draft Pseudocode for System's Algorithm	28-Jul-2023	2-Aug-2023	5	100%
6	Identify Core Components	31-Jul-2023	1-Aug-2023	1	100%
	Prototyping				
7	Design and Formulate Sensor Holders Mechanisms	31-Jul-2023	1-Aug-2023	1	100%
8	Acquire Components	1-Aug-2023	9-Sep-2023	8	100%
9	Fabricate Sensor Holders	1-Aug-2023	6-Sep-2023	5	100%
10	Verify Components Functionalities	9-Aug-2023	11-Aug-2023	2	100%
11	Develop Wireless Communication Module Prototype	2-Aug-2023	4-Aug-2023	2	100%
12	Develop Proximity Detection Prototype and Collision Avoidance Subsystem Prototype	11-Aug-2023	16-Aug-2023	5	100%
13	Construct Robot Chassis and Movement System	9-Aug-2023	15-Aug-2023	6	100%
14	Script and Evaluate Robot Locomotion	15-Aug-2023	22-Aug-2023	7	100%
15	Design Puck Holder	23-Aug-2023	26-Aug-2023	3	100%
	Integration				
16	Incorporate Wireless Communication Module into GUI	4-Aug-2023	6-Aug-2023	2	100%
17	Incorporate Collision Avoidance Subsystem into Robot Base	22-Aug-2023	29-Aug-2023	7	100%
18	Develop Puck and Color Sensing (PSCS) Algorithm	16-Aug-2023	18-Aug-2023	2	100%
19	Develop Patterning & Flicking Algorithm	29-Aug-2023	4-Sep-2023	6	100%
20	Develop Puck Holder Mechanism	26-Aug-2023	30-Aug-2023	4	100%
21	Assemble Robot	30-Aug-2023	5-Sep-2023	5	100%
22	Incorporate Puck Holder with PCSC Algorithm	4-Sep-2023	7-Sep-2023	3	100%
23	Finalize System Integration	7-Sep-2023	29-Sep-2023	12	100%
24	Test Robot Functionality	14-Sep-2023	19-Sep-2023	5	100%
	Optimization				
25	Optimize Robot Locomotion	19-Sep-2023	24-Sep-2023	5	100%
26	Optimize Sensing Subsystems	24-Sep-2023	29-Sep-2023	5	100%
27	Optimize Puck Manipulation (Flicking)	24-Sep-2023	30-Oct-2023	6	100%
28	Robot Debugging	30-Sep-2023	5-Oct-2023	5	100%
29	Rehearse Robot Performance	5-Oct-2023	14-Oct-2023	9	100%
30	Prepare Final Report and Final Presentation	5-Oct-2023	14-Oct-2023	10	100%
	Assessment submission				
1	Weekly Progress Reports		Weekly		100%
2	Project Proposal		12-Aug-2023		100%
3	Project Presentation		12-Oct-2023		100%
4	Project Report		20-Oct-2023		100%
5	Peer Evaluation		20-Oct-2023		100%