# MA4012 Mechatronics Engineering Design

Design of a compact autonomous vehicle

1

**SCHOOL OF MECHANICAL AND AEROSPACE ENGINEERING**

**NANYANG TECHNOLOGICAL UNIVERSITY, SINGAPORE**

**ACADEMIC YEAR**

**2018/2019 S2**


**Idriss Chelikh**
**N1801436C**

**Brenda Tham Jia Hui**
**U1521052H**

**Ju Wen Bo**
**U1621585K**

**Phua Boon Yong Marcus**
**U1621049G**

**Low Wei Lun**
**U1622377E**

**Yang Rui**
**U1621293H**

## Abstract

An Autonomous Vehicle is to be designed to perform basic functions such as edge detection, target tracking, searching and retrieval. The vehicle will be evaluated against other teams' vehicles in an arena competition to search and retrieve tennis balls. The team which collects the most tennis ball will be the winner of each match. This report serves to list the design considerations, design and technical specifications.


2

# Table of Contents

# List of Figures

## List of Tables

# 3

# Objective

The objective of this project is to develop real-life applicational skills in the area of mechatronic engineering design. To execute systematic design engineering process in the aspect of conceptual designing, embodiment design incorporation and the detailed designing of a system. This includes the software programming, control and hardware design, logic design and system performance optimizations.

These all come together in the design of the robot presented in this report.

The key objectives of the robot to be designed is listed below as follows:

1. Reflective lined tape detection on the edge of the arena to stay within the boundaries of the arena.
2. Target searching of tennis balls, opposing vehicles and relative position.
3. Retrieval mechanism for capturing and unloading of said tennis ball.
4. Good stability and workmanship.

# Chapter 1 : Product Design Specification

This chapter will cover the design specifications expected of the robot. It will first cover the limitations imposed by the rules of the competition to set the boundaries of the design not to be crossed.

Next will be the hardware specifications of the robot; namely its structure design, transmission system, sensor application and retrieval system. Subsequently by the software/coding specifications; which sets the precedence for the logic control of the robot.

This chapter will be concluded with the list of supplied materials from the lab for the assignment.

## 3.1 Design Limitations

1. Maximum dimensions of 300mm x 300mm x 300mm and with no increase in footprint upon event commencing.
2. More than half the vehicle must be created from parts provided by the lab.
3. Only one 6-cell AA rechargeable battery pack provided from the lab is allowed to power the vehicle.
4. No additional sensors, servos, motors are allowed over what is provided.
5. Only one tennis ball can be carried at any one time. (additional balls must be released immediately)
6. Throwing or rolling of the ball to the collection point is prohibited.
7. There is no limitations on the number of limit switches allowed to be mounted on the robot.

## 3.2 Hardware Function Design Specification

**Structure**

1. Sufficient structures and fixtures for required actuators and sensors for robot function to be mounted on inclusive of microprocessor and battery pack.
2. Structure design must consider the defence and protection of exposed wirings if any.
3. Overall structure design should not exceed 1.5kg for weight and power consumption management.
4. Structures to assist the retrieval system to position the ball for a higher retrieval rate.
5. Ability to withstand head-on and side collisions without robot being disabled.
6. Do not exceed 300mm x 300mm x 300mm in dimension.

**Movement**

1. Reliable drive or transmission system for linear movement of robot; maximum deviation of linear movement during forward/rear of 100mm over a distance of 1m.
2. Rapid and fine linear movement for travelling and positioning.
3. Reliable drive or transmission system to enable 360° rotation about a pivot point.
4. Rapid and fine rotational motion for quick turning or positioning.

**Retrieval**

1. Retrieval mechanism to pick up a tennis ball of 65mm with a success rate of 80%.
2. Storage/securing capability to transport tennis ball after retrieval even in a collision situation during return to collection area.
3. Retrieval and/or storage design should ensure only one tennis ball is picked up/stored at once.

4. Retrieval mechanism should be simple, easy to maintain, troubleshoot and repair.

**Sensors**

1. Sufficient and appropriate usage of sensors to detect the boundaries of the arena.
2. Sufficient and appropriate usage of sensors to detect a tennis ball of 65mm.
3. Sufficient and appropriate usage of sensors to detect opposing robots to avoid collision and/or entanglement.
4. Sufficient and appropriate usage of sensors to detect when tennis ball has been successfully retrieved.
5. Sufficient and appropriate usage of sensors to detect relative position and orientation to the collection area.
6. Appropriate usage of sensor to activate robot upon commencement of match and deactivate the robot when necessary.

## 3.3 Software/Coding Function Design Specification

As the design of the software/coding is intertwined with the physical application and positioning consideration of the sensors. The specifications here will be linked to the sensor function specifications defined in Section 1.2.

**Software/Coding**

1. Boundary sensing: Stop the robot from moving any further and reposition itself to steer away from the boundary to resume searching. Additionally, make the appropriate repositioning depending on the side of boundary trespass.
2. Tennis ball detection: Detect the tennis ball from a distance of 150mm in a 2.4m by 1.2m arena, then directing the robot to move towards it. Detect when the tennis ball is at a distance sufficient and engage the necessary actuators needed to retrieve it. Differentiate between tennis ball and other objects in the arena.
3. Robot detection: Detect when there is a chance of collision with the opposing robot within 30mm and reposition itself to avoid collision. Differentiate between opposing robot and other objects in the arena.
4. Tennis ball capture detection: Detects the capture of the tennis ball in the retrieval mechanism and directs the robot to return to the collection area and engage the actuators needed to unload the ball.
5. Position and orientation: Track and provide the necessary values for the robot to reorient itself to return to the collection area to unload the ball.
6. Start/Stop: To ease handling of the robot for troubleshooting and control in the arena. A start switch to initiate the code within 0.25s for the match and a stop switch the kill, reset and standby the code.

## 3.4 List of materials provided by lab

| S/ N | Description of item | Quantit y | Remarks |
|---|---|---|---|
| 1 | Vex ARM Cortex-Based Microcontroller | 1 | |
| 2 | Vex USB A-A Tether Cable | 1 | |
| 3 | NiMH Battery Pack 7.2V, 3000mAH | 1 | |
| 4 | Battery Extension Cable | 1 | |
| 5 | Vex Smart Charger and AC Power Cord | 1 | |
| 6 | Vex Gear Kit | 1 | set |
| 7 | High Strength Gear Kit, P/N: 276-2250 | 1 | set |
| 8 | Wheel (Low Friction) | 4 | |
| 9 | Vex Metal & Hardware Kit | 1 | lot (list in appendix) |
| 10 | Vex Continuous Rotation Motor (276-2163) | 2 | |
| 11 | Position Servo Motor (Vex Servo) | 1 | |
| 12 | 2-Wire Motor 393 | 2 | |
| 13 | Motor Controller 29, P/N: 276-1668 | 2 | |
| 14 | Sharp Distance Sensor (10 To 80Cm) | 3 | |
| 15 | Sharp Distance Sensor (4 To 30Am) | 1 | |
| 16 | Reflective Sensor (OPB704W) | 4 | |
| 17 | 2 pcs Allen Keys (5/64" And 3/32"), 1 pc 9mm Spanner, 1 pc Screwdriver | 4 | |
| 18 | Limit Switch with Interface Cable | 5 | |
| 19 | Digital Compass (1490) | 1 | |

*Table 1: List of materials provided by lab*

# Chapter 2 : Embodiment Design

Going through the process of embodiment designing allows for a systematic design to ensure the three universal rules for embodiment design namely, **Clarity**, **Simplicity** and **Safety**.

## 4.1 Rules of Embodiment Design

At a glance, the user should be able to determine the purpose of a product. **Clarity** is important for the function of a product to be explicitly clear for the user to prevent unintended uses or failures.

This ties in with the **Safety** aspect where the inappropriate or mishandling of the product can result in harm to the user and damage to the product.

The final aspect, **Simplicity** deals with reducing complexity of the parts for modular assembly and reducing the number of parts further reducing reliability failure. A balance is needed between lesser parts but more complex ones to make production effective.

These three rules are universal, and all designs must satisfy them.

## 4.2 Principles for Embodiment Design

The principles cover four aspects, **Force Transmission**, **Division of Tasks**, **Self-help** and **Stability and Instability**. These principles are not universal and are not applicable for all designs.

## 4.3 Embodiment Design application

The embodiment design rules and principles applied in the robot will be covered subsequently in the conceptual and detailed design chapters.

# Chapter 3 : Conceptual Design

## 5.1 Market research

A literature search on autonomous tennis ball picking mechanisms presented a few ideas for consideration. A Kickstarter project called the Tennibot [1, Fig. 1] is one such result. It utilizes a stationary position tracking station which tracks Tennibot on the court and autonomous or manual control via phone by the user. Tennibot utilizes a **wide angle camera** with two **inward rotating rollers** to detect and launch any tennis balls caught in its mouth into a **trailing bucket**. It also utilizes a form of **differential steering**. **Guiding arms** were also installed to funnel any balls into its mouth during its forward motion

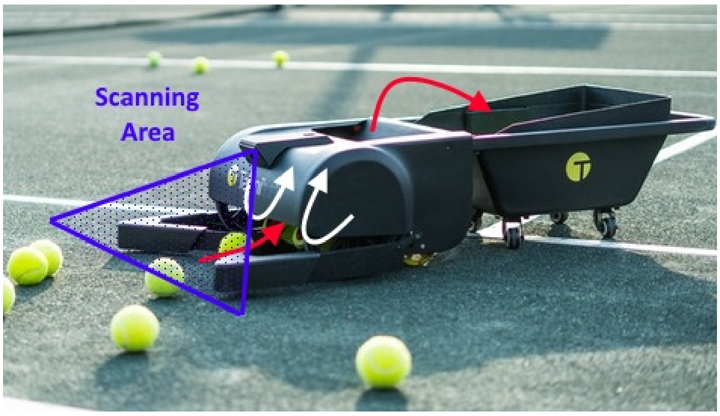



*Figure 1: Tennibot working concept*

## 5.2 Function analysis and preliminary logic flow-chart

To aid the team in having a common direction in the design of the robot. A function analysis and a preliminary logic flow-chart is first agreed upon.

### 5.2.1 Function analysis

The main function analysis is illustrated below in Fig. 2.

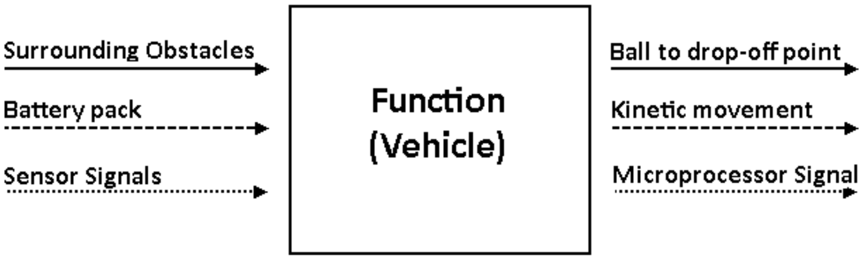



*Figure 2: Main function analysis*

### 5.2.2 Preliminary logic flow-chart

The preliminary logic flow-chart illustrated in Fig. 3 provided an overall perspective of the tentative sequential actions of the vehicle, which sets the context for the team to further develop the sub-functions of the vehicle.

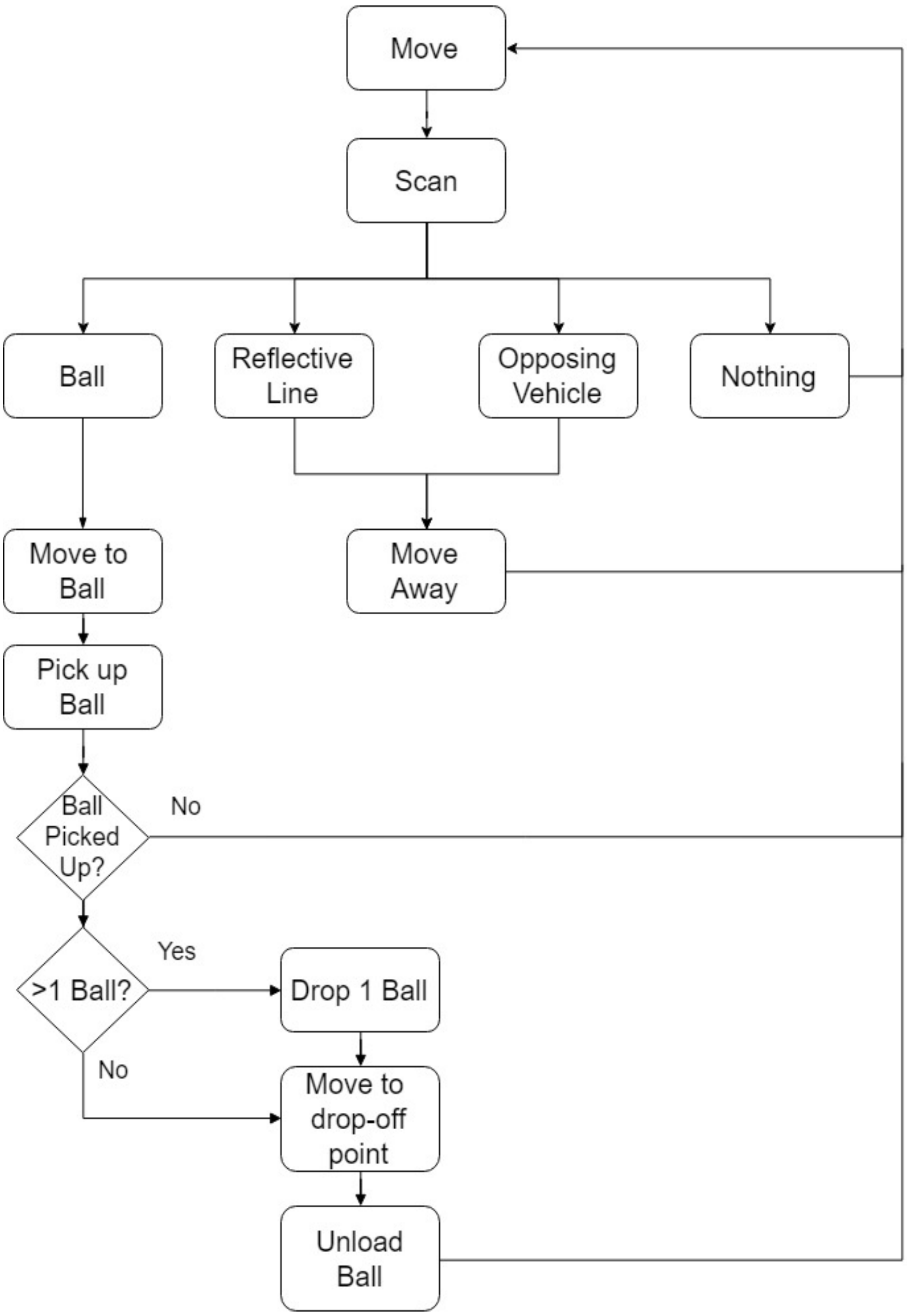



*Figure 3: Preliminary logic flow-chart*

### 5.2.3 Sub-function analysis

Illustrated below in Fig.4 is the sub-function analysis.

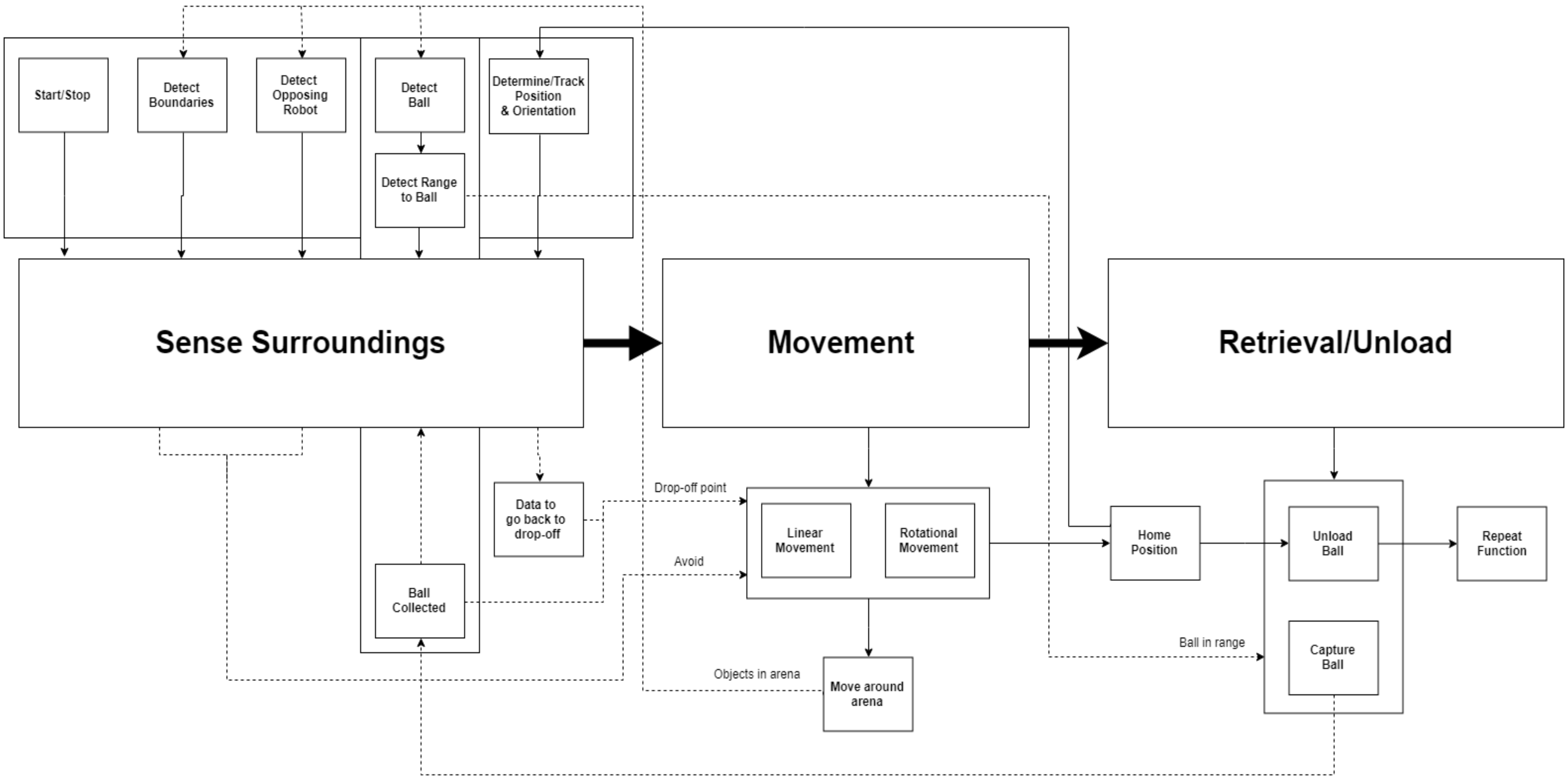



*Figure 4: Sub-function analysis*

## 5.3 Morphological chart

From the sub-function analysis and flow-chart above, we infer that two main design aspects of the robot, **Movement** and **Retrieval** need to be decided upon before structural, sensor utility and software/coding can be developed upon.

This section will cover the concepts and ideas generated for these two aspects by the team.

### 5.3.1 Movement

- M1 – 2 rear wheels driven by 2 motors individually with 2 front rollers.

- M2 – 2 rear wheels driven by 2 motors. 2 front wheels free spinning on a common shaft which is rotated by a motor.

- M3 – 2 wheels powered by 2 motors with 1 front roller

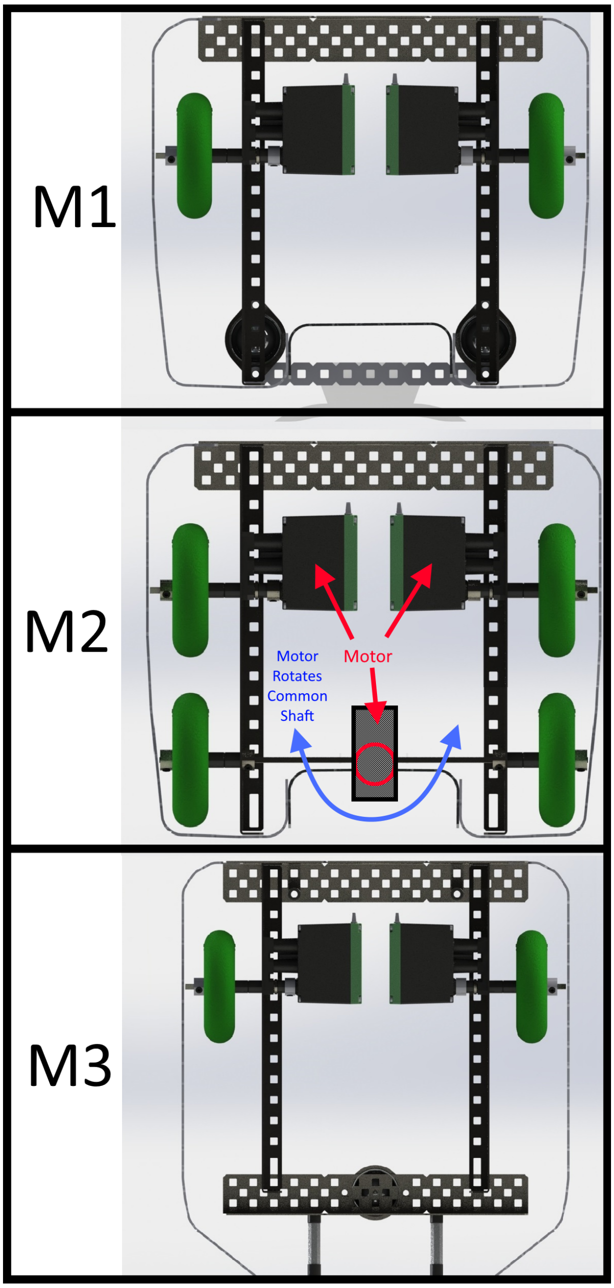



*Figure 5: Movement Morphological Chart*

Using various characteristics as a basis, a comparison table was made for **Movement** to aid us in deciding the subsequent direction to design our structure around.

| Move | M1 | M2 | M3 |
|---|---|---|---|
| Stability | • | • | |
| Fine turning | • | | • |
| Simple design | • | • | • |
| Less drag | • | • | • |

*Table 2: Comparison table for Move*

M2 uses the **Turntable Steering** method which maneuvers by orientating the axles of both wheels pointing towards a common point [2, Fig. 6]. M2 is a simple design and achieves the linear requirements, however it is unable to turn on the spot which does not fulfill the **Movement** design specification as the ability of the vehicle for efficient and fine positioning to capture the ball or avoid obstacles is limited. Additional complexity will also be invited into the programming and calibration of the vehicle as compared to M1 and M3. They make use of **Differential Steering** which will enable the vehicle to rotate around the center point of both rear wheels as shown in Fig. 7.

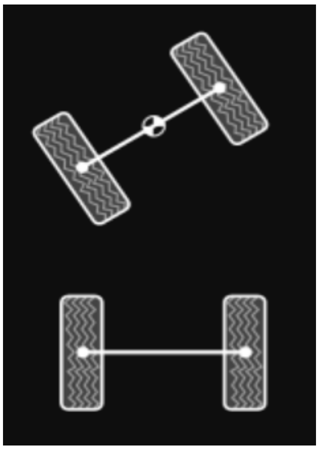


*Figure 6: Turntable steering*

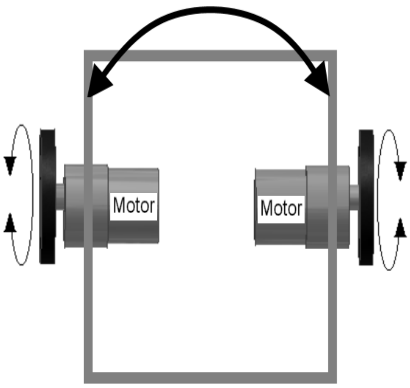



*Figure 7: Differential steering*

Amongst the three concepts, **M1** is chosen as the **Movement** concept as it provides better stability compared to M3 in a situation where collision occurs between two vehicles. Both have appealingly good stability in a head-on/head to rear collision. However, M2 with only one front roller has lower stability in a rear diagonal collision as compared to M1.

### 5.3.2 Retrieval

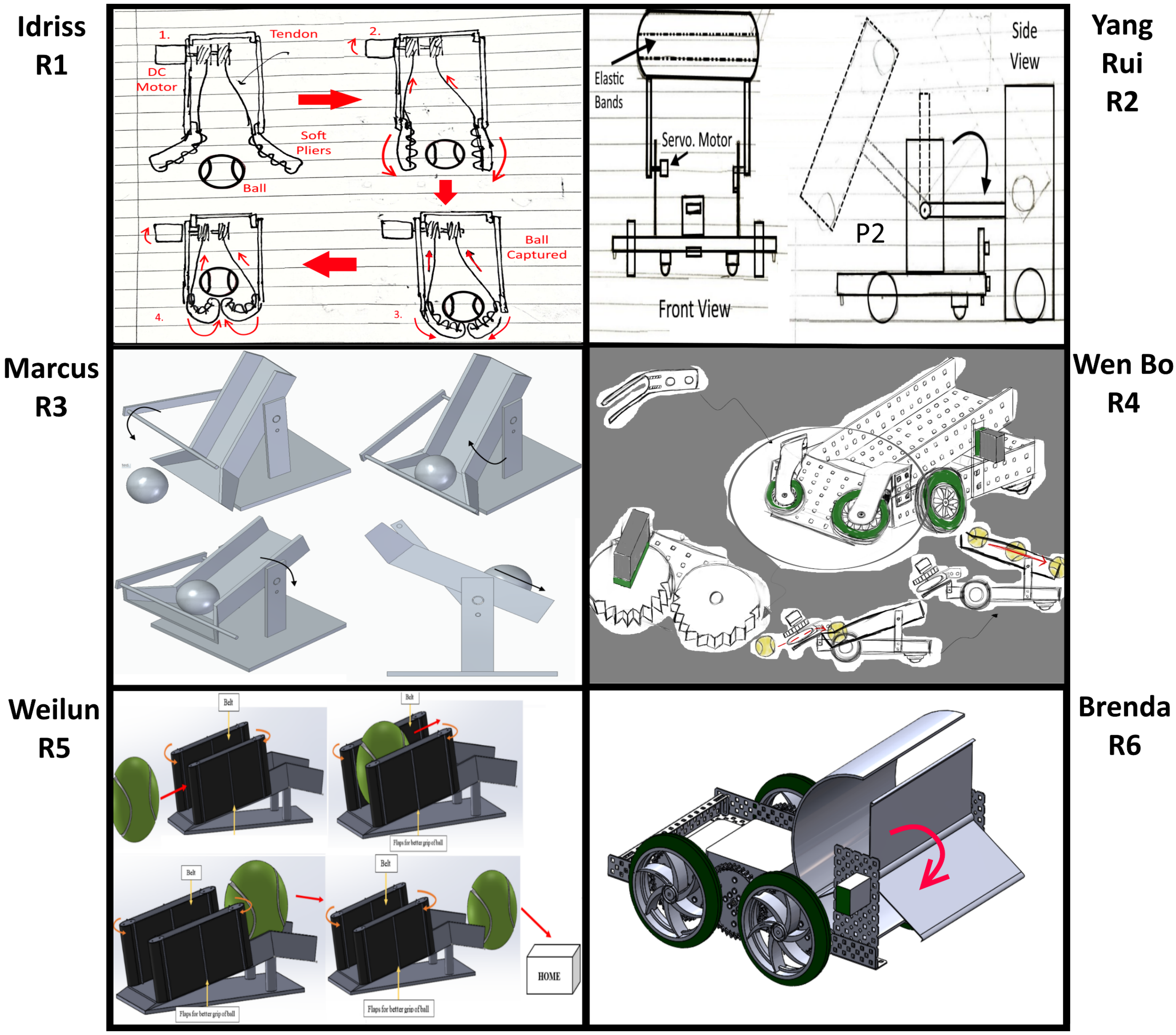



*Figure 8: Retrieval Morphological Chart*

- R1 – Silicon soft pliers are designed with internal tendons. The tendons are motor driven to retract the pliers, the material choice for the pliers are to be of sufficient elasticity for manipulation and recover to its original shape when tension from the tendons are released. The pliers will then be lifted and tilted backwards over the robot followed by easing the tension on the tendons to unload the tennis ball.
- R2 – A cylindrical shape tube will be equipped with elastic bands of sufficient tension to allow a tennis ball to get through them when the tube is pressed down over it but does not allow it to fall back out. The tube will then be tilted over backwards over the robot to unload the tennis ball.
- R3 – This idea utilizes a scooping concept; the robot will constantly move forward towards a detected ball, when it is within capture range the handle will lower to trap the ball within the scoop. The lever and scoop will then tilt upwards to unload the tennis ball by gravity.
- R4 – This concept follows the approach of Tennibot (Section 3.1), with the addition of an unloading mechanism for its storage.
- R5 – This concept also follows the approach of Tennibot, instead with two conveyor belts rotating inwards. The robot will also similarly move forward to any detected balls which funnels in the tennis ball between the belts. The belts will stop rotating when the ball crosses the middle of the robot and resumes rotation at the collection area.

- R6 – A flapper driven by a continuous motor will constantly rotate, the robot will also similarly move forward to any detected balls to funnel the tennis ball under the flapper. The rotation will stop and hold the ball in place until the collection area where it would then continue its rotation and flip the ball out of the 'c-shape' and into the drop-area zone.

Similarly a comparison table was made for **Retrieval** as shown in Table 3 below.

| Retrieval | R1 | R2 | R3 | R4 | R5 | R6 |
|---|---|---|---|---|---|---|
| Able to pick ball | • | • | • | • | • | • |
| Accuracy | | • | • | | | |
| Able to store ball | • | • | • | • | • | • |
| One ball only | • | | | | | |
| Flexibility | | • | • | | | |
| Simple design | | • | • | • | • | • |
| Simple to install | | • | • | • | | • |
| Moving parts | | | | • | • | • |

*Table 3: Comparison table for Retrieval*

All R options appear feasible and when operated in favorable conditions can achieve the capturing of a tennis ball**.** However, in reality favorable conditions do not present themselves often. Our design needs to consider besides its **ability to operate in favorable conditions** and its **ability to operate in its most unfavorable conditions**. A list of unfavorable situations or conditions and their perceived likelihoods values are listed below. (on a scale of 1 to 5, where 1 is least likely to occur and 5 the most likely to occur)

**<u>Conditions</u>**

1. Ball rolling away from vehicle (5)
2. Ball rolling across in-front of vehicle (5)
3. Ball in a corner (4)
4. Vehicle hit by opposing vehicle from the side while picking (3)
5. Vehicle hit by opposing vehicle from the rear while picking (2)

6. Vehicle hit by opposing vehicle from the front while picking (2)
7. Vehicle hit by opposing vehicle with ball in transit (2)
8. Vehicle hit by opposing vehicle with ball while unloading (2)
9. Vehicle hits another vehicle while returning to collection area (sensing) (2)

The in-depth analysis of each concept will not be explored here but the ability and likely feasibility of the concepts to handle the above situations.

| **Concept** | **R1** | **R2** | **R3** | **R4** | **R5** | **R6** |
|---|---|---|---|---|---|---|
| **Situations** | 3,5,7,8,9 | 2,3,5,6,7,8,9 | 1,2,5,7,8,9 | 1,4,5,6,7,8,9 | 1,4,5,6,7,8,9 | 1,2,5,6,7,8,9 |
| **Weightage** | 11 | **19** | 18 | 18 | 18 | **20** |

*Table 4: Retrieval weightage concept weightage*

The strong contenders as seen from Table 3 and 4 is R2, R3 and R6, which will be further compared to make our decision.

R6's flappers require the tennis ball to be at an appropriate distance for it to be swept under for capture, or its rotating motion would likely nick the ball to move further away or sideward. The moving parts of R6 also pose a risk of being tangled up with an opposing robot if it fails to differentiate between the robot and a tennis ball.

R2 and R3 leverage on a wider capture zone but R2 requires better ball detection tuning. There is also a higher chance of entanglement for R3 compared to R2 due to its lever arm.

All 3 are viable options; however, there is fewer moving parts to be installed and the simplicity of design is the direction the team strives for hence R2 is selected as the concept of choice for our **Retrieval** design.

## 5.4 Prototype

### 5.4.1 Retrieval Conceptual Prototype

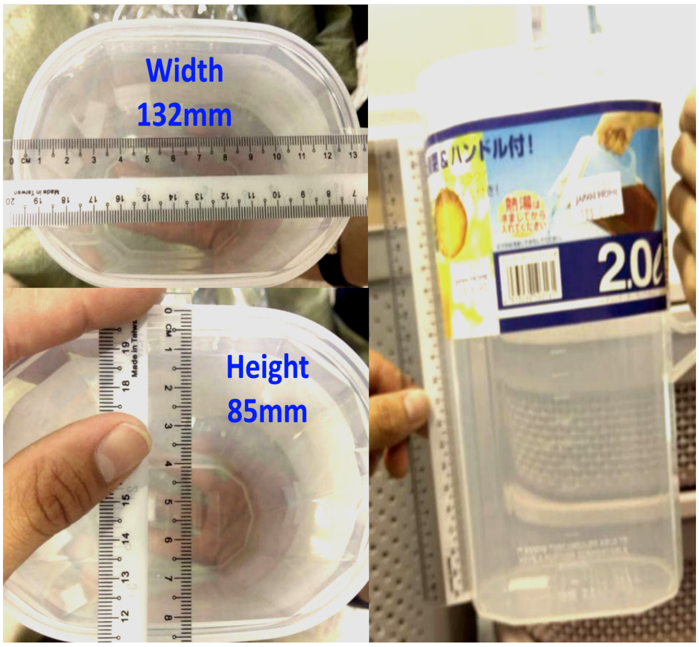



*Figure 9: Water storage container*

A store-bought water storage container from Japan Home (Fig. 9) was used to develop the prototype to test out the **Retrieval** concept. Excess material was removed to reduce weight and the load on the driving motor, and an opening was made for the ball to roll out when tilted back. A slot for a limit switch was also made which will tell the robot that a ball has been collected. Grooves were also cut into the lip of the container to allow mounting of the elastic bands as shown in Fig. 10 below.

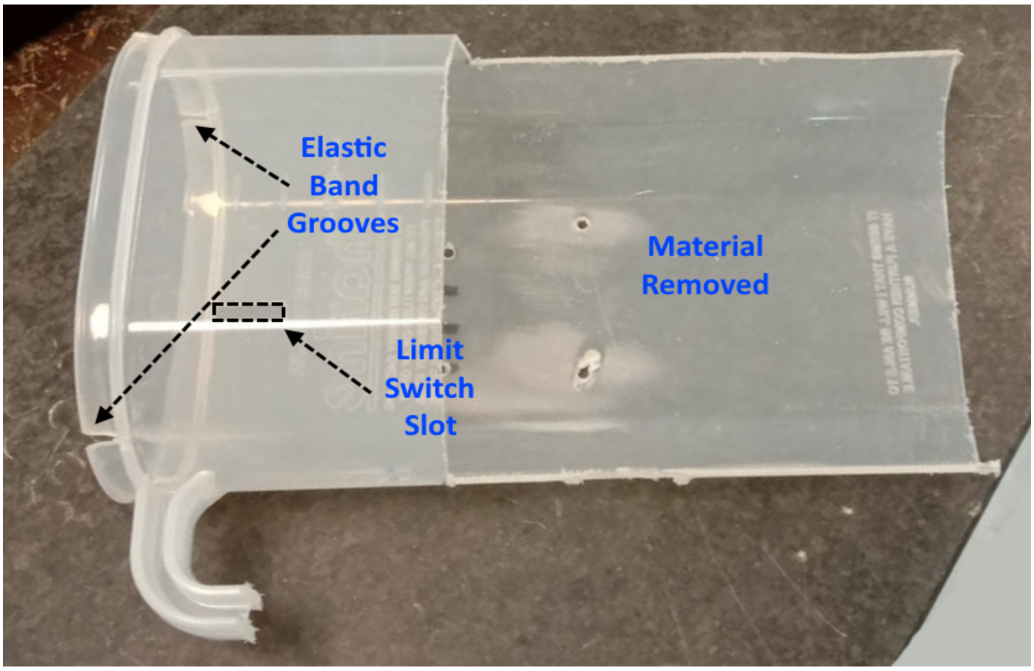



*Figure 10: Retrieval prototype*

The elastic bands and limit switch were installed, and sharp corners and edges were taped up for safety purposes. The prototype is then mounted onto an arm linked to a driving motor which will be used to lower it over the tennis ball as shown in Fig. 10. The concept uses the weight of the prototype is to aid in lowering it over to capture the ball (**Self-help**).

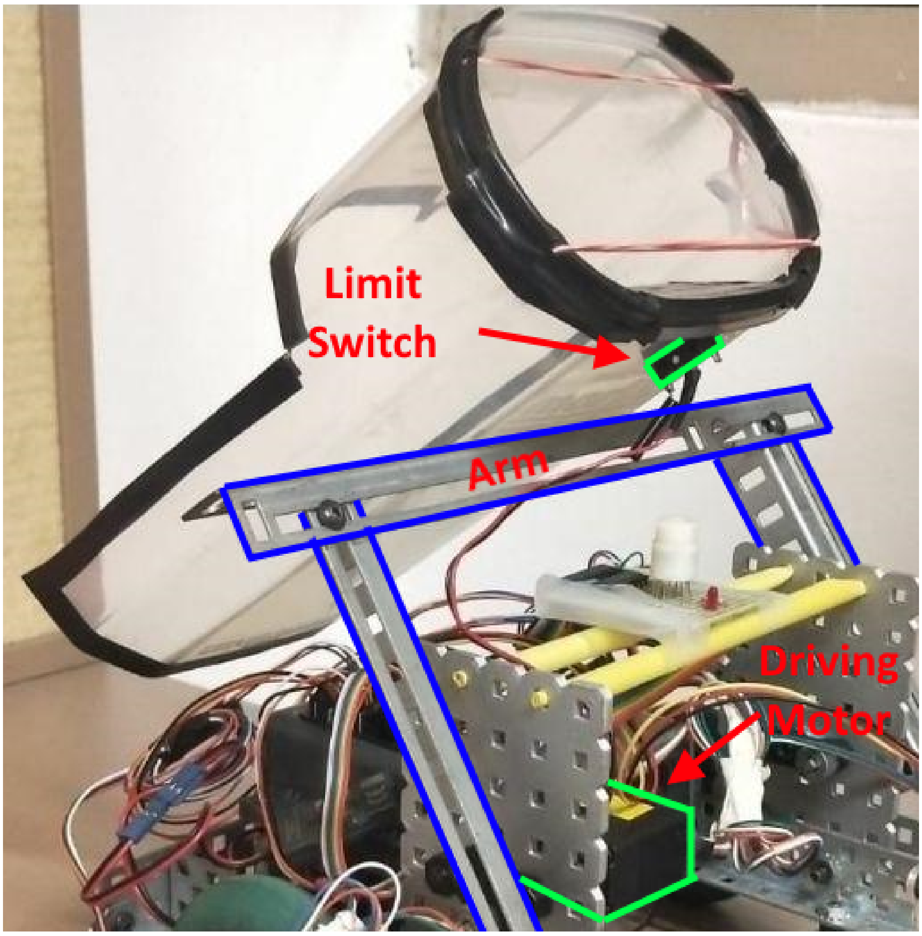



*Figure 11: Retrieval prototype mounted in armed/unload position*

Preliminary testing of the prototype has shown success in capturing, securing and unloading tennis balls which lends credibility to our choice of conceptual design and fulfills 3 out of 4 of our **Retrieval** design specifications. As the mouth opening is too wide, there is a possibility of capturing two tennis balls unwittingly.

However, after 5 – 10 attempts of testing the prototype, the motor was found to be unable to supply enough power to raise the mechanism to lift the ball and retract to its armed/unload position.

Further investigation entailed that the driving motor used is a servo motor, with a stall torque of 0.7344 Nm (data sheet in Appendix). The motor has likely been in usage for several years, there is suspected wear of the gears. The motor has a rating voltage of 4.4-9.1 volts. However, with a supply voltage of 5 volts, there is a definite reduction in torque. The actual torque for the motor used was estimated to be about 0.35Nm. The length between the motor shaft centre to the centre of mass of the cup was about 136mm.

The prototype was measured to be 0.11kg , the arm and fixtures amounted to 0.15kg. The total weight has nearly exceeded the lifting force of the driving motor which has not considered the weight of the tennis ball (0.0585kg). Thus, reducing the weight of fixtures and the capturing mechanism was essential to generating enough force to lift the captured tennis ball.

Hence the team has decided to 3D print the capture mechanism to limit the mouth opening size to achieve this specification and also to greatly reduce its weight for motor efficiency and capturing force.

### 5.4.2 Sensor mounting

To increase the amount of flexibility of mounting the sensors , 3D printed parts will be designed to mount the sensors when deemed necessary.

#### 5.4.2.1 Front/Rear detection

For front and rear detection, two mounts as seen in Fig. 12 is printed to hold one distance sensor horizontally and one vertically. With this in mind, by installing the lower distance sensor vertically, the receiver is in line with the transmitter; reducing the chance of diffused reflection caused by sensing the edge of the tennis ball resulting in ambiguous readings. In addition, it shortens the receiving time of the reflected IR light (**Self-help & Division of tasks**).

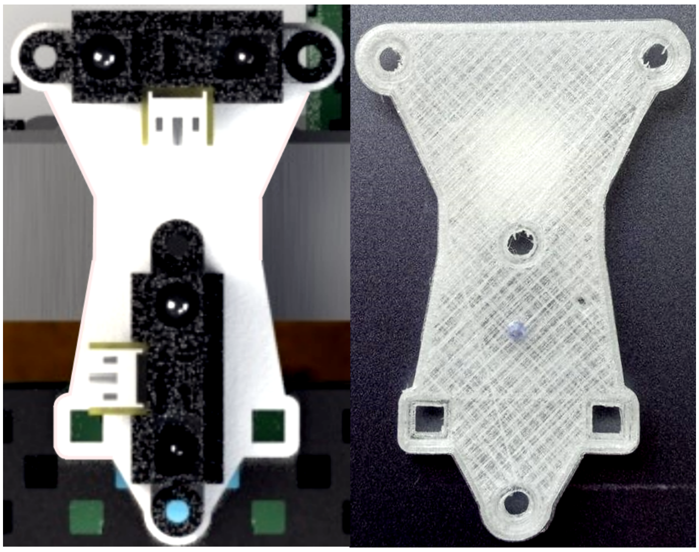


*Figure 12: Front and rear sensor mount prototype*

**Front sensors**

Putting this ideology into appreciation, the front sensors aims to improve the accuracy of the robot to capture the tennis ball; by reducing the reaction time of the system to detect the ball and for it to more accurately position itself facing the ball before it proceeds to pick it up. In contrast the upper distance sensor is installed horizontally, as the opposing vehicle is larger, the effects of diffused reflection is inconsequential to detect the opposing robot.

**Front sensors testing**

Testing of the set-up in contrast resulted in the robot having difficulty detecting the tennis ball. This led to suspicions that having the distance sensor placed horizontally limited the scanning fan of the sensor into a line which got glanced over at times when the robot turns too swiftly.

**Rear sensors**

The vertical rear sensors are for detecting the collection area wall, while the horizontal one is to 'peek' over the wall to confirm the collection area instead of an opposing robot.

**Rear sensors testing**

Operational testing of the rear sensors was successful.

**Further development**

It is believed that having only one distance sensor vertically to detect the ball is insufficient. Two distance sensors horizontally shall be attempted. Rear detection is successful but due to a logistic limitation of only four distance sensors, another means of detecting when the robot has reached the collection area has to be generated. Possible usage of reflective sensors or limit switches.

#### 5.4.2.2 Boundary detection

Boundary detection would make use of the reflective sensors. They would be placed at the corner extremities to cover all 4 quadrants of the robot as shown in Fig. 13.

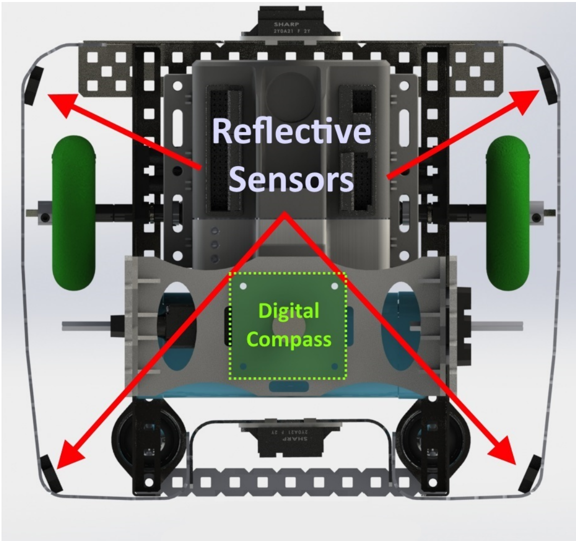


*Figure 13: Reflective sensor and digital compass positions*

Testing of boundary detection with the sensors have been relatively successful. A 30% chance of failure to detect is noticed. Suspicions do not lie with the mechanical design but rather the coding concept. Initially, boundaries were distinguished from the black arena floor when values returned by a reflective sensor were below a pre-specified limit value. However, these proved to be inefficient as the limit values changed each run. As a result, the robot was at times confused and operated in an unreliable and unintended way. A possible solution would be dynamic values for more robustness.

Testing of the set-up in contrast resulted in the robot having greater difficulty detecting the tennis ball. This led to suspicions that having the distance sensor placed horizontally limited the scanning fan of the robot to detect the tennis ball.

#### 5.4.2.3 Position/Orientation detection

According to its data sheet (attached in Appendix), the Digital Compass is internally designed to respond to a directional change similar to a liquid compass. Its only requirement is to be mounted in a vertical position. Testing conducted regarding the position of the digital compass as long as it is installed vertically has been successful. It will be installed at the top center of the robot as shown in Fig. 13.

#### 5.4.2.4 Ball capture detection

The limit switch position installation in the Retrieval prototype as seen in Fig. 11 is suitable for ball capture detection. The radius of the ball is wide enough to activate the limit switch most of the time. The concept for ball capture detection is sound. Improvements can be made to ensure that the captured ball has a higher activation chance of the limit switch.

### 5.4.3 Prototype Assembly

The assembled prototype is illustrated in Fig. 14 below.

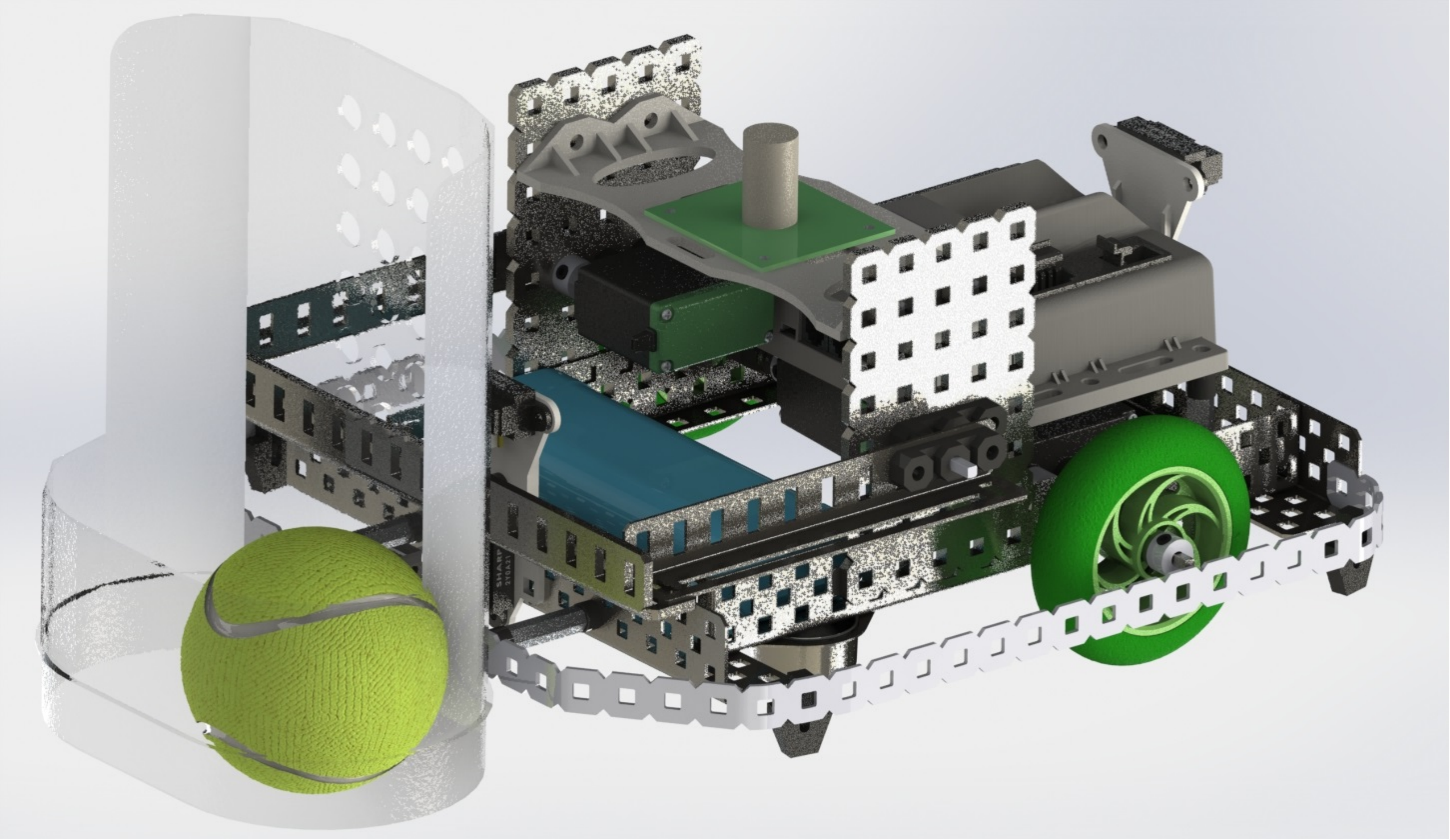


*Figure 14: Conceptual Prototype*

# Chapter 4 : Detailed Design

The detailed design of the robot chapter shall be discussed in three layers proceeding upwards from the bottom to show all its components. First mention of the components from the **Vex Metal & Hardware Kit** (item list attached in Appendix) in this chapter will be indicated **bold.**

## 6.1 Layer 1 – Transmission and basic structure

This layer will focus on the transmission system and its basic structure.

As concluded in Section 3.3.1, two rear wheels driven by two motors individually with two front rollers using differential turning will be the transmission system used to manoeuvre our robot.

Two Vex Continuous Rotation motors are installed into one end of a **chassis bumper** each. The shafts are directly connected to two wheels through the bumpers. The chassis bumpers are then held in place both facing inwards on a **chassis rail**. Work rollers (Fig. 14) are installed on the other end of the chassis bumpers each.

*Figure 15: Work roller*

Three **long bars** are cut and bent to form a railing around the bumpers and rails. The long bar at the front of the robot is concaved inwards to enable space for sensor installation to keep within the 300mm dimension limitation.

A 3D printed flexible concaved semi-circle like part was printed and installed onto the frontmost long bar. This part serves as a herding device to push away any tennis balls in the 'dead zone' (areas where the distance sensors are unable to detect the tennis ball) and also funnel any tennis balls within it closer to the centre point of the robot for easier capture.

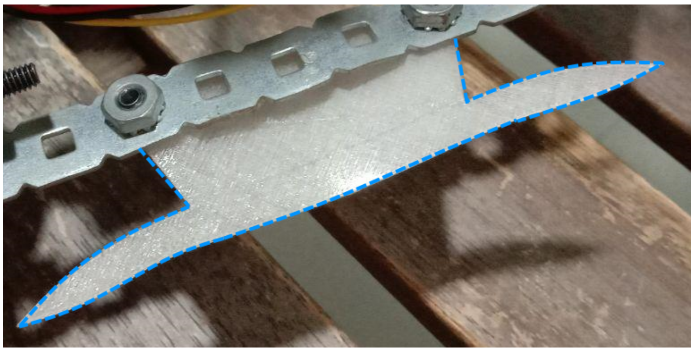


*Figure 16: 3D printed part*

Layer 1 is illustrated in Fig. 16 below.

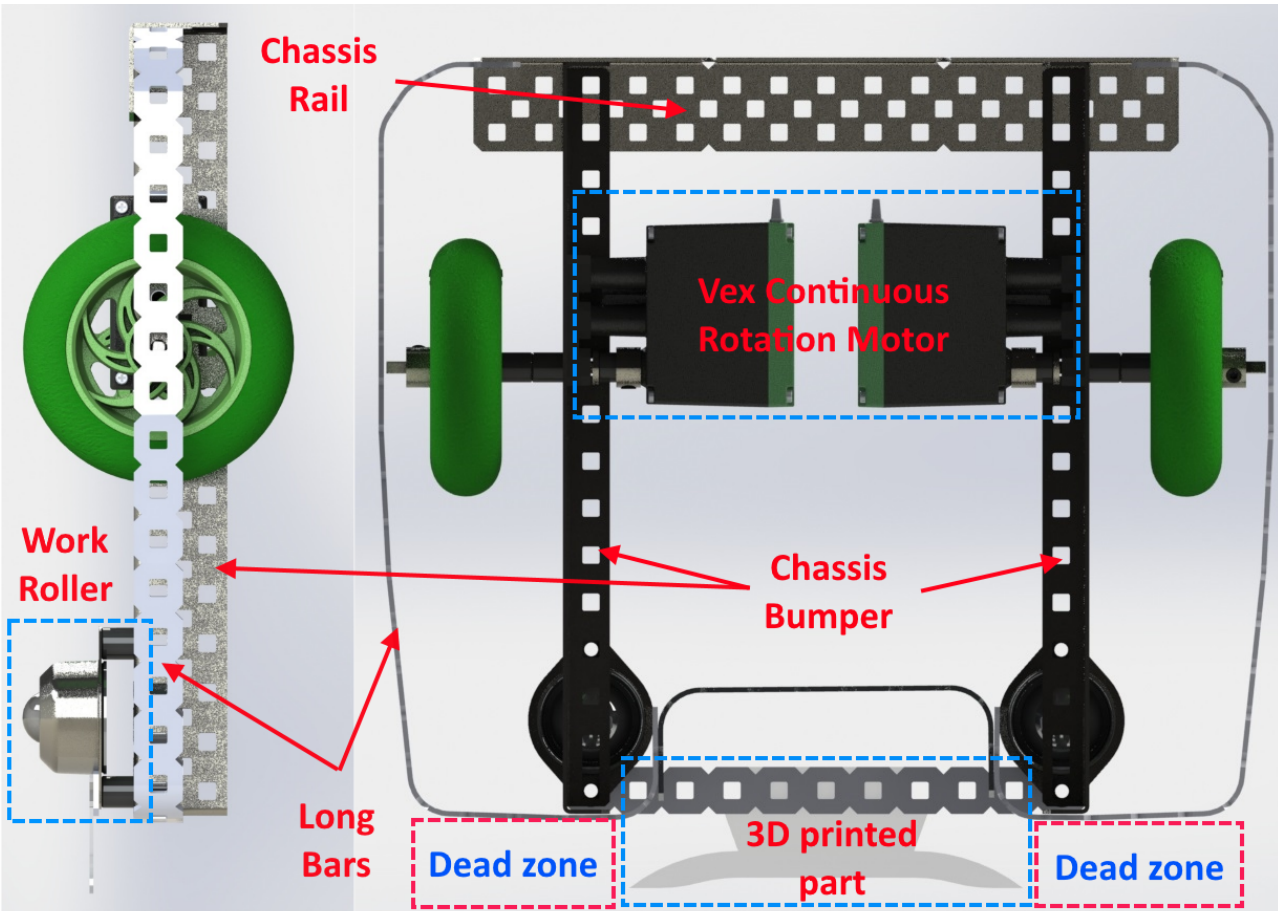



*Figure 17: Layer 1 – Transmission and basic structure*

### 6.1.1 Torque and friction calculations

## 6.2 Layer 2 – Sensor integration

The two rear corners of the Vex Microcontroller are installed on **threaded beams** over the motors on the chassis rail. The battery pack will rest in between the chassis bumpers. It is the significantly heaviest electronic component and by putting it as low as possible, it will bring the center of gravity lower providing better stability for the robot (**Self-help & Stability)**.

This layer will focus on the finalized positioning of the sensors, the thought processes implemented into its design and the coding functions of the sensors.

### 6.2.1 Front/Rear detection

In the initially conceptual design, there were two sensors placed at the front and two at the back. In the final phases of the project, this was deemed ineffective as at times, the robot would detect a ball, approach it but miss the ball due to a tendency to tilt slightly. The search function would then resume. To avoid this issue, one sensor was removed from the back and brought to the front and placed sideways to the lower sensor. A new front sensor

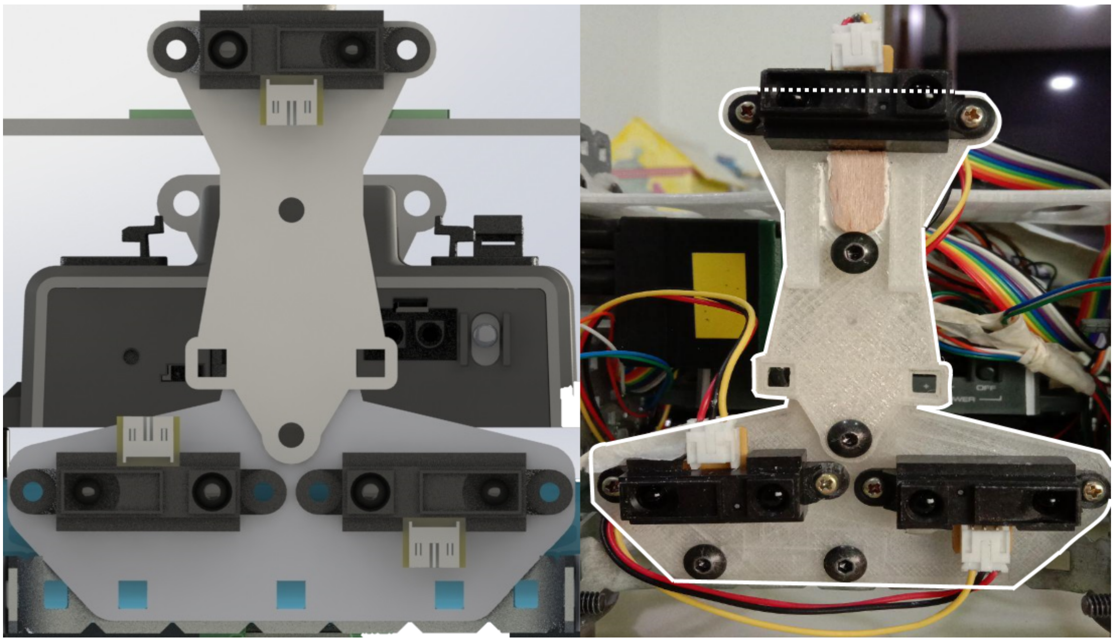


*Figure 18: New front sensor mount*

mount was 3D printed to mount the three sensors together as shown in Fig 18.

One back sensor was left at the back for detection of the collection area or pause in the event of enemy detection. To distinguish the

# Chapter 5 : Reflection

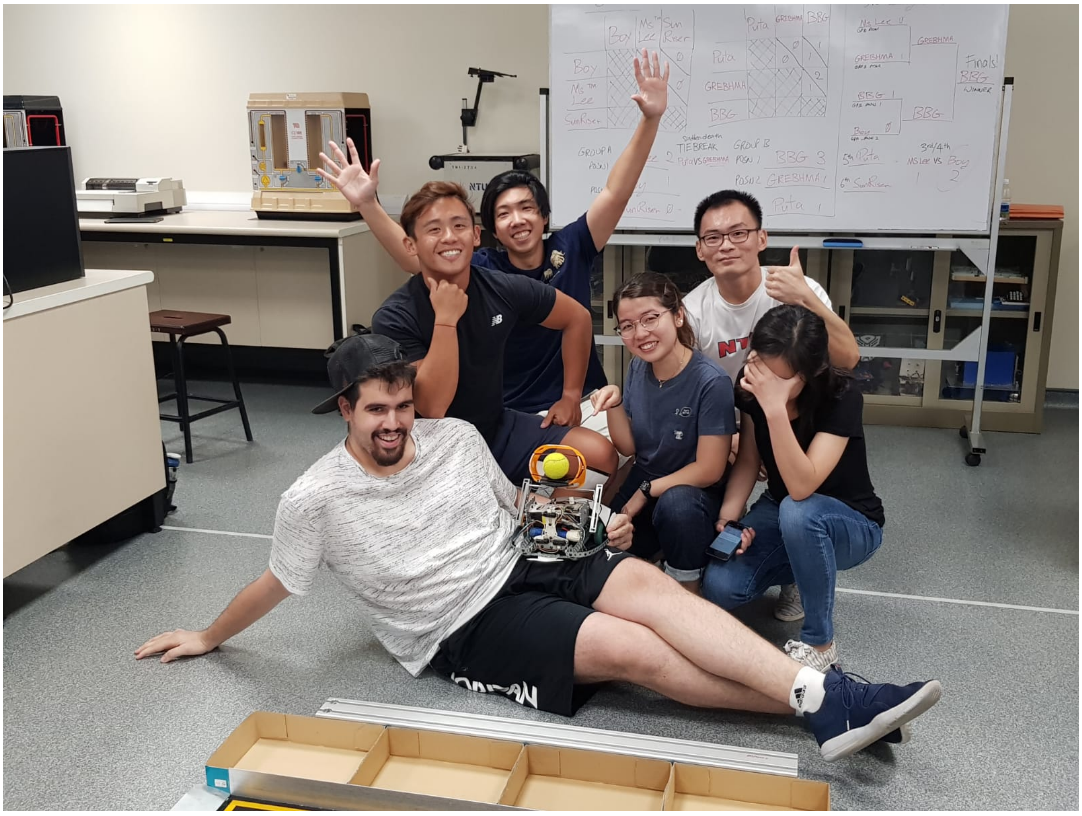
To win competition, our robot must bring a ball back to home as soon as possible. Therefore, our aim is to put detecting and catching the tennis ball as our highest priority. At the start, we were fixated on avoiding opponents, and that caused a less effective searching process. After refocusing on our top priority, our robot is able to detect a ball much more efficiently. Our robot is able to identify and approach the ball from a far distance of 40 cm. Furthermore, it is programmed to search for the ball in the upper half of the arena which increased efficiency in detecting balls. “Is ball caught?” algorithm was also focused on to minimize false signals. Moreover, we also make the effort to test our robot on the arena regularly to constantly improve and calibrate it. Most importantly, we feel that whether the robot will perform well on that fateful day depends a lot on luck and yes, it seems that we were lucky that day.

Having a small built robot with not many unnecessary parts also adds to its disadvantage. Our light and less robust robot can be easily be pushed by opponents with a more robust built. Furthermore, our highly mounted boundary detection sensors can trigger a false alarm when they detect a low built robot. This would cause the robot to run out of the arena. The biggest problem we faced is that the catching mechanism or algorithm is not very effective and efficient, resulting in a low catching rate.

As a team, one of our strengths is that we get input from everyone involved. Every member of our team is a leader in some way. Part of being a good leader is knowing how important it is to receive the best ideas from each member of their team. We attend group meetings where we discuss any challenges, issues, and problems. At these meetings, we often exchange ideas or brainstorm new ones with each other and come up with the best and most creative team solutions as potential answers to those perceived problems.

Furthermore, everyone is clear on the team progress, team decision, and any tasks that need to be completed in the future. We created an agenda for the team and at the end of the group meeting, the recorder of our group would then list down the responsibilities we share across the team through the WhatsApp group. Hence, our team is unique in a sense that each group member has his/her own unique character, and each have their own roles, where we are united together to work towards our main goal.

Overall, we learnt to listen more to others' feedback and opinions. Initially, everyone was closed off and are unwilling to listen to each other. After developing a high relationship throughout the process and going out for outings together, we learnt to care for each other, treating each member as our friends, and not just a group mate. This is moment when we let go of our ego, listen to each other, helping each other develop and work towards our common goal of winning the competition, and most importantly, having fun in the process.



# References


[1] "Tennibot: The World's First Robotic Tennis Ball Collector," *Kickstarter*, 2018. [Online]. Available: https://www.kickstarter.com/projects/770435035/tennibot-the-worlds-first-robotic-tennis-ball-coll.

[2] "Ackerman Steering," *DataGenetics*, 2016. [Online]. Available: http://datagenetics.com/blog/december12016/index.html.

# Appendix

## Datasheets

## VEX 3-wire servo motor

Why VEX EDR? Products For Educators For Competitors Support

Description | Kit Contents | Docs & Downloads | Outputs | Weight | Material Type

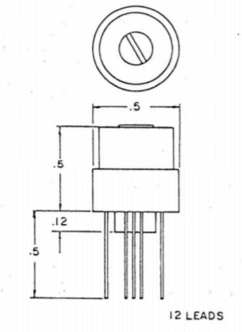
**3-Wire Servo**

- Rotation: 100 degrees
- Stall Torque: 6.5 in-lbs
- Voltage: 4.4 - 9.1 Volts (Motor life will be reduced operating outside this range)
- PWM Input: 1ms - 2ms will give full reverse to full forward, 1.5ms is neutral
- Black Wire: Ground
- Orange Wire: Power
- White Wire: PWM signal
- Current Draw: 20mA to 1.5 A per Servo
- Max Power: 4.9 W when rated @ 6V

**Note:** Performance varies slightly due to variations in manufacturing.

# Digital Compass (1490)

### No. **1490** DIGITAL SENSOR




No. **1490 Sensor** may be operated from input voltage of 5 to 20 volts DC with 8 to 13 recommended. Input should be both "spike" and polarity protected. Power requirement is 1 approximately 30 mils (0.030 amps).

Output will sink up to 25 mils (0.025 amps) per output channel. The sensor will switch so that no more than two adjacent output channels are gong at any one time.

Output is **open collector NPN** sinking the output to ground, thus does not add to the input requirement.

No. 1490 Sensor is internally designed to respond to directional change similar to a liquid filled compass. It will return to the indicated direction from a 90° displacement in approximately 0.5 to 1.0 seconds with no overswing.

Sensor No. 1490 should be operated in a vertical position. The sensor Indicates the horizontal component or compass component of the earth's field. If off vertical, some of the vertical component of the earth's field is introduced which may create some directional error. Generally, tilt up to 12° is acceptable with little error.

The sensor is manufactured for pins down operation but may be furnished for pins up operation on request at no extra cost. The sensor operates equally well pins up or down.

No. 1490 sensor weighs approximately 2.25 grams. The dimensions are shown on the drawing upper left Operating temperature is -20° C to +85° C. The sensor may be stored without damage in wider temperature limits and may be subjected to high flux levels (up to 1000 gauss) without permanent damage.

No. 1490 sensor and sensing systems are covered by issued patents and patents pending.

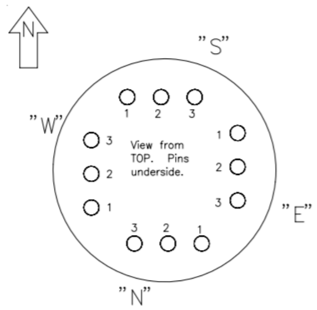
The pins are on 0.050 centers but may be distorted for 0.100 spacing without damage to the sensor or its measurements. The four $V_{cc}$ and four grounds may be common connected.

The Robson Company, Inc.
Dinsmore Sensor Div.
227 Hathaway St. E.
Girard, Pa. 16417 U.S.A.
Phone/Fax: +814 774 5914
E-Mail: crobson@robsonco.com
www.dinsmoresensors.com

Revised: 14 October 2003

### No. **1490** DIGITAL SENSOR

PIN-OUT FOR DIGITAL COMPASS SENSOR (No. 1490)




1= $V_{cc}$
2= Ground
3 = Signal

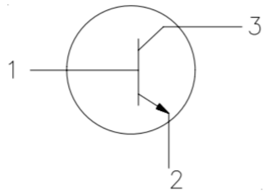
Vcc = 5 to 20 Volts; 8 to 13 recommended

Output will sink 25 mils @ 12 Volts

Temperature Range: -20° C to +85° C.

Reverse polarity will damage IC.

Output is Open Collector




The Robson Company, Inc.
Dinsmore Sensor Div.
227 Hathaway St. E.
Girard, Pa. 16417 U.S.A.
Phone: +814 774 5914 Fax: +814 774 2775
E-Mail: crobson@robsonco.com
www.dinsmoresensors.com

Revised: 14 October 2003

**Code**