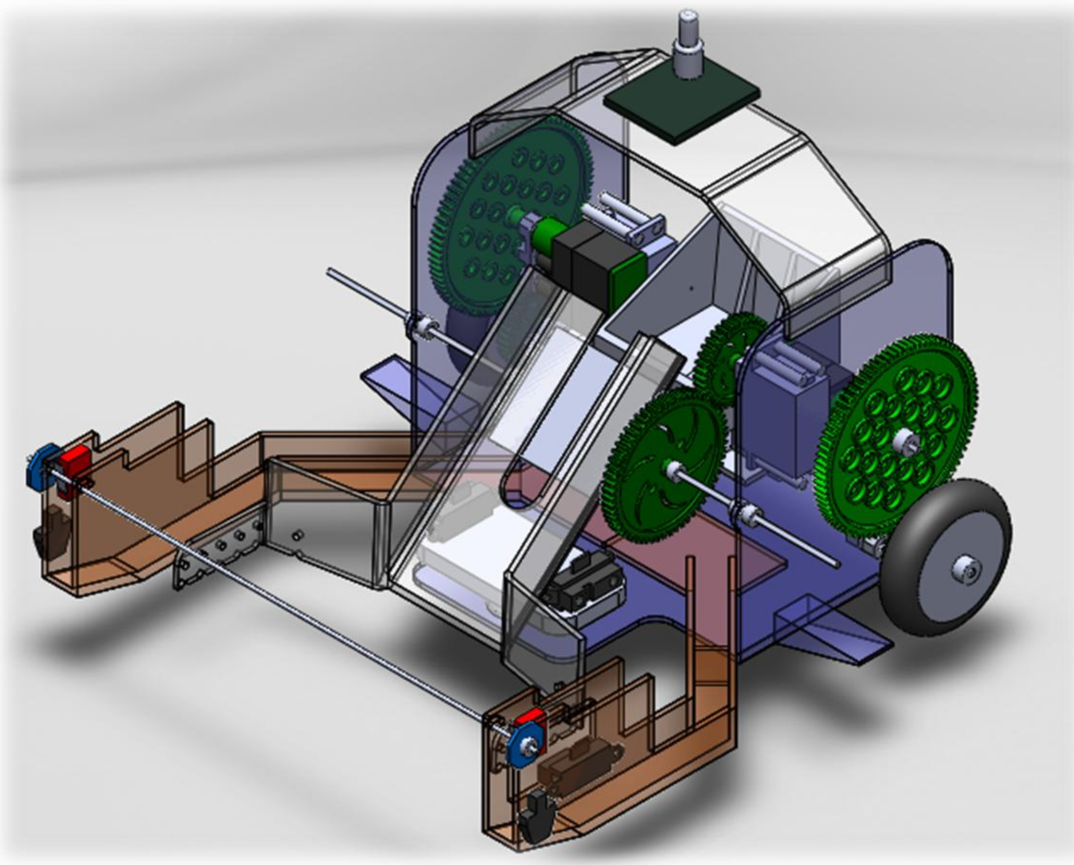
Mechatronic Systems Design and Analysis

Design
of a
Compact Autonomous Vehicle

TARA 2



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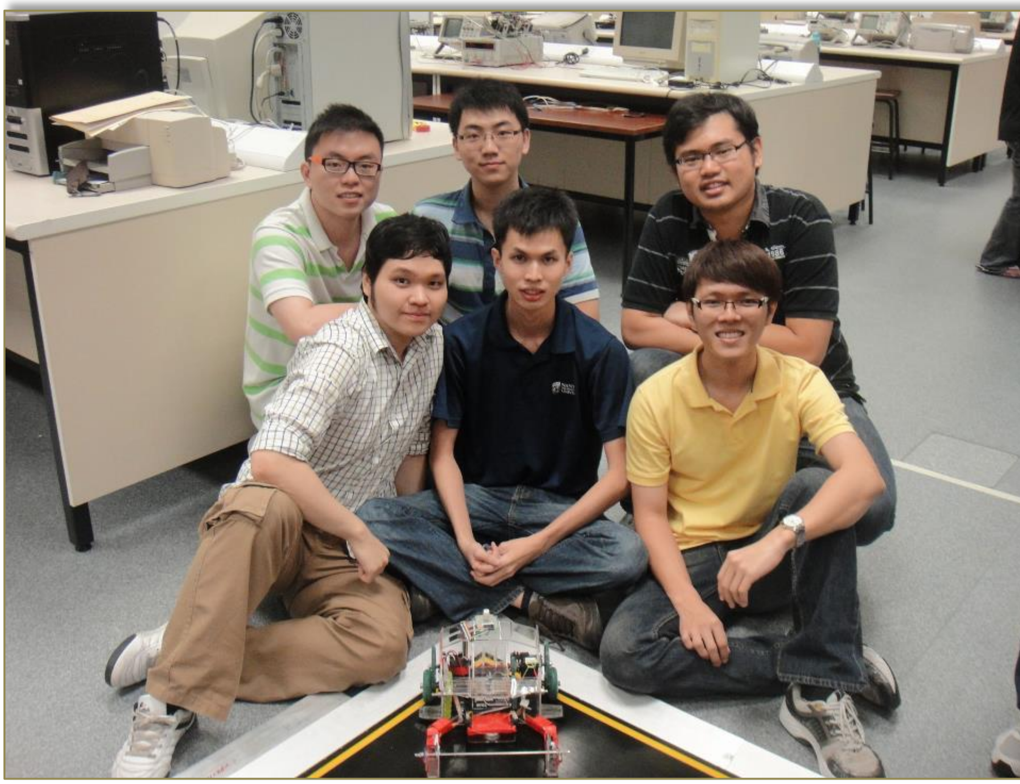

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1 INTRODUCTION

This project is done as part of the required coursework for MP4010 – Mechatronics Systems Design and Analysis. This report documents the entire process of design, fabrication and programming of a mechatronics system which is an autonomous tennis ball collection vehicle. Firstly, the design requirements of the vehicle are described in the product design specifications. After that, the conceptual and detailed designs are discussed with important calculations. Computer Aided Drawings of the general assembly and individual parts are shown to provide visualization of the physical object. Several critical parts of the vehicle are selected to be analyzed using finite element analysis to determine the structural integrity. Last but not last, strategy and programming of the vehicle are explained in detail.

2 PRODUCT DESIGN SPECIFICATIONS

3 CONCEPTUAL DESIGN

Conceptual design is the very first stage of a design process that focus on generating ideas and designs, with preliminary drawings that comprise of simple plans and sections. A flow chart is shown below to illustrate the overview of conceptual design. Each process in conceptual will be discussed in details.

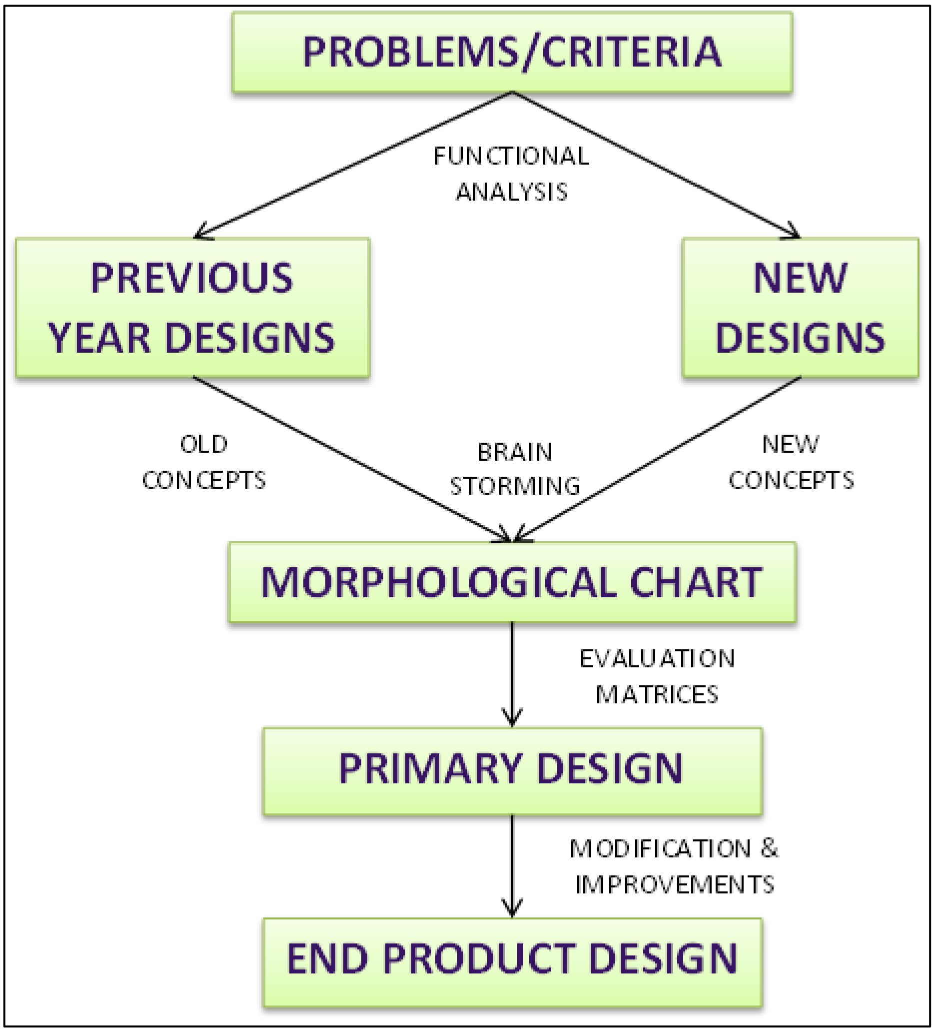

Figure 1: Stages in Conceptual Design

3.1 Problems/Criteria

The main target of this conceptual design is to produce a vehicle that is able to detect, collect, and return tennis ball within a specified arena. There are several criteria which have been specified and need to be achieved.

- Fast and light
- Simple and efficient mechanism for ball collecting and releasing
- Maximum dimension 30cm x 30cm x 30cm
- Limited to given number of motors and sensors

3.1.1 Objective Tree

The objective tree is illustrated in following figure.

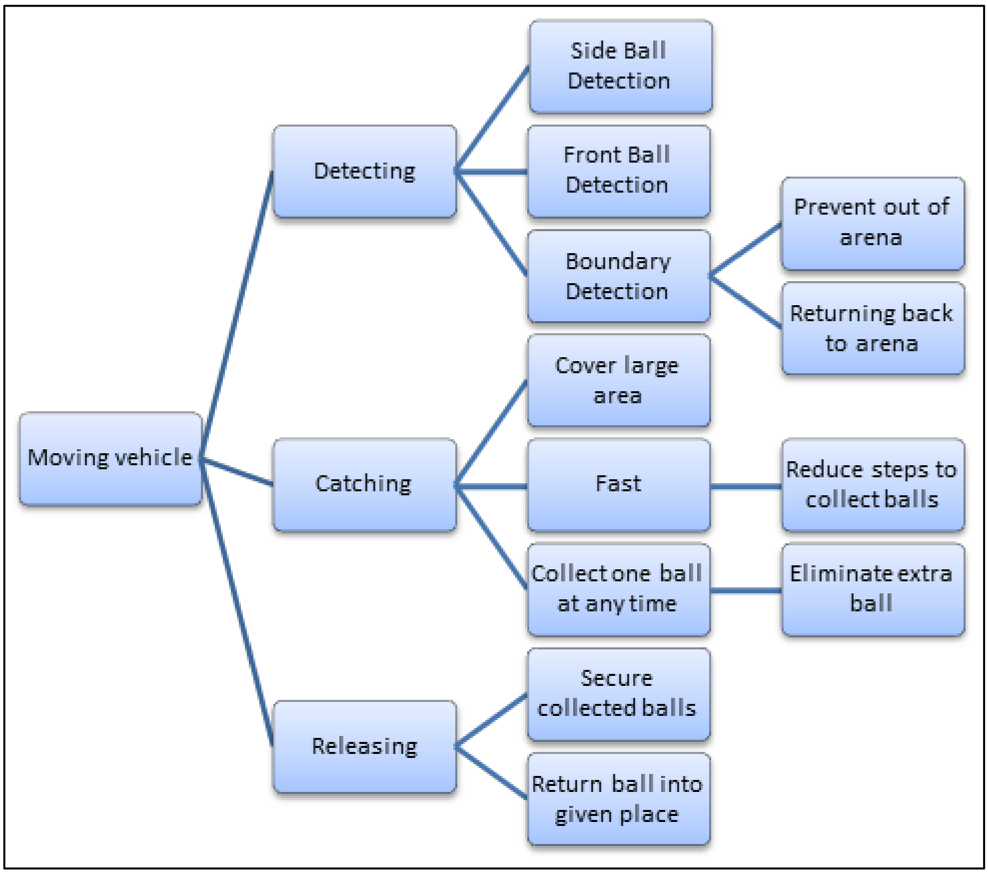

Figure 2: Objective Tree

3.2 Function Analysis

The objective of function analysis is to help relate inputs and outputs and the transformation between them. Figure below shows the simplified version of function analysis.

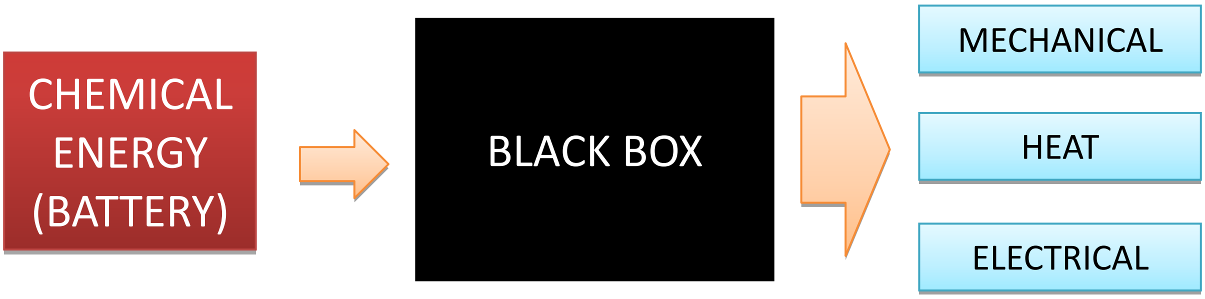

Figure 3: Simplified Version of Function Analysis

Chemical energy from battery will flow into a black box and convert into 3 type of different energy: Mechanical, Heat, and Electrical. The details of Black Box are shown in the figure below.

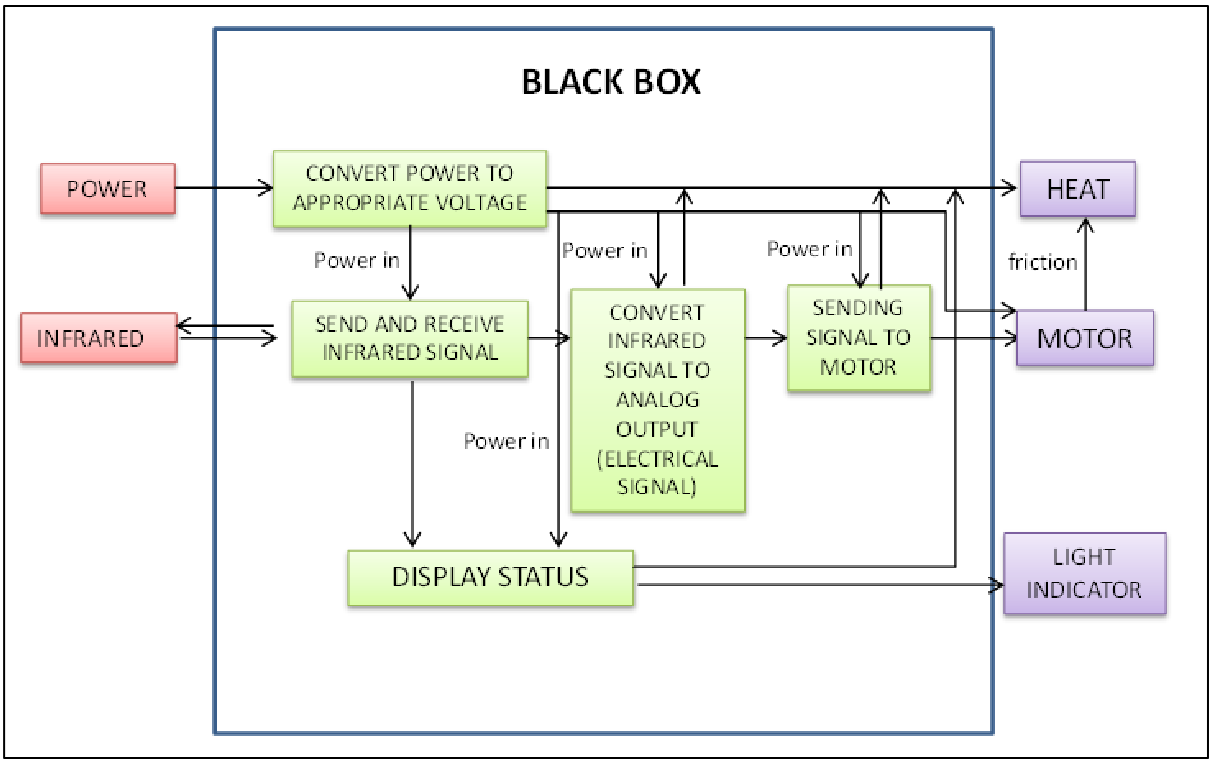

Figure 4: Detailed Function Analysis

3.3 Existing Design VS New Design:

In this stage, all information about successful previous designs is collected. All the previous designs are reviewed and studied to determine the strength and weaknesses. Figure below shows some examples of previous designs.

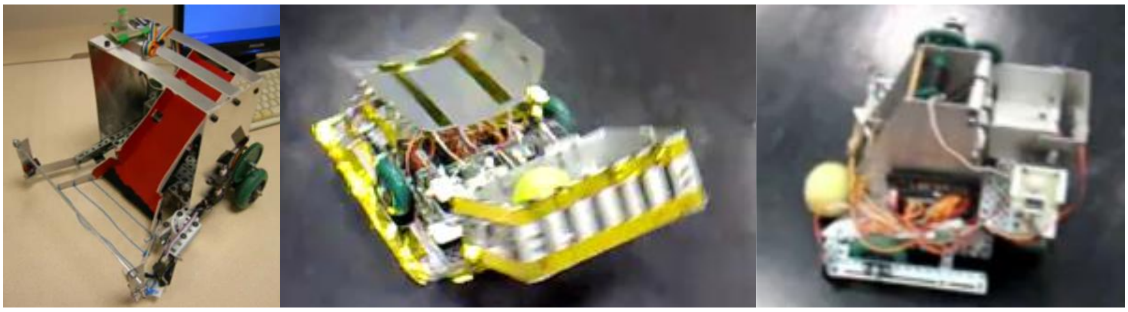

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Figure 5: Existing versus New Design

Not all existing designs are applicable in the conceptual design of the project as the rules and regulation have changed considerably compare to previous years. Modification or changes need to be made on the existing designs to further improve the performance. In order to analyse the advantages and disadvantages of the different parts of the design, the main design is divided into 4 sub-functions:

- Moving mechanism
- Catching mechanism
- Ball releasing mechanism
- Extra functions

3.4 Morphological Chart:

Blank 4

Figure 6: Morphological Chart

From the weightage evaluation matrix above, three designs are selected from each mechanism.

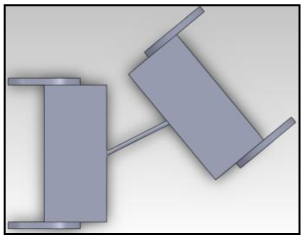
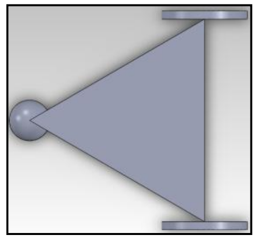
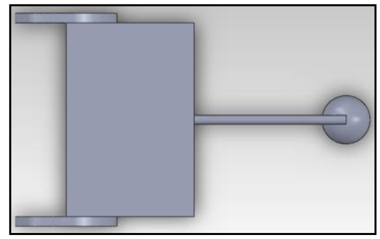
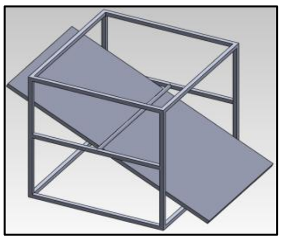
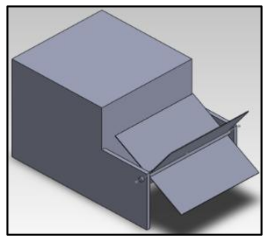
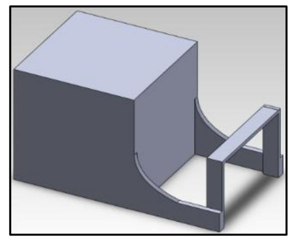
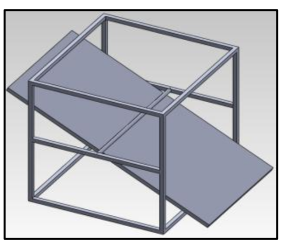
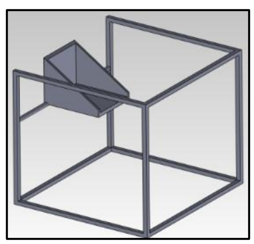
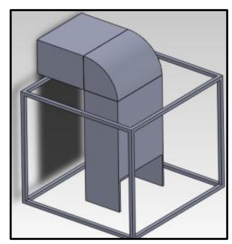
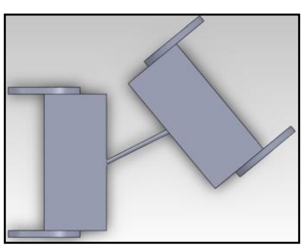
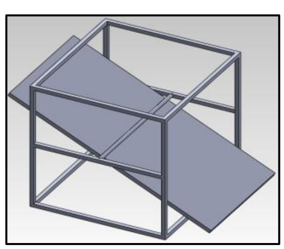
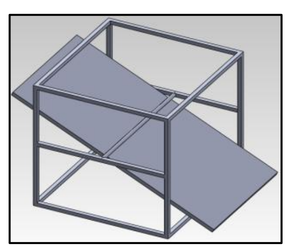
Rank 1	Rank 2	Rank 3
		
		
		
The score for Extra Function is too low to be considered in the primary design. However, consideration will be given at the end product design to further improve the vehicle.		

Figure 7: Design Ranking from 1 to 3 for Each Sub-function

Primary Design (combination of 3 designs with highest score from each mechanism)

 +  + 

3.5 Primary Design VS Final Design

Different combinations of solutions for sub-function can be formed from the figure above. For the primary design, the vehicle will be formed by selecting all the best designs from the weightage matrix. However, the design has been continuously modified to improve its performance during fabrication and testing.

The detailed process of modifications and improvements can be divided into 3 phases: Phase 1, 2, and 3

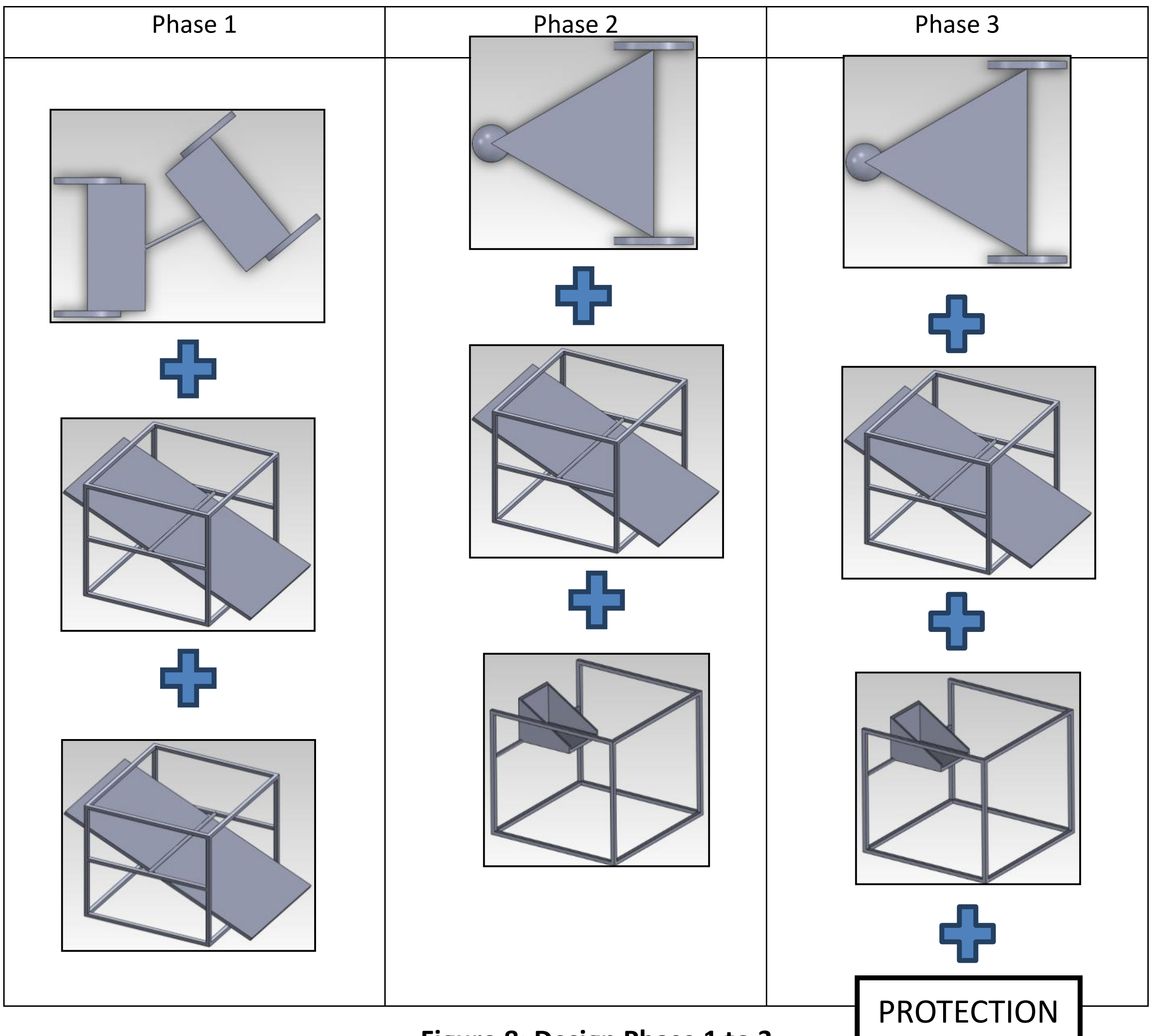


Figure 8: Design Phase 1 to 3

3.5.1 Phase 1

The initial design (Phase 1) is a combination of a two-part moving mechanism and a simple scooping catching and releasing mechanism. Ball will be collected using the scoop and released when the scoop is tilted an angle with respect to ground.

Advantages

Two-part moving mechanism allows big stationary turning angle, which enables the vehicle to rotate to any direction once it detects any ball. For the catching and releasing mechanism, the main advantage is the large catching range and simple mechanism to secure and release the ball.

Disadvantages

The fabrication of two-part moving mechanism is complicated and there is a force concentration on the connection join between the two parts. This in turn will weaken the structure of the vehicle.

As for the scoop design, the large catching range enables it to catch more than one ball at a time, which is forbidden in the competition. In order to solve the problem, some modifications are made which lead to the Phase 2 design stage.

3.5.2 Phase 2

The main aims of Phase 2 are to find alternate ways to solve the problems at phase 1, and at the same time try to retain the advantages of Phase 1 design. As a result, a 3 wheel-design has been selected with two normal rear wheels (one at each side) and a front roller at the centre of the car. Scoop remains as the catching mechanism, but the ball release mechanism is modified. A basket which only allows one ball to be stored in it is mounted at the back of the vehicle. This mechanism receives the ball from scoop and releases it once the vehicle is back to the ball collection area.

Advantages

By using a small basket, the problem of catching two balls due to large catching range is solved. The basket allows one ball to be stored in it and another ball (if caught) will be released by rolling back down to arena when the scoop is returned to initial position. Another modification is made to the moving mechanism by implementing a 3 wheel-design. As a result, the vehicle can perform a full rotation while staying at the same spot. Besides that, the structure of the vehicle is stronger with only one part.

Disadvantages

The problem encountered in this stage is mainly the structural integrity of the scoop. The scoop has large catching range but the structure is weak and fragile. During an initial testing of the vehicle in the arena, the scoop broke after collision with the wall. In order to solve this problem, a protector frame is to be mounted outside the scoop to absorb the impact from collision. And with this change, the conceptual design reaches to the final stage - Phase 3.

3.5.3 Phase 3

In this phase, the main focus is to increase the structural integrity of the scoop and two solutions are proposed. Firstly, scoop can be strengthened by using harder materials such as steel. However, this solution is not chosen because harder materials may increase the weight of the scoop, which may exceed the torque supplied by the motor. The second solution is to install an outer protector frame, which helps to absorb the impact from collision. However, the tradeoff of having such a protector frame is the reduced catching range.

4 DETAILED DESIGN

This chapter describes the detailed design for several aspects like

1. Ball catching design – scoop and basket
2. Structural design – clearance from ground, outer frame support bar
3. Manoeuvring design - ball roller, braking system
4. Others – front bar, handling bar

4.1 Ball Catching Design

4.1.1 Scoop Design

The main function of the scoop is the catch any ball that is within its range. When a ball is sensed at the scoop, the servo motor will rotate and lift up the scoop. The scoop has many design features which enhance its catching ability, as shown in figure below.

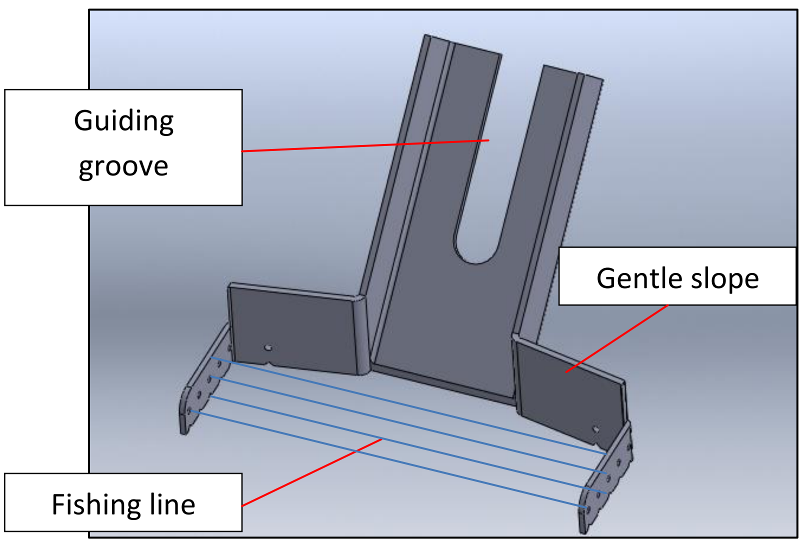


Figure 9 Scoop Design

Firstly, the shape of the scoop is designed in such a way that there are two gentle slopes at each side to guide the ball from the wide horizontal opening to narrow channel. These slopes reduce the chances of the ball bouncing away from the scoop. This is because the reaction force will act on the ball at an angle and push the ball towards the center of the scoop.

Besides that, the base of the scoop is formed by tying fishing line zigzag across the wide opening. This fishing line base provides a good support to keep the ball at place while the scoop is being lifted to transfer the ball down to the basket. The fishing line base is better that a metal plate or cardboard because it is durable and has low friction. Fishing line is chosen instead of metal wire or string because of it is highly stretchable and almost unbreakable. The high elasticity enables the base to retain its original shape even after collision with other cars.

In addition to that, the front edge of the scoop has only a small clearance of 3mm. This small clearance ensures that the scoop does not make contact with the ground when moving. This eliminates the friction between the scoop and the ground which will result in energy lost. However, the scoop cannot be lifted too high to avoid contact with ground because it still needs to be low enough to allow the ball to roll inside. Thus, a clearance of 3mm is selected as the ball can still roll inside the scoop easily and the scoop will not touch the ground even in bump area.

Last but not least, there is a guiding groove in the middle of the channel. The guiding groove enables to ball to roll down straightly inside the channel to the basket. This help to stabilize the ball rolling motion and reduce the chances of the ball falling out of the scoop.

4.1.2 Basket design

The main function of the basket is to hold the ball at a secured position and release it when the car reaches home position. The basket will be rotated 90 degree to let the ball roll down to the container. The basket must be positioned above the home wall which is 6cm tall. Ramp is also added to the base of the basket to ease the rolling of ball.

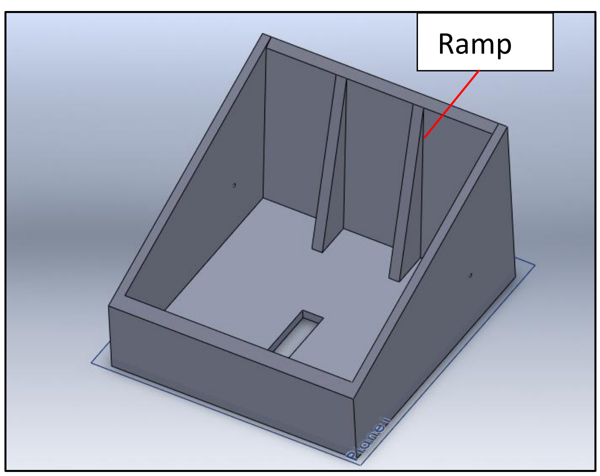


Figure 10 Basket Design

4.2 Structural Design

4.2.1 Clearance from the ground

From the figure below, it could be seen that the robot has a clearance of 11.8 mm from the ground. The clearance is important to ensure the wheel of the robot remains touching the ground even though the robot lifts up due to the slope of the arena. In addition, the clearance from the ground should not be too high else the robot is not stable when maneuvering.

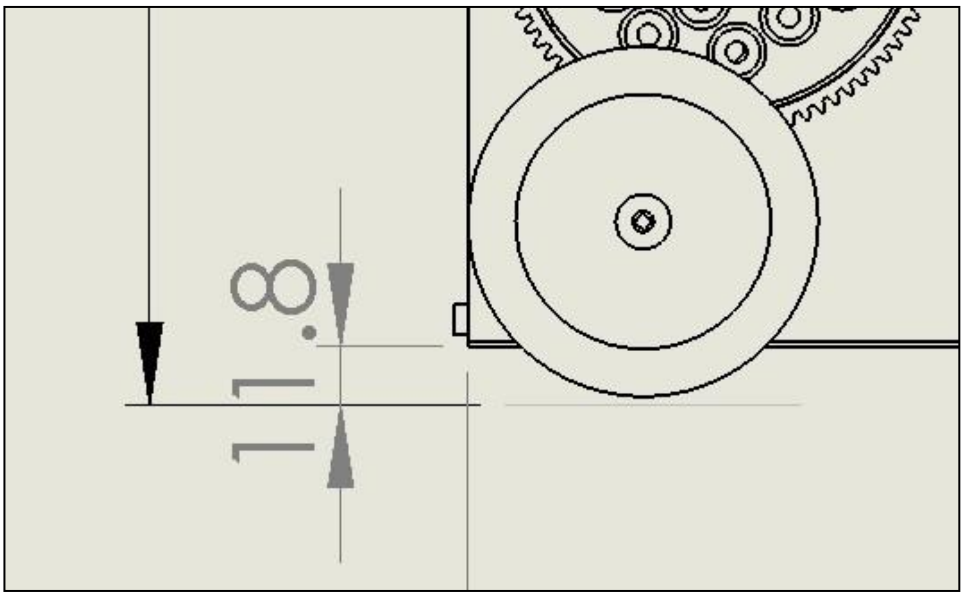


Figure 11: Robot clearance from the ground

Furthermore, the arena floor is not flat and it is bumpy, therefore it is important to ensure that the chassis of the robot does not touch the ground when it is moving. The chassis of the robot might touch the floor due to vibration or jerk when the robot is maneuvering.

4.2.2 Outer Frame Support Bar

Outer frame support bar is designed to protect the scope of the robot. The design of the scope which maximizes the chance of catching a ball has a drawback which makes the structure to be weak. It could be easily broken when the robot hits on to the wall or an opponent robot hits the scope at a high speed. Therefore, it is critical to protect the scope from the opponent.

In addition, the outer frame protector serves as a second functionality that prevents opponent robot from getting stuck into the robot body in figure below. It is essential to ensure opponent robot does not stuck on to the wide opening of the robot because a lot of power will be wasted to drag the opponent robot. Besides, the opponent robot might damage the position of the hardware in the robot. Furthermore, the range sensor mounted will constantly sense that opponent and mistakenly assume it as a tennis ball. This will trigger our robot to constantly move backward and turn to catch it. Therefore, it is important to design a frame to protect the robot.

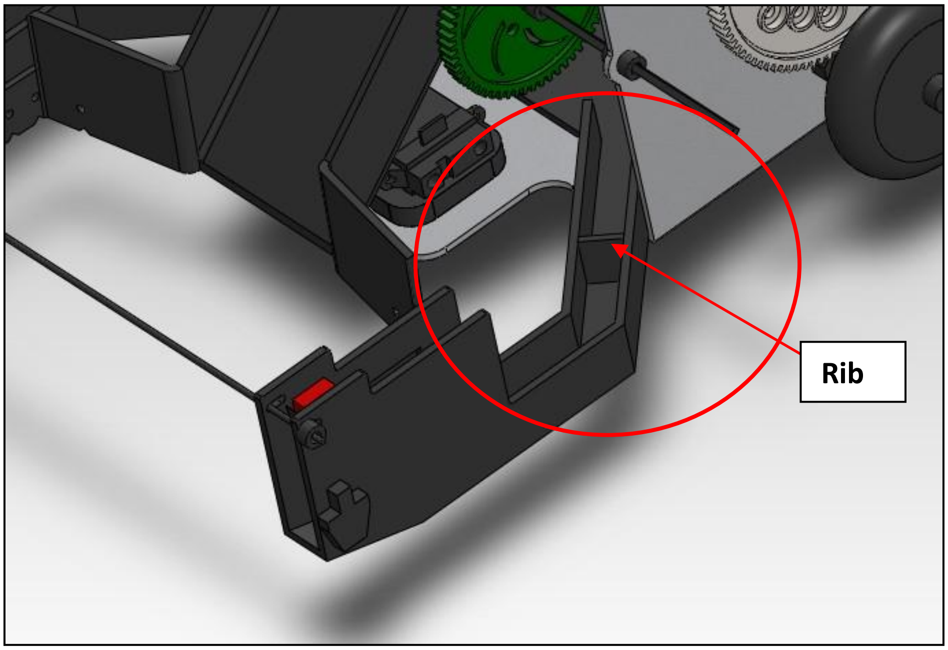


Figure 12: Outer Frame Support Bar

Ribs are attached between the 2 acrylic plates of the protector at a frequent interval to enhance the structure rigidness and strength. With this design, the outer protector is able to withstand the force applied on to the protector when opponent robot crashed at our robot.

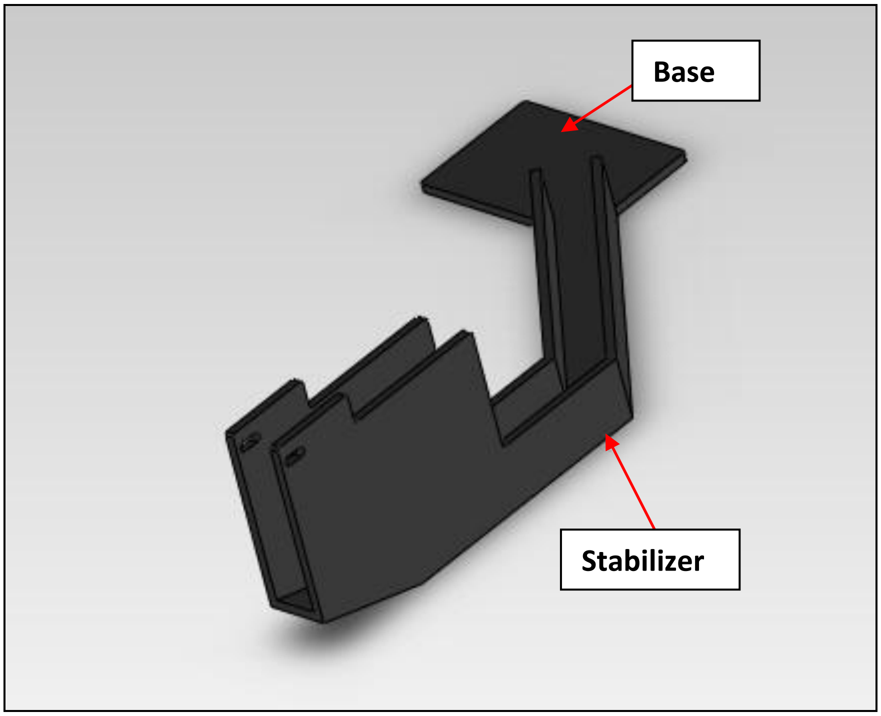


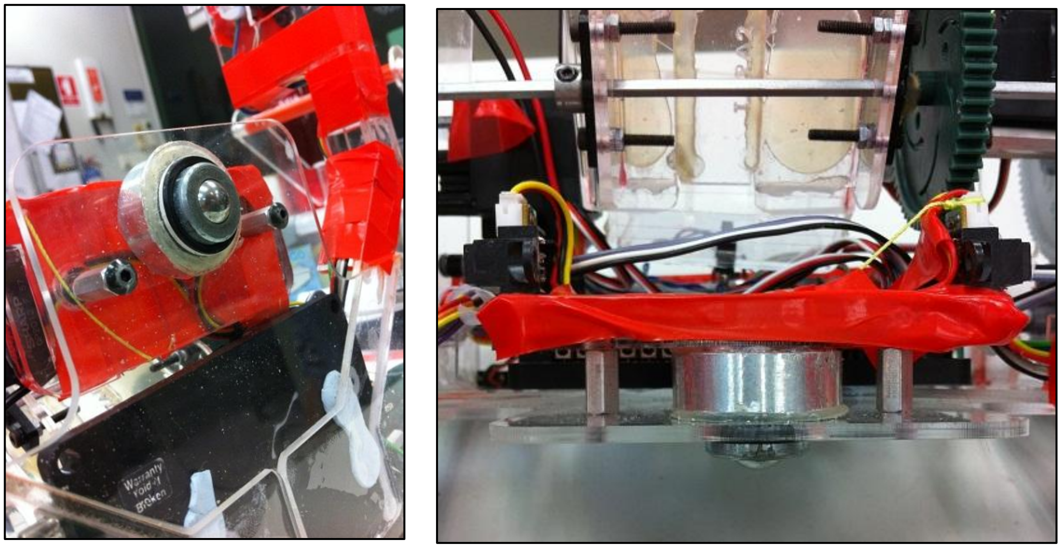
Figure 13: Left side outer protector frame

In addition, the protector frame has a large surface area for the base to be attached with the robot chassis. This large area of attachment is essential to provide sufficient mounting force with robot's body to ensure that when the protector is hit by opponent, the massive shear force will not tear the connection apart.

Furthermore, stabilizer is attached at the bottom of the protector shown in figure above. The stabilizer is a rectangular (1 cm x 1.5 cm) shape of acrylic attached on to the protector. This helps to prevent the protector from sagging or deviates too much due to vibration. It is important because a range finder sensor is attached at the protector, any deviation on the protector will affect the readings return by the sensor. As a result, the scope will be triggered because the value returned by the sensor is rubbish due to the vibration of the protector. Installing the stabilizer reduces the variation of the protector due to vibration.

4.3 Maneuvering design

4.3.1 Ball Roller

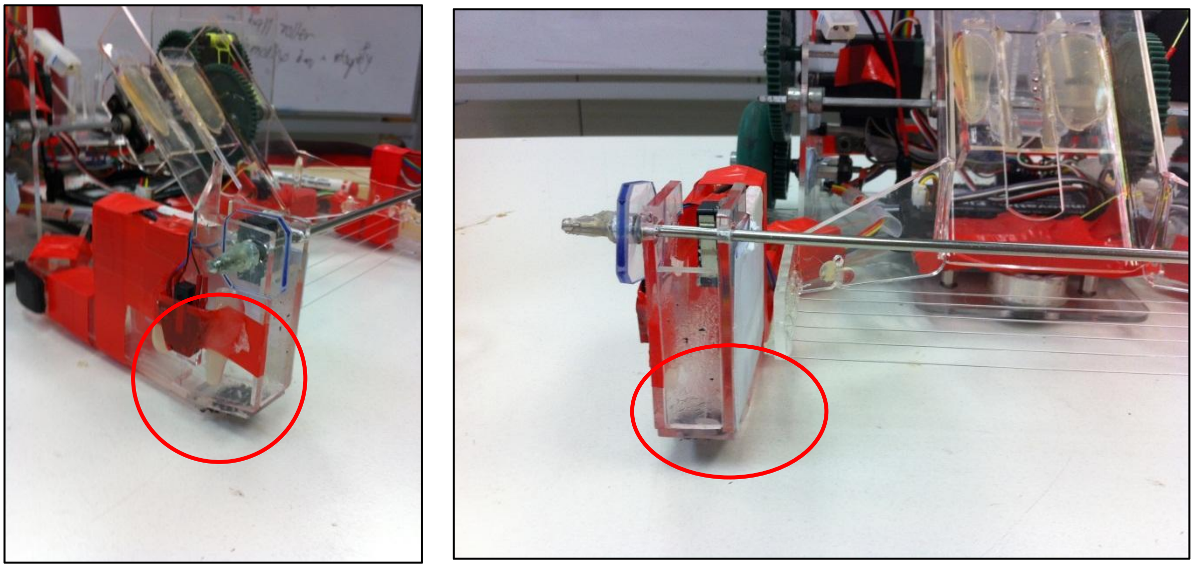


(a) (b)

Figure 14: Ball Roller from Different Views

The roller functions as the third wheel of the car. Introduction of the roller provides several cutting edges for current design. First, it enables freely rotating in 3 axes (e.g., x, y and z). The car could rotate easily by activating 2 behind wheels with different angular velocity. Second, the location of the roller (third wheel) is far away from 2 behind wheels (>1/2 the car's length). It provides the stability for the car. Also, 2 screws with one plate attached at the top of the roller (as shown in figure above) secures the roller attaching with the floor, make the car run smoothly and balancing with 3 wheel in triangular shape.

4.3.2 Breaking system



(a) (b)

Figure 15: Braking System from Different Views

The breaking system is shown in figure above. With light weight because of using Acrylic Glass for whole structure, the car can achieve high velocity as compared with using steel. Therefore it is necessary to design a primary system for preventing car moving out the area. This breaking system is employed for that purpose.

Basically, the shape design for breaking system is coped from the shape of the ramp at area. We utilized that feature for our car and design the slanted surface at front bottom of the car. This is to make sure that the slanted surface with contact fully with the ramp at area when the car is hitting the ramp. We achieve the maximum contact area between two surfaces. However, we attach some rubber at the slanted surface of the car, to increase the friction coefficient between it and ramp surface. Due to large contact area, high friction coefficient; the breaking system can help preventing the car moving out the arena.

4.4 Others

4.4.1 Front Bar

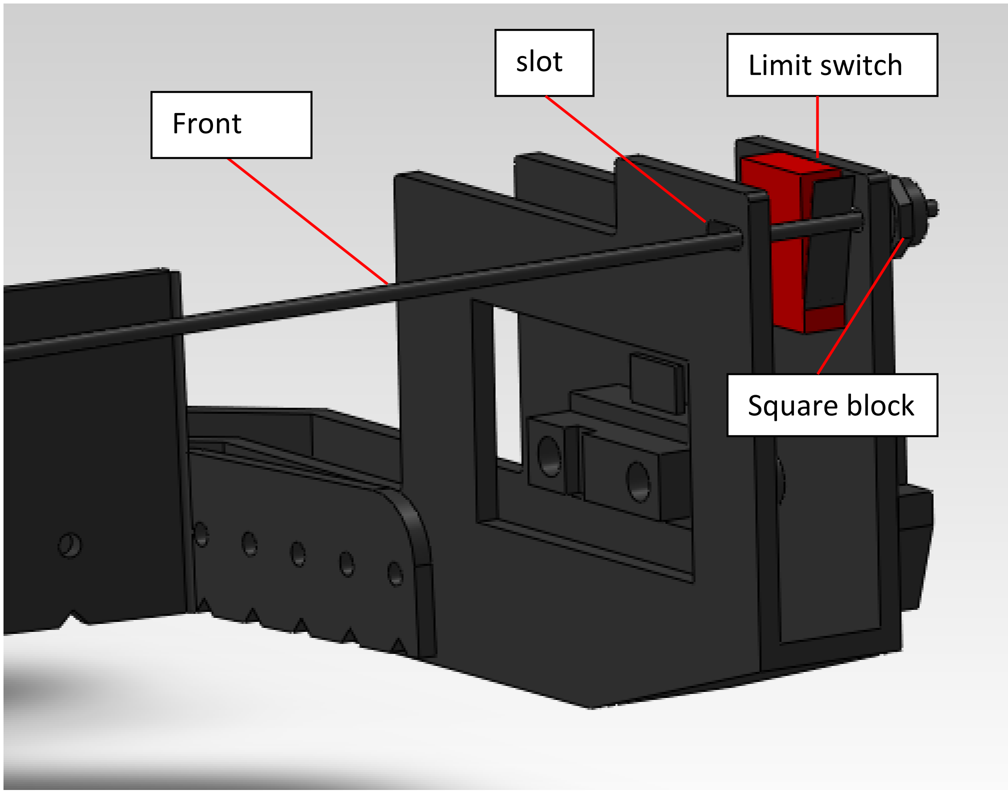


Figure 16: Front Bar at the Slot of Support Bar

Front bar is placed in the slot at the front part of protector frame. At each end of the bar, there are two front limit switches, each at a side. Basically, the front bar has two main functions. First function is to detect the enemy. Whenever the bar is pushed inwards the car, limit switch would be triggered and avoid enemy function is executed. This helps to prevent direct engagement with the enemy at scoop area and cause any damage to the scoop. Second function is to detect the wall of the container during back home function. Square block protruding out from the protector frame actually helps to push the bar inwards and then triggers the limit switch. This method differentiates the boundary at home position from enemy or any side boundary.

4.4.2 Handle Bar

There are few purposes to install the handle bar shown in Figure 4. It acts a handle bar to allow the handler of the robot to hold the robot easily. Besides, it enables the compass to install on top of it. It is important to place the compass away from any metal materials, as it will distort the magnetic field of the compass. As a result, the directions returned by the compass will not be accurate and it will affect during the game play.

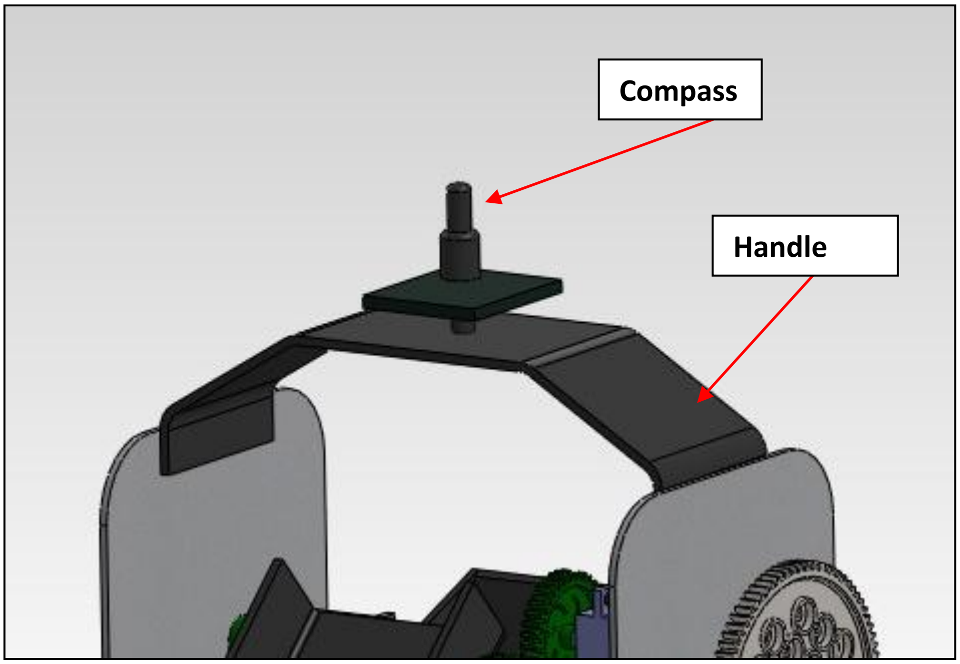


Figure 17: Handle Bar Design

Furthermore, the handle bar acts as a beam to strengthen the robot chassis. When the robot is hit by opponent's robot, the chassis might buckle and weaken the structure of the robot. Besides, the buckling might cause the alignment of robot to run. The misalignment causes severe problems to the wheel and the sensors mounted on the chassis. By installing the bar, it provides a reaction force to the chassis which prevents buckling.

5 DESIGN CALCULATIONS

This chapter describes the calculations to determine suitability of gear ratio for (1) ramp, considering the torque requirement and turning angle; (2) wheel.

5.1 Servo motor for the ramp

<u>To determine the torque needed for servo motor</u>

The scope can carry 2 tennis balls = 2 x 60g

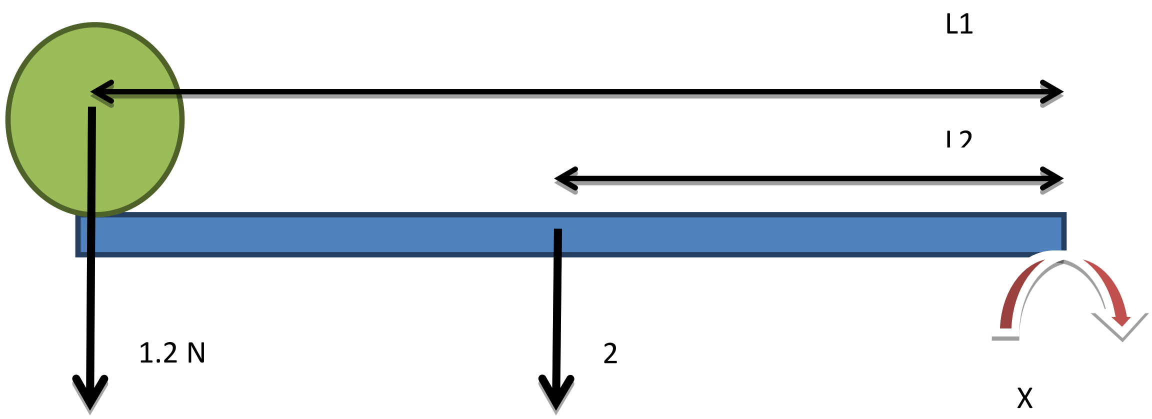
= 120 g

The mass of the scope = 200 g (from the CAD drawing)

Total mass of the scope and the ball = 120 + 200

= 320 g

Assumption:



Taking g = 10 m/s^2

Weight of 2 tennis balls = 0.12 x 10

= 1.2 N

Weight of the scope = 0.2 x 10

= 2 N

Therefore, the total torque required by the servo motor at A = (1.2 x0.18) + (2 x 0.09)

= 0.396 Nm

From the datasheet, the servo motor can provide up to 4.1 kgcm (0.41 Nm) at 6V. The servo motor can provide sufficient torque to rotate the scope with 2 tennis balls.

To determine the gear ratio for the servo motor

When the servo motor is tested, it is found that the program cannot control the servo motor to rotate for 180˚ even though the motor is physically capable of doing so. This problem is due to the limitation of the microcontroller and as a result, the angle of rotation is reduced. Therefore, it is important to take this into consideration when designing the scoop so that the ball can roll down when it is tilted.

36 tooth gear and 60 tooth gear which gives gear ratio of 1.67 are used to connect the servo and the ramp. With this gear ratio, the servo motor still capable to rotate the ramp up to 100/1.67 = 60˚, which is sufficient to let the ball roll down to the basket.

5.2 To determine the speed of the robot

From the datasheet, the continuous motor can run up to 100 rpm at 7.5 V. However, when the motor is tested to run at full speed, it is observed that the speed of motor can only go up to 60 rpm. This might be due to wear and tear of the motor. Therefore, 60 rpm will be used in the calculation, as this represents the real characteristics of the current motor speed.

<u>First Design</u>

Complying with the design requirements to produce a fast vehicle, a 5:1 gear ratio is used for our first design (60 tooth gear and 12 tooth gear are used). Therefore, the rpm of the wheel, w_{wheel}:

$w_{wheel} = 5 \times w_{motor}$

$= 5 \times 60$

$= 300$ rpm

Therefore, the linear velocity of the vehicle = (300 x 2∏/60) x 0.035 = 1.1 m/s

However, several problems are encountered when the vehicle is moving at high speed. Firstly the output torque of the wheel is very low (after divided by 5). This causes the vehicle to get stuck easily at the boundaries and also be pushed away by opponents. Besides that, it is difficult to control the vehicle to sense and catch the ball when it is running at high speed. Thus, a smaller gear ratio is used to solve the problem.

<u>Second Design</u>

For the second design, 84 tooth gear and 36 tooth gear are used. This combination gives the gear ratio of 2.33.

$w_{wheel} = 2.33 \times 60$

$= 139.8$ rpm

Thus, the linear velocity of the vehicle = (139.8 x 2∏/60) x 0.035 = 0.512 m/s

From the calculation, the speed of the vehicle is reduced to about 50% of the initial design. However, the higher output torque makes it harder to be pushed by opponent and it is able to move back when it reaches the slope at the edge. Due to the lower speed and inertia, the vehicle has less overshoot after sensing boundary and able to return back to the arena faster.

6 FINITE ELEMENT ANALYSIS (FEA)

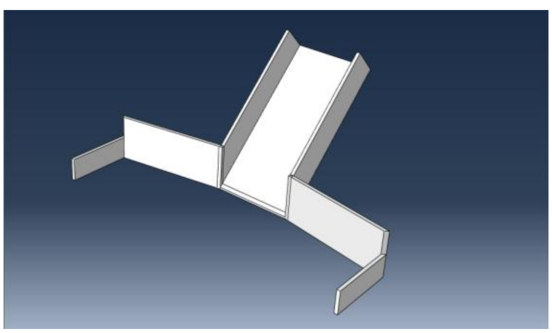
Abaqus, a suite of software applications for FEA is used in this project to determine the structural integrity of the car. Two components under impact force at worst case scenario are being simulated. They are the scoop (Phrase 1 and 2) and support bar (Phrase 3). FEA involves 3 stages, they are pre-processing, processing and post-processing, which is commonly known as result and discussion.

6.1 Pre-processing

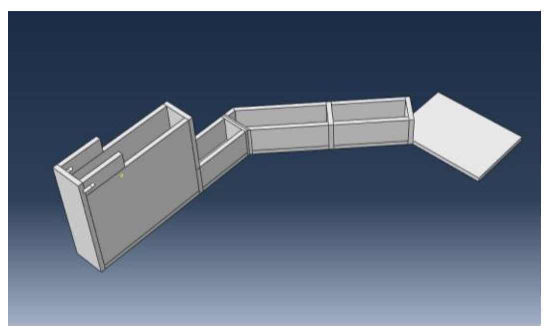
Pre-processing stage describes all necessary work to be done before carrying out a simulation.

6.1.1 Modeling

First and foremost, scoop (Phrase 1 and 2) and support bar (Phrase 3) are modeled in Abaqus/CAE, as shown in figure below. Details of drawing like chamfer, fillet and slot are omitted to ease the meshing algorithm. However, this assumption is valid as the focus of simulation is the overall structural integrity and not local strength.



(a)



(b)

Figure 18: Model of (a) Scoop and (b) Support Bar

6.1.2 Material Properties

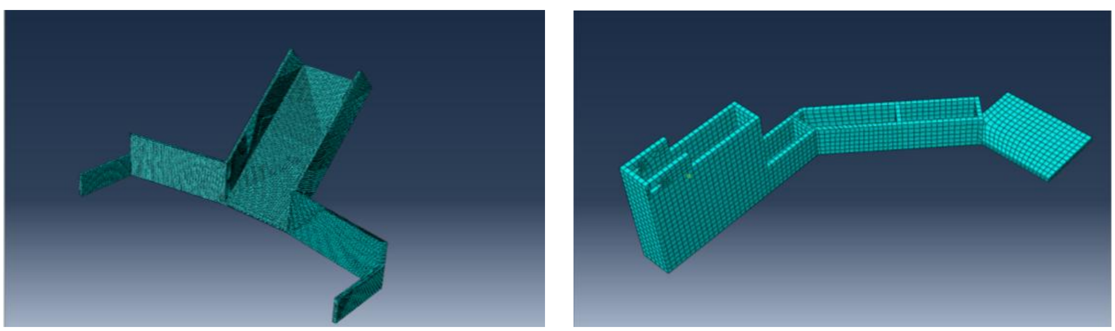
Plexiglas G acrylic sheet is used in the project. Material properties assigned to the parts are showed in table below.

Table 1: Material Properties for Acrylic Glass Sheet

Properties	Value
Density (kg/m^3)	1190
Young modulus, GPa	3.102
Poisson ratio	0.35
Maximum tensile strength, MPa	72.4
Rupture tensile strength, MPa	72.4

6.1.3 Meshing

Both parts are meshed using C3D8R element. It is a Continuum (solid) element, with 8 nodes in 3-Dimentional space and using Reduced-integration. It is like a general purpose brick with only one integration point at the centroid of element. Figure below shows the meshing of parts with global seed size of 0.001m. The meshing has aspect ratio of less than 10 and face corner angle of value between 10 and 160 degree.



(a) (b)

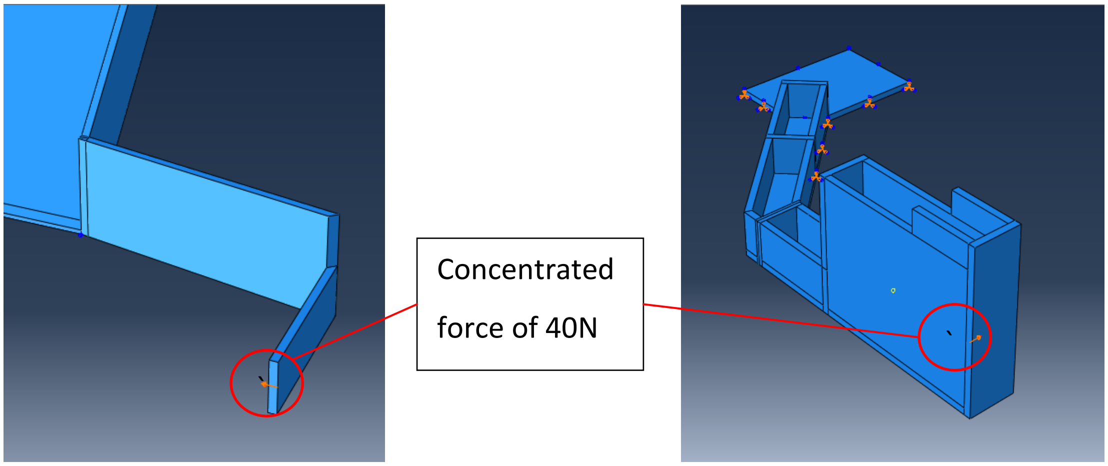
Figure 19: Meshing of (a) Scoop and (b) Support Bar with seed size of 0.001m

6.1.4 Step

A static, general step is created for force application.

6.1.5 Load and Boundary Condition

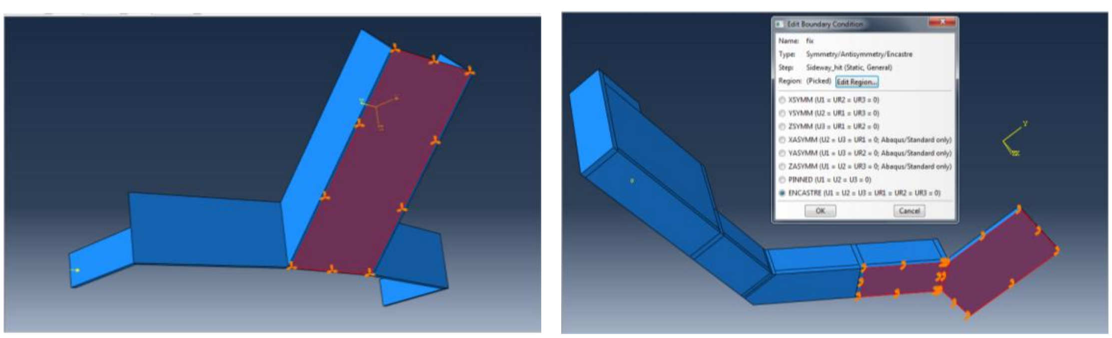
To illustrate worst case scenario, a concentrated force is applied to a point at the edge of both components, as shown in figure below. Force applied is 40N, assuming a head on collision with a 2.0kg car, both with acceleration of 1g.



(a) (b)

Figure 20: Load Act on (a) Scoop and (b) Support Bar

Encastre boundary condition is applied to the surfaces as highlighted in figure below. In another words, they are fixed to the space and has zero x, y and z axis translational and rotational motion. This condition is valid as both parts are assumed to be static and held by neighbour parts during collision.



(a) (b)

Figure 21: Surface in (a) Scoop and (b) Support Bar that are bounded by Boundary Condition

6.2 Processing

Job is generated with desired model and is submitted for running.

6.3 Post-processing

According to API RP2A, industry standard for working stress design for steel, maximum bending stress shall be less than 0.75 of maximum yield strength. Acrylic glass fails in brittle manner. It breaks without going through plastic deformation process. Since steel has higher toughness due to plastic region, the factor of 0.75 could be readily used for acrylic glass as a safe estimation.

Maximum tensile and rupture strength for acrylic glass is 72.4MPa. Hence, the maximum allowable bending stress is 54.3MPa. Any area with equivalent Von Mises Stress above this value is considered fail and highlighted in grey colour.

6.3.1 Scoop (Phrase 1 and 2)

With 40N of applied force to the end of scoop, two grey colour regions are found at the bending side of scoop, as in figure below. This means that Von Mises Stress at those particular areas have exceeded maximum allowable bending stress. The structural integrity of scoop is considered fail under the application of this concentrated force. This finding tallies with the first prototype design where the scoop broke into 3 parts during a head on collision with side wall, as discussed in early part.

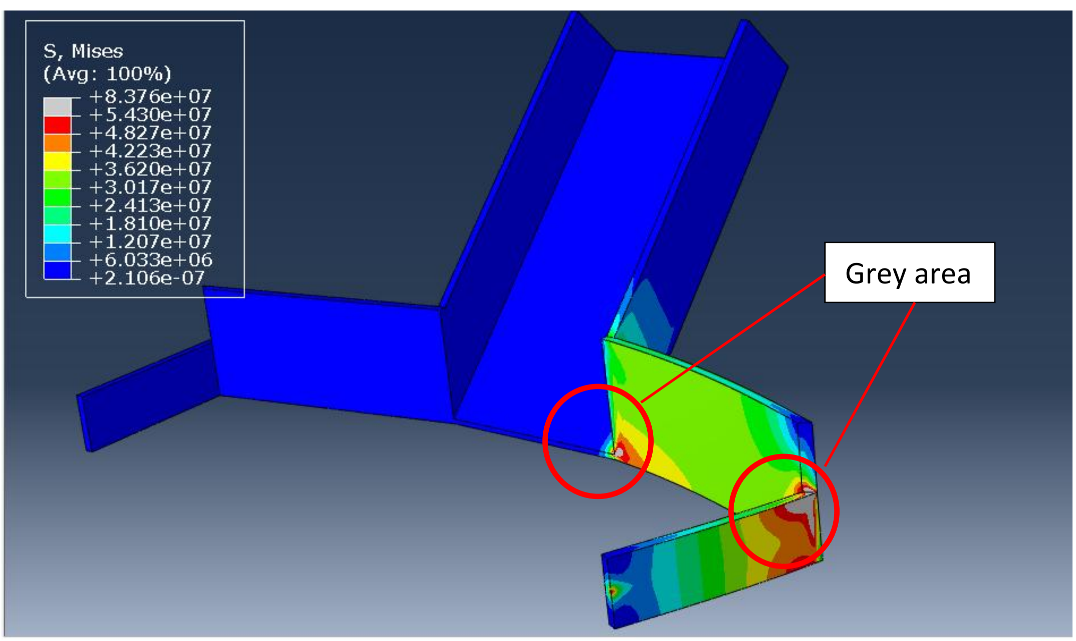


Figure 22: Deformed shape of Scoop – Von Mises Stress

There are several ways to improve current situation. First method is to increase the toughness of scoop through adding web to hold the wing of the scoop. Second method is to change the material for scoop to metal. And third method is to prevent any impact loading onto the scoop. First method is scrapped as adding a web increases the probability of pushing the ball away from scoop. Second method is not feasible as motor isn't enough to provide required torque as metal is much heavier. Also, metal with such long span has relatively high flexibility as well. Hence, third idea is considered by introducing a support bar around the scoop.

6.3.2 Support Bar (Phrase 3)

With 40N of applied force to the end of protector frame, no grey area is found in the figure below. Instead, maximum stress found is just 29.5MPa which is far lower than maximum allowable bending stress. The support bar is considered tough and strong enough to resist head on collision with enemy and able to provide a layer of protection to the scoop at inner area.

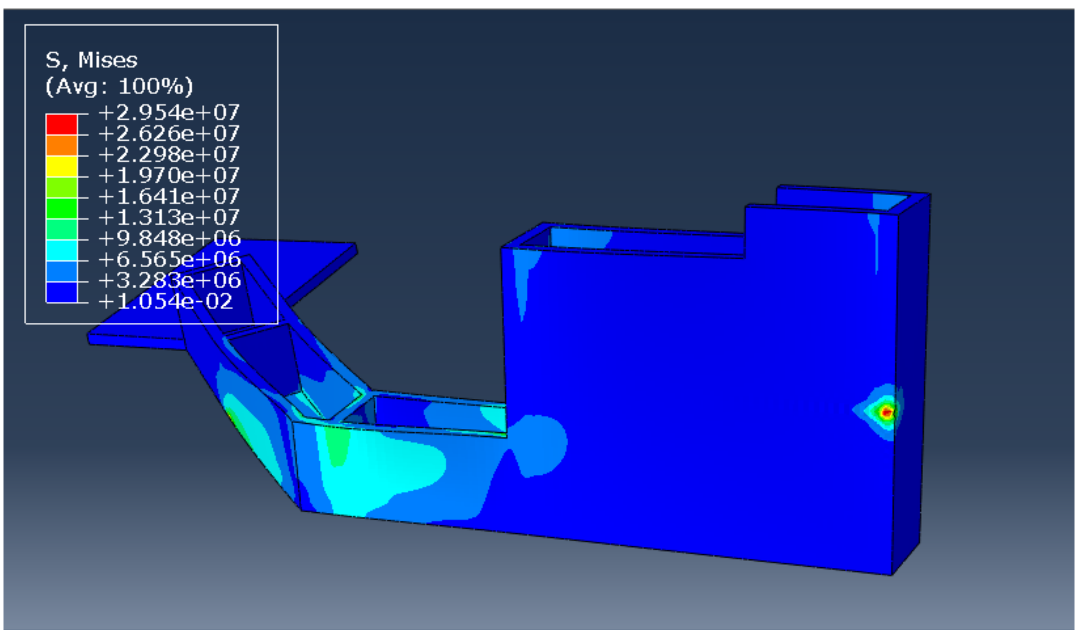


Figure 23: Deformed shape of Support Bar – Von Mises Stress

With displacement plot, it's found that maximum deflection happens at the end of support bar, with the value of 7.2mm. This deflection is tolerable as the clearance between support bar and scoop is 10mm at each side.

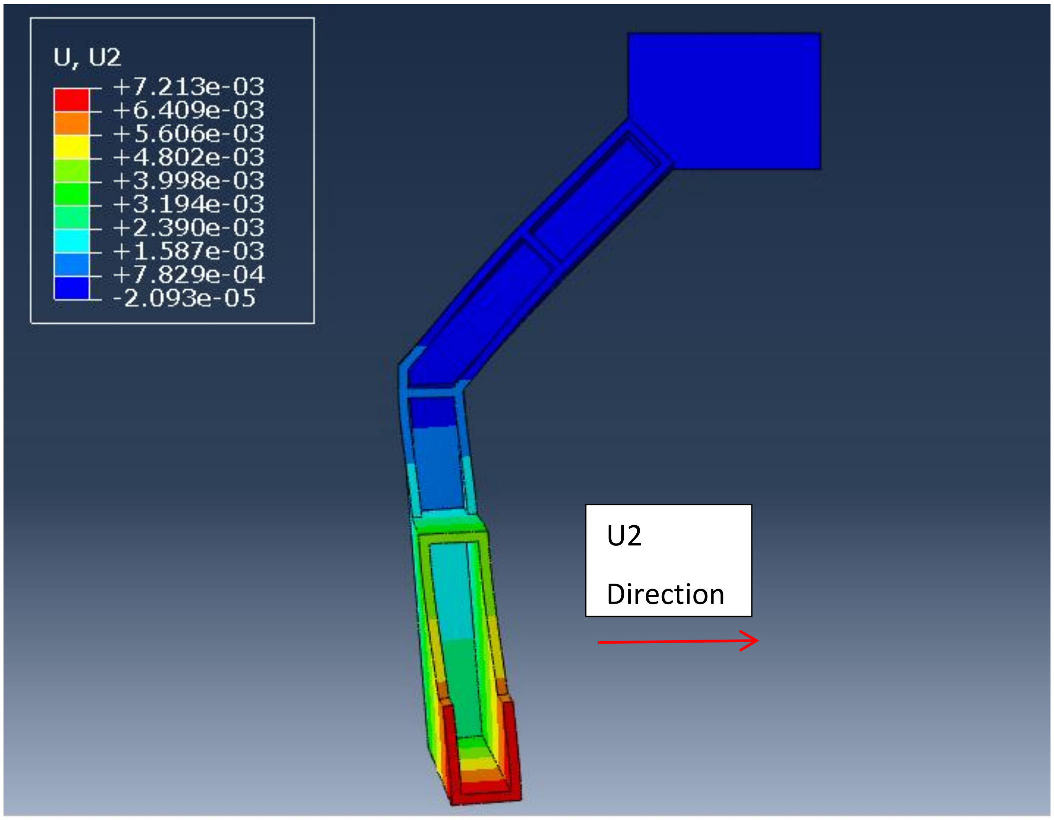


Figure 24: Deformed shape of Support Bar – Displacement

Hence, in conclusion, structural integrity of car is achieved with extra protection using support bar.

7 ASSEMBLY DRAWINGS

This section provides (1) assembly drawing and (2) exploded view of TARA 2

7.1 Assembly Drawing

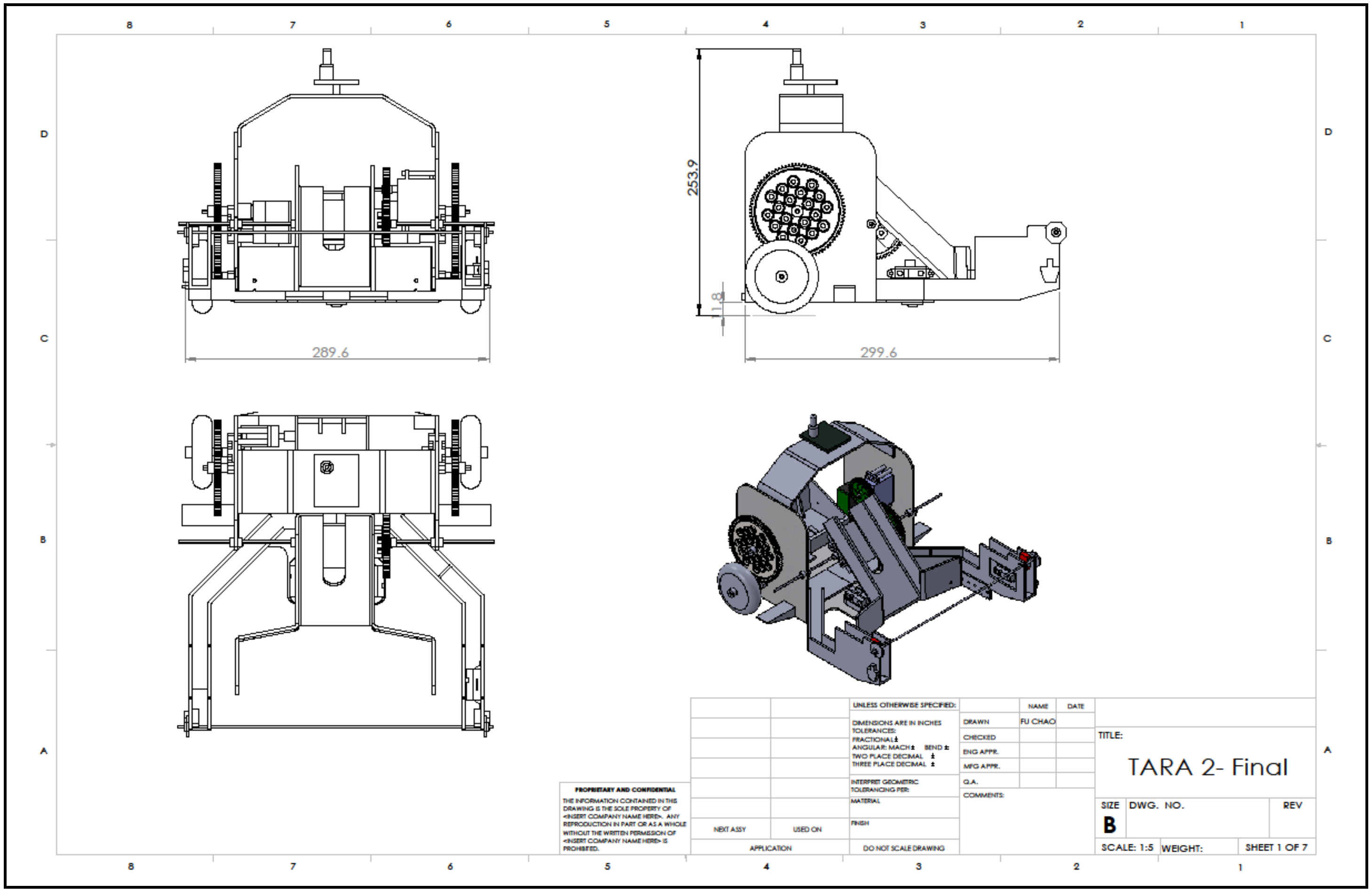
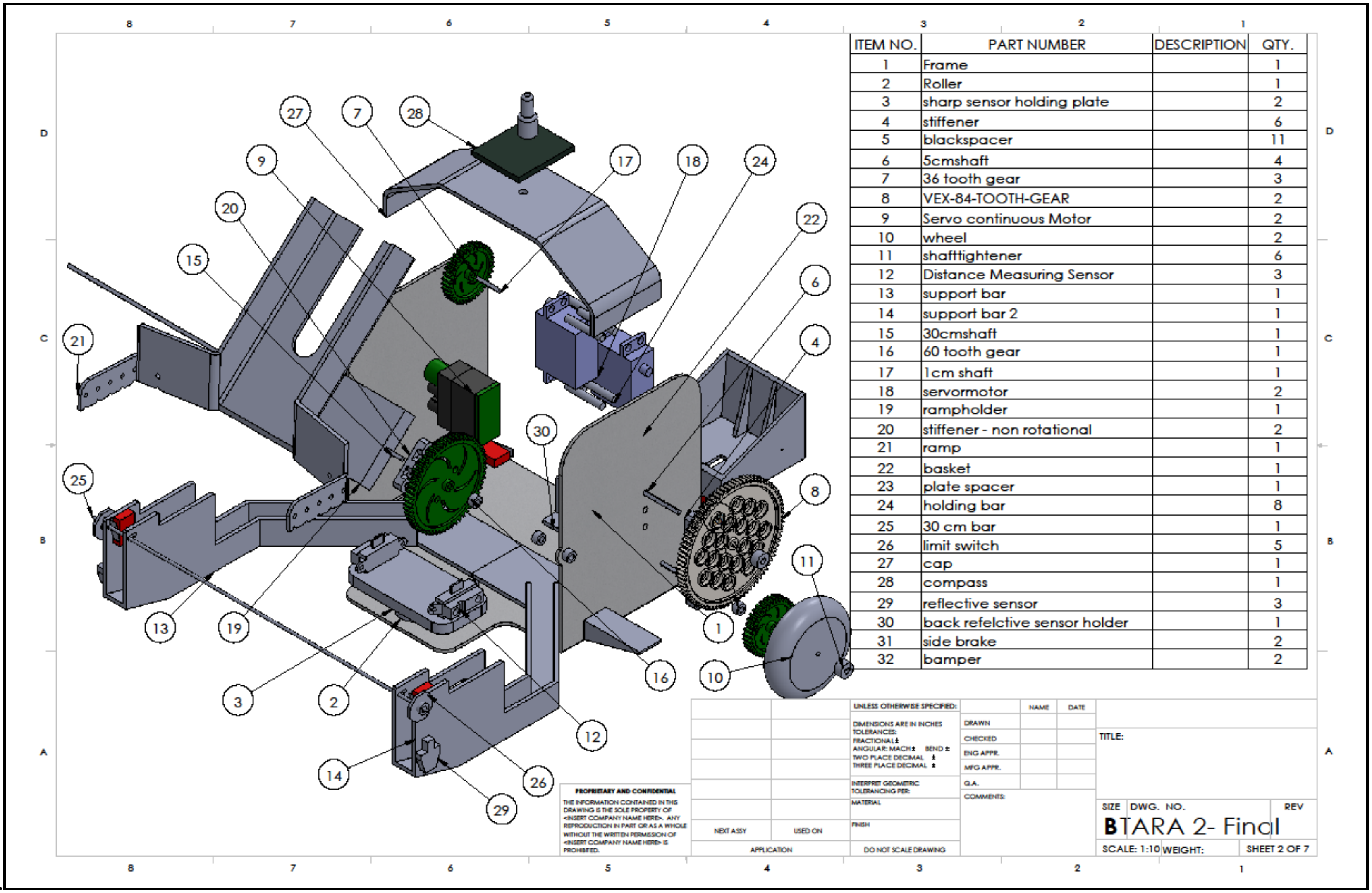


Figure 25: Assembly Drawing of TARA 2

7.2 Exploded View



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame		1
2	Roller		1
3	sharp sensor holding plate		2
4	stiffener		6
5	blackspacer		11
6	5cmshaft		4
7	36 tooth gear		3
8	VEX-84-TOOTH-GEAR		2
9	Servo continuous Motor		2
10	wheel		2
11	shafttightener		6
12	Distance Measuring Sensor		3
13	support bar		1
14	support bar 2		1
15	30cmshaft		1
16	60 tooth gear		1
17	1cm shaft		1
18	servormotor		2
19	rampholder		1
20	stiffener - non rotational		2
21	ramp		1
22	basket		1
23	plate spacer		1
24	holding bar		8
25	30 cm bar		1
26	limit switch		5
27	cap		1
28	compass		1
29	reflective sensor		3
30	back refelctive sensor holder		1
31	side brake		2
32	bamper		2

Figure 26: Exploded View of TARA 2

8 PART DRAWINGS

This section gives mechanical drawings for non-standard fabricated parts, includes scoop, basket, support bar, frame and cap.

8.1 Scoop

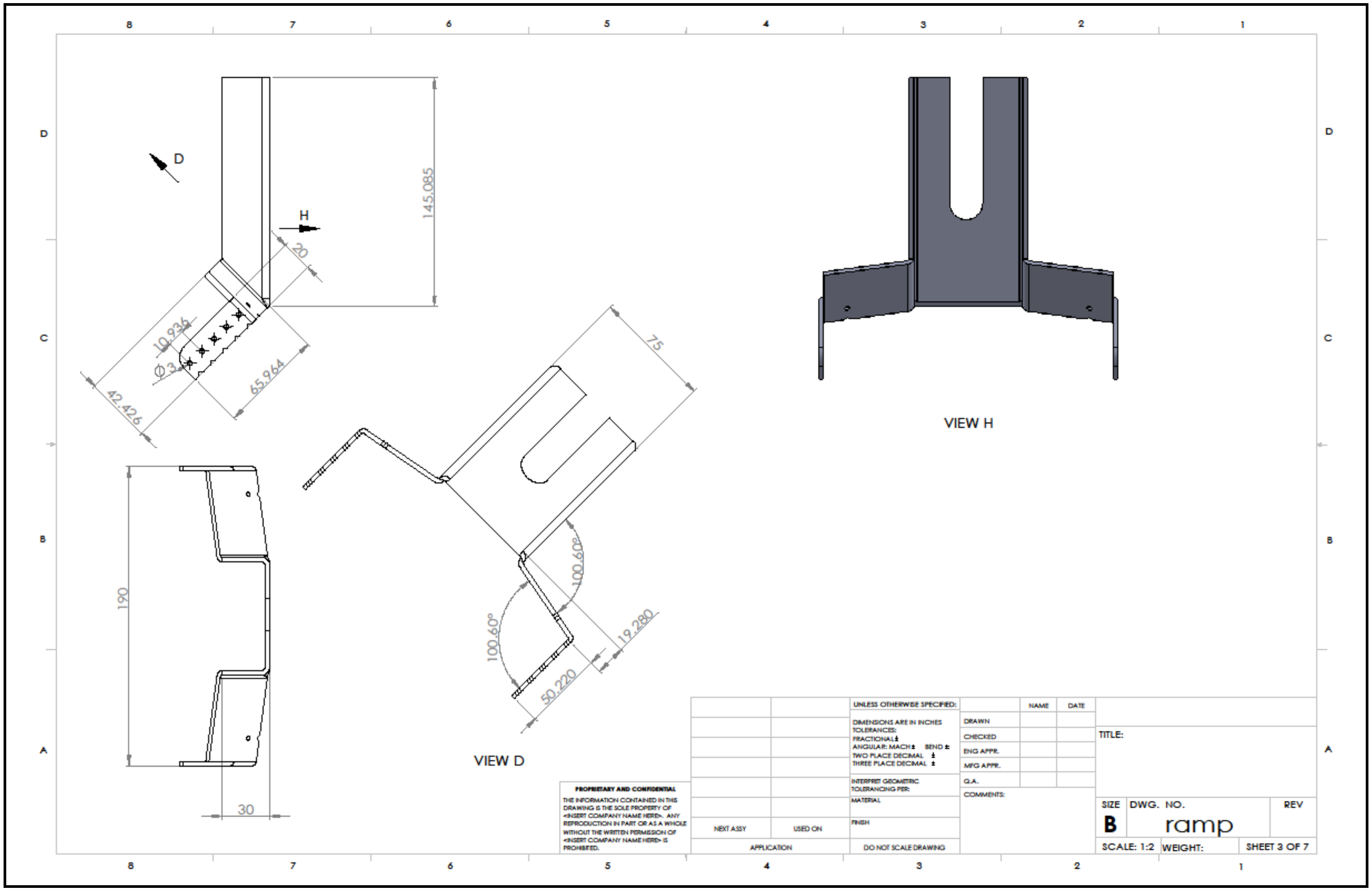


Figure 27: Mechanical Drawing - Scoop

8.2 Basket

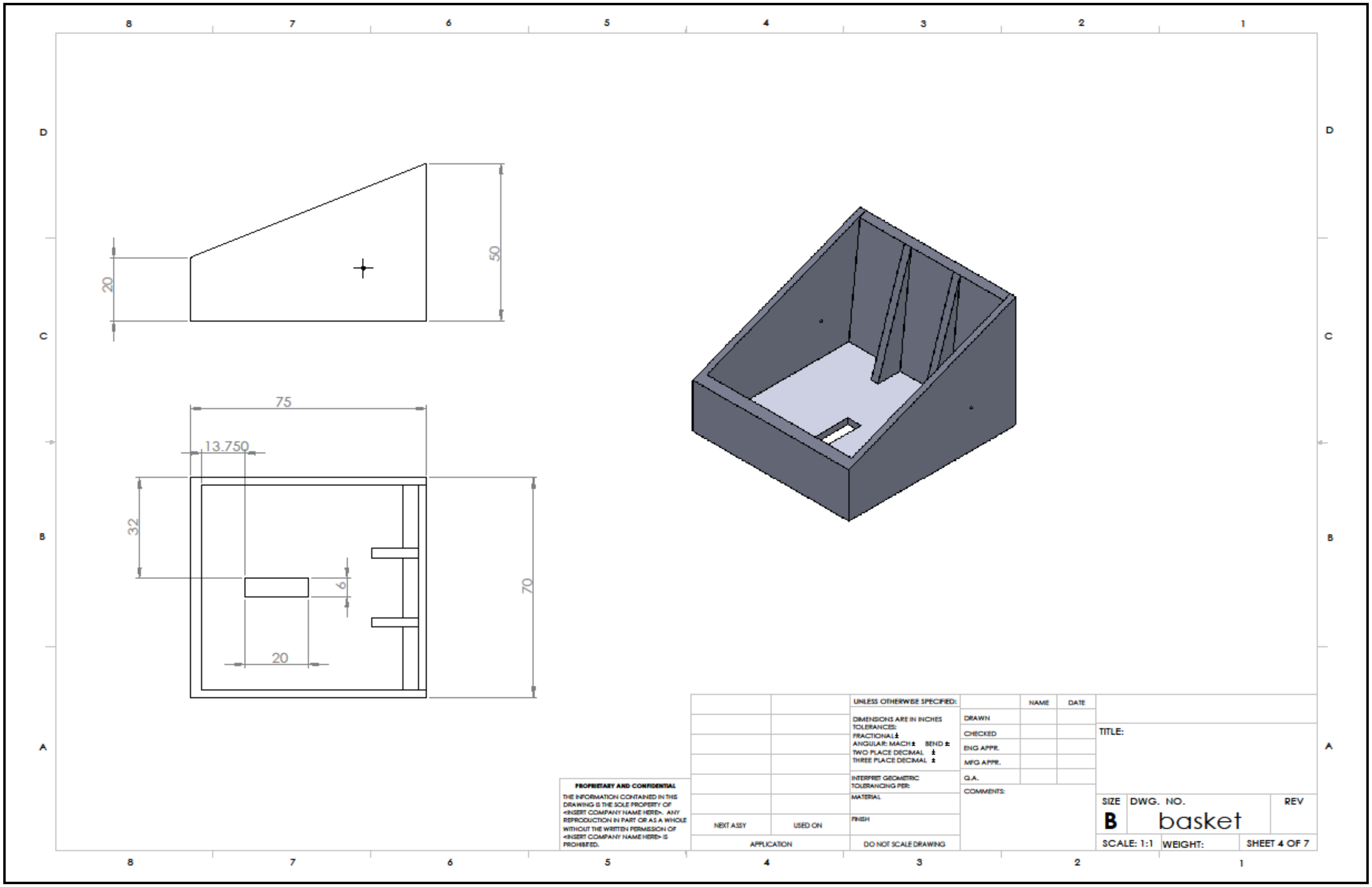


Figure 28: Mechanical Drawing - Basket

8.3 Support Bar

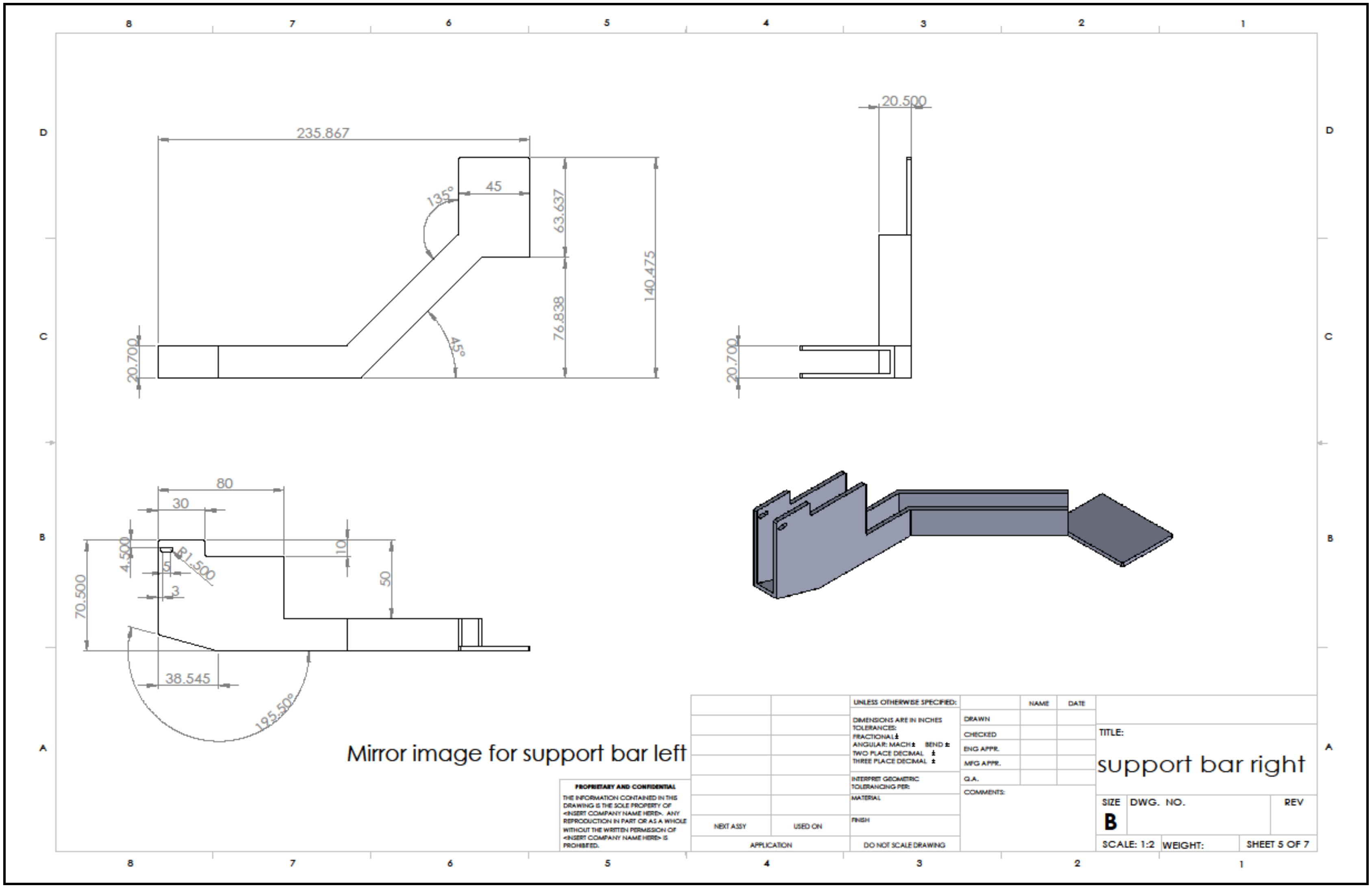


Figure 29: Mechanical Drawing - Support Bar

8.4 Frame

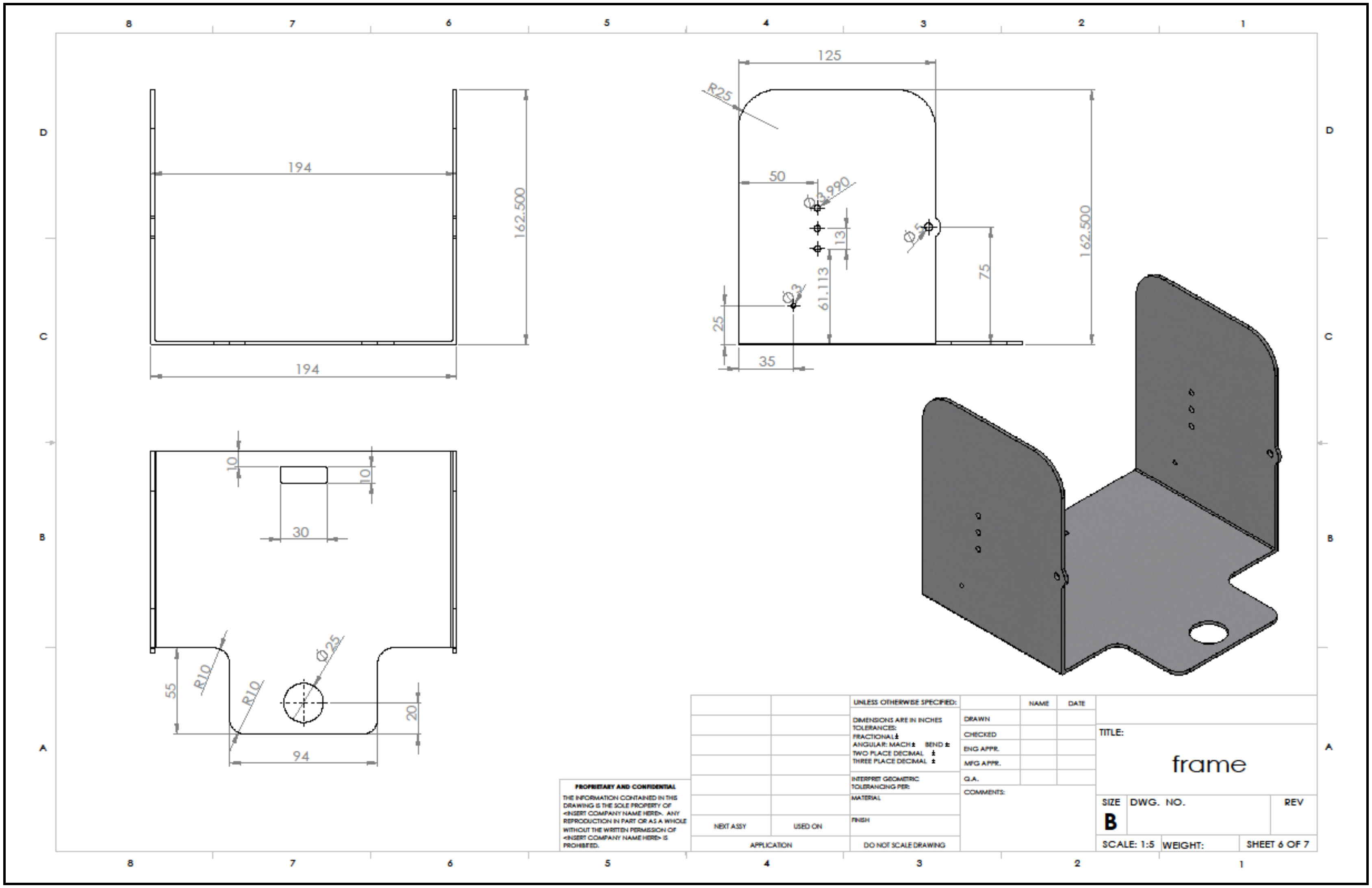


Figure 30: Mechanical Drawing - Frame

8.5 Cap

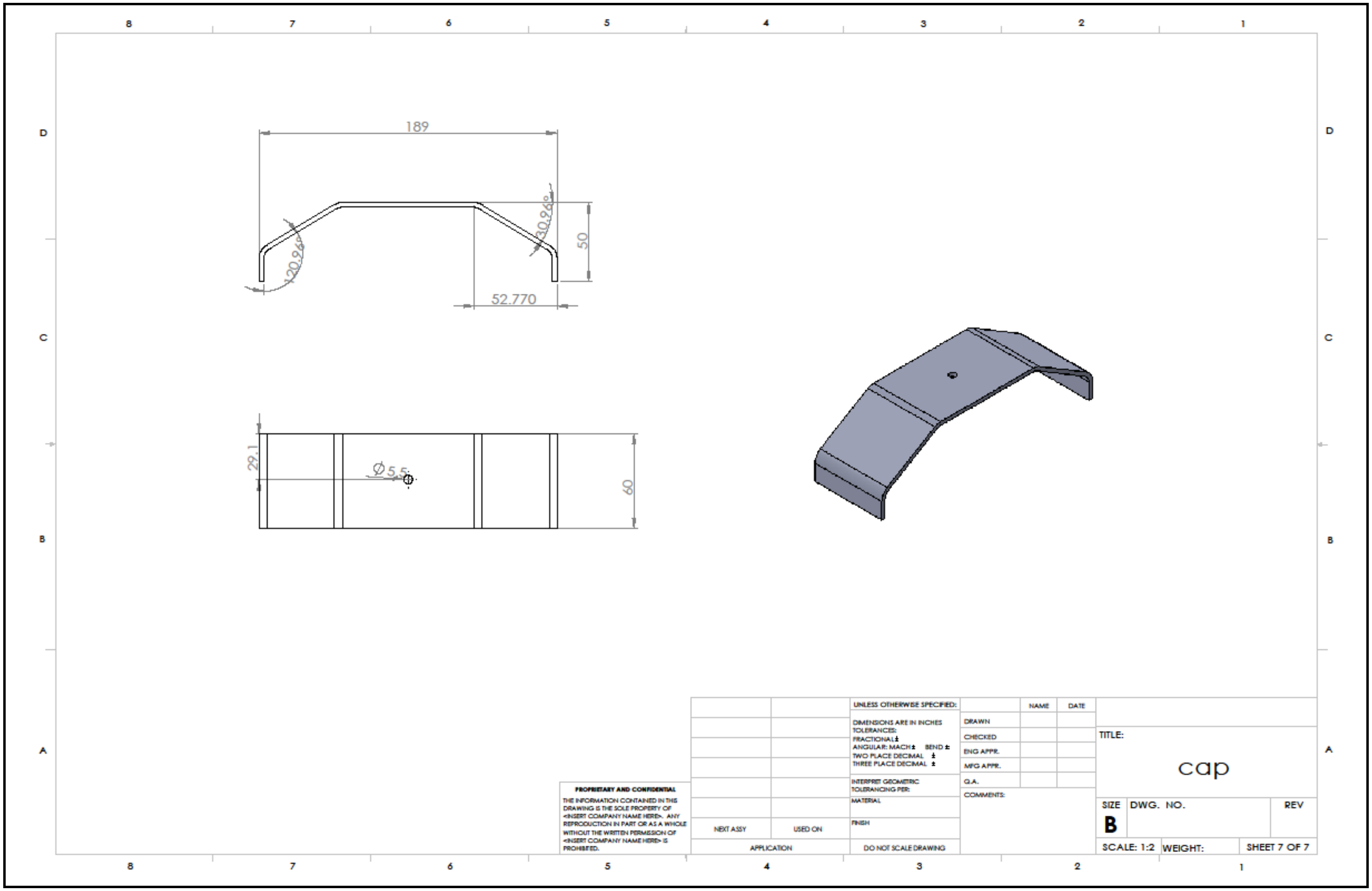


Figure 31: Mechanical Drawing – Cap

9 PROGRAMMING

This section describes the program flow includes the main program, avoid boundary, orient home, back home and side ball checking and catching.

9.1 Program Description

Before discussion, two common platforms are built. First, orientation of car is divided into 8 sectors where they are named in square bracket as below, with home position at the bottom. (Number)' represents the line between 2 sectors. Each sector has its unique value by combining four reading from compass using bitshift operator as follow:

value = (west<<3) + (south<<2) + (east<<1) + north

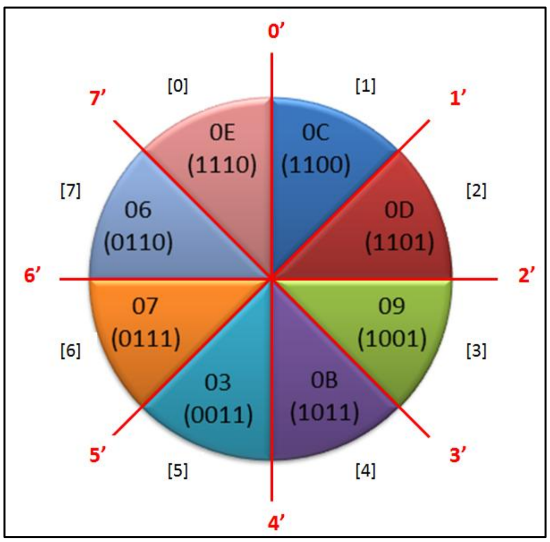


Figure 32: Compass Reading for Each Sector

Second platform is the game strategy. Counter clockwise sweeping method is deployed all the time, except case 3 and 4 (refer to *avoid_enermy ()* flow chart). Whenever a boundary is sensed, the car would self-orientate to continue the sweeping process. To fully cover the arena, side ball catching function is introduced.

Main Program with *Avoid_boundary ()*

Flow of the main program could be found in Flow Chart 1. Firstly, configuration data are initialized. Servo motors are set to initial position and car is put under ready-to-start mode. A continuous check is done to back left limit switch to trigger the start.

Program starts by moving the car forward. Next, boundary checking is performed. As there are 3 reflective sensors, 2 at the front and 1 at the behind, 8 different combinations are possible. If the car detects any boundary, *avoid_boundary ()* is triggered. 7 different strategies are used to counter all possible cases, as shown in the Flow Chart 2. Basically, counter clockwise sweeping is used. For example (case 2), when right sensor is detected and current compass shows orientation [5] or [6], the car reveals its position at the left hand side of arena, view from home position, and facing the home position. It would then turn left to 4' line and return a value of 5. However, for case 3 and 4, clockwise sweeping method is chosen. Look into case 3, orientation [0] or [7] reveals the car position at the left hand side of arena, but facing away from home position as opposes the case discussed above. It's wise to change the sweeping direction to avoid the car from turning back to its old track.

After boundary checking, the car checks the two front limit switches if it hits any enemy. Avoid enemy function is triggered if the signal is high. The car would move backward by fixed distance and make a right turn before looping back to start of main program.

Next, the car would perform a check on the limit switch mounted at the basket to determine if there is any ball. If yes, back home function would be triggered. Back home function is described in next sub-chapter. Main program continues with scoop checking using sharp sensor at one end of support frame. Bandwidth elimination method is deployed. In another words, existence of ball would change the value return by sharp sensor and trigger the ball to basket function, which involves lifting and lying down of scoop.

If check scoop function return zero, check side ball function is triggered. Side ball detection and catching mechanism are described in next sub-chapter as well. If the return is negative, it loops back to the start of main program.

Orient_home ()

Flow of the *orient_home ()* could be found in Flow Chart 3. It is a sub-function to orient the car towards the home position. First, it checks the current compass position to decide the turning direction. Compass orientation is divided to two portion, left and right. Least turning angle is achieved by turning clockwise when the current compass position is at right hand side, vice versa. If the first turning fails, the car turns to another direction. If both turning fails, the car turns to position away from home and exit with return of 0. Else, the return of this sub-function is 1.

Back_home ()

Flow of the *back_home ()* could be found in Flow Chart 4. This function is activated when ball in basket signal is triggered. It is divided to two main parts. First part of program describes the orientating and returning of cars towards home position while second part describes ball releasing mechanism. For each part of program, following sensors have to be triggered. Reflective sensors are checked to ensure the object hit by the car is the wall for home position but not enemy.

a. Either front left reflective sensor and left limit switch, or front right reflective sensor and right limit switch
b. Either back left reflective sensor and left limit switch, or back right reflective sensor and right limit switch

First part of the program starts by calling orient home function. Several cases that might happen in first part are considered, as followed.

1. The car is at distance away from home position. Turning of car is allowed.

   After successful orientating towards home position, the car moves towards the home position until condition (a) is fulfilled. Then, the car moves backward by fixed distance and makes a 180 degree turn to position away from home. The car is then moving backwards until condition (b) is met.

2. The car is very near from home position. Turning of car is restricted.

Since the car fails to turn in CW/CCW direction, it orients itself to position away from home before exiting orient home function. The car is then moving backwards until condition (b) is met, or it exceed the maximum number of loop (timeout).

3. The car is stuck with sideway/ front inclined ramp. Turning of car is restricted.

As in case 2, the car is moved backwards with full force to get out of stuck situation. It is then looped back to restart back home.

4. The car senses the boundary.

Since the car is moving forward, there are only left and right sensors that might be triggered. As long as boundary is sensed, the car will move backwards and re-orientate the car towards home position and loop continues.

Check_ball()

Flow of the *check_ball ()* could be found in Flow Chart 5. Side check ball is a sub-function to detect the presence of tennis ball at both sides of the car using two sharp sensors that are mounted at the left and right side of the car. The polling of sensor data will be executed in every execution of main program loop. If the value returned is within an accepted range, it will count as an object is detected and a counter will be incremented. Assuming the speed of the car is constant and the tennis ball is stationary, we determined through calibration that passing through a tennis ball will take approximately 50 cycles of main loop execution. Thus, the enemy threshold, enemy_size is set as 50. In other words, if an object is sense continuously for more than 50 cycles, it will not be treated as a ball and the car will not move to catch it.

The side_check_ball function starts by initializing the l_object=0 and r_object=0 once for the entire time when the function is called. It will then get the sensor values from both side sharp sensors and stored them in left_dist and right_dist. It will check for the left side then the right side. If left_dist is between the minimum and maximum value, the l_object will be incremented by one. If the left_dist is less than minimum value, it means no object is detected. The function will then check the value of l_object.

- If l_object is 0, it means that it has not detected any object prior to this execution cycle. No action is needed so left is set as 0.
- If l_object is less or equal to enemy_size, it means that the car has just detected a ball on the left side. Thus left is set as 1.
- If the l_object is more than enemy_size, it means that the car has just detected an enemy or wall. No action is needed so left is set as 0.

The same thing is executed for the right side and right will be set as 0 or 1 according to r_object. If left is 1, this function will return a value of 2. If right is 1, this function will return a value of 1. Else, this function will return a value of 0. These return values will be captured by the main program. For return value of 1 & 2, the main program will call the *catch_ball ()* function with the return value as function parameter. For return value of 0, the main program will simple jump back to beginning and start a new execution loop.

Catch_ball()

Flow of the *catch_ball ()* could be found in Flow Chart 6. It is a sub-function to catch a ball when it is sensed at the left or right side of the car. This function is called with a side value of 2 indicates ball at left side and 1 indicates right side. Firstly, the current car orientation is determined by checking the compass reading. According to the compass reading, a back_index of either facing home or facing opposite home is determined. The back_index will be used to orientate the car after all execution in this sub-function has finished.

If the side is 2, the car will move backward for a fixed distance, stop and rotate to the left for a certain angle. All these movements are calibrated at the arena to ensure maximum range of capture. Similar actions are executed for side = 1, but the car turns to the right instead of left. After turning has completed, the car will move forward and constantly checking the scoop for ball. If a ball is sensed, the scoop will be lifted up and this function will return 1. If no ball is sensed, the car will check for boundary. If any boundary is sensed, the car will stop, move back, rotate to back_index orientation and will return 0 to jump back to the main program. This loop will continue to run if no ball or boundary is sensed until timeout (300 iterations).

9.2 Program Flow Chart

Five flow charts are provided under this section. They are:

1. Main Program
2. *Avoid_enemy ()*
3. *Orient_home ()*
4. *Back_home ()*
5. *Check_ball ()*
6. *Catch_ball ()*

Figure 33: Flow Chart 1 - Main Program

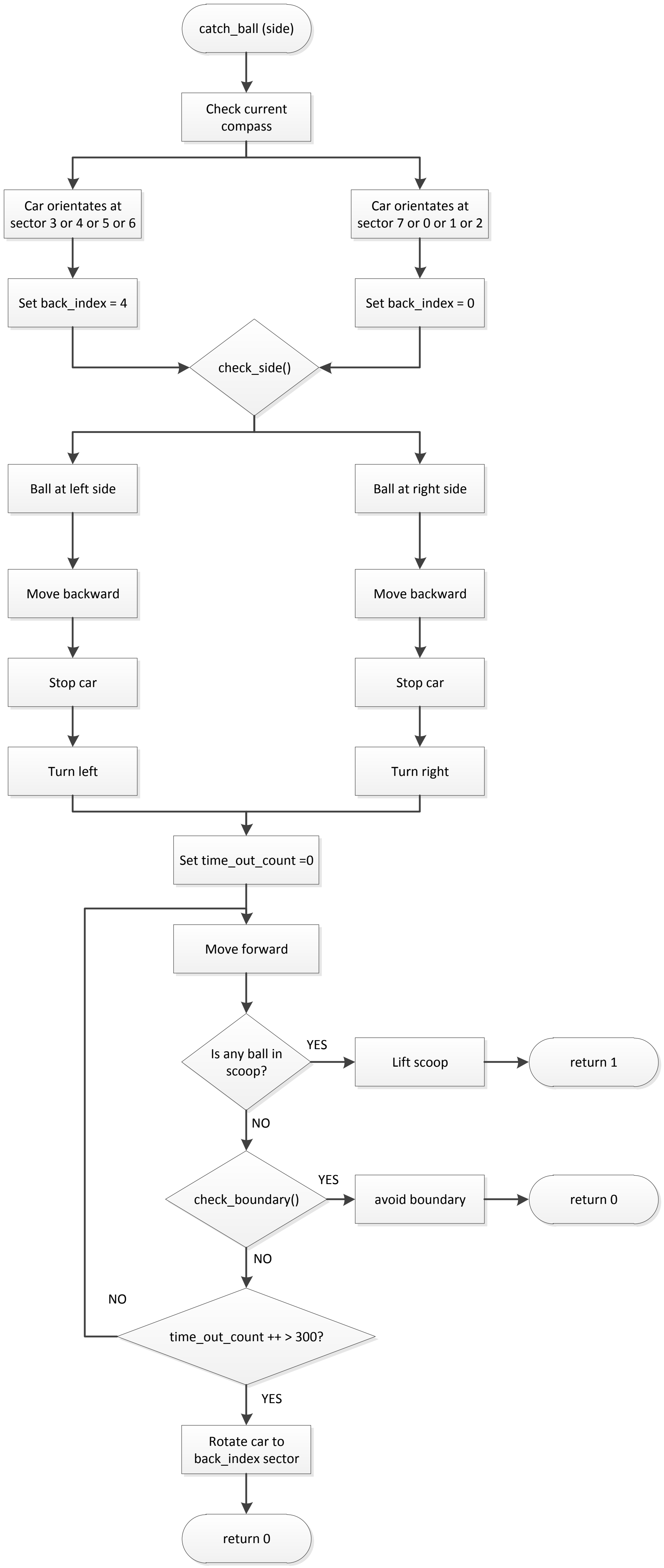
Figure 34: Flow Chart 2 – *Avoid_boundary ()*

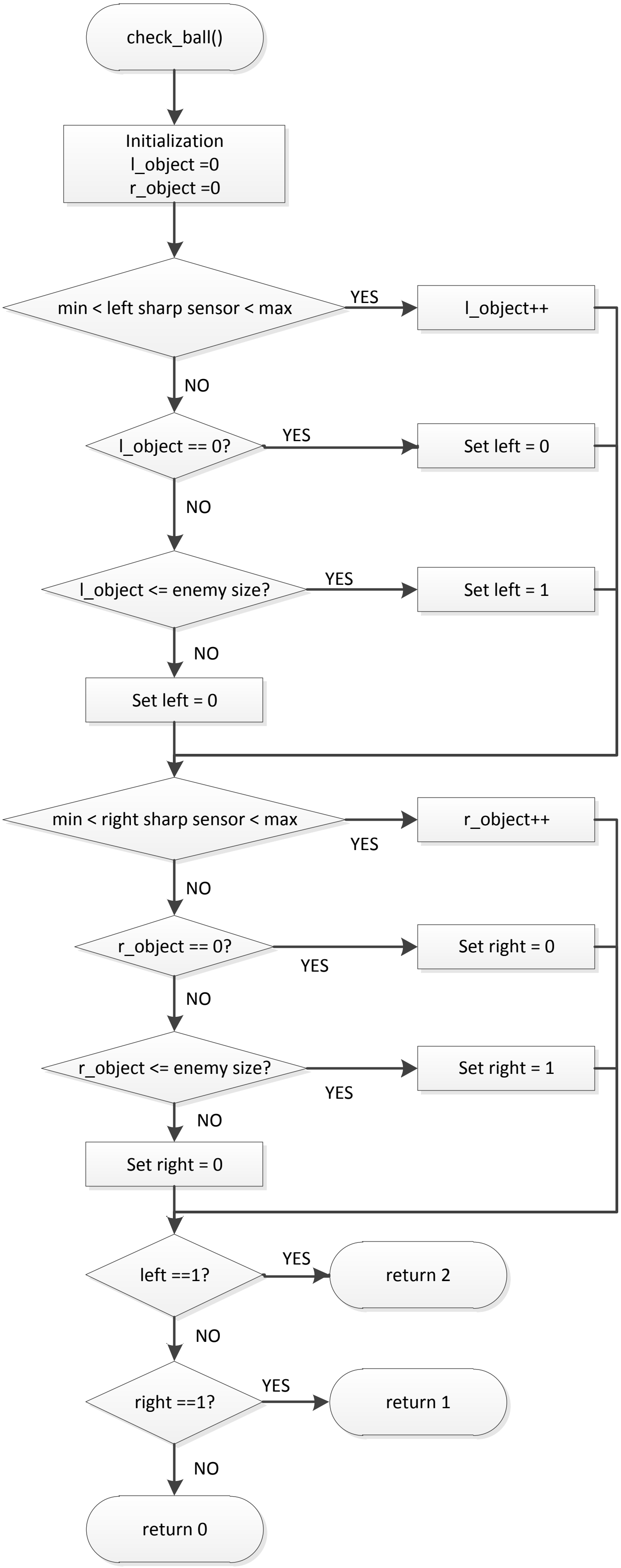
Figure 35: Flow Chart 3 – *Orient_home ()*

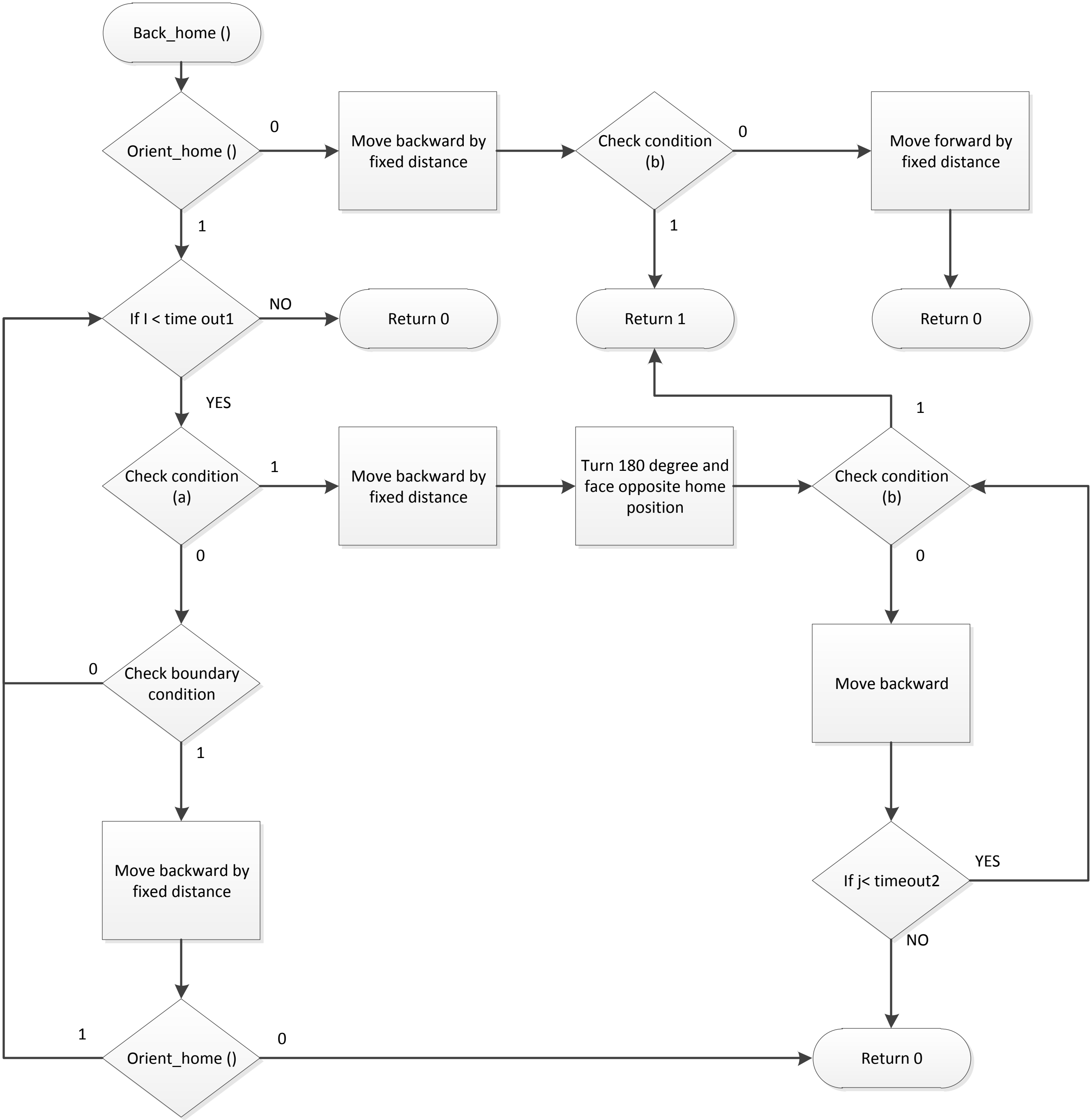
Figure 36: Flow Chart 4 – *Back_home ()*

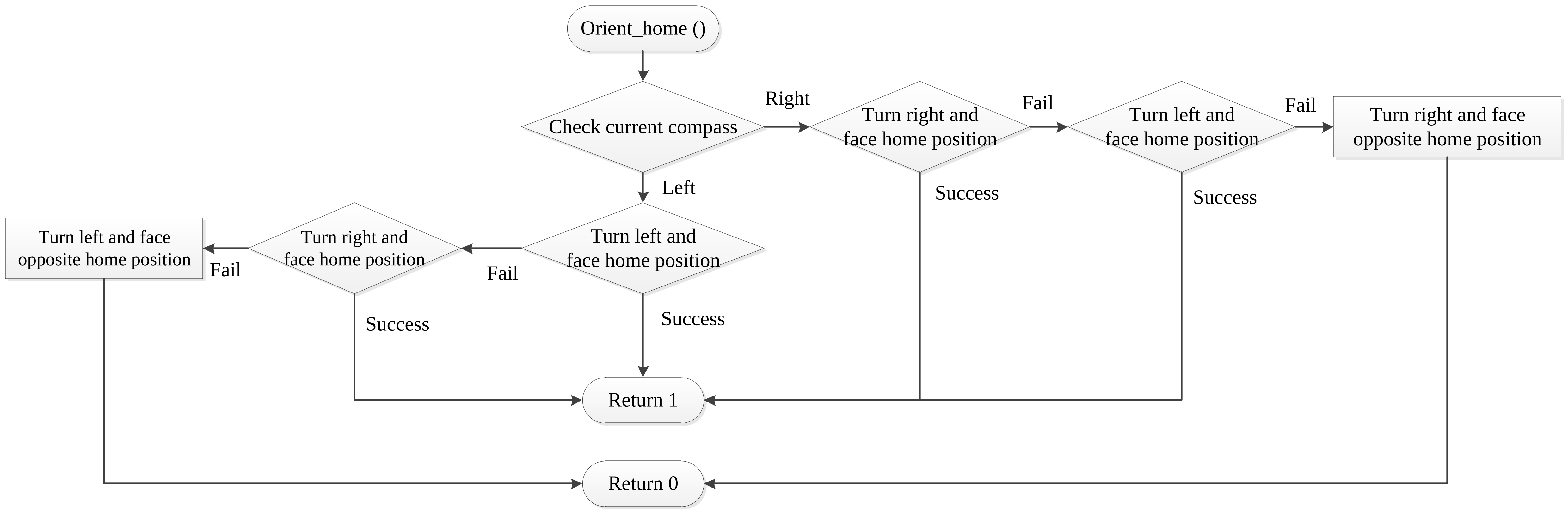
Figure 37: Flow Chart 5 – *Check_ball ()*

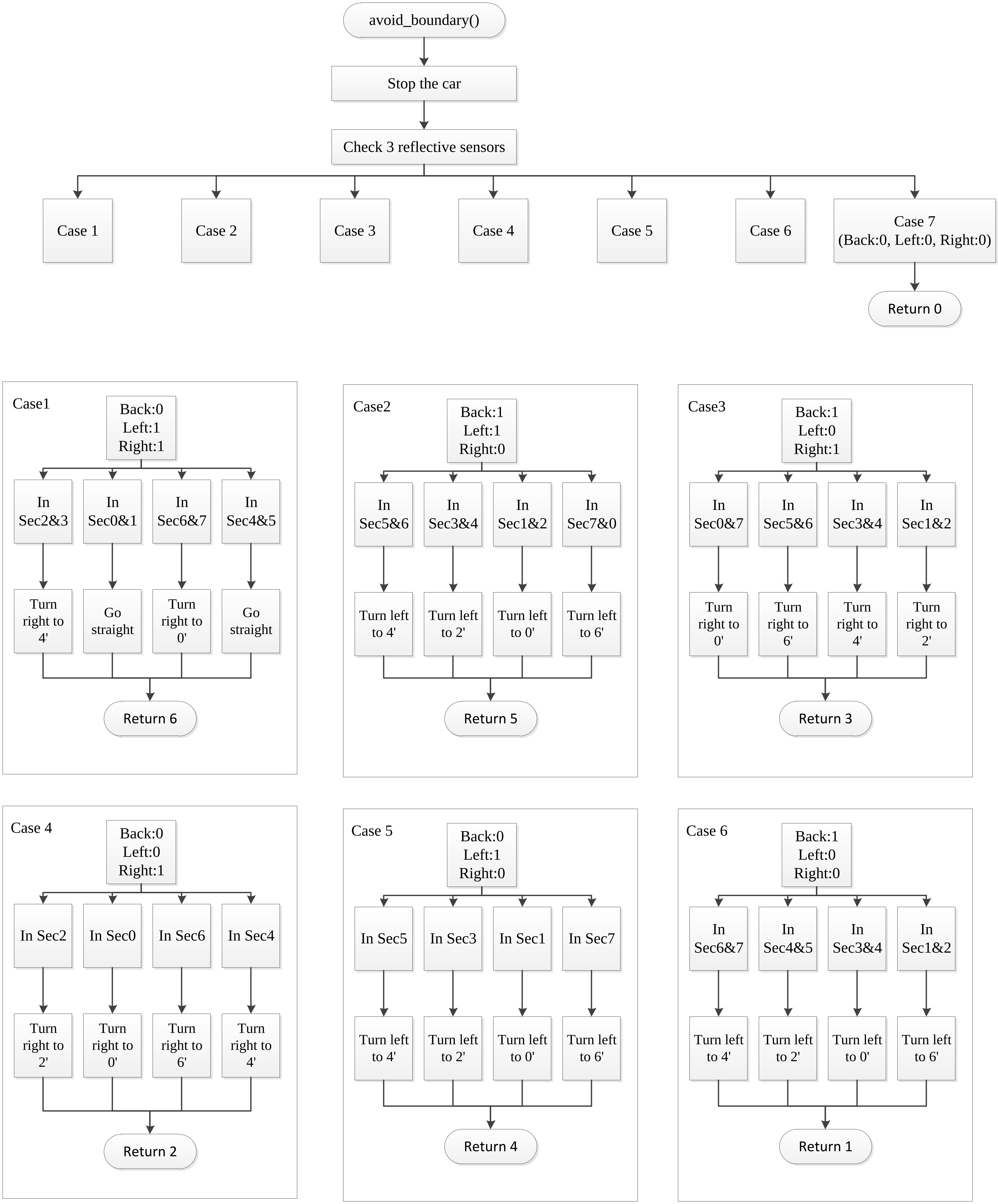
Figure 38: Flow Chart 6 – Catch_*ball ()*

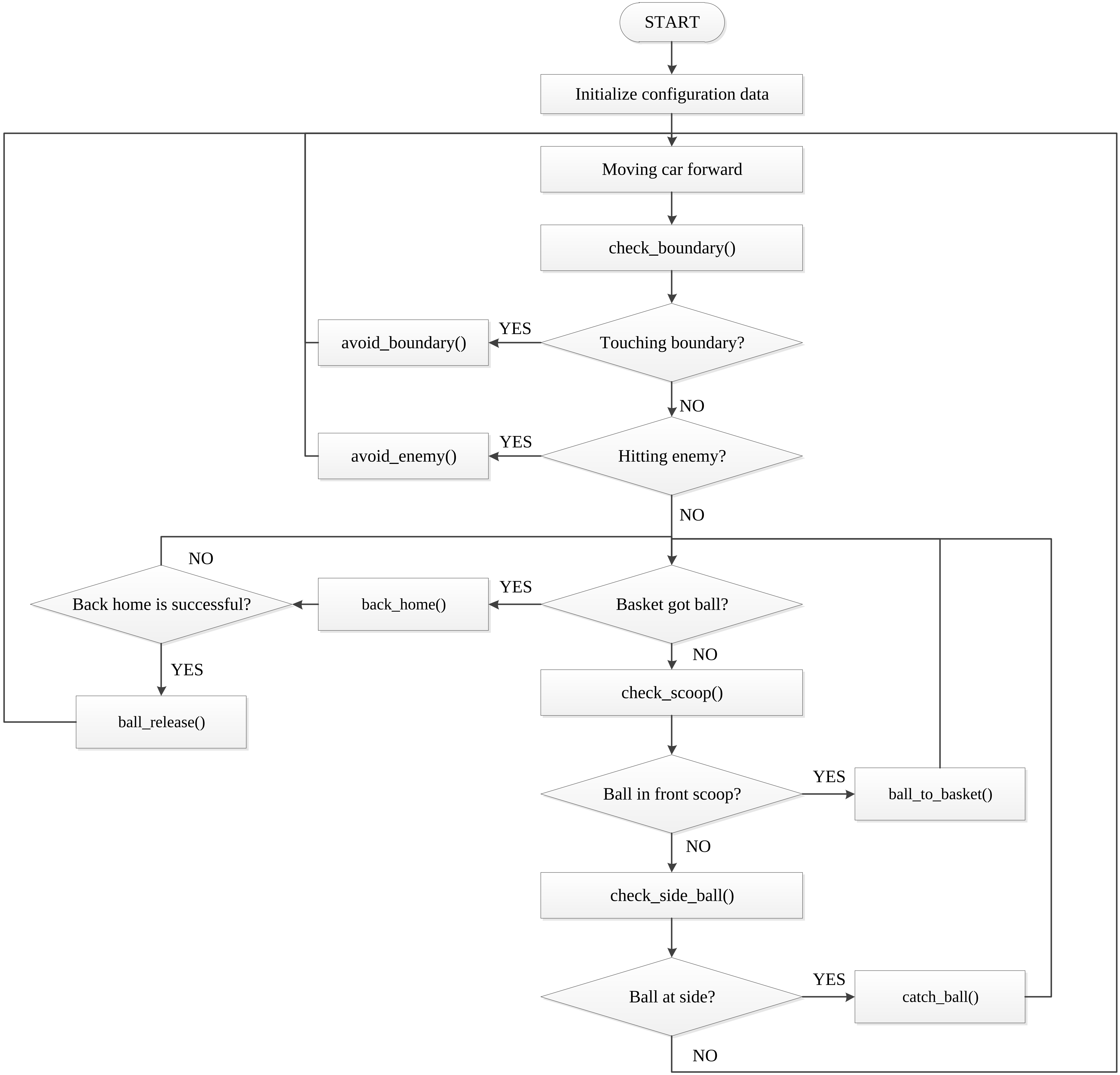

catch_ball (side)
Check current compass
Car orientates at sector 3 or 4 or 5 or 6
Car orientates at sector 7 or 0 or 1 or 2
Set back_index = 4
Set back_index = 0
check_side()
Ball at left side
Ball at right side
Move backward
Move backward
Stop car
Stop car
Turn left
Turn right
Set time_out_count =0
Move forward
Is any ball in scoop?
YES
Lift scoop
return 1
NO
check_boundary()
YES
avoid boundary
return 0
NO
NO
time_out_count ++ > 300?
YES
Rotate car to back_index sector
return 0


check_ball()
Initialization
l_object =0
r_object =0
min < left sharp sensor < max
YES
l_object++
NO
l_object == 0?
YES
Set left = 0
NO
l_object <= enemy size?
YES
Set left = 1
NO
Set left = 0
min < right sharp sensor < max
r_object++
YES
NO
r_object == 0?
Set right = 0
YES
NO
r_object <= enemy size?
Set right = 1
YES
NO
Set right = 0
left ==1?
YES
return 2
NO
right ==1?
YES
return 1
NO
return 0


Back_home ()
Orient_home ()
0
Move backward by fixed distance
Check condition (b)
0
Move forward by fixed distance
1
1
If I < time out1
NO
Return 0
Return 1
Return 0
YES
1
Check condition (a)
1
Move backward by fixed distance
Turn 180 degree and face opposite home position
Check condition (b)
0
0
Check boundary condition
0
Move backward
1
Move backward by fixed distance
If j< timeout2
YES
NO
1
Orient_home ()
0
Return 0


Orient_home ()
Check current compass
Right
Left
Turn right and face home position
Fail
Turn left and face home position
Fail
Turn right and face opposite home position
Success
Success
Turn left and face home position
Fail
Turn right and face home position
Fail
Turn left and face opposite home position
Success
Success
Return 1
Return 0

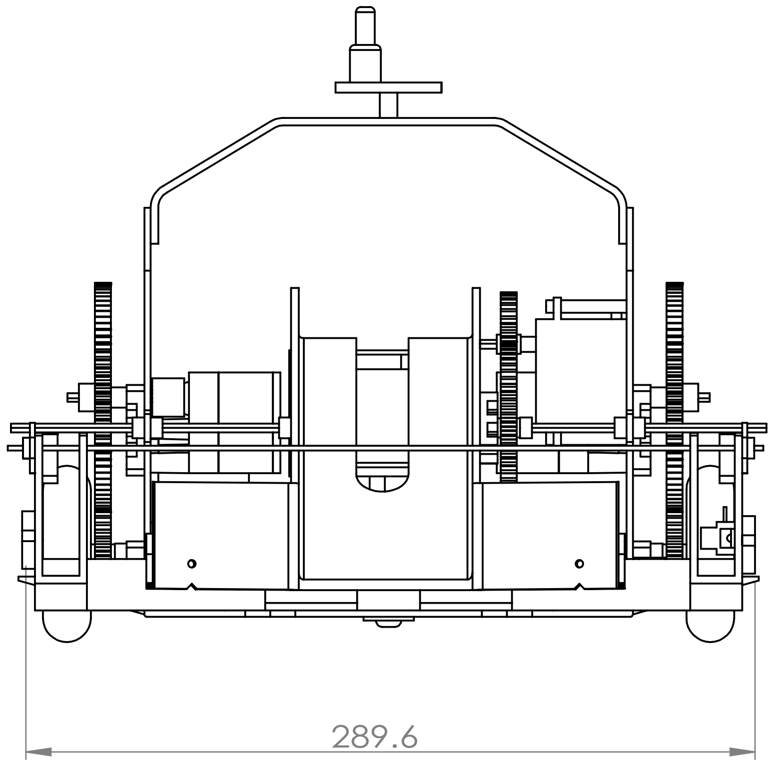

avoid_boundary()
Stop the car
Check 3 reflective sensors
Case 1
Case 2
Case 3
Case 4
Case 5
Case 6
Case 7 (Back:0, Left:0, Right:0)
Return 0
Case1
Back:0 Left:1 Right:1
In Sec2&3
In Sec0&1
In Sec6&7
In Sec4&5
Turn right to 4'
Go straight
Turn right to 0'
Go straight
Return 6
Case2
Back:1 Left:1 Right:0
In Sec5&6
In Sec3&4
In Sec1&2
In Sec7&0
Turn left to 4'
Turn left to 2'
Turn left to 0'
Turn left to 6'
Return 5
Case3
Back:1 Left:0 Right:1
In Sec0&7
In Sec5&6
In Sec3&4
In Sec1&2
Turn right to 0'
Turn right to 6'
Turn right to 4'
Turn right to 2'
Return 3
Case 4
Back:0 Left:0 Right:1
In Sec2
In Sec0
In Sec6
In Sec4
Turn right to 2'
Turn right to 0'
Turn right to 6'
Turn right to 4'
Return 2
Case 5
Back:0 Left:1 Right:0
In Sec5
In Sec3
In Sec1
In Sec7
Turn left to 4'
Turn left to 2'
Turn left to 0'
Turn left to 6'
Return 4
Case 6
Back:1 Left:0 Right:0
In Sec6&7
In Sec4&5
In Sec3&4
In Sec1&2
Turn left to 4'
Turn left to 2'
Turn left to 0'
Turn left to 6'
Return 1

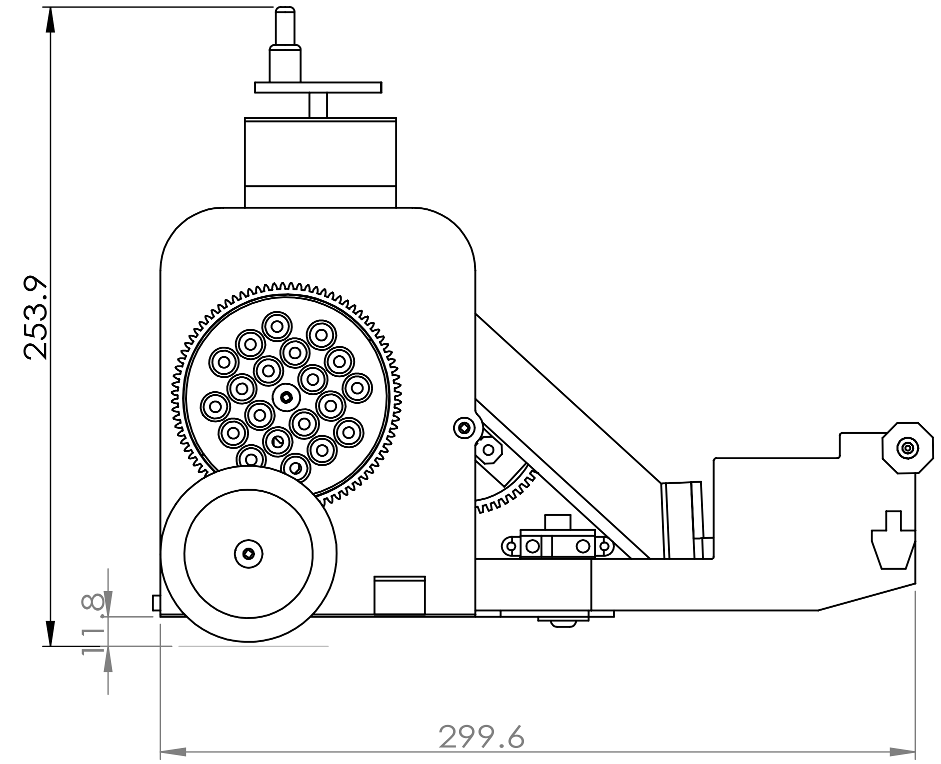

START
Initialize configuration data
Moving car forward
check_boundary()
Touching boundary?
YES
avoid_boundary()
NO
Hitting enemy?
YES
avoid_enemy()
NO
Basket got ball?
YES
back_home()
Back home is successful?
NO
YES
ball_release()
NO
check_scoop()
Ball in front scoop?
YES
ball_to_basket()
NO
check_side_ball()
Ball at side?
YES
catch_ball()
NO

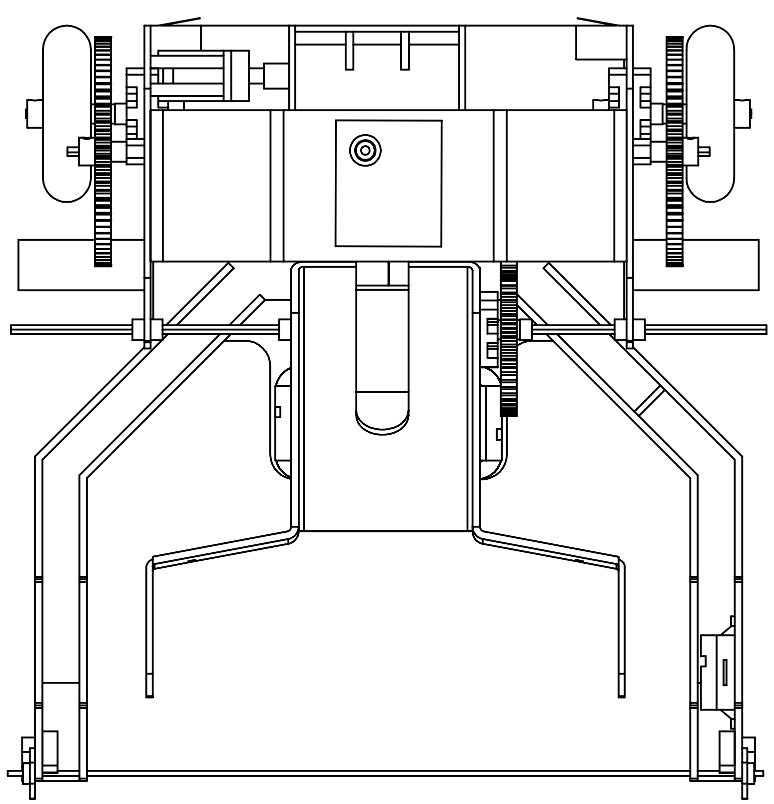
10 APPENDIX

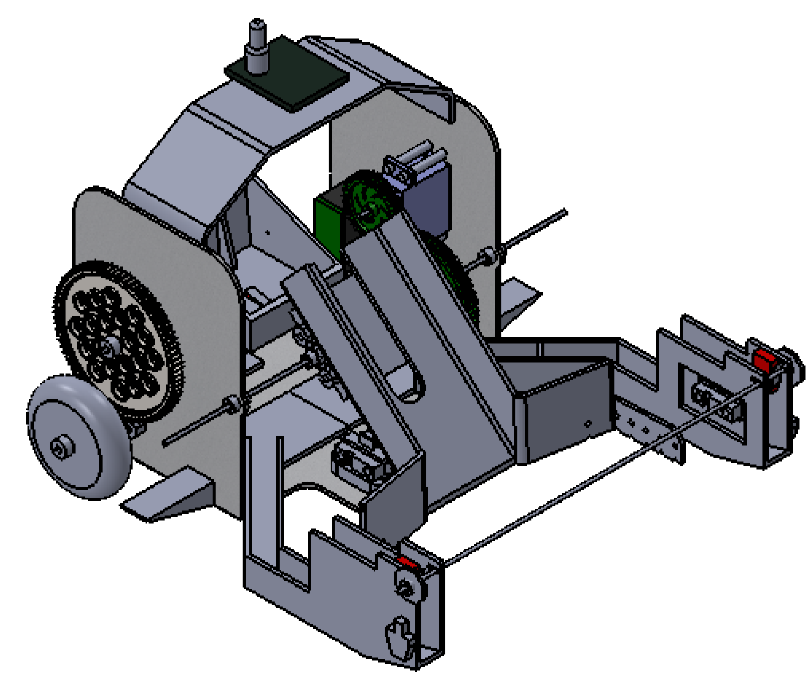
10.1 Acrylic Sheet Product Data Sheet

10.2 User_routines.c Program









PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

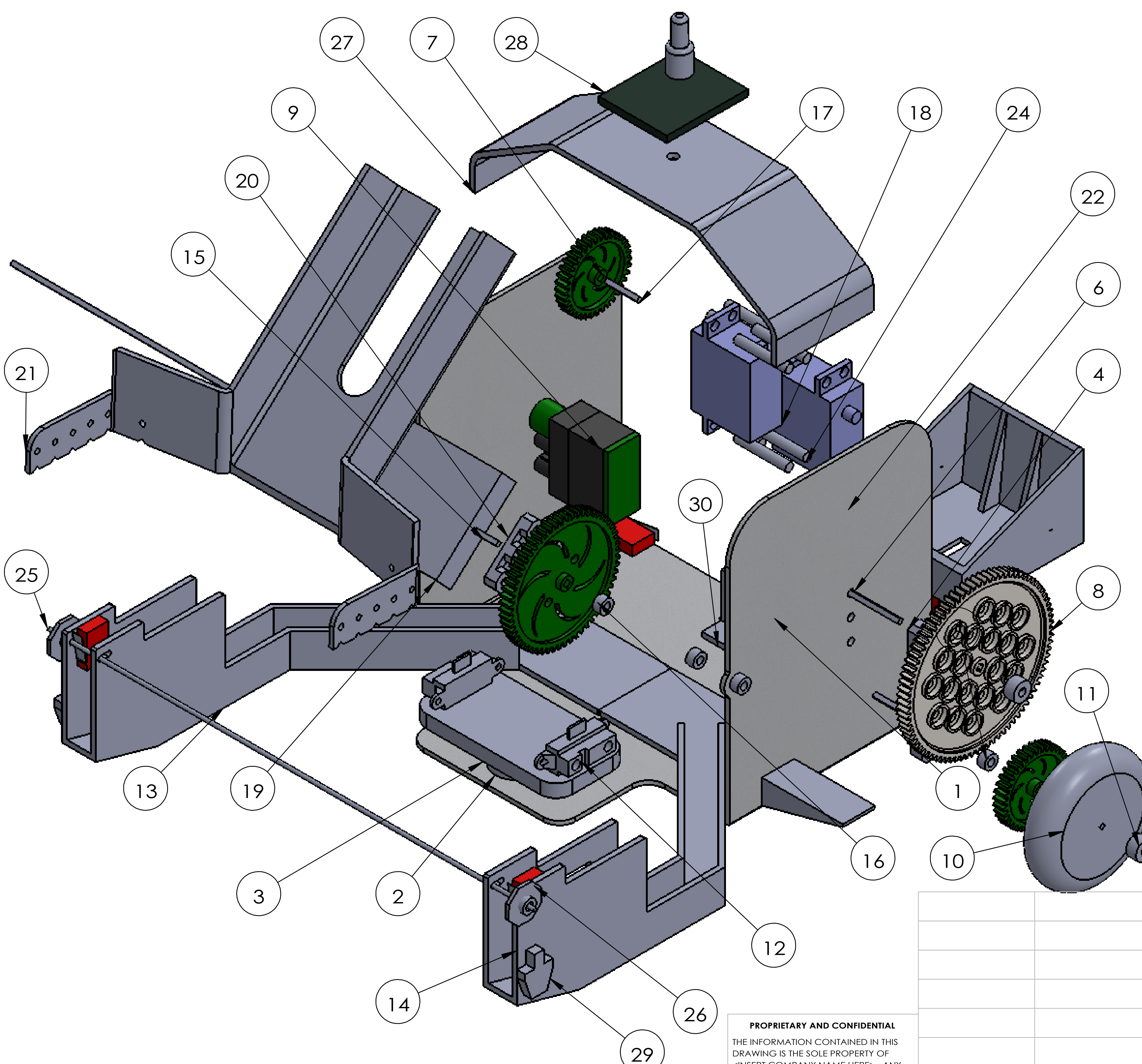
	NAME	DATE
DRAWN	FU CHAO	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

TARA 2- Final

SIZE	DWG. NO.	REV
B		

SCALE: 1:5 WEIGHT: SHEET 1 OF 7



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame		1
2	Roller		1
3	sharp sensor holding plate		2
4	stiffener		6
5	blackspacer		11
6	5cmshaft		4
7	36 tooth gear		3
8	VEX-84-TOOTH-GEAR		2
9	Servo continuous Motor		2
10	wheel		2
11	shafttightener		6
12	Distance Measuring Sensor		3
13	support bar		1
14	support bar 2		1
15	30cmshaft		1
16	60 tooth gear		1
17	1cm shaft		1
18	servormotor		2
19	rampholder		1
20	stiffener - non rotational		2
21	ramp		1
22	basket		1
23	plate spacer		1
24	holding bar		8
25	30 cm bar		1
26	limit switch		5
27	cap		1
28	compass		1
29	reflective sensor		3
30	back refelctive sensor holder		1
31	side brake		2
32	bamper		2

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

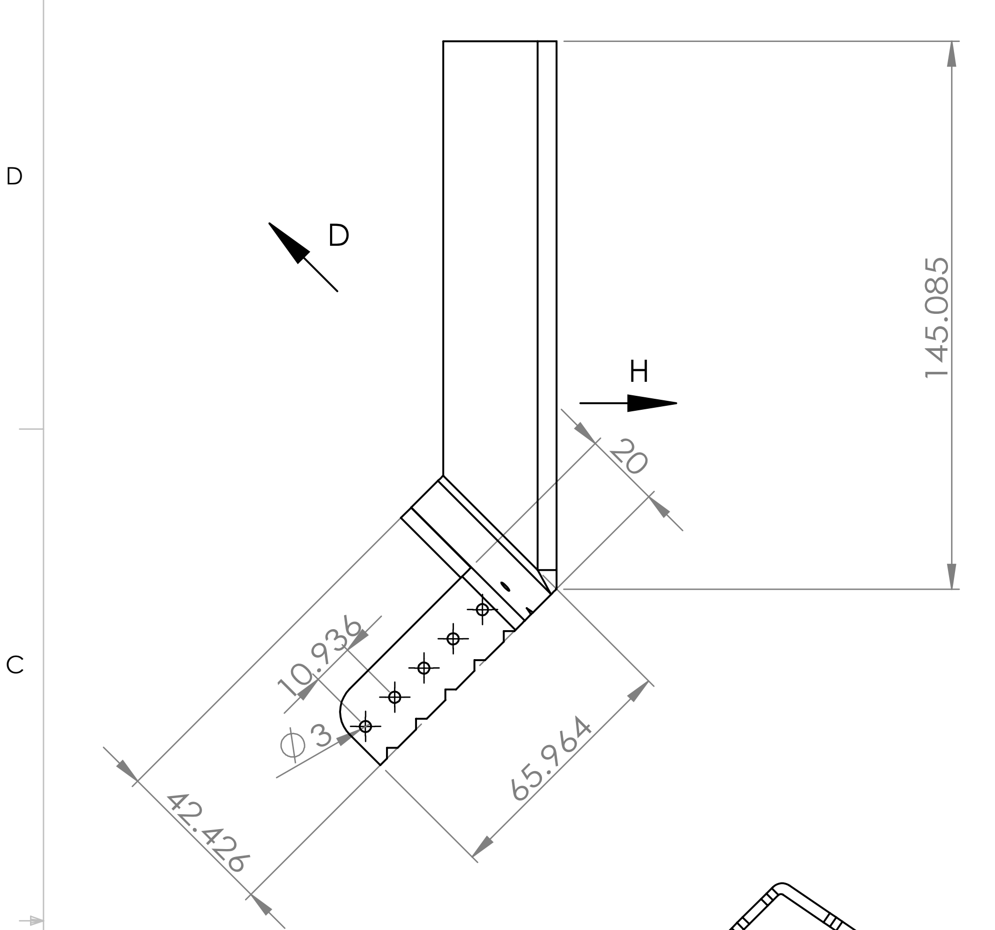
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

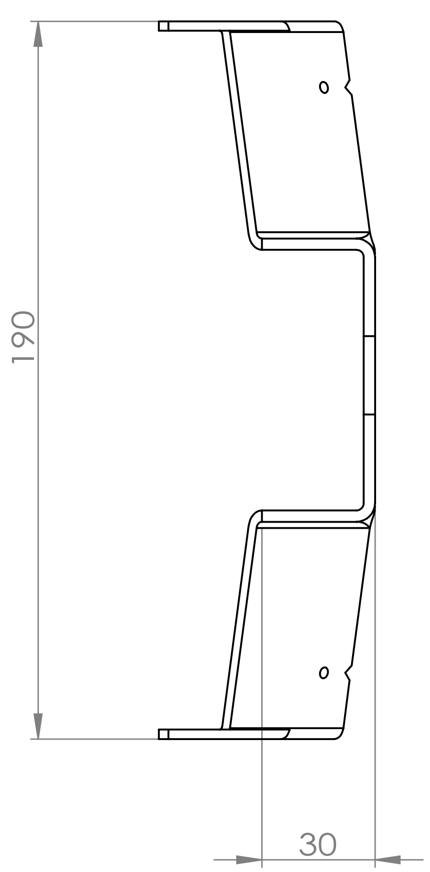
COMMENTS:

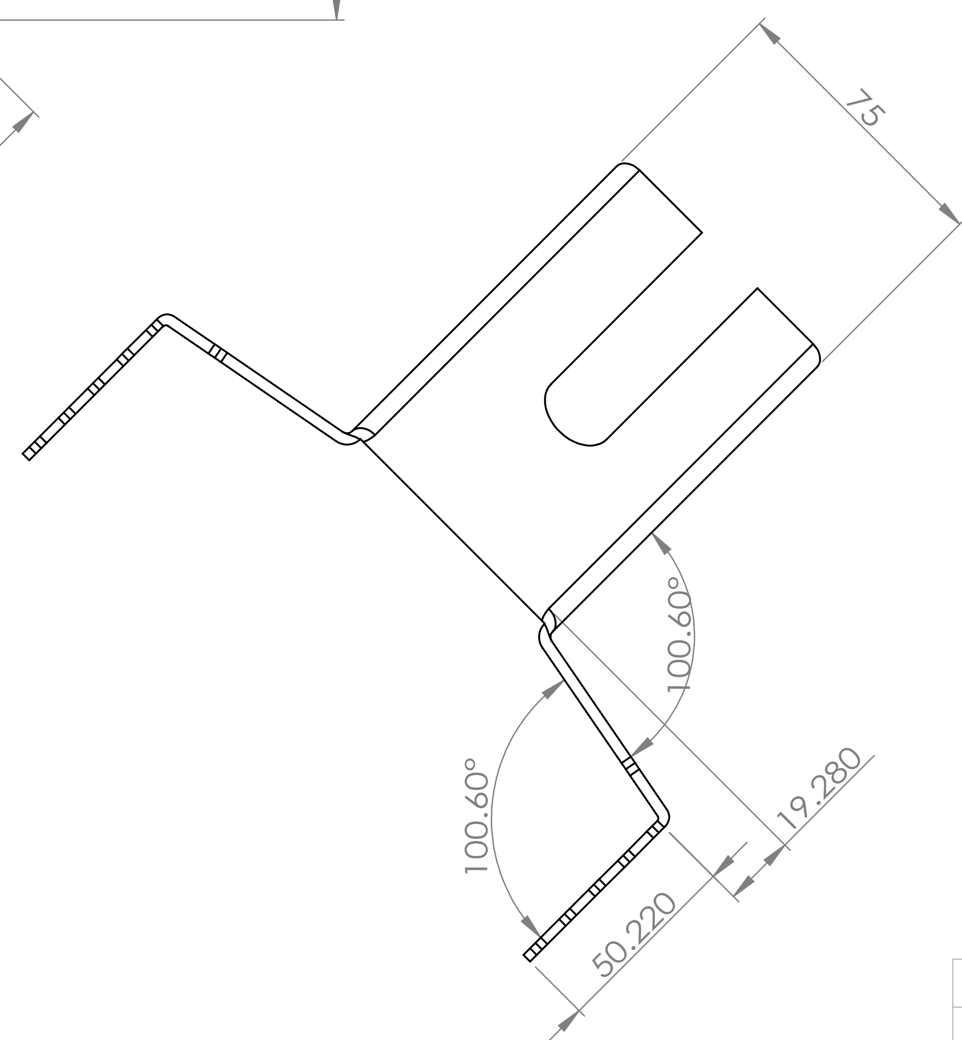
TITLE:

SIZE **B** DWG. NO. TARA 2- Final REV

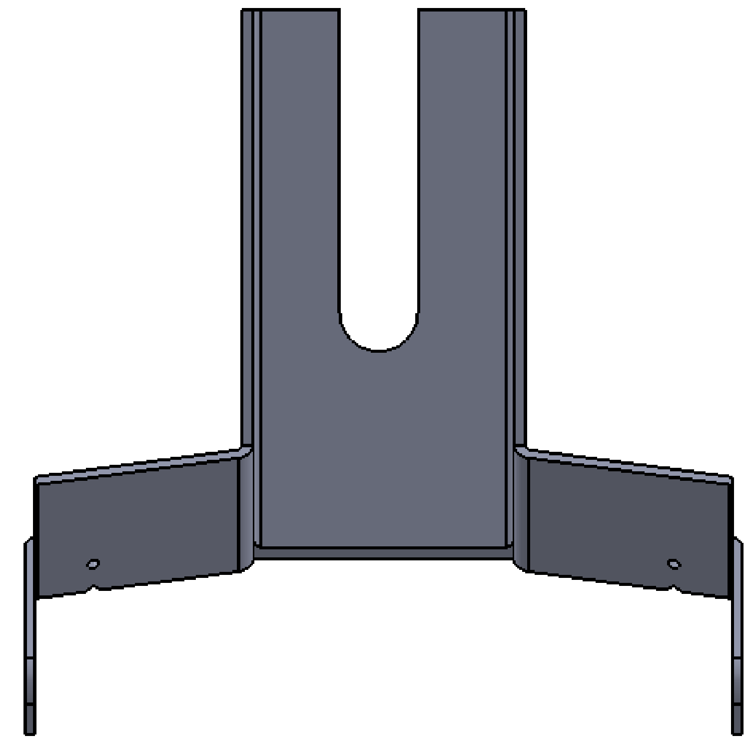
SCALE: 1:10 WEIGHT: SHEET 2 OF 7







VIEW D



VIEW H

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NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

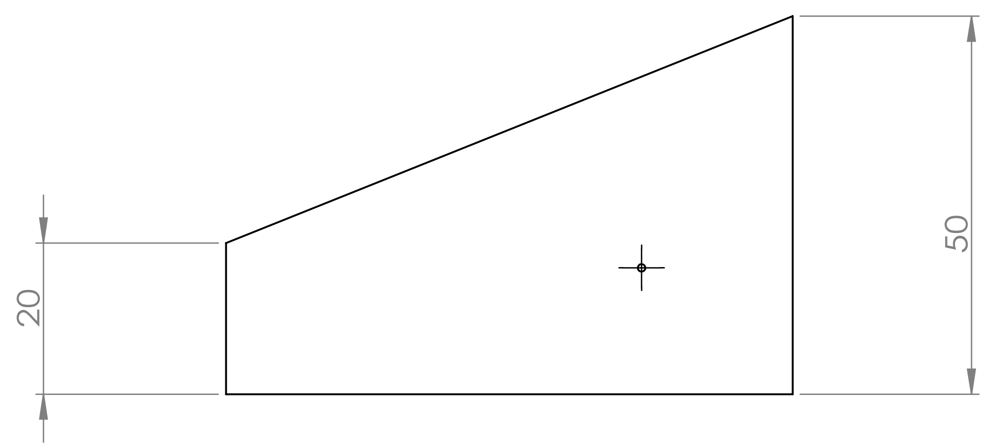
DO NOT SCALE DRAWING

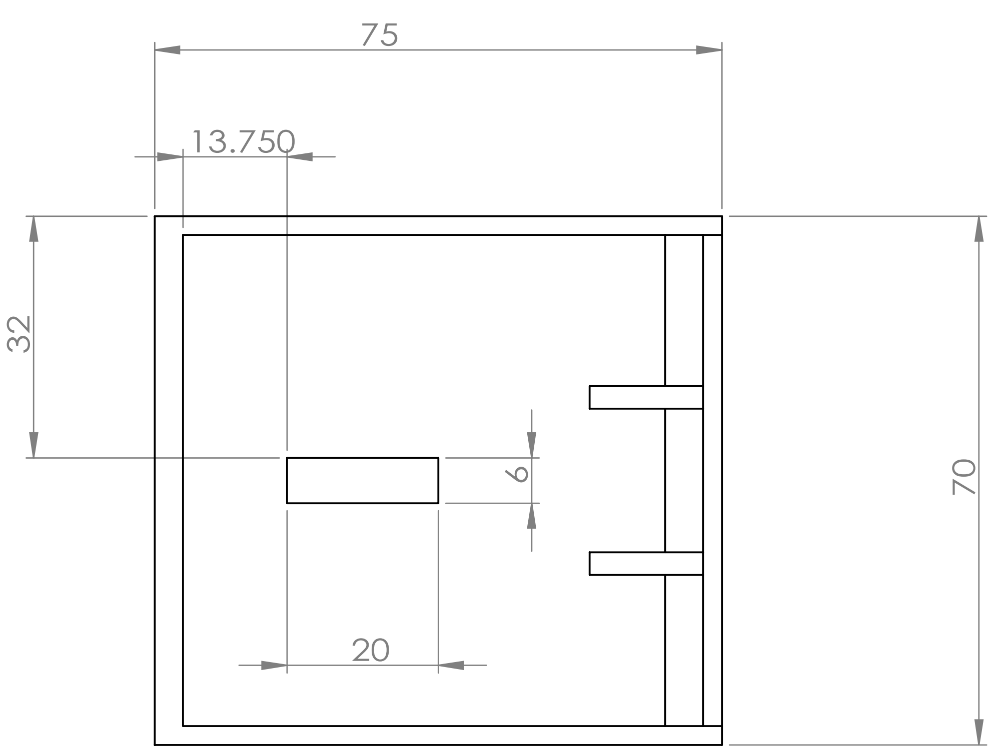
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

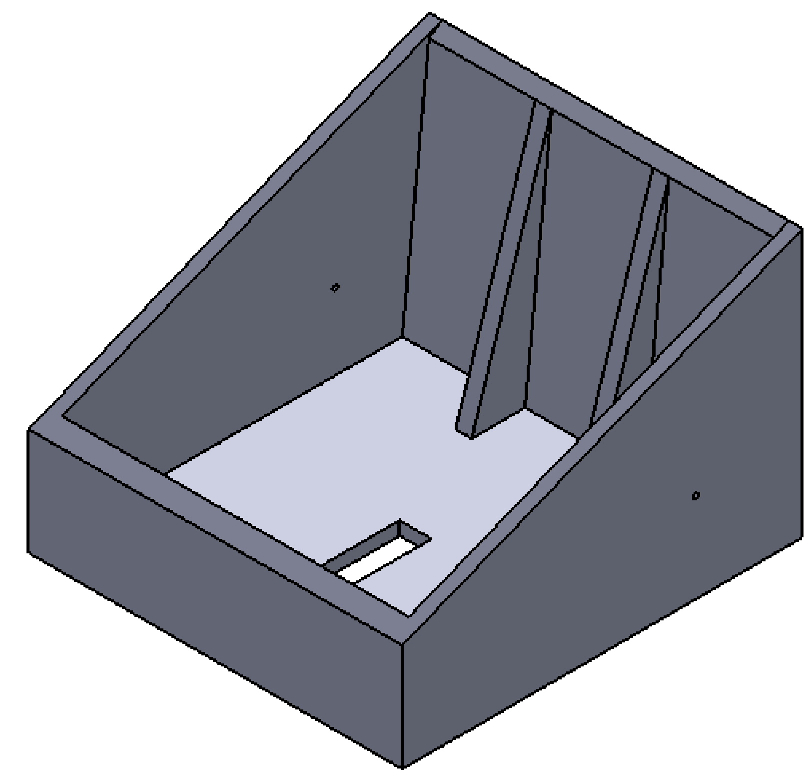
COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
B	ramp	
SCALE: 1:2	WEIGHT:	SHEET 3 OF 7





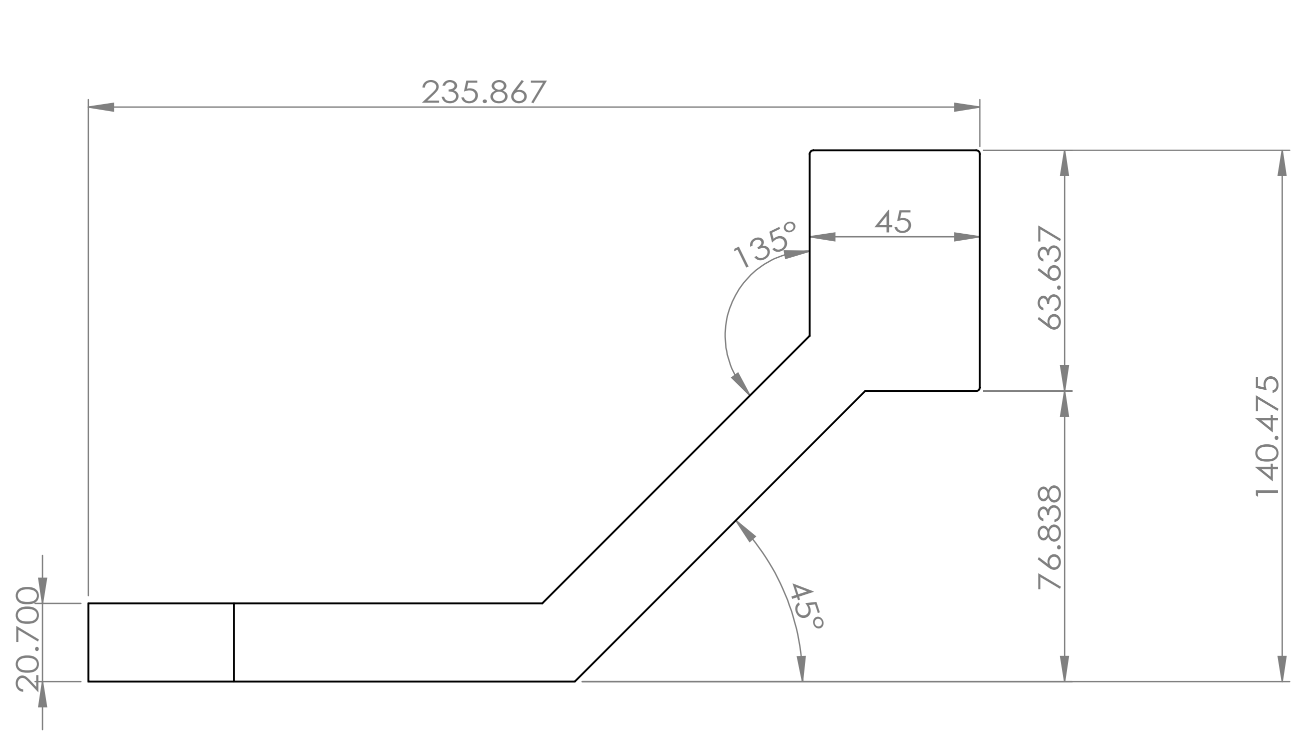


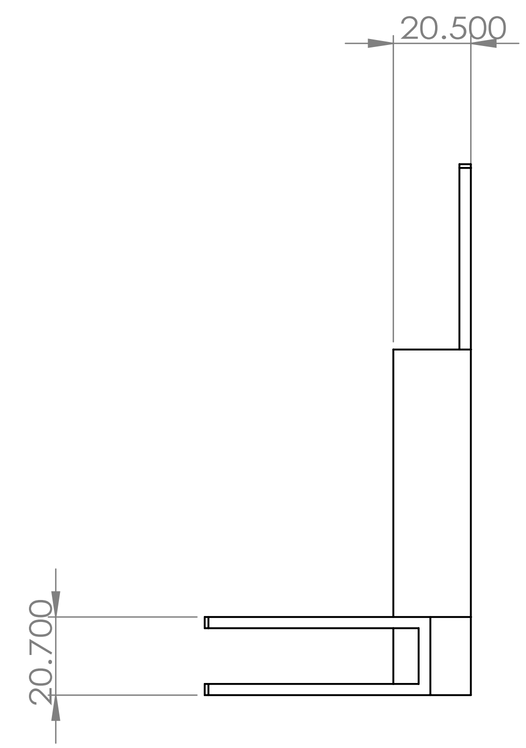
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

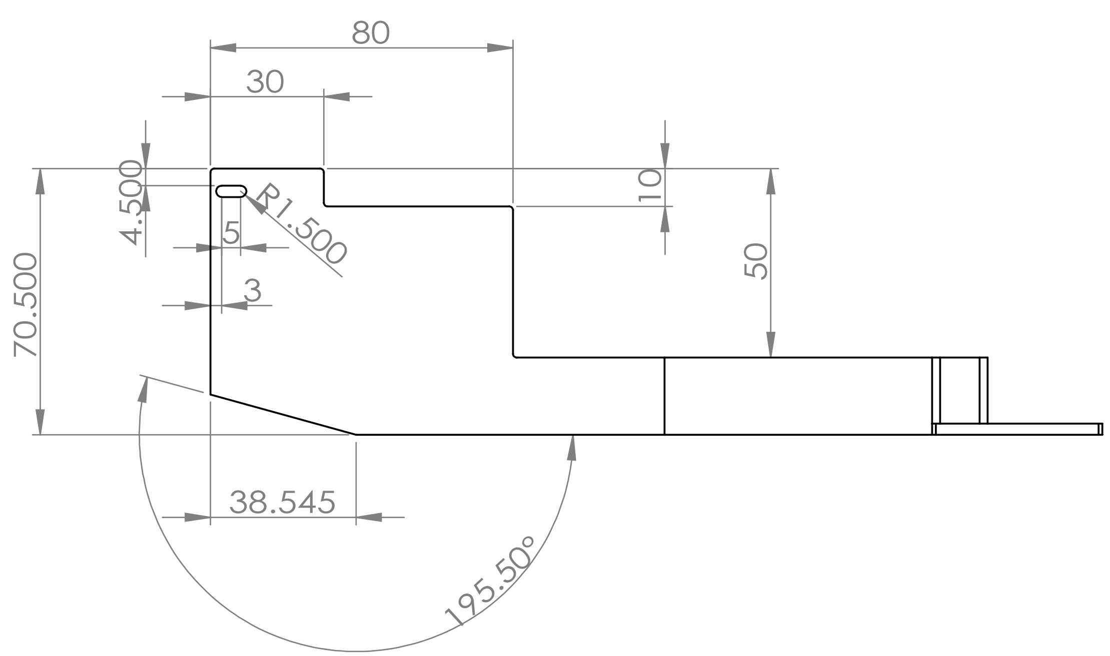
TITLE:

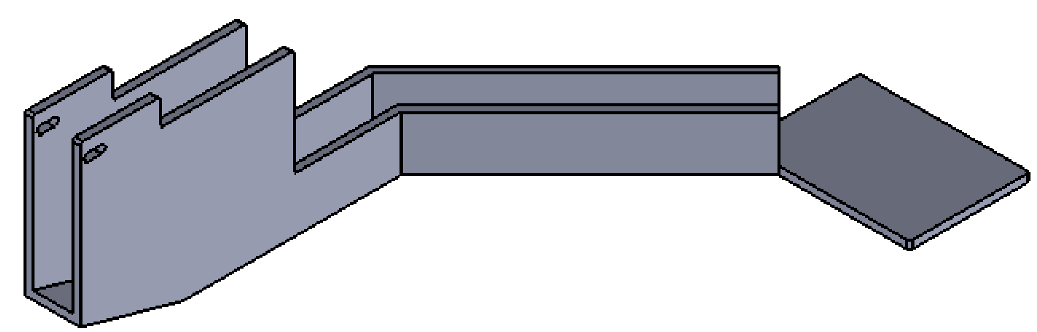
SIZE	DWG. NO.	REV
B	basket	

SCALE: 1:1 WEIGHT: SHEET 4 OF 7









Mirror image for support bar left

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TOLERANCES:
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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
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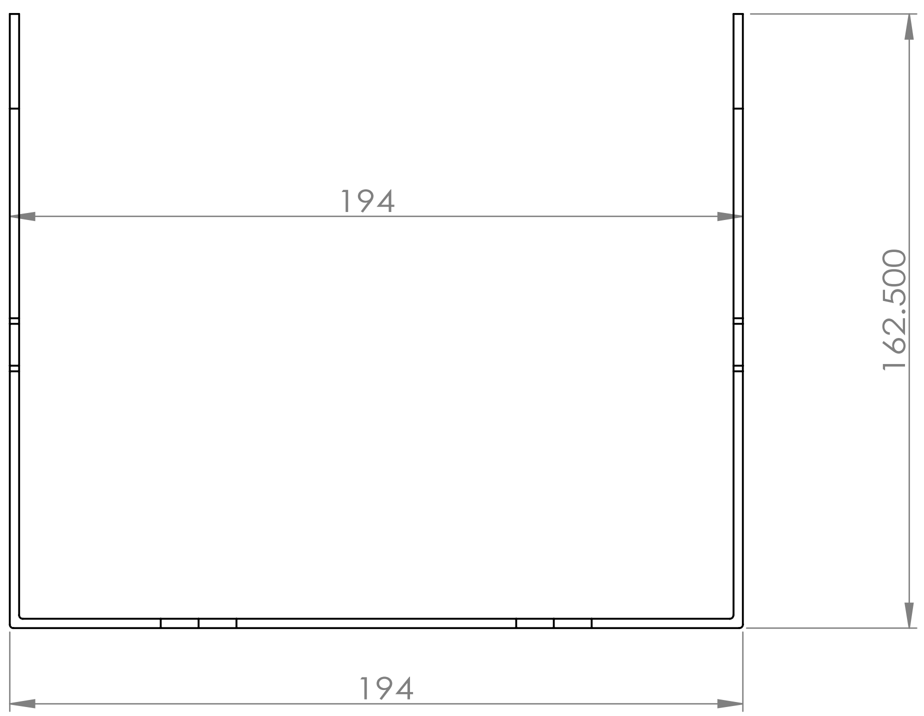
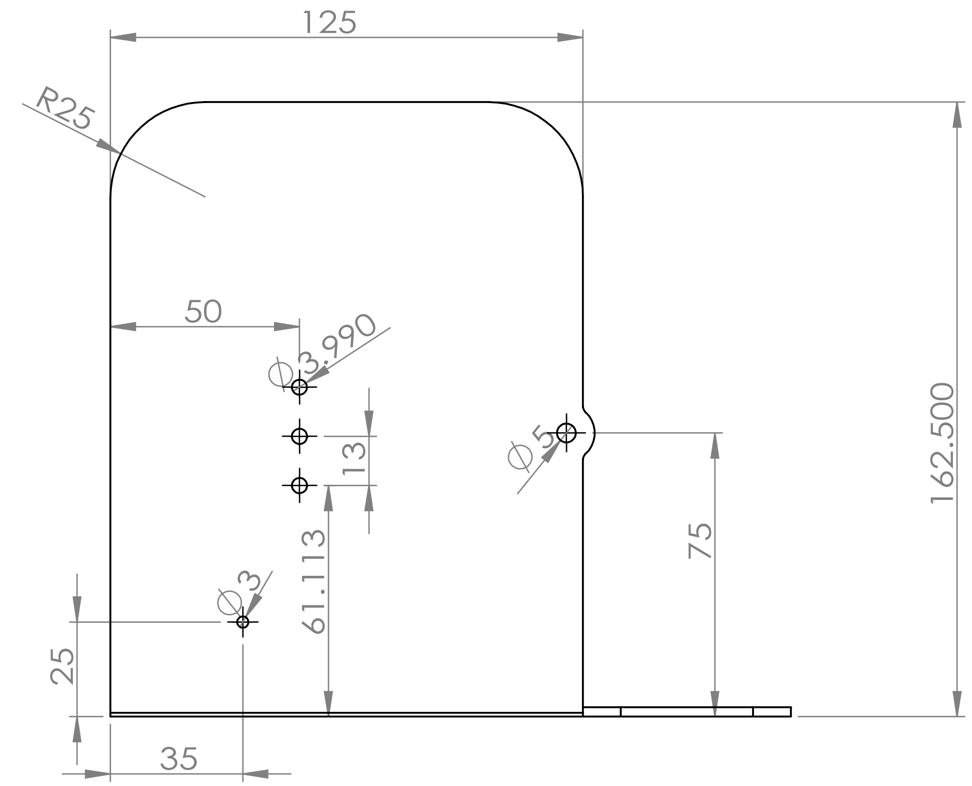
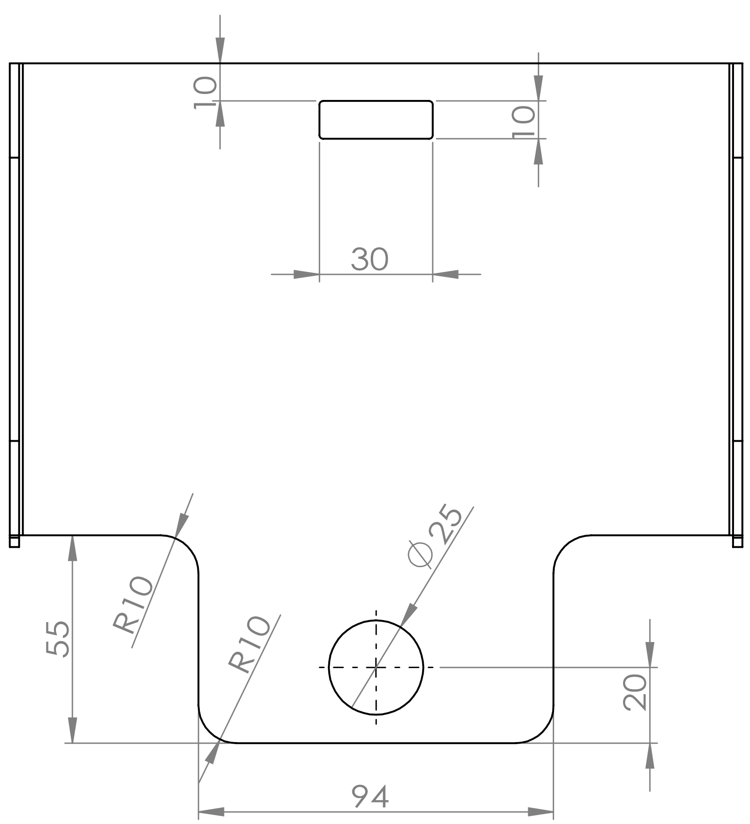
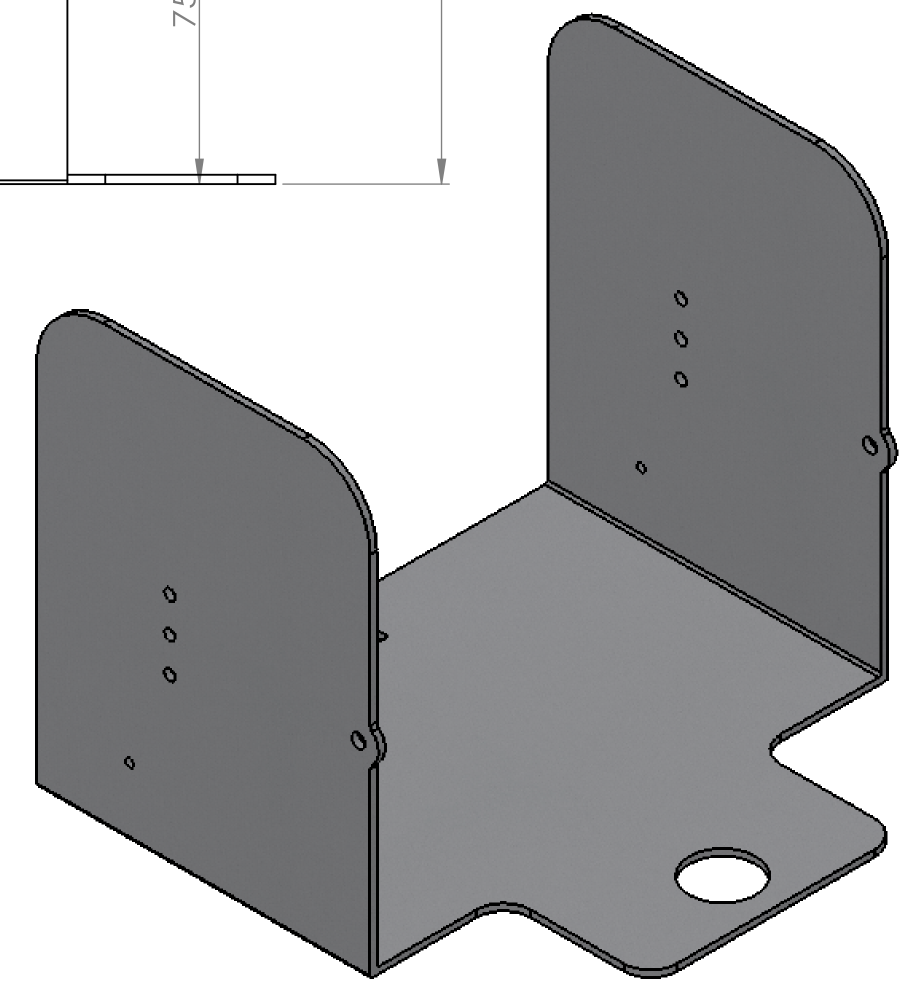
SIZE	DWG. NO.	REV
B		

SCALE: 1:2 WEIGHT: SHEET 5 OF 7









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MFG APPR.		
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TITLE:

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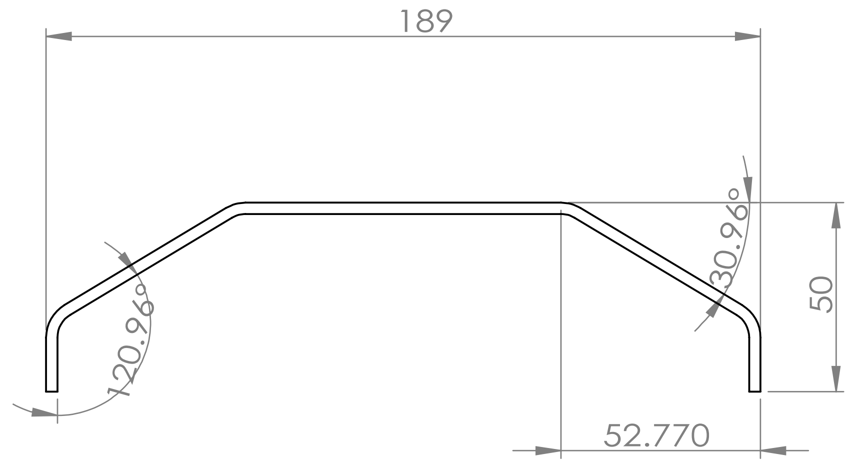
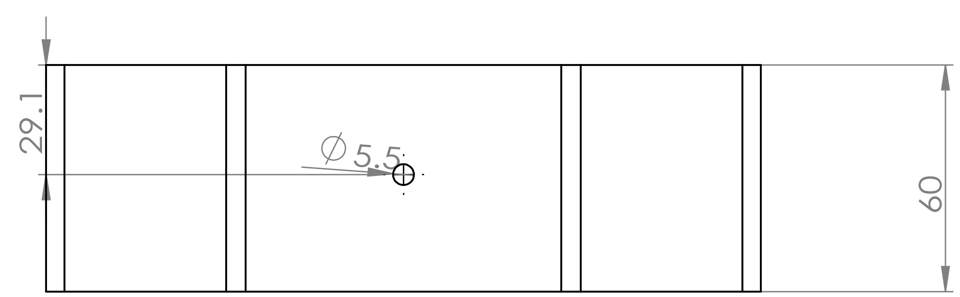
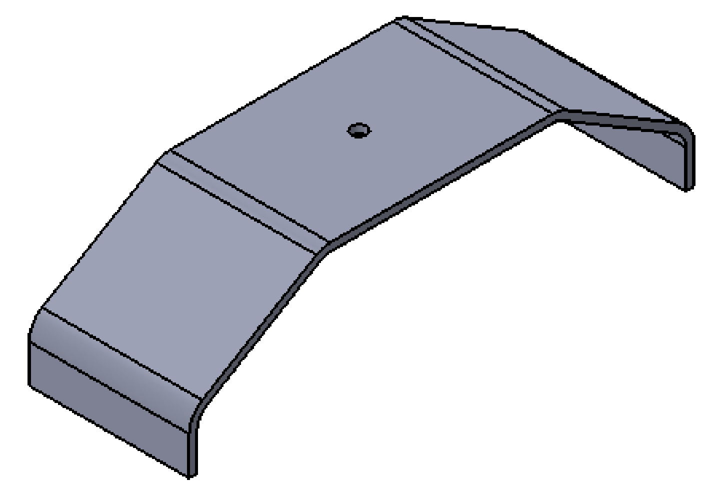
SIZE	DWG. NO.	REV
B		

SCALE: 1:5 WEIGHT: SHEET 6 OF 7







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NEXT ASSY	USED ON
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DO NOT SCALE DRAWING

	NAME	DATE
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MFG APPR.		
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SIZE	DWG. NO.	REV
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SCALE: 1:2 WEIGHT: SHEET 7 OF 7