I. Design of Defensive Robot (DR)

Overall dimensions and estimated weight:

Weight – 9.68 kg   Length – 800 mm
Width – 750 mm   Height – 550 mm
Extended:
Length – 1050 mm   Height – 900 mm

Defensive robot is developed on a manually operated quad-holonomic drive with a velocity-controlled loop for each omni wheel. The robot is controlled by X box 360 controller.

Defensive robot consists of a gripper and 4 arms with cup shaped end. It does not have a throwing mechanism. The gripper is used to pick the arrows in the team's half field, pass the arrows to the TR and also to intercept the opponent's arrow. The 4 arms are used to rotate Type-II and Type-III tables. The complete structure of Defensive robot is shown in Fig1.

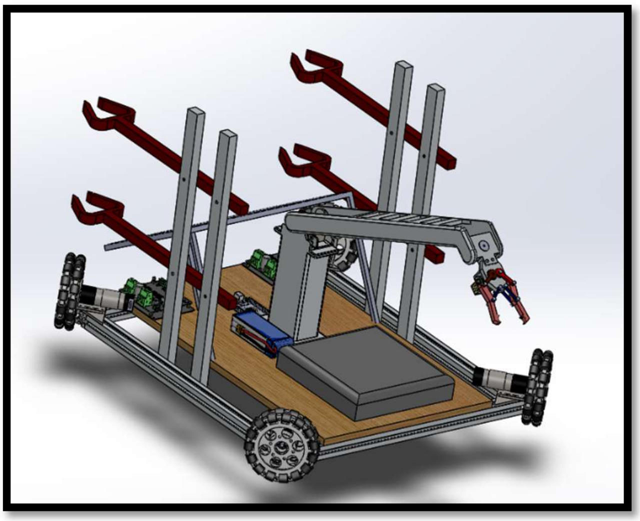

Fig1 – Defensive Robot

Actuators and Sensors:

- Planetary DC Geared Motor 468 RPM 72.6N-cm (Drive) – 4 pcs
- Magnetic Pickup rotary encoders (inbuilt)
- MG995 Metal Gear Servo Motor (Stall Torque- 12 kg-cm at 6.6 V) – 2 pcs

Arrow picking and passing mechanism

A four-bar linkage gripper is used for **picking mechanism** (marked with **G**) as shown in Fig2. MG995 Servo motor is used for actuating the gripper.

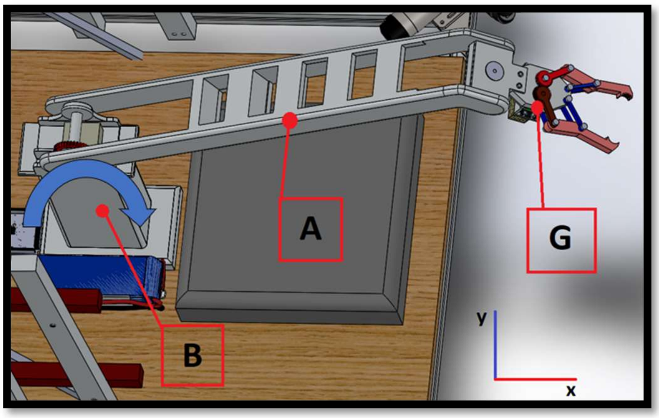

Fig2 – Gripper of DR

The gripper is mounted on an aluminium arm (marked with **A**) at an angle of 120 degrees with the arm. The other end of the arm is pivoted on a base (marked as **B)** and actuated by another MG995 servo motor to rotate it about y-axis. The complete structure of the gripper can be seen in Fig2.

Justification and Calculations

- The gripper claws need to be in vertical orientation to grip the arrow. The base has a length of 258 mm and the arm has a length of 518 mm. This arrangement makes an angle of approximately 30 degrees with the horizontal when arm is about to touch the ground. So, to make the gripper claws vertical when it is touching the ground, gripper has been aligned at 120 degrees with the arm (90 degrees + 30 degrees).
- The minimum distance between the claws in closed position is 10.6 mm, and the diameter of the arrow body is 12 mm. So, the arrow will be gripped tightly between the claws.

To **pick** the arrow the arm will move down so that the arrow is in between the gripper. Gripper will grip the arrow from near its tail. Once it is gripped the arm will rotate about the pivot to raise the arrow. When the arrow is at the desired height the Defensive Robot (DR) will move to the Throwing Robot (TR) to **pass** the arrow (Refer Fig3)

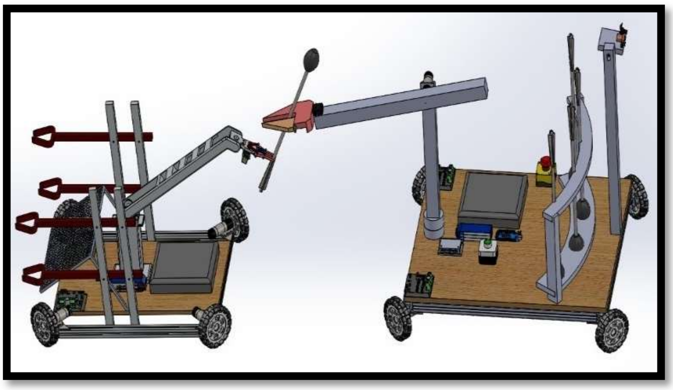

Fig3- Arrow passing and receiving mechanism

II. Design of Throwing Robot (TR)

Overall dimensions and estimated weight:

Weight – 16.45 kg Length – 962 mm
Width – 890 mm Height – 897 mm
Extended:
Length – 1496 mm Height – 1410 mm
Width – 1115 mm

Throwing robot is developed on a manually operated quad–holonomic drive with a velocity-controlled loop for each omni-wheel. The robot is controlled by X box 360 controller.

Throwing Robot consists of a throwing arm to throw the arrows in the pots. The same arm picks arrows from the arrow rack and receives arrows from the DR. The complete structure of Throwing Robot is shown in Fig4.

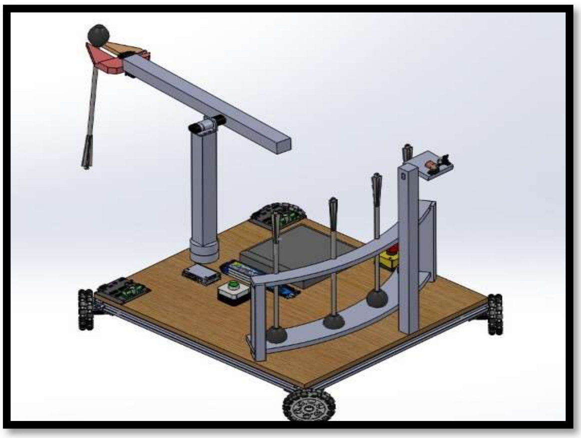

Fig4 – Throwing Robot

Actuators and Sensors:

- Planetary DC Geared Motor 468 RPM 72.6N-cm (Drive) – 4pcs
- Magnetic Pickup rotary encoders (inbuilt)
- TFMini-S Micro LiDAR Distance Sensor (Operating Range 0.1-12 metres)
- FPV camera
- Mega Torque Planetary Encoder DC Geared Motor along with DC servo drive (750 RPM, 39 Kg-cm)
- MG995 Metal Gear Servo Motor (Stall Torque- 12 kg-cm at 6.6 V) – 2 pcs
- MG90S Servo Motor (Stall Torque- 2.2 Kgf-cm)
- Nema 17 Stepper Motor (45 N-cm)

Arrow picking and receiving mechanism

A gripper(**G**) based on rack and pinion mechanism (shown in Fig5) is used for **picking** and **receiving** the arrows. The rack and pinion mechanism is actuated by MG995 Servo motor. The gripper is mounted on an aluminium arm (**A)** which is pivoted on a base (**B)**. The gripper can also rotate around x axis actuated by MG995 Servo motor. The arm has z axis as the axis of rotation actuated by Mega Torque Planetary Encoder DC Geared Motor.

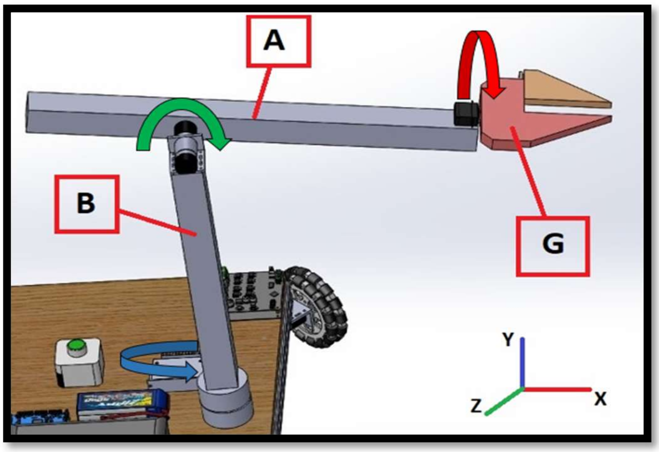

Fig5 – Throwing arm

For **picking** an arrow from the arrow rack the arm will first rotate until it is parallel to the ground and it is outside the robot's body (as shown in Fig4). The robot will then align its gripper with an arrow on the rack, grip it and rotate the arm a little such that the arrow is outside the rack. After moving the robot away from the arrow rack, gripper is given a rotation of 180 degrees (x axis as the axis of rotation, refer Fig5) such that the arrow head points upwards.

Then the width between the gripper claws is increased to be more than 12mm such that arrow body (diameter of arrow body is 12 mm) slips down under the influence of gravity and stops when arrow head is encountered.
For **receiving** an arrow from the defensive robot, the defensive robot will place the arrow (arrow head pointing upwards) in between the claws of the TR's gripper until it grips it (Refer Fig3).

Justifications

- In accordance to rule **2.4.1(c)**, a rack has been made on TR (Shown in Fig6 as **R**) to load arrows on it in the 1-minute setting time. For picking the arrows placed in a circular Rack inside the TR, rotation is given to the base of the throwing arm about y axis (Refer Fig 5). Arrows are fixed at certain angles and to reach these angles, a Nema 17 stepper motor operated with micro stepping drive is used.
- The rack has 4 holes of diameter 35 mm so that the head of the arrows are locked in it whose maximum diameter is 40 mm. Support to arrow body is also provided at top. All these ensures that the arrow does not fall down when the drive is being moved. The fifth arrow is placed in gripper itself.

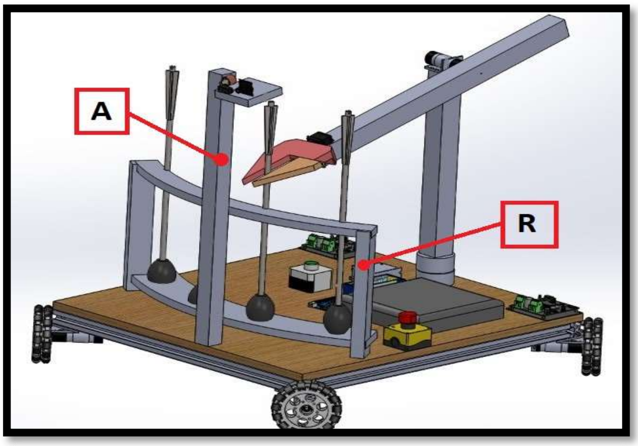

Fig6 – Gripper picking arrow from inside rack

III. Throwing Mechanism

Throwing mechanism consists of a throwing arm (shown in Fig5 and described under the heading "Arrow picking and receiving mechanism") and an aiming mechanism (shown in Fig6 as **A**). Only one arrow is thrown at a time.

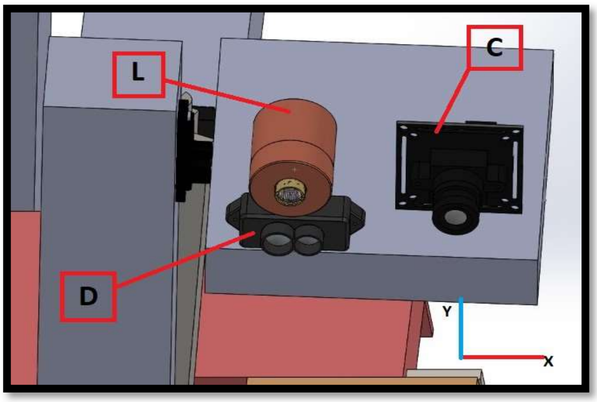

Fig7 – Aiming Components

Aiming mechanism has two purposes:

- It aims the laser at the pot which assures that the throwing arm is in line with the target pot.
- Using LiDAR installed in the aiming mechanism we get horizontal distance of target pot from LiDAR which is used for calculating the velocity with which the arrows will be thrown at the pot.

Aiming mechanism is placed in line with the throwing arm at a height of 897mm from the ground. This mechanism consists of a TFMini-S Micro LiDAR (Shown as **D** in Fig7), a FPV camera (Shown as **C** in Fig7), and a **type-II laser** (Shown as **L** in Fig7). All the three components are fixed on a small board which has a MG90S Servo Motor attached to it. The servo motor rotates the board (x axis as the axis of rotation) which allows us to aim the laser at the pots accordingly. The FPV camera sends its live video stream to its app which is installed in an android device. In the same android device, we have created an android app to control the stepper motor. Both apps will be used simultaneously in split screen mode for aiming purpose.

Justification and Calculations

In Fig8, d is the slant distance between LiDAR and target pot which we get from LiDAR itself.
θ is the angle by which the servo motor has rotated with horizontal axis.
x is the horizontal distance between LiDAR and target pot.
Thus,
using the formula $\cos(\theta) = x / d$
We will get the horizontal distance,

$$\mathbf{x = d * \cos(\theta)}$$

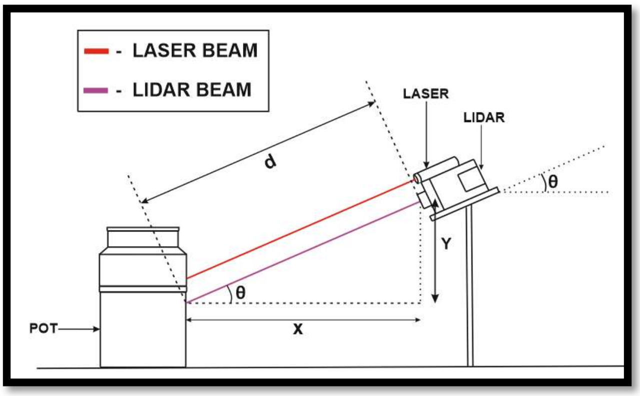

Fig8 – Aiming calculations

Once the throwing arm grips an arrow, the drive moves to a target pot. When the laser light is targeted on the pot, the horizontal distance from the target pot to the LiDAR is calculated (*At this instant the throwing arm is parallel to the ground outside the body of the robot, as shown in Fig4*). Using this distance (x), the required RPM for rotating the motor is calculated. The motor then rotates with the calculated RPM to rotate the throwing arm until it makes an angle of 45 Degrees with the horizontal. This is ensured with the help of optical encoder installed in the dc motor and a PID controlled algorithm. As the gap between the claws of gripper is set to be more than 12mm (diameter of the arrow body) the arrow body passes through the claws of the gripper, thus, the arrow is thrown in the air and follows a parabolic path and drops at an angle of 80 degrees (with the horizontal) inside the pot.

Justification and Calculations

For the arrow to drop at an angle of 80 degrees (with the horizontal) inside the pot, the slope of the parabolic trajectory at that point must be **tan (100°)** (as shown in Fig9).

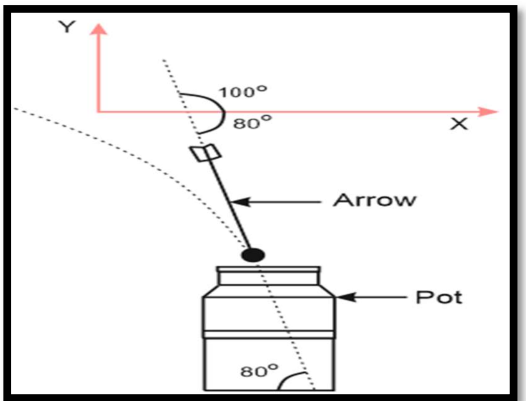

Fig9 – Required slope of trajectory

The equation of trajectory of parabola is given by,

$$y = x\tan\theta - gx^2/2u^2\cos^2\theta$$

Let, y_0 and x_0 be the vertical and horizontal distance of target pot from the gripper at the instance it is about to throw the arrow. As the angle till which arm will rotate is 45 degrees, the angle of projection of projectile also becomes 45 degrees (as shown in Fig10).
(**Angle between gripper arm and arrow is 90 degrees**)

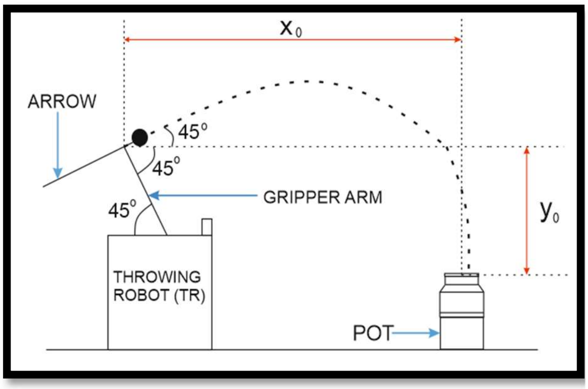

Fig10 –Throwing mechanism calculations

x_0 is calculated by adding horizontal distance between LiDAR and pot, fixed horizontal distance between LiDAR and base of throwing arm, horizontal component of throwing arm and radius of the target pot.
y_0 is not calculated as it is not needed in the calculation.
Consider the point of projection as the origin, then the coordinates of opening of pot becomes (x_0,- y_0). By differentiating the equation of trajectory of parabola at (x_0,- y_0) we get the slope at this point as,

$$\frac{dy}{dx} = \tan\theta - gx_0/u^2\cos^2\theta$$

This slope must be equal to **tan (100°).** Hence, equating both the equations we get u as,

$$u = \sqrt{gx_0}/\sqrt{\cos^2\theta(\tan\theta - \tan 100°)}$$

Putting θ=45°,we get,

$$u = \sqrt{gx_0}/(1.83)$$

Using, $\omega = u/l$, where l is the length of the throwing arm, we can calculate the required RPM of rotating the arm.

IV. Table Pushing Mechanism and Arrow Interception Mechanism

Table Pushing Mechanism

Table Pushing Mechanism consists of 4 arms with cup shaped ends (Fig11). It is a rigid structure in which the arms are attached in pairs on both sides of the Defensive Robot. These arms are about 100mm outside the drive of the robot. The first pair of arms are attached with rod R1 and R2 and the second pair is attached between rod R3 and R4 as shown in Fig11.
The lower arms are at a height of 215mm from the ground and the upper arms are at a height of 415mm from the ground.

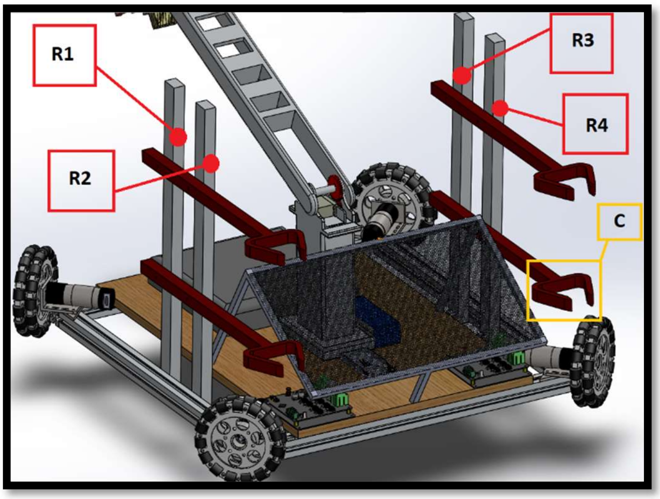

Fig11 – Table Pushing Mechanism

Justification and Calculations

- There is no common height between the handles of type-II and type-III tables. Hence, arms are fixed at varying heights.
- The opening width of the cup shaped end is about 35mm which is just more than the diameter of the handle i.e. 30mm. Also, its depth is about 40mm, this ensures that there is no contact between the pot and the arm (Shown in Fig11 as **C**).
- Also, the height of the arms is set so that they hold the middle portion of the handle while rotating the table which ensures that the orthogonal projection of any part of the robot to the ground does not overlap with the orthogonal projection of the pot to the ground.
- The whole structure is fixed opposite to the gripper so that there is no chance of the gripper touching any pots while the table is being rotated.

To push the table, the defensive robot is aligned parallel to the diagonal of the table. When the handle is in front of the opening of the cup shaped end of the arm, the DR is moved forward until the handle is completely inside it. After that the drive is moved in a circular manner so that it drags the handle along with it, thus rotating the table.

Arrow Interception Mechanism

The gripper shown in Fig2 is used for arrow interception mechanism. This mechanism will be used for defending type-I pot only.
The gripper picks the arrow on the ground from near its tail and starts raising it until it is above the type-I pot. Once the arrow is at the required height the holonomic drive will start to rotate in clockwise and counter clockwise direction continuously making small oscillations. This action will wave the arrow which in turn will deflect the arrows thrown at the type-I pot by the opposite team.

Justification and Calculations

- In accordance to rulebook, the height at which the arrow will be raised above the Type-I pot is given such that the arrow is not touching the pot.
- The height given also ensures that the orthogonal projection of any part of the DR to the ground does not overlap with the orthogonal projection of Type-I pot to the ground.

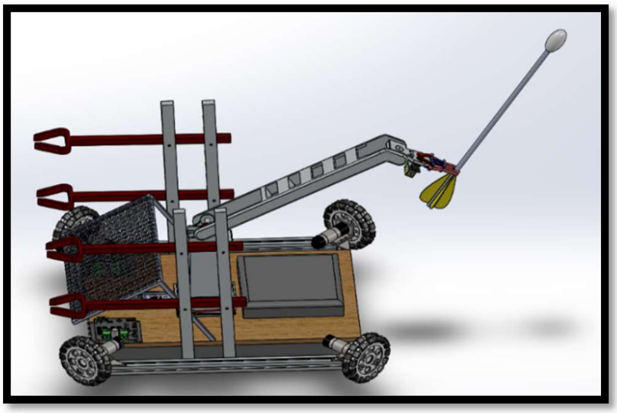

Fig12 – Arrow Interception Mechanism