Design Details Document
Team Robocon - AKGEC

1 INTRODUCTION

This document focuses on the justifications and calculations of various subsystems of the two robots discussing several new designs. It contains the chronological design process that our team during the prototyping phase, by the integration of the subsystems into a complete robot. It focuses on how two robots collaborate to score for Try and the Goal Kick.

2 PASS ROBOT

According to the theme, the Pass robot will be responsible for picking the try ball and passing it to the Try robot. The task of the Pass Robot is further divided into different tasks viz., Try ball picking and passing. These different design components of the pass robot are discussed below.

2.1 Drivetrain Selection

The Drive selected for the Pass Robot is a **tank drive with Mecanum wheels**, i.e., it applies the force of the wheel at a 45° angle to the robot rather than one of its axes. By applying the force at an angle, we can vary the magnitude of the force vectors to **gain translational control** of the robot. The robot can move in any direction while keeping its front in a constant compass direction [1]. The base of the Drive is made up of using **3003-H14 Aluminium Sheet (400mm x 500mm) of thickness 4mm and weight 2.149Kgs** *(Fig. 1)*. The aluminium sheet **ensures uniform weight distribution** on the base [2] also it eliminates the joints from the drivetrain, making it lightweight.

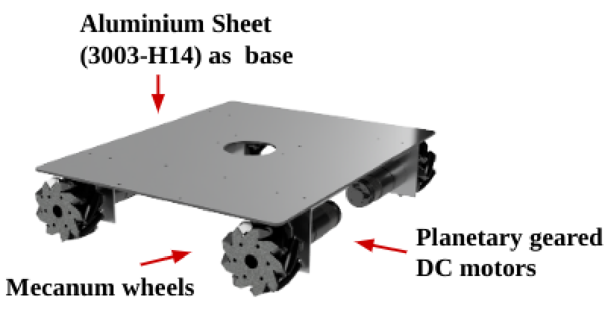


Fig 1: Tank drive with Mecanum wheels

2.1.1 Wheel and Motor Selection: The **Mecanum wheel minimizes the skidding** of the robots while passing the rugby as it is having more traction. For calculating motor variables, various parameters including the weight of the robot, traction of the wheels as required. After the CAD design was finalized, the weight of the robot was calculated to be about 15kgs. The wheels available to us were used to calculate the coefficient of friction. These values of weight and friction, along with an expected time for completion of the task were then used to calculate the required power, which came out to be 50W. The 24V DC **Planetary Geared motors with 49.5W power and 1620 RPM** were best suited for the drivetrain.

2.2 Picking Mechanism

The Pass robot is allowed to pick one try ball at a time from the ball rack. The placement of the try balls in the ball rack is fixed i.e. the semimajor axis of the ball must be kept vertical to the ground. For picking the ball from this orientation, **angular style air Gripper** *(Fig. 2)* with the double-acting cylinder and 20 mm bore working at 5 bar pressure was used.

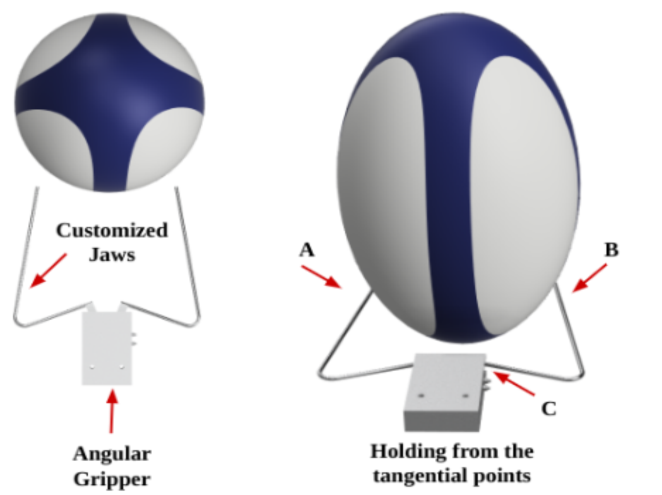


Fig 2: Gripper Design for picking try ball

2.2.1 Customized Jaw design: Drawing inspiration from the **forklift mechanism**, our aim was not only to pick the ball but also releasing it while passing it to the TR. Upon analyzing the various gripping and lifting mechanisms that are used in Robotics and logistics, the options were narrowed down to **angular gripping mechanisms**. To make the task of releasing try ball easier we designed the jaws of the angular grippers in a way that holds the try ball in a vertical position. *(Fig. 3)* The jaws of the gripper are made to hold the try ball from **three tangential points**. This helped in maintaining one fixed position of the try ball while passing it to the Try robot. The ultrasonic sensors (HC-SR04) were mounted on the pass robot used with PID controller for aligning the robot with the try ball which helped in perfect picking of the try ball. With proper PID tuning we were able to align the robot with the try ball perfectly.

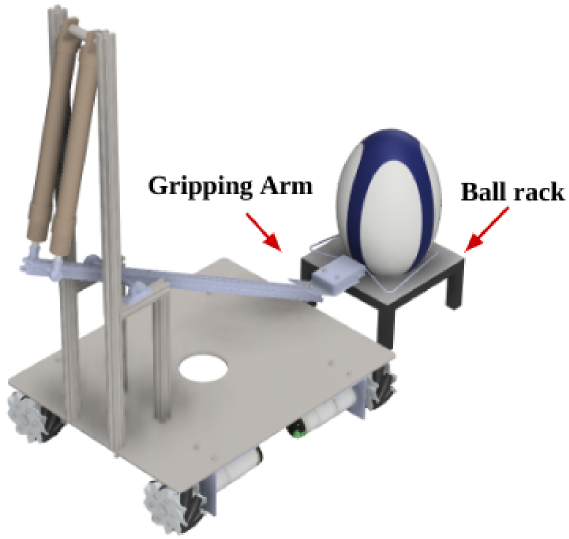


Fig 3: Picking the try ball from Ball rack

2.3 Passing Mechanism

The try ball needs to be passed to TR. The PR holds the try ball in the angular gripper attached at one end of the Pneumatic 'First-class Lever' mechanism, which is used to pass the try ball to the TR by throwing the ball. The design is **inspired by various 'First-class Lever' mechanisms**. The passing mechanism consists of a throwing arm made from an **aluminium profile of length 740mm and cross-section (20mm x 20mm)** in which the angular gripper is attached at one end. At the effort on the other end, a pair of similar **pneumatic cylinders (Stroke length 200mm, Diameter 25mm, Force 220 N)** are attached with rod eye that act as actuators for the arm. The other end of cylinders is hinged on two parallel **aluminium profiles (20mm x 20mm) of length 780mm** mounted on the drivetrain.

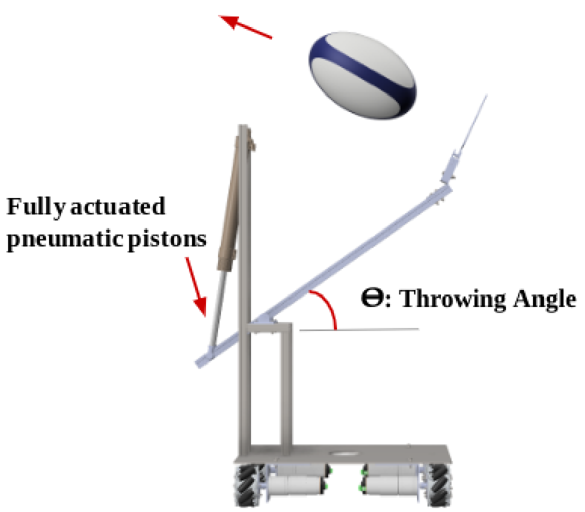


Fig 4: Passing the try ball by throwing

The arm is pivoted around an axle which is attached to U-shaped profile structures using plumber blocks. The mechanism is a **First Class Lever** with the fulcrum(axle) in the middle, the effort (pistons) and the load(try ball) on the opposite ends. *(Fig. 4)* The PR would pick the ball using the angular gripper. **Directional Control Valves (5/2 way, 24V DCV)** was used for the forward actuation of the pneumatic cylinders which in turn performed the throw. It was observed from the experimental data that when a Rugby ball is thrown, there are a few factors that determine its trajectory, velocity at which the ball leaves gripper, the angle of throw and rotation of the ball. With the use of **Flow control valve** in the DCV and regulating the air pressure in the pneumatic bottles we were able to achieve the desired **trajectory for the try ball**. The experimental results of throwing try ball while passing it to the Try Robot is plotted on a Line chart *(Fig 5)*, which shows that for a pressure range of 5.1-5.7 bar at angle ranging 45º-70º, the throwing range shows a **deviation of 100-200mm**, which is a remarkable accuracy for receiving the try ball by the Try Robot.

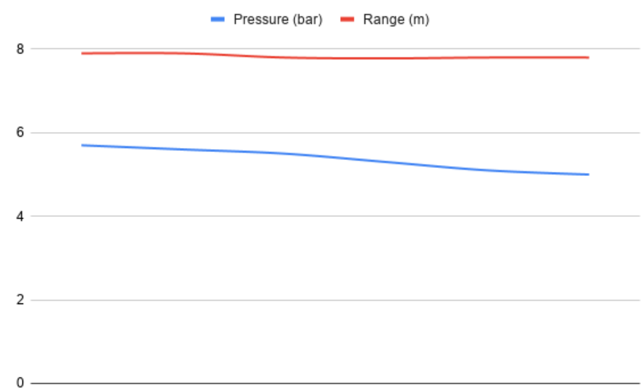
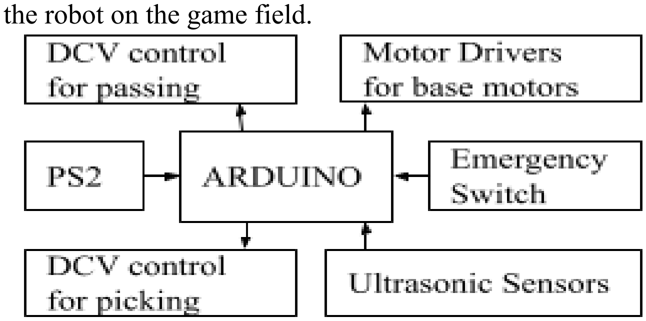


Fig 5:

Line chart of throwing range vs pressure

2.4 Sensors and Actuators Integrated

The Pass Robot has several subsystems, all of which have to work in unison for the robot to function properly. These subsystems include various sensors and actuators. Planetary geared motors (Rated Voltage: 24VDC) are used for the motion of the robot on the game field.



.**Fig 6: Component diagram of Pass Robot**

Ultrasonic sensors (HC-SR04) are used for alignment of the robot with the ball rack. Angular grippers with customized jaws are used for picking up the try ball. **Pneumatic cylinders (Stroke length:200mm, rod diameter:25mm)** in 'First-class Lever' mechanism used for passing the try ball by the means of throwing. The inputs from the users were taken through a PS2 /PS4 controller. **Emergency switches (ContactRating:600V/10A)** are installed in different subunits for safety *(Fig 6)*. The robot contains a total of seven actuators and six sensors.

3 TRY ROBOT

Try Robot is responsible for making try and kick Fig 13. The TR is **semi-autonomous** and is controlled by a **dualshock PS2/PS4 controller** by manual operator. Autonomous movement can be overridden at any point and movement of TR could be controlled manually by the operator. The task of the Try Robot is further divided into different tasks viz. Drive cum chassis designing, receiving, placing Try ball and Kicking process.

3.1 Drivetrain Selection

The holonomic drive train will be used for Try robot chassis. A four-wheel (4WD) holonomic drive train will help for **omni-directional motion**. It is useful as this robot has to move through the congested area in the kicking zone. The base of the Drive is made up of using **3003-H14 Aluminium Sheet (600mm x 600 mm) of thickness 4mm and Weight 3.869 Kg.** The aluminum sheet ensures uniform weight distribution on the base [2] also it eliminates the joints from the chassis making it lightweight.

3.1.1 Gear Assembly and Wheel Arrangement

In the drivetrain for the Try Robot we had certain requirements of acceleration and velocity, for the same purpose we used **Spur Gearbox Assembly with a gear ratio of 2:1** *(Fig 7)*.

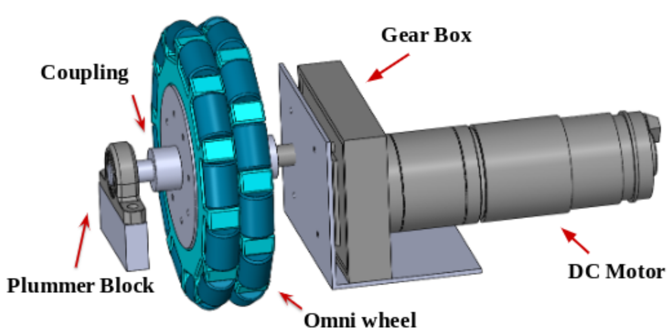


Fig 7: Spur GearBox Assembly in Try Robot

3.2 Receiving Mechanism

The PR has a trapezoidal netted basket structure with a **wider top face (530mm x 536mm) and narrower bottom (570mm x 104.47mm)** which facilitates the higher probability in receiving. The basket has a trapezium-shaped downswing backdoor hinged with the base of the basket having a cavity. This backdoor can be opened or closed using a Pneumatic Cylinder which is hinged at one of its edges. The inner surface is entirely made up of nylon net, clamped to the frame and backdoor of the basket such that net lags (tension in the net is approximately negligible when the gate is closed). The two backward poles of the frame are hinged to provide angular movement to the receiving face of the basket, so as to fold the basket (using Pneumatic Cylinder which is hinged at the edge) to prevent it from coming in the path of kicking leg. According to the rulebook, the TR can receive the ball at any point in the receiving zone. The PR provides us an excellent **throwing range of ball up to 8-9m** and hence the TR can be placed at different positions for receiving. The net used in TR has **negligible tension at the time of receiving** and hence would absorb the momentum of the ball and prevent it from bouncing back.All equations used for calculations are mentioned below Fig 8

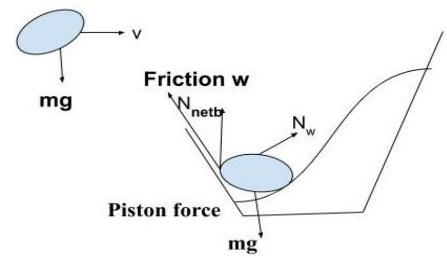


Fig 8: FBD of Receiving Basket

$\mu_s N_{net\,B} \cos(\theta) = mg \sin \Theta + N_w \cos \Theta$ (1)

$N_{net\,B} \sin \Theta_+ + \mu_s N_w \sin\Theta = mg\cos\Theta$ (2)

Where, μ_s =coefficient of friction, $N_{net\,B}$ = normal due to bottom contact of net, Θ = angle of gate from horizontal

M = mass of ball, N_w= normal due to contact with gate

3.3 Trying Mechanism

According to Rulebook, Trying is the process of placing the try ball in the try spot. **Design inspiration of this mechanism is taken from the dumping vehicles,** where a truck opens a back door and increases the base angle through the use of hydraulics which pushes the waste out of the truck. A similar mechanism for the Trying was developed using a **trapezoidal netted basket structure with a backdoor** *(Fig. 9)* **(425.98mm x 570 mm)** on it. Initially the try ball rests on the inner surface of the basket. The backdoor in the trapezoidal netted basket and a fully netted structure prevents the try ball from falling from the robot. Initially the tension in the basket net is almost negligible as the ball rests on net and on the backdoor in the basket. On reaching the try spot, the pneumatic piston attached with the backdoor will open the door resulting in the tension on the net structure connected with the backdoor. A **downward pull towards the backdoor equal to *mgsin*θ** will start to act which creates the pushing action to the try ball out of the robot through the **cavity(252.63mm x530mm)** and place it inside the try spot. The **backdoor opening angle will be in the range of 100-120º.**

2.3.1 Justification & Calculations

While receiving the ball in the try robot, the velocity and momentum of the try ball was dropped at very fast rate because of net and later completely take it to the rest inside the **trapezoidal netted basket.**When try robot is reaching the try spot, ball comes to rest by net and backdoor of the basket, when the TR reached the try spot then pneumatic cylinder is actuated with the help of **FCVs**, when the gate is open with certain force, the net gets stretched and creates tension which pushed the ball forward with certain force. Ball bounced by the net tension force reaches the gate opening, which now becomes horizontal, so now the ball drops in the try spot from a certain height, so that the ball doesn't roll and comes out of the try spot.Equations needed for Calculations are mentioned below Fig 10).

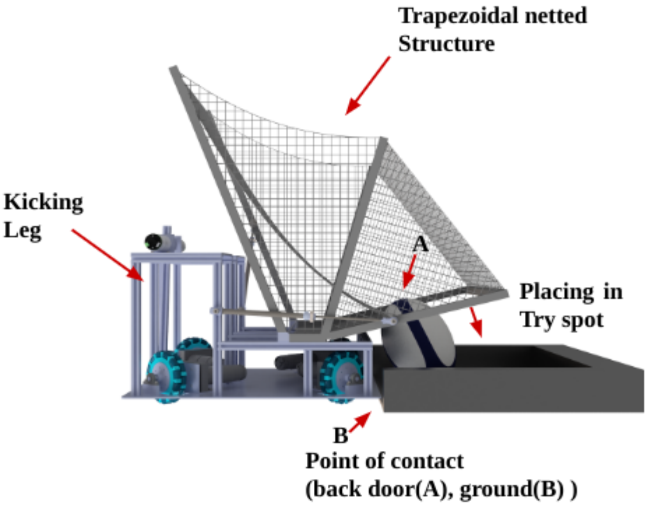


Fig 9: Placing Try ball through back door

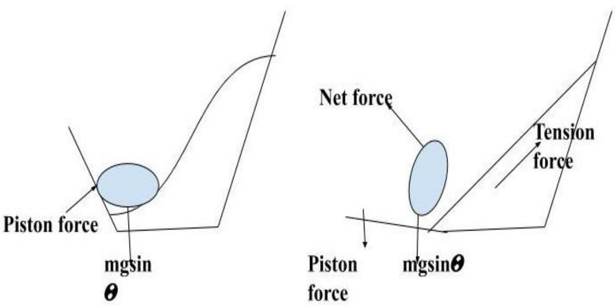


Fig 10: FBD of Trying Mechanism

As total energy of the ball is conserved,

$$mgh = mv^2/2 + I_x w^2/2 \text{ (friction by net is neglected)} \quad (3)$$

$$I_x = 2m\, b^2/5 \quad (4)$$

$$mgh = mv^2/2 + m\, b^2w^2/5 \quad (5)$$

$$gh = v^2/2 + b^2w^2/5 \quad (6)$$

$$\mu_r gx = v^2/2 + b^2w^2/5 \text{(stoppage in try spot)} \quad (7)$$

Where, μ_r=coefficient of rolling friction, h=receiving height, v=velocity of ball, w=angular velocity of ball, I_x=moment of inertia about x-axis of ball, b=minor axis of ball, x=travelling distance in try spot

3.4 Kicking Mechanism

According to the rulebook the robot is allowed to kick the kick balls after a successful try. The TR after the successful placement of Kick ball on the Tee will move to the kicking zone on an optimum and short path programmed according to the respective KZ (kicking zone). **RPLiDAR A1M8** and ultrasonic sensors are used for the movement of TR in the kicking zone and passing zone. RPLiDAR helped in measurements of longer distance for the movement in the kicking zone and mapping the area. The sample rate of upto 8000 times of RPLiDAR helped the robot in **2D mapping** quickly and accurately. PID controller with Ultrasonic sensors would be used for rotation of TR at a particular angle for kicking the ball from a kick zone. The problem faced during the kicking process was that, some of the poles in kicking zones were in the path of the kick ball trajectory, this had to be overcome by proper positioning and an accurate rotation of the chassis and finding a suitable kicking angle Fig 11 using PID controller [3].

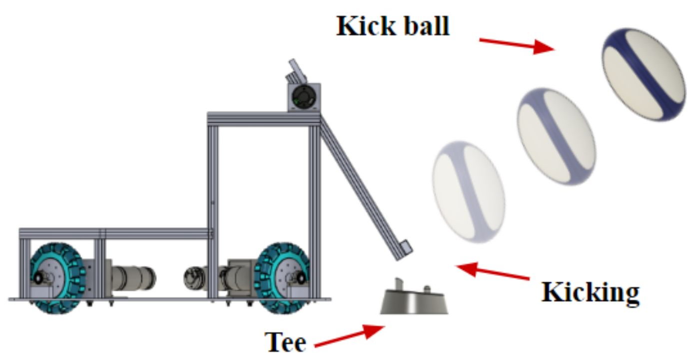


Fig 11: Kicking Mechanism

Structural Details

The mechanism consists of an **aluminium profile of length 400mm and cross-section area 20mm x 20mm** attached to shafts of two 18V DC planetary motors using coupling. The lower end of the leg has a **small flat cuboidal piece(60mm x 25mm x15mm)** mounted so as to make an inverted 'T', which is the hitting end. The other end of the leg has a **counter weight (around 600g)** so as to increase the couple action. The two motors are mounted on two wooden platforms using **metal L-plates**. The wooden platforms in turn are attached to four **U-shaped metal profile structures** of **dimensions 340mm x 210mm**(two for each of the wooden platforms). The U-shaped structures are mounted on the chassis such that the lower end of the leg hits the lower half (around **100-120 mm above ground level**) of the ball, so as to provide a desired elevation and range to the ball. To accomplish the kicking action, both the motors rotate simultaneously to provide the vertical rotation of the leg. The rotation is controlled using a **magnetic motor encoder (ME-37).** The encoder is used to rotate the leg to a desired angle to alter the impact of kick as required. The rotation speed can be varied to change the elevation and range according to different kick zones. For kicking, the **leg first rotates around 180 degrees in backward (negative) direction from the initial position** to attain a certain gravitational potential energy. Then, it rotates around **220 degrees in forward (positive) direction,** from that position it kicks the ball placed in between Fig 12. After kicking,the leg comes to its initial position using the PID controller.

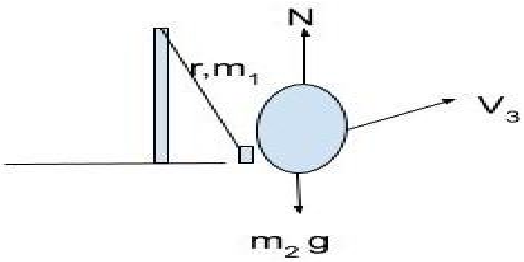


Fig 12: FBD of Kick Ball (instant of collision) [4]

According to conservation of linear momentum,

$$m_1v_1 = m_1v_2 + m_2v_3 \quad (v_2<<v_1) \tag{8}$$

$$m_1r_1w_1 = m_1r_1w_2 + m_2v_3 \quad (e<1) \tag{9}$$

$$h = (v^2 \sin^2\alpha)/2g \tag{10}$$

$$r = (v^2 \sin 2\alpha)/g \quad (r \leq 11m) \tag{11}$$

$$t = 2v \sin\alpha / g \quad (t \leq 1.5\ s) \tag{12}$$

Where, m_1=mass of leg, m_2= mass of ball, v_1=initial velocity of leg, v_2=velocity of leg after collision, v_3=velocity of ball, α=projectile angle, w_1=initial angular velocity of leg, w_2= angular velocity of leg after collision, r=length of leg

3.5 Sensors and Actuators Integrated

The Try robot is equipped with Planetary geared motors (Rated Voltage: 24VDC) and ultrasonic sensors (HC-SR04) for the movement. **RPLiDAR A1M8 - 360-Degree Laser Scanner** is used for mapping of arena and detecting the objects for longer distance. There are two pneumatic cylinders, one for **folding the basket (diameter 12mm,stroke length 160mm)** and other piston used for the **actuation of gate (diameter 12mm, stroke length 200mm). RaspberryPi 3(Model B)** is used for controlling the RPLiDAR. Two Encoded planetary gear motors **(18V DC, 256RPM)** providing the rated torque of **39 kg cm** are used to rotate the kicking leg with high momentum. PS2 /PS4 controllers are used to control each and every motion of the robot. Emergency switch(contact rating:600V/10A) is installed for sudden deactivation of the try robot in some accidental cases.

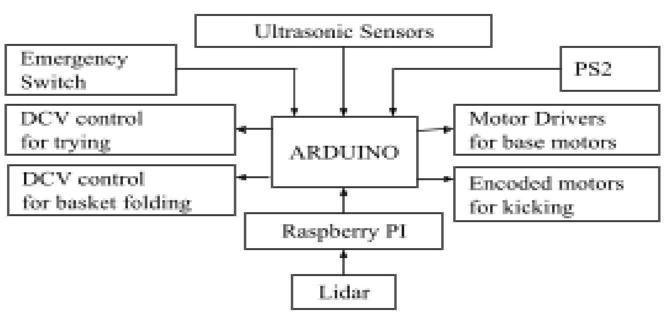


Fig 13: Component Diagram of Try Robot

4 RESULTS

We used the pneumatic 'First-class Lever' mechanism as this arrangement was efficient and capable of attaining various required distances. Nylon net was used to absorb the energy of the ball and prevent bouncing which is also used for trying. Motor based kicking mechanism was chosen to provide an impulse at a specific angle for a proper elevation and range while kicking. Development and upgrades of mechanisms resulted in accomplishment of tasks and a proper coordination between the robots to fulfil the theme-”**Robo rugby 7s**”.

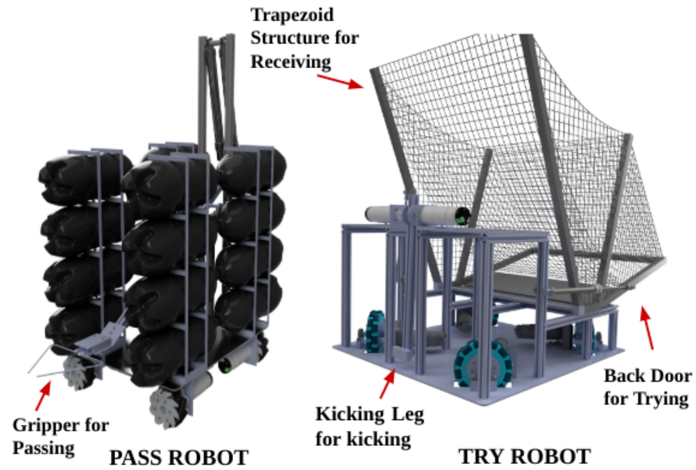


Fig 14. Final robot design

4.1 Assumptions/Dependencies

The Trajectory of the kick balls after kicking will depend on the kicking angle, impact with which it is being kicked[5] and the placement of the kickball on the Tee in the kicking zone.

4.2 Safety Concerns

In the fabrication of robots only the **certified and reliable components** were used which will give the best results and ensure safety during the game.

5 CONCLUSION

The complete design (Fig 14), fabrication and testing of the two robots were completed in a period of four months. The prototype of a Pass robot was able to pick and pass the try ball to the Try robot which successfully receives and completes the try for getting a kicking opportunity. The kicking process is completed successfully from all the three kicking zones.

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