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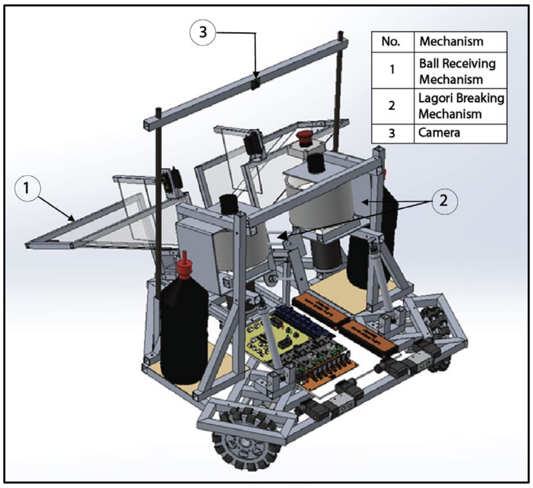

Figure 1: Design of Seeker R1

I. Design of Seeker Robot 1 (Seeker R1)

A. Overall Dimensions (in mm) and Estimated Weight (in Kgs):

Dimensions: 760 mm x 860 mm x 752 mm (l x b x h)
Estimated Weight: 21 kg

B. Type of Drive: The drive used for the locomotion of the robot is a three-wheeled omni holonomic drive having **PMDC motors (Torque: 18 kg-cm, RPM: 600).** Three-wheeled omni drive is used because of its simplicity, rich maneuverability, and ease of control. **Inertial Measurement Unit (IMU) (MPU6050)** consisting of a 3-axis gyroscope and 3-axis accelerometer, is used for measuring the robot's orientation in the X-Y plane. Two Incremental **Optical Rotary Encoders (PPR: 360, Operating voltage: 3.3 V)** coupled with smaller omni wheels, are placed along the X and Y axes and are used to resolve locomotion along the respective axes. The chassis and all the mechanisms used are made using Aluminum 8011 hollow square sections because of its optimum strength to weight ratio.

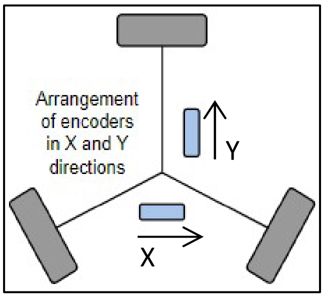

Figure 2: Alignment of Rotary Encoders

C. Ball receiving mechanism:

1. Construction: The mechanism is made up of a structure that is designed to receive all three balls from the 'Picking and Passing' mechanism. As illustrated in Figure 3.1, two flaps actuated by a **Tower Pro MG995 Servo motor** (**Torque: 13 kg-cm**) restrict the mobility of the balls on the side, while the centre ball descends directly into the Lagori breaking mechanism's guideway.

2. Working: The 'Picking and Passing' mechanism delivers all three balls to the ball receiving mechanism. The centre ball lands directly in the 'Lagori Breaking' mechanism's guideway. The other two balls are held in place by the flaps while the centre ball is shot. The flaps are then opened one by one, allowing the balls to fall in the guideway as seen in Figure 3.2.

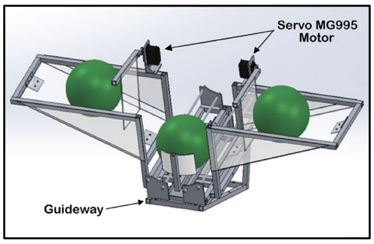

Figure 3.1: Ball Receiving Mechanism

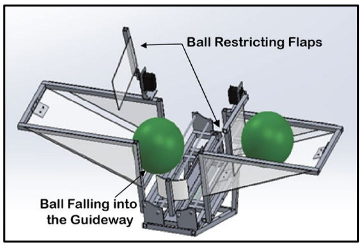

Figure 3.2: Flap opening and ball moving onto the guideway

3. Calculations:

Selection Criteria for Servo Motor:

Mass to be rotated by the servo motor $(m) = 0.0685$ kg
Distance of centre of mass from axis of rotation $(r) = 0.140$ m
Angle made by the ball receiving mechanism w.r.t ground $(\alpha) = 65°$

$$Force\ exerted\ due\ to\ the\ weight\ of\ the\ flap\ (F_p) = m \times g = 0.0685 \times 9.81 = 0.67\ N$$

$$Force\ exerted\ by\ the\ ball\ on\ the\ flap\ (F_b) = m \times g \times \cos\alpha = 0.2\ \times 9.81\ \times 0.422 = 0.82\ N$$

Total force on the flap (F) = $F_p + F_b\ = 0.671 + 0.829 = 1.50\ N$

$$\boldsymbol{Torque\ required\ by\ the\ servo\ motor\ (\tau) = r \times\ F = 0.140\ \times 1.501 =\ 2.14\ kg - cm}$$

∴ **Tower Pro MG995 Servo motor (Torque: 18 kg-cm) is selected.**

D. Brief Description of Lagori breaking (Seeker R1):

1. Construction: The mechanism consists of two wheels (rotors) **(Diameter: 150 mm, Height: 95 mm Material: Polypropylene)** actuated using two **PMDC motors (Torque: 5.5 kg-cm, RPM: 3350).** To get the feedback from the rotors, two **Incremental Optical Rotary Encoders (PPR: 360, Operating voltage: 3.3 V)** have been used. The rotors are inclined at an angle of **18°** with respect to ground, and are at a distance of **270 mm** measured from the centre of one rotor to the other. A guideway is used to ensure that the ball passes through the centre of the rotors. The guideway is mounted at an angle of inclination of $\mathbf{25^{\circ}}$ w.r.t. the ground, and is actuated using a **double acting pneumatic cylinder (Stroke length = 160 mm, Bore diameter = 16 mm)** (Figure 4.3).

2. Working: The ball is placed on the guideway with the help of 'Ball Receiving' mechanism. The ball is pushed towards the rotors with the help of pneumatic cylinder, mounted beneath the guideway. The momentum of the rotors is transferred to the ball. The ball follows a projectile motion due to the inclination of the rotors w.r.t. ground, and hits the Lagori at a height of 0.5 m (h) from the ground during its descend. The rotors are at a height of 0.4 m (H) from ground.

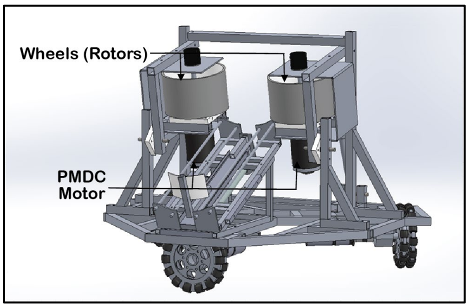

Figure 4.1: Initial Position

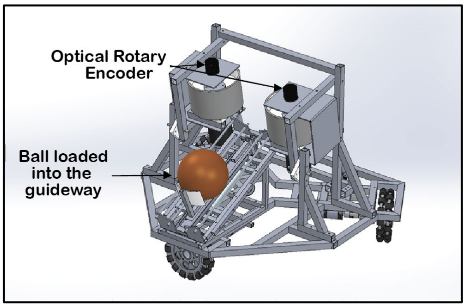

Figure 4.2: Intermediate Position

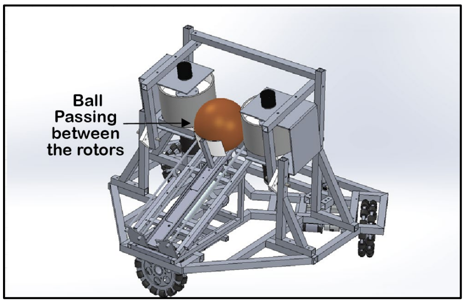

Figure 4.3: Final Position

MATLAB simulation is done for visualizing the trajectory projection of the shooting mechanism. Primarily, the initial velocity of the ball leaving the rotors is calculated to be 7.85 m/s, thereafter, the trajectory is projected to hit the Lagori at 0.5 m above the ground, which is found to be optimal height to break the Lagori. (Figure 4.4)

3. Calculations:

$Distance\ along\ x\ axis\ (s_x) = 3.5\ m$

$Distance\ along\ y\ axis\ (s_y) = h - H = 0.1\ m$

$Angle\ of\ Shooting = 18°, t = time$

$s_x = u_x \times t$

$\mathbf{3.5 = u \times \cos(18°) \times t \ldots\ldots (1)}$

$s_y = u_y \times t + 0.5 \times a_y \times t^2$

$0.1 = u \times \sin(18°) \times t - 4.9 \times t^2$

$Substituting\ values\ From\ Equation\ (1)$

$\mathbf{t = 0.46\ sec\ and\ u = 8\ m/s \ldots\ldots (2)}$

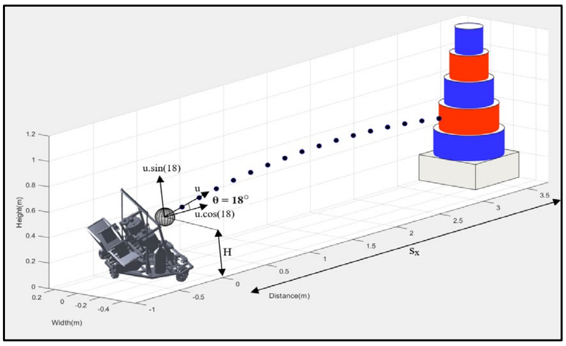

Figure 4.4: MATLAB 3D plot of Shooting Mechanism for Lagori Breaking

$After\ shooting\ u = v_b, whereas, u_b = 0$

$\mathbf{By\ principle\ of\ Conservation\ of\ Linear\ Momentum}$

$2 \times m_r \times u_r + m_b \times u_b = 2 \times m_r \times v_r + m_b \times v_b$

$2 \times 0.45 \times u_r + 0.2 \times 0 = 2 \times 0.45 \times v_r + 0.2 \times 8.008$

$\mathbf{v_r - u_r = -1.77\ m/s \ldots\ldots (3)}$

Kinetic energy given to ball by one rotor = $0.5 \times (0.5 \times m_b \times u^2) = 3.20\ J$

Δ Kinetic energy of one rotor = (Δ Kinetic energy of ball) / 2

$0.5 \times Moment\ of\ Inertia \times ({w_i}^2 - {w_f}^2) = 3.20\ J$

$({u_r}^2 - {v_r}^2) = 24.82$ $\quad Substituting\ values\ From\ Equation\ (3)$

$\mathbf{u_r = 7.898\ m/s\ and\ RPM = 1005.66}$

Where,

$m_r = Mass\ of\ rotors$

$m_b = Mass\ of\ ball$

$v_r = Final\ velocity\ of\ rotor$

$u_r = Initial\ velocity\ of\ rotor$

$v_b = Final\ velocity\ of\ ball$

$u_b = Initial\ velocity\ of\ ball$

$w_i = Initial\ angular\ velocity\ of\ rotors$

$w_f = Final\ angular\ velocity\ of\ rotors$

II. Design of Seeker Robot 2 (Seeker R2)

A. Overall Dimensions (in mm) and Estimated Weight (in Kgs):

Dimensions: 950 mm x 960 mm x 1320 mm (l x b x h)

Estimated Weight: 27 kg

B. Type of Drive: The drive used for Seeker R2 is similar to the one used for Seeker R1. Please refer to the 'Type of Drive' of Seeker R1 for the details of the same.

C. Piling up of Lagori Discs:

No.	Mechanism
1	Picking and Passing
2	Structure of Ball on Head
3	Gripper
4	Lagori rack
5	Pneumatic Flaps

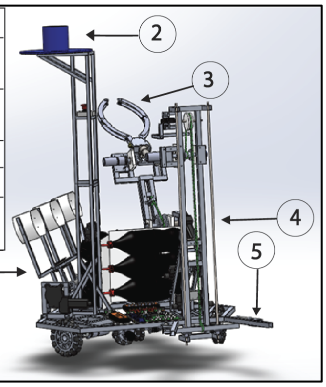

Figure 5: Design of Seeker R2

1. Construction: A mechanical gripper consisting of worm and worm wheel is actuated by a **PMDC Johnson motor (Torque: 6 kg-cm, RPM: 300).** The motor stops when the Lagori hits the **limit switch (max voltage: 30 V DC, max current: 5 A)** placed on claw of the gripper. The gripper rotates using a **PMDC RS-555 motor (Torque: 40 kg-cm, RPM: 550)**, coupled with a **10k ohm multi-turn potentiometer (Analog Output).** The gripper arm is rotated through an angle of **120°**

using **PMDC power window motor (Torque: 80 kg-cm, RPM: 70)** and a **10k ohm multi-turn potentiometer.** A **double acting pneumatic cylinder (Stroke length: 100 mm, Bore diameter: 12 mm),** placed beneath the rack, pivots it from **25°** to **90°** w.r.t. ground. The rack consists of pneumatically actuated flaps, consisting of two **double acting pneumatic cylinders (Stroke length: 25 mm, Bore diameter: 8 mm)**. The flaps slide up and down along two stainless steel rods **(Diameter: 8 mm, length: 950 mm),** and this sliding motion is achieved with the help of a rope and pulley system actuated by a **PMDC RS-555 motor (Torque: 40 kg-cm, RPM: 550).**

2. Working: For better understanding and considering standard nomenclature, **1st Lagori disc: smallest Lagori disc (diameter: 200 mm).** The Lagori discs that are displaced can be stacked irrespective of their orientation. In general, the individual Lagori discs are picked using the gripper arm consisting of a mechanical gripper (Figure 5.3). As per the Lagori disc's orientation, the mechanical gripper is aligned, owing to the mechanism's 2 Degree of Freedom. For stacking the Lagori discs in the rack, the pneumatic cylinder beneath the rack is fully extracted, increasing its angle of inclination to **30°**. The Lagori disc is gripped by the mechanical gripper and the arm is rotated by **120°** from its initial position. Thereafter the Lagori disc is released in the rack (Figure 5.5).

The Lagori discs are always stacked in descending order of dia., with the largest Lagori disc being picked up first among the remaining ones. For the Lagori discs to be stacked in the rack, the pneumatic flaps slide downward, allowing the remaining Lagori discs to be stacked on top of each other. A mechanical flap controlled by a **Tower Pro MG958 Servo motor (Torque: 18 kg-cm)** (Figure 5.2), keeps the stacked Lagori discs in place. Once all the required Lagori discs have been stacked, the pneumatic cylinder beneath the rack is retracted, making the rack perpendicular to the field. Seeker R2 then locomotes to the Lagori base and the Lagori discs are released by opening the pneumatic flaps.

In one of the situations, where a Lagori disc falls near the base, the rack can also be used to directly pile it (Figure 5.4). The Lagori disc is gripped by the pneumatically operated flaps, which then slide upward. The Lagori disc is pivoted around the fixed Lagori base (FAQ – 1.17- 2), and the pneumatic cylinder beneath the rack is extracted at the same time, tilting the rack, and piling the Lagori disc on the Lagori base in the required orientation and sequence.

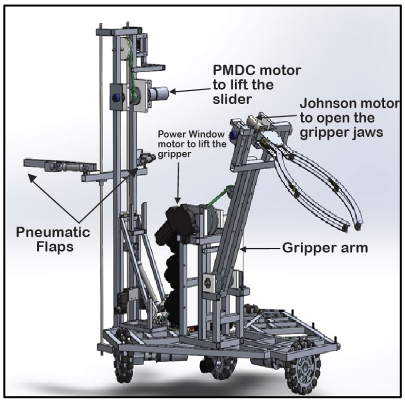

Figure 5.1: Design of Piling up of Lagori Discs mechanism

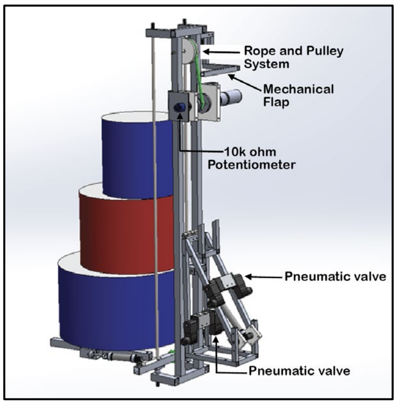

Figure 5.2: Lagori discs stacked on rack and slider

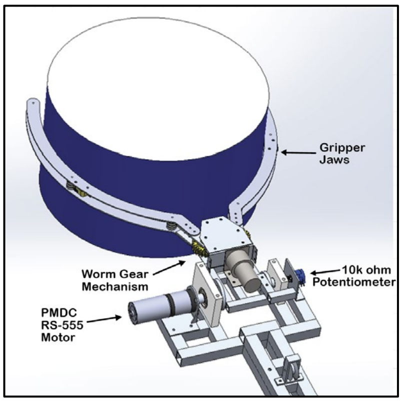

Figure 5.3: Mechanical Gripper

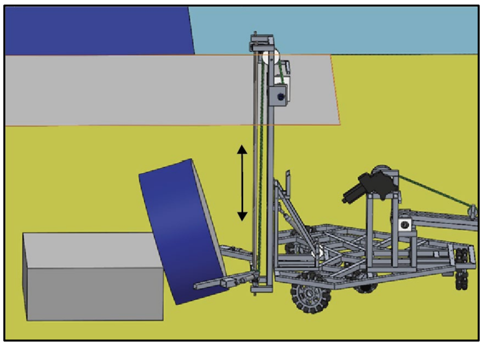

Figure 5.4: 5th Lagori disc being directly piled on the base

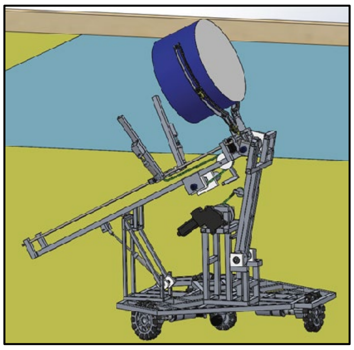

Figure 5.5: Lagori disc being released in the rack

1. Torque for rotating the gripper arm (τ):

$Total\ mass\ to\ be\ lifted\ considering\ lagori\ discs\ (m) = 2.28\ kg$

$Distance\ of\ centre\ of\ mass\ from\ axis\ of\ rotation\ (r) = 0.216\ m$

$F_{net} = m \times g \times \cos\theta = 2.28\ \times 9.81\ \times \cos 65\ =\ 9.44\ N$

$From\ F.B.D$ (Figure 5.6), $F_{net} = Tension\ in\ rope(T)$

$\therefore\ \boldsymbol{\tau = r \times T = 0.216\ \times 9.44 = 20.700}$ **kg-cm**

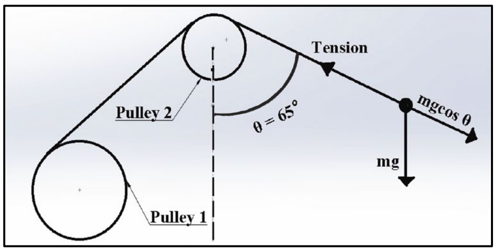

Figure 5.6: Free body diagram of gripper arm

2. Torque required to pull the pneumatic flaps using rope and pulley system (τ):

$Mass\ to\ be\ pulled\ (m) = 1.195\ kg$

$Force\ exerted\ by\ the\ rack(F) = m \times g \times \sin\theta = 8.281\ N$ (Figure 5.7)

$Distance\ from\ shaft\ of\ motor\ to\ the\ point\ of\ application\ of\ force\ (r) = 0.342\ m$

$\therefore \boldsymbol{\tau = r \times F = 0.342 \times 8.281 = 28.88}$ **kg-cm**

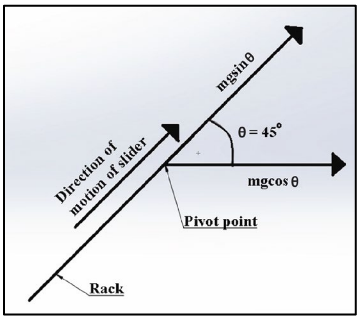

Figure 5.7: Free body diagram of motion of pneumatic flaps

3. Gripping force:

$Total\ mass\ to\ be\ gripped(m) = 0.550\ kg$

Coefficient of friction between gripper material and Lagori (μ) = 1 (By comparing the standard datasheets for the material of the gripper and lagori)

$Number\ of\ teeth\ on\ gear\ (z_g) = 25$

$Number\ of\ starts\ of\ worm\ (z_w) = 1$

$$Gripping\ force\ (F) = \frac{m \times g}{\mu} = \frac{0.550 \times 9.81}{1} = 5.39\ N$$

$Distance\ from\ centre\ of\ gear\ to\ the\ point\ of\ application\ of\ force\ (r) = 0.1612\ m$

$Torque\ to\ be\ provided\ by\ the\ gear\ (\tau_{gear}) = r \times F = 0.1612 \times 5.39 = 8.86\ kg - cm$

$$\therefore \boldsymbol{Torque\ to\ be\ provided\ by\ the\ worm\ (\tau_{worm}) = \frac{z_w \times \tau_{gear}}{z_g} = \frac{1 \times 8.86}{25} = 3.614\ kg - cm}$$

$\tau_{worm} = (\tau_{motor})\ used\ for\ gripper$

4. Torque for rotating the gripper:

$Mass\ of\ gripper(m) = 0.83\ kg$

$Force\ (F) = m \times g = 0.83 \times 9.81 = 8.134\ N$

$Distance\ of\ centre\ of\ mass\ from\ axis\ of\ rotation\ (r) = 0.250\ m$

$\therefore \boldsymbol{Torque\ (\tau) = r \times F = 0.250 \times 8.134 = 20.74\ kg - cm}$

III. Design of Hitter Robots (Hitter R1 and Hitter R2)

A. Brief Description of the Mechanism of Hitter R1 of Hitting of Ball on Head (BOH):

1. Working: In order to calculate the distance between the robot and the 'Ball On Head' (BOH), **curve fitting algorithm** is implemented, using computer vision (Figure 6.1).

BOH along with base plate is detected using **HSV (Hue Saturation Value)** masking, to trace both BOH and base plate using RaspberryPi Camera Module v2.1. To find out pixel height and pixel width of BOH, contours are used. The BOH is being verified using deep learning **yolo algorithm**. Hereafter, these pixel values are plotted against actual distance of BOH from the robot. Then, the best fitted curve equation is derived. Using this equation, distance of BOH from the robot is calculated in the live-feed. This processing is done on **Jetson Nano**, and the value is passed to the **microcontroller** using **I2C protocol**.

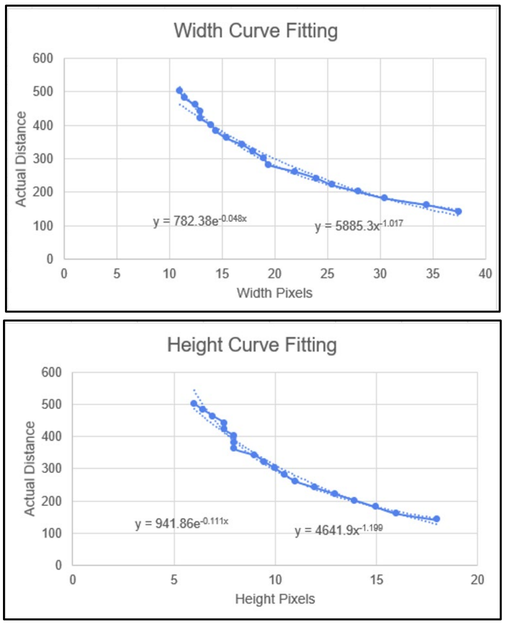

Figure 6.1: Calculation of pixels using Curve-fitting algorithm

2. Calculations: In order to hit the ball on head, the 'Lagori Breaking' mechanism is lifted at an angle of **40°(θ)** w.r.t. ground. For lifting the mechanism, **two double acting pneumatic cylinders (Stroke length: 100 mm, bore diameter: 16 mm)** are used.

1. Lifting Force Calculations:

Mass of rotor assembly (m) = 4 kg

Force acting at the pivot point of assembly (F_1) = $m \times g \times \cos\theta = 4 \times 9.81 \times \cos 40 = 30.03\ N$

Balancing the Moments about the pivot point of piston (Figure 6.2)

$F_1 \times d_1 = F_2 \times d_2$

$30.03 \times 0.09 = F_2 \times 0.2$

$\therefore$ ***Force required by the piston to rotate the assembly*** $\boldsymbol{(F_2) = 13.51\ N}$

2. *Projectile Calculations*:

[By following the same procedure as Lagori Breaking calculations using](#)

$s_x = 3.5\ m\ and\ s_y = 1\ m$

$\therefore \boldsymbol{u_{rotor} = 7.48\ m/s\ and\ RPM = 952.35}$

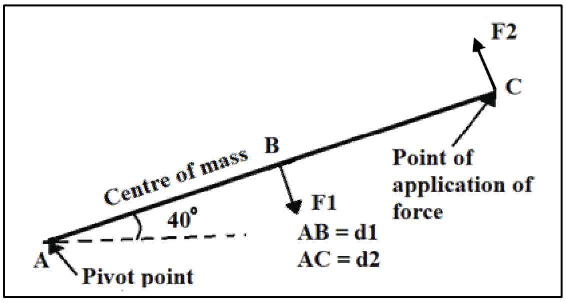

Figure 6.2: Pivot calculation for lifting of Lagori Breaking mechanism

B. Ball Picking and Passing Mechanism (Hitter R2):

1. Construction: The mechanism consists of three grippers, connected together by a link structure, actuated by one **double acting pneumatic cylinder (Bore diameter: 12 mm, stroke length: 80 mm)** and the whole structure rotates through an angle of **120°** using a **PMDC power window motor (Torque: 80 kg-cm, RPM: 70).** The fixed arms are mounted at a distance of 300 mm from each other, which is the same as the distance between the balls positioned on the rack. One arm of the gripper is fixed while the other is moving.

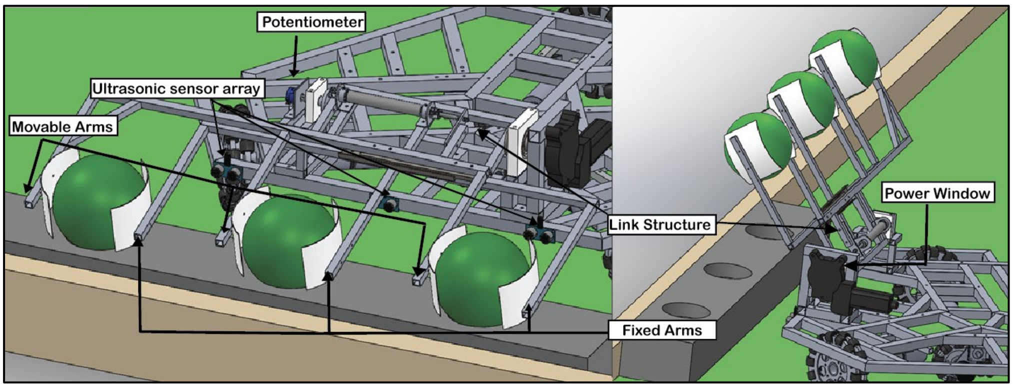

Figure 7: Design of Picking and Passing Mechanism (Hitter R2)

2. Working: Initially, the piston of the pneumatic cylinder is retracted, opening the claws of the gripper. The Hitter Robot R2 approaches the ball rack, and the grippers are aligned with the ball rack with the help of an **Ultrasonic Array** consisting of **three Ultrasonic sensors (Digital Output, Operating Voltage: 5 V).** The extraction of the piston moves the link structure, gripping all the three balls simultaneously (FAQ – 2.2-8). After all the three balls are gripped (Figure 7), the whole structure is rotated by **120°** using a **power window motor** and feedback from a **10k ohm multi-turn potentiometer (Analog output)**. Hitter R2 then locomotes towards Hitter R1 and passes the balls to R1(Figure 8).

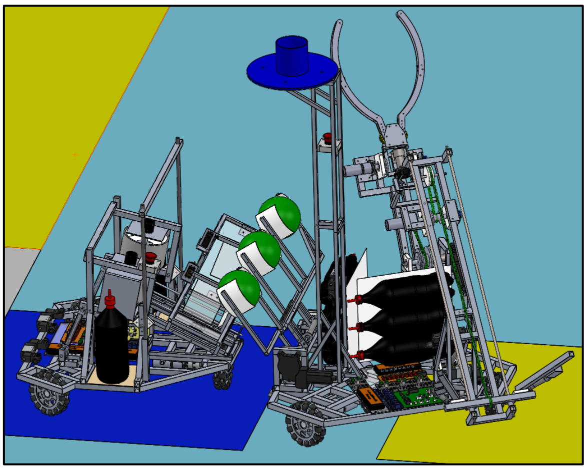

Figure 8: R2 passing the balls to R1

3. Calculations:

1. Gripping Force Calculations:

Mass of Ball (m) = 0.2 kg

Coefficient of Friction between ball and gripper (μ) = 0.6 (By comparing the standard datasheets for the material of the gripper and ball)

$$Gripping\ Force = \frac{m \times g}{\mu} = \frac{0.2 \times 9.81}{0.6} = 3.27\ N$$

$\therefore \boldsymbol{Total\ Force\ of\ 3\ Grippers\ = 3.27 \times 3 = 9.81\ N}$

The piston used provides a constant force of 11.3N(as per datasheet), which is greater than the required force and suitable to grip the balls.

2. Selection of Motor:

Mass to be Rotated (m) = 2.5 kg

Distance of Centre of Mass from axis of rotation (r) = 0.1 m

Since there is a requirement of stalling the motor at a particular angle of inclination, power window motor having stall torque of 80 kg-cm is used.