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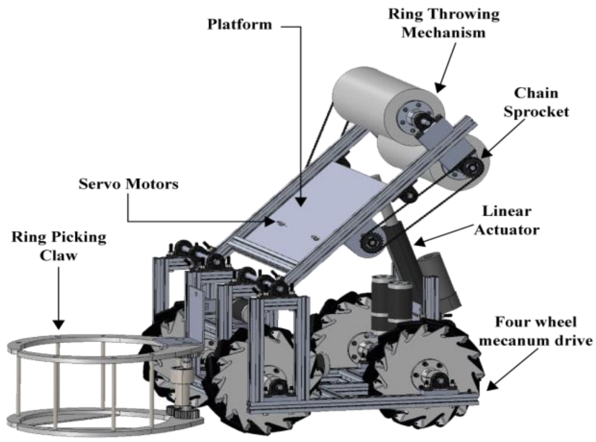
I. Design of Rabbit Robot (RR)

A. Overall dimensions (in mm) and Estimated weight (in kg)

Dimensions:-
At the start:- $390.2 \times 499.31 \times 489.6$
During the game:- $690 \times 499.31 \times 569.2$
Estimated weight:- 14



Isometric view of RR

B. Type of Drive:-

Four-Wheel Holonomic Mecanum Wheel Drive.

C. Type of actuators integrated:-

1. linear actuator (413.685 kpa, 15 mm/s, 300 mm).
2. Planetary geared motor (400 rpm, 24 rpm, 1600 rpm).
3. Johnson Motor (60 rpm).
4. Servo motor. (60 $kg - cm$).

D. Type of sensors integrated:-

1. Raspberry pi-4
2. Arduino Mega (2560)
3. Limit Switch
4. Laser Sensor
5. Kill switch
6. Relay modules
7. MPU-6050
8. Camera Module

E. Brief description of Ring picking Mechanism:-

The objective of the task is to pick a stack of rings from the ring zone and pass each ring to the ring-throwing mechanism. The claw system shown in Figure 1, is used to pick the rings. Motor A and spur **gears are used to move the claw arms.** The claw of the RR will be placed in front of the stack of rings with zero ground clearance. **Both arms will be opened as the motor is rotated.** Now, the claw will grab a stack of rings. **The entire claw with a stack of rings is rotated upside down** on the platform by a planetary geared motor. Again, **the claw's arms will be opened, allowing rings to be pushed** into the throwing mechanism one by one using a servo motor.

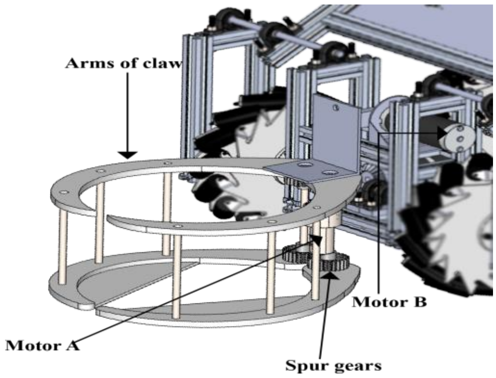


Figure 1: Ring picking Mechanism

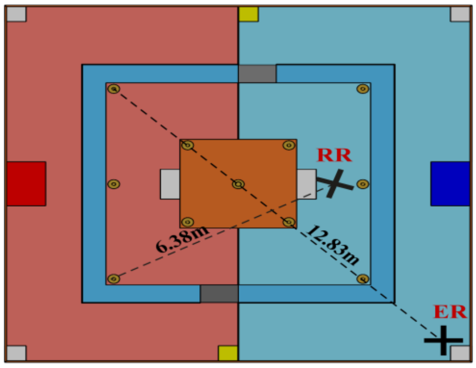


Figure 2: Position of bots in the arena

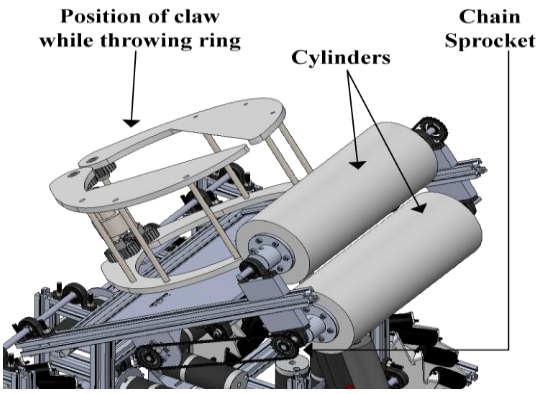
Calculations / Justifications:-
Two frictional forces are acting while grabbing the ring.
i) between wood (ground) and material of claw(f_1) ii) between PLA and Ring (f_2),
Weight of claw (m_1) = 0.5 kg, Weight of stack of 10 rings (m_2) = 0.11 × 10 = 1.1 kg,
Weight of claw with 10 rings (M) = (m_1) + (m_2) = 1.6 kg,
Coefficient of friction between Wood and PLA (μ_1) = 0.4
Coefficient of friction between PLA and Ring (μ_2) = 0.6
$f_1 = \mu_1 \times M \times g$ = 0.4, × 1.6 × 9.81 = 6.28 N, $f_2 = \mu_2 \times m_2 \times g$ = 0.6 × 1.1 × 9.81 = 6.48 N.
Total frictional force (f) = $f_1 + f_2$ = 12.76 N.
From 3D modeling in Solid Works, the Center of mass of the claw with the ring from motor (r) = 0.114 m,
Minimum required torque of motor A to oppose f frictional force: (T) = $f \times r$ = 12.76 × 0.114 = 1.46 Nm,
For motor B, the axis of rotation of the claw system is along the shaft of motor B.
COM of the claw of axis of the rotation (X_c) = 0.17 m,
COM of 10 rings from the axis of rotation (X_r) = 0.2 m,
Mass of claw (M_c) = 0.5 kg, Mass of 10 rings (M_r) = 1.1 kg, COM of claw and ring from the axis of rotation

$$(X) = \frac{M_r \times X_r + M_c \times X_c}{M_r + M_c} = \frac{1.1 \times 0.2 + 0.5 \times 0.17}{1.1 + 0.5} = 0.19\ m.$$

By finding the location of COM, we are finding the minimum torque required of motor B to rotate the system:
(T) = $M \times g \times X$ = 1.6 × 9.81 × 0.19 = 2.98 Nm = 298 Ncm.
So, we are using a **planetary gear motor of 700** Ncm torque to rotate the claw system.

F. Brief description of Ring throwing Mechanism (RR):-

In the RR's ring-throwing mechanism, planetary geared motors are used to rotate cylinders using a chain sprocket. Two cylinders are parallelly placed on the horizontal axis. **Cylinders rotate in opposite directions** with high rpm **so the ring can be projected through it.** A servo motor placed on the platform, behind the stack of rings, **pushes each ring towards the cylinders**. The ring will be passed through the cylinder and projected toward the desired pole. **The angle of Projection can be changed using linear actuator** placed beneath the throwing mechanism.



Ring Throwing Mechanism

Justification for not including jumping mechanism in RR:-
As both RR and ER are **capable of throwing rings onto any pole** in the arena. Hence we chose to use our resources judiciously and not to use any mechanism for jumping. The efficiency of the throwing ring is a maximum around 45^0 of the angle of projection.

Calculations / Justifications:-

From figure 2, the maximum possible distance between the pole and the throwing mechanism of RR is x = 6.38 m, the angle of projection (ϑ) =45^0, the relative height of the pole w.r.t height of projection y = height of pole - height of projection = 0.8 - 0.52 = 0.28 m, Radius of cylinder (r) = 0.05 m.
Let u be the required velocity for throwing the ring into the pole.
According to the equation of the trajectory of projectile motion of rings,

$$u = \sqrt{\frac{g \times x^2}{(x \times tan\vartheta - y) \times 2cos^2\vartheta}} = \sqrt{\frac{9.81 \times (6.38)^2}{(6.38 \times (tan45^0) - 0.28) \times 2 \times (cos^2 45^0)}} = 8.09\ m/sec$$

Minimum required rpm of the cylinder (motor) for throwing ring,
Angular velocity of motor, $\omega = \frac{u}{r} = \frac{8.09}{0.05}$ = 161.80 rad/sec = 1545.07 rpm.

So, we are using a **planetary geared motor of 1700** rpm to rotate the cylinders of the throwing mechanism.

II. Design of Elephant Robot (ER)

A. Overall dimensions (in *mm*) and Estimated weight (in *kgs*)

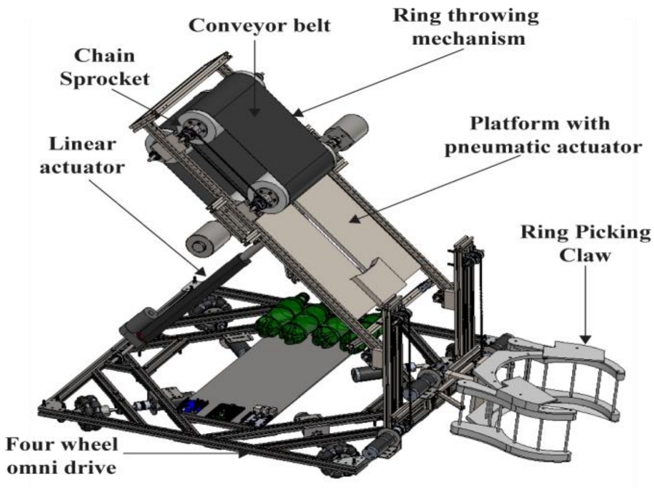
Dimensions: -
At Start:- 962 × 896 × 1100
During the game :- 1182.035 × 800 × 1176.57
Estimated Weight:- 25

B. Type of Drive:-

Four-Wheel Holonomic Omni Wheel drive.

C. Type of actuators integrated:-

1. Pneumatic Actuator (15 *cm* & 5 *cm*).
2. Linear Actuator (400 *mm*, 7 *mm/s*, 1500 *N*).
3. Planetary geared motor (18 *rpm*, 400 *rpm*).
4. E-V Motors (2500 *rpm*).



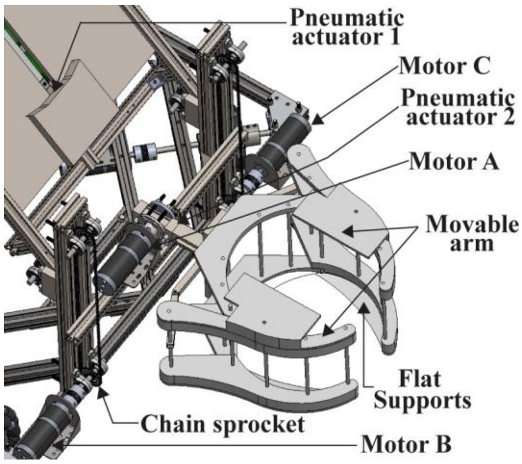
Isometric view of ER

D. Type of sensors integrated:-

1. Raspberry Pi 4
2. Arduino Mega (2560)
3. Kill switch
4. Mpu-6050
5. 5V Relay Module
6. Camera Module
7. Laser Sensor
8. Limit Switch

E. Picking up the Ring from the ground. (ER):-

As shown in fig, a claw system with pneumatic actuators is used to pick rings. **With the help of connecting links, movable arms are attached to the shaft** of the pneumatic actuator 2 (shown in the figure). The **claw will be opened and closed, concerning the back-and-forth motion of the shaft.** A claw is placed in front of a stack of rings, with zero ground clearance. After grabbing, the stack of rings, the claw will be closed and the **chain sprocket mechanism pulls the claw with rings to the height of the platform.** Now the **entire claw is rotated upside down on the platform** using a planetary geared motor. Here, Claw itself is used as a stacker for the rings. Next, using the pneumatic actuator 1, **rings will be pushed into the throwing mechanism one by one**.



Ring Picking Mechanism

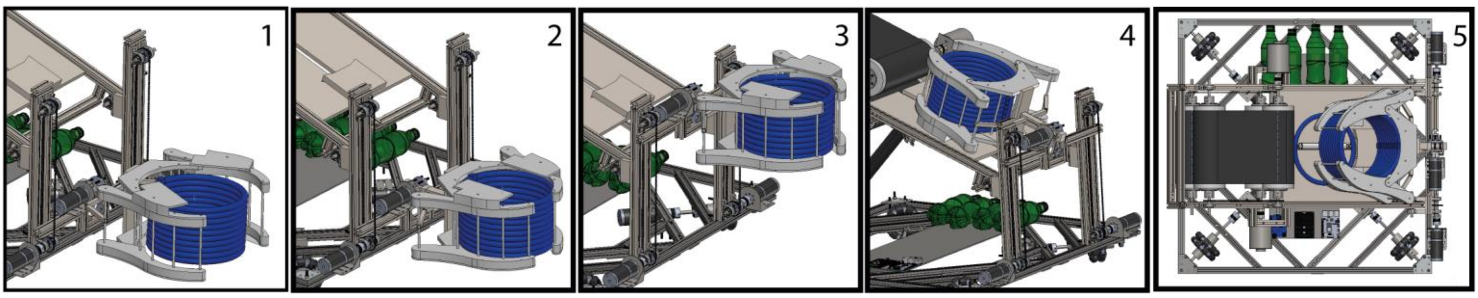


Figure 2: Working of picking mechanism

Calculation / Justifications:-

Calculation to lift claw system:-

After grabbing the rings, The ER will lift up the claw system.

Mass of planetary motor (M_p) = 0.831 kg, length of aluminum extrusion (l_e)= 43.061 cm ,

Mass of extrusion (M_e) = 0.18473 kg , Radius of sprocket (R_c)= 1.6 cm,

Mass of claw and stack of 10 rings (M_s)= 1.4 + 1.1 = 2.5 kg.

Total mass lifted by chain sprocket, $M_T = (M_e + M_p + M_s) = 0.18473 + 0.831 + 2.5 = 3.1573\ kg$.

As shown in the picking mechanism, the mass is not uniformly distributed due to the planetary motor. So, the tension in both chains is different.

Hence, Center of mass of planetary motor (X_p) = 14.35 cm.

Center of mass of Aluminium Extrusion (X_v) = 21.53 cm.

$M_T \times g = T_1 + T_2$,

$$X = \frac{X_p \times M_p + X_v \times M_c + X_e \times M_e}{M_p + M_c + M_e} = \frac{14.35 \times 0.831 + 21.53 \times 2.5 + 21.53 \times 0.1847}{00.831 + 2.5 + 0.1847} = 19.83\ cm$$

Tension in first chain (T_1) = $\frac{X \times M_T \times g}{l_e} = \frac{19.83 \times 3.515 \times 9.81}{43.061} = 15.88\ N$

Tension in second chain (T_2)= $\frac{(l_e - X) \times M_T \times g}{l_e} = \frac{(43.061 - 19.83) \times 3.515 \times 9.81}{43.061} = 18.60\ N$

After finding the tension and location of COM, minimum torque required,

$(\tau) = T_2 \times R_c = 0.2848\ Nm = 28.48\ Ncm$ (Since $T_2 > T_1$)

So, we are using a **planetary geared motor with a torque of 45** Ncm.

Calculations for rotation of claw system:-

From 3D modeling in Solid Works, we got the Centre of mass of Claw = X_c = 17.069 cm,

(Distance X_c is from the horizontal axis of rotation).

Mass of claw (M_c) = 1.4 kg , Mass of ring (M_r) = 0.11 kg,

Mass of stack = Mass of ring × 10 = 1.1 kg.

COM of the ring from the horizontal axis of rotation = X_r = 26.825 cm.

So, The COM of the whole system (claw + stack of rings) while picking is Xs.

$$X_s = \frac{M_c \times X_c + M_r \times X_r}{M_c + M_r} = \frac{1.4 \times 17.06 + 1.1 \times 26.82}{1.4 + 1.1} = 21.35\ cm$$

COM of the whole system lies at a distance of 21.35 cm from the horizontal axis of rotation.

Torque (Tq) = Ms × g ×X_s = 2.5 × 9.81 × 21.35 = 523.60 Ncm = 5.2267 Nm.

So, we are using a **planetary geared motor of 18** rpm **and 700** Ncm **torque** to rotate the claw.

F (a) Ring throwing mechanism (ER):-

In this mechanism, we have used two conveyor belts supported by two pairs of cylinders, rotating in opposite directions. We've used a pneumatic actuator to push the rings through two conveyor belts one by one. **Due to the opposite directional motion of conveyor belts, the ring is pulled between the conveyors, and their momentum is transferred to the rings resulting in its projectile motion**. The camera integrated with the Raspberry Pi 4 is fitted into the mechanism in order to find the desired range of the pole from the throwing point. We are using a linear actuator to change the angle of projection in order to attain desired height and range to place the rings into the correct pole.

Calculations / Justifications:-

For calculating the radius of the cylinder used in the throwing mechanism,

We have an E-Bike motor of 2500 rpm, from figure 2, the maximum distance between the throwing mechanism of ER and the pole is x m.

x = 12.83 m.

Let u be the required velocity for throwing the ring into the pole and the relative height of the pole from throwing the mechanism should be,

$$u = \sqrt{\frac{g.x^2}{(x.tan\vartheta - y)2cos^2\vartheta}} = \sqrt{\frac{9.81 \times (12.83)^2}{(12.83 \times (tan45^0) - 0.16) \times 2 \times (cos^2 45^0)}} = 11.28\ m/sec$$

$$r = \frac{u}{w} = \frac{60 \times 11.28}{2500 \times 2\pi} = 0.043\ m \qquad \text{(From } u = r \times \omega)$$

So, the **minimum required radius of the cylinder is 4.3** *cm*.
Hence, we have taken the **radius of the cylinder as 5** *cm* ....(calculation 1).

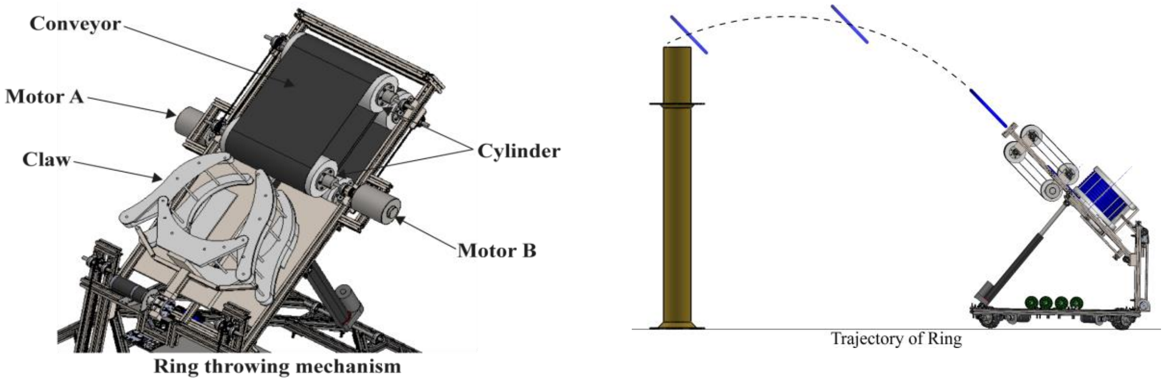


Figure 3: Ring throwing mechanism & Ring trajectory

F (b) Ring passing mechanism (ER):-

As both ER and RR are capable of picking and throwing rings at every pole in the arena, so it is not essential to pass the ring from ER to RR.

Calculation for Ring throwing Mechanism to Centre Pole (ER):-

y = height of pole - height of projection = (0.8 + 0.2) - 0.84 = 0.16 m.
Mass of ring (m) = 0.11 kg, Radius of Cylinder (d) = 5 cm (from calculation I)
Pole height (h) = 1.5 m, Angkor Wat area height (h_w) = 0.2 m,
Ankor center area height (h_c) = 0.2 m.
Assume, the angle of throwing ring = 45^0,
Effective height of pole from throwing mechanism = (h + hw + hc - projection height)
= 1.5 + 0.2 + 0.2 - 0.84 = 1.06 m
The distance between the pole and ring throwing mechanism is x = 7.18 m
For velocity of projection, the equation for the trajectory of the projectile,

$$u = \sqrt{\frac{g.x^2}{(x.tan\vartheta - y)2cos^2\vartheta}} = \sqrt{\frac{9.81 \times (7.18)^2}{(7.34 \times (tan45^0) - 1.06) \times 2 \times (cos^2 45^0)}} = 9.09\ m/sec.$$

Required rpm of the cylinder (motor) for throwing the ring on to the center pole,

$$\omega = \frac{u}{r} = \frac{9.09}{0.05} = 181.80\ rad/sec.$$

Minimum Required rpm of motor = 1736.06 *rpm*. Hence, using a **2500** *rpm* **EV motor**, ER can throw rings onto the pole in the Angkor wat center area, with conveyor belts having **cylinders of 5** *cm* **radius**.

Link to CAD models:

https://drive.google.com/drive/folders/1HhzOmAYP3SKB_VfVptlUArHsOL5O56Bb?usp=sharing