DESIGN DETAILS DOCUMENT
GTU ROBOTICS CLUB

Objective: The objective of this proposed document is to explain the mechanism and working of both the Robots according to the theme of ABU Robocon 2022.

1. Type of Drive for Robots R1 and R2:

As per the game theme and requirements, Holonomic Quad drive is a suitable for both the Robots R1 and R2.

The constructed Holonomic Quad drive consists of four Omni wheels at an angle of 45° which provides the maximum number of directions with more resultant velocity compared to other drives [1]. By controlling the speed and direction of the motor, we can drive the Robot in a continuous curved path like that of an elliptical movement.

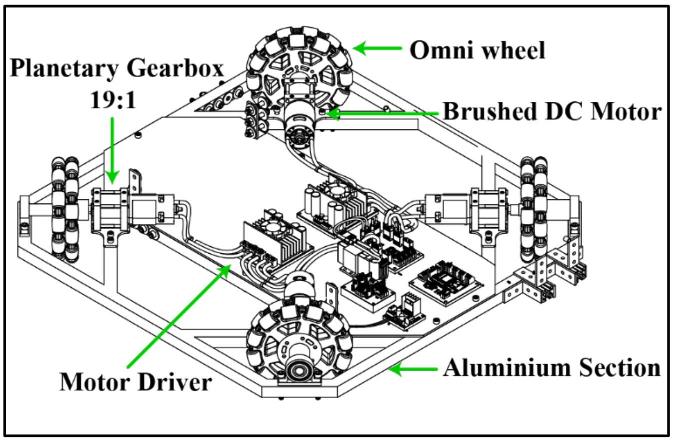

Figure 1: Quad holonomic drive with Omni wheels

The wheel alignment provides minimum slippage and resistance to backlash. The whole drive structure also provides several advantages like stability, better weight distribution and agile motion. The Robot's structures are constructed using aluminium 6061(19x19mm) for good weight to strength ratio and weldability. Omni wheels of 152mm diameter are used with 775 DC motors (10,000 RPM at 12V and 8 kg·cm torque) with gearbox of 19:1 which provides 152 kg·cm torque, sufficient to drive the Robot. The motors are driven by high current motor drivers with a burst current of up to 120A.

Incremental encoders are used for the relative displacement of the Robot and IMU sensors are used for the gyroscopic navigation, integrated with PID algorithm for stable and accurate driving.

2. Robot R1:

2.1 Introduction:

Robot R1's primary task is to break the Lagori tower in seeker time and to displace the seeker R2's Ball on Head (BOH) in the hitter time, while it piles up the Lagori discs. The dimensions of Robot R1 are 889mm x 806mm x 702mm (LxWxH).

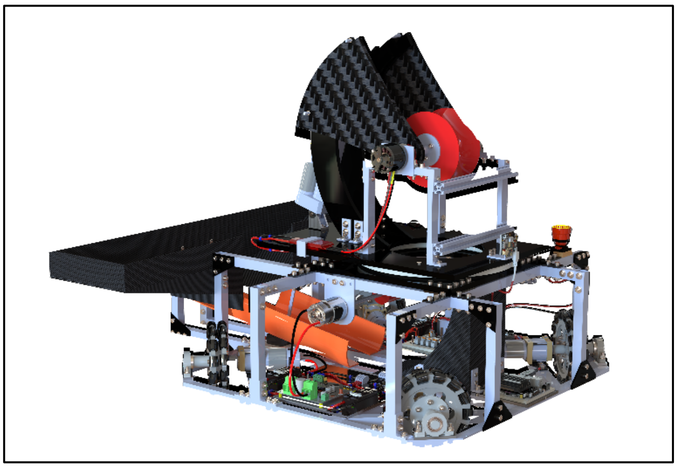

Figure 2.1: R1 Robot

2.2 Ball Receiving Mechanism:

2.2.1 Principle:

Using gravitational pull, the ball receiving mechanism collects and passes the ball into the throwing mechanism.

2.2.2 Construction:

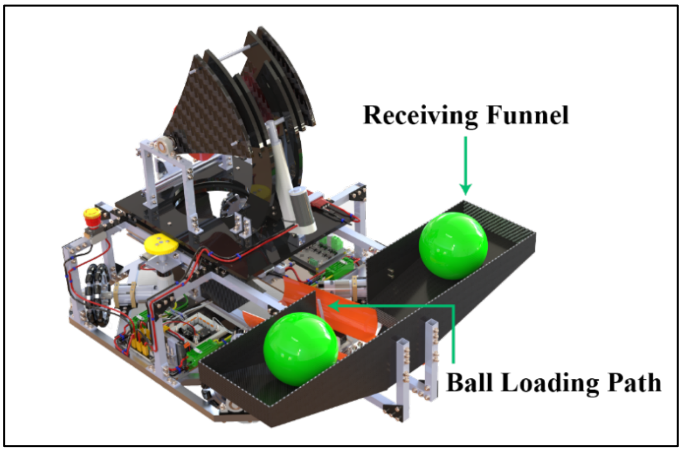

Figure 2.2.2: Construction of receiving mechanism

A funnel-shaped body fabricated using Carbon Fiber is mounted at the edge of Robot to receive upto three balls at a time. A barrier operated by servo motor divides the funnel and loading zone, allowing one ball to pass at a time. The sliding surfaces for adjacent balls are mounted at slight angle difference to allow ball sliding in consecutive manner (refer figure 2.2.3; 1-2-3). The received balls slide into the loading zone one by one.

2.2.3 Working:

The Robot R2 releases the balls into the receiving funnel during the hitter time. The controlled barrier allows to slide one ball at a time. The loading zone consists of a sliding path and an arc-shaped guide, through which the ball is lifted using roller mechanism which further leads the ball to throwing mechanism.

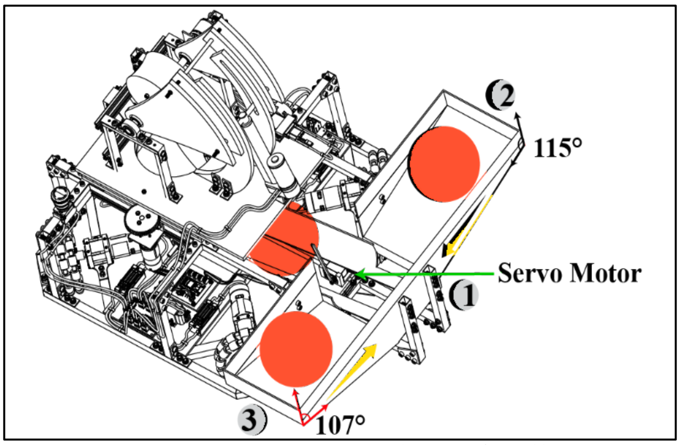

Figure 2.2.3: Step-wise working of Ball receiving

2.2.4 Justification:

The proposed ball receiving mechanism provides reliability and uses minimum actuators to function the mechanism. The unique funnel-shaped structure allows consecutive ball receiving to ensure effective ball loading.

2.3 Lagori breaking:

2.3.1 Principle:

Using the concept of the projectile motion and laws of conservation, the Lagori breaking mechanism throws the ball with required initial velocity through a single roller and arc-shaped structure to provide the desired throwing trajectory towards Lagori pile [2].

2.3.2 Construction:

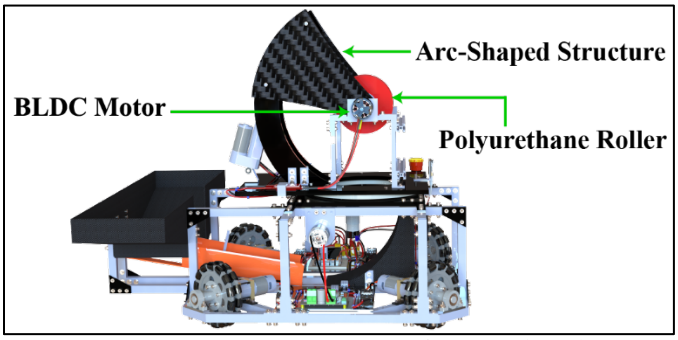

Figure 2.3.2: Construction of Lagori breaking

The throwing mechanism is constructed with a Polyurethane roller of diameter 140mm and an arc-shaped structure to create throwing trajectory. The roller shaft is connected to Propdrive 5050 outrunner BLDC motor (580KV). The mechanism is mounted on a polymer platform at the centre of which a circular opening is kept to load the ball into the throwing mechanism.

2.3.3 Working:

The stepwise working of Lagori breaking mechanism is given in figure 2.3.3. The receiving mechanism brings the ball into loading zone (1). Using external feedback sensor, all the controllable parameters of the mechanism are fixed as per the required trajectory for Lagori break.

The loading zone thrusts the ball upwards into the throwing mechanism (2) and is drawn into the circular path with help of the roller actuated by BLDC motor (3). The ball is thrown in the required trajectory, follows projectile motion and collides on the Lagori pile to break it (4).

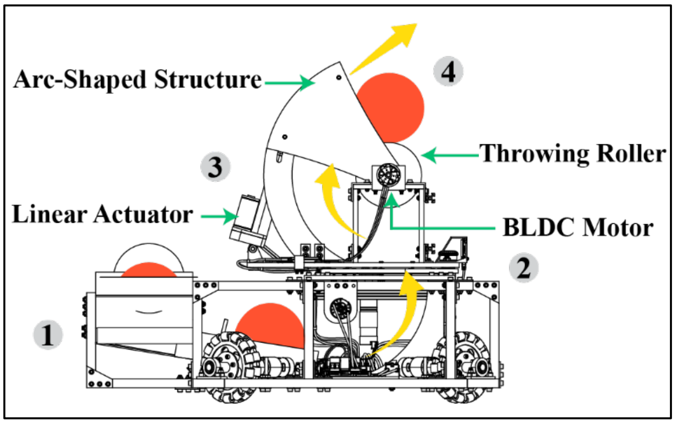

Figure 2.3.3: Step-wise working of Lagori Breaking mechanism

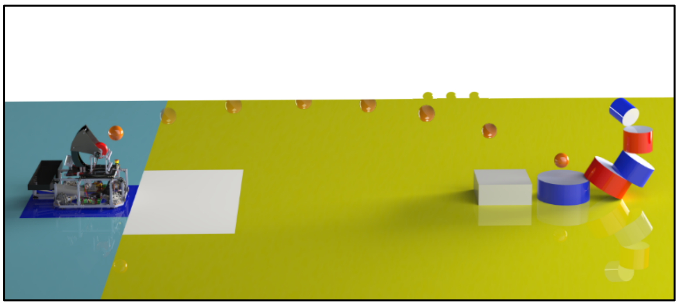

Figure 2.2.3: Simulation of Lagori Breaking

2.3.4 Calculations:

The work done required to displace the Lagori out of Lagori spot with force greater than applied frictional force, can be used to calculate the necessary parameters for ball throwing.

$\therefore F = 1.568\ N$ $\qquad (\because F = \mu M g)$

(Frictional co-efficient between Lagori and Lagori spot, μ = 0.1; total mass of Lagori pile, M = 1.6 kg; gravitational constant, g = 9.8 m/s²)

Work done (W) required is $0.47\ joule$

(The displacement needed for Lagori breaking, x = 0.3m)

To provide required work done, the Lagori pile needs to have enough kinetic energy ($K.E = \frac{1}{2}mv^2 = Work\ done$) at the time of impact with ball, for which it needs velocity (v) of $0.76\ m/s$. The collision between Lagori pile and ball needs to provide the required minimum velocity to the Lagori pile. Using the laws of conservation of momentum and energy, the minimum required velocity for ball can be derived as,

$$\therefore M_b v_i^b + M_l v_i^l = M_b v_f^b + M_l v_f^l$$

$$\therefore \frac{1}{2}M_b(v_i^b)^2 + \frac{1}{2}M_l(v_i^l)^2 = \frac{1}{2}M_b(v_f^b)^2 + \frac{1}{2}M_l(v_f^l)^2$$

(mass of ball, M_b = 0.2 kg; mass of Lagori pile, M_l = 1.6 kg; initial velocity of ball, v_i^b; initial velocity of Lagori, v_i^l = 0 m/s; final velocity of ball, v_f^b; final velocity of Lagori, v_f^l = 0.76 m/s)

Using these relations, the value for initial velocity (v_i^b) before impact of the ball is calculated as **3.41 m/s**. We have to provide more than 3.41 m/s speed to the ball to break the Lagori Tower. Maximum allowed velocity of 8.3 m/s (30 km/h) as per the rulebook (2.1.10) is used which is sufficiently greater than minimum requirement to break the Lagori Tower.

$$\therefore y = x \tan\theta - \frac{gx^2}{2v^2(\cos\theta)^2}$$

```
% CALCULATION FOR BREAKING LAGORI

y = -0.075 ;
% y is relative position of lagori target in y-axis
x = 3.5;
% x is relative position of lagori target in x-axis
u = 8.3;
% u is the considered value for initial
% velocity of ball

% converting the formula for projectile
% motion in terms of a,b,c for
% solving roots of quadratic equation for
% tanget of initial angle of projection
a = (9.8 * (x^2)) / (2 * (u^2));
b = -x;
c = (((9.8 * (x^2)) / (2 * (u^2))) + y);
tang = (- b - sqrt(b^2 - (4 * a * c))) / (2 * a);
angle = atan(tang) / 0.017

angle =

   13.9730

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Figure 2.3.5: Angle calculation

As per practical trials, in order to break the Lagori tower, we need to hit the ball at 500mm height in Lagori tower. The required angle with given parameters is found to be 13.97° *(refer figure 2.3.5)*.

Motor requirement

To achieve the maximum permitted speed, the required RPM in the rollers is calculated as 1132 ***(considering radius of rollers: 0.07 m).*** For the motor to provide 1132 rpm on load, the rpm without load was found to be around 3500 from multiple test runs. The selected BLDC motor (580KV) provides the required rpm to the rollers, which also provides sufficient torque with less weight.

2.4 Hitting of Ball on Head:

2.4.1 Principle:

Image processing and Machine learning are implemented to trace the ball's location [3]. The concept of projectile motion with a single roller is applied to throw the ball in the required trajectory.

2.4.2 Construction:

A depth-sensing camera is mounted on the front of Robot R1 for ball detection. The angle of arc shaped structure with respect to roller can be changed through a linear actuator concentric to the roller as shown in the figure. The structure is mounted on polymer platform which consists of a circular opening with turntable bearing between them. The bearing is connected to a half gear at its edge. The structure resembles to a turret and can be rotated with axis at the center of the bearing through a pair of half gear and spur gear actuated by a 775 motor.

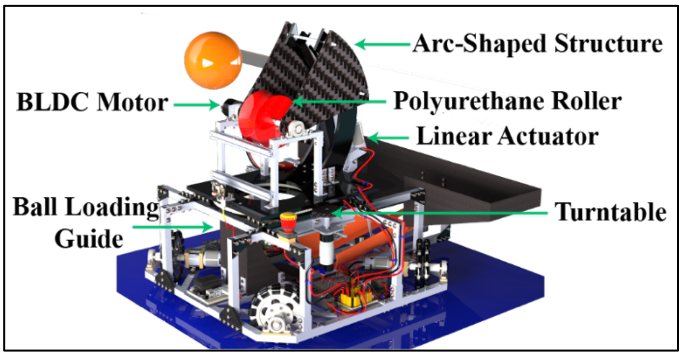

Figure 2.4.2: Construction for displacing BOH

2.4.3 Working:

The sensor detects the ball and traces the location. The depth-sensing camera provides the coordinates of the BOH. The camera inputs are processed by a single-board computer. The computer further communicates with the microcontroller which provides output to the actuators according to position of BOH. Once the trajectory for throwing is set, the ball is loaded into the throwing mechanism to displace the BOH.

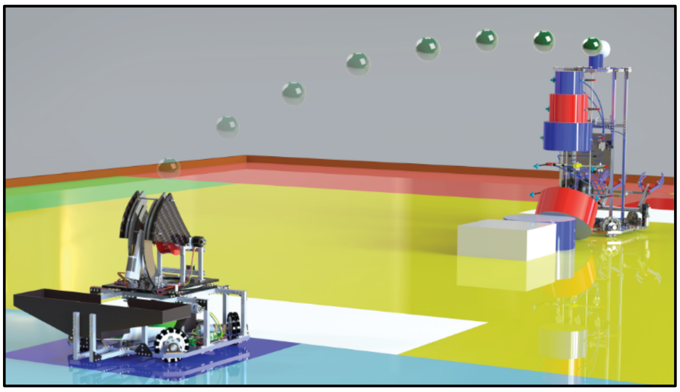

Figure 2.4.3: Simulation of Displacing BOH

2.4.4 Calculations:

The projectile motion of hitter ball

Considering that maximum initial velocity of 8.3 m/s is provided to the hitter ball, according to the rule book (2.1.10). Using these factors and the equation of projectile motion, the relationship between the distance of BOH and angle required to throw the ball can be determined.

$$\therefore y = x \tan\theta - \frac{gx^2}{2v^2(\cos\theta)^2}$$

The equation is converted into quadratic equation with $\tan\theta$ as a variable.

$$\therefore \left(\frac{g*x^2}{2*u^2}\right)(\tan\theta)^2 + (x)\tan\theta + \left(\frac{g*x^2}{2*u^2} + y\right) = 0$$

The height of BOH is in the range of 1.3m-1.35m. Considering a range of 1-7m for calculating maximum distance the hitter ball can reach. Solving the quadratic equation, the maximum range from which the BOH can be displaced is 6.38m at 49.07°(refer figure 2.4.4.1), which suffice our requirement as per game theme.

```
% CALCULATION FOR CALCULATING BALL ON HEAD

y = 0.625 ;
% y is relative position of lagori target in y-axis
x = [1:0.01:7];
% x is range of relative position of lagori target in x-axis
u = 8.3;
% u is the considered value for initial velocity of ball

% converting the formula for projectile motion in terms
% of a,b,c for solving roots of quadratic equation for
% tangent of initial angle of projection
a = (9.8 .* (x.^2)) ./ (2 .* (u.^2));
b = -x;
c = (((9.8 .* (x.^2)) ./ (2 .* (u.^2))) + y);
tang = (- b - sqrt(b.^2 - (4 .* a .* c))) ./ (2 .* a);
theta = atan(tang) / 0.017;
theta = real(theta);

% finding point of maxima for distance
[peaks,locs] = findpeaks(theta);
x_max = x(locs)
angle_max = peaks

x_max =

    6.3800

angle_max =

   49.0720

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Figure 2.4.4.1: Maximum range calculation

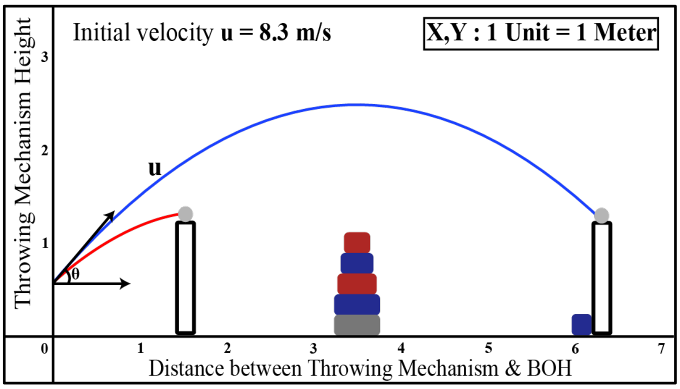

Figure 2.4.4.2: Range [4]

3. Robot R2:

3.1 Introduction:

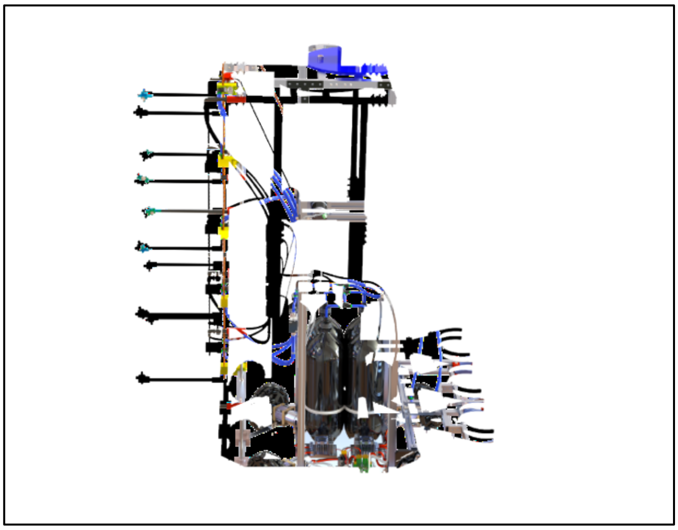

Figure 3.1: Robot R2

Robot R2's primary task is to pick and pile the broken Lagori discs during the seeker time and to pick and pass the hitter balls to Robot R1 during the hitter time. The dimensions of Robot R2 are 923.8mm x 794.8mm x 1230mm (LxWxH).

3.2 Ball Picking and Passing Mechanism:

3.2.1 Principle:

The ball picking mechanism uses air compression as a form of energy to grab and hold the balls from ball rack using 3D printed grippers.

3.2.2 Construction:

The 3D printed grippers are dynamic and connected in such a manner that it can be operated by actuating a linear section.

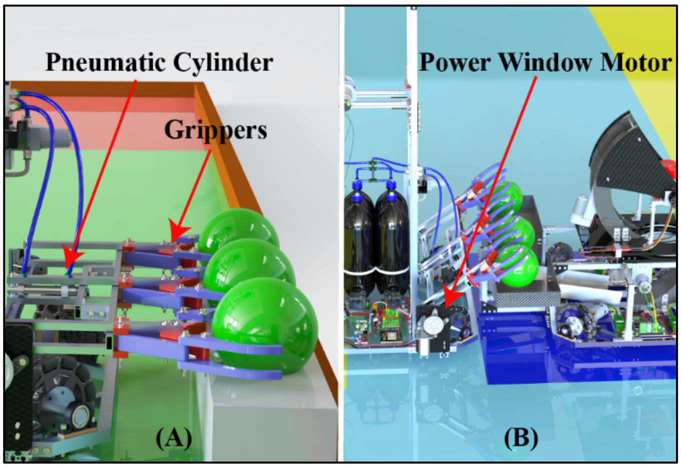

Figure 3.2.2: (A)Ball picking, (B)Ball passing

Three such linear sections are connected on a single section actuated through a pneumatic cylinder to grab all the balls at once. All the grippers can be lifted through a power window motor connected to the shaft.

3.2.3 Working:

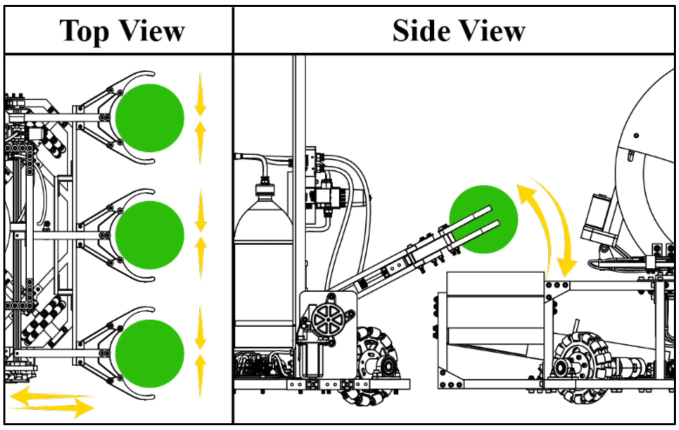

*Figure 3.2.3: Working (**Top View:** R2 Gripping hitter ball, **Side View:** R2 Passing ball to R1)*

When the Robot R2 is acting as Hitter Robot R2, it is driven and positioned with respect to the ball rack. The grippers are closed in order to grab the balls. The controller receives the feedback from the gripper. To pass the balls, Robot R2 positions the gripped balls on top of receiving funnel of Robot R1. Once the Robots are aligned, the grippers release the balls into the receiving funnel.

3.2.4 **Justification**:

This ideated and prototyped solution for ball picking and passing provides firm holding ability due to finger-like structure. Using a common actuator fulfills the required task with less weight on mechanism.

3.3 **Lagori Picking and Piling**:

3.3.1 **Principle**:

The Lagori picking mechanism uses air compression as energy source to grab the Lagori discs. In order to store and pile the Lagori discs, rotational motion of the motor is transformed into the vertical linear motion.

3.3.2 **Construction**:

The stepwise construction of Lagori piling mechanism is given in figure 3.3.2. Two SS304 1161mm (Length) and 8mm (O.D.) pipes are mounted parallelly, 185mm apart(2). Five custom actuating grippers are mounted on the pipe(3), and these five grippers are tied with a nylon rope and the grippers are guided by a linear bearing.

This rope is guided by pulley at a specific height and is further wounded on motor shaft with help of which the grippers are lifted to the required height(1). A free to rotate 3D printed part is connected at the end of each arm of the grippers in order to balance the Lagori discs regardless of their orientation.

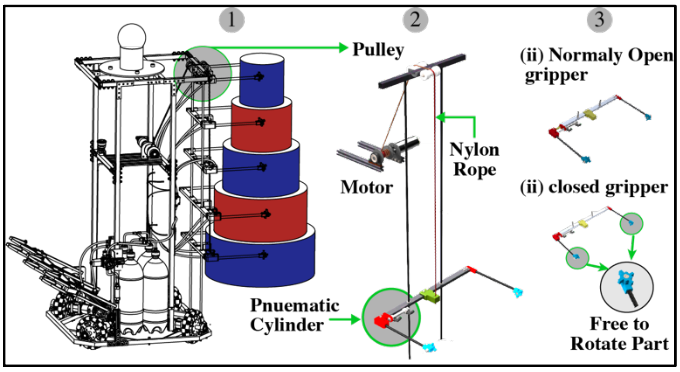

Figure 3.3.2: Construction for Lagori piling

3.3.3 **Working**:

The Robot R2 is positioned in front of each Lagori disc to pick it and store it in its respective gripper. To pile the Lagori in correct order, the Robot picks the Lagori discs in ascending order. i.e., starting from smallest to largest. Once the Robot is aligned in front of a Lagori disc, the gripper is closed.

The Lagori disc aligns in correct orientation due to its mass distribution. After picking each Lagori disc in order, the motor wounds the rope to pull up 205mm of section through pulley mechanism. After five such consecutive cycle of picking and liftin g, all five Lagori discs are picked by the gripper in proper order. The Lagori pile is lifted and placed on the Lagori spot.

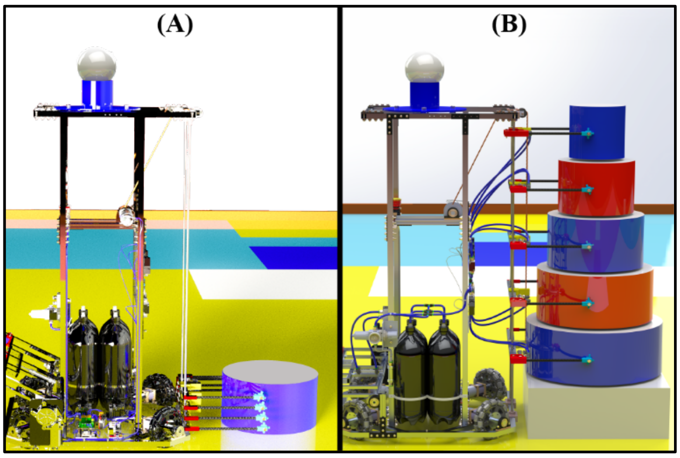

Figure 3.3.3: (A)Lagori picking, (B)Lagori piling

3.3.4 **Calculations**:

In order to lift the gripper mechanism along with Lagori discs, the motor needs to apply sufficient torque and force for pulling the rope keeping in mind the tangential force on the motor shaft. The maximum weight at any given instant on the rope is equal to the tension on the rope, which can be calculated as,

$$\therefore T = F = (m_g + m_l)g$$

(Tension in the rope, T; weight of grippers, M_g = 2.7kg; weight of Lagori pile, M_l = 1.44kg; gravitational acceleration, g = 9.8m/s^2; the calculated tension ≈ 40.5 N).

Torque can be calculated as the function of perpendicularly applied force multiplied with radius at which force is applied.

$\therefore \tau = F \times r$ ***(radius of motor shaft = 0.008m)***

The required torque of the motor for piling mechanism calculated from the above equation is 3.2 kg·cm. Considering the requirement, 775 DC motor with gearbox is selected.

REFERENCES

[1] *J. Parmar, "Selection of Wheels in Robotics," IJSER, vol. 5, no. 10, pp. 339-343, October 2014.*

[2] *K. P. K. &. S. Wójcicki, "Mathematical Analysis for a New Tennis Ball Launcher," Acta Mechanica et Automatica, vol. 5, pp. 110-119, 2011.*

[3] *Y. G. G. J. Ya Xiong, "An autonomous strawberry-harvesting robot: Design, development, integration, and field evaluation," Journal of field robotics, 7 August 2019.*

[4] *"Desmos graphing calculator," [Online]. Available: https://www.desmos.com/calculator/j9vafxvwoc.*