Design Details Document

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Design of Defensive Robot (DR):

Specifications:

Length	978mm (Full extension)
Width	953mm (Full extension)
Height	711mm (Full extension)
Weight	24.5 Kg (Approximately)

Type of Drive (4-wheel Holonomic Omni drive):

The **Holonomic cross drive with Omni wheels** (Fig. 1.1) is selected for its capability to move to any coordinate in the X-Y plane by calculating the instantaneous resultants of all 4 wheels, while also providing control over the rotation about the Z-axis. Thus, the Holonomic Omni cross drive has an advantage in terms of maneuverability and traction. The Defensive Robot's chassis is made up of a 6061-grade aluminium angle beam (12.7mm x 12.7mm x 2mm) which is lightweight, structurally rigid, and ensures sturdiness. Additionally, rollers are fixed on the sides of the chassis as shown in Fig 2(b), such that the DR can move using the baffle as a reference.

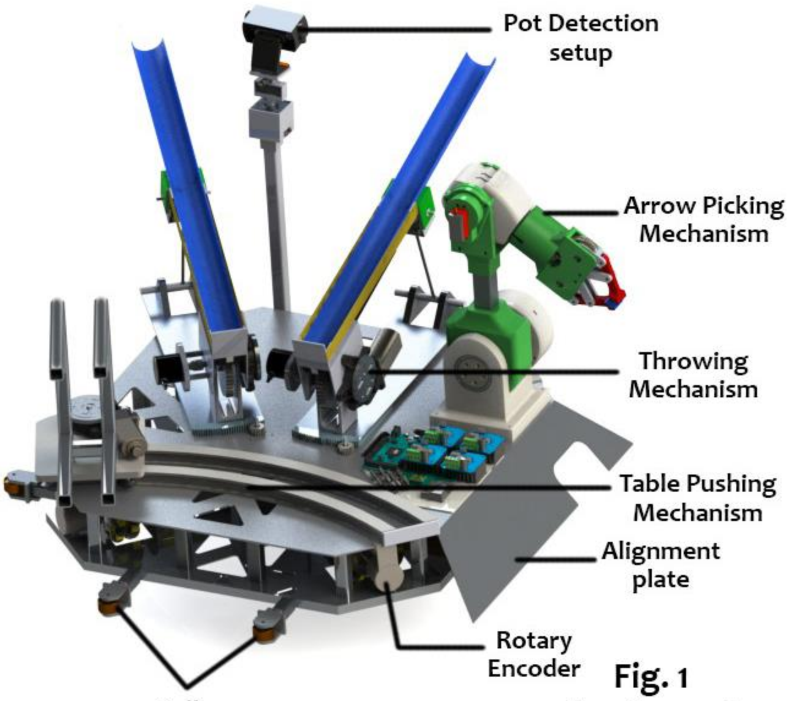


Fig. 1
Defensive Robot

The DR's locomotion is semi-autonomous. It can be completely controlled by a manual operator using a PS2 controller and can also be programmed to reach a specified coordinate by pressing a button on the controller. Using encoders on all the wheels and an IMU (Inertial Measurement Unit) at the center of the chassis gives the accurate position and orientation of the robot by implementing sensor fusion. Feedback data from these sensors is sent to ROS (Robot Operating System), the software running on Raspberry Pi, which processes and issues commands to the Arduino Due. Subsequently, Arduino sends appropriate signals to the motor drivers that control the locomotion of the robot.

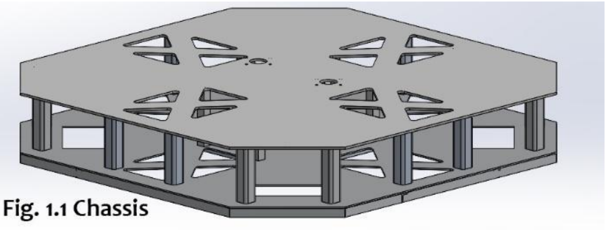


Fig. 1.1 Chassis

Arrow picking and passing mechanism:

The arrow picking and passing mechanism consists of a robotic arm with 3 Degrees of freedom and an alignment sheet. The base joint has a stepper motor while the other joints are controlled by high-precision servo motors (Stall torque 10 kg-cm). The end effector of this arm has 2 co-planar claws. Since the arrow's body is cylindrical,

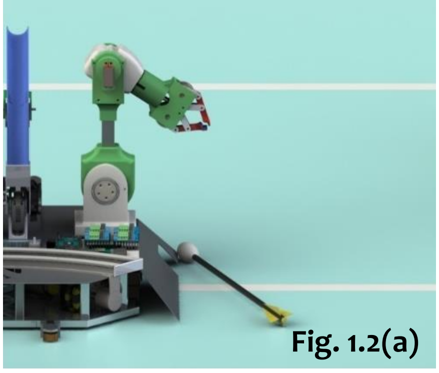


Fig. 1.2(a)

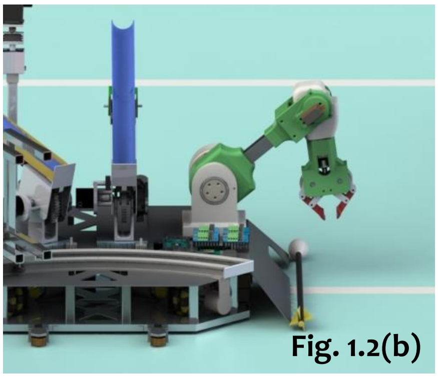


Fig. 1.2(b)

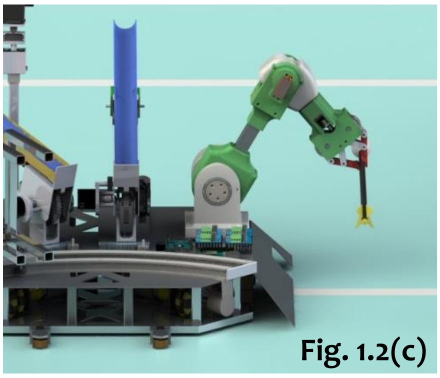


Fig. 1.2(c)

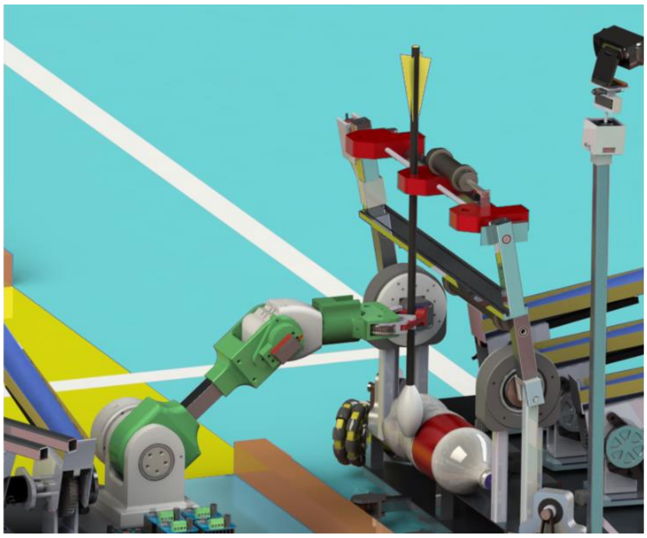


Fig. 1.3 DR passing the arrow to TR

each claw has a “V” notch with friction padding for enhanced grip. The end effector has a worm gear meshed with 2 worm pinions that are attached to the claws and are actuated by a servo motor.

To pick an arrow from the ground, the DR uses the alignment sheet to push the arrow for parallel alignment with the DR, as shown in Fig.1.2 (b). Since the arrow is now parallel to the end effector’s gripper, it can easily be grabbed by operating just the base joint and the claws, as illustrated in Fig 1.2(c). In this way, the arrow can be picked from the ground irrespective of its orientation. Additionally, if required, the end joint can be rotated to adjust the orientation of the arrow, before passing it to the Throwing Robot (TR).

To pass the arrow, the DR moves toward the grabbing proximity of the TR. After aligning with TR, DR adjusts the joints of the robotic arm and passes the arrow to the grabber clips of the TR as shown in Fig. 1.3.

Design of Throwing Robot (TR)

Specifications:

Length	968mm (Full extension)
Width	954.6mm (Full extension)
Height	864.6mm (Full extension)
Weight	21.5 Kg (Approximately)

Type of Drive:

The same Holonomic cross drive with Holonomic base (Fig. 1.1) used in DR is employed for the Throwing Robot (TR). Four Planetary geared motors are used for locomotion. Sensor data from the Arduino Due is transmitted to Raspberry Pi, the main processor of the system. Odometry is achieved through sensor fusion of encoders and IMU using ROS. Here PS2 controller is used for maneuvering. Additionally, rollers are also fixed on the sides of the TR’s chassis to assist the wall following with baffles as the reference as shown in Fig. 2(b).

Fig. 2 Throwing Robot (TR)

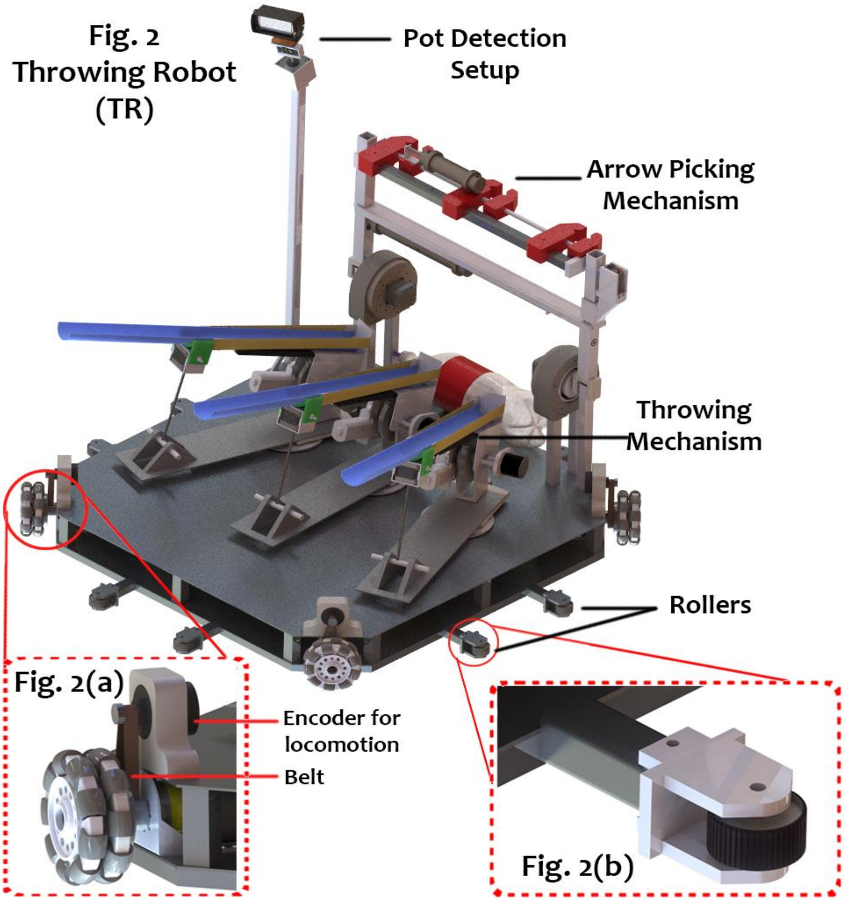
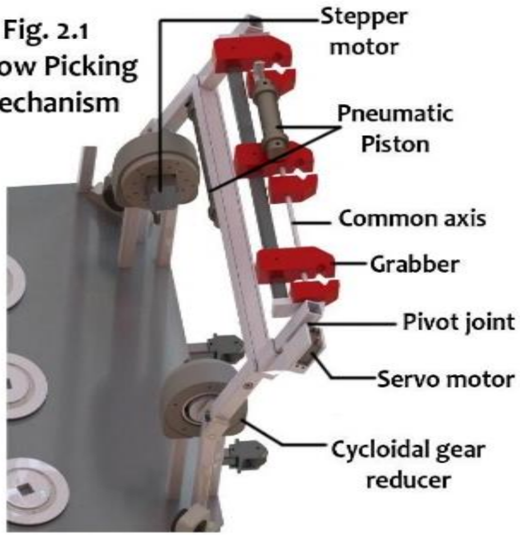


Fig. 2.1 Arrow Picking Mechanism



Arrow picking and receiving mechanism

Picking arrows from the rack is done by a mechanism with 2 degrees of freedom. The end effector of this mechanism consists of 3 grabber clips. Each clip has a “V” notch with friction padding for enhanced grip as illustrated in Fig. 2.2. The clip is made up of two segments, one of which is fixed, while the other is movable. The movable part of each of the grabber clips is connected via a common axis. This common axis is actuated using a pneumatic piston (25mm stroke length), which is

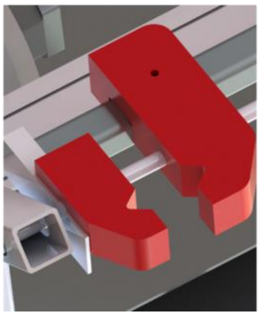


Fig. 2.2 Grabber

responsible for holding an arrow in the "V" notch. These grabbers are mounted on a frame that is held with a pivot joint attached to a servo motor.

To pick and load arrows from the arrow rack, the angular displacement of the grabber mechanism is needed. This requires high torque which is achieved by using a cycloidal reducer mounted onto each of 2 NEMA-17 stepper motors (Stall torque: 5.5 kg-cm). These motors are operated via a single high current driver to ensure synchronized movement. In order to reach the furthermost arrows on the rack, the grabbers can slide laterally to align themselves with the arrows by using a pneumatic actuator (200mm stroke length). After grabbing the arrows, they are then aligned back to the launcher to complete the loading.

To load the arrows, the servo motor of the frame rotates the pivot joint, thereby rotating the arrows to bring their head upwards and repositioning them parallel to the launcher. The same mechanism is used to receive the arrow from DR, the only difference being that the arrow is received from DR's passing mechanism instead of the arrow rack.

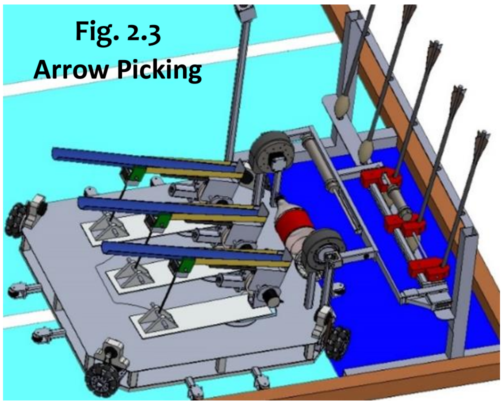


Fig. 2.3
Arrow Picking

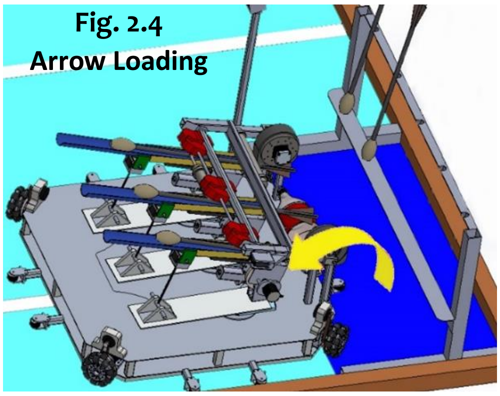


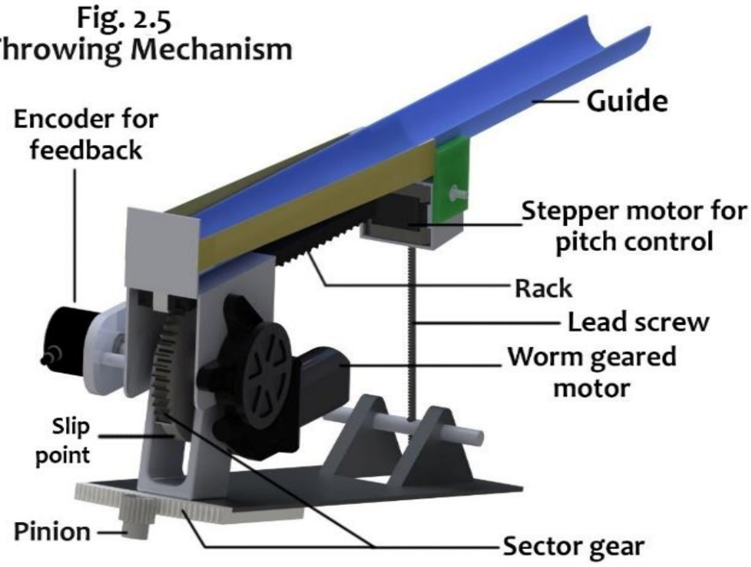
Fig. 2.4
Arrow Loading

Throwing Mechanism

The throwing mechanism comprises multiple layers of Thera-band attached to the rack and the sector gear driven by a worm geared motor. The Thera- band provides a certain level of elastic resistance when it is stretched. This elastic property of the Thera-band with Y = 2.75MPa makes it a good choice to store the required energy for launching an arrow.

When the motor drives the sector gear along the rack, it pulls the Thera-band, thereby storing potential energy in the band. This stored energy is released when the gear reaches its slip point. Thus, providing enough energy to launch the arrow through the guide. To achieve the required launching speed of the arrow, the band has to be stretched to a specified distance. This is done using a sector gear with teeth present along 240mm of its circumference. This ensures that the band is stretched only up to a distance till the sector gear reaches its slip point.

Fig. 2.5
Throwing Mechanism



To land the arrow in the desired pot, Image processing is implemented and the pot is detected using the color detection algorithm on the image captured by the camera, while the accurate distance to the pot is determined using a LiDAR sensor. A laser pointer is used to estimate the exact incidence of LiDAR on the pot for the operator's assistance. The launching velocity of the arrow is calculated using the elasticity equations of the Thera-band.

Considering Y= 2.75 MPa

A= (6) x (0.63×10^{-3}) x(30×10^{-3}) m^2

∵The system has 6 Thera-Band layers

$\Delta l = 0.237\ m,\ l_i = 0.35\ m,$

$$v = \sqrt{\frac{Y.A.\Delta l^2}{l_i.m}}$$

$$\Rightarrow v = 9.6 m/s \simeq 10 m/s$$

Where Y= Young's modulus,
A=cross sectional area,
Δl= change in length,
l_i= length of Thera-band,
m=mass.

From the Elasticity equations $u = 10 m/s$

$$x = u\cos\theta.t \quad \Rightarrow \quad t = \frac{x}{(u\cos\theta)}$$

$$y - y_0 = u\sin\theta.t - \frac{1}{2}gt^2$$

$$\Rightarrow y - y_0 = u\sin\theta.\frac{x}{(u\cos\theta)} - \frac{1}{2}g\left(\frac{x}{u\cos\theta}\right)^2$$

Once the velocity is determined, the launching angle (pitch) is evaluated using the projectile equations as illustrated in the calculations. This ensures that the landing angle (θ) is maintained around $45° \pm 10°$ for all pots considering horizontal range (x) to be achieved by the arrow's projectile and height of the pot (y)

$$\Rightarrow y - y_0 = usin\theta . \frac{x}{(ucos\theta)} - \frac{1}{2} g \left(\frac{x}{ucos\theta} \right)^2$$

$$\Rightarrow y - y_0 = x.tan\theta - \frac{1}{2} g \left(\frac{x}{ucos\theta} \right)^2$$

$$\theta = \frac{tan^{-1}\left(\frac{y - y_0}{x} \right) + sin^{-1}\left(\frac{gx^2 + (y - y_0)v^2}{v^2\sqrt{x^2 + (y - y_0)^2}} \right)}{2}$$

Where θ = Launching Angle,
y=height of the destination pot,
y_0= launching height,
g= acceleration due to gravity,
x=Horizontal Range
t= time of flight,
v = launching velocity

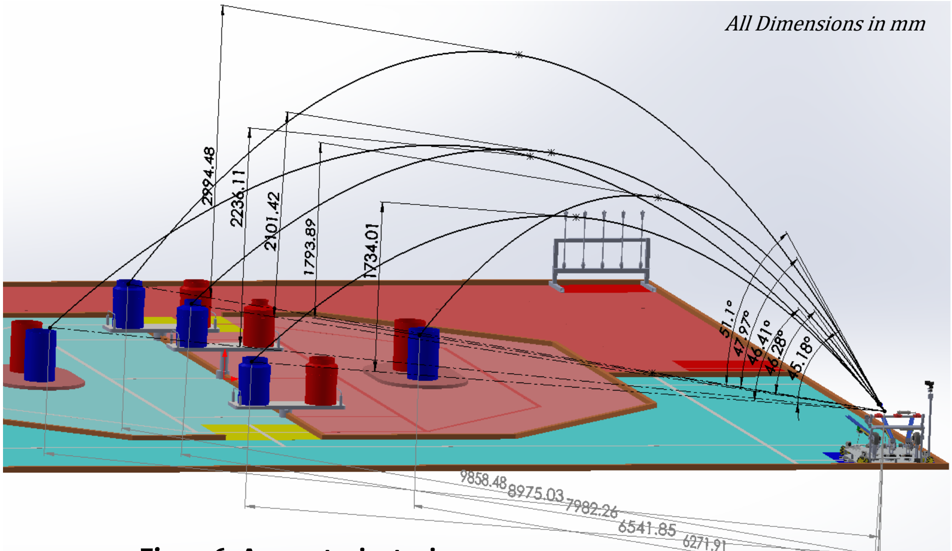


Fig. 2.6 Arrow trajectories

In order to achieve faster twinning, 3 launchers on TR and 2 launchers on DR (for 2 preloaded arrows) are fabricated such that each launcher can throw an arrow in any of the pots, considering the point "Two robots can throw arrows into the same pot at the same time" mentioned in Q2.4-19 of the official FAQ dated 15/01/2021.

Table Pushing Mechanism and Arrow Interception Mechanism

Pushing/Turning: The table pushing mechanism has 2 forks that are driven by a worm gear motor over a curved track as shown in Fig. 2.7. Each holding fork is a 2-pronged structure that can hold a table's handle. They are designed in such a way that each of the forks can hold/move either type-II or type-III tables, placed at different heights. The mechanism moves on the curved track with the help of a timing pulley that is attached to the shaft of the worm geared motor and a timing belt that is fixed to the ends of the outer rail. The structure also has rollers on its base to support its movement over the track. The setup holds the table's handle in such a way that when the pulley rotates, the entire mechanism slides over the curved track and moves the table accordingly. To align the DR with the table before pushing, a line following sensor (LSA -08) and 2 rollers on the side of the DR are used. These rollers are connected to a common piston such that on extension the rollers touch the baffle under the table for support.

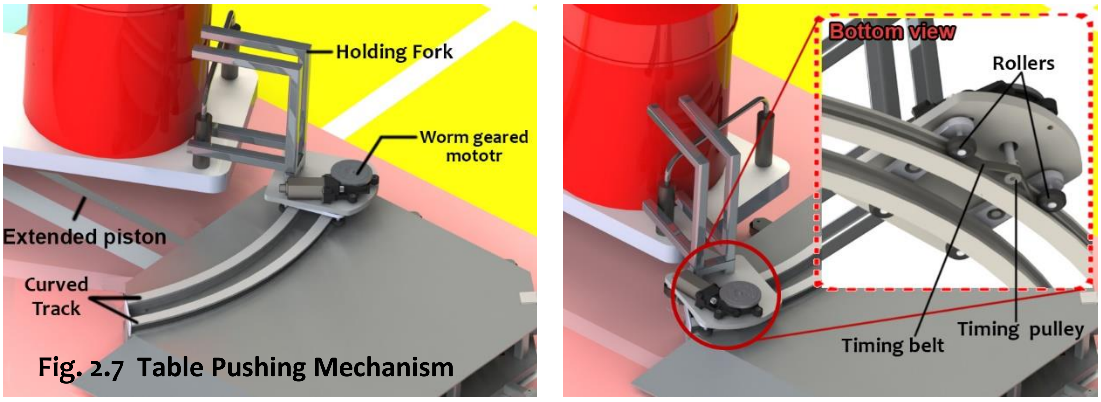


Fig. 2.7 Table Pushing Mechanism

Interception: The arrow interception mechanism uses the same robotic arm that was used to pick and pass arrows to the TR. The arm is fixed on the DR chassis in such a way that it can pick an arrow from the ground and also intercept the opponent's incoming arrows. To achieve this, the arm holds an arrow in the "V" notch of the claw, which has friction padding that ensures that the arrow doesn't slip out from its grip. By

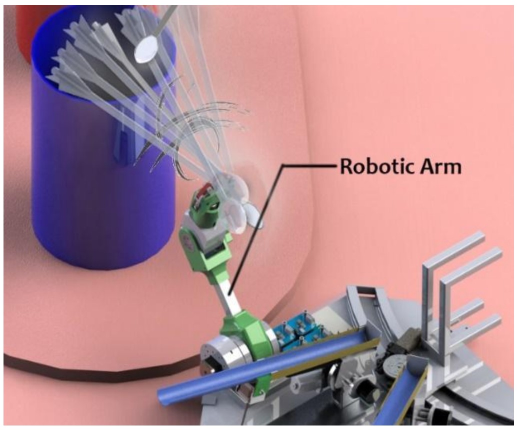


Fig. 2.8 Arrow Interception

rotating the end joint of the arm, the arrow held by the claw can be waved, thereby intercepting the opponent's arrow. The maximum height up to which the end effector with an arrow in its claw can reach is 800mm, which is enough to deflect any arrow coming in the proximity of the pot as shown in Fig. 2.8.

The Robotic arm is chosen so that the DR can perform multiple tasks like picking, passing, and intercepting arrows using one mechanism, making it less complex and reducing the hardware on the robot. The arm is programmed such that it can reach the predefined position with its orientation vector, making it semi-autonomous.

List of Actuators and sensors integrated for TR and DR:

Actuators used:

S.No.	Component	Specifications	Required Power	Usage
1.	Planetary geared motor	350 RPM, 24V DC, 8kg-cm (stall torque), 84W (Rated power)	38W	**Locomotion (TR & DR):** 4 motors attached to the wheels of each robot
2.	Worm Geared (Power Window) motor	100RPM 12VDC, 2.9N-m (Stall Torque), 180W (Rated Power)	48W	**Table pushing (DR):** To actuate the holding fork **Throwing (TR & DR):** To control the rotation of sector gear on each launcher
3.	Stepper Motor (Nema-17)	1.2A/Phase (Supply Current), 5.5N-m (Holding Torque), 14.4W /Phase (Rated Power)	8.4 W/Phase	**Throwing (TR & DR):** 2 steppers to adjust yaw and pitch of each launcher. A stepper to adjust LiDAR and laser on each robot **Arrow Interception (DR):** To actuate the base joint of the robotic arm **Arrow picking and receiving (TR):** 2 steppers for angular displacement of the grabber
4.	Servo Motor MG996R	5V DC, 10kg-cm (Stall Torque)	10W	**Arrow picking and passing (DR):** 3 servo motors to manipulate the joints of the robotic arm **Arrow picking and receiving (TR):** To rotate the pivot joint
5.	Pneumatic Piston with solenoid	12V DC, 25mm,200mm & 420mm stroke length	1.2 W	**Picking & Receiving (TR):** One to control the grabber clips and another one to slide the grabber to align it with the furthermost arrow on the rack **Table Pushing (DR):** To extend the rollers before pushing the table

Sensors used:

S. No	Component	Specifications	Usage
1.	Optical Rotary Encoder	Incremental type, 5-24V DC, PPR=360, CPR=1440	**Locomotion (TR & DR):** Attached to all 4 wheels of both the robots to estimate their position & orientation **Throwing (TR & DR):** Providing feedback to the worm gear motor of each launcher
2.	IMU MPU-6050	3-axis gyroscope and accelerometer	**Locomotion (TR & DR):** To estimate the orientation, acceleration & velocity of robot
3.	Magnetic Rotary encoder	12 Bit Precision, 3.3V DC, CPR=4096	**Throwing (TR & DR):** To ensure that the control angles of launchers are maintained (2 are used, for yaw & pitch)
4.	TF mini-LiDAR	4.5-6V DC, Range is 0.3-12 meters	**Throwing (TR & DR):** To determine the accurate distance between the robot and the pot
5.	Camera	5VDC, 60fps, 78°FoV	**Throwing (TR & DR):** Placed on each robot for pot detection
6.	LSA-08	12V DC, 26mA Array of 8 IR Frequency 200Hz	**Table Pushing (DR):** To align DR before pushing the table