DESIGN DETAILS DOCUMENT | Robocon India 2021

SPCE ROBOCON | Sardar Patel College of Engineering, Mumbai

1. Introduction & Purpose

Team SPCE Robocon has been participating in Robocon India since 2010. The team secured 9th rank in 2020.

The report highlights the fabrication process of the two robots in compliance with the guidelines mentioned in the rulebook and design goals set by our team for each robot.

We have utilized the following softwares to develop a technically sound design: CATIA V5®, SOLIDWORKS®, ANSYS®, ADAMS® and EAGLE®.

2. Defending Robot (DR)

2.1. Design Goals

2.1.1. Compact: Chassis within 800x800mm

2.1.2. Repeatability & Accuracy of Mechanisms: Greater than 97%

2.1.3. Holds multiple arrows

2.2. Chassis Design

(*l*×*b*×*h*: 700×600×890 mm; Weight 11 kg)

AISI 1018 Mild Steel (MS) square sections (*0.5"×0.5"×1.2mm*) are welded using argon welding to form the chassis. MS was selected over Aluminium due to greater flexural strength. Medium Density Fiberboard (MDF) fixtures are manufactured by laser cutting to ensure that the chassis rods are welded in the same plane and there is no thermal deformation of rods while welding. Chassis links are positioned in compliance with maximum deformation (*0.0743mm*) data, as obtained on ANSYS® - shown in Fig. 2.2.

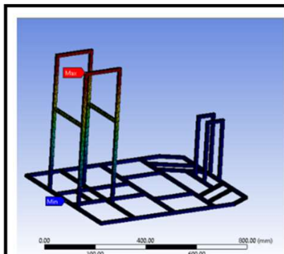


Fig 2.2.

2.3. Locomotion & Drive

DC geared planetary motors of 750 RPM are used to drive three bidirectional omni wheels. *(Bearing type, ϕ100 mm).* Three-wheel holonomic drive is preferred over a four-wheel drive, considering the reduced weight of the robot and lower capital requirements. Additionally, as three points define a plane, a three wheeled robot also ensures contact with the ground at all times, providing greater stability. Couplers are used for transmission of motor power to the wheels. A unibody aluminium coupler fails due to abrasive wear, if coupled to the motor shaft and thus motor couplers are made in two parts. D-slotted MS coupler press fits (*Ø10H7p6*) in D-shaped motor shaft and aluminium flange supports the wheel. Three cast nylon mounts (manufactured via waterjet machining & milling) are used to avoid cantilever loading on motor mounts.

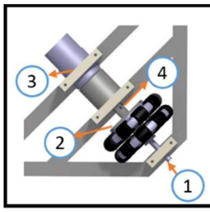


Fig.2.3.	
1	Aluminium coupler
2	MS coupler
3	Cast nylon mounts
4	Indent ϕ3

2.4. Picking Arrows from the ground

2.4.1. Picking Mechanism

This mechanism aims at picking arrows from the ground in the inner area and throwing them or transferring them to the TR according to the match situation. The assembly consists of two aluminium rods bolted at 150° with respect to each other. This ensures that Arm1 remains parallel to the ground, when engaged in picking the arrows.

A servo motor [10kg-cm, 0.6A] is mounted atop Arm 1. It is used to actuate an L-shaped aluminium strip, which is directly coupled to it. Two aluminium strips are attached to the bottom surface of Arm 1, stretched outwards and remain fixed. A DC motor [30 RPM,12V] is attached to Arm 2 via an aluminium shaft. The shaft is coupled to the motor by an aluminium coupler. A cast nylon mount is used to support the shaft.

The aluminium strips [Part 5 of Fig 2.4.1] attached to the end of Arm 1 slide under the gap between the body of the arrow and the ground when the said arrow lies flat on it. Once a sufficient fraction of the strips has passed through the gap, the servo motor is actuated. This enables the L shaped strip attached to it, to clamp the arrow. After the arrows are gripped, the DC motor is actuated. The assembly rotates about the shaft for close to 120° with respect to the horizontal. At this position the servo motor is actuated in the opposite direction such that it unclamps the arrows. The angle of rotation is kept such that the arrow sets in a correct position for a successful loading on the cartridge mentioned in Section 2.4.2.

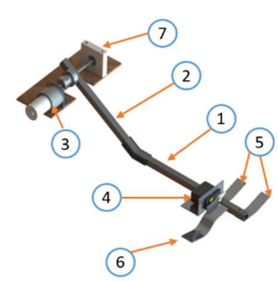


Fig.2.4.1.	
1	Arm 1
2	Arm 2
3	Motor
4	Servo Motor
5	Aluminium Strips
6	L Shaped Strip
7	Cast Nylon Mount

2.4.2. Loading Mechanism

The mechanism aims at collecting multiple arrows and throwing them using the throwing mechanism mentioned in section 2.6. The purpose is to save time of locomotion of the robot for throwing each arrow from the outer area after collecting it from the ground in the inner area.

Storage of 4 arrows is carried out through the use of a cartridge, shown in Fig 2.4.2. Arrows are held vertically in the notches made in the two parallel aluminium discs. The structure has one rotational degree of freedom about the axis of symmetry, powered by a stepper motor [NEMA 23,16.9 kg-cm]. Arrows are rotated into position and pushed off using an overhead mechanism consisting of an aluminium strip "finger" coupled to a servo motor [10 kg-cm,0.6A]. The motor is actuated once an arrow is in position and the finger then pushes against the head, causing the arrow to slide off the cartridge and into the notched aluminium plate of the throwing mechanism.

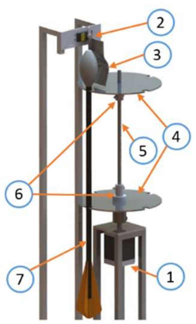


Fig.2.4.2.	
1	Stepper Motor [NEMA 23]
2	Servo Motor
3	Finger
4	Slotted Circular Plates
5	Aluminium Rod
6	Coupler
7	Arrow

2.5. Passing of Arrows

The passing of arrows from the Defending Robot (DR) to the Throwing robot (TR) is done using the claw which is used for picking the arrows from the ground [Section 2.4.1]. The assembly is rotated so as to transfer the arrow to a position appropriate for being accepted by the claw mechanism on the TR [Section 3.4]

2.6. Throwing the Arrows

2.6.1. Throwing

Mechanism used to achieve optimal projection of the arrow utilises the rotational kinetic energy imparted to it through an extended Mild Steel arm directly coupled to two DC Motors [300 RPM,12V]. The indicated motion is produced by actuating the motors that induce rapid angular acceleration in the arm. At one end of the arm is a slotted aluminium plate for notching the arrow, from which it is subsequently released. The opposite end of the Mild Steel arm is supplemented by a counterweight to cancel the equilibrium torque generated by the weight of the arrow and arm. This reduces the torque requirement for swinging, down to only the amount needed for achieving an appropriate angular acceleration.

Owing to the simplicity and the small number of moving parts in the mechanism, losses are kept to a minimum. Accuracy obtained is high since the trajectory is dependent only on the start and end position of the arrow and arm, and the motor RPM, all of which can be controlled accurately. With mild steel as the material of choice, deformation is kept to a minimum even under fatigue loading.

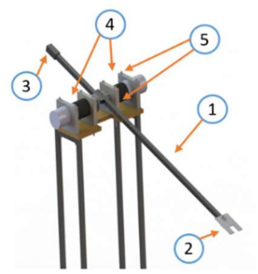


Fig.2.6.1.	
1	Mild Steel Arm
2	Slotted Aluminium Plate
3	Counterweight
4	Motors
5	Cast Nylon Mounts

2.6.2. Calculations for motor specifications

To find minimum required motor specifications:

All dimensions in SI Units

Equation of trajectory is:

$$y = x\tan\theta - \frac{gx^2}{2u^2}(1 + \tan^2\theta)$$

where,
θ = Launch Angle of Projectile = 60° *(verified using ADAMS®)*
u = Launch Velocity = To be determined
g = Gravitational Acceleration = 9.81 m/s^2
y, x = Coordinates in the Plane of Trajectory

Setting origin of 2-D coordinate plane at launch point with vertical Y axis, trajectory must pass through **(5, -0.073)** to successfully enter the pot.

Using these values,
u = 7.5 m/s **(Launch Velocity)**

Corresponding angular velocity of arm at launch is
$\omega = \frac{u}{R}$ where, R = length of swinging Arm = 0.52m

Thus,
ω = 14.7 rad/s **(Angular Velocity of Arm at Launch)**

Required motor RPM (min.) is given by

$\frac{\omega \times 60}{2\pi} = 140$ **(Min. RPM required for Motor)**
Now,

ϕ = Angle swept through Arm swing = 75° *(obtained experimentally)*
ω_i = Initial angular velocity of Arm = 0 rad/s
α = Min. required angular acceleration of Arm = To be determined
I = Moment of inertia of Arm & Arrow = 0.0312 kg-m^2

Assuming constant torque from motor and hence constant angular acceleration,

$$\omega^2 - \omega_i^2 = 2\phi\alpha, \ \boldsymbol{\tau} = \mathbf{I} \times \boldsymbol{\alpha}$$

Using the values,
α = 82.6 rad/s^2 **(Min. Angular Acceleration of Arm)**

τ = 4 N-m **(Min. Required Motor Torque)**

Ultimately two motors have been used on each arm with a torque of 2.9N-m, and RPM = 300.

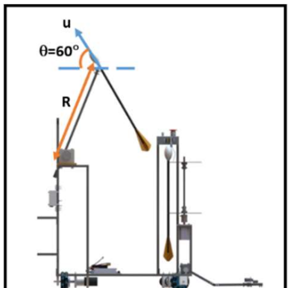


Fig 2.6.2.

2.6.3. Validation using ADAMS®

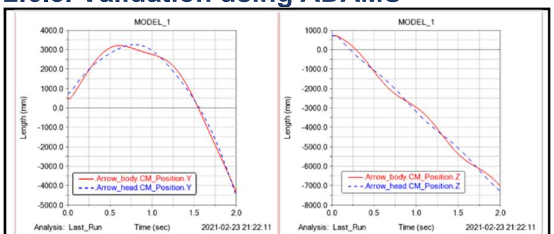


Fig 2.6.3.1 (a) Fig 2.6.3.1 (b)

Fig 2.6.3.1 Shows graphs of Y and Z positions v/s Time. Arrow trajectory lies in the YZ Plane with Y axis vertical. Thus, it can be seen that at t=1.5 sec in Graph(a) Arrow height is the same as that of Pot. At the same time Z position is 5 m, verifying range values.

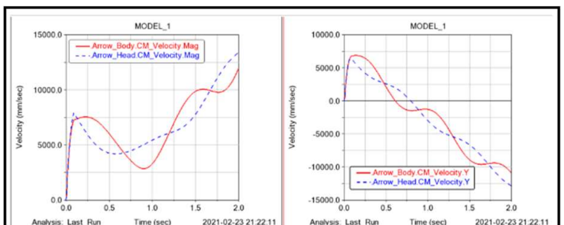


Fig 2.6.3.2 (a) Fig 2.6.3.2 (b)

Fig 2.6.3.2 Shows graphs of Velocity in Y direction and Total Magnitude of Velocity of Arrow v/s Time. At the moment of launch, i.e., at Vel. (Max), Launch Angle is given by 90 - $\cos^{-1}(v_y/|v|)$ = 90 - $\cos^{-1}(6.4/7.5)$ = 58.6° Hence, Launch Angle is verified.

2.6.4. Sensors

Camera (Logitech C270 HD Webcam) & LIDAR (TFMini) sensors are mounted on the vertical links of the robots to predict the distance between the target (pots) and the robot. Red **Lasers** (Class 1) are used to distinguish the target from the surroundings.

Special Feature

2.6.5. Image Processing

Image Processing Techniques are used for the purpose of identifying throwing target (Pot) and then gauging the distance between the Robot and the Pot for high accuracy of arrow trajectory. A two-camera setup is used with a laser pointer in between.

The said laser pointer produces a bright spot on the targeted pot which is identified in both images and the coordinates of its centre in the image are extracted. [Fig 2.6.5]

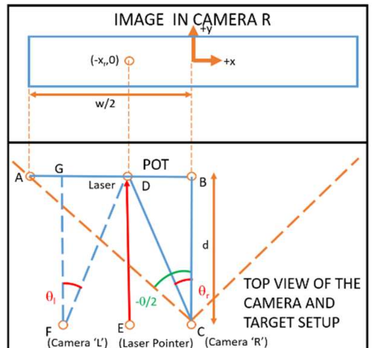


Fig 2.6.5

Then,

$$\frac{x_r}{\left(\frac{w}{2}\right)} = \frac{DB}{AB} = \frac{tan(\theta_r)}{tan(\frac{\theta}{2})}$$

where,
θ represents the wide angle of the lens
w is the pixel width of the image
x is the pixel coordinate of the laser image
Subscripts **'l'** and **'r'** denote corresponding values of the left and right cameras respectively.

The above formula can be used to find the angle subtended between the normal to the camera and the line joining the center of the camera to the pot, θ_r and θ_l for the right and left camera respectively.

$$tan(\theta_r) = \frac{2x_r}{w} \times tan(\frac{\theta}{2}),\ tan(\theta_l) = \frac{2x_l}{w} \times tan(\frac{\theta}{2})$$

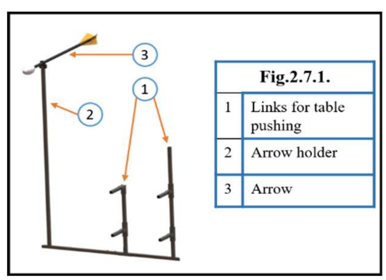
Finally, distance to the pot is

$$FG = \frac{CF}{(tan(\theta_r) + tan(\theta_l))}$$

2.7. Table Pushing & Arrow Interception

2.7.1. Table Pushing

Table pushing is done using aluminium links fixed to the chassis. [Fig 2.7.1] These links are inserted in the gap between the table handle and the pot table after which the robot is rotated, thus rotating the links along with it. The links serve the purpose of either rotating the table or holding the Pot Table at any desired position, as the situation demands.



2.7.2. Arrow Interception

The mechanism used for deflecting approaching arrows utilizes a preloaded arrow (loaded in setting time), horizontally fixed to a rigid link at the top of the robot. [Fig 2.7.1] This arrow is spun around to bat away any approaching arrows en route into the pots. The arrow holder is a custom made aluminium piece, to perfectly hold the arrow body without damaging or losing grip over it.

3. Throwing Robot (TR)

3.1. Design Goals

3.1.1. Precise Maneuvering.
3.1.2. Repeatability and Accuracy of Mechanisms: Greater than 97%
3.1.3. Stores multiple arrows in minimum time.

3.2. Chassis Design

(*l*×*b*×*h*: 826×608×567 mm, Weight 15 kg)

Similar to DR, AISI 1018 MS square sections (*0.5” ×0.5” ×1.2mm*) were welded using argon welding to form a rectangular chassis. Medium Density Fiberboard (MDF) fixtures were used in the welding of the Throwing Robot chassis. This ensures the chassis rods are welded in the same plane and that there is no thermal deformation. Position of chassis links and trusses was finalized based on the maximum deformation (*0.2265 mm*) data obtained from analysis on ANSYS® as shown in Fig. 3.2.

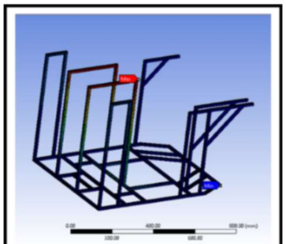


Fig 3.2.

3.3. Locomotion & Drive

DC geared planetary motors of 300 RPM are used to drive three bidirectional omni wheels. *(bearing type, ϕ100 mm)*. A lower RPM motor was chosen to achieve greater precision in minor adjustments made during pre-throw positioning. The locomotion & drive characteristics of the TR are similar to that of the DR, since size and shape of the chassis have also remained similar. Hence, three-wheel holonomic drive is preferred over a four-wheel drive. Coupler specifications and mounting for the wheels are as described in Section 2.3.

3.4. Picking Arrows from the Rack

The mechanism to pick arrows from the rack is designed to pick 3 arrows at once. This ensures saving of time without taking up excessive space on the chassis in line with the Design Goals. The mechanism consists of 3 claws, which spatially complement the throwing mechanism [Section 3.5.]. Each claw consists of two fixed aluminium rods and a bent movable aluminium strip coupled to a servo motor [10 kg-cm,0.6A], acting as the “arms”. The movement of the movable arms is independent of each other. All arms have a rubber bat grip attached to its front end to ensure firm grip on the arrows. Cast Nylon Mounts provide support to the mechanism at appropriate places.

Once the arrows are grabbed, the mechanism is rotated 180° in the anticlockwise direction when seen from the left according to Fig 3.4.1. The rotation allows the arrows to attain their starting position before being thrown [Section 3.5.]. A stepper motor [NEMA23; 16.9 Kg.cm] is used for the said rotation. Stepper motors provide high torque for rotation, and accurate amount of rotation according to the requirements. The mechanism has only two degrees of freedom which reduces the variability in operation and ensures repeatability. In order to account for the radius of rotation of the arrows, the throwing arm is first raised and later lowered to notch the arrow.

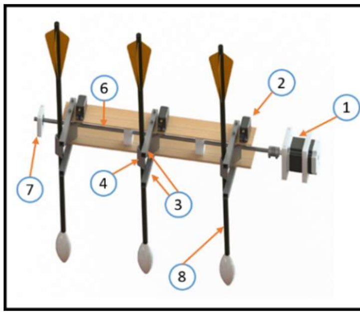


Fig.3.4.1.	
1	Stepper Motor [NEMA 23]
2	Servo Motor
3	Fixed Arm
4	Movable Arm
5	Wooden Base Plate
6	Mild Steel Shaft
7	Cast Nylon Mount
8	Arrow

3.5. Throwing the Arrows

This mechanism is similar to the one discussed in Section 2.6. The TR uses 3 rotating arms which lie parallel to each other. The mechanism complements the 3 claws which are designed to pick the arrows from the rack. Each arm is coupled to two motors of 300 RPM. Having two motors ensures that the required range is achieved, while also satisfying the torque requirements. Using separate motors for each arm ensures that the arrows can be thrown one at a time.

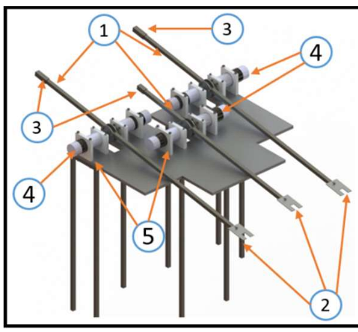


Fig.3.5.1.	
1	Mild Steel Arms
2	Slotted Aluminium Plate
3	Counterweight
4	Motors
5	Cast Nylon Mounts

3.5.1. Calculations for motor specifications

The calculations for motor specifications are similar to those mentioned in Section 2.6.1. with the exception of the swinging arm length **R = 0.44 m and 0.60 m** for the central arm and the edge arms respectively [Fig 3.5.1] Similarly, setting origin of the 2-D coordinate plane at the launch point with vertical Y axis, trajectory must pass through **(5, 0.02) and (5, -0.12)** respectively to successfully enter the pot.

Using these values,
u = 7.52 m/s for Central Arm
u = 7.5 m/s for Other Two Arms

Therefore, Required Angular Velocity of Arms is
ω_i = 17.1 rad/s for Central Arm
ω_i = 12.5 rad/s for Other Two Arms

Corresponding Min. Motor RPMs are given by

$$\frac{\omega \times 60}{2\pi}$$

Min. Required RPM = 164 for Central Arm
Min. Required RPM = 120 for Other Two Arms

α = 111.7 rad/s^2 for Central Arm
α = 60 rad/s^2 for Other Two Arms

Since, Moments of Inertias of the Arrow and Arms are given by
I = 0.0372 kgm^2 for Central Arm
I = 0.0738 kgm^2 for Other Two Arms

Required Motor Torques are
τ = 4.2 N-m for Central Arm
τ = 4.4 N-m for Other Two Arms
Ultimately two motors have been used on each arm with a torque of 2.9 N-m, and RPM = 300 to account for losses.

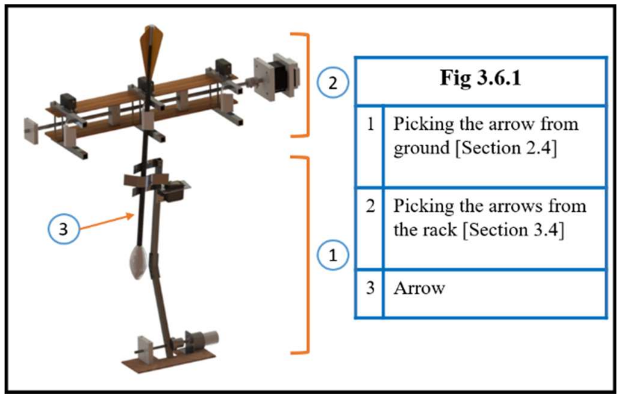
3.5.2. Sensors

Refer Section 2.6.4.

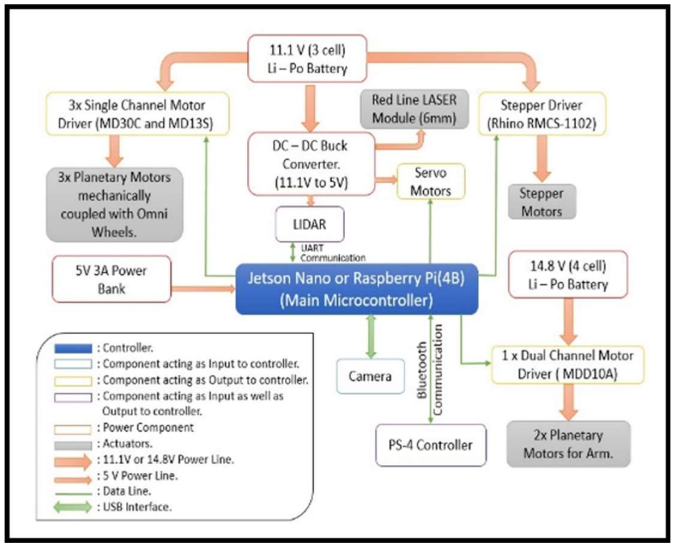
3.6. Receiving the Arrows

The receiving of arrows from DR is completed by the claw used to pick up the arrows from the rack. The design of the mechanism is discussed in Section 3.4.
The claw on the DR [Section2.4.] holds the arrow at an angle suitable for gripping by the TR claw in a head downwards position. This ensures the correct starting position of the arrow, for throwing by the TR.

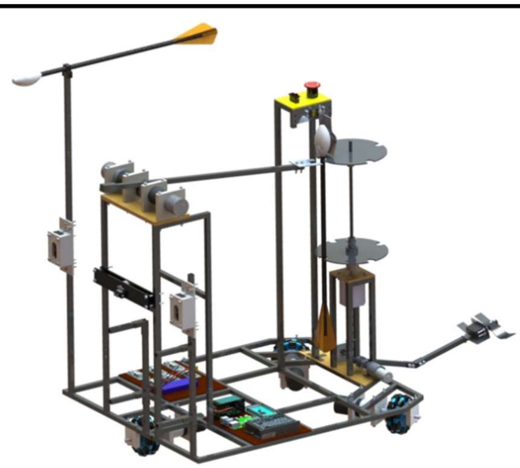
The claw on the DR [Section2.4.] holds the arrow at an angle suitable for gripping by the TR claw in a head downwards position. This ensures the correct starting position of the arrow, for throwing by the TR.

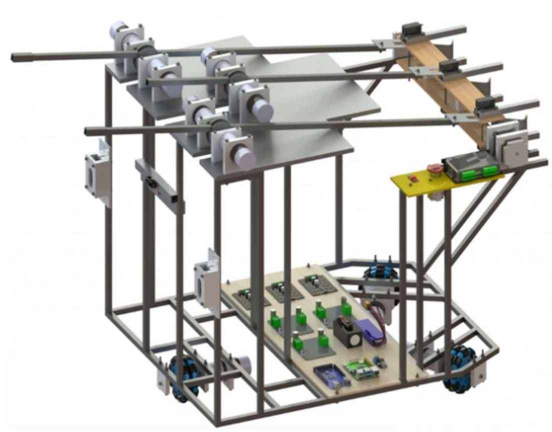


4. Power Flow (DR & TR)



Computer Aided Rendered Models


Defending Robot (DR)


Throwing Robot (TR)