Design Report

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ABSTRACT

This year's Robocon problem statement required us to build two Robots, with freedom to choose either an autonomous or a completely manual setup for both; the Passing Robot (PR) and the Try Robot (TR).
Both the bots are completely manually controlled using handheld controllers, which use WiFi IEEE802.11 protocol for wireless communication with the bot. PR carries a servo-motor based gripper to latch onto a rugby ball on the "try ball rack" and places it on a conveyor belt which guides the ball to two high RPM motors, with balloon tyres to provide appropriate restitution and launch the ball towards the TR. The TR catches the ball using a shock-absorbing net and the ball rolls down into a cavity. A DC motor actuated gripper holds the ball until the first try is executed in one of the "try zones". The final kick is also executed by the TR in order to divide the complexity among the two bots. This allows the PR, which already has a complex conveyor mechanism, to have a lighter weight. The TR executes the kick from various distances from the "conversion post", using an electrically actuated pneumatic piston.

Key words. Passing Robot (PR) Try Robot (TR) Try Ball Rack Try Zones Conversion Spot Wireless Communication (IEEE802.11) Balloon Tires Conveyor Mechanism Pneumatic Piston

1. Try Robot Specification

1.1. Dimensions

The overall dimensions of TR are 950mm x 930mm x 1300mm.

1.2. Weight

The estimated weight of TR is 25 kg.

1.3. Material Selection

The chassis frame has been built using lightweight Aluminium 6061 Alloy, with welding as the primary manufacturing source.Because of the weight constraints and to minimize the load on the base motors this aluminium alloy proved to be the best alternative.

1.4. Drive Mechanism

A mecanum based four wheel drive is used for the base drive to provide maneuverability advantages, which helps in avoiding the obstacles in the kicking zone. Each wheel is attached to a Planetary geared motor, which provides a torque of 30 Kg-cm, which is enough to take the load of the entire bot while rotating at 600 RPM at 24 volts (DC). The motors are operated using Cytron MDD10A motor drivers which can handle peak currents up to 30A for a short duration and a constant current of 10A, while supporting 3.3V level logic signals given by the ARM micro-controller.

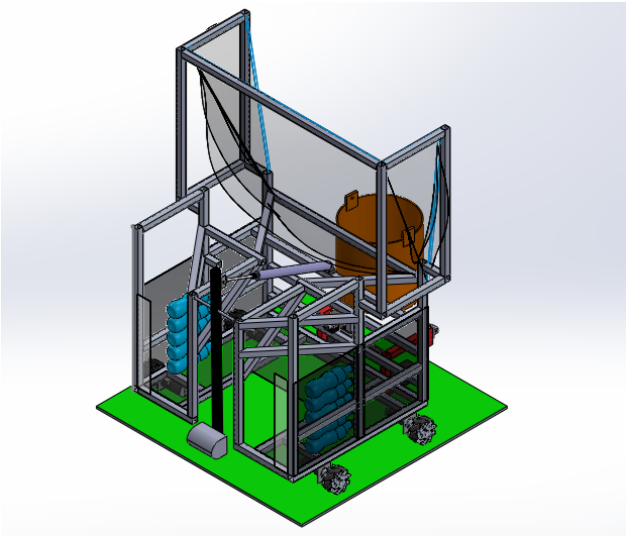

Fig. 1. CAD design for the Try robot - isometric view 1

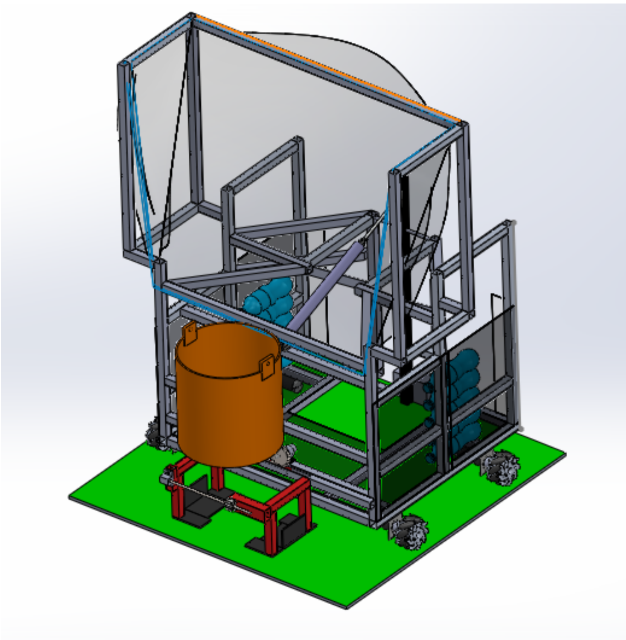

Fig. 2. CAD design for the Try robot - isometric view 2

1.5. Sensors and Actuators

The Electronic subsystems for the bot are divided into separate circuit boards in order to ensure a modular setup. To every dc motor on the base drive, there is an ACS712 Hall effect current sensor which monitors the magnitude of current being drawn by that motor at a given instant of time. The analog signal is given to the on-board ADC of the STM32f401RE micro-controller.
For our bots, we'll be using a battery management system module to streamline the process of managing and maintaining the source of power. We have created a web hook on our local servers with our BMS that constantly monitors power levels and usage which facilitates us to analyze performance and reliability under constant loads.
The web portal uses MQTT protocol over the local network to send data to and fro from STM with the NodeMCU to the Raspberry Pi. The portal also acts as a remote control center for our bot where we can fine tune parameters and functions without having to access the STM32F4 microcontroller directly. This enables us to have faster and more efficient fine-tuning and testing through an interactive interface. The portal allows configurations of motor speed, direction, gripper control tuning, actuation of pneumatic system, battery management and monitoring, etc For the kicking mechanism, we are using an electrically actuated pneumatic piston. A separate circuit board is in place with a two-channel 5V relay module which takes signals from the micro-controller to control direction control valves; which in turn actuate/retract the pneumatic piston.

1.6. Ball Receive Mechanism

The Rugby ball after being thrown from the PR is caught by the shock absorbing material on the TR. We have used a net for this purpose. The entire upper surface of the TR is covered with this material to maximize the catching area. From here, the ball falls into a cylindrical cavity which directs it to a gripper, the shape of which makes sure that the try ball stays in the gripper. The ball is thrown at an angle of 60°by the PR. The TR can catch the ball if it falls within the vertical range of 0.6m to 1.3m. Below we get the trajectory equation of the projectile.

$$x = x_0 + v_{0x}t + \frac{1}{2}xt^2 \tag{1}$$

$$y = y_0 + V_{0y}t + \frac{1}{2}gt^2 \tag{2}$$

$$y = 0.6 + V_0(\frac{\sqrt{3}}{2})t + \frac{1}{2}(-9.8)t^2 \tag{3}$$

From (1) we get,

$$t = \frac{x}{V_{0x}} = \frac{x}{V_0 cos(\theta)} = \frac{x}{V_0 cos(60)} = \frac{6}{V_0} \tag{4}$$

Substituting value of t in (1) and (3),
y=1.2m and x=0.6m.
We get velocity of rugby ball thrown by PR as 6.2m/s. We have balloon of radius 11.5cm; we conclude that we need 512 RPM motors for balloon tires.

1.7. Try Mechanism

A gripper actuated by a rack and pinion mechanism holds the try ball received from the catching mechanism. The shape of the gripper resembles a jaw to provide a firm grip on the Rugby ball. On reaching the try spot, the pinion is rotated by a DC motor rated at 100RPM, which opens the end effector. This makes the ball fall on the try spot. The sides of the gripper are made of ABS sheet for its light weight and flexibility. This mechanism for the gripper allows us to reinstate the try ball if accidentally it falls out of the try spot. The gripper also proves to be a backup mechanism if in case the pass execution between PR and TR fails and the Rugby ball falls somewhere else instead of the designated target on the TR.

1.8. Kicking mechanism

We use a pneumatic based hitting mechanism to hit the try ball from the kicking zone into the conversion post. A 32mm bore diameter, 300mm stroke length double acting pneumatic cylinder with a hitting arm connected to it is used for this mechanism. The arm is pivoted at a point 116mm from the piston. We use

Fig. 3. Ball recieve and try mechanism

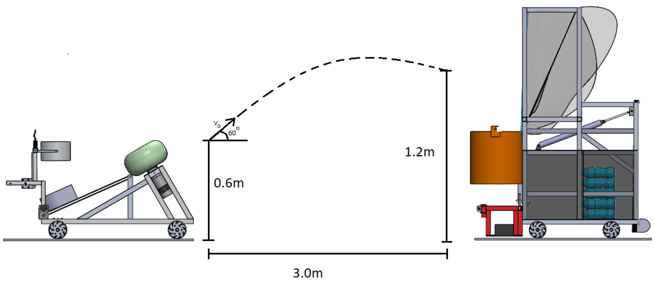

Fig. 4. Trajectory of ball pass and recieve mechanism

backwards stroke instead of forward because the air pressure acting on the piston covers more area in backward stroke than the forward one. As the pressure affected area is more in backward stroke the force generated will also be greater than the forward stroke as the force is directly related to the cross-sectional area. The pneumatic pistons are electrically controlled using 5V relay circuits for switching using signals from the micro-controller.
Using the law of conservation of linear momentum, where $e = 0.6$ is the coefficient of restitution

$$m_1 v_1 = e m_2 v_2 \tag{5}$$

where m_1 is the mass of the shooting leg
m_2 is the mass of the rugby ball.
Using Torque balance equation:

$$F_1 y = F_2 x \tag{6}$$

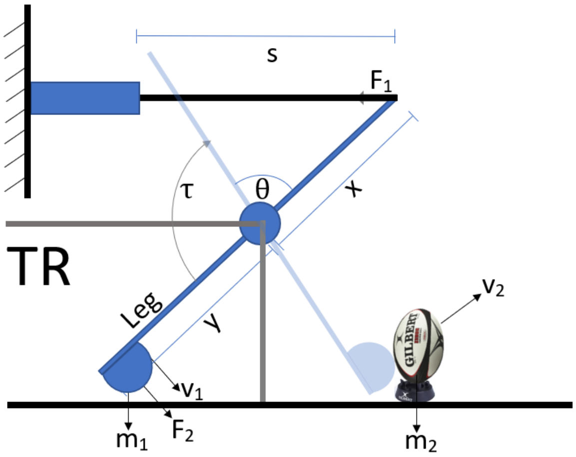

Fig. 5. Kicking mechanism on the try robot

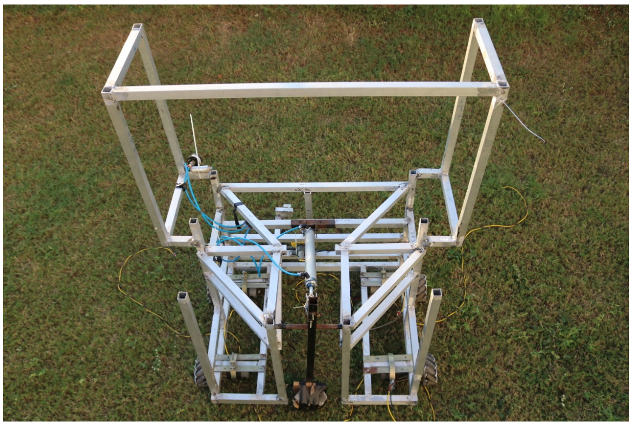

Fig. 6. Kicking mechanism on the try robot

$$v_1 = 6.7 m/s \tag{7}$$

where v_1 is the leg velocity. The value came with approximate mass of ball and leg.

Now,

$$s = r\theta \tag{8}$$

s is the stroke length of piston
Now by equating the torque we get

$$I\alpha = F_1 r \tag{9}$$

$$\alpha = \frac{600y}{\frac{m(x+y)^2}{3} + x^2 m} \tag{10}$$

x and y are the upper and lower leg lengths respectively
Now

$$v_2 = r\omega \tag{11}$$

Therefore

$$\omega = \frac{6.7}{y}\omega^2 = 2\alpha\theta \tag{12}$$

Therefore

$$\left(\frac{6.7}{y}\right)^2 = 2\frac{s}{x}\frac{600y}{\frac{m(x+y)^2}{3} + x^2 m} \tag{13}$$

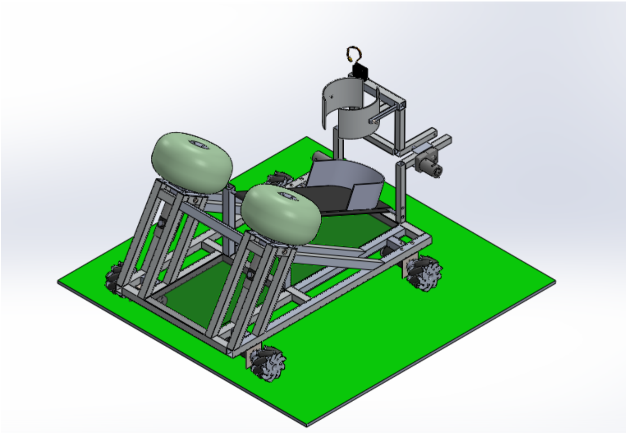

Fig. 7. CAD design for passing robot

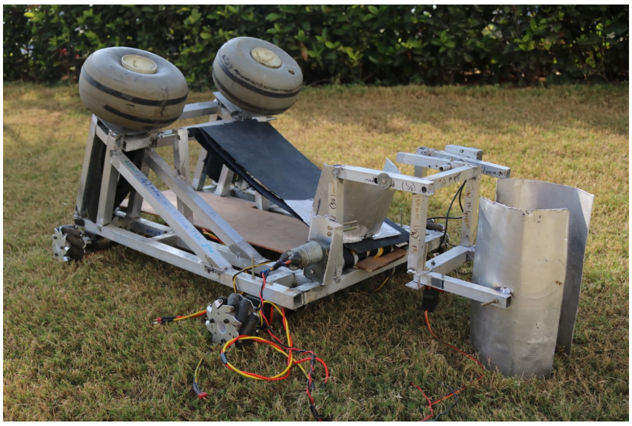

Fig. 8. Pick and place mechanism

For the required 600N force and 11m/s velocity of the ball, iteration of available stroke length and bore diameter has been done. Then for appropriate ratio of x and y, $s = 300mm$ and $d = 32mm$ was chosen.

2. Passing Robot

2.1. Dimensions

The overall dimensions of PR are 984mm x 636mm x 516mm.

2.2. Weight

The estimated weight of PR is 18 kg.

2.3. Drive Mechanism

The base of the Passing Robot also has a 4-wheel mecanum drive. This ensures that the bot can efficiently rotate about the centre of its frame as the axis of rotation to ensure quick pick and pass of the ball.

2.4. Ball pick and pass mechanism

PR starts from PR Start Zone with the start signal. It travels to the Try Ball Rack and grabs a single Try Ball using an adaptive curved shaped gripper which is actuated by a servo motor. After gripping the Try ball, the gripper system rotates using a Square gear motor by about 202°, such that the Try ball comes over the conveyor belt region. The gripper opens up, using the mentioned servo motor, and the Try ball drops down and gets placed on the belt. Another Square gear motor, attached to the shaft of the conveyor belt, rotates in order to make the belt move and the try ball is guided towards passing mechanism. In passing mechanism, there are two high RPM planetary DC motors and balloon tires attached to them. These motors are aligned at an angle of 60°. The mechanism is based on Pitching Machine which is a common sight during tennis practices. Its principle is that if two wheels are rotating in opposite directions then the object placed between the gap created by two wheels will be projected linearly with a velocity almost equal to the tangential velocity of the rollers.

PR Gripper Calculation:
Since both the surfaces of the end-effector are in contact with the ball, therefore friction acting on ball is two times as of friction on one surface:

$$f = 2\mu N \tag{14}$$

where f is the friction

$$f = mg \tag{15}$$

$$N = \frac{mg}{\mu} = \frac{(0.4)(9.8)}{0.86} = 4.55N \tag{16}$$

$$\tau = (4.55)(0.151) = 0.68705Nm \tag{17}$$

$$\tau = 7.0059kgcm \tag{18}$$

Minimum of 7kgcm Servo motor torque requirement
For the square gear motor, we have

$$r = 32.8cm \tag{19}$$

The standing torque τ, thus comes out to be equal to:

$$\tau = (1Kg)(9.8)(0.328) = 3.2144N - m = 32.077kgcm \tag{20}$$

A square geared motor of dynamic torque 32 kgcm is required
For $H = 0.6m$

$$H = \frac{v^2(sin\theta)^2}{2g} \tag{21}$$

Now for an angle of 60

$$v = 3.96m/s \approx 4m/s = r\omega \tag{22}$$

therefore

$$\omega = 34.78rad/s = 332.32rpm \tag{23}$$

Two approximately 500rpm High torque motor requirement

The conveyor belt is on a pinion of 40mm diameter and attached to a square geared motor; minimum of 0.25m/s belt speed required to feed it into rotating balloon tires in appropriate time.

1. radius of pinion: r
2. length of conveyor: L

Assuming a speed of 0.25m/s is required:

$$V = 0.25m/s = r\omega \tag{24}$$

$$w = \frac{0.25}{r} = 1.25rads^{-1} \tag{25}$$

$$RPM = 11.93rpm \approx 12rpm \tag{26}$$

Therefore 20RPM square geared motors have been chosen for this purpose

2.5. Sensors and Actuators

The Passing Robot, just like TR, consists of a custom battery management system and fault detection system for the base drive motor. A servo motor based end-effector grips the try ball firmly and a square gear high torque DC motor turns to place the ball on a conveyor belt, again driven by a square gear motor to guide it towards the passing mechanism.
ACS712 hall effect current sensors provide accurate real time values of current drawn by each motor.
The web portal which displays the vital signs of the bot in the TR is also implemented for the PR.

3. Breakthroughs and Forthcoming Tasks

3.1. Progress so far

1. Manufacturing of chassis has been completed
2. The Testing for the kicking mechanism has been successfully done. A range of 10m is achieved, which is same as the distance between k3 zone and the conversion spot.
3. PR's passing mechanism and TR's ball receive mechanism have been tested together with an efficiency of about 85%.
4. Base test with the WiFi controller has been tested with maneuverability testing with mecanum wheels.
5. All electrical subsystem have been tested. BMS with the real time fault analysis has also been implemented on local host.

3.2. Tasks to be implemented

1. The conveyor belt mechanism needs fine tuning
2. Base-drive motor speed mapping using rotary encoders needs to be implemented, to provide better control for the bots motion.
3. Finalized PCB boards have been designed and are under fabrication process