Design Detail Report

Team Phoenix

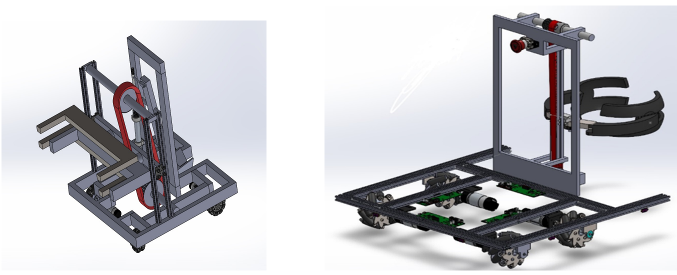
HARVEST DAY

College: *IIT PATNA*
Team Leader: *Panav Arpit Raaj*
E-mail: *panav_2101ee48@iitp.ac.in* | *Mobile:* *+91 9606158818*

I. INTRODUCTION

For this year's ABU Robocon Problem statement, we must build two robots:
Robot 1(R1) is either manual or automatic
Robot 2(R2) that must be automatic

We have ensured that the automatic bot will be simple and prioritize tasks in zone 3. The Manual Bot will focus on planting saplings and transferring the grain to the Storage Area (Zone 3). We have used reinforcement learning to ensure an optimal strategy and effective use of both bots.



(a) Manual Bot **(b) Automatic Bot**

Fig.1

II. STRATEGY

After completely analyzing the rule book of ABU ROBOCON '24, we came up with this strategy to maximize our chances of victory:

- The R1 and R2 will both start from the start zone.
- The R1 will first go to area 1 to pick and plant 2 saplings at a time.
- The R2 will go directly to area 3 to capture silos. First the R2 bot will scatter the paddy rice by ramming. This will reduce the probability of empty grain interfering in our picking mechanism.
- After planting the 6 saplings, the R1 will proceed to area 2. The R1 bot will prioritize transferring grains to supply the R2 bot with the paddy rice it needs to capture silos.
- After transferring 6 Grains, the R1 will move back to sapling area and repeat the 6 saplings, 6 grain transfer process
- Meanwhile the R2 bot will actively capture silos. To do this, it will use a Q- Table generated using Reinforcement Learning. This table holds a list of silo states and their corresponding Q value. In case the robot encounters a new state, it will use a priority list to decide its next action.

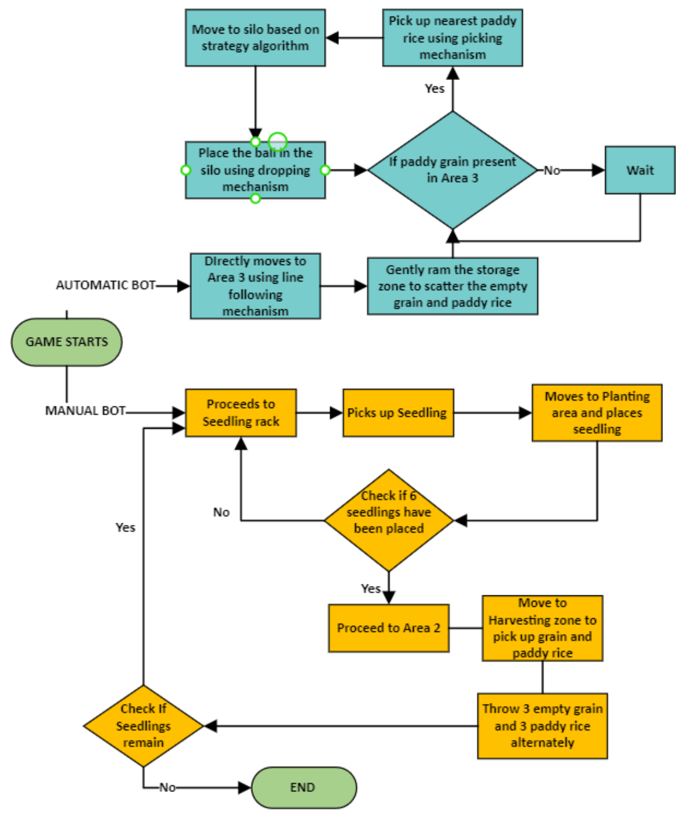


Fig 2. The Strategy Flowchart

III. DRIVE MECHANISM OF R1 AND R2

A. *Manual Bot (R1):*

Type of drive :
Four Wheel Holonomic Omni Drive

Overview of the drive :
These robots will have a parallel 4-wheel omni drive with size 60cm x 60cm. The frame is made of aluminum bars for strength and flexibility. It uses 100mm wheels controlled by 24V motors for movement in any direction. We are using an omni drive with a simpler version of X drive enhancing agility with bearings reinforced on ends for support.

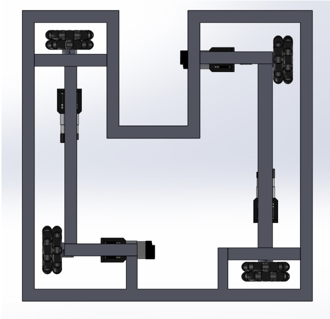


Fig 2.1 The Manual Bot Drive

B. *Automatic Bot (R2) :*

Type of drive :

Four Wheel Rectangular Mecanum Drive with X configuration

Overview of the drive :

These robots will have a parallel 4-wheel holonomic Mecanum drive with size 63cm x 60cm. The frame is made of aluminum extrusions for strength and flexibility in modifications. It uses 100mm diameter mecanum wheelscontrolled by 24V motors for movement in any direction. We are using a mecanum drive with an X configuration (rollers on wheels point towards center when seen from top) for better control

Fig 2.2 The Automatic Bot Drive

IV. MECHANISMS OF R1 AND R2

A. *Manual Robot (R1)*

1.1 Seedling Picking and Planting:

*a) **Description**:* Our robot – I is a manual bot is designed to pick up and place two saplings simultaneously. The sapling-picking mechanism consists of two claws controlled by a pneumatic actuator. A stepper powered belt-pulley mechanism will be used to lift both the saplings. The Stepper will be attached to a 20T pulley whereas the driven shaft will be attached to a 60T pulley for torque increase. Once the robot reaches the planting zone, we will bring back the two held saplings to ground level and release claws to place the sapling in the planting circle.

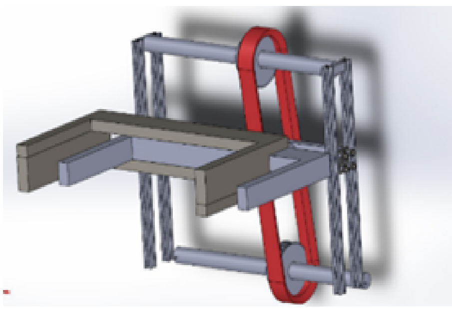
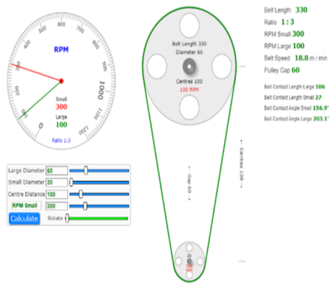


Fig 3: Throwing Mechanism of R1

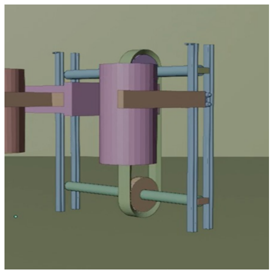
*b) **Possible Shortcomings:-**:* Saplings are placed 25 cm apart and need to be released 50 cm apart.

*c) **Solution:-** :* We will pick alternate saplings at 50 cm apart and drop them at 50 cm apart..

*d) **Simulations:-** :* We have simulated the movement of the picking mechanisms using pulley simulation tools and ROS.



(a) Fig.4 (a) A picture of the pulley simulation



(b) A picture of the entire mechanism being simulated

Fig.4

*e) **Calculations**:*

i. To pick seedling using pneumatic actuator

Mass of Seedling (m) = 335g + 5g
Weight of seedling (W) = 3.8 N
Radius of upper section of seedling (r) = 2.1 $\times 10^{-2}$ *m*
Radius of area of contact = a
Deformation = d
Elastic modulus of PVC (E_1) *= 3.4 GPa*
Elastic modulus of Silicone Rubber Foam (E_2) *= 3.95 MPa*
Poisson's Ratio of PVC (μ_1) *= 0.4*
Poisson's Ratio of Silicone Rubber Foam (μ_2) *= 0.48*
Force applied by claws on the seedling = F
Static friction between seedling and rubber foam = f

Now according to contact mechanics,

$$\mathrm{a} = \sqrt{r \times d}$$

$$\mathrm{F} = \frac{4}{3} \times E^* \times r^{\frac{1}{2}} \times d^{\frac{3}{2}}$$

$$\frac{1}{E^*} = \frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}$$

On Substitution,

$$E^* = 5.13 \times 10^6\, Pa$$
$$a = 1.45 \times 10^{-3} \times F^{\frac{1}{3}}\, m$$
$$A = 6.6 \times 10^{-6} \times F^{\frac{2}{3}}\, m^2$$

We know that F = P × A,

$$F = P \times 1.2 \times 10^{-5} \times F^{\frac{2}{3}}$$
$$F^{\frac{1}{3}} = P \times 1.2 \times 10^{-5}$$

Now, for claws to pick the seedling,

$$2 \times f \geq W$$
$$2 \times \mu \times F \geq W$$

On Substitution,

$$P \geq 2.2 \times 10^5\, Pa \tag{IV.1}$$

$$or,\, P \geq 32\, Psi \tag{IV.2}$$

Conclusion: From calculations, we found out that in order to lift the seedlings, our pneumatic actuator has to give a pressure of at least 32 psi

B. Torque required to lift mechanism

Mass of mechanism to be lifted = 900 gm
Radius = 0.01m
Gear Efficiency = 0.9
Converting mechanism mass to force using gravity,

$$F = 0.9\,kg \times 9.81\,m/s^2 \approx 8.83\,N \tag{IV.3}$$

Using Torque equation,

$$\tau = \frac{8.83N \times 0.01m}{0.9} \approx 0.098\,N-m = 9.8\,N-cm \tag{IV.4}$$

If we reduce this torque three times using pulley ratio we get,

$$\tau_2 = \frac{9.8}{3} = 3.267\,N-cm \tag{IV.5}$$

Using Pulley Ratio to meet the Torque Requirements :

$$\tau_{Large\,pulley} = r \times F = r_2 \times F = 3 \times 3.267 = 9.801\,N-cm \tag{IV.6}$$

$$\tau_{small\,pulley} = r \times F = r_1 \times F = 3.267\,N\text{–}cm \tag{IV.7}$$

1.1.4 Justification

*a)**Advantages:-***

- This mechanism allows us to pick more than one sapling at a given time
- The mechanism is simple and robust, and less prone to structural faults

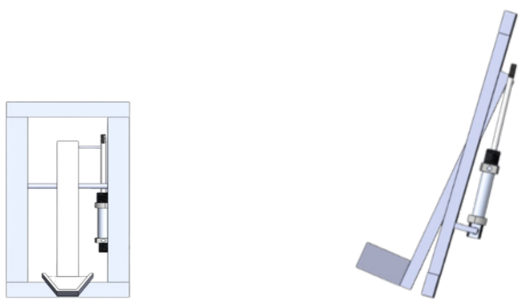
*b)**Possible Shortcomings:-***

- More torque is needed to lift both seedlings simultaneously
  - **Solved by using pulley ratio**
- The saplings get tilted very slightly, which may cause complications while picking and planting them.
  - **Solved using foam lining**

*1) **1.2 Paddy Rice and Empty Grain Picking and transfer to storage zone***

: **a) Description:-**Our manual robot will transfer the paddy rice and empty grain to storage zone by imparting it a projectile motion, this will be achieved using pneumatic actuators and a lever mechanism that provides a speed advantage, it has been tested physically and has achieved a range of 2.5 meters The end-effector is designed to lift the ball rather than kick it with only horizontal velocity at an angle of 36.8 degrees.

b) Calculations:-



(a) Front View **(b) Side View**

Fig.: Shooting Mechanism R1

A. To pick seedling using pneumatic actuator *One of the most important components of the manual bot is the shooting mechanism. The range our shooting mechanism must cover is 2.2 meters and the maximum height of the paddy rice can reach is 0.4 meters.*

Projectile Motion Equations:

$$Launch\ Angle\,(\theta)\ Calculation(\theta) := \frac{1}{2} * arcsin[\frac{(g*R)}{v^2}] \tag{IV.8}$$

Substituting the values to find the launch angle.

$$Maximum\ Height\,(H)\ Calculation:\ H = \frac{[v^2(sin\theta)^2]}{2g} \tag{IV.9}$$

- V: Initial Velocity (m/s)
- θ: Launch Angle (degrees)
- R: Desired Range (m)
- g: Acceleration due to gravity

Optimal Launch Configuration

- Launch Angle (θ): 36.027°
- Initial Velocity (V): 4.761 m/s (as calculated)
- Achieved Range (R): 2.2 m
- R: Desired Range (m)
- Height Clearance (H): 0.54m (as calculated)

c) Simulations

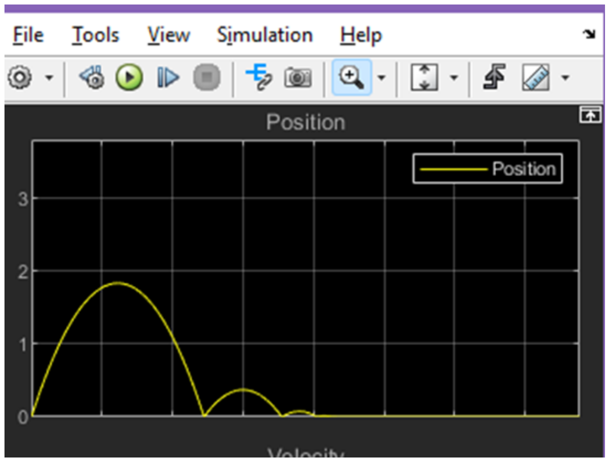


Fig 6 : Simulation of air resistance and coefficient of restitution in MATLAB

d) Justification

*a)**Advantages:-***

- Pneumatic systems draw comparatively less current and do not need a separate battery
- No need for a picking, and loading mechanism
- Pneumatic systems can generate enough force to project the paddy rice to the other side

*b)**Disadvantages:-***

- A separate canister of compressed air is required for the pneumatic system to operate, which occupies considerable space
  - **Solved by optimizing space usage and maximizing pressure.**

B. ***Automatic Robot (R2)***

Picking paddy rice and transferring to silos

*1) **Navigation**:* We will utilize the following subsystems to aid in autonomous navigation :

Subsystem	Sensors	Reference/ Reason
Cube Pilot Orange +	IMU x3, GPS x1	Can be used to setup waypoints with extreme precision
Odometry	Hall Effect Encoder x4	To use Speed PID on motors
Laser	Reflective Sensor x8	To localize Robot using Walls and obstacles on all sides
Line Following	LSA08 x4	Sensors on 4 sides to navigate maze
OpenCV	Pi Camera x2	To aid in Area 3 silo and picking operations

The cube orange autopilot will interface with raspberry Pi. It will be based on PX4 firmware and facilitate context-aware decision-making. The raspberry Pi will employ reinforcement learning in silo placing strategy. The fusion of image processing and inertial measurement sensors along with LSA08 on Arduino MEGA will help the automatic bot excel in complex scenarios.

Fig. : Cube Pilot Orange

2) ***Grain Picking and Silo Scoring***:

- The automatic robot will be equipped with a claw-like system on its body to facilitate the picking of paddy rice. This claw is powered by a motor to control its actions.
- This Claw will be attached to a belt-pulley mechanism which will lift the claw along with the paddy rice.

The claw will then release the paddy rice into the desired silo.

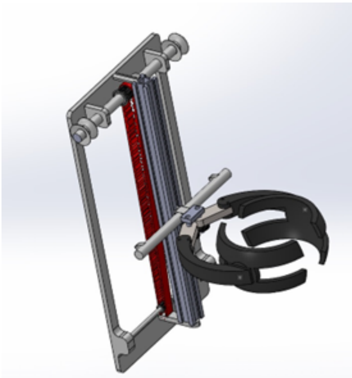


Fig. : Grain Picking

3) ***Mecanum Drive Simulation***: We defined an arbitrary path to generate PWM values for holonomic mecanum wheel steering in Matlab.

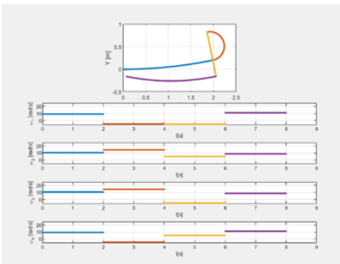


Fig. : Mecanum Drive Simulation

4) ***Calculations***:

i. Claw Mechanism

Torque output of motor (τ_1) = *3.6 N-cm*
Radius of larger gear (r_1) =
Radius of smaller gear (r_2) =
Efficiency of conversion (η) = *0.9*
Torque on smaller gear $(\tau_2) = \frac{r_1}{r_2} \times \tau_1 \times \eta$ = *6.48 N-cm*
Distance of point of contact from center of smaller gear (d) = 15 cm
Normal Force on the paddy rice (N) $= \frac{\tau_2}{d}$ = *0.432 N*
Coefficient of friction of paddy rice (μ) = *0.5*
Max weight which can be lifted $(W_{max}) = 2 \times \mu \times N$ = *0.432 N*
Weight of paddy rice (W) = 0.325 × (1 + 0.5) = 0.34125 N

Now, since W_{max} > W
Therefore, our mechanism can pick up the paddy rice.

ii. Ball and Pulley Mechanism

Weight of entire system (W) = 0.8 kg $\times 9.8\ m/s^2$ *= 7.84 N*
Radius of Pulley (r) = 1 cm
Torque Required $(\tau) = W \times r$ = *7.84 N-cm*
Using a pulley ratio of 60 Teeth : 16 Teeth
Pulley Ratio $= \frac{Diameter\ of\ Driven\ Pulley}{Diameter\ of\ Driving\ Pulley} = \frac{44mm}{15mm} \approx 3$

Required Torque $= \frac{7.84}{3}$ = *2.61 N-cm*

Hence our robot has a sufficiently powerful Nema-17 stepper motor which can apply the required torque (4.7 Kg-cm).

5) ***Justification***:

Advantages

- Since the claw is directly attached to the body without an arm mechanism, our inverse kinematics calculations become much simpler and less prone to malfunctioning.

Disadvantages

- Without an arm mechanism, the claw is very constrained, and the bot must be very precise while positioning itself.

V. OBJECT RECOGNITION ALGORITHMS

The program detects colored balls in video frames using a machine learning model, using Pytorch with OpenCV. It uses the HSV (Hue, Saturation and Value) color space for improved color thresholding in dynamic lighting. Adaptive thresholding mitigates noise in non-ideal conditions.

We have integrated pytorch with OpenCV, which will be used to differentiate between two separate overlapping paddy rice and increase the efficiency of our paddy rice selection algorithm. We will also utilize perspective transform to obtain a near overhead view of the balls, which will aid in inverse Kinematics.

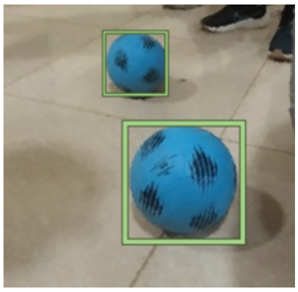


Fig. : OpenCV Paddy Rice Detection

VI. LINE FOLLOWING MECHANISM

LSA08 sensors will be placed on all sides of automatic bot, allowing to maintain orientation and move without turning our bot. This path will be stored in a string format in our program, (a) Path 1 from starting zone and (b) Path 2 from the reset zone.

In increase efficiency while moving, we will use an adaptive PID controller to minimize the error. It will have Aggressive and normal PID values used depending on deviation from set point. ESP32 has enough interrupt pins to use PID control on many motors, hence this will be handled by ESP32.

The advantages of infrared sensors using APID over normal cameras are :

- Infrared sensors have higher frames per second and greater accuracy
- They allow simultaneous multi-directional sensing
- They have very low latency

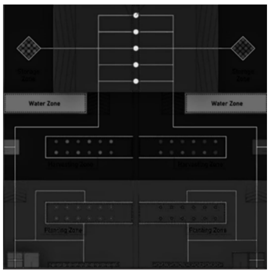


Fig. : Line Following

VII. DEAD RECKONING

While travelling in area 3, the robot will often have to go off the line to pick up grain. It will use its cameras and motor encoders to calibrate its movement. After successful collection, the robot will use this mechanism to return to the line and reach the silo to place the paddy rice.

For proper orientation we will use a Kalman filter and sensor fusion on multiple inertial measurements units and Motor Encoders.

Simulation

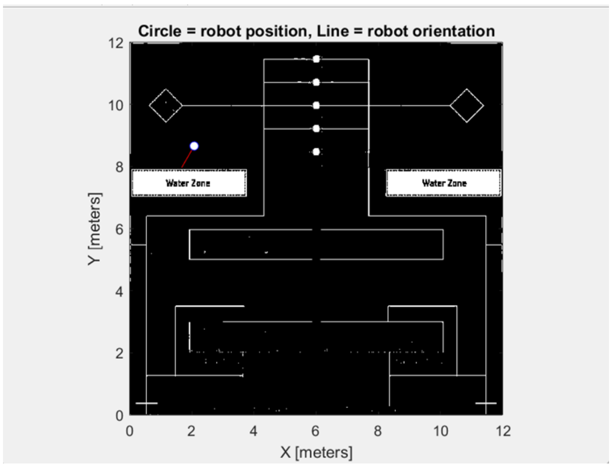


Fig. : A dead reckoning simulation on Matlab. Here the bot is moving to a position 1.5 m away at a specified angle.

VIII. REFLECTIVE LASER SENSORS

We will use 8 Laser reflective sensors, 2 on each side of the bot. It will aid us in the following :

- Aligning with Silo
- Localization using distance from walls on 4 sides
- Following walls and avoiding collisions
- Finding exact silo being targeted by finding distance from wall.

Our automatic robot will be equipped with castor wheels on the sides of its body. This will allow it to slide along the silos which will increase the speed with which it reaches a particular silo.

IX. PERSPECTIVE TRANSFORMATION

For the automatic bot to work properly, it must precisely control its picking mechanism to collect paddy rice. For this we must use inverse kinematics.

The automatic robot will use the data from the OpenCV program to find the centroids of the paddy rice. Then it will use perspective transformation, which will convert a 60-degree view to an overhead view. This transformation preserves collinearity and incidence which will help with our inverse kinematics calculations.

On detecting paddy rice, our robot will rotate by a small angle delta theta till it aligns perfectly with the target. PID control will be used here too to ensure the robot is aligned to the target even while in motion.

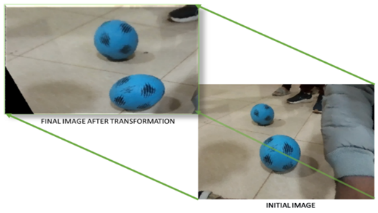


Fig. : Perspective Transformation

X. REINFORCEMENT LEARNING

To decide which silo to target while placing paddy rice, our automatic robot will use a Q- Table which has been generated using Q-Learning. This table considers many factors a finite algorithm cannot do.

Graph Simulation

The graph below shows the outcome when a reinforcement learning bot plays against a finite bot. After just a few hundred training iterations our algorithm figures out the best strategy and starts winning nearly every single match..

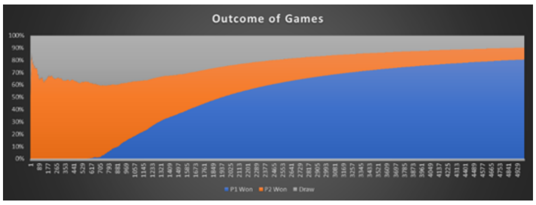


Fig. : Reinforcement Learning Graph

XI. PID CONTROL OF MOTORS

PID stands for Proportional Integral Derivative. We are using PID control for precise position and speed control of our drive. This allows for the automation of navigation procedures. The controller adjusts motor power based on current error, accumulated error, and rate of change of error using proportional, integral, and derivative of the error data read by the encoder or other sensors.

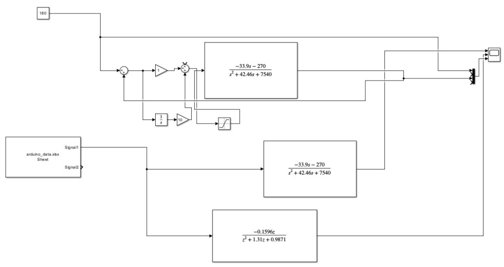


Fig. : PID Model

The model shows a PID configuration having input at S and Z configurations where the signal1 is taken from the microcontroller as input signal and is given into S and Z configuration.The input of PWM signal is at 180 and its saturation value is at 255. PID control in S configuration represents Laplace domain using the Laplace transform which allows to analyse linear time-invariant systems,whch is given as:

$$G(s) = Kp + Ki(\frac{1}{s}) + kdS \tag{XI.1}$$

,where s is the complex frequency function

In the Z configuration it represents Z domain using Z transform which is used for analysing and designing discrete-time or digital control of the controller,which is given as :

$$G(z) = Kp + Ki(\frac{1}{1-z^{-1}}) + Kd(1-z^{-1}) \tag{XI.2}$$

,where z is the complex variable in the Z-domain.

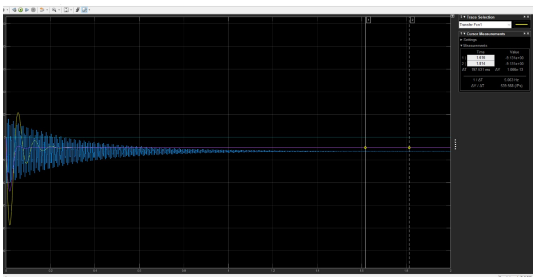


Fig. : PID Simulation Graph

The PID simulation is done within a time frame of 2 sec and stiblity is achieved at 0.8 sec.

In order to implement PID, Arduino UNO, MEGA have insufficient Interrupt pins. Therefore, we decided to use NodeMCU ESP32.

XII. COMMUNICATION SYSTEM

ESP32 was the optimal choice, because it has 32 Interrupt pins that are needed for PID Control, also it has reliable wireless communications.

R1 will be controlled wirelessly using Wi-Fi. The team will be using the Nodemcu ESP32 module for wireless communication.

To control the robots with precision, the team has developed a custom-made app for the competition. This app provides more flexibility and control over the robots than handheld PS2 controllers. The app will also allow the team to monitor and control various parameters of the robots in real-time.

XIII. CONCLUSION

Our robots for ABU Robocon 2024 have all the necessary mechanisms to ensure maximum chances of success. Our manual bot is equipped with

- Multi-sapling picking
- A limb-inspired pneumatic kicking
- Parallel 4-wheel mecanum drive with x-configuration.

Our automatic bot uses

- Claw-forklift mechanism to place paddy rice in the saplings.
- PID – enhanced line following algorithms to help it traverse the game arena.
- Reinforcement learning algorithms to choose the best strategy to implement while placing paddy rice.

To simplify the game strategy the automatic bot will focus solely on area 3 and will have reduced weight and complexity. The calculations and results achieved are in accordance with the dimensions and limitations specified in the rule book of ABU Robocon 2024.