DESIGN DETAILS of Pass & Try Robots for ROBOCON 2020

MIT Academy Of Engineering, INVICTUS ROBOTICS

I. INTRODUCTION

This report states the details about the functionality of the Pass and Try robots. The robots have been Designed for Manufacture and Assemble **(DFMA)**. All mechanisms have been designed and programmed to match either side of the mirrored game field and switched easily. All the claims in this document are based on calculated results and successful experimentation by prototyping. Both robots are designed for semi-autonomous operations.

II. PASS ROBOT

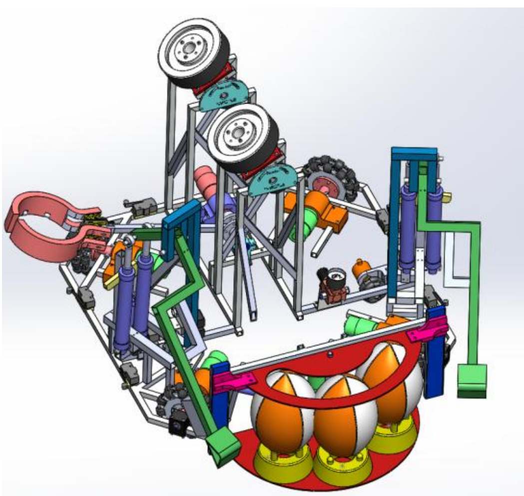

Fig. 1: Pass Robot

The Pass Robot (Fig. 1) fits in a box of dimensions **910*780*600 mm** & can expand up to **910*1050*600 mm** during game play. It weighs approximately **24 kg**. The chassis is built from 1/2" aluminum hollow square tubes.
The mechanisms incorporated in the Pass Robot are explained as follows:

DRIVE SYSTEM:

The Pass Robot is driven by a **4-wheeled cross configuration Omni Drive** for high holonomic mobility & maneuverability. Torque required to drive each wheel is calculated to be **9.93 kg-cm**, so MegaTorque **750 RPM** planetary geared DC motor with a rated torque of **39 kg-cm** is coupled with 127 mm diameter Omni wheels for a top speed of **3.52 m/s**.

The Kinematic model is as follows:

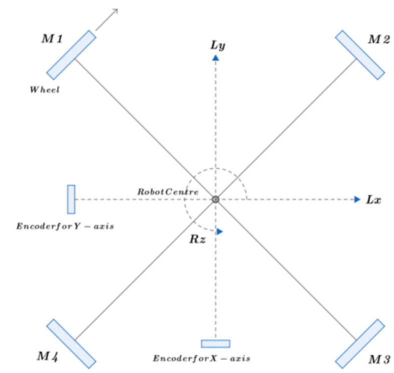

Fig. 2: Four wheeled cross Omni orientation

Each motor speed is computed as follows:

$$\mathbf{M_1 = - L_X - L_Y - R_Z}$$
$$\mathbf{M_2 = - L_X + L_Y - R_Z}$$
$$\mathbf{M_3 = + L_X + L_Y - R_Z}$$
$$\mathbf{M_4 = + L_X - L_Y - R_Z}$$

Where,

$\mathbf{M_i}$ Final Drive Motor PWM
$\mathbf{L_X}$ Linear Speed in X-axis
$\mathbf{L_Y}$ Linear Speed in Y-axis
$\mathbf{R_Z}$ Velocity of Rotation about Z-axis

Note: If the motor PWM ($\mathbf{M_1}$, $\mathbf{M_2}$, $\mathbf{M_3}$, $\mathbf{M_4}$) is evaluated to be negative, it denotes a change in direction of rotation of the motor shaft at the computed magnitude.

BALL PICKING MECHANISM:

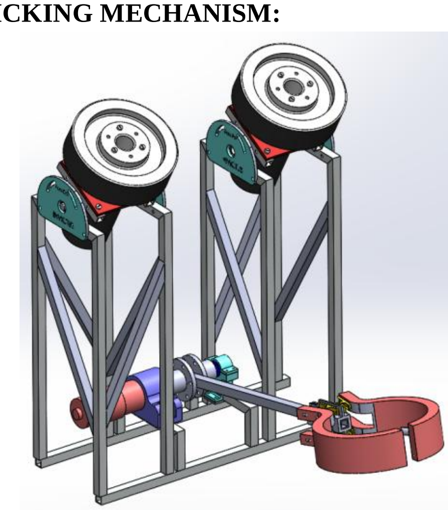

Fig. 3: Try Ball picking and Passing Mechanism

The Ball picking mechanism (Fig. 3) employs a **directly rotated, 1 DOF arm** with a **spring loaded passive gripper** as end effector for gripping the try ball. The gripper has small rollers at its bottom surface which allows smooth entry onto the try ball. The mechanism is light in weight & easy to control. It is positioned at an offset from the center of the chassis so that the gripping arm aligns with the first ball (Fig. 1). This reduces the aligning time significantly.
The arm is made of hollow aluminum square tube & the gripper is 3D printed using PLA.
MegaTorque **100 RPM** planetary geared DC motor with a rated torque of **255 kg-cm** is used to drive the arm and the angle is measured using a potentiometer.

PASSING MECHANISM:

The passing mechanism is an **Angled Pitching Mechanism** (Fig. 3) which consists of two wheels spinning outwards at high RPM & projecting the ball passing between them at a high velocity. This mechanism had the highest score in consistency, efficiency, design simplicity and symmetry which were the crucial parameters in selecting the mechanism.
It uses two AndyMark™ am-0255 337W motors with **5310 RPM** & a stall torque of **24.72 kg-cm**.
The velocity & angle of projection have been calculated as follows:

Taking ground as reference and '$\boldsymbol{u}$' as magnitude of velocity of ball,

Projection angle	$= 10.5^{\circ}$
Initial height of the ball	$= 0.55\ m$
Horizontal distance to travel	$= 3.975\ m$
Desired height of the ball (x = .975 m)	$=0.58 \pm 0.245$ m
Height achieved	= 0.58 m

Considering horizontal travel,

$$\boldsymbol{t = \frac{3.975}{u.\cos(10.5°)}} \qquad \text{----------} \textbf{ (eq. 1)}$$

Considering vertical travel,

$$\boldsymbol{0.58 - 0.55 = [u.\sin(10.5°) \times t] - [0.5 \times 9.81 \times (t^2)]}$$

Substituting **'t'** from **(eq. 1)** in above equation, we get;

$$\boldsymbol{u = 10.63\ m/s}$$

Hence, the above required velocity is achieved by,
Moment of Inertia of roller (I) $= 11.2 \times 10^{-4}\ kg.m^2$
Mass of ball $= 0.34\ kg$
Angular velocity of roller at no load ($\boldsymbol{\omega_1}$) $= 556\ rad/sec$
Angular velocity of roller at load ($\boldsymbol{\omega_2}$) $= 540.35\ rad/sec$
Applying conservation of energy,

$$\boldsymbol{2 \times \frac{1}{2} \times I\omega_1{}^2 - 2 \times \frac{1}{2} \times I\omega_2{}^2 = \frac{1}{2} \times 0.34 \times (v_{ball})^2}$$

Putting the values in the above equation, we get;

$$\boldsymbol{v_{ball} = 10.63\ m/s}$$

KICKING MECHANISM:

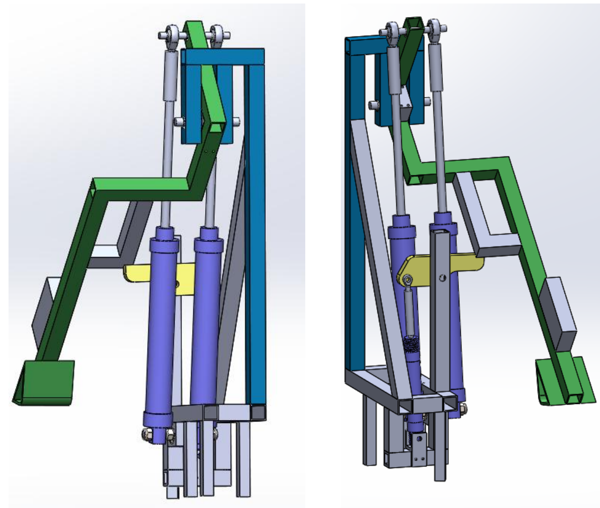

Fig. 4: Kicking Leg Front & Rear View with latch

The **Kicking Mechanism** comprises of a simple **90° Bell Crank Lever** with a velocity ratio of 1:4 (Fig. 4) actuated by pair of pneumatic double acting cylinders (150 mm stroke, 25 mm bore), coupled in parallel to achieve a larger force. The bell crank design is compact and the foot is **convex** in shape & designed such that the optimum projection angle of **30°** with the horizontal is attained during kicking.
To compensate for the instant expansion of air in the cylinders which results in a drop in efficiency of the leg, a **latch** (Fig. 4) is provided before the leg. This allows the pressure to accumulate and equalize at the back of the piston which provides more than enough impulse to the leg for a powerful kick. It is actuated by a 50 mm stroke, 16mm bore, pneumatic double acting cylinder.
The kicking mechanism is mounted only on the Pass Robot since its start zone is closer to the kick ball rack and would make tee and kick ball loading quicker.
The kicking calculations are as follows:

Taking ground as reference and **'$\boldsymbol{u}$'** as magnitude of velocity of ball and calculations from centre of mass of ball,

Projection angle	= 30°
Initial height of the of ball	= 0.1548 m
Horizontal distance to be travelled (x)	= 9 m
Desired height of the ball (at x)	= 2.1548 m

Considering horizontal travel,

$$\boldsymbol{t = \frac{9}{u.\cos(30°)}} \qquad \text{----------} \textbf{ (eq. 2)}$$

Considering vertical travel with factor of safety,

$$\boldsymbol{2.1548 - 0.1548 = u.\sin(30°) \times t - \frac{1}{2} \times 9.81 \times t^2}$$

Putting '**t**' from **(eq. 2)** in above equation we get,

$$\boldsymbol{u = 12.8\ m/s}$$

Hence, the above requirement is achieved by,

Mass of leg (m_{leg}) = 807 gram

Time of impact = 0.07 s

Coefficient of restitution (e) = 0.8

Moment of inertia of leg (I) = 843.3×10^{-4} kg. m^2

Torque = $306\ N \times 0.114 = 34.885\ N.m$ (at **5 bar**)

Angular velocity at impact (v_{leg}) = 28.9569 rad/s

Velocity of foot (theoretical):

$= 0.4353 \times 28.9569 = \mathbf{12.6\ m/s}$

Therefore;

Actual launch velocity of ball:

$= v_{leg} \times (1 + e) \times (\frac{m_{leg}}{m_{leg}+m_{ball}})$ = *15.95 m/s*

TEE AND KICK BALL PLACING MECHANISM:

Since the Pass Robot will traverse the path from PRSZ to KZ3 for kicking, **autonomously**, the Tee and Kick Balls are loaded in the robot itself (Fig. 5). This makes it easier to locate the ball after placing it in the kick zone as compared to manual placing. The Tee and Kick Ball is pushed off its platform by a pneumatic double acting cylinder (200 mm stroke, 25 mm bore). The platform then rotates (MegaTorque 100 RPM motor) to place the next tee and ball.

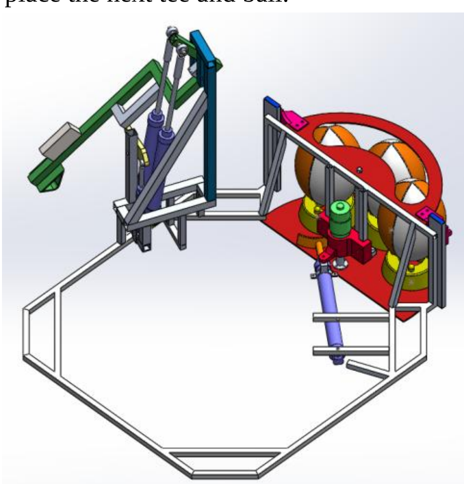

Fig. 5: Tee and Kick Ball placing

III. TRY ROBOT

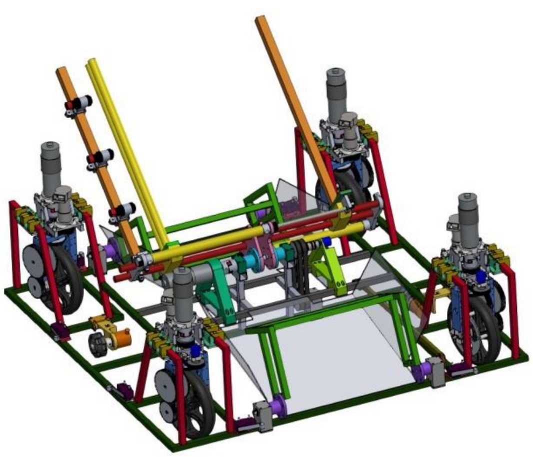

Fig. 6: Try Robot

The Try Robot (Fig. 6) fits in a box of dimensions **925*982*585 mm** & can expand up to **925*1120*767 mm** during game play. It weighs approximately **22 kg**. The chassis is built from 1/2” aluminum hollow square tubes.

The mechanisms incorporated are explained as follows:

DRIVE SYSTEM:

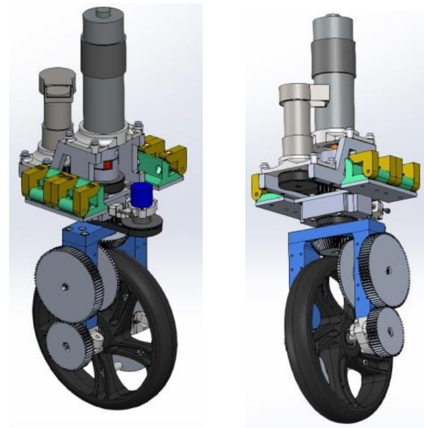

Fig. 7: Swerve Drive

The Try Robot employs a four wheel **Swerve Drive,** (Fig. 7) i.e. all wheels can steer about their individual vertical axis passing through the point of contact of the wheel and the ground using a system of coaxial shafts. There is no castor angle and the entire weight of each drive is focused directly on the wheels, improving traction and speed significantly. Both the steering motor and potentiometer are coupled to externals coaxial shaft by timing belt and pulley to avoid backlash.

Through calculation, **19.47 kg-cm** of torque is required to drive each wheel. MegaTorque **750 RPM** planetary geared DC motor with a rated torque of **39 kg-cm** is used to drive Oxelo™ scooter wheels, **175 mm** in diameter for a top speed of **8 m/s**. Rhino IG32 **200 RPM** planetary geared DC motor with a rated torque of **15 kg-cm** is used to steer each wheel. A multi turn potentiometer is used for closed loop steering control.

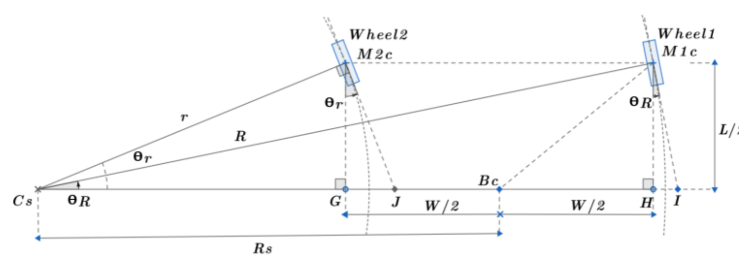

Fig. 8: Kinematic Model for Swerve Drive (θ_r, θ_R)

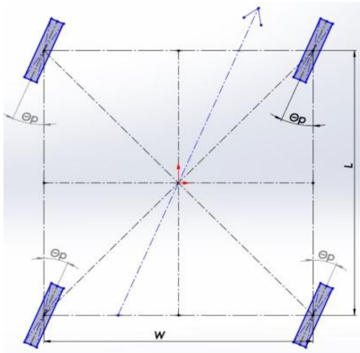

Fig. 9: Parallel Steer (θ_P)

The Steering angle of each wheel is computed as (Fig. 9):

R_s = Steering radius of robot
R = Steering radius of wheels further to the steering centre
r = Steering radius of wheels closer to the steering centre
B_C = Centre of steering
C_S = Centre of steer
Θ_R = Angle of steer of outer wheels
Θ_r = Angle of steer of inner wheels
Θ_P = Angle of parallel steer
L = 722.20 mm
W = 706.84 mm

$$\boldsymbol{S_1 = \theta_1 + \theta_P + \theta_r}$$
$$\boldsymbol{S_2 = \theta_2 + \theta_P + \theta_R}$$
$$\boldsymbol{S_3 = \theta_3 + \theta_P - \theta_R}$$
$$\boldsymbol{S_4 = \theta_4 + \theta_P - \theta_r}$$

Where:

$\boldsymbol{S_1}$, $\boldsymbol{S_2}$, $\boldsymbol{S_3}$, $\boldsymbol{S_4}$ = Target angles of steering of each wheel
$\boldsymbol{\theta_1}$, $\boldsymbol{\theta_2}$, $\boldsymbol{\theta_3}$, $\boldsymbol{\theta_4}$ = Initial homed angles of each wheel

$$\boldsymbol{\theta_R} = \left[\tan^{-1}\left(\frac{\left(\frac{L}{2}\right)}{\left(\frac{1}{R_S}\right)+\left(\frac{W}{2}\right)}\right)\right]$$

$$\boldsymbol{\theta_r} = \left[\tan^{-1}\left(\frac{\left(\frac{L}{2}\right)}{\left(\frac{1}{R_S}\right)-\left(\frac{W}{2}\right)}\right)\right]$$

CATCHING MECHANISM:

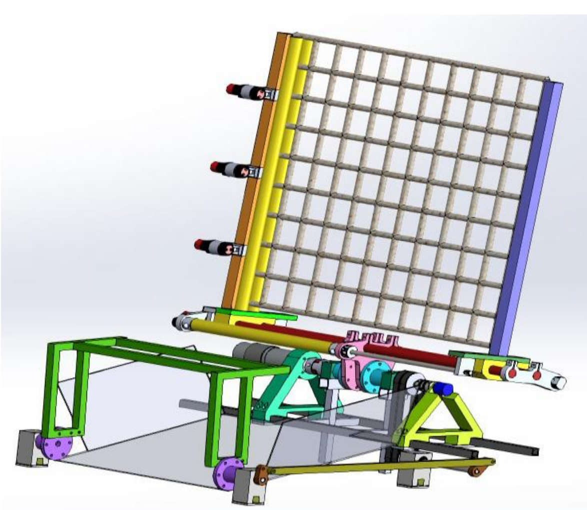

Fig. 10: Catching and Try Mechanism

The catching mechanism is a **Snapping Net Mechanism** (Fig. 10). It consists of three vertical aluminum tubes, of which, two slide linearly (Blue square tube & Yellow cylindrical tubes) on guide rods of stainless steel (Red cylindrical rods) and one is fixed (Orange square tube) with reference to them. The net is attached between the Blue and Orange tubes and passes through the gap between the Yellow cylindrical tubes. This ensures **optimum slack** in the net to catch the Pass Ball between Blue & Yellow tubes. The net covers a maximum area of **525*490 mm^2** which compensates for any deviation in the trajectory of the pass ball. Blue & Yellow tubes are actuated by pneumatic double acting cylinders (250mm stroke, 16mm bore). Three IR proximity sensors are mounted on Orange rod to detect the entry of the ball.

The mechanism can tilt in both directions which then becomes the Try Mechanism.

TRY MECHANISM:

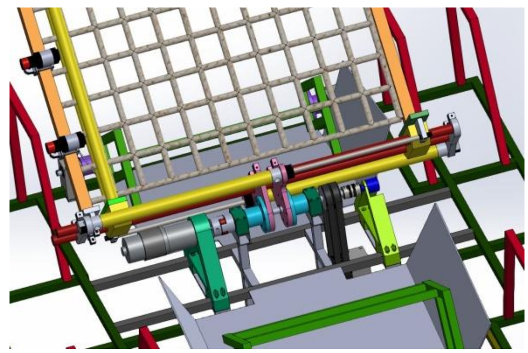

Fig. 11: Drive for Try mechanism

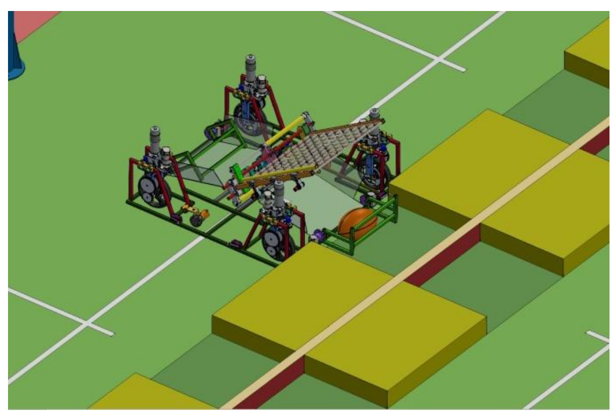

Fig. 12: Try robot performing try on arena

The Catching Mechanism with the ball first tilts in the direction it would perform the try. The **same drive** also opens the **ball cage** (shown in Green)(Fig. 10) by a **Four Bar linkage**. The mechanism then opens and drops the ball onto a **slide** made of **Polycarbonate sheet** (good shock absorber to prevent bouncing of the ball). The ball rolls from the slide into the cage and onto the try spot (Fig. 12). The mechanism then tilts in reverse, retracting the cage, performing a successful try.

MegaTorque **100 RPM** planetary geared DC motor with a rated torque of **255 kg-cm,** coupled with a potentiometer is used to tilt the Catching mechanism.

IV. ELECTRONICS

Arduino Due is used as the micro-controller for both robots. All the sensors, solenoids, motor drivers, etc. are controlled through a **Central PCB**. In the Try Robot, a **dedicated drive PCB** for each swerve module contains the whole electronic system of that drive which is connected with the central PCB using **RS232 and DB9** connectors for signals and power. Other signal connections are made through standard locking **PTR** connectors. RedGear Wireless 2.4GHz controller is used for semi-autonomous operation. **SmartElex 15S Motor Drivers** are used for driving all motors in both robots.

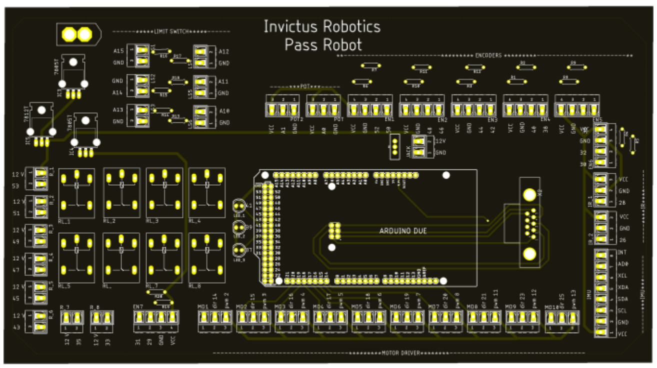

Fig. 13: Pass robot PCB

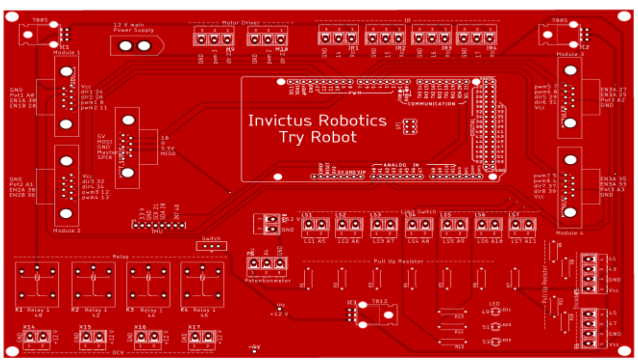

Fig. 14: Try robot PCB

V. CONTROL METHODOLGY

The **semi-autonomous** nature of both robots helps to increase their speed and accuracy while performing certain precise and timed operations. The autonomous part of the Pass Robot includes aligning with the ball rack and PRSZ for picking and passing the Try Ball respectively, localizing while travelling to KZ3 and placing & kicking of Kick Ball. Whereas, the manual part of the robot includes providing a trigger for the execution of the next autonomous task.

For localization, one encoder in X and Y axes each are hinged freely for getting its coordinates in the Cartesian plane. For getting those coordinates, **Optical Incremental Quadrature Encoders** of 600 PPR, coupled with Omni wheels of diameter (d) 58 mm, rolling freely on the ground. Hence, to cover **'D' mm** distance, the encoder counts required would be;

$$\mathbf{X = 182.12 / (2400 * D)}$$

Where, circumference of the wheel is; **3.14 * d = 182.12 mm** and **2400 encoder counts** are recorded per rotation.
The velocity of the robots would be manipulated in the **PID Control** block with ‘X’ encoder counts as input.

To avoid the minor offset due to slippage or localization error, a pair of **limit switches** on either side of the robot is mounted to align at certain checkpoints for **Absolute Odometry.**
Control System Block for Odometry:

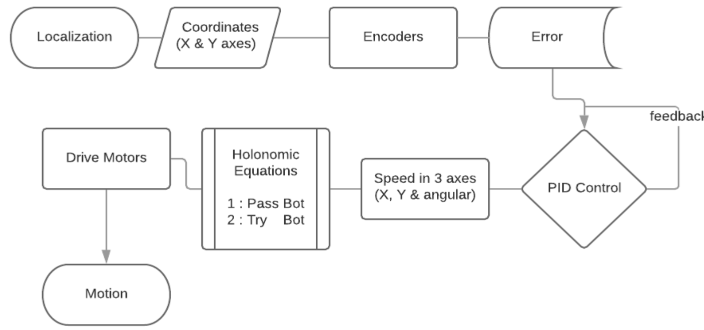

Fig.15: Flowchart of Mapping