AIN SHAMS UNIVERSITY-

FACULTY OF ENGINEERING

[MCT443s]

Design of Autonomous systems

Major Task: Furuta Pendulum

Team 9

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GitHub Repository : https://github.com/Musa2004-me/Mecanum-Wheel-Robot

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Table of Contents

Table of Figuers

Introduction

Autonomous wheeled mobile robots play a critical role in modern intelligent transportation systems, warehouse automation, and service robotics. A key capability of such robots is the ability to navigate structured environments while maintaining lane alignment and avoiding obstacles in a safe and efficient manner. These tasks require the integration of perception, control, and decision-making algorithms within a reliable robotic platform.

In this project, an autonomous mobile robot is designed and simulated using the Robot Operating System 2 (ROS 2 Humble) and the Gazebo Classic simulation environment. The robot is required to perform lane-keeping over a fixed distance and execute obstacle avoidance maneuvers involving lane transitions. While the project description targets a differential drive platform, this work adopts a Mecanum-wheel robot, which provides holonomic motion and enables independent control of forward, lateral, and rotational movements.

The use of a Mecanum drive introduces additional flexibility during navigation, particularly during lane changes and obstacle avoidance, where lateral motion can be achieved without large heading changes. The project focuses on developing perception algorithms using camera and range sensors, implementing feedback control strategies for lane keeping, and designing a decision-making logic to manage obstacle detection and lane transitions. All components are integrated and validated in simulation, demonstrating a complete autonomous navigation system.

Objectives

The main objective of this project is to design, implement, and validate an autonomous Mecanum-wheel mobile robot capable of lane keeping and obstacle avoidance in a simulated environment, as follows:

Robot Design and Modeling

- Design a Mecanum-wheel mobile robot that fits within the provided track constraints.
- Develop a kinematic model suitable for holonomic motion control.

Perception System Development

- Implement camera-based lane detection to estimate lane position and lateral error.
- Utilize range sensing (LiDAR) for reliable obstacle detection.
- Read sensor data directly from simulated sensors, in compliance with project requirements.

System Integration and Validation

- Integrate perception, control, and decision-making modules within ROS 2.
- Validate system performance through simulation in Gazebo.
- Analyze the robot's behavior during both lane keeping and obstacle avoidance phases.

Robot Platform Description (Mecanum Robot)

- The robot is based on a four-wheel Mecanum drive configuration, enabling holonomic motion (independent control of longitudinal, lateral, and rotational velocities).
- Each wheel is equipped with rollers angled at 45°, allowing omnidirectional movement without changing robot orientation.
- Compared to a differential drive robot, the Mecanum platform provides greater maneuverability, especially during lane transitions and obstacle avoidance.

We used four Mecanum wheels in our project. The wheel topology was the same as figure 2. The direction and the velocity of the diagonal wheels were set independently. Using the same speed in each wheel at the same time during the operation led us to get eight directions for the robot's motion without changing its orientation. By changing the velocities of the diagonal wheels we achieved a motion between 0° to 360°. For example, to accomplish a transversal motion to the right, the right wheels were rotated against each other inwardly, while the left wheels were rotated against each other outwardly (See Figure 4). By using the same technique we achieved all eight different motions shown in Figure 4.

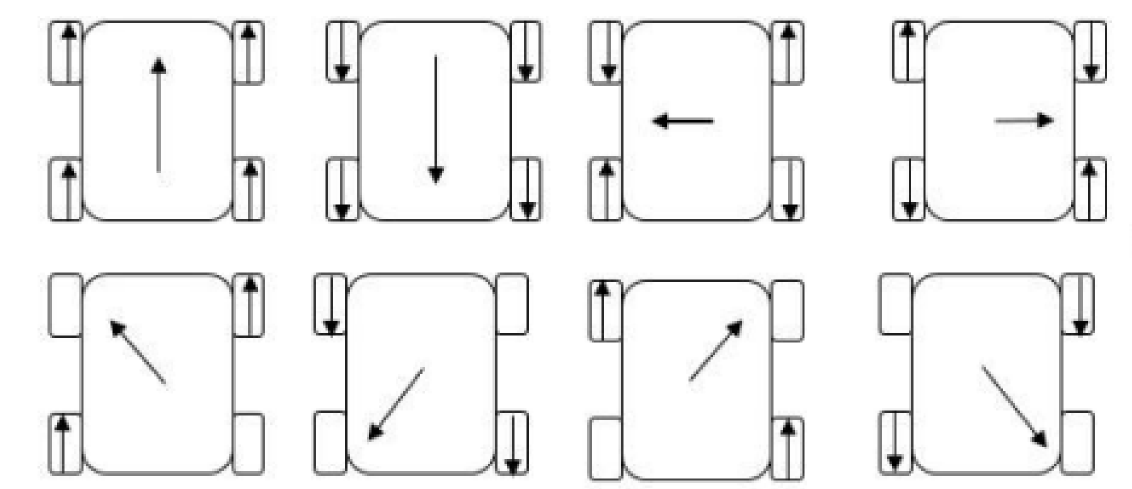


Figure 1 Motions of Omnidirectional platform

Mecanum Wheels

In this design, similar to the Omni wheel, There are a series of free moving rollers attached to the hub but with an 45° of angle about the hub's circumference but still the overall side profile of the wheel is circular.

Omnidirectional motion can be reached by mounting four Mecanum wheels on the corners of a four-sided base. Because of the angled rollers, the mechanical design is much more difficult, but due to the smoother transfer of contact surfaces a higher loads can be supported.

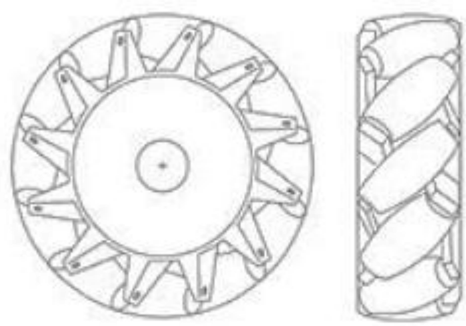


Figure 2 Mecanum wheel design

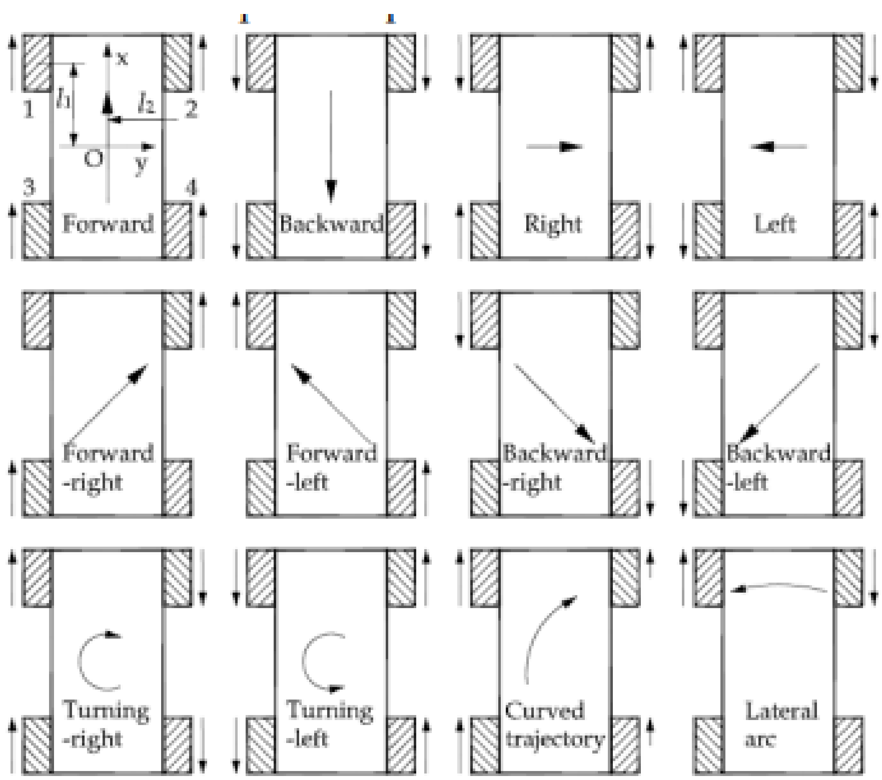


Figure 3 Robot motion according to the direction and angular speed of the wheels

KINEMATIC

Kinematic Model of the Mecanum Robot

- The robot motion is described using Mecanum wheel kinematics, mapping wheel angular velocities to robot velocities:
    - Longitudinal velocity v_x
    - Lateral velocity v_y
    - Angular velocity ω_z
- Forward and inverse kinematic equations were implemented to convert:
    - Desired robot velocities → wheel speeds
    - Wheel feedback → robot motion estimation

Justification for Using Mecanum Drive

- Although the project specification targets a differential drive robot, a Mecanum robot was selected because:
    - It supports lateral (sideways) motion, which simplifies lane changing.
    - It reduces the need for large heading changes during obstacle avoidance.
    - It allows smoother and faster transitions between lanes while maintaining stability.
- The control strategy was designed to respect the same task objectives (lane keeping and obstacle avoidance) defined in the project description.

The configuration parameters and system velocities are defined as follows:

- x, y, θ, robot's position (x, y) and its orientation angle θ (The angle between X and X_R);
- X G Y, inertial frame; x,y are the coordinates of the reference point O in the inertial basis;
- $X_R O Y_R$, robot's base frame; Cartesian coordinate system associated with the movement of the body center;
- $S_i P_i E_i$, coordinate system of ith wheel in the wheel's center point P_i ;
- O, P_i, the inertial basis of the Robot in Robot's frame and $P_i = \{X_{P_i}, Y_{P_i}\}$ the center of the rotation axis of the wheel i ;
- $\overrightarrow{OP_i}$, is a vector that indicates the distance between Robot's center and the center of the wheel ith;
- l_{ix}, l_{iy}, l_{ix}, half of the distance between front wheels and l_{iy} half of the distance between front wheel and the rear wheels.
- l_i, distance between wheels and the base (center of the robot O);
- r_i , denotes the radius of the wheel i (Distance of the wheel's center to the roller center)
- r_r, denotes the radius of the rollers on the wheels.
- α_i, the angle between OP_i and X_R ;
- β_i, the angle between S_i and X_R ;
- γ_i , the angle between v_{ir} and E_i ;
- ω_i [rad/s], wheels angular velocity;
- $v_{i\omega}$ [m/s], $(i = 0,1,2,3) \in R$, is the velocity vector corresponding to wheel revolutions
- v_{ir}, the velocity of the passive roller in the wheel i;
- .$[w_{si} \;\; w_{Ei} \;\; \omega_i]^T$, Generalized velocity of point P_i in the frame $S_i P_i E_i$;
- $[v_{S_i} \;\; v_{E_i} \;\; \omega_i]^T$, Generalized velocity of point P_i in the frame $X_R O Y_R$;
- v_x, v_y [m/s] - Robot linear velocity;
- ω_z [rad/s] - Robot angular velocity;

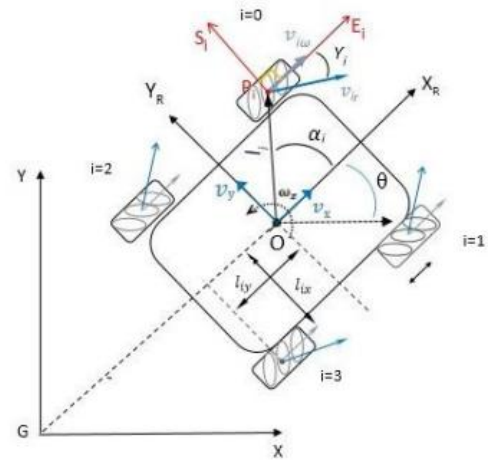


Figure 4 Wheels Configuration and Posture definition

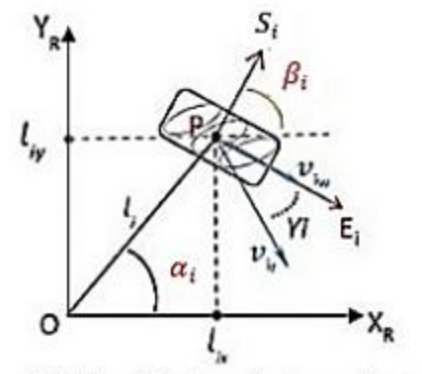


Figure 5 wheel 1 in the robot coordinate

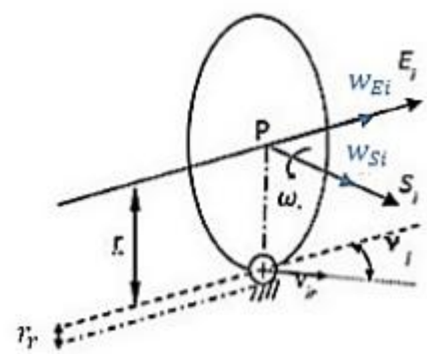


Figure 6 wheel 1 motion principle

So, we can calculate the velocity of the wheel i and the tangential velocity of the free roller attached to the wheel touching the floor:

$$v_{ir} = \frac{1}{cos\ 45} r_r \omega_i \ , \ w_{Ei} = r_i \omega_i \quad [4], \ i = 0,1,2,3. \qquad \text{eq. 1}$$

considering the equations (eq.1) , the velocity of the wheel i in the frame $SiPiEi$, can be derived by:

$$v_{S_i} = v_{ir} \sin \gamma_i.$$

$$v_{E_i} = \omega_i r_i + v_{ir} \cos \gamma_i.$$

$$\begin{bmatrix} v_{S_i} \\ v_{E_i} \end{bmatrix} = \begin{bmatrix} 0 & \sin \gamma_i \\ r_i & \cos \gamma_i \end{bmatrix} \begin{bmatrix} \omega_i \\ v_{ir} \end{bmatrix} = {}^{w_i}T_{P_i} \begin{bmatrix} \omega_i \\ v_{ir} \end{bmatrix}. \qquad \text{eq. 2}$$

The transformation matrix from velocities of the ith wheel to its center:

$${}^{w_i}T_{P_i} = \begin{bmatrix} 0 & \sin \gamma_i \\ r_i & \cos \gamma_i \end{bmatrix}.$$

The velocity of the wheel's center translated to the X_ROY_R coordinate system can be achieved by equation 7.

$$\begin{bmatrix} v_{iX_R} \\ v_{iY_R} \end{bmatrix} = \begin{bmatrix} \cos \beta_i & -\sin \beta_i \\ \sin \beta_i & \cos \beta_i \end{bmatrix} \begin{bmatrix} v_{S_i} \\ v_{E_i} \end{bmatrix} = {}^{w_i}T_{P_i} {}^{P_i}T_R \begin{bmatrix} \omega_i \\ v_{ir} \end{bmatrix}. \ \text{eq. 4}$$

Then, the transformation matrix from the ith wheel's center to the robot coordinate's system can be obtained from equation 5.

$${}^{P_i}T_R = \begin{bmatrix} \cos \beta_i & -\sin \beta_i \\ \sin \beta_i & \cos \beta_i \end{bmatrix}. \qquad [5] \qquad \text{eq. 5}$$

Since the robot's motion is planar, we also have:

$$\begin{bmatrix} v_{iX_R} \\ v_{iY_R} \end{bmatrix} = \begin{bmatrix} 1 & 0 & -l_{iy} \\ 0 & 1 & l_{ix} \end{bmatrix} \begin{bmatrix} v_X \\ v_Y \\ \omega \end{bmatrix} = T' \begin{bmatrix} v_{X_R} \\ v_{Y_R} \\ \omega_R \end{bmatrix}. \qquad \text{eq. 6}$$

Where:

$$T' = \begin{bmatrix} 1 & 0 & -l_{iy} \\ 0 & 1 & l_{ix} \end{bmatrix}. \qquad \text{eq. 7}$$

From (eq.3) and (eq.5), the inverse kinematic model can be obtained:

$${}^{w_i}T_{P_i}\,{}^{P_i}T_R \begin{bmatrix} \omega_i \\ v_{ir} \end{bmatrix} = T' \begin{bmatrix} v_{X_R} \\ v_{Y_R} \\ \omega_R \end{bmatrix}, i = 0,1,2,3. \qquad \text{eq. 8}$$

As r_i ≠ 0 , 0 < |γ_i| < π/2 , det(^P_i T_R) ≠ 0, det(^w_i T_(P_i)) ≠ 0

hence, by merging equations 4 and 6 the robot's base velocity (at point O) related to the rotational velocity of the ith wheel can be obtained from eq. 9.

$$\begin{bmatrix} \omega_i \\ v_{ir} \end{bmatrix} = {}^{w_i}T_{P_i}^{\ -1} . {}^{P_i}T_R^{\ -1} . T' \begin{bmatrix} v_{X_R} \\ v_{Y_R} \\ \omega_z \end{bmatrix}, i = 0,1,2,3. \qquad \text{eq. 9}$$

According to eq.3 and eq.4 there is a relationship between variables in each robot's wheels frames and its center. And with the inverse kinematic, the velocity of the system can be obtained by implementing v_{ir} the linear velocity and ω_i the rotational speed of wheel ith in eq.10 and the contrary in eq.11.

$$\begin{bmatrix} v_{X_R} \\ v_{Y_R} \\ \omega_z \end{bmatrix} = T^+ \begin{bmatrix} \omega_i \\ v_{ir} \end{bmatrix} \qquad \text{eq. 10}$$

$$\begin{bmatrix} \omega_i \\ v_{ir} \end{bmatrix} = T \begin{bmatrix} v_{X_R} \\ v_{Y_R} \\ \omega_R \end{bmatrix} \qquad \text{eq. 11}$$

Where $T = {}^{w_i}T_{P_i}{}^{-1} . {}^{P_i}T_R{}^{-1} . T'$, $T^+ = (T^T T)^{-1} T^T$.

$$T = \begin{bmatrix} \cos\beta_i & -\sin\beta_i \\ \sin\beta_i & \cos\beta_i \end{bmatrix}^{-1} . \begin{bmatrix} 0 & \sin\gamma_i \\ r_i & \cos\gamma_i \end{bmatrix}^{-1} . \begin{bmatrix} 1 & 0 & -l_{iy} \\ 0 & 1 & l_{ix} \end{bmatrix}$$

Considering the fact that $l_{ix} = l_i \cos a_i$ and $l_{iy} = l_i sin a_i$, and assuming that the wheels are in a same size, the transformation matrix is:

$$T := \frac{1}{-r} \begin{bmatrix} \frac{\cos(\beta_i - y_i)}{\sin(y_i)} & \frac{\sin(\beta_i - y_i)}{\sin(y_i)} & \frac{li \sin(-\alpha_i + \beta_i - y_i)}{\sin(y_i)} \\ -\frac{r\cos(\beta_i)}{\sin(y_i)} & -\frac{r\sin(\beta_i)}{\sin(y_i)} & -\frac{li \sin(-\alpha_i + \beta_i)\, r}{\sin(y_i)} \end{bmatrix}; \qquad \text{eq. 12}$$

$$T^+ = \frac{1}{li^2+1} \begin{bmatrix} -\frac{1}{2}\left(li^2 \sin(\beta_i) - li^2 \sin(-\beta_i + 2\alpha_i) + 2\sin(Bi)\right) r & \frac{1}{2} li^2 \sin(y_i - \beta_i + 2\alpha_i) - \frac{1}{2}\sin(-y_i + \beta_i)\, li^2 - \sin(-y_i + \beta_i) \\ \frac{1}{2} r \left(li^2 \cos(\beta_i) - li^2 \cos(-\beta_i + 2\alpha_i) + 2\cos(\beta_i)\right) & -\frac{1}{2} li^2 \cos(y_i - \beta_i + 2\alpha_i) + \frac{1}{2}\cos(-y_i + \beta_i)\, li^2 + \cos(-y_i + \beta_i) \\ \cos(\alpha_i - \beta_i)\, li\, r & \cos(\alpha_i - \beta_i + y_i)\, li \end{bmatrix}$$

eq. 13

Since there is a relation between independent variables vir and ωi in each joint and the systems angular and linear velocity, assuming that there is no wheel slipping on the ground, the system inverse kinematic can be obtained by eq.14.

$$\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{bmatrix} = \frac{-1}{r}\begin{bmatrix}\frac{\cos(\beta_1-\gamma_1)}{\sin\gamma_1} & \frac{\sin(\beta_1-\gamma_1)}{\sin\gamma_1} & \frac{l_1\sin(\beta_1-\gamma_1-\alpha_1)}{\sin\gamma_1}\\ \frac{\cos(\beta_2-\gamma_2)}{\sin\gamma_2} & \frac{\sin(\beta_2-\gamma_2)}{\sin\gamma_2} & \frac{l_2\sin(\beta_2-\gamma_2-\alpha_2)}{\sin\gamma_2}\\ \frac{\cos(\beta_3-\gamma_3)}{\sin\gamma_3} & \frac{\sin(\beta_3-\gamma_3)}{\sin\gamma_3} & \frac{l_3\sin(\beta_3-\gamma_3-\alpha_3)}{\sin\gamma_3}\\ \frac{\cos(\beta_4-\gamma_4)}{\sin\gamma_4} & \frac{\sin(\beta_4-\gamma_4)}{\sin\gamma_4} & \frac{l_4\sin(\beta_4-\gamma_4-\alpha_4)}{\sin\gamma_4}\end{bmatrix}\begin{bmatrix}v_X\\ v_Y\\ \omega_z\end{bmatrix}. \qquad \text{eq.14}$$

$$T = \frac{-1}{r}\begin{bmatrix}\frac{\cos(\beta_1-\gamma_1)}{\sin\gamma_1} & \frac{\sin(\beta_1-\gamma_1)}{\sin\gamma_1} & \frac{l_1\sin(\beta_1-\gamma_1-\alpha_1)}{\sin\gamma_1}\\ \frac{\cos(\beta_2-\gamma_2)}{\sin\gamma_2} & \frac{\sin(\beta_2-\gamma_2)}{\sin\gamma_2} & \frac{l_2\sin(\beta_2-\gamma_2-\alpha_2)}{\sin\gamma_2}\\ \frac{\cos(\beta_3-\gamma_3)}{\sin\gamma_3} & \frac{\sin(\beta_3-\gamma_3)}{\sin\gamma_3} & \frac{l_3\sin(\beta_3-\gamma_3-\alpha_3)}{\sin\gamma_3}\\ \frac{\cos(\beta_4-\gamma_4)}{\sin\gamma_4} & \frac{\sin(\beta_4-\gamma_4)}{\sin\gamma_4} & \frac{l_4\sin(\beta_4-\gamma_4-\alpha_4)}{\sin\gamma_4}\end{bmatrix}. \qquad \text{eq. 15}$$

And for the forward kinematic according to the eq.10, we have:

$$\begin{bmatrix}v_X\\ v_Y\\ \omega_z\end{bmatrix} = T^+\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{bmatrix} \qquad \text{eq. 16}$$

The Relation between Motions and the Translation MATRIX

Analyzing the motion of a four Mecanum wheeled robot brings out the following conclusion: According to the inverse kinematic, there is a relationship between velocities in each joint and the robot's center velocity, thus, the velocity of the robot's center is reflected by and obtained from an individual wheels velocity. According to the robot kinematic, inverse kinematics can be achieved when the rank of the system is less than the rank of the Jacobian matrix for each wheel of the robot that reduces the degree of freedom of the robot's joints. Hence in a four Omni-differential design, the kinematic works with following conditions:

- R Jacobian full column rank, i.e. if rank (R) = 3, the robot performs a better movement.
- The rank of the Jacobian matrix column dissatisfaction, i.e. if the rank (R)

FOUR MECANUM OMNIDIRECTIONAL SOLUTION

Typical Mecanum four system shown in Figure 2; the parameters of this configuration are shown in table 1. In this configuration wheels sizes are the same.

Table 1. Robot Parameters

i	Wheels	α_i	β_i	γ_i	l_i	l_{ix}	l_{iy}
0	1sw	$\pi/4$	$\pi/2$	$-\pi/4$	l	l_x	l_y
1	2sw	$-\pi/4$	$-\pi/2$	$\pi/4$	l	l_x	l_y
2	3sw	$3\pi/4$	$\pi/2$	$\pi/4$	l	l_x	l_y
3	4sw	$-3\pi/4$	$-\pi/2$	$-\pi/4$	l	l_x	l_y

By replacing the parameters of Table 1 in matrix (eq. 15) and considering eq.14 we have come up with:

$$T = \frac{1}{r}\begin{bmatrix} 1 & -1 & -(l_x + l_y) \\ 1 & 1 & (l_x + l_y) \\ 1 & 1 & -(l_x + l_y) \\ 1 & -1 & (l_x + l_y) \end{bmatrix}, \qquad \text{eq. 17}$$

$$T^+ = \frac{r}{4}\begin{bmatrix} 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & -1 \\ -\frac{1}{(l_x+l_y)} & \frac{1}{(l_x+l_y)} & -\frac{1}{(l_x+l_y)} & \frac{1}{(l_x+l_y)} \end{bmatrix}; \qquad \text{eq. 18}$$

According to equations (10) and (11) for Forward and Inverse kinematics there is:

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} = \frac{1}{r}\begin{bmatrix} 1 & -1 & -(l_x + l_y) \\ 1 & 1 & (l_x + l_y) \\ 1 & 1 & -(l_x + l_y) \\ 1 & -1 & (l_x + l_y) \end{bmatrix}\begin{bmatrix} v_x \\ v_y \\ \omega_z \end{bmatrix}. \qquad \text{eq. 19}$$

$$\begin{cases} \omega_1 = \frac{1}{r}(v_x - v_y - (l_x + l_y)\omega), \\ \omega_2 = \frac{1}{r}(v_x + v_y + (l_x + l_y)\omega), \\ \omega_3 = \frac{1}{r}(v_x + v_y - (l_x + l_y)\omega), \\ \omega_4 = \frac{1}{r}(v_x - v_y + (l_x + l_y)\omega). \end{cases} \qquad \text{eq. 20}$$

And

$$\begin{bmatrix} v_x \\ v_y \\ \omega_z \end{bmatrix} = \frac{r}{4}\begin{bmatrix} 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & -1 \\ -\frac{1}{(l_x+l_y)} & \frac{1}{(l_x+l_y)} & -\frac{1}{(l_x+l_y)} & \frac{1}{(l_x+l_y)} \end{bmatrix}\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \qquad \text{eq. 21}$$

Longitudinal Velocity:

$$v_x(t) = (\omega_1 + \omega_2 + \omega_3 + \omega_4) \, . \, \frac{r}{4} \qquad \text{eq. 22}$$

Transversal Velocity:

$$v_y(\mathrm{t}) = (-\omega_1 + \omega_2 + \omega_3 - \omega_4) \, . \, \frac{r}{4} \qquad \text{eq. 23}$$

Angular velocity:

$$\omega_z(t) = (-\omega_1 + \omega_2 - \omega_3 + \omega_4) \, . \, \frac{r}{4(l_x + l_y)} \qquad \text{eq. 24}$$

The resultant velocity and its direction in the stationery coordinate axis (x, y, z) can be achieved by the following equations (eq. 25, 26):

$$\rho = \tan^{-1}\left(\frac{v_y}{v_x}\right), \qquad \text{eq. 25}$$

$$\boldsymbol{v_R} = \sqrt{\boldsymbol{v_x}^2 + \boldsymbol{v_y}^2}. \qquad \text{eq. 26}$$

The results were systematically obtained by using kinematic equations that were similar to those achieved from the experimental results. The results show that the platform performs full omnidirectional motions. This shows that by using Mecanum wheels in the platform the robot can achieve any direction between $\mathbf{0}$ ° to $\mathbf{360}$ °without changing its orientation.

CAD Design

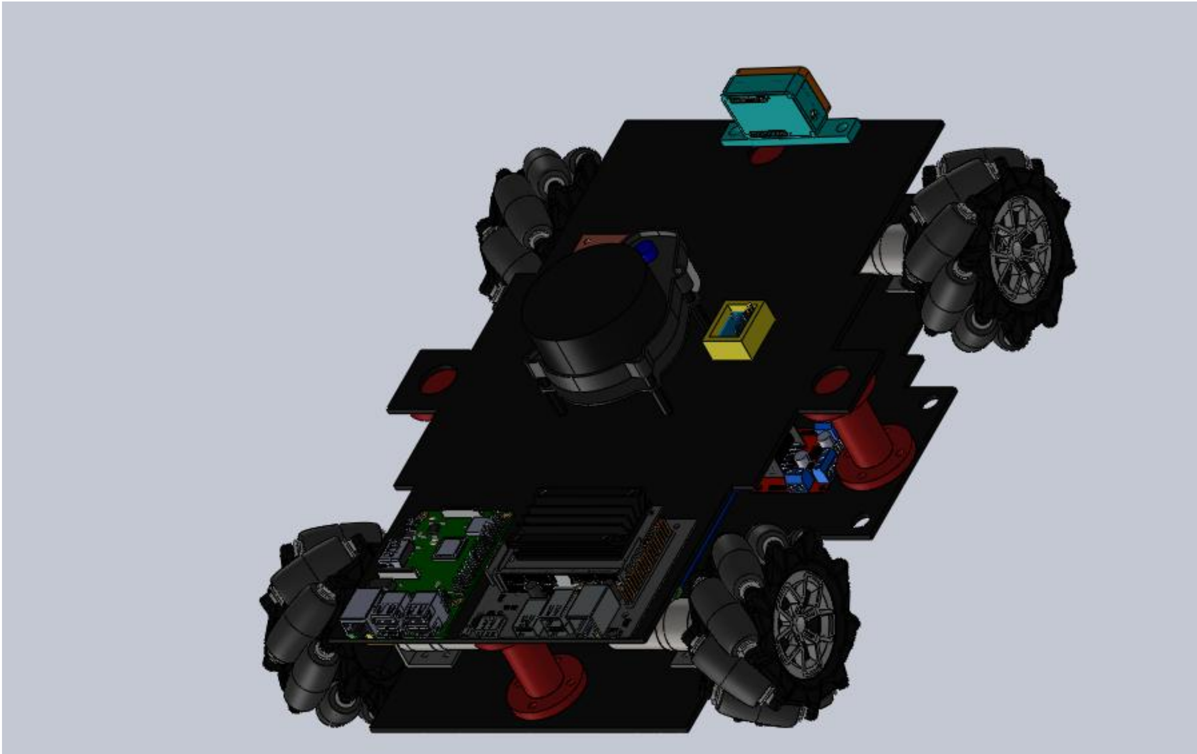


Figure 7 Robot CAD Model without Covering

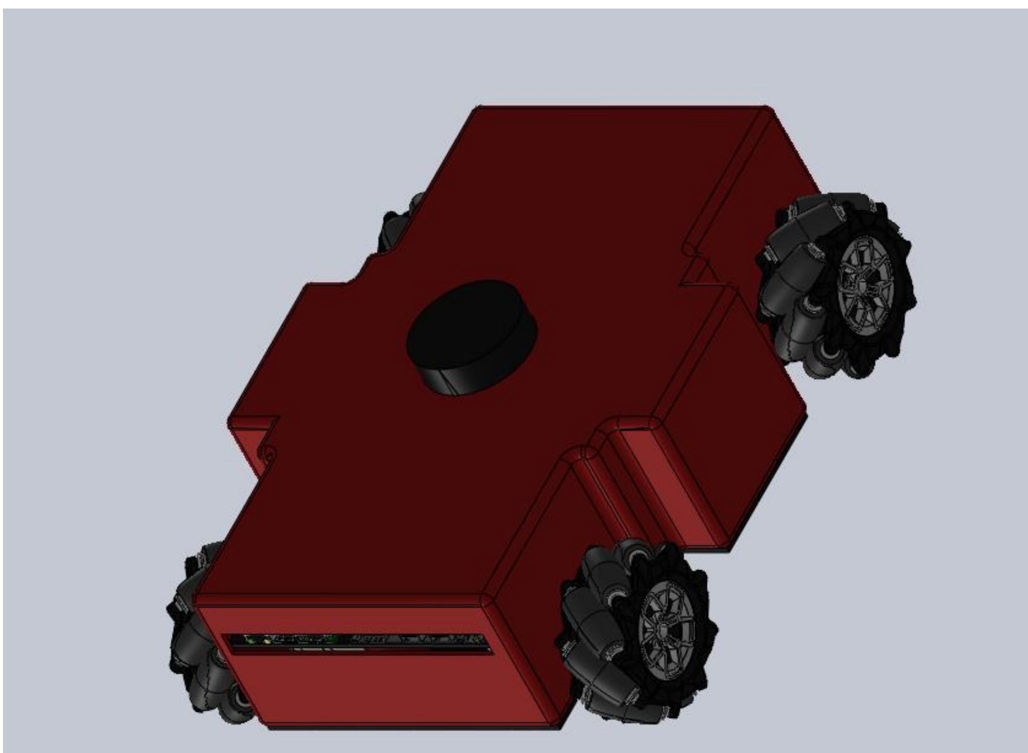


Figure 8 Robot Model with covering CAD Model

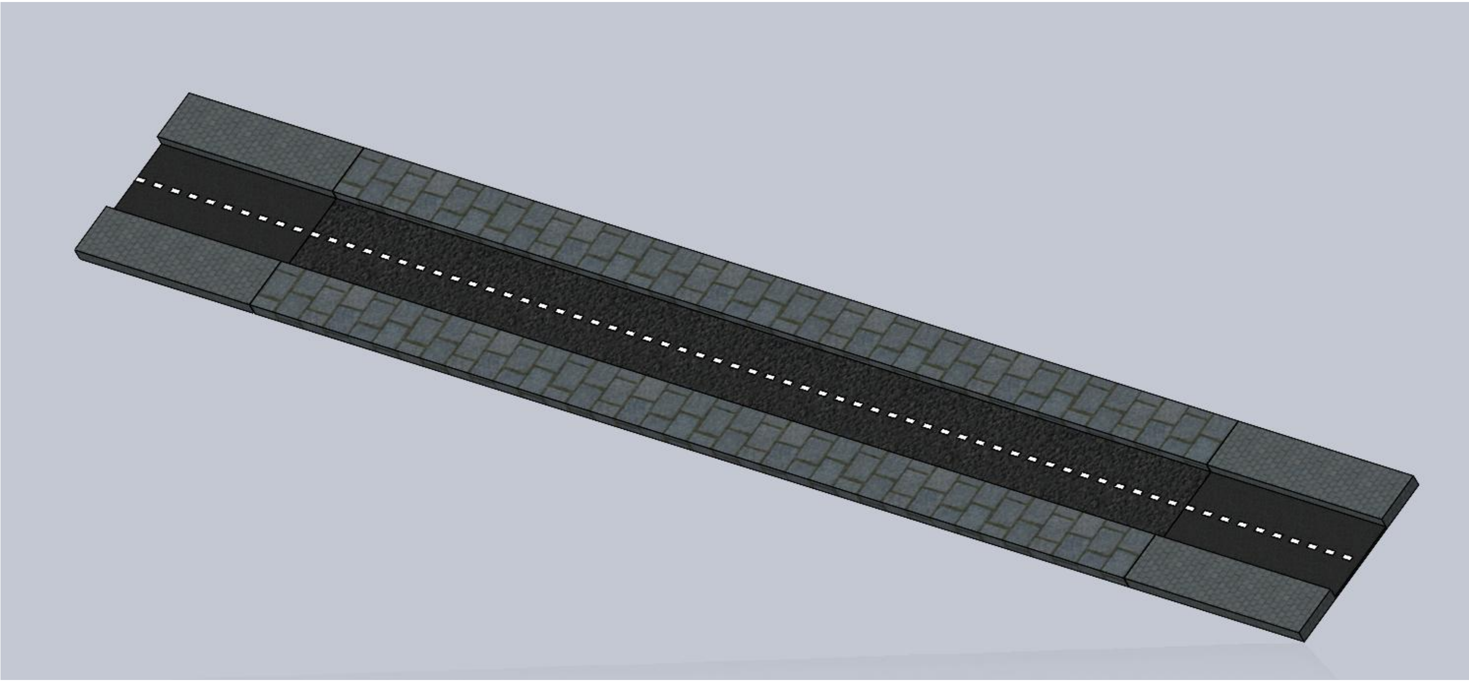


Figure 9 Track 01CAD Model

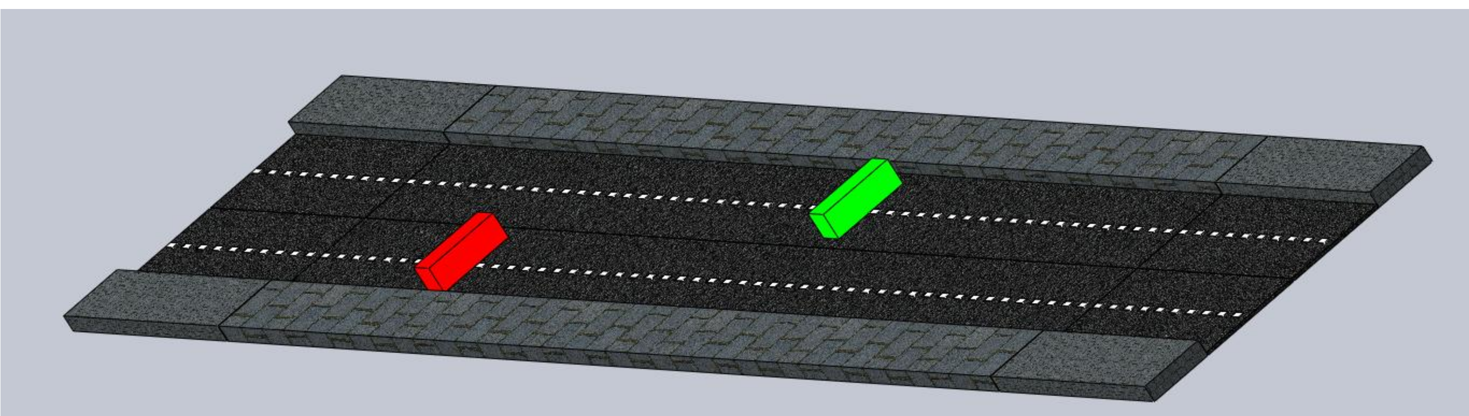


Figure 10 Track 02 CAD Model

Project Package(mec)

– The mec package is a complete ROS2 setup for a mecanum-wheeled robot, including models, meshes, controllers, launch files, scripts, RViz configuration, and simulation worlds for testing motion, perception, and scenarios.

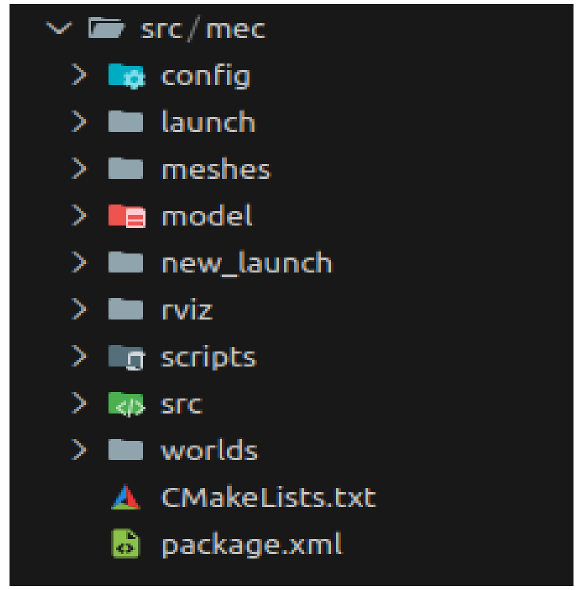


Figure 11 mec package folders

1) Model Folder Description

– The model folder contains all URDF/Xacro files responsible for defining the robot structure, sensors, control interfaces, and simulation environments.
The modeling approach is modular, allowing easy maintenance, scalability, and reuse.

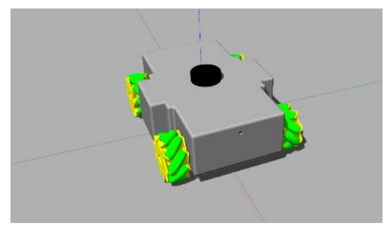


Figure 12 urdf model

2) Meshes Folder Description

– The meshes folder contains all 3D STL models used to represent the robot and the simulation environment in Gazebo. These models are used only for visualization and collision representation and do not include control or logic.

3) Worlds Folder Description

– Contains Gazebo world files for robot simulation, including tracks, obstacles, and empty environments.

4) Rviz Folder Description

– Holds RViz configuration files to visualize the robot, sensors, and environment in ROS2.

5) Config Folder Descreption

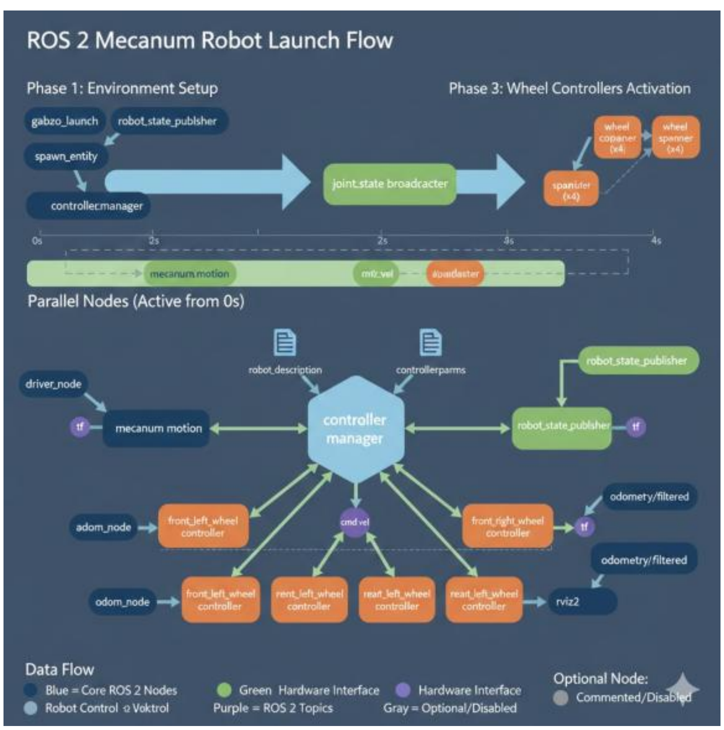
– This contains the control settings for the robot, specifically the mecanum wheels:
  - controller_manager: Manages all controllers, sets the update rate, and broadcasts joint states.
  - Wheel velocity controllers: Each wheel has a ForwardCommandController to control its velocity.
- In short, this file connects the motors to the simulation and defines how wheel velocities are controlled.

6) New_launch Folder Description

– Contains ROS2 launch files to start the robot, its drivers, perception nodes, and simulation environments.

– There are 3 files

1- driver_Track01.launch.py
2- driver_Track02.launch.py
3- perception.launch.py



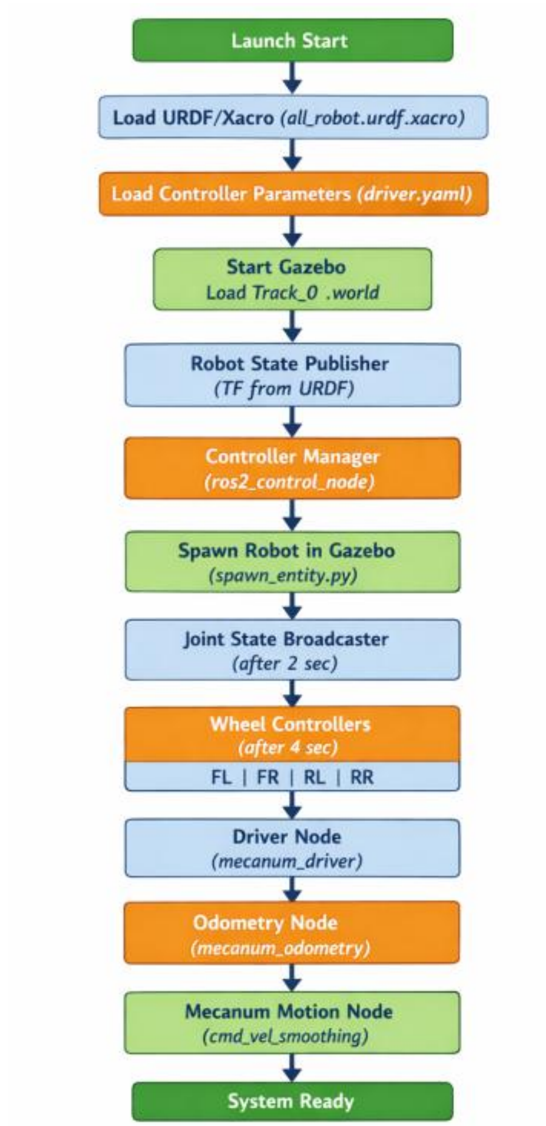


Figure 13 High-Level Flow (Launch Sequence)

7) Scripts Folder Description

– Includes Python scripts for robot control, sensor processing, lane detection, obstacle avoidance, and scenario management.

1- driver_node.py

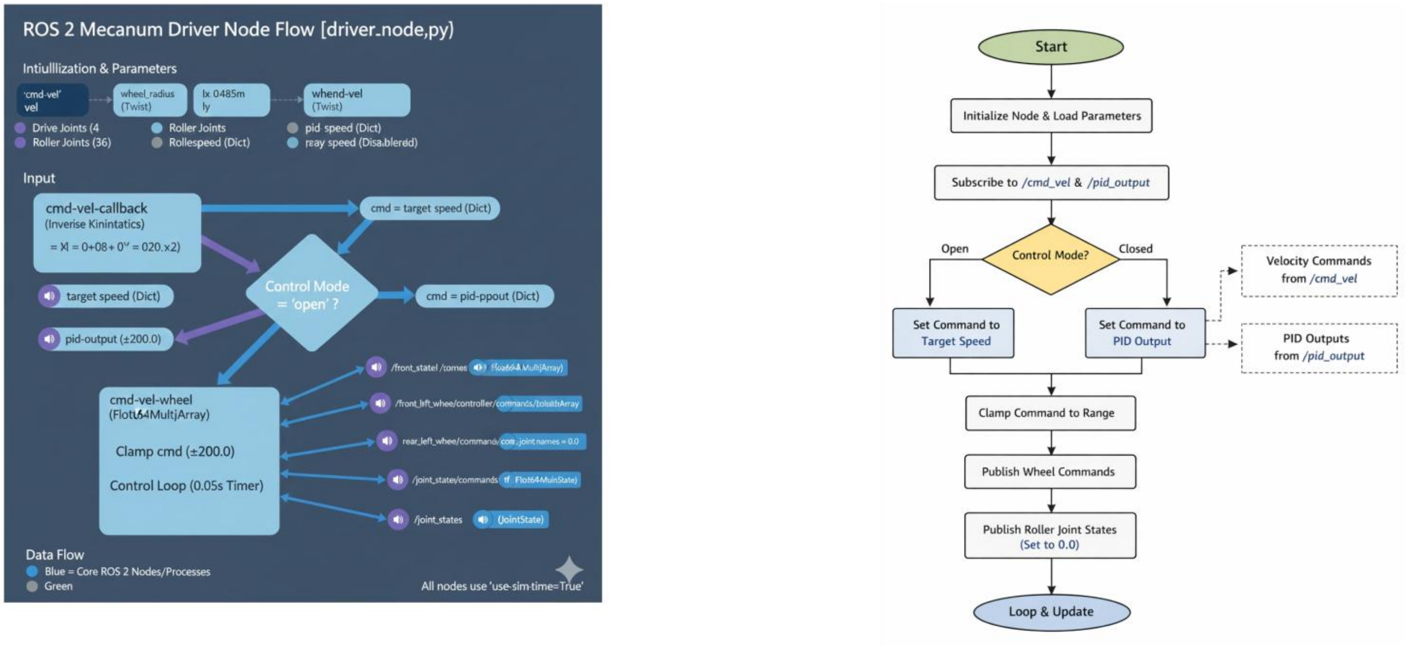


Figure 14 flowchart of driver_node

2- lane_detection_node.py

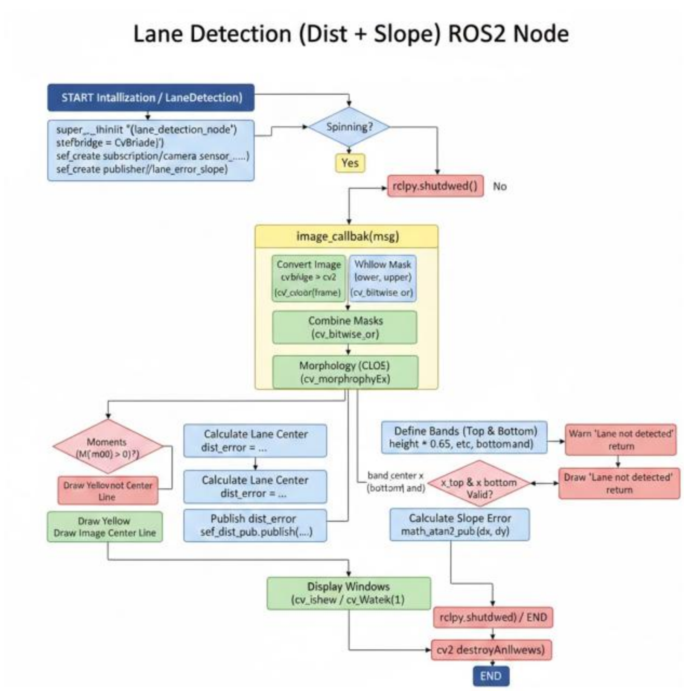


Figure 15 flowchart of lane_detection_node

3- obstacle_Detection_Node.py

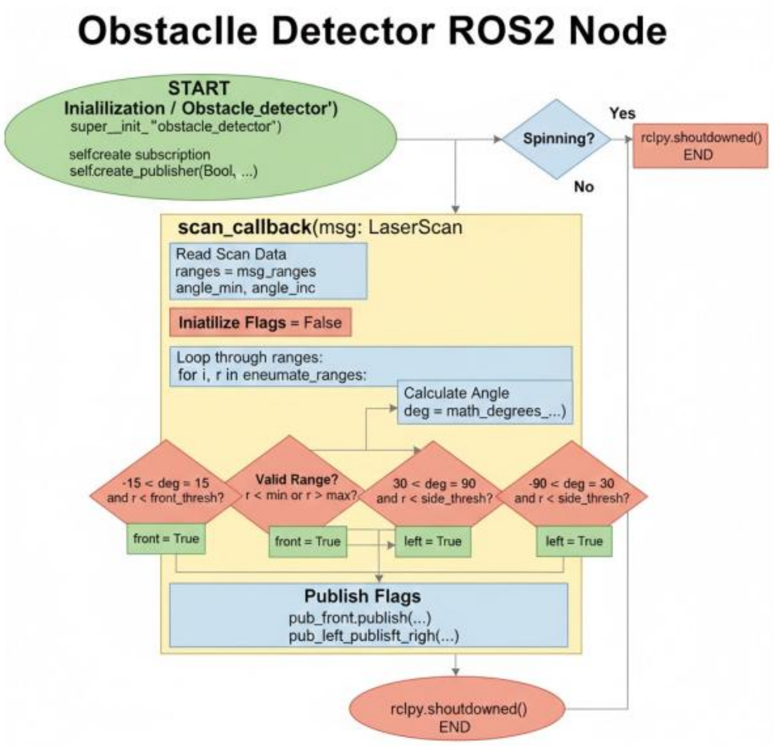


Figure 16 flowchart ofobstacle_detection_node

4- mecanum_motion.py

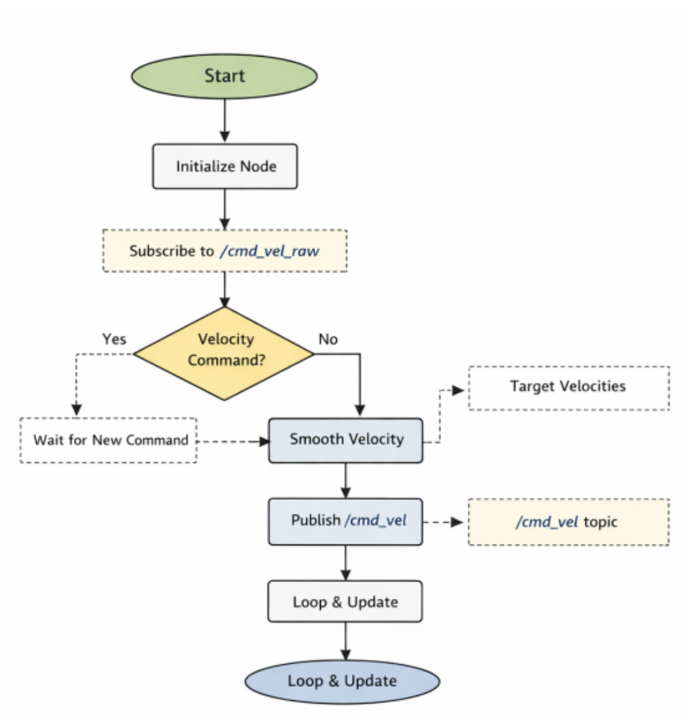


Figure 17 flowchart of mecanum_motion

5- imu.py

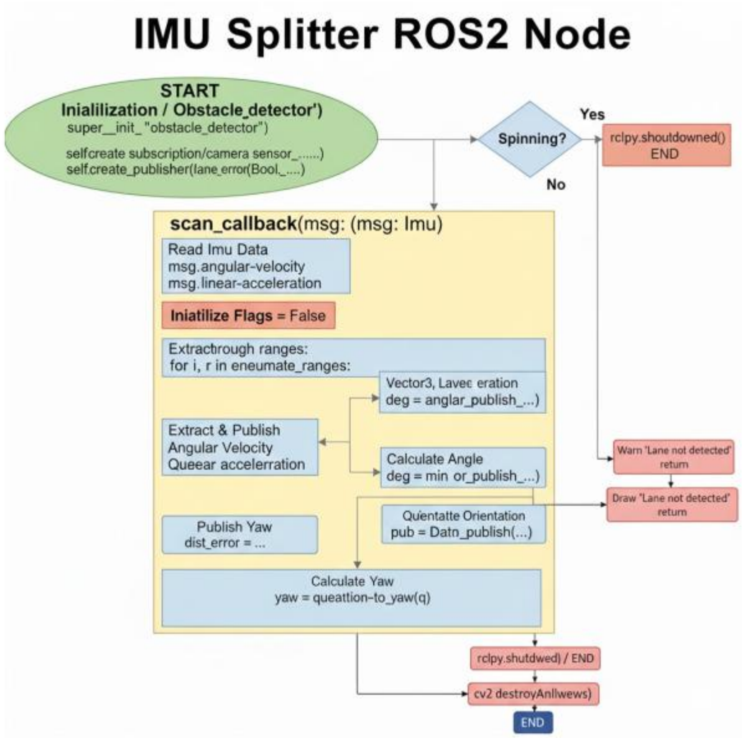


Figure 18 flowchart of imu_node

6- odom_node.py

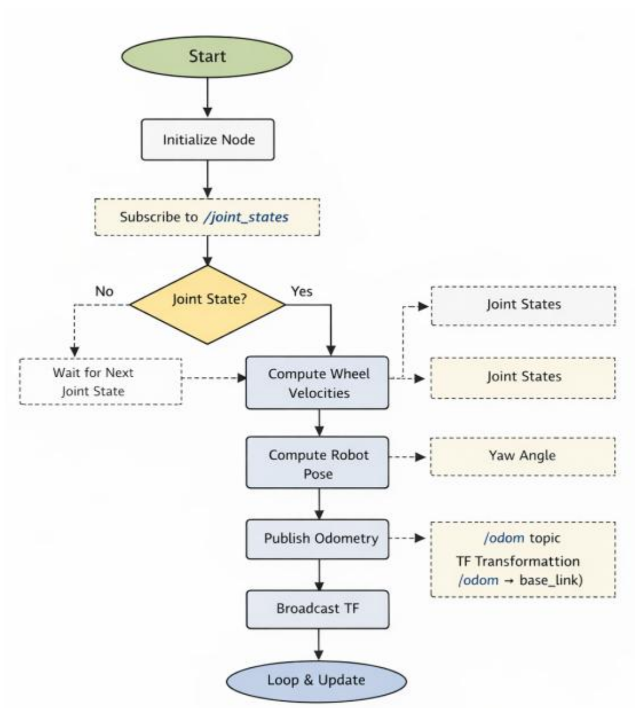


Figure 19 flowchart of odom_node

7- scenario_01.py

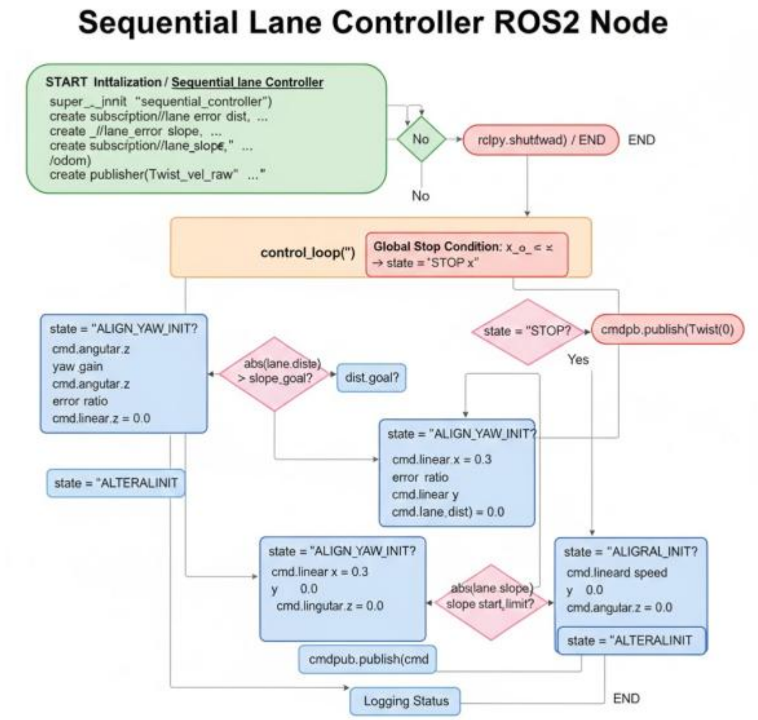


Figure 20 flowchart of scenario_01

8- scenario_02.py

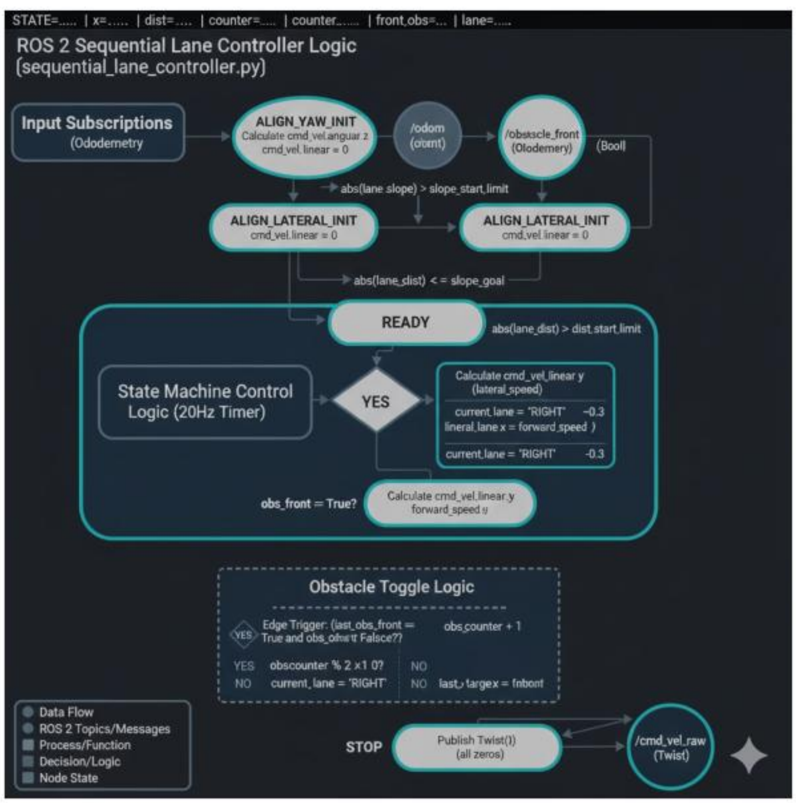


Figure 21 flowchart of scenario_02

REFERENCES

[1] O. Diegel, A. Badve, G. Bright, J. Potgieter, and S. Tlale, “Improved Mecanum Wheel Design for Omni-directional Robots,” no. November, pp. 27–29, 2002.

[2] I. Doroftei, V. Grosu, and V. Spinu, Omnidirectional Mobile Robot - Design and Implementation, Bioinspiration and Robotics Walking and Climbing Robots, no. September. I-Tech, 2007.

[3] R. P. A. van Haendel, “Design of an omnidirectional universal mobile platform,” National University of Singapore, 2005.

[4] T. A. Baede, “Motion control of an omnidirectional mobile robot,” 2006.

[5] X. Li and A. Zell, “Motion control of an omnidirectional mobile robot,” 2006