MODERN CONTROL THEORY

&

DESIGNING TECHNIQUES

PROJECT REPORT ON

UNMANNED GROUND VEHICLE

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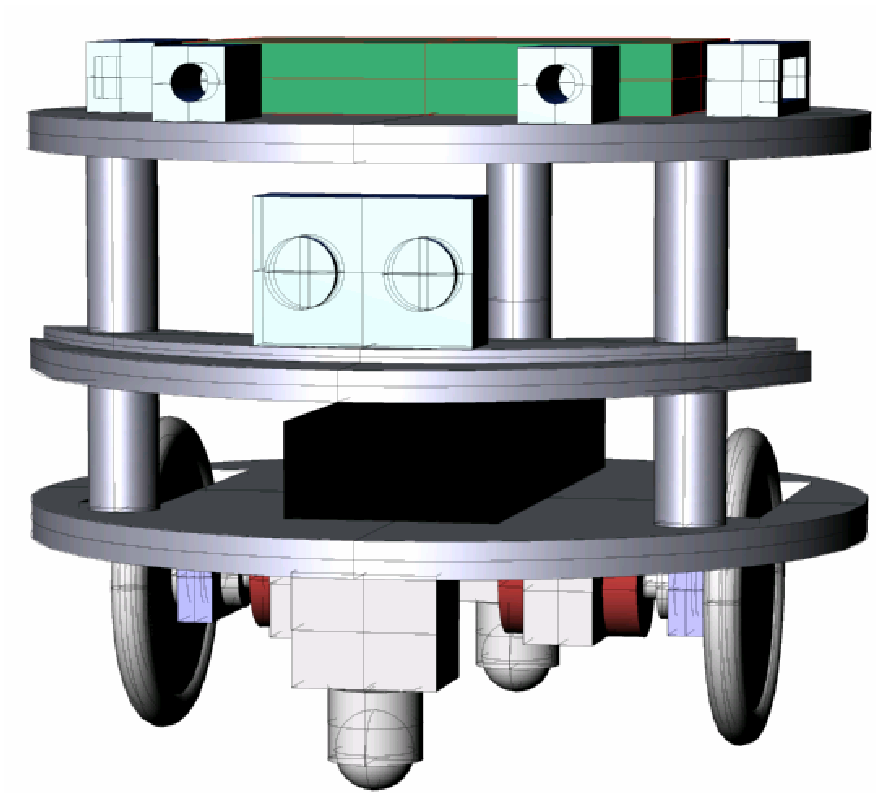
Secondly, we would also like to thank the team members who cooperated a lot in finalizing this project within the limited time frame.

❖ UNMANNED GROUND VEHICLE – INTRODUCTION

An Unmanned Ground vehicle (UGV) is a robot used to augment human capability in both civic and military activities in open terrain. It is used as a human replacement in several dangerous military operations such as handling explosives, diffusing bombs and front line reconnaissance. Generally, the vehicle will have a set of sensors to observe the environment, and will either autonomously make decisions about its behavior or pass the information to a human operator at a different location who will control the vehicle through tele-operation.

The UGV is the land-based counterpart to unmanned aerial vehicles and remotely operated underwater vehicles. Unmanned robotics is being actively developed for both civilian and military use to perform a variety of dull, dirty, and dangerous activities.



Interest in mobile robots has continuously increased in recent years because of the broad range of potential applications. Among them, the differential-drive wheeled mobile robots have exhibited certain superior performance over other types of robots. For example, they are highly mobilisable and the wheel configuration is relatively simple. Due to the advantages, the robots are considered as an ideal candidate for the jobs like supporting disabled persons, mowing lawn and cleaning snow.

In this project, we design the control for the differential drive wheeled mobile robots. We have traversed the robot on a pre-defined path consisting of forward paths and right & left turns.

The basic types of Unmanned Ground Vehicles are:

- Human Controlled
- Autonomous

Human controlled UGVs are basically the UGVs that are controlled by a human operator who can observe the motion in real time in his vicinity and takes decisions for the motion accordingly. It is more like a remote controlled car, but equipped with umpteen number of controls for various tasks. Some of these are task specific as well.

Autonomous UGVs are those that are capable of motion on their own and can perform their tasks independently with the help of its senses that are provided by the various sensors it is equipped with. These UGVs can be related to a line follower, light follower, sound follower, obstacle avoider or any other similar robots. However, these have a large spectrum of functionality and usage.

❖ OBJECTIVE OF THE PROJECT

The aim of the project is to design the control system and the parameters for a UGV an also observe the various parameters that define the state of the control system.
The following objectives have been achieved by us in the project.

- Design of Control System for a UGV
- Design of the Open Loop CS and obtaining the time and frequency responses and stability parameters for the same.
- Design of the Closed Loop CS and obtaining the time and frequency responses and stability parameters for the same.
- Simulation of the control system of the proposed UGV and visualization plots of map traversal by the robot in MATLAB.

❖ PROPOSED UGV

The UGV that we have designed has locomotion based on the principle of Differential drive in robotics. For the closed loop system, using the angular velocities of the two wheels, linear velocity of the robot and its angular velocity have been calculated using which the current position of the robot has been found at every instant.

- **Specifications of the UGV**

Two DC motors with the stall torque of 11 Kg-cm are used to control then motion of the robot. The maximum output power is 2.4W. The corresponding speed is 12.35rad/sec. The equivalent time constant of the motors is measured by the step responses. The value is about 33.2ms.

Based on the data sheet of the motors, the parameters of the motors are chosen as follows: the armature resistance and inductance are 1 Ω and 0.001H, respectively. The torque constant and back-emf constant of the motors are chosen as 0.0191 Kgm/A and V/rad/sec. The inertia of the motor rotor is 7.2e-6 Kgm2/s2. The viscous coefficient of the motor is 3.6e-6 Kgm. The driven wheels with the radius r, of 5.08cm are chosen. The distance between the two wheels, R, is 24cm.

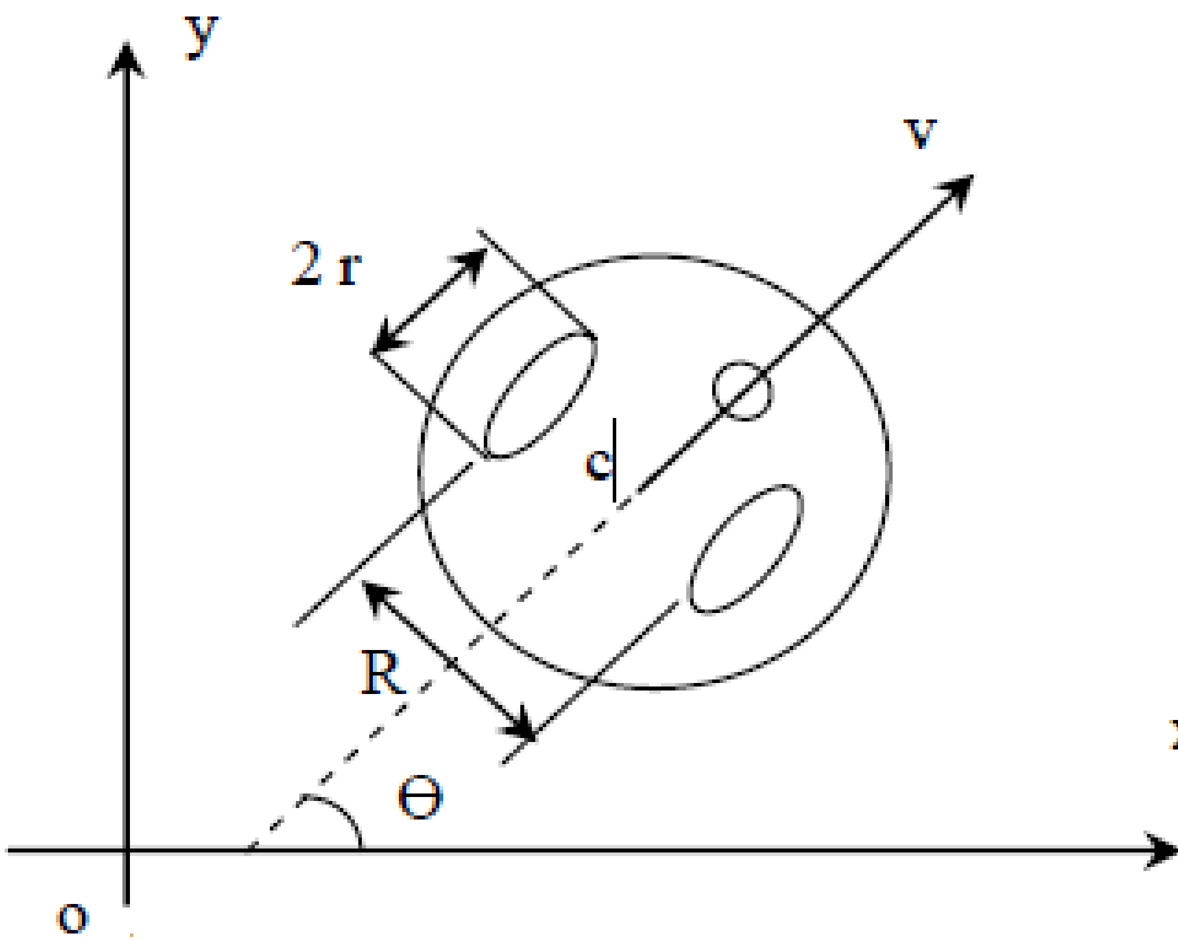


Figure 1: Frame and variable description of the differential-drive wheeled mobile robot

- **Kinematics of the system**

Each of the two motors provides a torque to drive a wheel, which is proportional to the velocity of the wheel. Since the velocities of t0he two wheels can be controlled separately, the resultant velocity at the center of the robot and angular velocity can drive the robot in any desired direction.

Transformation from the angular velocities of each wheel, w1 and w2, to the center velocity, Vc, and the angular velocity of vehicle, Wc is as follows:

The center velocity is $V_c = r * \frac{(w_1+w_2)}{2}$

And the angular velocity, $W_c = r * \frac{(w_2-w_1)}{R}$

W_c is the derivative of velocity angle, θ. We can see that compared to the normal systems, the system has two distinguished characters:
(a) Since two wheels are controlled by two motors with different signals when engaging in turning or other maneuver actions, the system is a multi-input and multi-output system.
(b) With the involvement of the transformation between the position, velocity, angular velocity at the gravity center of the robot in x-y coordinate and the angular velocities of each wheel, the system is described by a highly nonlinear model. Moreover, since the angle of the velocity at the gravity center can change largely between 0^0 and 360^0, the system is required to operate at different operating points. Therefore, the conventional nonlinear system design, using a linearized system around an operating point, often results in a poor performance.

With reference to the design proposed above, we deduce the following equations

$$\dot{x} = \frac{r}{2}\cos\theta\, w_2 + \frac{r}{2}\cos\theta\, w_1$$

$$\dot{y} = \frac{r}{2}\sin\theta\, w_2 + \frac{r}{2}\sin\theta\, w_1$$

$$\dot{\theta} = \frac{r}{R}(w_2 - w_1)$$

Therefore, the above equations can be simplified to form:

$$\theta = \int W_c\, dt$$

$$dx = V_c \cos\theta$$

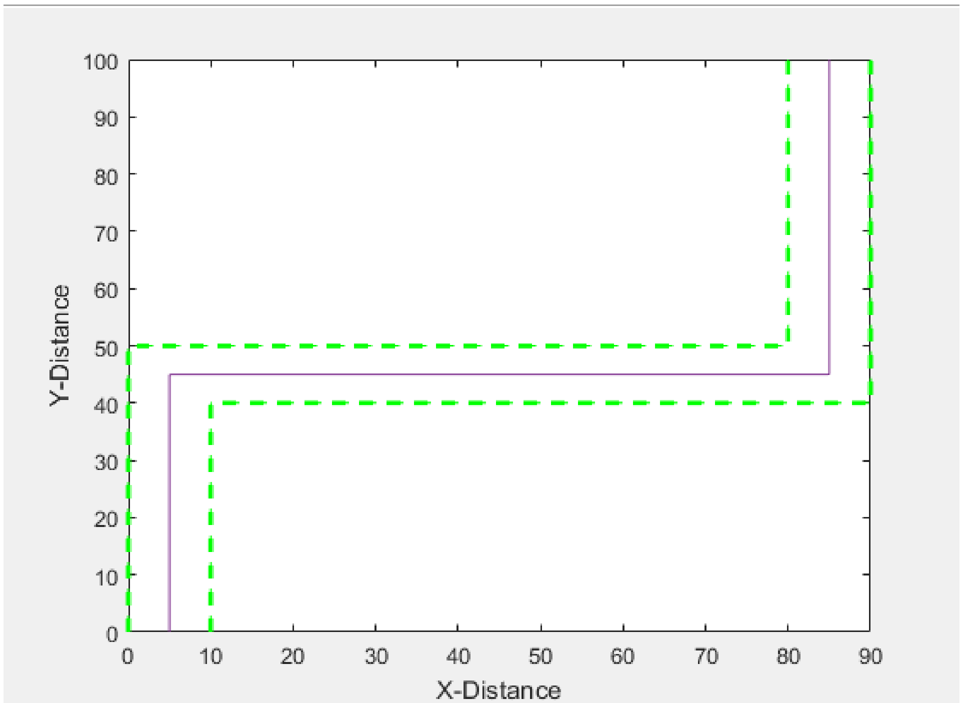
$$dy = V_c \sin\theta$$

And, x_p and y_p (current positions of robot) can be determined by:

$$x_p = \int dx + 5$$
$$y_p = \int dy$$

To the x-coordinate, a bias of 5 meters is added because initial position is taken as (5,0) instead of (0,0).

- **Path of motion of the UGV**



Description of path: The path of robot starts from (5,0). The robot, first, has to turn 90^0 left to change its orientation towards y-axis. Then, it goes forward upto y=45 meters, takes a 90^0 right and heads towards (45,85) where it again turns 90^0 left. Finally it heads forward and stops at (85,100).

In the proposed UGV, we assume an already mapped path for locomotion of the UGV. Generally, an autonomous UGV is supposed to study its surroundings and map the path for its motion thereafter. However, we feed a pre-decided path for the motion and the UGV is supposed to have a feedback system that ascertains its motion and ensures that the desired and the required motion are both in sync.

❖ RESPONSES OF THE SYSTEM

The system has been operated for various conditions. The results obtained were obtained for all the different conditions.

- **Open Loop System**

Open Loop DC Motor Response

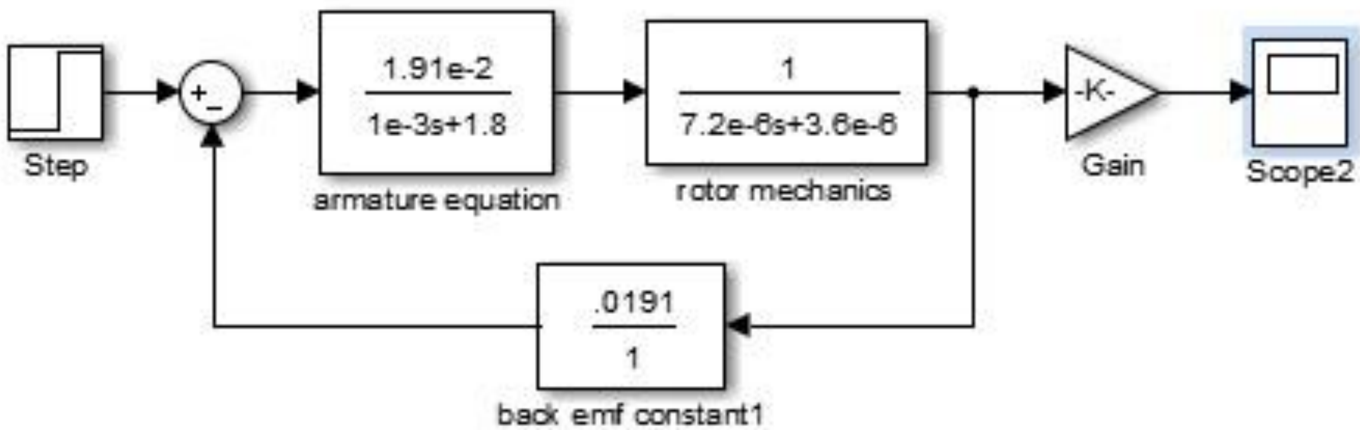
Transfer Function:

$$\frac{0.000382}{7.2e-09\, s^2 + 1.296e-05\, s + 0.0003713}$$

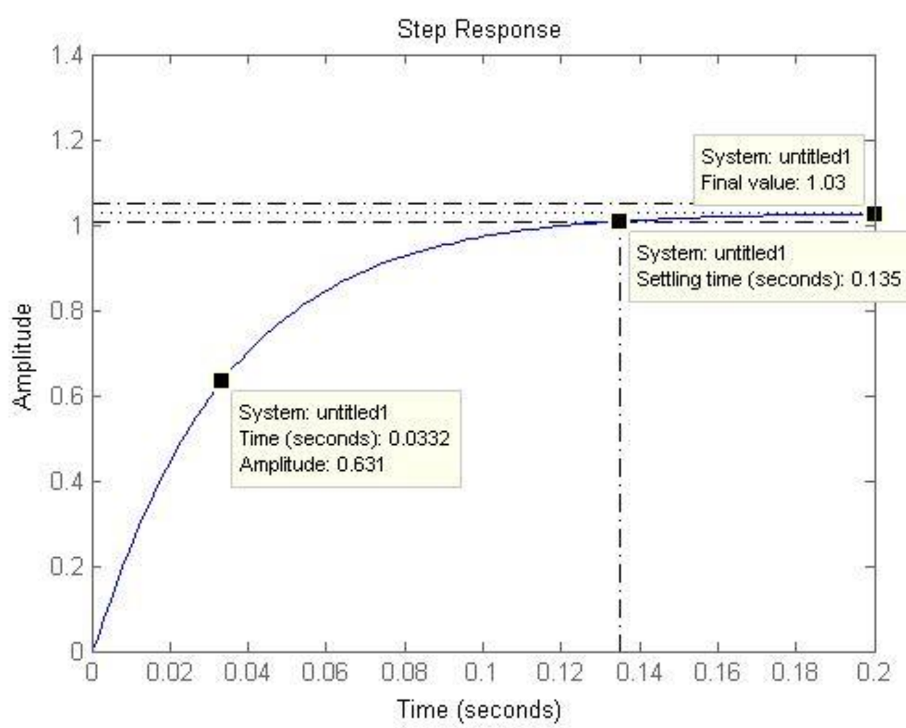
Roots of the function are: 1.0e+03 * [-1.7709 -0.0291]

wn =227.0881

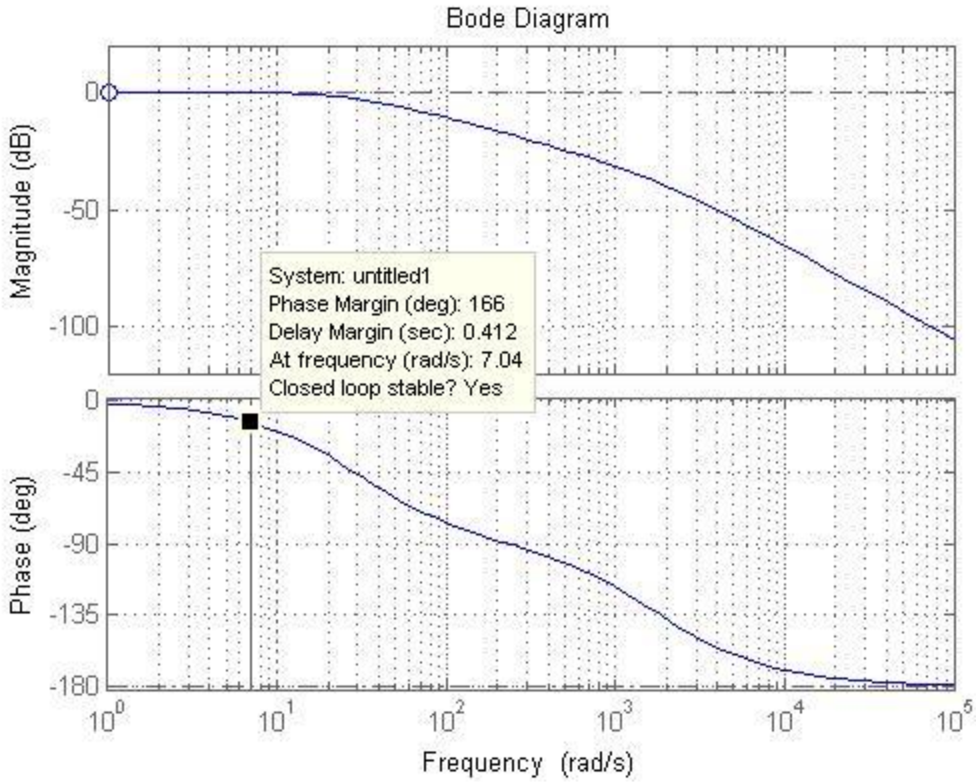
del = 3.9632



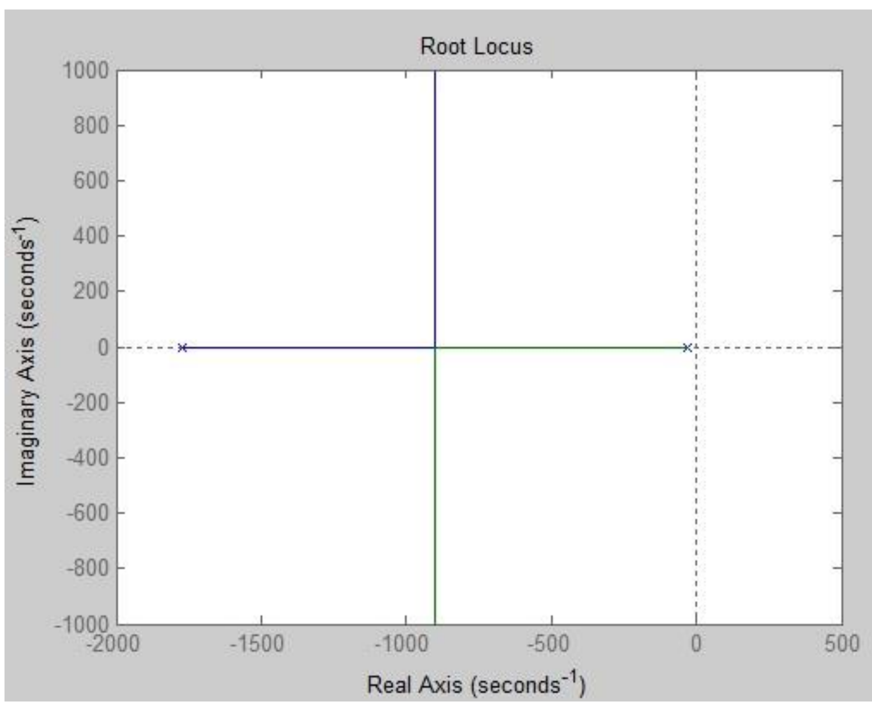
Step Response: (Time Response)



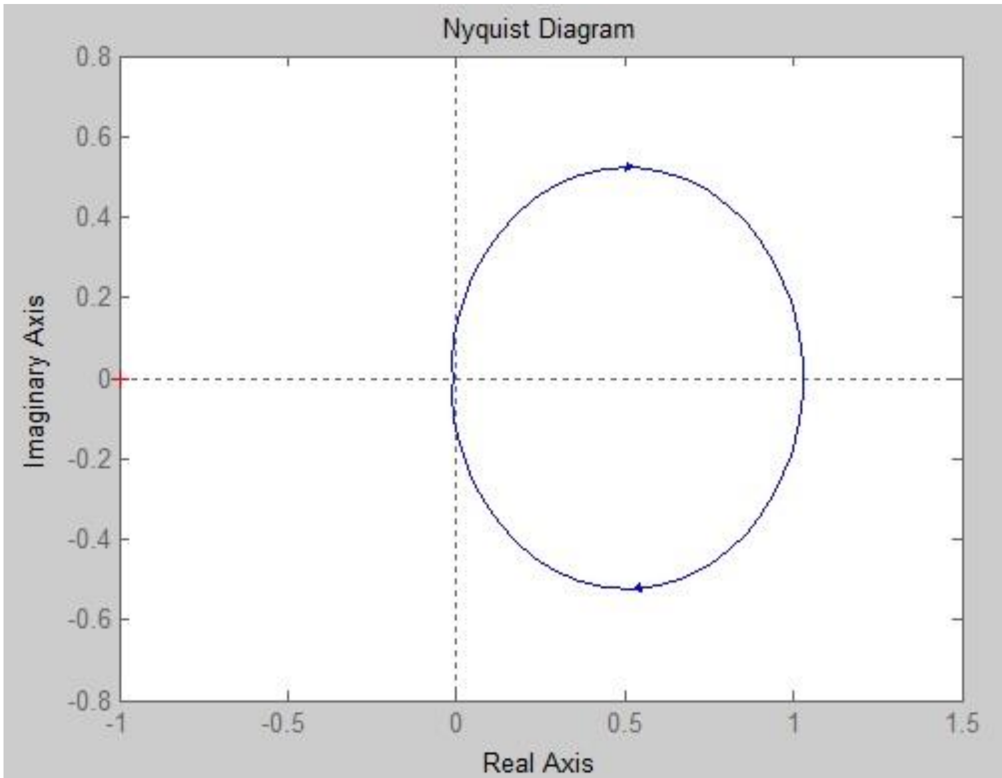
Bode Plot: (Frequency Response)



Root Locus



Nyquist Plot:



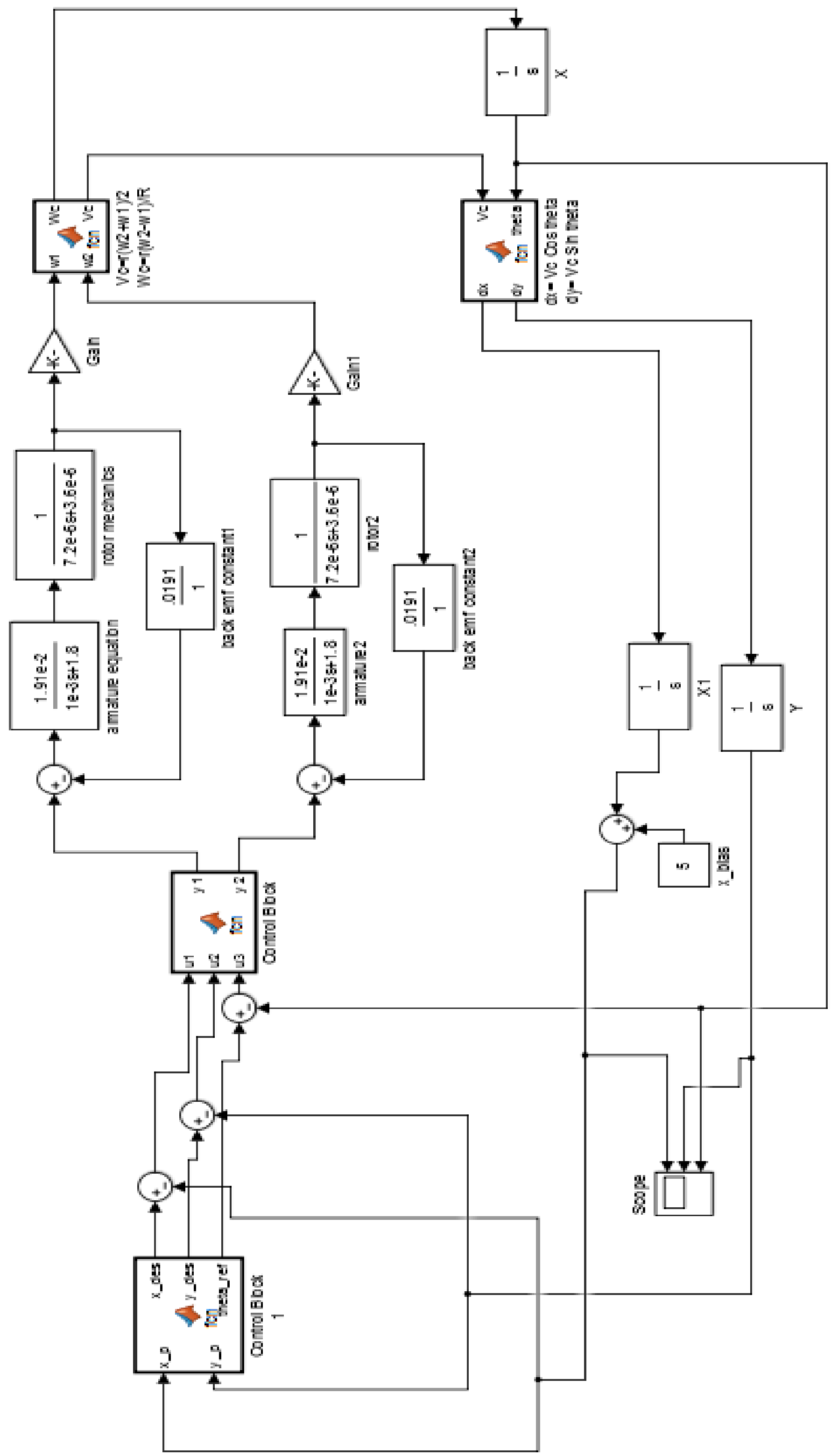
MATLAB Code & Various Parameters of CL System

```
G1=tf([1.91e-2],[1e-3 1.8]);
G2=tf([1],[7.2e-6 3.6e-6]);
H=tf([.0191],[0 1]);
G=G1*G2;
T=feedback(G,H);
stepinfo(T*0.02);
[y t]=step(T*0.02);
ess=abs(1-y(end))
```

Result-

RiseTime: 0.0755
SettlingTime: 0.1350
Overshoot: 0
Undershoot: 0
Peak: 1.0282
PeakTime: 0.2515
ess (%)=2. 57

- **Closed Loop System**



Algorithm:

- Initially the bot starts at (5,0) oriented towards x-axis (theta=0^0).
- The desired values of (x,y) are set using Control Block 1. At initial position condition, x_des and y_des are set as (5,45). Theta_ref is set as π/2.
- Since x_p and y_p are initially (5,0) and theta is 0^0, the respective errors are:

  u1= x_des-x_p=0
  u2= y_des-y_p=45
  u3= x_des-x_p= π/2
- The errors u1, u2 and u3 are fed to Control Block. The error u3 is used to create difference in angular velocity, dw, so that the vehicle can take gradual turns to orient itself correctly.

  dw=K*u3, K=4.49 (by hit n' trial)
- Finally, the Control Block outputs two voltage levels for the two dc motor transfer functions.

  y1=12V-dw
  y2=12V+dw
- The dc motor transfer function inputs y1(and y2) and outputs w1(and w2). Using the individual angular velocities of the wheels, the overall velocity of the robot, Vc, and the overall angular velocity of the robot, Wc, is calculated:

  Vc=r*(w1+w2)/2
  Wc=r*(w2-w1)/R
- Integration of Wc gives θ:

$$\theta = \int W_c \, dt$$

- Using θ and Vc, dx and dy are calculated:

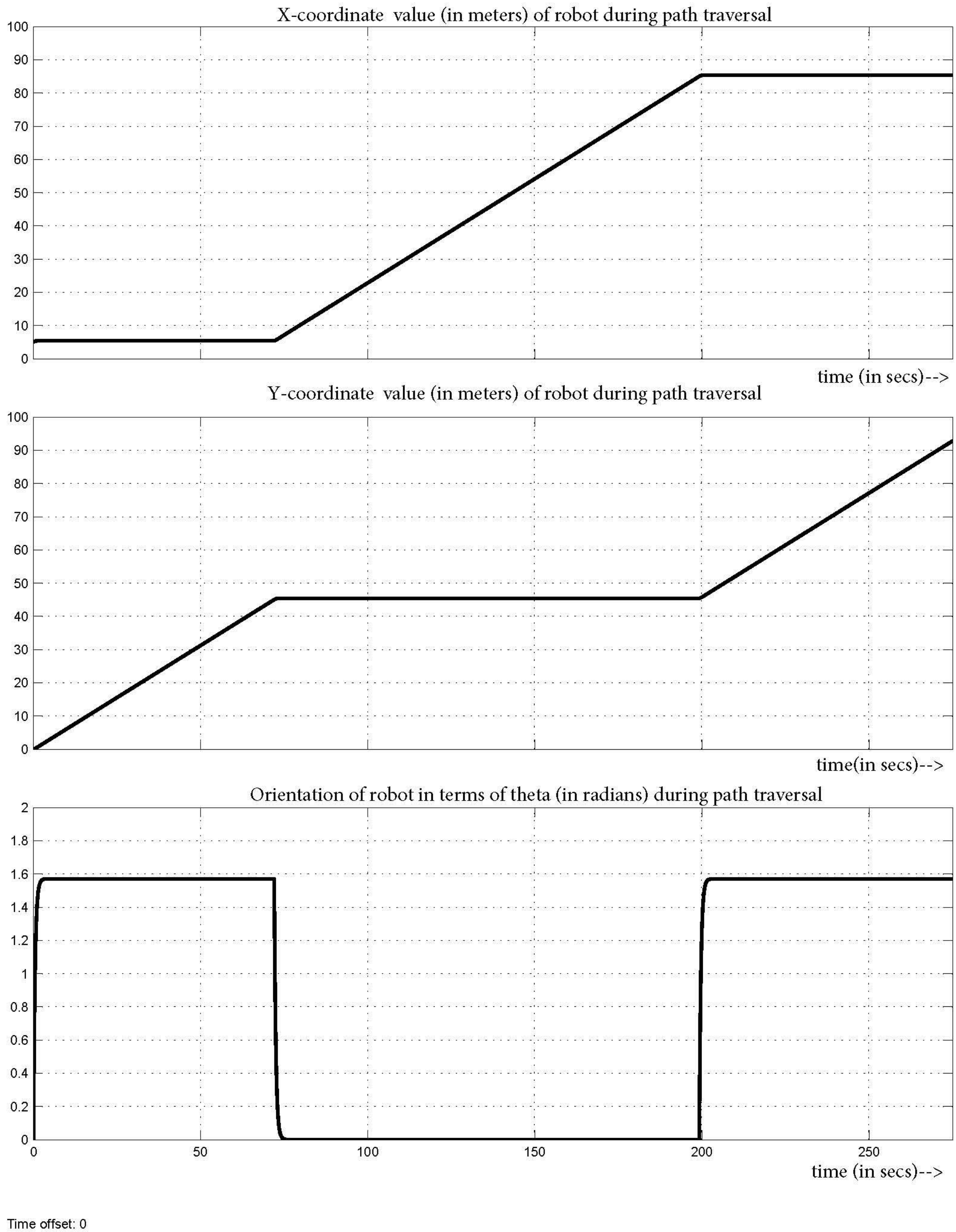
$$dx = V_c \cos\theta$$
$$dy = V_c \sin\theta$$

- Integration gives current position of robot (x_p,y_p):

$$x_p = \int dx + 5$$

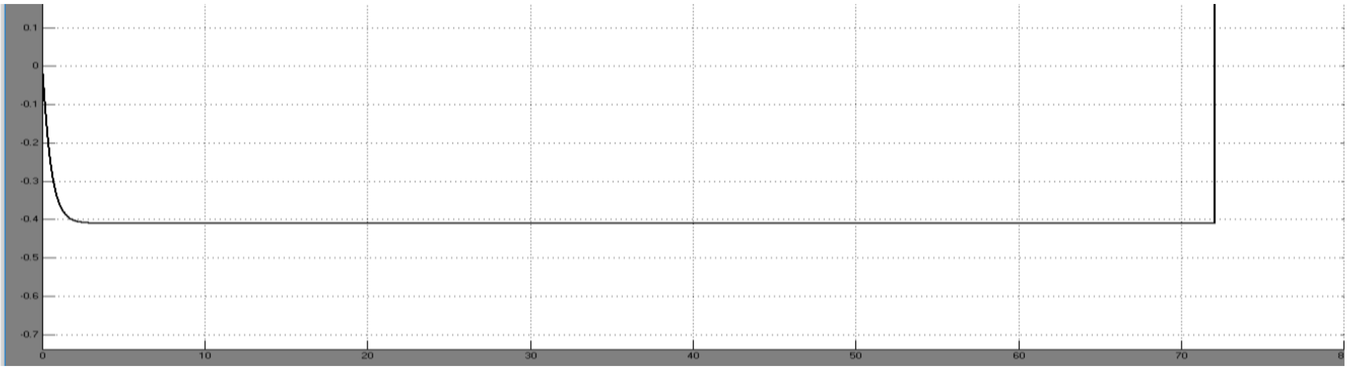
$$y_p = \int dy$$

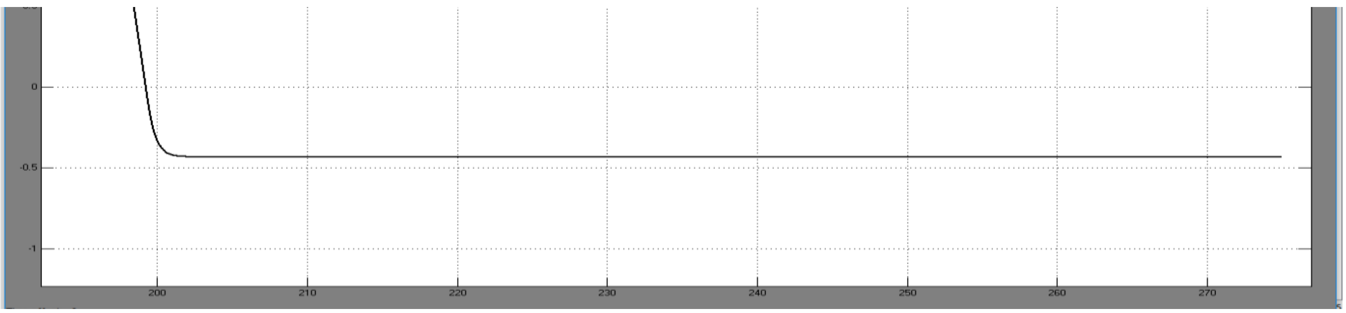
- To the x-coordinate, a bias of 5 meters is added because initial position is taken as (5,0) instead of (0,0).
- The current positions x_p, y_p and θ are logged. Finally, x_p and y_p are used again to update x_des and y_des until the robot reaches (85,100).


X-coordinate value (in meters) of robot during path traversal
time (in secs)-->
Y-coordinate value (in meters) of robot during path traversal
time(in secs)-->
Orientation of robot in terms of theta (in radians) during path traversal
time (in secs)-->
Time offset: 0

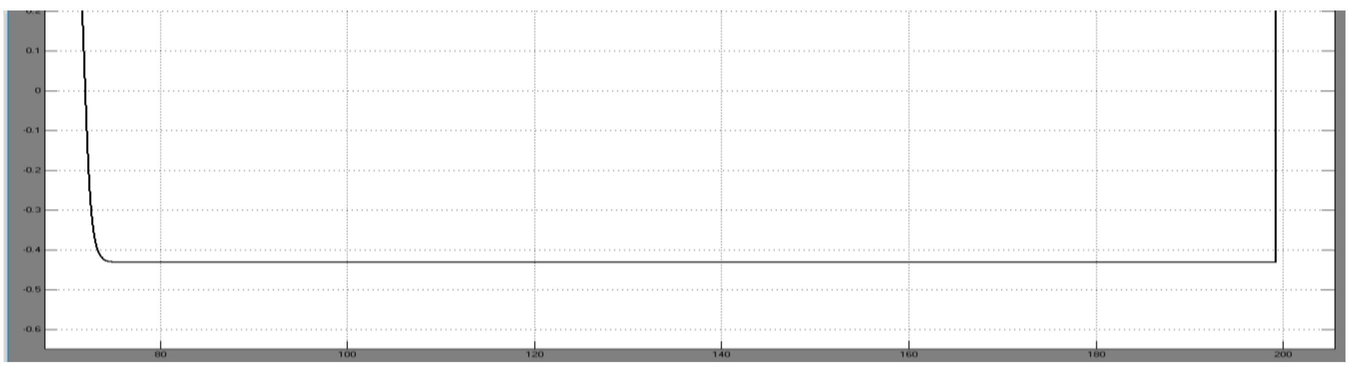
ERROR PLOT IN THE DESIRED CORDINATES

ERROR IN X COORDINATES (DESIRED VALUE (i) X = 5 (ii) x = 85)

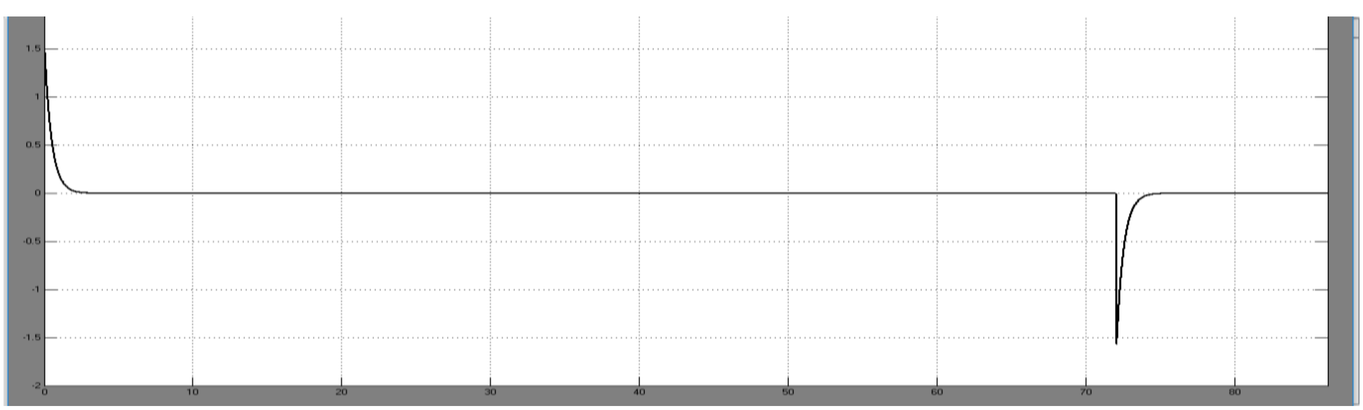




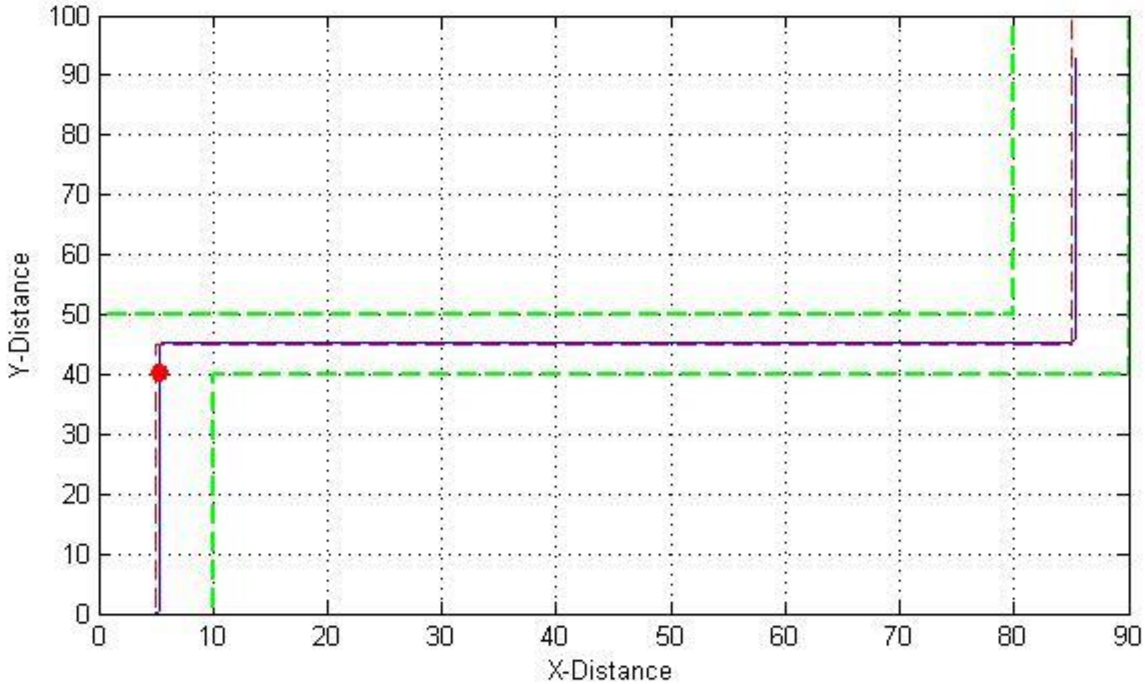
ERROR IN Y CORDINATES (DESIRED VALUE Y = 45)



ERROR IN θ



Position plot of robot's path:



Conclusion

In this project, we designed a closed loop control system for an Unmanned Ground Vehicle based on Differential Drive. The need for UGV comes when human presence on the vehicle is undesirable. The proposed design of the vehicle is able to traverse along a pre-fed map consisting of walls. The vehicle tries to be in the middle of the road by aligning itself parallel to the road as soon as possible. The vehicle is successful in avoiding hitting with the walls. However, there is an error of max ±50cm when a sharp turn comes. This error needs to be reduced using tuned PID controllers. Also, despite lots of advantages, the control design for the mobile robots is not uncomplicated. The MIMO control system tends to become more and more non-linear. Thus, proper techniques need to be introduced to consider this non-linearity as efficiently as possible. This project can be further extended by exploring the effect of various linearization algorithms, employing controllers to reduce errors and interfacing SimuLink with SolidWorks for better visualization.

References

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