# Assignment 2
# EE/CE 468/468 Mobile Robotics
# Habib University – Fall 2023


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October 25, 2023

1. Problem 2

## Code

```
function [phiDotL, phiDotR] = wheelSpeed(v, omega, waypoints, pose)
    % Path constants
    stopThreshold = 0.1;
    slowThreshold = 0.3;

    % Robot constants
    trackWidth = 0.381;
    wheelRadius = 0.195/2;

    % Convert velocity and heading angular velocity to wheel speeds
    phiDotL = (v - trackWidth/2*omega)/wheelRadius;
    phiDotR = (v + trackWidth/2*omega)/wheelRadius;

end
```

2. Problem 3

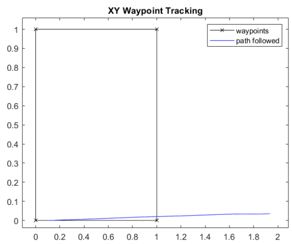
## Code

```
function [LinVel, AngVel] = pidPathFollower(Waypoints,Pose)
    persistent n;
    x = Pose(1);
    y = Pose(2);
    phi = Pose(3);
    R = [cos(phi) sin(phi); -sin(phi) cos(phi)];
```

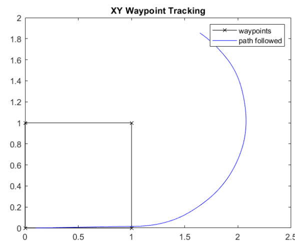
```
    if (isempty(n))
        n = 2;
    end
    % Completed the path
    if n > length(Waypoints)
        LinVel = 0;
        AngVel = 0;
    else

    xg = Waypoints(n, 1);
    yg = Waypoints(n, 2);
    phig = Waypoints(n, 3);

    ep = R*([xg; yg]-[x; y]);
    xe = ep(1);
    ye = ep(2);
    epsilon = 0.02;

    if sqrt(ye^2 + xe^2) < epsilon
        n = n + 1;
    end

    % kp = 0;
    % kd = 0;

    % kp = 10;
    % kd = 0;

    % kp = 50;
    % kd = 0;

    % kp = 50;
    % kd = 10;

    % kp = 50;
    % kd = 0.5;

    kp = 60;
    kd = 0.08;
    LinVel = 0.2*xe + 0.1;
    K = kp*(ye) + kd*sin(phig - phi);
    AngVel = LinVel*K;

    end
end
```

## Discussion

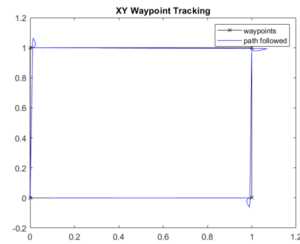
I have added some graphs of when I was tuning the values of $k_p$ and $k_d$



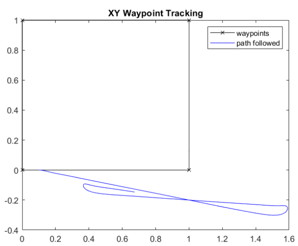

(a) $k_p = 0, k_d = 0$



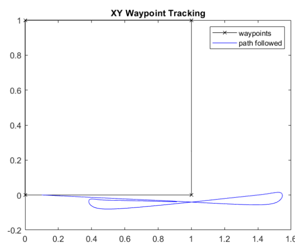

(b) $k_p = 1, k_d = 0$



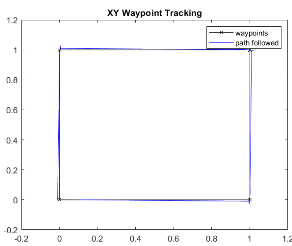

(c) $k_p = 50, kd = 0$




(d) $k_p = 50, k_d = 10$




(e) $k_p = 50, k_d = 2$




(f) $k_p = 50, kd = 0.5$

I began with both $k_p$ and $k_d = 0$, then I started increasing $k_p$ as initially I was getting a very straight path, as I gradually increased $k_p$ the path started converging to the waypoints.

Similarly, after I had tuned $k_p$, I started with a high value of 10 as $k_p$ converged at a higher value, but, this time around my path got even worse, so I realized that the value was too high, then I gradually started decreasing but it was not until I decreased $k_d$ below that I started getting some promising results.

## Waypoint Tracking

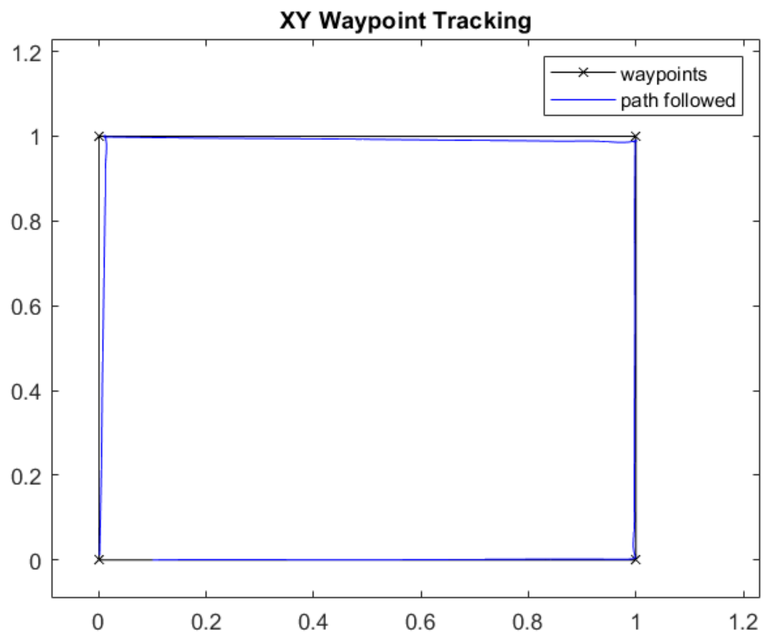



Figure 1: PID Path Follower

3. Problem 4

## Discussion

The square in the previous problem was achieved with $\epsilon = 0.02$, however, that did not work too well with other shapes as it was overfitted for a square.

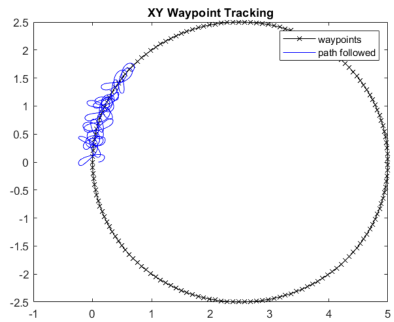



Figure 2: Circle with $\epsilon = 0.02$

Nonetheless, by increasing $\epsilon$ to 0.11 we were able to achieve some very good results. We observed that the robot had some trouble figuring out the path initially as it's orientation was different than the waypoints, but it was still able to perform very well once it was on track.

## Waypoint Tracking

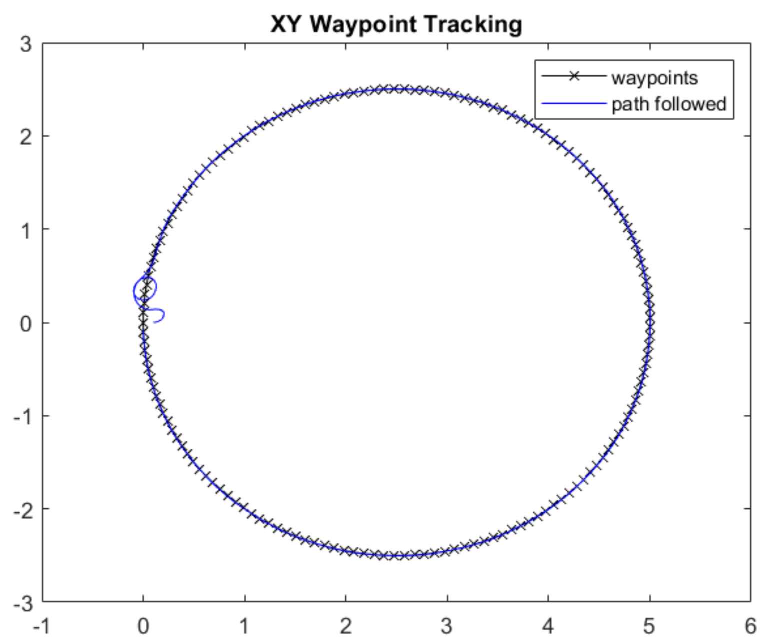



Figure 3: Circle

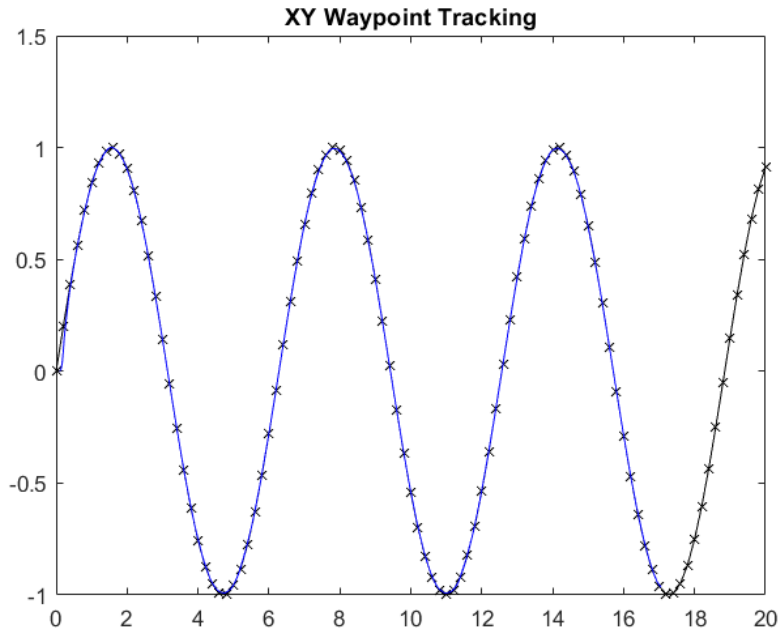



Figure 4: Wave

4. Problem 5

## Code

```
function [v, w] = PurePursuitPathFollower(Pose, WayPoints)
    % Define the lookahead distance
    lookahead_dist = 0.08;

    % Extract the heading angle from the pose
    phi = Pose(3);

    % Calculate trigonometric values for coordinate transformation
    cos_phi = cos(phi);
    sin_phi = sin(phi);

    % Create a rotation matrix for coordinate transformation
    Rot_Mat = [cos_phi, sin_phi; -sin_phi, cos_phi];

    % Initialize a persistent state variable to keep track of the current
        ↪ waypoint
    persistent n;
```

```
    if (isempty(n))
        n = 2; % Start with the second waypoint
    end

    % Check if all waypoints have been reached
    if n > length(WayPoints)
        v = 0; % Set linear velocity to zero
        w = 0; % Set angular velocity to zero
    else
        % Extract the current position
        x = Pose(1);
        y = Pose(2);

        % Calculate the slope of the line connecting the robot to the
            ↪ current waypoint
        m = (WayPoints(n,2) - y) / (WayPoints(n,1) - x);

        % Generate a set of angles to sample candidate goal points
        angles = 0:0.05*pi:2*pi;

        % Calculate x and y coordinates of candidate goal points
        x_cord = x + lookahead_dist * cos(angles);
        y_cord = y + lookahead_dist * sin(angles);

        % Calculate distances from the current waypoint to the candidate
            ↪ goal points
        if m == 0
            distances = abs(y_cord - y);
        elseif isinf(m)
            distances = abs(x_cord - x);
        else
            distances = abs(y_cord - m * x_cord - (WayPoints(n,2) - m*
                ↪ WayPoints(n,1)));
        end

        % Filter out candidate goal points that are too far from the path
        valid_indices = distances < 0.2;
        goal_pointx = x_cord(valid_indices);
        goal_pointy = y_cord(valid_indices);

        % Calculate the distances between candidate goal points and the
            ↪ current waypoint
        dists = sqrt((goal_pointx - WayPoints(n, 1)).^2 + (goal_pointy -
            ↪ WayPoints(n, 2)).^2);

        % Find the index of the minimum distance
```

```
        [min_d, min_idx] = min(dists);

        % Update the goal point based on the index of the minimum distance
        goal_point = [goal_pointx(min_idx); goal_pointy(min_idx)];

        % Extract the x and y coordinates of the current waypoint
        xg = WayPoints(n, 1);
        yg = WayPoints(n, 2);

        % Calculate the error in position relative to the current waypoint
        pose_diff = [xg; yg] - [x; y];

        % Transform the position error into the robot's local coordinate
            ↪ frame
        curr_error = Rot_Mat * pose_diff;
        x_curr_error = curr_error(1);
        y_curr_error = curr_error(2);

        % Calculate the Euclidean distance from the robot to the current
            ↪ waypoint
        d = sqrt(y_curr_error^2 + x_curr_error^2);

        % Define a small value for comparison
        epsilon = 0.02;

        % Determine robot velocity based on the position error
        if d > epsilon
            v = 0.3; % Set linear velocity
            goal_point_diff = goal_point - [Pose(1); Pose(2)];

            % Transform the goal point error into the robot's local
                ↪ coordinate frame
            trans_gpd = Rot_Mat * goal_point_diff;

            % Calculate steering angle based on the transformed error
            lambda = 2 * trans_gpd(2) / lookahead_dist^2;
            w = 0.5 * lambda; % Set angular velocity
        else
            % Proceed to the next waypoint
            n = n + 1;
            v = 0; % Set linear velocity to zero
            w = 0; % Set angular velocity to zero
        end
    end
end
```

## Discussion

The above *Pure Pursuit path following* algorithm was tested on different values of look-ahead distance, linear velocity and the constant of angular velocity. Different metrics yielded different results. It is important to note that smaller values of look-ahead distance resulted in better results of the robot tracking the waypoints. However, only changing the look-ahead distance was not important, since the value of look-ahead distance was kept small, it was imperative that the linear velocity was not very high because that was resulting in bad tracking and almost skidding of the gazebo robot. This is why it is important that a combination of a small look-ahead distance value with a slow linear velocity. The angular velocity was also managed in a manner that did not result in sudden turns, and a higher constant resulted in the robot turning sharply which was resulting in inaccurate path following.

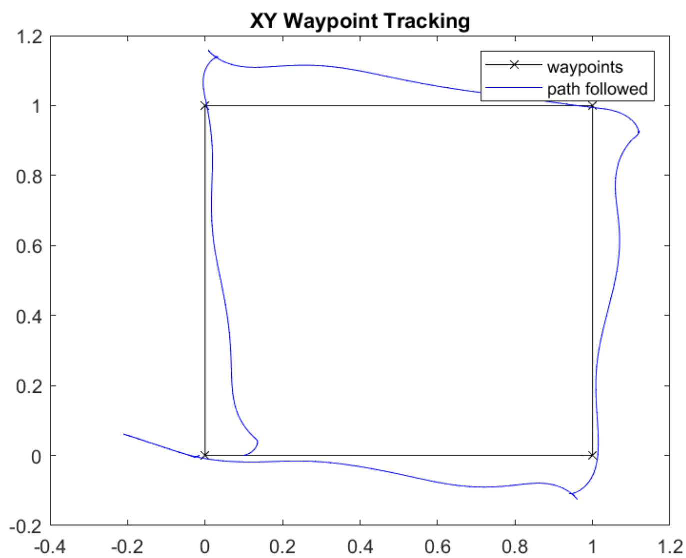



Figure 5: This is robot tracking at a small look-ahead distance value 0.08 but a relatively bigger linear velocity of 1

## Waypoint Tracking

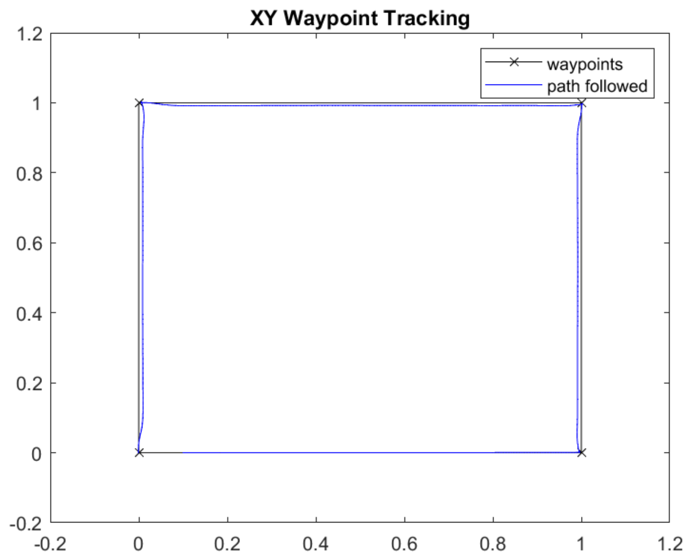



Figure 6: Square

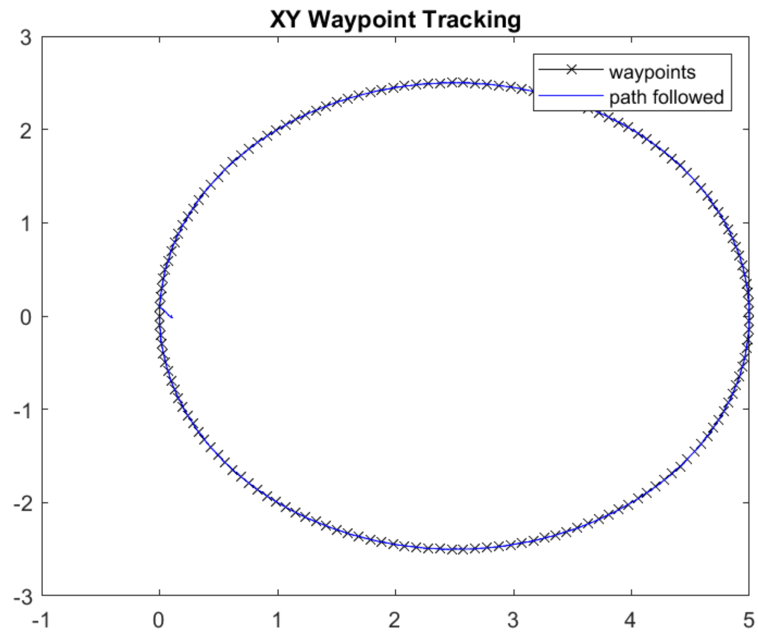



Figure 7: Circle

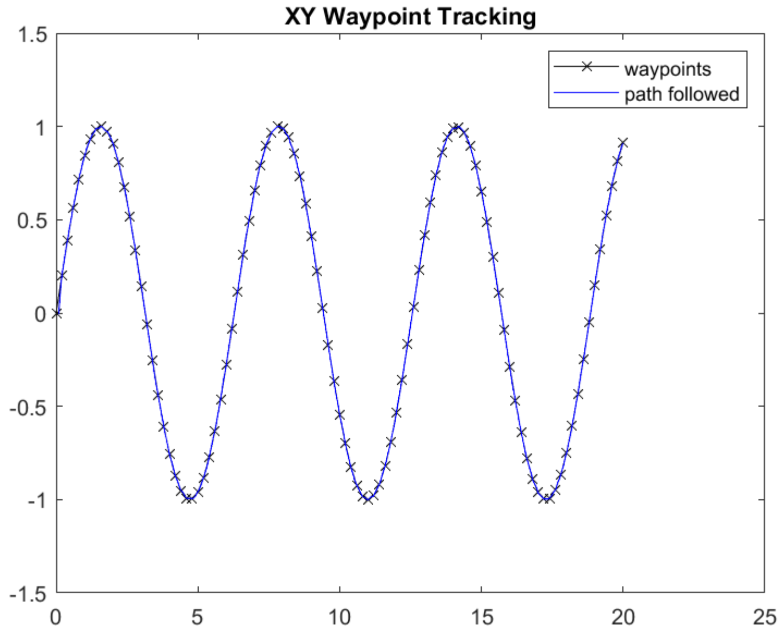



Figure 8: Wave

5. Problem 6

## Code

```
function odo_pose = Odometery(wheelSpeed)
    persistent x;
    persistent y;
    persistent phi;
    phiDotL = wheelSpeed(1);
    phiDotR = wheelSpeed(2);
    if isempty(x)
        x = 0;
        y = 0;
        phi = 0;
        odo_pose = [x; y; phi];
    else
        trackWidth = 0.381;
        wheelRadius = 0.195/2;
        LinVel = (phiDotL + phiDotR) * wheelRadius/2;
        AngVel = (phiDotR - phiDotL) * wheelRadius/trackWidth;
```

```
        x = x + (LinVel * 0.01/2 * (cos(phi) + cos(phi + 0.01 * AngVel)));
        y = y + (LinVel * 0.01/2 * (sin(phi) + sin(phi + 0.01 * AngVel)));
        phi = phi + 0.01 * AngVel;
        odo_pose = [x; y; phi;];
    end
end
```

## Waypoint Tracking

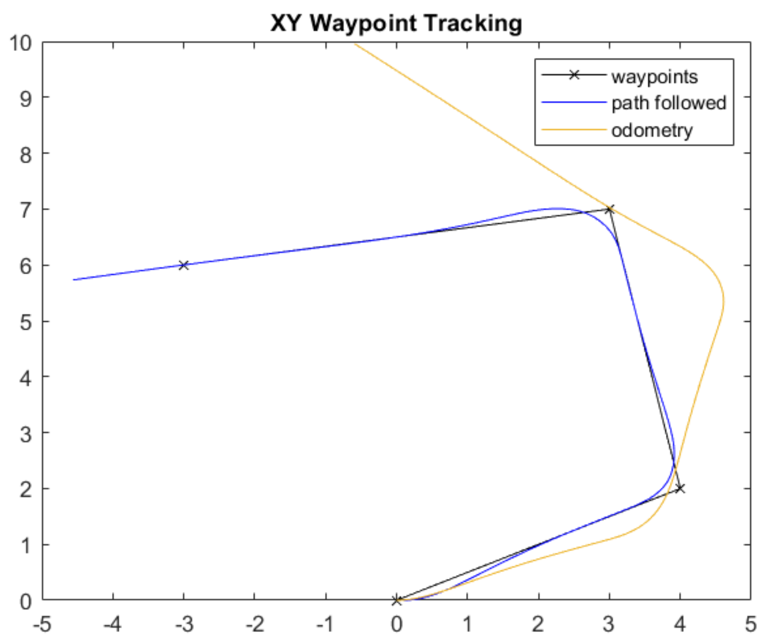



Figure 9: Caption

## Discussion

We can see that using the default pure pursuit controller, our robot has followed the path correctly however the odometry is way off track. There are a couple of notable observations that can be made from the graph.

1. The initial straight path of odometry to the 1st waypoint is not that off track, however when the robot turns i.e the angular velocity increases, the sensors are unable to accurately measure that which leads to the cross-track error. Once again as the robot turns, the odometry shown has an angle lesser than the actual robot path

2. On the second hand, we see little error along the direction of the robot i.e the straight paths taken by the robot are similar in length to those of the intended path.

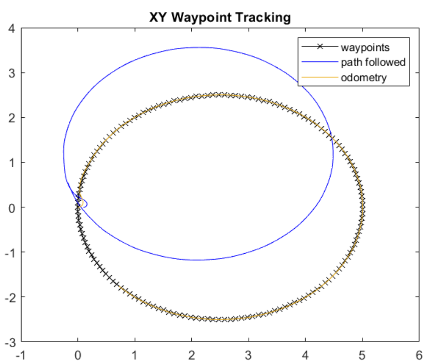
6. Problem 7

## Discussion

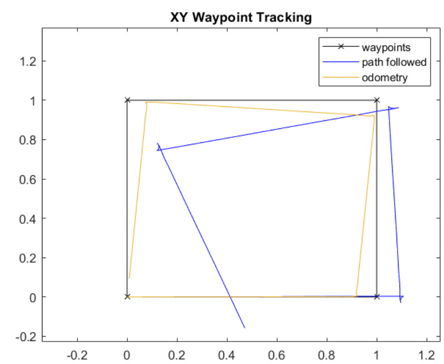
We observed that the shape tracked by the robot was almost the same for the circle and the wave as the intended path, however, both were translated a little. We also observed that the error in the measurement was increasing which was more visible in the wave.

As for the square, we saw similar behavior from the odometry from the previous part, it underestimated the angular velocity of the robot which resulted in the robot turning more than it should.

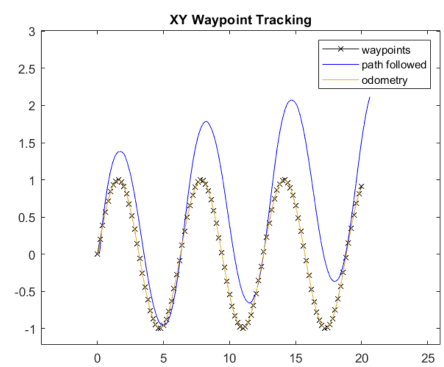
### Waypoint Tracking




(a) PID Circle




(b) PID Square




(c) PID Wave

7. Problem 8

(a) Part a

**Solution:**

### Ali Asghar Yousuf

20 hours

### Muhammad Azeem Haider

22 hours

(b) Part b

**Solution:**

### Ali Asghar Yousuf

1. Q1
2. Q3
3. Q4
4. Q6

### Muhammad Azeem Haider

1. Q1
2. Q2
3. Q5
4. Q7

(c) Part c

**Solution:**

### Ali Asghar Yousuf

I applied my understanding of pid controllers to attempt problems 3 and 4. The velocities of robot $(v, \omega)$ depend on the error in position and the heading angle. As for problem 6, I applied my understanding of the kinematics of a differential drive robot to calculate the linear and angular velocities of the robot and use that to calculate the pose of the robot.

- I faced a number of challenges while attempting this homework, the first one was obviously figuring out MATLAB as it was my first time using it. Setting up gazebo was pretty simple as compared to my preconceived notions.
- I was pretty confused about the PID controller at first, but after reading the slides and asking some friends, I was able to understand the concept and implement it.

## Muhammad Azeem Haider

The bulk of my time in this homework was spent on first figuring out how to setup Matlab with gazebo simulator, once that was done, the second biggest challenge was writing Pure Pursuit Path Following algorithm. The research paper from Carnegie Mellon University explains the algorithm in a simple manner but it proved to be a time consuming task because I was unable to figure out what was the best way to calculate the distance from the current position to the goal position. Question 7 was comparatively simpler but the result achieved was not as good because of the sensors used in Matlab I believe. I would still want to brush up prior concepts that were used in the Pure Pursuit Path Following algorithm.