HW4 ME5501 – Robotics and Unmanned Systems

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Problem 1

Complete the following ROS tutorials at `https://docs.ros.org/en/foxy/Tutorials.html`

- Understanding ROS Nodes
- Understanding ROS Topics

Save a screenshot of the Turtlebot simulator and show/print the screenshot.

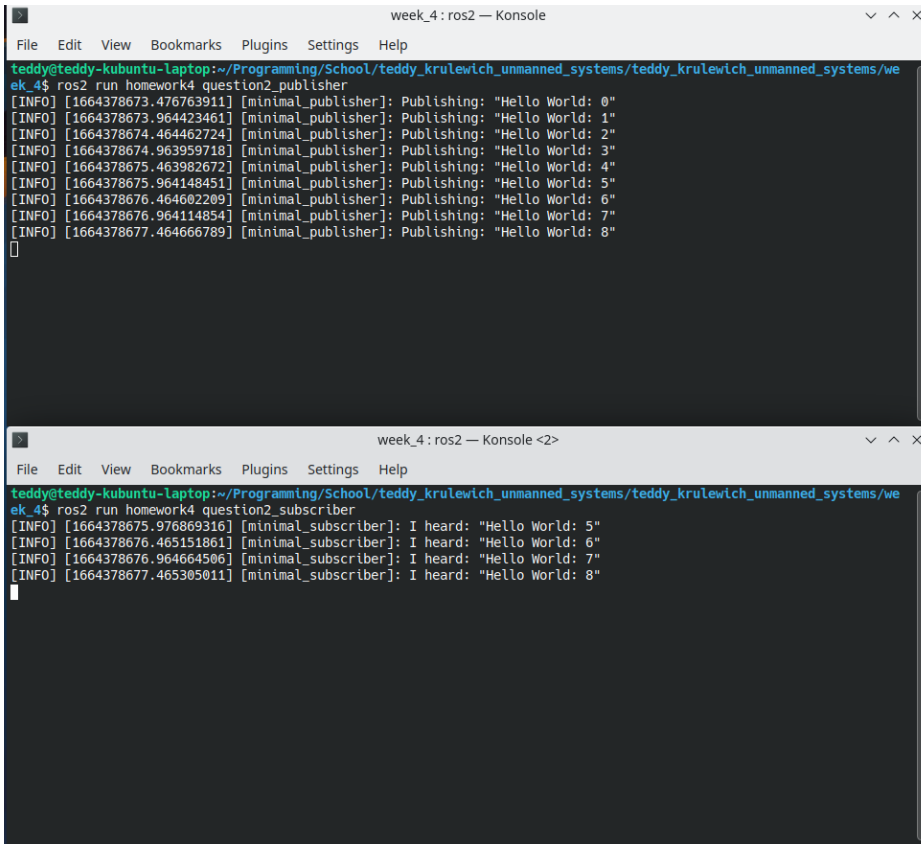
Screenshot of Turtlebot Simulator

Problem 2

Complete the following ROS tutorials at
`http://wiki.ros.org/ROS/Tutorials`

- 12. Writing a Simple Publisher and Subscriber (Python)
- 13. Examining the Simple Publisher and Subscriber

Save a screenshot of the running code in tutorials 13, and print these screenshots to turn in.



Screenshot of subscriber and publisher running

Problem 3

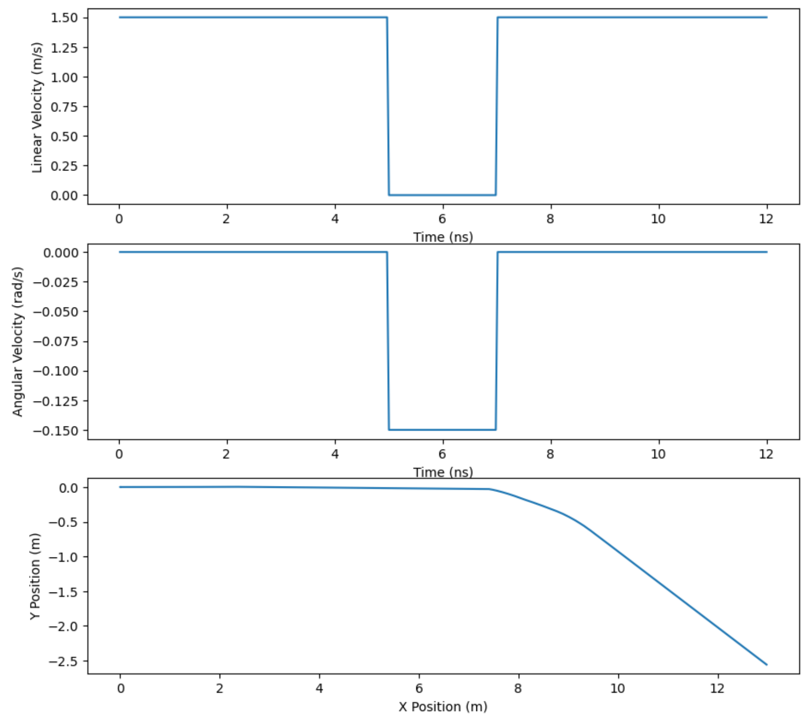
For this problem you will be using ROS2 and Gazebo to simulate the Turtlebot3 Burger platform. Help in loading the simulation can be found at `http://emanual.robotis.com/docs/en/platform/turtlebot3/simulation/`.

Make sure to go to the Gazebo part of the E-manual. When setting the model type, replace "${TB3_MODEL}" with "burger."

Create a ROS2 node that makes the Turtlebot3 travel forward at 1.5 m/s (remember this speed is much faster than it can do in real life) for 5 seconds, then turns to the right at 0.15 rad/s for 2 seconds, then continues forward at 1.5 m/s for another 5 seconds before stopping. Log the position data, and velocity & angular velocity commands.

Create a subplot of the x & y position data, velocity & angular velocity commands versus time.

Submit your Python code.



Plot of position data, velocity, and angular velocity commands versus time

```python
import rclpy
from rclpy.node import Node

from geometry_msgs.msg import Twist
from nav_msgs.msg import Odometry

import matplotlib.pyplot as plt
import numpy as np
import math

def euler_from_quaternion(x:float, y:float, z:float, w:float) -> tuple:
  """
```

```
  Convert a quaternion into euler angles (roll, pitch, yaw)
  roll is rotation around x in radians (counterclockwise)
  pitch is rotation around y in radians (counterclockwise)
  yaw is rotation around z in radians (counterclockwise)
  """
  t0 = +2.0 * (w * x + y * z)
  t1 = +1.0 - 2.0 * (x * x + y * y)
  roll_x = math.atan2(t0, t1)

  t2 = +2.0 * (w * y - z * x)
  t2 = +1.0 if t2 > +1.0 else t2
  t2 = -1.0 if t2 < -1.0 else t2
  pitch_y = math.asin(t2)

  t3 = +2.0 * (w * z + x * y)
  t4 = +1.0 - 2.0 * (y * y + z * z)
  yaw_z = math.atan2(t3, t4)

  return roll_x, pitch_y, yaw_z # in radians


class TurtleBotController(Node):
  # A commanded foward and rotation velocity for the turtlebot with
  #  a specified duration
  class VelocityCommand:
  def __init__(self, linear, angular, duration):
  self.twist = Twist()
  self.twist.linear.x = linear
  self.twist.angular.z = angular
  self.duration = duration

  def __init__(self):
  super().__init__('turtlebot_controller')

  # create a publisher to send velocity commands to the turtlebot
  self.cmd_vel_publisher = self.create_publisher(Twist, 'cmd_vel', 10)
  # create a subscriber to read sensor data
  self.odom_subscriber = self.create_subscription(Odometry, 'odom',
  self.odom_callback, 10)

  # will store a list of commands to execute
  self.velocity_commands = []

  # store the time the node was started
  self.start_time = self.get_clock().now().nanoseconds
  self.time_command_started = self.start_time

  # when all commands are executed will be true
  self.done = False

  # tracks the state of commands, position, and angle over time
  self.state_records = { 'cmd_vel_linear': [], 'cmd_vel_angular': [],
  'x': [], 'y': [], 'theta': [] }



  def add_move_command(self, linear, angular, duration):
```

```python
  self.velocity_commands.append(
  TurtleBotController.VelocityCommand(linear, angular, duration))

  def odom_callback(self, msg):
  time = self.get_clock().now().nanoseconds
  # the total time elapsed since the node started
  time_elapsed_total = time - self.start_time

  # the time elapsed while executing current command
  time_elapsed_command = time - self.time_command_started

  # store current sensor data for logging and plotting
  self.state_records['x'].append(
  (time_elapsed_total, msg.pose.pose.position.x))

  self.state_records['y'].append(
  (time_elapsed_total, msg.pose.pose.position.y))

  theta = euler_from_quaternion(
  msg.pose.pose.orientation.x,
  msg.pose.pose.orientation.y,
  msg.pose.pose.orientation.z,
  msg.pose.pose.orientation.w)[2]

  self.state_records['theta'].append((time_elapsed_total, theta))

  # if we have not finished executing commands
  if len(self.velocity_commands) > 0:
  # if the current command has executed for the specified duration
  # then move on to the next command
  if time_elapsed_command >= self.velocity_commands[0].duration:
  self.velocity_commands.pop(0)
  self.time_command_started = self.get_clock().now().nanoseconds

  # if there are no remaining commands we are done!
  if len(self.velocity_commands) == 0:
  # publishes an empty Twist velocity causing the
  # turtlebot to stop moving
  self.cmd_vel_publisher.publish(Twist())
  self.get_logger().info('No more commands')

  self.done = True
  return

  # store the current command velocities for logging and plotting
  self.state_records['cmd_vel_linear'].append(
  (time_elapsed_total, self.velocity_commands[0].twist.linear.x))

  self.state_records['cmd_vel_angular'].append(
  (time_elapsed_total, self.velocity_commands[0].twist.angular.z))

  # publish the velocity command to the turtle bot
  self.cmd_vel_publisher.publish(self.velocity_commands[0].twist)

def main(args=None):
  rclpy.init(args=args)

```

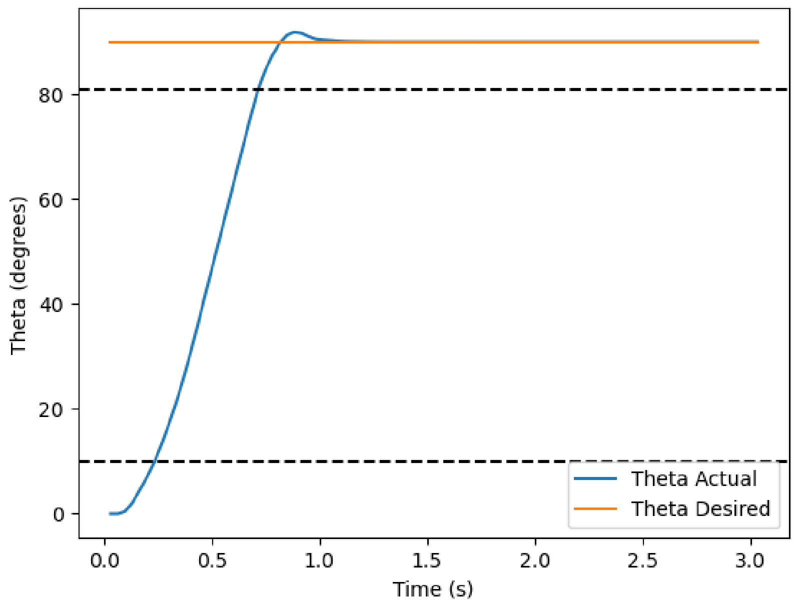
```python
  # create a turtlebot
  turtlebot_controller = TurtleBotController()

  # command the turtlebot to move forward at 1.5 m/s for 5 seconds
  turtlebot_controller.add_move_command(1.5, 0.0, 5000000000)
  # then comand the turtlebot to turn at 0.15 rad/s for 2 seconds
  turtlebot_controller.add_move_command(0.0, -0.15, 2000000000)
  # then command the turtle bot to move forward at 1.5 m/s for 5 seconds
  turtlebot_controller.add_move_command(1.5, 0.0, 5000000000)

  # while the turtle bot hasn't finsihed executing its commands, update the node
  while not turtlebot_controller.done:
  rclpy.spin_once(turtlebot_controller)


  fig, ax = plt.subplots(3, 1)

  # plot the linear velocity command vs time
  ax[0].plot([x[0] / 1000000000 for x in
  turtlebot_controller.state_records['cmd_vel_linear']],
  [x[1] for x in turtlebot_controller.state_records['cmd_vel_linear']],
  label='linear')

  ax[0].set_xlabel('Time (ns)')
  ax[0].set_ylabel('Linear Velocity (m/s)')

  # plot the angular velocity command vs time
  ax[1].plot([x[0] / 1000000000 for x in
  turtlebot_controller.state_records['cmd_vel_angular']],
  [x[1] for x in turtlebot_controller.state_records['cmd_vel_angular']],
  label='angular')

  ax[1].set_xlabel('Time (ns)')
  ax[1].set_ylabel('Angular Velocity (rad/s)')

  # plot the x and y position of the turtlebot, showing the path
  ax[2].plot([x[1] for x in turtlebot_controller.state_records['x']],
  [y[1] for y in turtlebot_controller.state_records['y']], label='y')

  ax[2].set_xlabel('X Position (m)')
  ax[2].set_ylabel('Y Position (m)')


  plt.show()


  turtlebot_controller.destroy_node()
  rclpy.shutdown()


if __name__ == '__main__':
  main()
```

Problem 4

Create a ROS2 node/script that uses a feedback controller to control the heading of the Turtlebot3. Once you have adequately tuned the controller, collect the data (by writing to a log file) from a 90 degree step input (use a forward speed of 0.15 m/s).

Create a plot of the desired and actual heading versus time. What is the rise time, settling time, and percent overshoot of your controller?

Submit your Python code.



Plot of desired and actual heading versus time

The rise time was 0.70 - 0.2191 = **0.4809 seconds.**
The settling time was 1.3 - 0.8042 = **0.4958 seconds.**
The percent overshoot was 100 * (91.855 / 90.0 - 1.0) = **2.06%**.

I updated the previous code in Problem 2 by adding a PID controller

```
class PID:
  """
  Simple PID controller for a single variable
  """
```

```python
  def __init__(self, kp, ki, kd):
  self.kp = kp
  self.ki = ki
  self.kd = kd

  self.last_error = 0
  self.integral = 0

  self.output = 0

  def update(self, error, dt):
  """
  Update the PID controller using new error value
  """
  self.integral += error * dt
  derivative = (error - self.last_error) / dt

  self.output = self.kp * error + self.ki * self.integral + self.kd * derivative

  self.last_error = error
```

I modified the constuctor adding the following

```python
class TurtleBotController(Node):
  def __init__(self):
  super().__init__('turtlebot_controller')
  ...
  ...
  # used to calculate dt between updates
  self.last_update = self.start_time

  # desried heading
  self.desired_theta = None
  self.current_theta = None

  self.theta_controller = PID(1, 0.5, 0.0)
```

I modified the callback function as follows

```python
def odom_callback(self, msg):
  # if we are done dont execute anything else
  if self.done:
  return

  # if we have not set a desired heading
  if self.desired_theta is None:
  self.done = True

  # get current time and time elapsed since the node was started
  time = self.get_clock().now().nanoseconds
  time_elapsed = time - self.start_time

  # get the dt in seconds since the last update
  dt = (time - self.last_update)


```

```
    # read sensor data to get position and heading
    self.current_x = msg.pose.pose.position.x
    self.current_y = msg.pose.pose.position.y
    self.current_theta = euler_from_quaternion(
    msg.pose.pose.orientation.x,
    msg.pose.pose.orientation.y,
    msg.pose.pose.orientation.z,
    msg.pose.pose.orientation.w)[2]

    # store sensor data for logging and plotting
    self.state_records['x'].append((time_elapsed, self.current_x))
    self.state_records['y'].append((time_elapsed, self.current_y))
    self.state_records['theta'].append((time_elapsed, self.current_theta))

    # create a Twist for the velocity command
    twist = Twist()
    # move forward at 0.15 m/s
    twist.linear.x = 0.15


    # if more than 3 seconds have elapsed, stop the turtlebot
    if time_elapsed > 3000000000:
    twist.angular.z = 0.0
    self.cmd_vel_publisher.publish(twist)
    self.done = True
    return

    # run a PID controller using the error in heading
    self.theta_controller.update(self.desired_theta - self.current_theta, dt)

    # set the angular velocity to the output of the PID controller
    twist.angular.z = self.theta_controller.output

    twist.angular.z = clamp(twist.angular.z, -2.84, 2.84)

    # publish the velocity command to the turtlebot
    self.cmd_vel_publisher.publish(twist)

    # store the velocity command for logging and plotting
    self.state_records['cmd_vel_linear'].append((time, twist.linear.x))
    self.state_records['cmd_vel_angular'].append((time, twist.angular.z))

    self.last_update = time
```

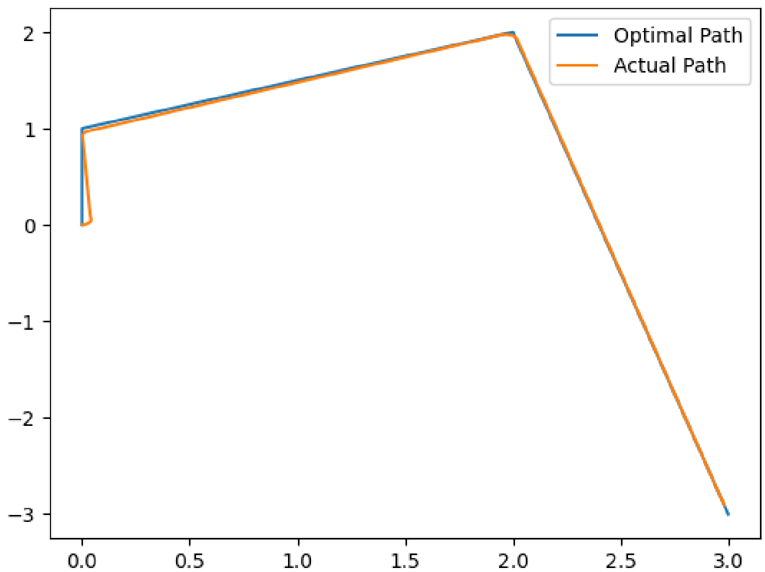
I modified the main function as follows

```
def main(args=None):
  rclpy.init(args=args)

  turtlebot_controller = TurtleBotController()

  turtlebot_controller.desired_theta = math.pi / 2

  while not turtlebot_controller.done:
  rclpy.spin_once(turtlebot_controller)
  ...
  ...
```

Problem 5

Create a ROS2 node that follows the given set of prescribed waypoints: [0,0], [0,1], [2,2], [3, -3]. Start your robot at [0,0]. Create a plot of the X, Y coordinates to show how well your robot follows the desired path. Use a maximum translational speed of 0.15 m/s.

Submit your Python code.



Plot of desired and actual X and Y coordinates versus time

I created a Waypoint class and modified the constructor for the node as follows

```
class TurtleBotController(Node):
  class Waypoint:
  """
  A waypoint that the turtlebot will try to reach
  """
  def __init__(self, x, y):
  self.x = x
  self.y = y

  def __init__(self):
  super().__init__('turtlebot_controller')

```

```
  # create a publisher to send velocity commands to the turtlebot
  self.cmd_vel_publisher = self.create_publisher(Twist, 'cmd_vel', 10)
  # create a subscriber to read sensor data
  self.odom_subscriber = self.create_subscription(Odometry, 'odom',
  self.odom_callback, 10)


  # store the time the node was started
  self.start_time = self.get_clock().now().nanoseconds
  self.last_update = self.start_time

  # the turtle bot will continue updating until this is set to true
  self.done = False

  # store the state for logging and plotting
  self.state_records = { 'cmd_vel_linear': [], 'cmd_vel_angular': [],
   'x': [], 'y': [], 'theta': [], 'theta_des': [] }

  # current position and location of the turtlebot
  self.current_theta = None
  self.current_x = None
  self.current_y = None

  # create a PID controller for angular velocity
  self.theta_controller = PID(7, 0.0, 1.0)

  # the list of waypoints in order that the turtlebot will try to reach
  self.waypoints = []

```

I modified the callback function as follows

```
def odom_callback(self, msg):
  # get current time, time elapsed, and delta time
  time = self.get_clock().now().nanoseconds
  time_elapsed = time - self.start_time
  dt = time - self.last_update


  self.last_update = time

  # if there are no more waypoings, stop the turtlebot
  if len(self.waypoints) == 0:
  self.done = True
  twist = Twist()
  twist.linear.x = 0.0
  twist.angular.z = 0.0
  self.cmd_vel_publisher.publish(twist)
  return

  # read sensor data to get position and heading
  self.current_x = msg.pose.pose.position.x
  self.current_y = msg.pose.pose.position.y
  self.current_theta = euler_from_quaternion(
  msg.pose.pose.orientation.x,
  msg.pose.pose.orientation.y,
  msg.pose.pose.orientation.z,
```

```
msg.pose.pose.orientation.w)[2]

# get the current waypoing (top of list)
waypoint = self.waypoints[0]
# find its distance from the turtlebot
distance = math.sqrt(
(waypoint.x - self.current_x)**2 + (waypoint.y - self.current_y)**2)

# if the turtlebot is close enough to the waypoint, move on
if distance < 0.1:
self.waypoints.pop(0)
return


# find the angle between current position and waypoint
self.desired_theta = math.atan2(
waypoint.y - self.current_y,
waypoint.x - self.current_x)

# adjust desired angle so that it turns the shortest way
if self.desired_theta - self.current_theta > math.pi:
self.desired_theta = self.desired_theta - 2 * math.pi
elif self.desired_theta - self.current_theta < -math.pi:
self.desired_theta = self.desired_theta + 2 * math.pi

# store the sensor data and desired heading for logging and plotting
self.state_records['x'].append((time_elapsed, self.current_x))
self.state_records['y'].append((time_elapsed, self.current_y))
self.state_records['theta'].append((time_elapsed, self.current_theta))
self.state_records['theta_des'].append((time_elapsed, self.desired_theta))

# set the translational velocity to 0.15 m/s
twist = Twist()
twist.linear.x = 0.15

# use PID controller to set the angular velocity
self.theta_controller.update(self.desired_theta - self.current_theta, dt)
twist.angular.z = self.theta_controller.output

# cap the angular velocity at 2.84 rad/s
twist.angular.z = clamp(twist.angular.z, -2.84, 2.84)

# publish the velocity command to the turtlebot
self.cmd_vel_publisher.publish(twist)

# store the velocity command for logging and plotting
self.state_records['cmd_vel_linear'].append((time_elapsed, twist.linear.x))
self.state_records['cmd_vel_angular'].append((time_elapsed, twist.angular.z))

```

I modified the main function as follows

```
def main(args=None):
  rclpy.init(args=args)

  turtlebot_controller = TurtleBotController()

```

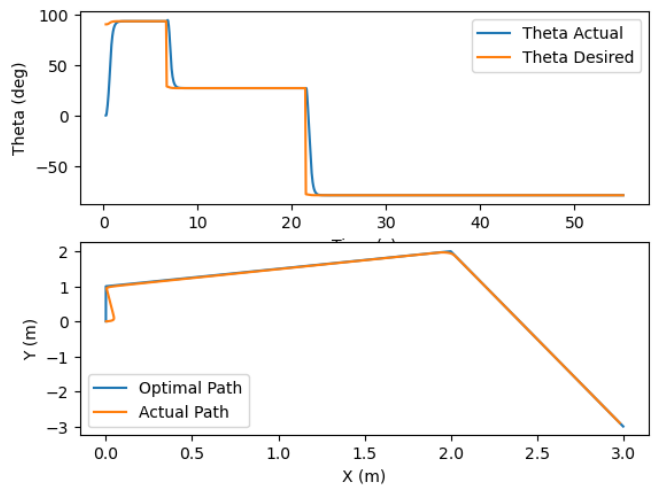
```
turtlebot_controller.done = False
turtlebot_controller.add_waypoint(0, 0)
turtlebot_controller.add_waypoint(0, 1)
turtlebot_controller.add_waypoint(2, 2)
turtlebot_controller.add_waypoint(3, -3)

while not turtlebot_controller.done:
  rclpy.spin_once(turtlebot_controller)
...
...
```

Problem 6

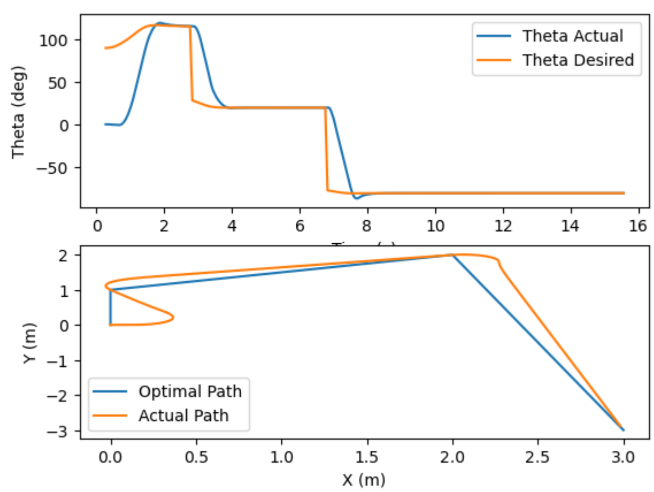
Redo Problem 5 with speeds ranging from 0.15 – 1.5 m/s (use at least 4 speeds) and provide the results regarding the ability of the turtlebot to follow the desired path/waypoints. A single plot showing the deviation from the desired path for each speed is the minimum acceptable information. Discuss the results, what is the max speed we should use for the simulation environment of the turtlebot (if we want to go as fast as possible)?

I found a speed of 1.05 m/s to be the fastest in reaching the waypoings, however, the path taken was far from optimal. In an empty map that path might work, but if there were obstacles, it likely would have collided with something.

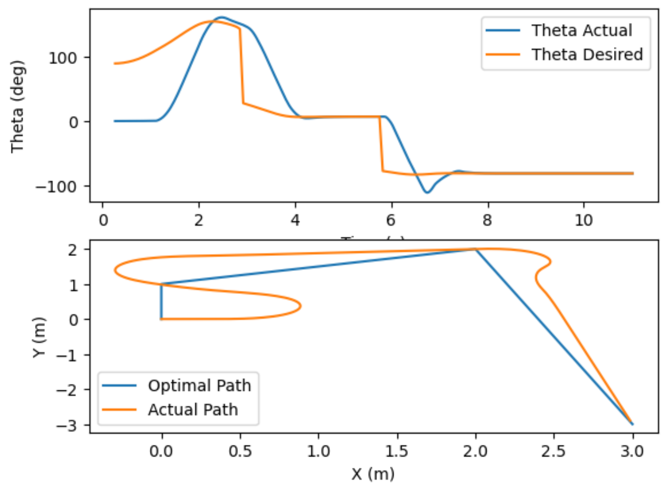
A speed of 0.6 m/s was reasonably close to the optimal path and reasonably quick.



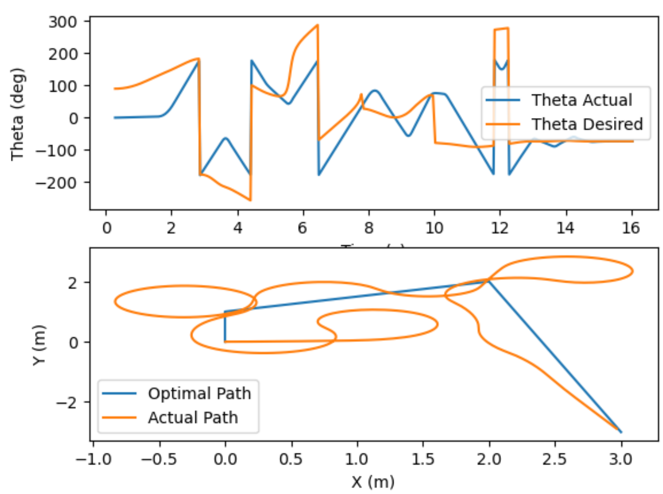
Speed = 0.15 m/s, Time to complete = 55.23 seconds



Speed = 0.6 m/s, Time to complete = 15.63 seconds



Speed = 1.05 m/s, Time to complete = 11.08 seconds



Speed = 1.5 m/s, Time to complete = 16.61 seconds