Autonomous Drone Control and Navigation in Cluttered Environments using RRT*

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Late Days Used: 3

***Abstract*—This project presents implementation of Motion Planning and Controller Tuning for the DJI Tello quadrotor on a Blender Simulation environment. It consists 4 parts - map reading, path planning, trajectory generation and controller tuning. The quadrotor is tuned to navigate from the start position to the goal position through a pre-mapped or known 3D environment.**

I. Environment

The DJI Tello drone and trajectory visualization is performed in a Blender environment with Python scripting. Sample maps are provided as "mapx.txt" file and are used for testing the algorithm and controller. :

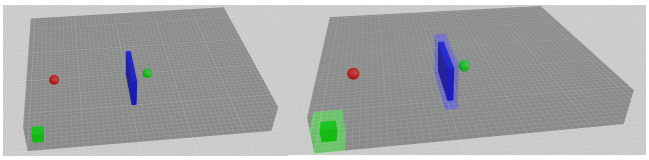


Fig. 1. Sample Environment

II. Implementation

A. Reading and Rendering the Map

We are considering the maps described in the ".txt" file provided to render our environment in blender. It contains the coordinates of the boundaries and the block obstacles that exist within the environment of the drone. These obstacles are considered to be bloated when trying to calculate the trajectory.

These are rendered in blender using the functions described in the "map.py" code. The waypoints and trajectory of the final path are also similarly rendered.

B. Implementation of Path Planner

Rapidly Exploring Random Trees - Star (RRT*)

The algorithm attempts to find a path from a start point to a goal point while avoiding specified obstacles, expanding a tree of paths across the search space until the goal is reached.

Deeper Look

Tree Expansion: The algorithm iteratively expands the tree from the start position by performing the following steps for a specified number of iterations *numNodes*:

1. **Random Sampling:** Generate a random point in the search space(p1)

2. **Find Nearest Node:** Find the closest node(p2) to the randomly sampled point(p1) from the existing nodes.

3. **Steering:** Generate a new node(p3) by steering from the nearest node(p2) towards random node p1(by some pre-defined distance or until p1 is reached).

4. **Collision Check:** Verify that the path from closest node(p2) to new node(p3) doesn't intersect with any obstacle.If not p3 is a valid node

Node Addition: Optionally, the algorithm explores if p3 can be connected to other nearby nodes in a manner that might provide a lower-cost path.
Rewiring: It checks other nodes and if a path from p3 to another node is shorter than the existing path to that node (and doesn't intersect with obstacles), the parent of that node is changed to p3.

5. **P3 is valid:** A new node p3 is added to the tree, with its parent set to p2 and its cost calculated as the distance from p2 plus the cost of p2

6. **P2 is within a certain distance from the goal**: it checks whether a direct path from p2 to the goal is free from obstacles. If it is, it adds the goal to the tree, connected to p3, and terminates the algorithm.

The algorithm is implemented in 3D Space. Distances and we chose the following parameters:

a. The minimum acceptable distance to goal as 1.0
b. The number of nodes being sampled as 5000.
c. Neighbor search radius as 50
:

Table 2: RRT Algorithms

Algorithm 2.
T = (V, E) ← RRT*(z_{ini})

1 $T \leftarrow$ InitializeTree();
2 $T \leftarrow$ InsertNode(Ø, z_{init}, T);
3 ***for*** i=0 to i=N ***do***
4 $z_{rand} \leftarrow$ Sample(i);
5 $z_{nearest} \leftarrow$ Nearest(T, z_{rand});
6 (z_{new}, U_{new}) ← Steer ($z_{nearest}$, z_{rand});
7 ***if*** Obstaclefree(z_{new}) ***then***
8 $z_{near} \leftarrow$ Near(T, z_{new}, $|V|$);
9 $z_{min} \leftarrow$ Chooseparent (z_{near}, $z_{nearest}$, z_{new});
10 $T \leftarrow$ InsertNode(z_{min}, z_{new}, T);
11 $T \leftarrow$ Rewire (T, z_{near}, z_{min}, z_{new});
12 ***return*** T

Fig. 2. Pseudocode for RRT*

C. Trajectory Generation

1) **Fitting a Spline:**

- We are creating quintic trajectories. We are considering pairs of waypoints, taking the segment length and dividing by average velocity to find the time taken to traverse between the individual segment lengths. Acceleration at the waypoints are always zero

  Position, Velocity and Acceleration Trajectories are given by:
  $x = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5$
  $\dot{x} = a_1 + 2a_2 t + 3a_3 t^2 + 4a_4 t^3 + 5a_5 t^4$
  $\ddot{x} = 2a_2 + 6a_3 t + 12a_4 t^2 + 20a_5 t^3$

- **Bounding conditions for the quintic trajectories** are defined as such for the way-points:
  1. **Start and the First way-point:** the initial velocity and acceleration are zero, while the final velocity is the assumed average velocity(**v**).
  2. **Intermediate way-points:** The velocity profiles are such that the initial and final velocity are both set to **v**.
  3. **Final way-point:** The initial velocity is **v** and the final velocity and acceleration is zero.
- Through solving the equations above we get the coefficients for the spline equations and the time stamps corresponding to the positions in the path. The resultant spline is pruned and optimized.

2) **Pruning the Trajectory**:

3) The waypoints generated previously are checked for collision with our obstacles and the unnecessary waypoints are eliminated.

4) **Smoothing the Trajectory**:

   We are performing **gradient descent smoothing** The path (a sequence of points) by iteratively adjusting each point (except for the first and the last ones) based on its original position and the positions of its neighbors. The adjustment is governed by two weights (weight data and weight smooth) and continues until the total change for all points in one iteration is less than a defined tolerance.

Deeper Look: In repeated cycles, every point (except the first and last) is nudged: Partly toward its original position in the un-smoothened path. Partly toward the average of its neighbors in the smoothed path. These nudges continue until the points stop moving significantly (i.e., total movement across all points is below a tiny threshold).

D. Controller Strategy and Tuning Gains

The quadrotor is tuned to follow the desired trajectory generated from the path planned by RRT* algorithm without collisions. The controller designed for the quadrotor is a cascaded controller with outermost loop as the position controller and the penultimate loop as the velocity controller. The position controller uses PID controller with 3 sets of gains for x,y and z for a stable position control for positioning the quadrotor at desired locations. The velocity controller again uses PID controller with 3 sets of gains.

The position control loop and the velocity control loop are tuned individually with the given sample trajectory file with position, velocity and acceleration values corresponding to a helical trajectory. And the tuned parameters are verified with few more trajectory files to check the hovering of the quadrotor at a fixed location. The results of the tuned controller with the desired and actual positions, velocities are shown in the plots below.

The gains tuned are,shown in TABLE 1

TABLE I
PID CONTROLLER PARAMETERS

Parameter	K_p	K_i	K_d
position_x	1	0.1	0
position_y	1	0.1	0
position_z	1	0	0
velocity_x	1	0	0
velocity_y	1	0	0
velocity_z	3	0.3	0.1

PID gains for X and Y directions are kept same as it is a symmetric drone with same dynamics along both the axes. And the velocity control loop is tuned first by keeping the gains of the position control loop to 0 and considering one gain at a time starting with Kp followed by Ki and then Kd.

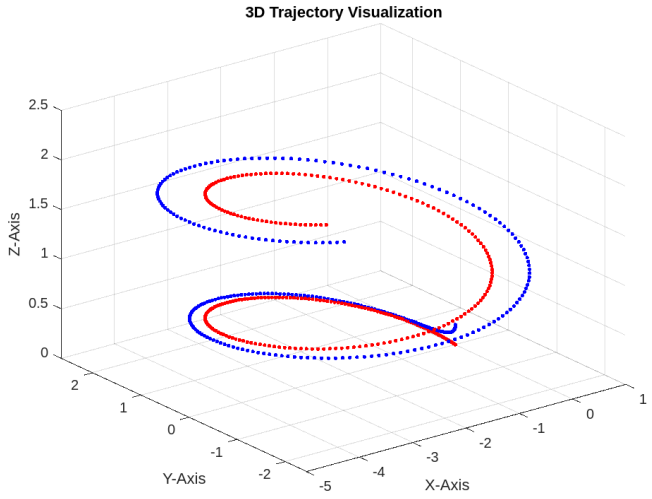
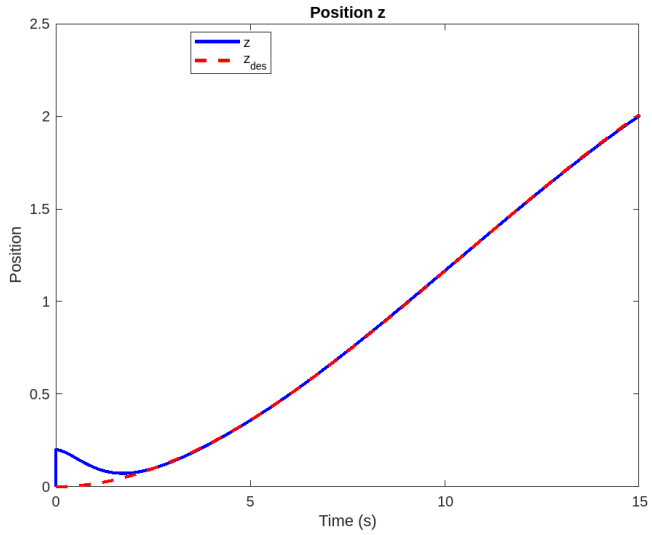
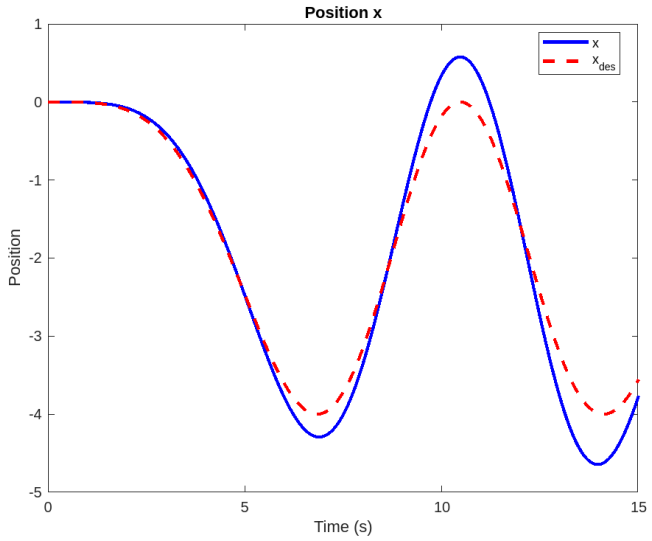
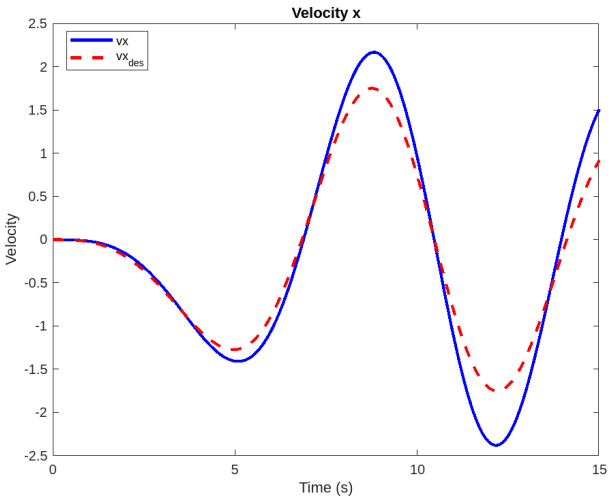
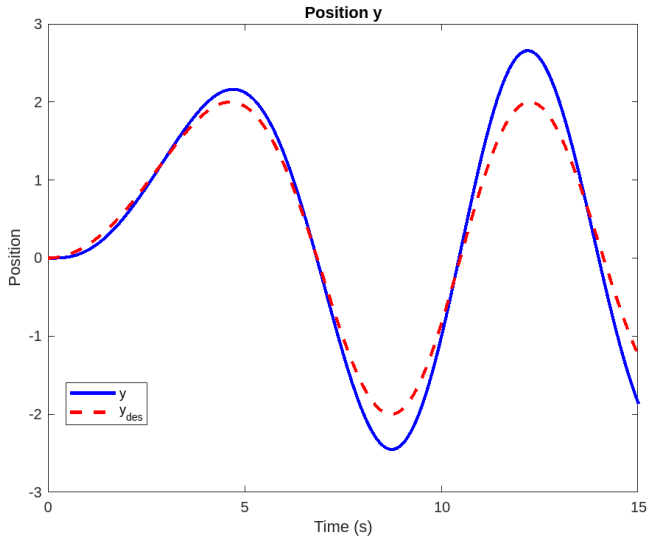


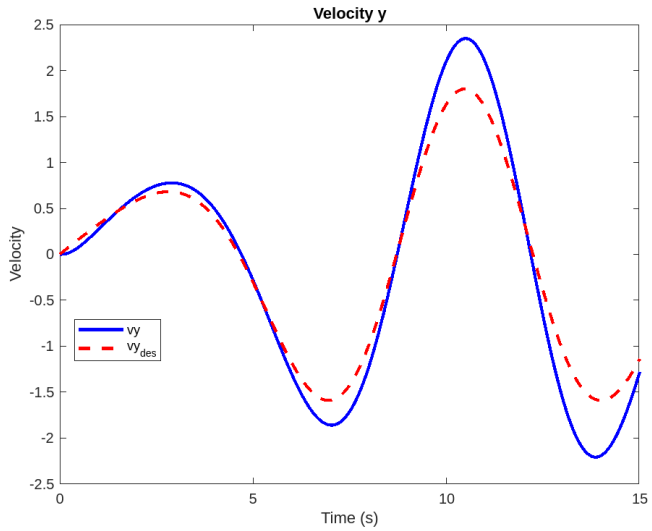
Fig. 3. 3D Trajectory

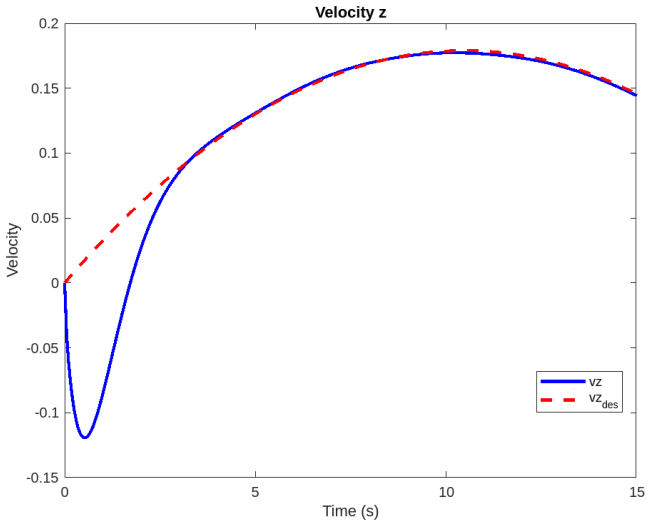












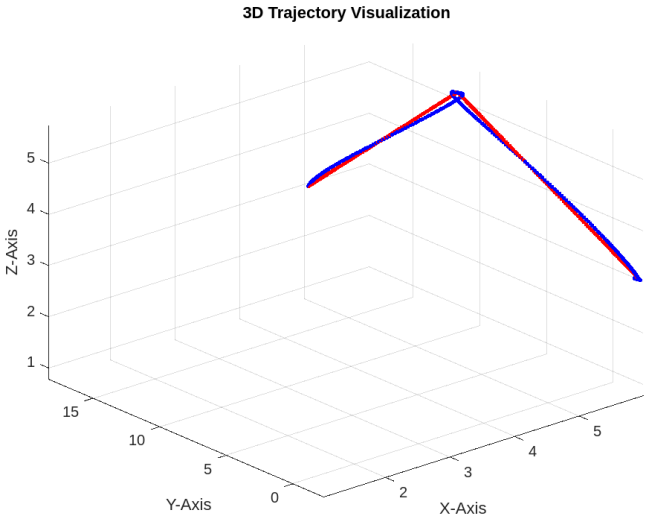


Fig. 12. Train set Map1: 3D Trajectory

III. Results

The output from the train and test sets are shown below.

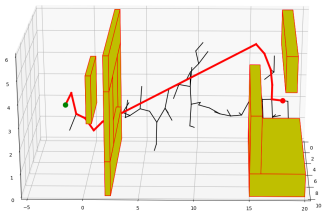


Fig. 10. Train Set: Map1

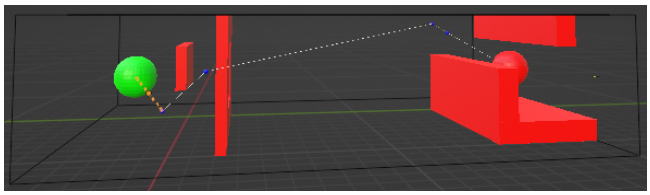
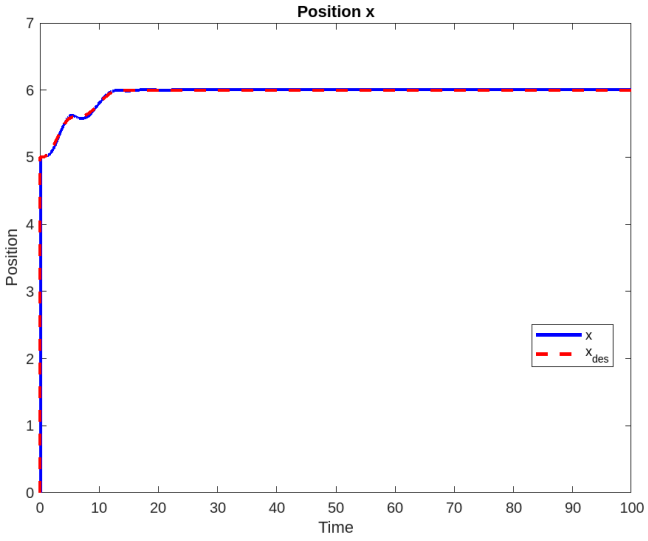
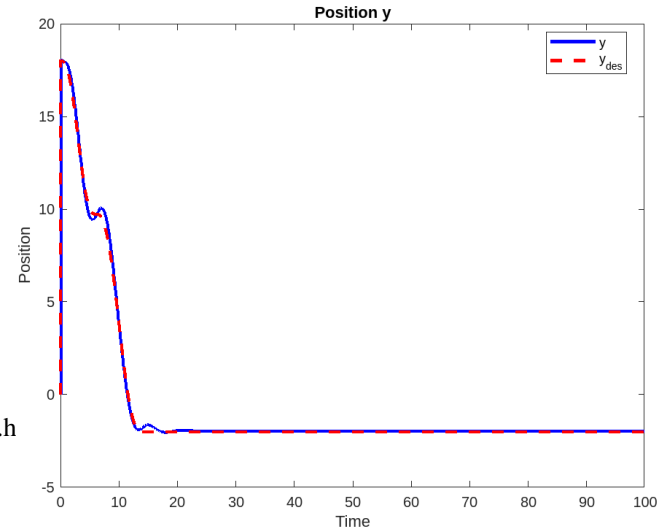


Fig. 11. Train Set: Map1



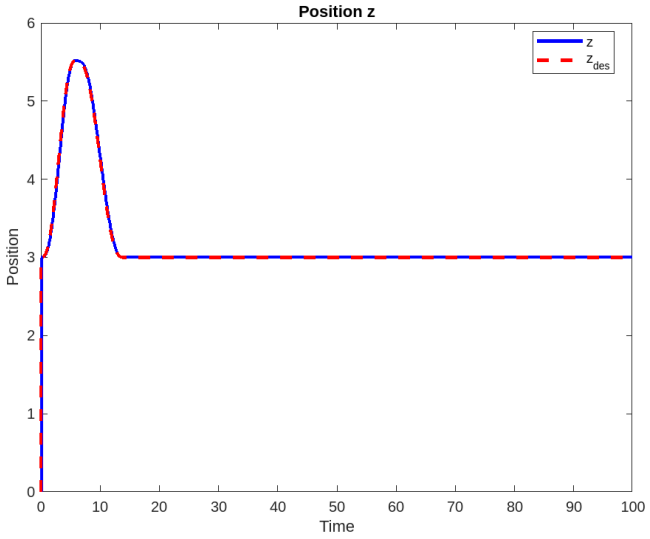


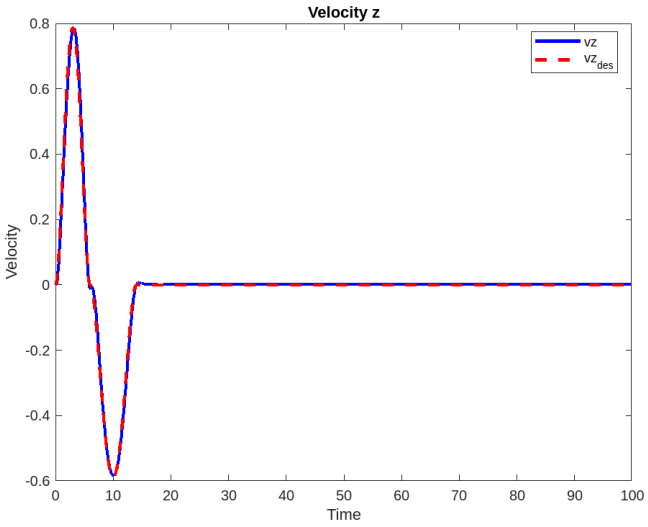
IV. References

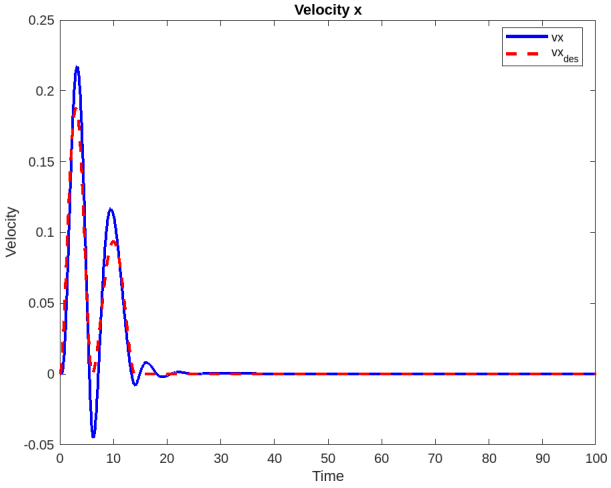
1 Principles of Robot Motion: Theory, Algorithms, and Implementations" by Howie Choset, Kevin M. Lynch, et al.

2 https://docs.px4.io/main/en/flight_stack/controller_diagrams.h

3 https://theclassytim.medium.com/robotic-path-planning-rrt-and-rrt-212319121378







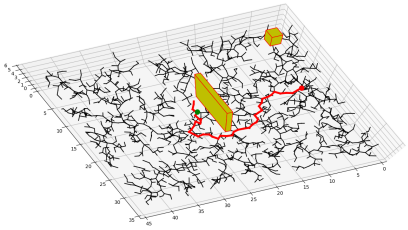
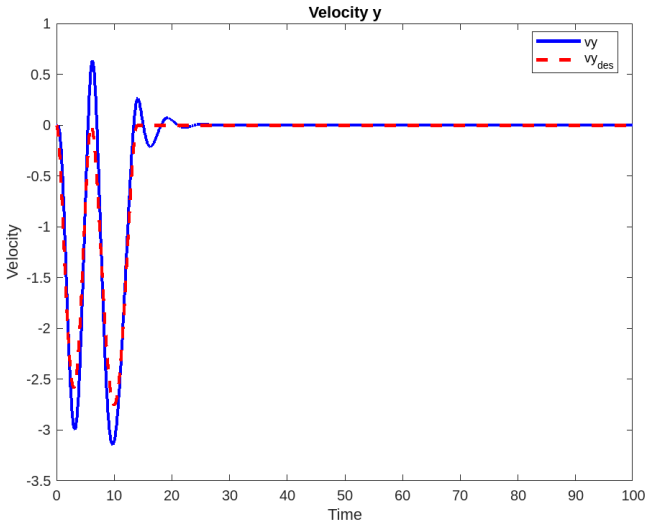


Fig. 19. Train Set: Map4



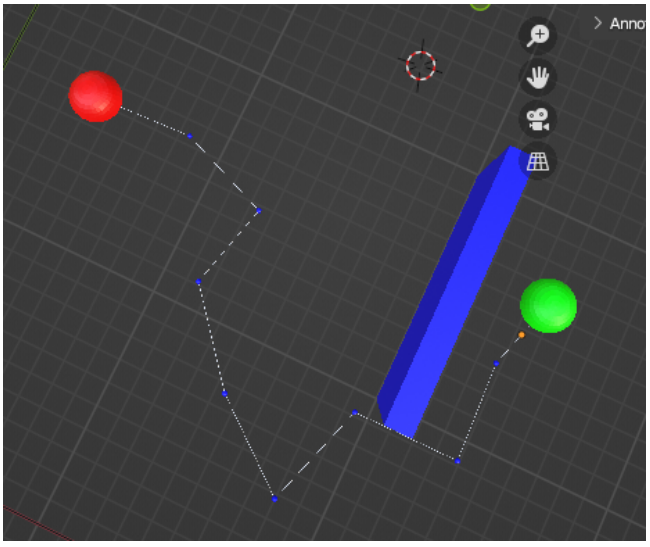


Fig. 20. Train Set: Map1

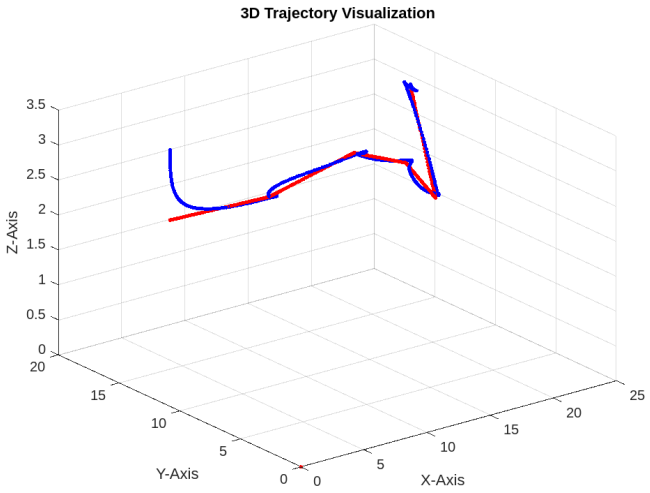
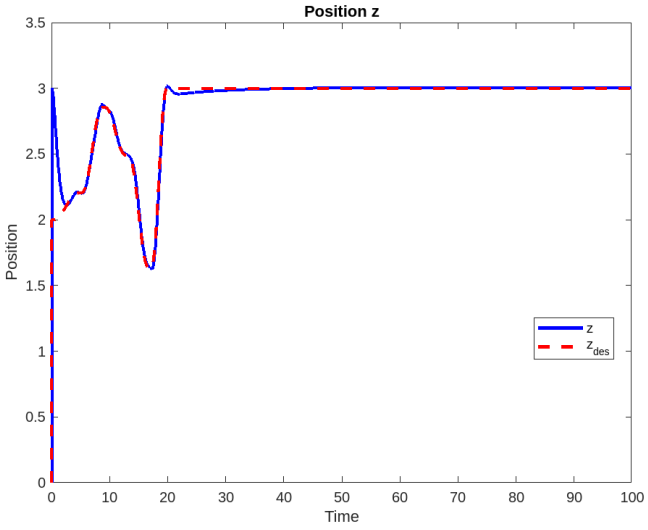
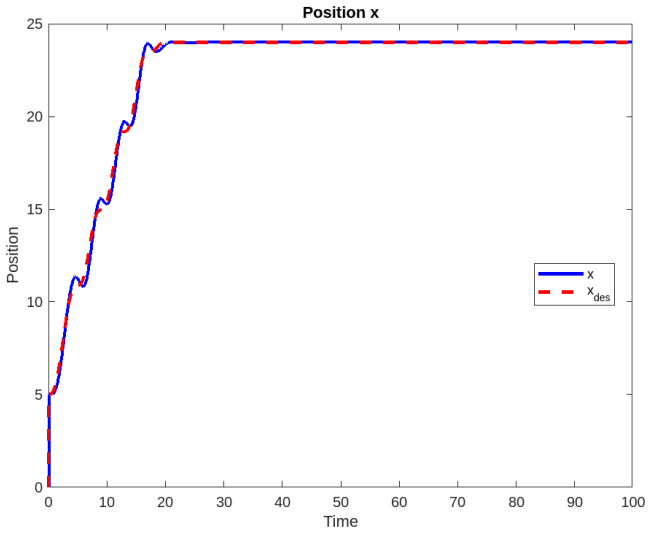
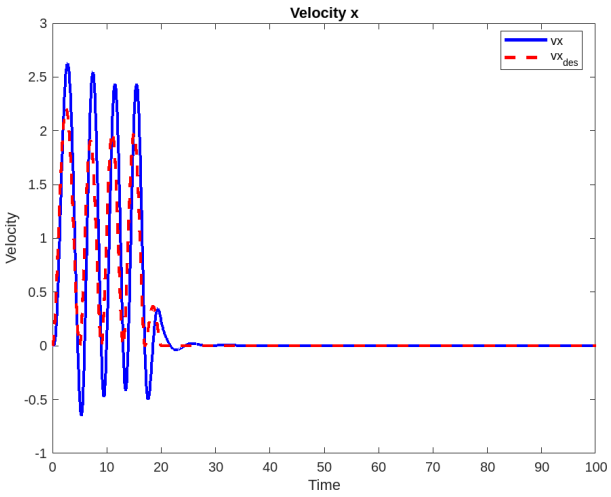
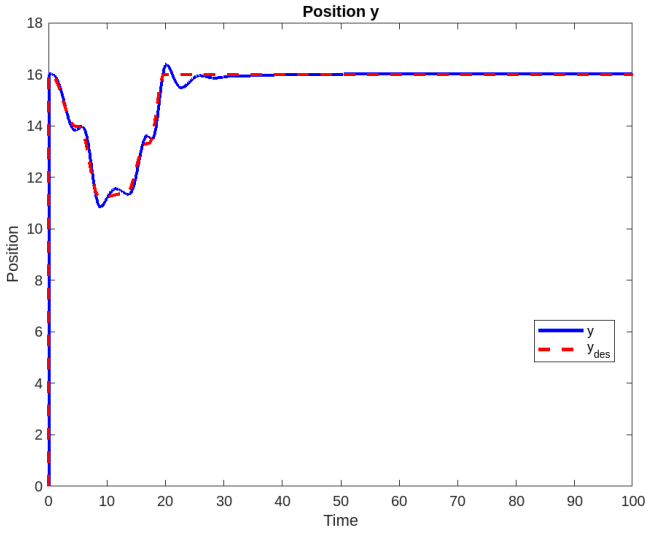


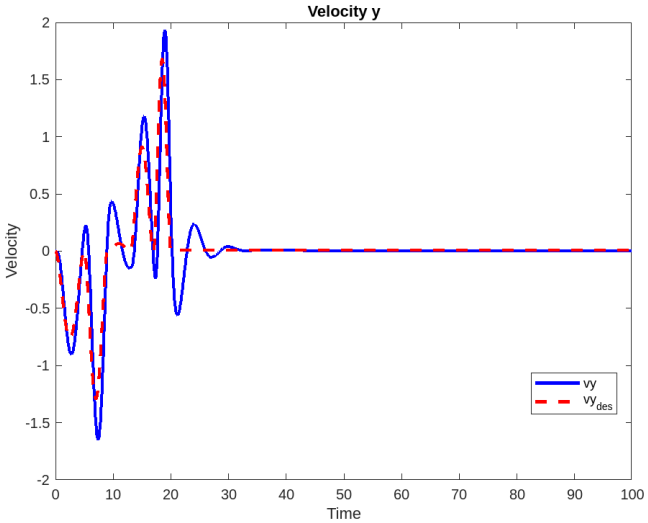
Fig. 21. Train set Map4: 3D Trajectory

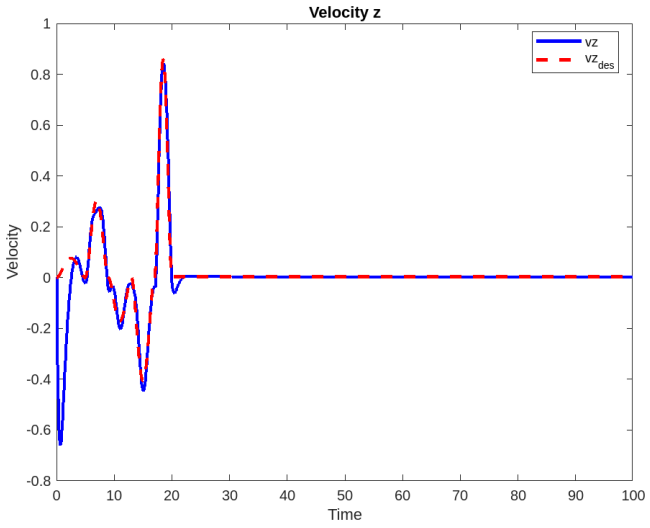












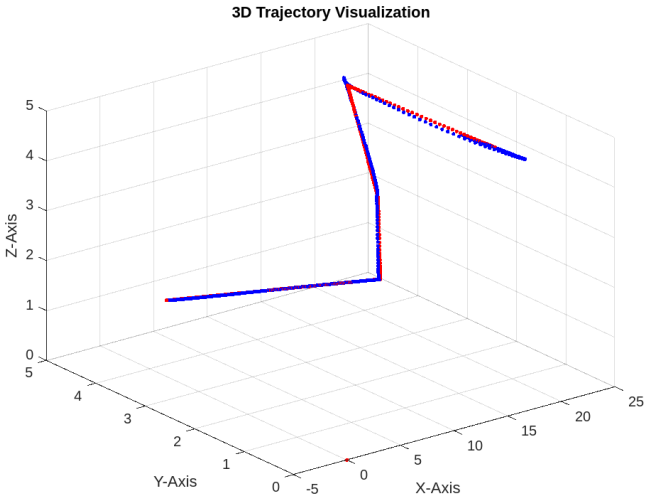


Fig. 30. Test set Map3: 3D Trajectory

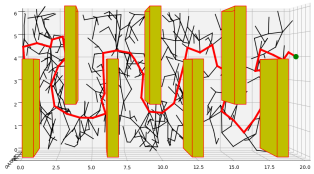
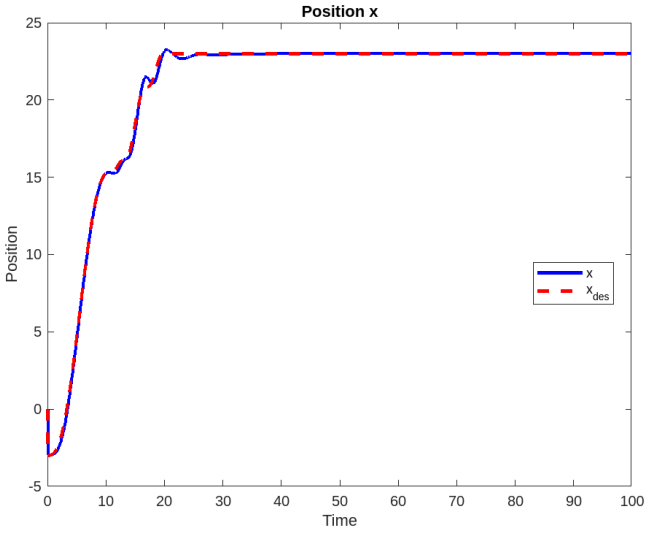


Fig. 28. Test Set: Map3



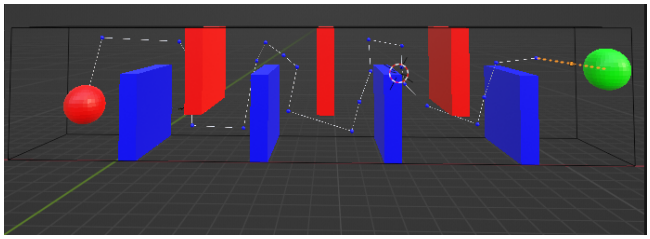
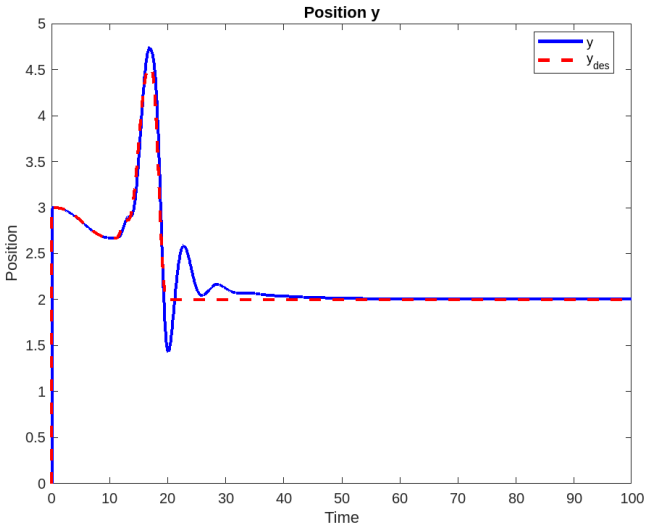
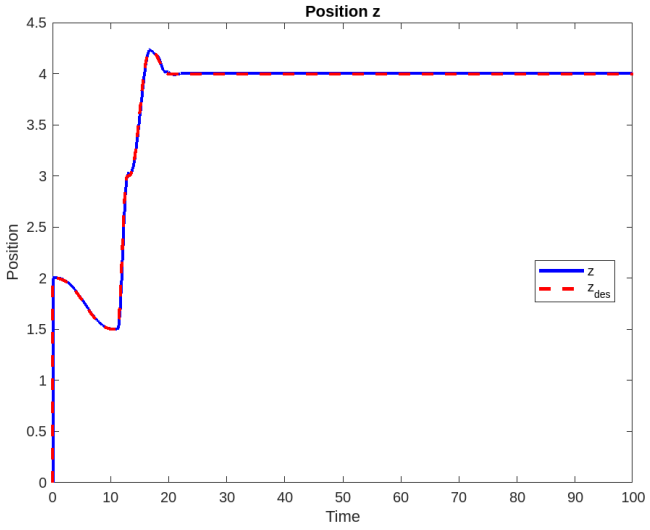
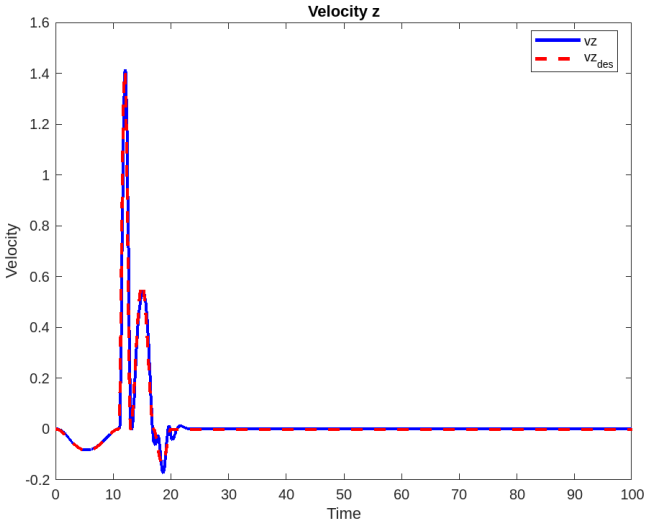
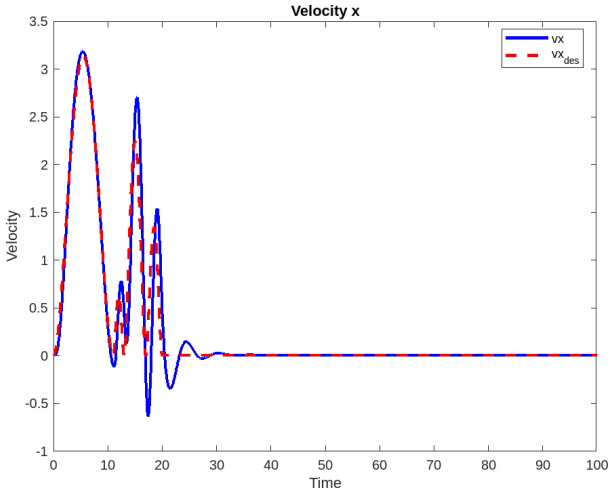


Fig. 29. Train Set: Map1









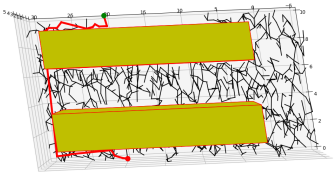
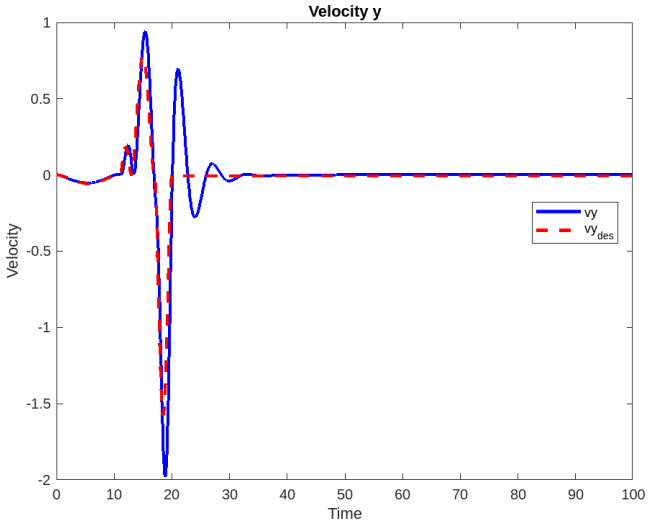


Fig. 37. Test Set: Map2



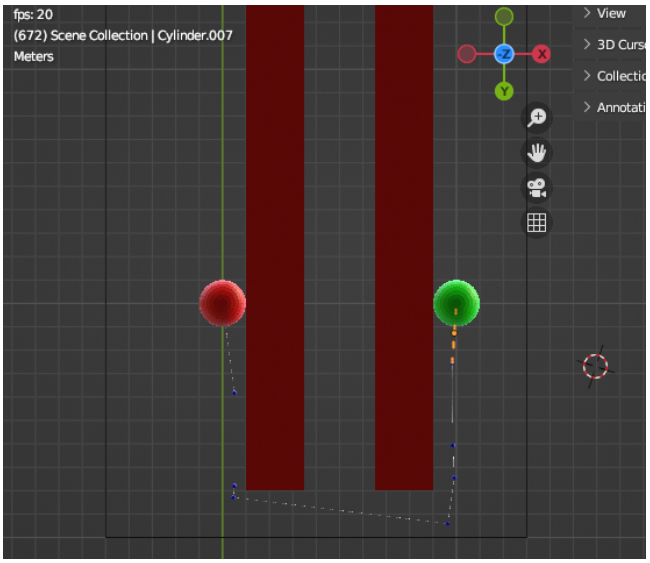


Fig. 38. Train Set: Map1

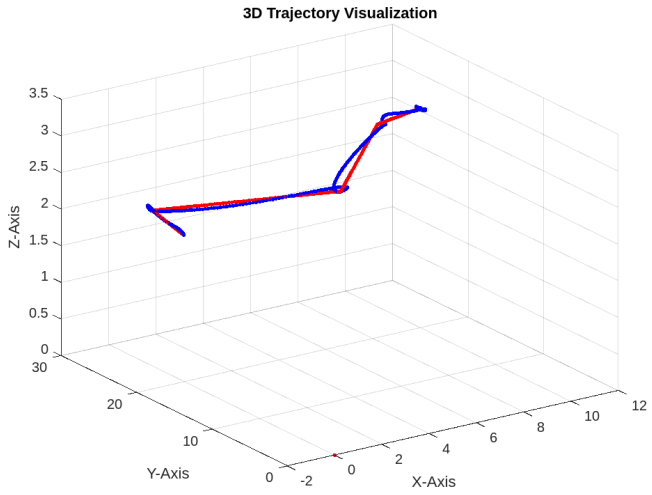
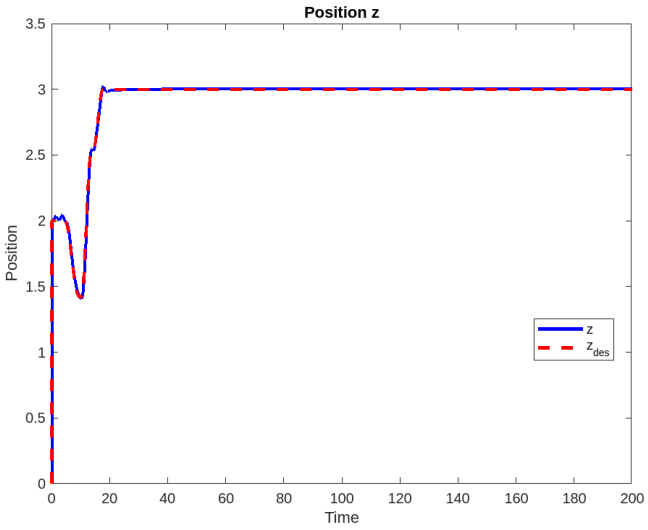
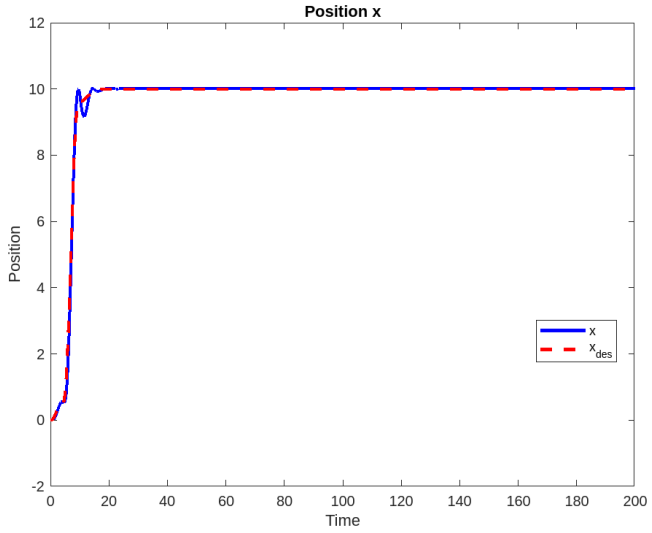
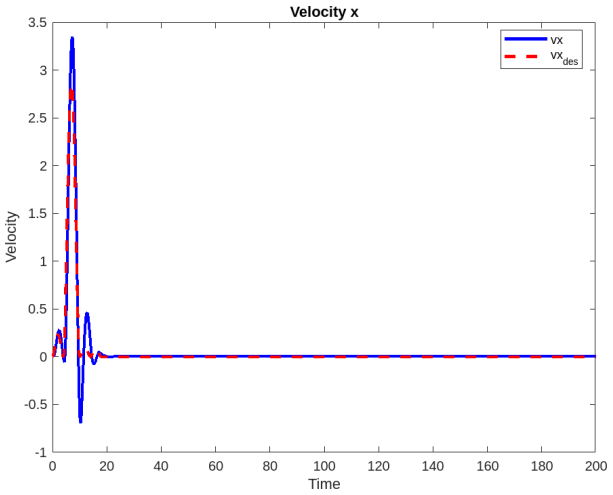
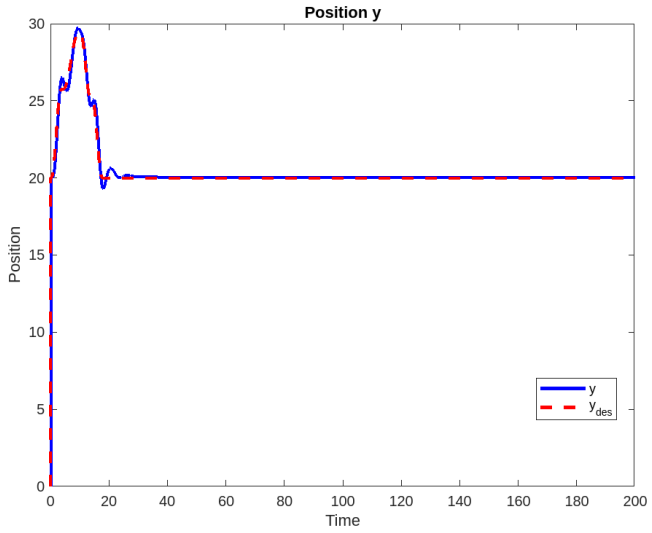


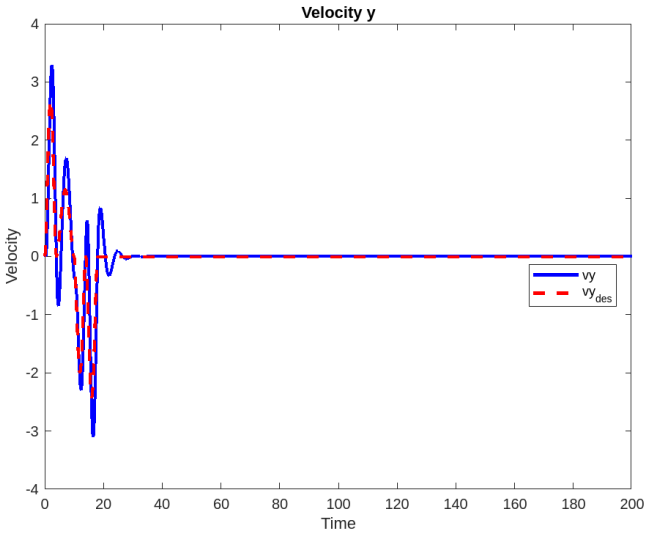
Fig. 39. Test set Map2: 3D Trajectory

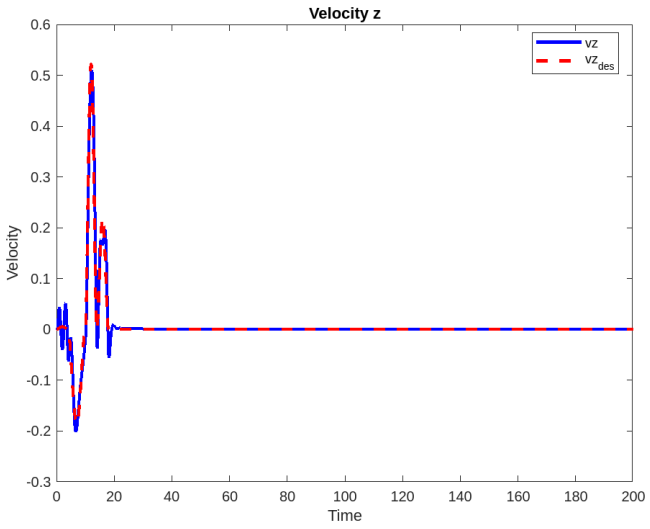








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vz
vz_des
Velocity
Time
0.6
0.5
0.4
0.3
0.2
0.1
0
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20
40
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