```
In [ ]: # The autoreload extension will automatically load in new code as you edit files,
        # so you don't need to restart the kernel every time
        %load_ext autoreload
        %autoreload 2

        import numpy as np
        from P1_astar import AStar
        from P2_rrt import *
        from P3_traj_planning import compute_smoothed_traj, modify_traj_with_limits, SwitchingController
        import matplotlib.pyplot as plt
        from HW1.P1_differential_flatness import *
        from HW1.P2_pose_stabilization import *
        from HW1.P3_trajectory_tracking import *
        from utils import generate_planning_problem
        from HW1.utils import simulate_car_dyn

        plt.rcParams['figure.figsize'] = [14, 14] # Change default figure size
```

```
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload
```

Generate workspace, start and goal positions

```
In [ ]: width = 100
        height = 100
        num_obs = 25
        min_size = 5
        max_size = 30

        occupancy, x_init, x_goal = generate_planning_problem(width, height, num_obs, min_size, max_size)
```

Solve A* planning problem

```
In [ ]: astar = AStar((0, 0), (width, height), x_init, x_goal, occupancy)
        if not astar.solve():
            print("No path found")
```

Smooth Trajectory Generation

Trajectory parameters

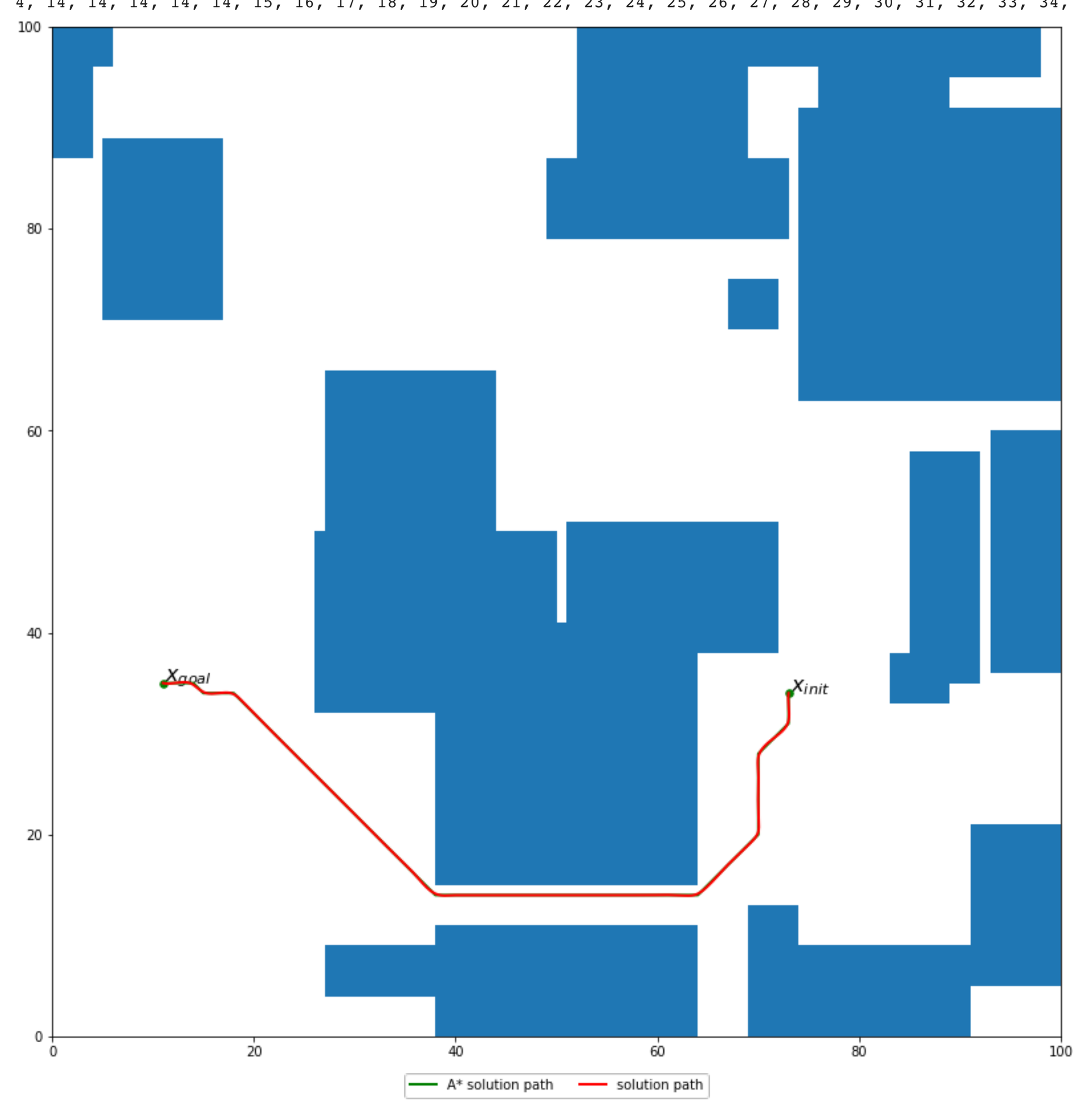
(Try changing these and see what happens)

```
In [ ]: V_des = 0.3  # Nominal velocity
        alpha = 0.1   # Smoothness parameter
        dt = 0.05
        k_spline = 3
```

Generate smoothed trajectory

```
In [ ]: t_smoothed, traj_smoothed = compute_smoothed_traj(astar.path, V_des, k_spline, alpha, dt)

        fig = plt.figure()
        astar.plot_path(fig.number)
        def plot_traj_smoothed(traj_smoothed):
            plt.plot(traj_smoothed[:,0], traj_smoothed[:,1], color="red", linewidth=2, label="solution path", zorder=10)
        plot_traj_smoothed(traj_smoothed)
        plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True, ncol=3)
        plt.show()
```

```
len 74
x [73, 73, 73, 73, 72, 71, 70, 70, 70, 70, 70, 70, 70, 70, 70, 69, 68, 67, 66, 65, 64, 63, 62, 61, 60, 59, 58, 57, 56, 55, 54, 53, 52, 51, 50, 49, 48, 47, 46, 45, 44, 4
3, 42, 41, 40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11]
y [34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 14, 1
4, 14, 14, 14, 14, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 34, 34, 34, 35, 35, 35, 35]
```



Control-Feasible Trajectory Generation and Tracking

Robot control limits

```
In [ ]: V_max = 0.5 # max speed
        om_max = 1 # max rotational speed
```

Tracking control gains

Tune these as needed to improve tracking performance.

```
In [ ]: kpx = 2
        kpy = 2
        kdx = 2
        kdy = 2
```

Generate control-feasible trajectory

```
In [ ]: t_new, V_smooth_scaled, om_smooth_scaled, traj_smooth_scaled = modify_traj_with_limits(traj_smoothed, t_smoothed, V_max, om_max, dt)
```

```
V [0.27721286 0.27782596 0.27844262 ... 0.26751056 0.26637995 0.26526774]
om [ 0.12306838  0.12109622  0.11913689 ... -0.22062864 -0.22523372
 -0.22987912]
```

Create trajectory controller and load trajectory

```
In [ ]: traj_controller = TrajectoryTracker(kpx=kpx, kpy=kpy, kdx=kdx, kdy=kdy, V_max=V_max, om_max=om_max)
        traj_controller.load_traj(t_new, traj_smooth_scaled)
```

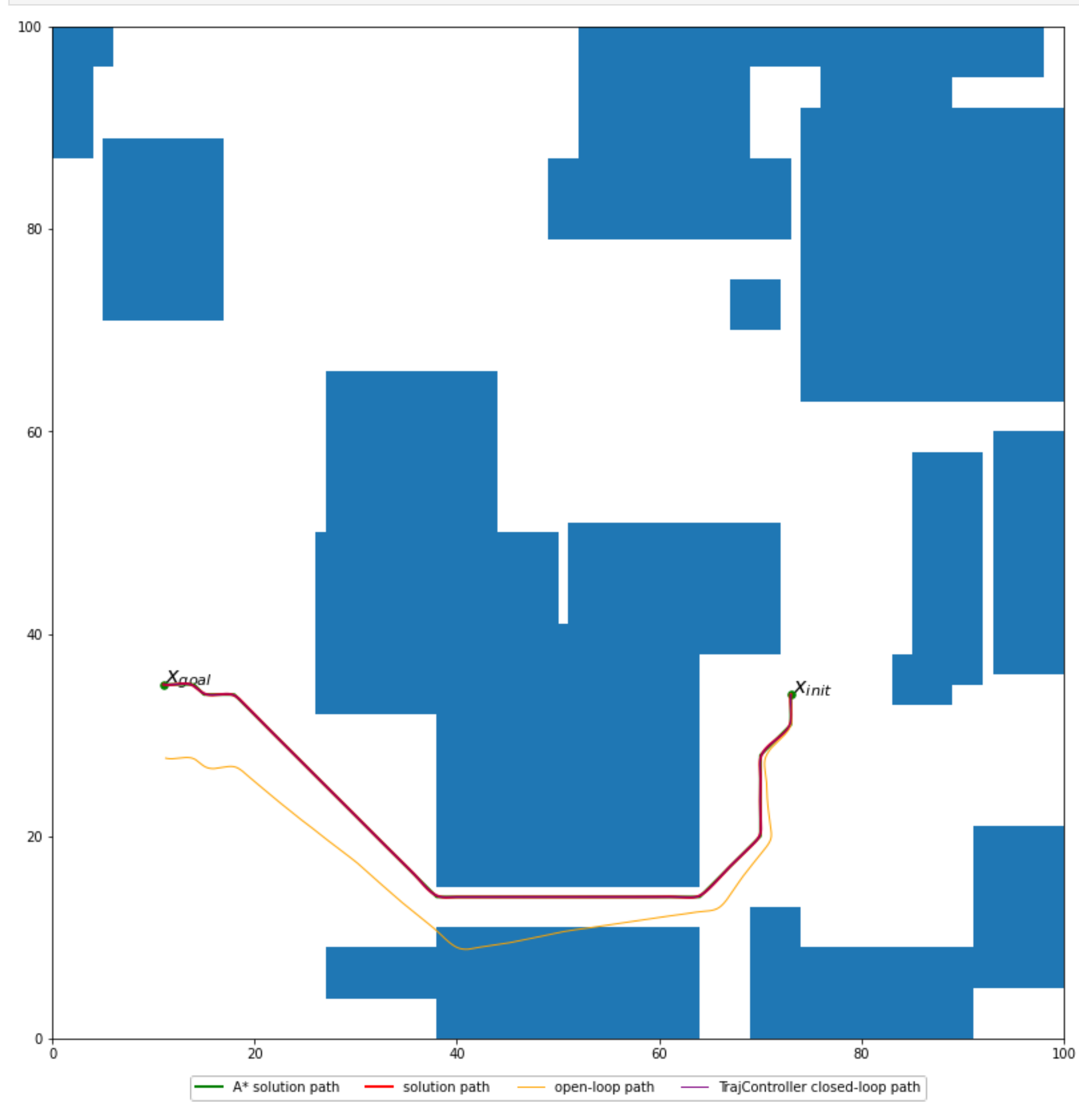
Set simulation input noise

(Try changing this and see what happens)

```
In [ ]: noise_scale = 0.05
```

Simulate closed-loop tracking of smoothed trajectory, compare to open-loop

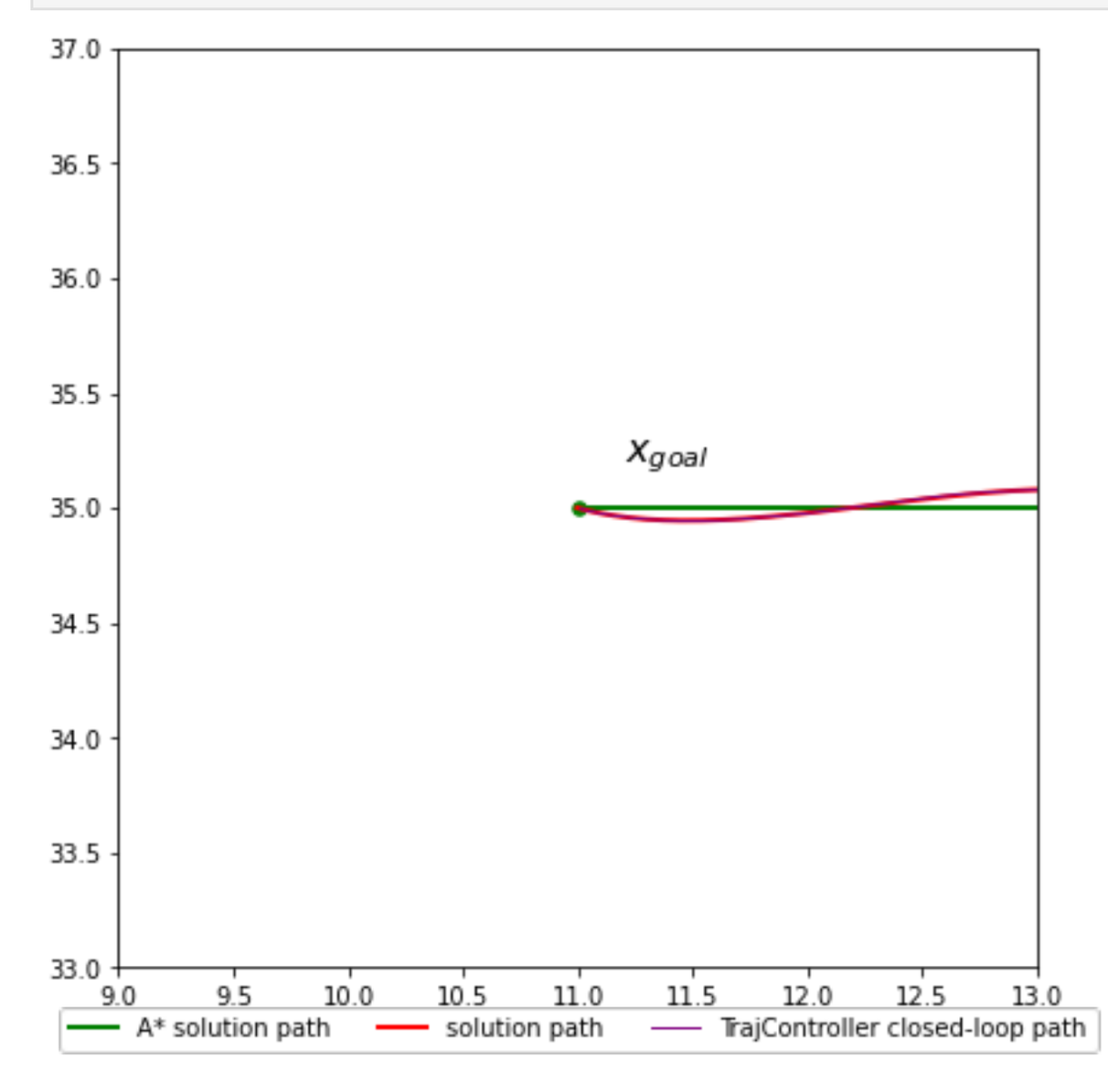
```
In [ ]: tf_actual = t_new[-1]
        times_cl = np.arange(0, tf_actual, dt)
        s_0 = State(x=x_init[0], y=x_init[1], V=V_max, th=traj_smooth_scaled[0,2])
        s_f = State(x=x_goal[0], y=x_goal[1], V=V_max, th=traj_smooth_scaled[-1,2])

        actions_ol = np.stack([V_smooth_scaled, om_smooth_scaled], axis=-1)
        states_ol, ctrl_ol = simulate_car_dyn(s_0.x, s_0.y, s_0.th, times_cl, actions=actions_ol, noise_scale=noise_scale)
        states_cl, ctrl_cl = simulate_car_dyn(s_0.x, s_0.y, s_0.th, times_cl, controller=traj_controller, noise_scale=noise_scale)

        fig = plt.figure()
        astar.plot_path(fig.number)
        plot_traj_smoothed(traj_smoothed)
        def plot_traj_ol(states_ol):
            plt.plot(states_ol[:,0],states_ol[:,1], color="orange", linewidth=1, label="open-loop path", zorder=10)
        def plot_traj_cl(states_cl):
            plt.plot(states_cl[:,0], states_cl[:,1], color="purple", linewidth=1, label="TrajController closed-loop path", zorder=10)
        plot_traj_ol(states_ol)
        plot_traj_cl(states_cl)
        plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True, ncol=4)
        plt.show()
```



Switching from Trajectory Tracking to Pose Stabilization Control

Zoom in on final pose error

```
In [ ]: l_window = 4.

        fig = plt.figure(figsize=[7,7])
        astar.plot_path(fig.number, show_init_label = False)
        plot_traj_smoothed(traj_smoothed)
        plot_traj_cl(states_cl)
        plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True, ncol=3)
        plt.axis([x_goal[0]-l_window/2, x_goal[0]+l_window/2, x_goal[1]-l_window/2, x_goal[1]+l_window/2])
        plt.show()
```



Pose stabilization control gains

Tune these as needed to improve final pose stabilization.

```
In [ ]: k1 = 0.1
        k2 = 2.0
        k3 = 1.0
```

Create pose controller and load goal pose

Note we use the last value of the smoothed trajectory as the goal heading θ

```
In [ ]: pose_controller = PoseController(k1, k2, k3, V_max, om_max)
        pose_controller.load_goal(x_goal[0], x_goal[1], traj_smooth_scaled[-1,2])
```

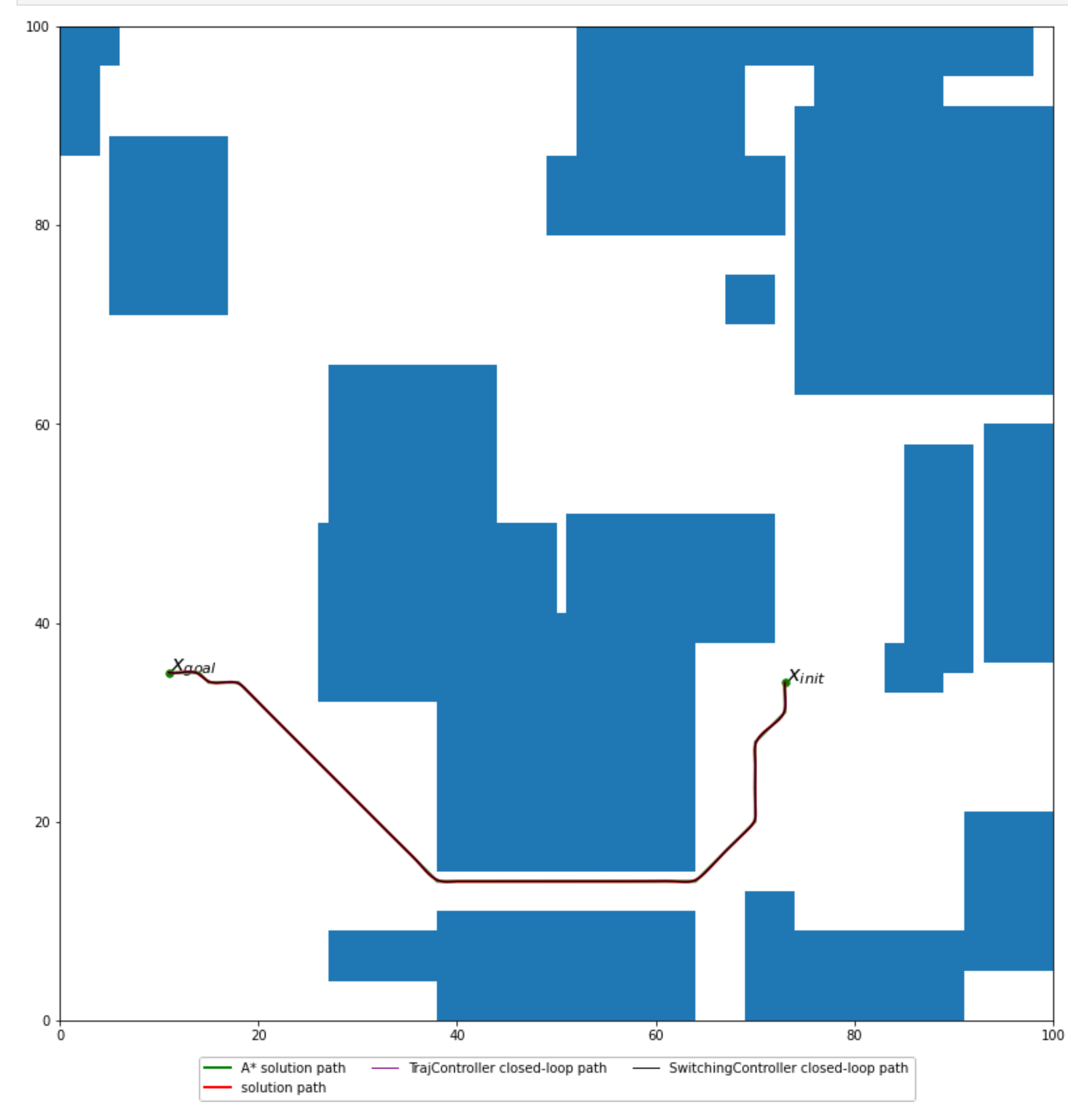
Time before trajectory-tracking completion to switch to pose stabilization

Try changing this!

```
In [ ]: t_before_switch = 2.0
```

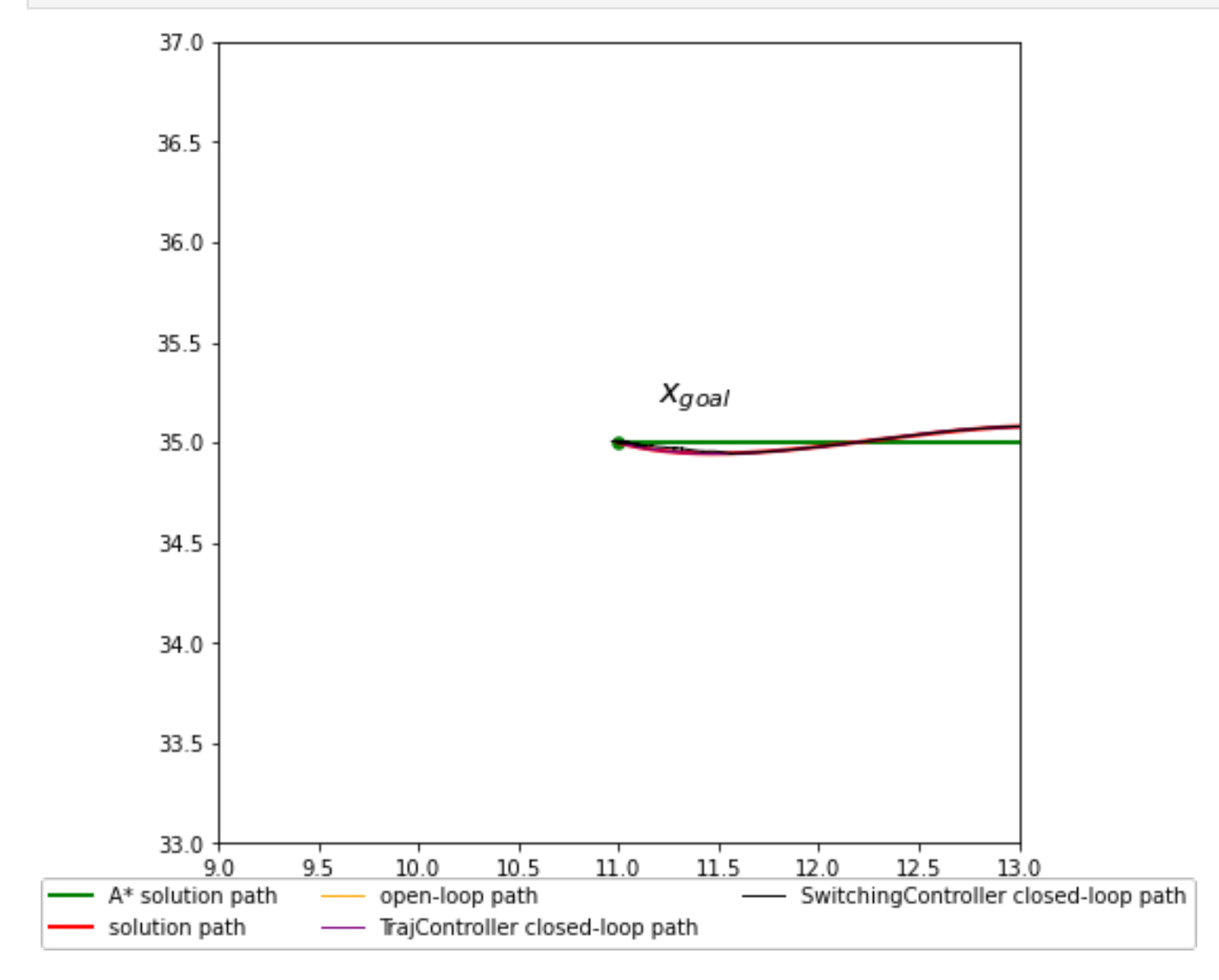
Create switching controller and compare performance

```
In [ ]: switching_controller = SwitchingController(traj_controller, pose_controller, t_before_switch)

        t_extend = 60.0 # Extra time to simulate after the end of the nominal trajectory
        times_cl_extended = np.arange(0, tf_actual+t_extend, dt)
        states_cl_sw, ctrl_cl_sw = simulate_car_dyn(s_0.x, s_0.y, s_0.th, times_cl_extended, controller=switching_controller, noise_scale=noise_scale)

        fig = plt.figure()
        astar.plot_path(fig.number)
        plot_traj_smoothed(traj_smoothed)
        plot_traj_cl(states_cl)
        def plot_traj_cl_sw(states_cl_sw):
            plt.plot(states_cl_sw[:,0], states_cl_sw[:,1], color="black", linewidth=1, label="SwitchingController closed-loop path", zorder=10)
        plot_traj_cl_sw(states_cl_sw)
        plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True, ncol=3)
        plt.show()
```



Zoom in on final pose

```
In [ ]: l_window = 4.

        fig = plt.figure(figsize=[7,7])
        astar.plot_path(fig.number, show_init_label = False)
        plot_traj_smoothed(traj_smoothed)
        plot_traj_ol(states_ol)
        plot_traj_cl(states_cl)
        plot_traj_cl_sw(states_cl_sw)
        plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=True, ncol=3)
        plt.axis([x_goal[0]-l_window/2, x_goal[0]+l_window/2, x_goal[1]-l_window/2, x_goal[1]+l_window/2])
        plt.show()
```

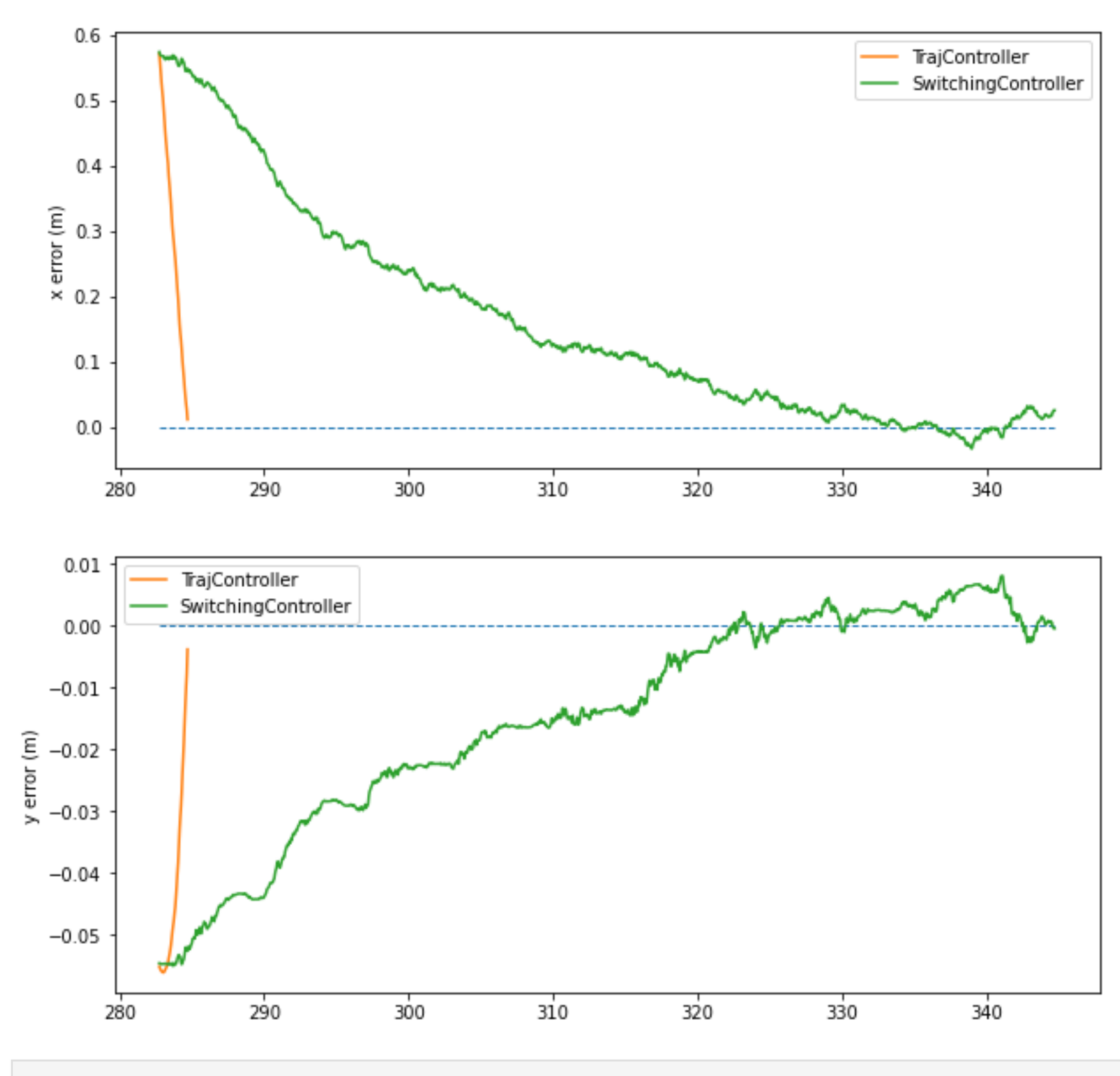


Plot final sequence of states

To see just how well we're able to arrive at the target point (and to assist in choosing values for the pose stabilization controller gains k_1, k_2, k_3), we plot the error in x and y for both the tracking controller and the switching controller at the end of the trajectory.

```
In [ ]: T = len(times_cl) - int(t_before_switch/dt)
        fig = plt.figure(figsize=[10,10])
        plt.subplot(2,1,1)
        plt.plot([times_cl_extended[T], times_cl_extended[-1]], [0,0], linestyle='--', linewidth=1)
        plt.plot(times_cl[T:], states_cl[T:,0] - x_goal[0], label='TrajController')
        plt.plot(times_cl_extended[T:], states_cl_sw[T:,0] - x_goal[0], label='SwitchingController')
        plt.legend()
        plt.ylabel("x error (m)")
        plt.subplot(2,1,2)
        plt.plot([times_cl_extended[T], times_cl_extended[-1]], [0,0], linestyle='--', linewidth=1)
        plt.plot(times_cl[T:], states_cl[T:,1] - x_goal[1], label='TrajController')
        plt.plot(times_cl_extended[T:], states_cl_sw[T:,1] - x_goal[1], label='SwitchingController')
        plt.legend()
        plt.ylabel("y error (m)")
```

```
Out[ ]: Text(0, 0.5, 'y error (m)')
```




```
In [ ]:
```