In [89]:
```
# The autoreload extension will automatically load in new code as you e
dit 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 DetOccupancyGrid2D, AStar
from P2_rrt import *
from P3_traj_planning import compute_smoothed_traj, modify_traj_with_li
mits, SwitchingController
import scipy.interpolate
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

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 [90]:
```
width = 100
height = 100
num_obs = 25
min_size = 5
max_size = 30

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

Solve A* planning problem

In [91]:
```
astar = AStar((0, 0), (width, height), x_init, x_goal, occupancy)
if not astar.solve():
    print "No path found"
```

Smooth Trajectory Generation

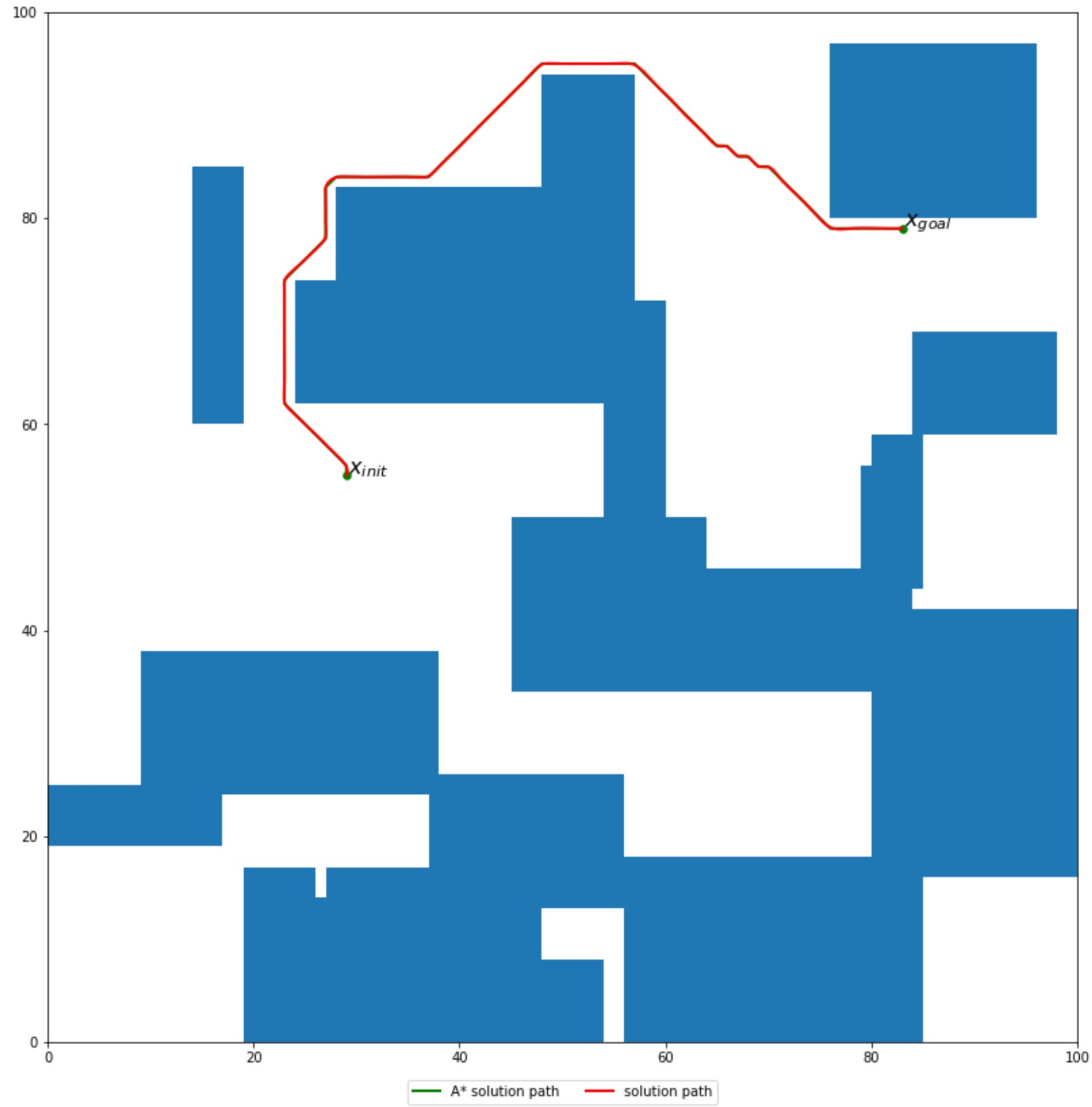
Trajectory parameters

(Try changing these and see what happens)

In [92]:
```
V_des = 0.3  # Nominal velocity
alpha = 0.1   # Smoothness parameter
dt = 0.05
```

Generate smoothed trajectory

In [93]:
```
traj_smoothed, t_smoothed = compute_smoothed_traj(astar.path, V_des, al
pha, 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", linew
idth=2, label="solution path", zorder=10)
plot_traj_smoothed(traj_smoothed)
plt.legend(loc='upper center', bbox_to_anchor=(0.5, -0.03), fancybox=Tr
ue, ncol=3)
plt.show()
```



Control-Feasible Trajectory Generation and Tracking

Robot control limits

In [94]:
```
V_max = 0.5 # max speed
om_max = 1 # max rotational speed
```

Tracking control gains

Tune these as needed to improve tracking performance.

In [95]:
```
kpx = 2
kpy = 2
kdx = 2
kdy = 2
```

Generate control-feasible trajectory

In [96]:
```
t_new, V_smooth_scaled, om_smooth_scaled, traj_smooth_scaled = modify_t
raj_with_limits(traj_smoothed, t_smoothed, V_max, om_max, dt)
```

Create trajectory controller and load trajectory

In [97]:
```
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)
```

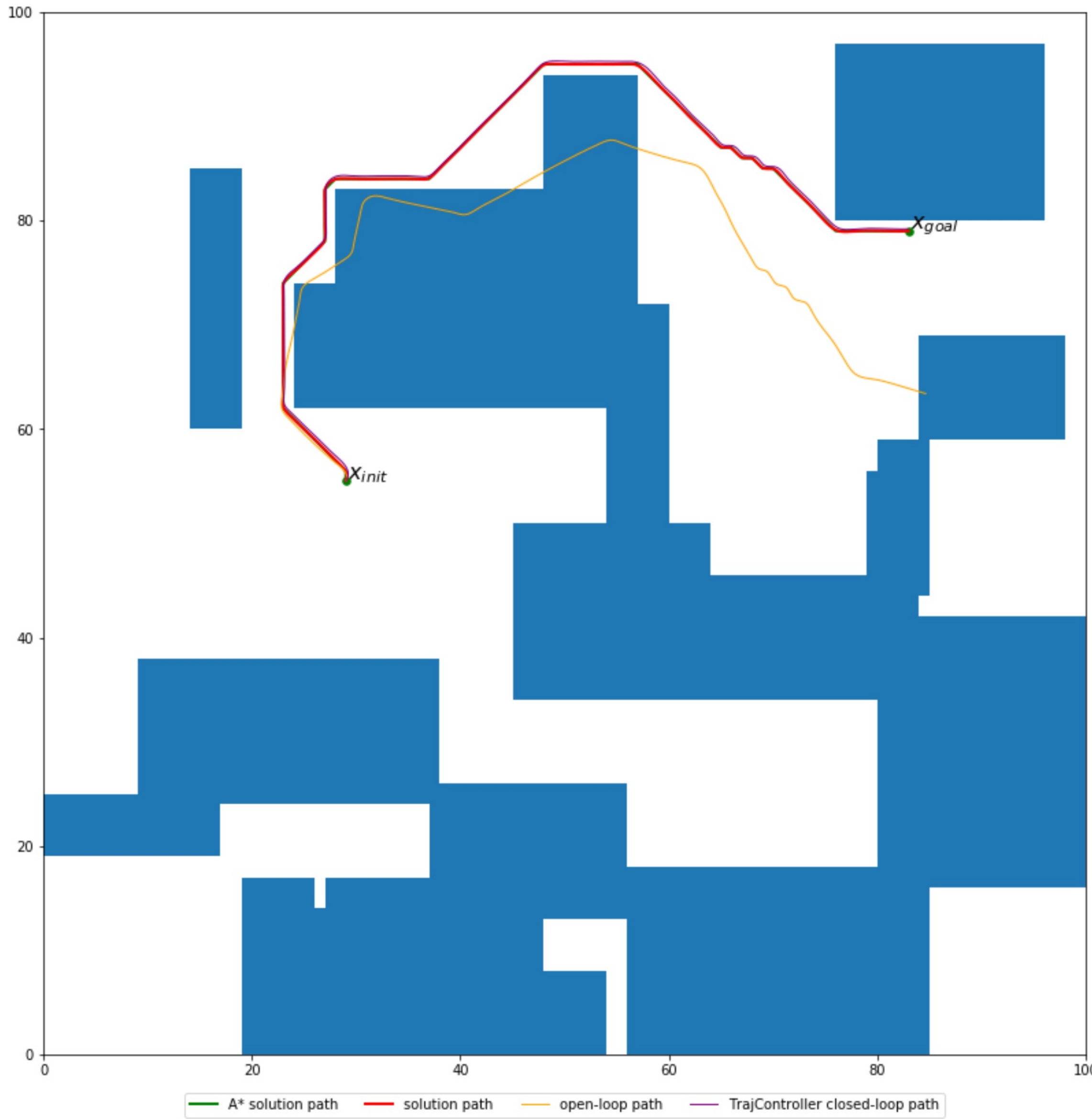
Set simulation input noise

(Try changing this and see what happens)

In [98]:
```
noise_scale = 0.05
```

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

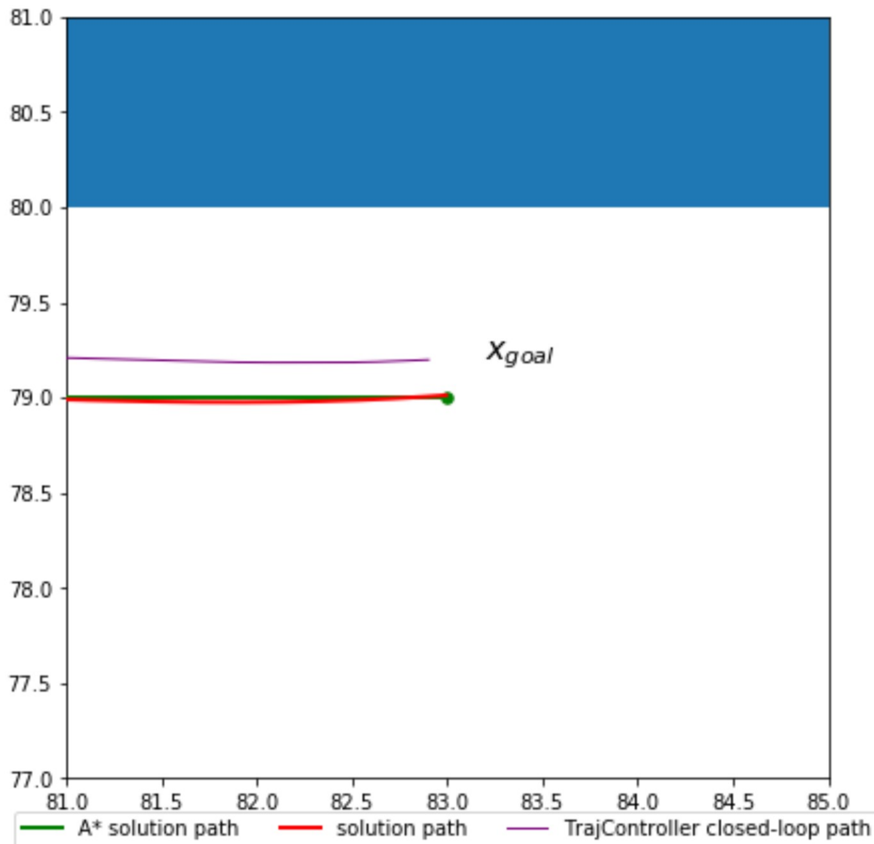
In [99]:
```
tf_actual = t_new[-1]
times_cl = np.arange(0, tf_actual, dt)
s_0 = State(x=x_init[0], y=x_init[1], V=V_max, th=traj_smooth_scaled[0,
2])
s_f = State(x=x_goal[0], y=x_goal[1], V=V_max, th=traj_smooth_scaled[-
1,2])

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, a
ctions=actions_ol, noise_scale=noise_scale)
states_cl, ctrl_cl = simulate_car_dyn(s_0.x, s_0.y, s_0.th, times_cl, c
ontroller=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=Tr
ue, ncol=4)
plt.show()
```



Switching from Trajectory Tracking to Pose Stabilization Control

Zoom in on final pose error

In [100]:
```
l_window = 4.

fig = plt.figure(figsize=[7,7])
astar.plot_path(fig.number)
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 [143]:
```
k1 = 0.2
k2 = 1.5
k3 = 1.5
```

Create pose controller and load goal pose

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

In [144]:
```
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

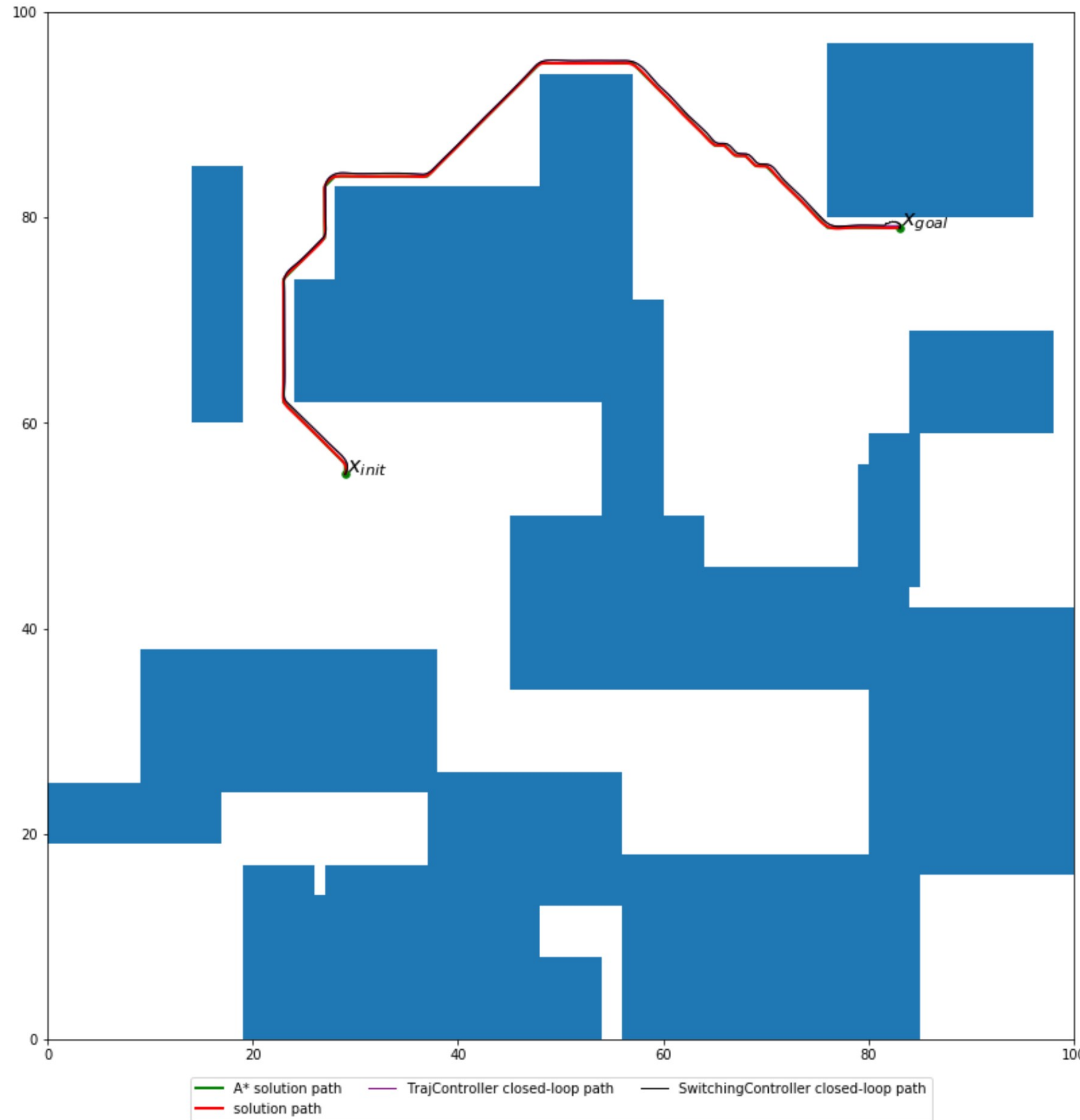
Try changing this!

In [145]:
```
t_before_switch = 5.0
```

Create switching controller and compare performance

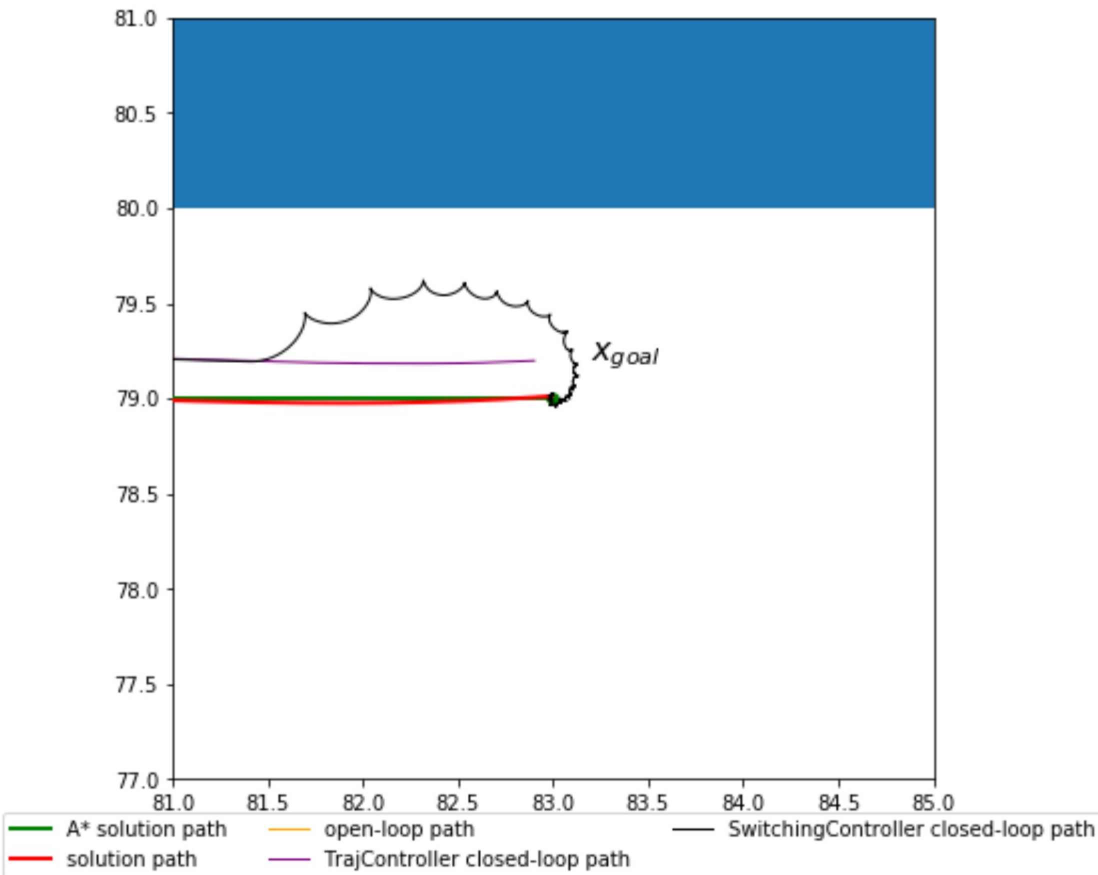
In [146]:

```
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 [147]:
```
l_window = 4.

fig = plt.figure(figsize=[7,7])
astar.plot_path(fig.number)
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()
```

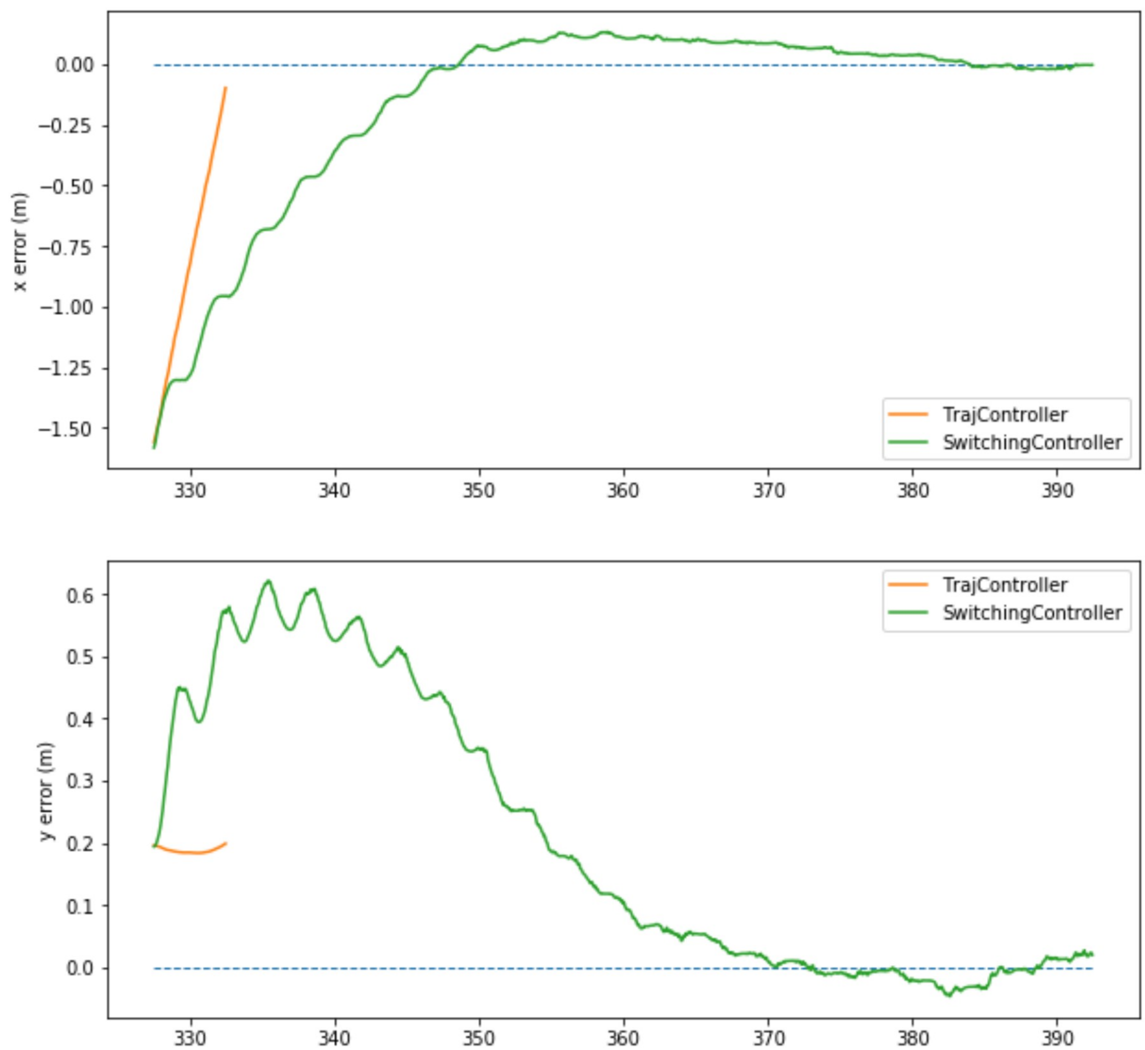


Plot final sequence of states

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 [148]:
```
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], linesty
le='--', linewidth=1)
plt.plot(times_cl[T:], states_cl[T:,0] - x_goal[0], label='TrajControl
ler')
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], linesty
le='--', linewidth=1)
plt.plot(times_cl[T:], states_cl[T:,1] - x_goal[1], label='TrajControl
ler')
plt.plot(times_cl_extended[T:], states_cl_sw[T:,1] - x_goal[1], label=
'SwitchingController')
plt.legend()
plt.ylabel("y error (m)")
```

Out[148]: `Text(0,0.5,'y error (m)')`



In [ ]: