TECHIN 516: Robotic Sensing And Mobility

Lab 4: Safe wandering using path planning algorithms

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1 Learning Objectives

1. Review and modify code to execute different path planning algorithms on a simulated turtlebot3.
2. Compare and contrast the performance of different algorithms (Djisktra and A*) as global planners in the ROS navigation stack.
3. Explore challenges and limitations of different planning algorithms to learn the trade-offs of choosing one over another.

2 Install and test the global_planner package

This global_planner package is one of the packages from the ros navigation stack meta-package. It provides a wrapper on the navigation class that allows to select the type of planning algorithm used for the global plan, using the information from a map. For this lab, we will assume the map has already been created and saved (.pgm and .yaml files). If you wish to try the global planner on a new environment, you can either launch the gmapping demo and save the new map, or add a gmapping node for SLAM in your launch file. Information about the navigation stack and the global planner can be found in the ROS wiki.

1. Download the zip file with the global_planner package from the course materials on canvas.
2. Extract the zip file and place the global_planner folder in your src folder in your workspace (/catkin/src/). You will need to build your package from the /catkin_ws/ directory. Make sure that all dependencies are installed before building the package:

   ```
   $ rosdep install --from-paths src --ignore-src -r -y
   $ catkin_make global_planner
   ```

3. Once the build has successfully finished, source your new workspace (source devel/setup.bash), launch a turtlebot3 gazebo instance and run the test_planner launch file:

   ```
   $ roslaunch turtlebot3_gazebo turtlebot3_world.launch
   $ roslaunch global_planner test_planner.launch
   ```

   You should be able to see the following topics as active after rostopic list:
   /move_base/GlobalPlanner/plan

/move_base/GlobalPlanner/potential

4. Once you find these topics in your list, your package is successfully installed. If you find any trouble with this, contact the instructors or TA.

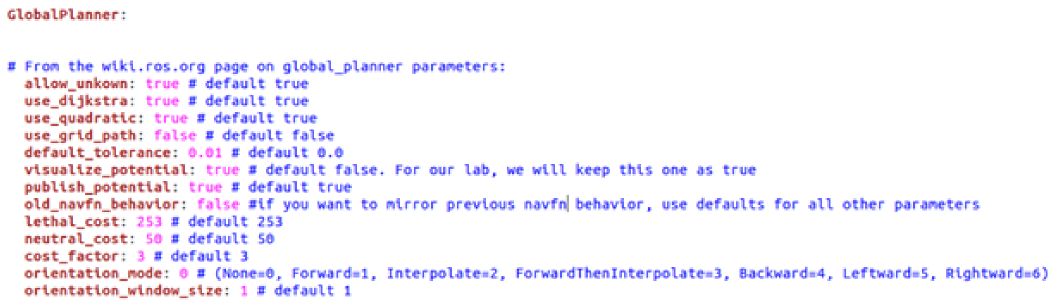
3 Path planning algorithms

3.1 Adding the global planner to the turtlebot3 navigation stack.

In previous labs, turtlebot3_navigation.launch is launched before we used the 2D Nav Goal. If you look into the launch file, you will notice it launches move_base.launch – it is where to configure the planners in turtlebot's navigation stack. We want to create a new navigation stack by duplicating the launch files and modifying the copied files as needed.

1. Make copies of launch files in the turtlebot3_navigation package:
   (a) move_base.launch $\rightarrow$ move_base_path_planning.launch: the changes made to this new file are related with adding the global_planner. Details will be provided later.
   (b) turtlebot3_navigation.launch $\rightarrow$ turtlebot3_path_planning.launch: the main difference in this new file is launching the move_base_path_planning.launch file created in step a.

       You need to make the change in the "turtlebot3_path_planning.launch" file on the move_base node to include the new move_base_path_planning.launch file
2. Download the parameters .yaml file (global_planner_params_burger.yaml) and place it in the turtlebot3_navigation/param folder. This file allows you to make changes to the global planner parameters. Refer to the ROS wiki for details on what each parameter does.
3. In the move_base_path_planning.launch file, add a global planner as a parameter of the move_base node in the launch file:
   (a) <param name="base_global_planner" value="global_planner/GlobalPlanner" />
   (b) <rosparam file="$(find turtlebot3_navigation)/param/global_planner_params_burger.yaml" command="load"/>



```
GlobalPlanner:


# From the wiki.ros.org page on global_planner parameters:
  allow_unkown: true # default true
  use_dijkstra: true # default true
  use_quadratic: true # default true
  use_grid_path: false # default false
  default_tolerance: 0.01 # default 0.0
  visualize_potential: true # default false. For our lab, we will keep this one as true
  publish_potential: true # default true
  old_navfn_behavior: false #if you want to mirror previous navfn behavior, use defaults for all other parameters
  lethal_cost: 253 # default 253
  neutral_cost: 50 # default 50
  cost_factor: 3 # default 3
  orientation_mode: 0 # (None=0, Forward=1, Interpolate=2, ForwardThenInterpolate=3, Backward=4, Leftward=5, Rightward=6)
  orientation_window_size: 1 # default 1
```

Figure 1: Global Planner yaml file.

3.2 Run the new navigation stack.

1. Launch a gazebo instance of the burger in the turtleworld3_world:

   ```
   $ roslaunch turtlebot3_gazebo turtlebot3_world.launch
   ```

2. Launch the new turtlebot3_path_planning.launch. Before sending any Navigation goals, remember to provide a 2DEstimate for the actual position of the robot in RViz. For this lab, we will disable the Global and Local costmaps that come as default in the RViZ configuration for navigation.

   ```
   $ roslaunch turtlebot3_navigation turtlebot3_path_planning.launch
   ```

   Tip: The 2DEstimate point with the RViz GUI provides the robot's initial position and orientation; a large mismatch between the robot's estimates and its actual position may result in a fatal error for the launched file.

3. Customize the RViz visualization components

   (a) Turn off the Global Map and Local Map, and add by topic the GlobalPlanner/potential topic as another map. Choose costmap to be the color scheme.

   (b) Change the topic of Planner Plan to GlobalPlanner/plan.

4. Publish four sequential points for the robot to navigate towards($P_0 \rightarrow P_1 \rightarrow P_2 \rightarrow P_3 \rightarrow P_0$). You may publish in the /move_base/goal topic through a node (path_planning_goal.py from Canvas), or you may use rostopic pub from the command line. You will need to pay attention to the contents of the message as the pose is given by a position vector and an orientation using quaternions.

   Notice: The visualization of the potential map doesn't look like what the figure shows.

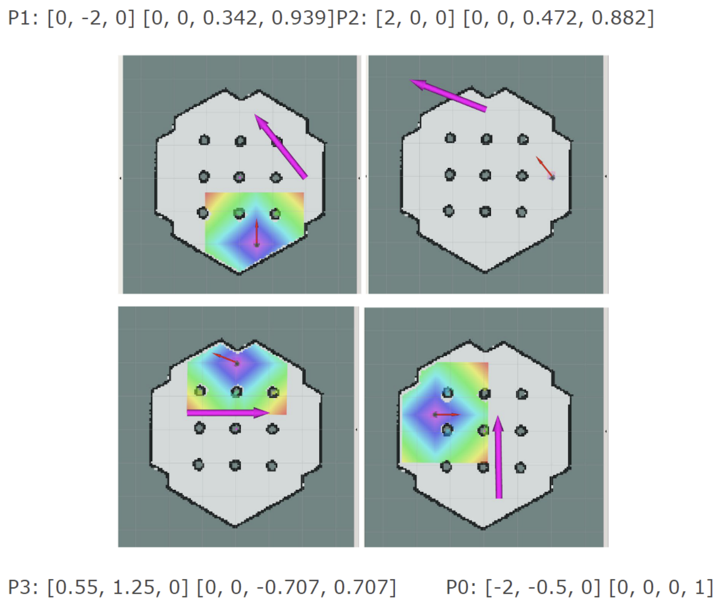

P1: [0, -2, 0] [0, 0, 0.342, 0.939]
P2: [2, 0, 0] [0, 0, 0.472, 0.882]
P3: [0.55, 1.25, 0] [0, 0, -0.707, 0.707]
P0: [-2, -0.5, 0] [0, 0, 0, 1]

Figure 2: Four sequential points.

5. This sequence you will attempt using two global planners: Djikstra and A* (you will need to change the parameters accordingly and report your best performing combination)
   (a) As it will come to your attention, when using dijkstra the planner works best if you use gradient descent and not a grid; the opposite is true for A*. Also the value for neutral_cost is relevant (lower for Dijkstra, medium for A*). The option of use_quadratic may or may not help. The cost_factor might influence how much the local planner will be used.
   (b) Some parameters can be changed dynamically using the command:

```
$ rosrun rqt_reconfigure rqt_reconfigure
```

Deliverables:

1. For both global planners, you will also gather the following quantitative information (highly recommend to create a table):
   (a) For each chunk of the path ($P_0 \to P_1$, $P_1 \to P_2$, $P_2 \to P_3$, $P_3 \to P_0$), report the travel time (rough estimation is ok.)

   NOTICE:
   For Dijkstra algorithm, gradient descent was used for optimization.
   For A* algorithm, grid path was used, and `neutral_cost` set to `100`.

Path	**Algorithm**	
	Dijkstra	*A* Search*
$P_0 \to P_1$	$23s$	$27s$
$P_1 \to P_2$	$16s$	$25s$
$P_2 \to P_3$	$22s$	$26s$
$P_3 \to P_0$	$18s$	$39s$
Total	$1m19s$	$1m57s$

   (b) Describe qualitatively whose path length was shorter for A* and Djikstra.

   Answer: The paths of the robot planned by both algorithms are demonstrated in Figure 3. It's quite hard to tell just by eyes, which path is longer. Each algorithm performs differently depending on the condition, in accordance with their strategy. The A* path made detours in the first chunk, but walked in straighter lines in the next two.

   (c) What did you observe from the potential map?

   Answer: The potentials of the path calculated by both algorithms are demonstrated in Figure 4. It's obvious that the colored areas are larger along the path of the Dijkstra one than the A* one. It means that A* algorithm considers fewer potential paths, or only expands certain nodes closer to the goal, while Dijkstra explores in all directions.

   (d) Discuss the advantages and disadvantages of the two path planning algorithm.

DIJKSTRA: a special case for A* without heuristics

Pros:

- finds the optimal path by exploring all possibilities
- requires only source and goal node
- less memory usage

Cons:

- more operation time and resource consumption in general
- assumes a finite graph
- works only with non-negative edge costs or weights

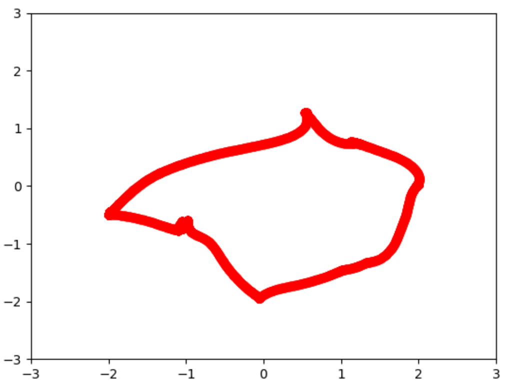
A* SEARCH: greedy best-first search with two cost functions

Pros:

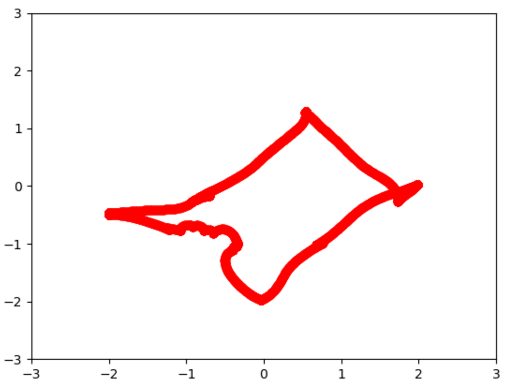
- achieves a trade-off between memory, time, and length
- explores the fewest number of nodes and paths
- less time complexity in theory

Cons:

- efficiency relies heavily on a good heuristic function
- finds optimal path only with admissible heuristic function
- more space complexity in theory



(a) Dijkstra



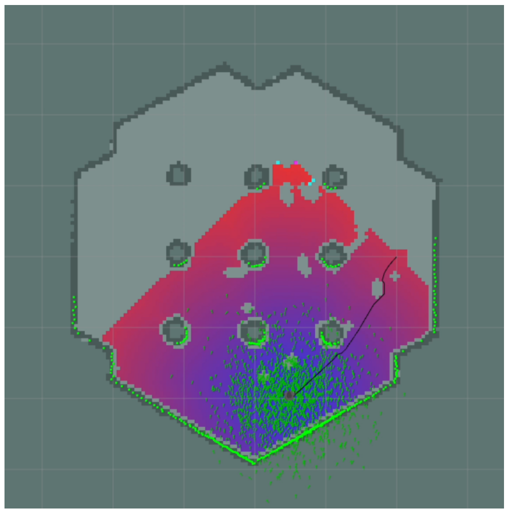
(b) A* Search

Figure 3: Plotting robot's paths planned by different algorithms.

2. Use your pillar model (created in Lab1), and add it as an obstacle in the turtlebot3_world. Turn on the Local Map visualization in Rviz. Attempt to send a 2DNavigationGoal where the robot has to circumvent the new obstacle.

   (a) Report your choice for obstacle location by taking a screenshot, and your robot's initial position as well as the selected goal position and orientation. (Tip: you may want to use the topic /move_base/goal, and echo it, to obtain position and orientation vectors)

   Answer: The obstacle, a pillar of which the radius is $0.2m$, is placed right to P_2, at


(a) Dijkstra

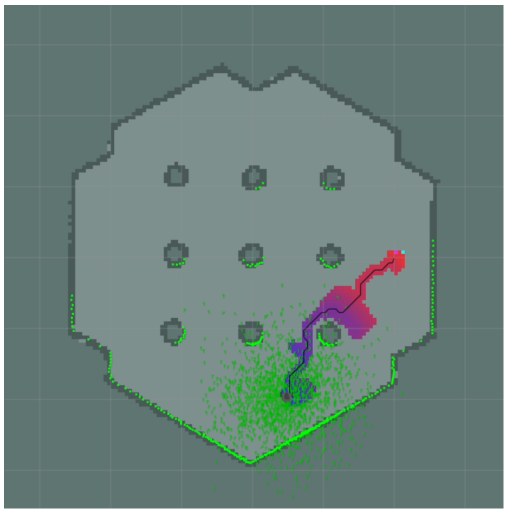
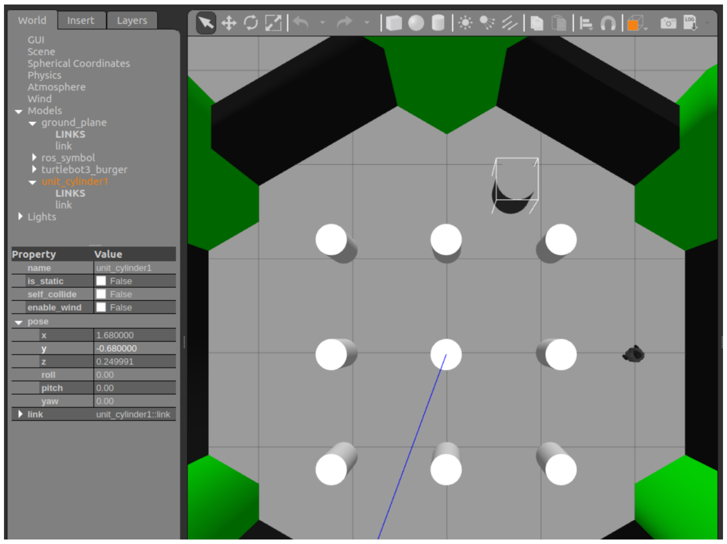

(b) A* Search

Figure 4: Calculating potentials by different algorithms.

the point `(1.68, -0.68, 0.25)`, as shown in Figure 5. The initial and goal nodes are set to P_1 and P_2 respectively for easier comparison. The obstacle is set such that it blocks the optimal path from P_1 to P_2 previously computed by the algorithm. It has to dynamically replan a new path that avoids the obstacle.
P_1: `(0, -2, 0)(0, 0, 0.342, 0.939)`;
P_2: `(2, 0, 0)(0, 0, 0.472, 0.882)`.



Property	Value
name	unit_cylinder1
is_static	False
self_collide	False
enable_wind	False
pose	
x	1.680000
y	-0.680000
z	0.249991
roll	0.00
pitch	0.00
yaw	0.00
link	unit_cylinder1::link

Figure 5: Position of pillar obstacle.

(b) Describe the actions of the robot:

i. Does the robot reach its intended goal in A* and Djikstra?

Answer: For the aforementioned setting, in which the obstacle has a medium radius, the robot almost always reaches the goal. There were a few edge cases, where the robot was stuck in a narrow aisle between pillars.

Doubling the radius of the obstacle, however, brings the success rate down to zero. With a larger pillar, the original path is completely blocked and a major retreat and detour is required. The robot under such algorithms is obviously not prepared.

ii. What did you observe from the global planner and local planner?

Answer: The indicator for the global planner is a thin, black, and solid black line between the start and end nodes, while that for the local planner is a much shorter line in a lighter color that constantly changes.

Although both indicators change, the local planner does it at a much faster speed. Based on their definition, it can be deducted that the global planner calculates the full path prior to operation and dynamically adjusts path during the process; the local planner generally follows the global planner, but modifies the full path if obstacles are detected along the way to prevent collisions.

Specifically, the global planner subscribes to the map, current position, goal position, and publishes a path between both positions; the local planner subscribes to the map and the path planned by global planner, and publishes command velocities for the robot to best accomplish the goal. Should there be unexpected objects on the path not detected or considered by global planner, the local planner would dynamically adjust `cmd_vel` for the robot to avoid them.

4 Path planning with the physical robot

This portion of the lab assignment will entail repeating the same process for testing the two global planners, now using the GIX map. You have already completed a map for this environment. If you do not have the .pgm and .yaml files associated with the GIX map you will have to run the gmapping demo and teleoperate the robot around the map before getting started.

We will have to repeat the connection instructions for the physical robot. Changes to be made in the environment variables and the /.bashrc file.

Instead of providing a sequence of 4 points as navigation goals, the physical implementation will include only 2 points, with two paths: One from $P_0 \rightarrow P_1$, and another $P_1 \rightarrow P_0$. P_0 will be your starting position (marked with a black X), P1 will be marked by a blue X.

Deliverables:

1. Using the global_planner with both algorithms (Dijkstra and A*) to report:

   (a) the travel time (rough estimation is ok.)

Answer: The travel time for the robot to travel between the black and blue crosses using the global_planner with Dijkstra algorithm is $36s$. Fast as it is, traveling with A* Search is even faster, which brings the total time down to $26s$. It's worth mentioning that path planning with A* broke the record, as it's two times faster than in the last lab patroling without a planning algorithm.

(b) If any collisions occur, note them and comment on possible causes of the collisions.

Answer: In the first few attempts, some possible collisions were detected in the laser scan and costmap, before the robot was blocked. The main reason for collisions is obstacles, which include those outlined on the map and those unexpected on the path.

Most of the time, misalignment between map and laser scan data and inappropriate occupancy grid threshold are to blame for the robot bumping into known objects. For other cases, the robot could be moving too fast to stop before encountering a block not considered by the map.

2. Reset the robot to the initial position P_0, and then add an obstacle in the map environment. Attempt the navigation to P_1 and comment on the execution using both planners:

   (a) Does the robot reach its intended goal in A* and Djikstra?

   Answer: Depending on the location of the obstacle, the robot demonstrated different capabilities to bypass it. If a relatively big obstable (tissue box size) stands in the path taken in the previous question, the robot won't be able to reach the goal with both algorithms. In the failed attempts, they repeatedly replan the path and walked back and forth when the obstacle was detected, before the action was aborted.

   For once, A* Search succeeded in reaching the goal after tilting the angle of its path a bit every time. The entire process took around 5 minutes.

   (b) What did you observe from the global planner and local planner?

   Answer: As described in the answer for 3.2.2.2, the global planner focused on the full path, while the local one dynamically edits the path to avoid detected obstacles.

   The global planner determines one path before execution and slowly switches to another in response to obstacles. As Dijkstra planned relatively smooth routes, A* appeared somewhat confusing. Its routes were more aggressive that left less space from obstacles and underestimated the size of the robot. After warnings, the routes were modified that followed the walls, which caused even more collision and stagnation.

   The local planner looks forward for a certain range to accommodate the obstacles, but not long enough to completely avoid them. Most of the time, the local planner only radically switched the orientation of the robot to make it walk back and forth, hoping to conjure up a path that would work. It didn't fully explore the vicinity of the obstacle to find the directions that effectively bypass it. This is expected to change with a more advanced planning algorithm and better local planner configurations.