Tutorial on Path Planning

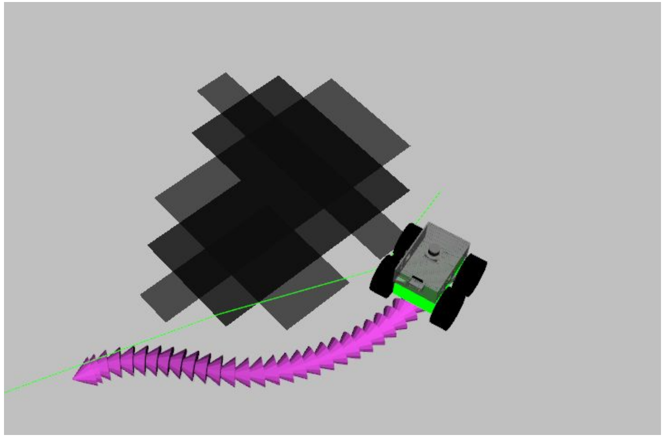
ETH Robotics Summer School

Nick Lawrance and Luca Bartolomei

5th July, 2022

Tutorial Objectives

- (Brief) introduction to Path Planning
- Description of path-planning pipeline:
  - Global Planning
  - Local Planning
- How to install and run the packages

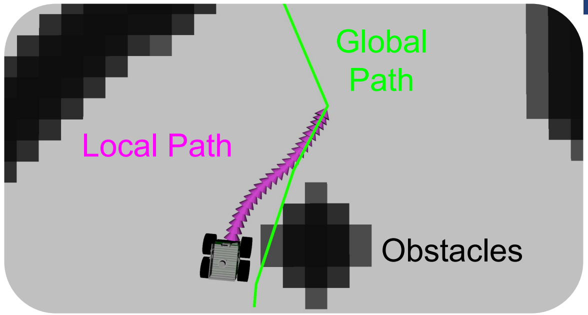


(Brief) introduction to Path Planning

Path planning:

- Autonomous goal-oriented navigation
- Obstacle avoidance

(Brief) introduction to Path Planning



- Hierarchical architecture

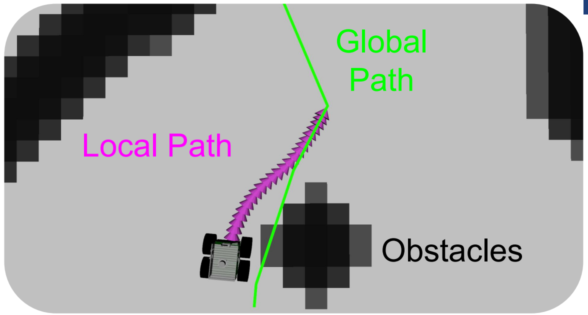
Global Planner →

- Coarse path to goal configuration
- Optimistic (unknown space is free)
- Low re-planning rate

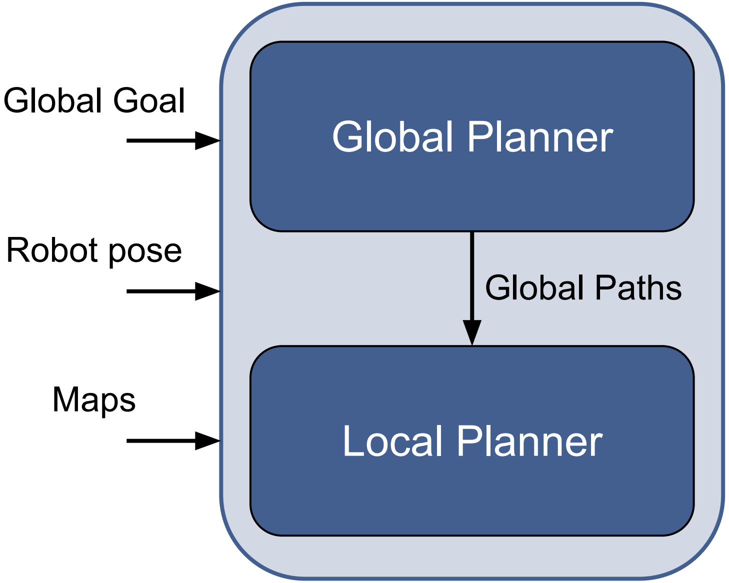
Local Planner →

- Local obstacle avoidance
- Feasible trajectories for controllers
- High re-planning rate

(Brief) introduction to Path Planning



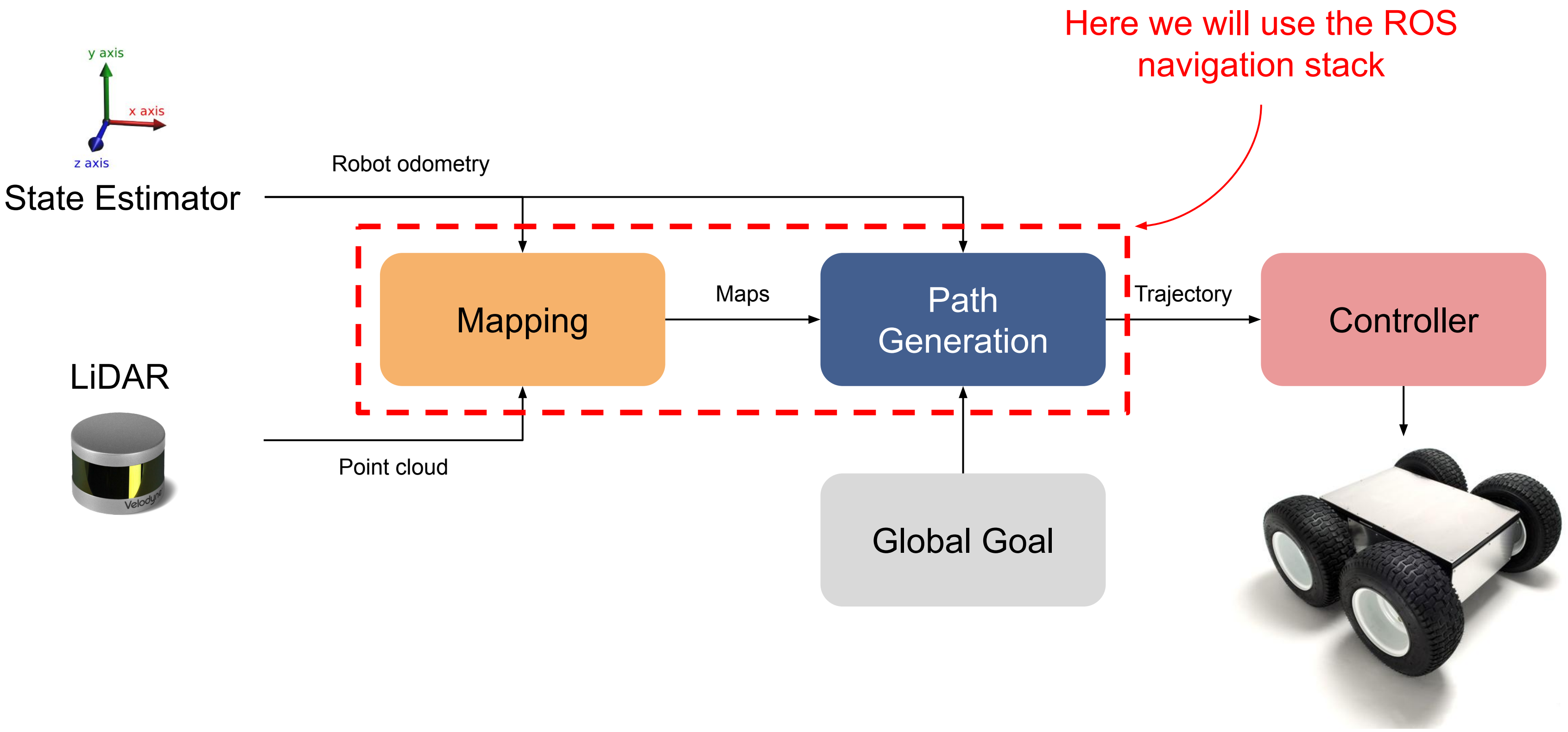
- Hierarchical architecture



- Coarse path to goal configuration
- Optimistic (unknown space is free)
- Low re-planning rate

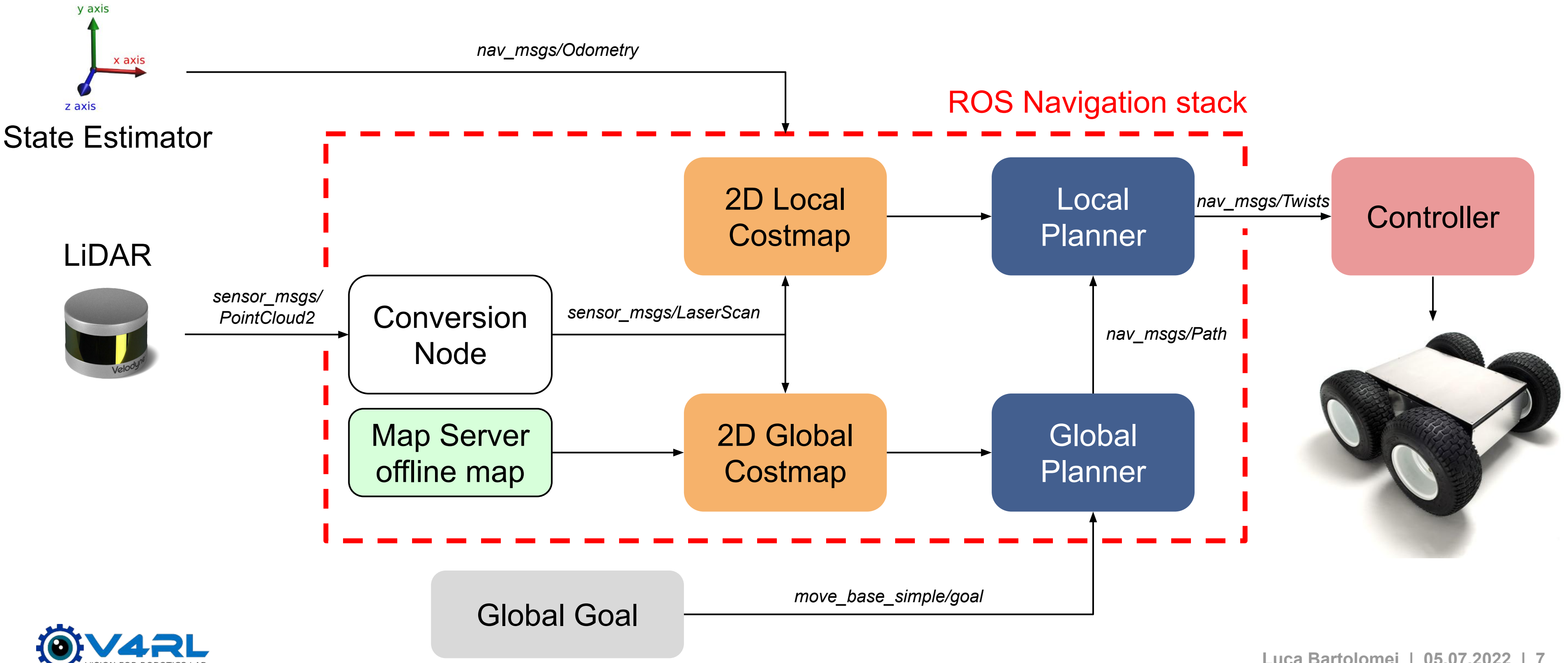
- Local obstacle avoidance
- Feasible trajectories for controllers
- High re-planning rate

Pipeline Overview



Detailed Pipeline

Docs: move_base - ROS Wiki

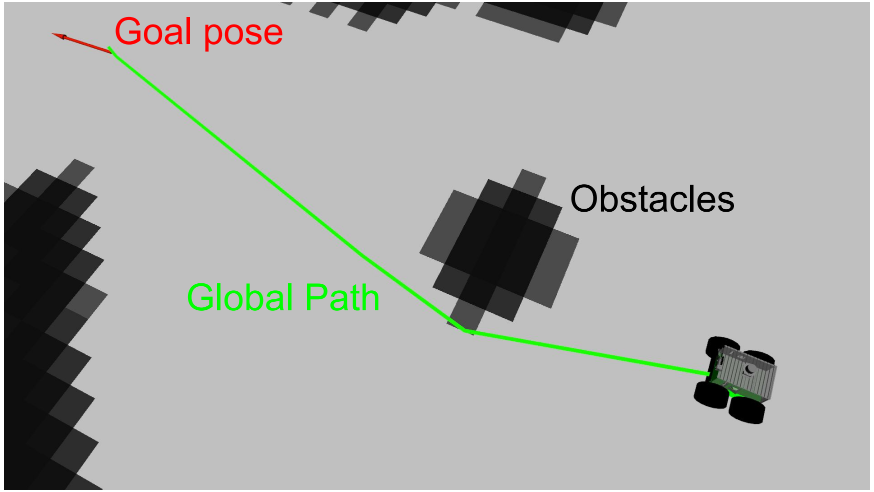


V4RL VISION FOR ROBOTICS LAB

Path Planner: Global Planner

Docs: move_base - ROS Wiki

- Path from current state to global goal
- Optimistic → unknown space = free



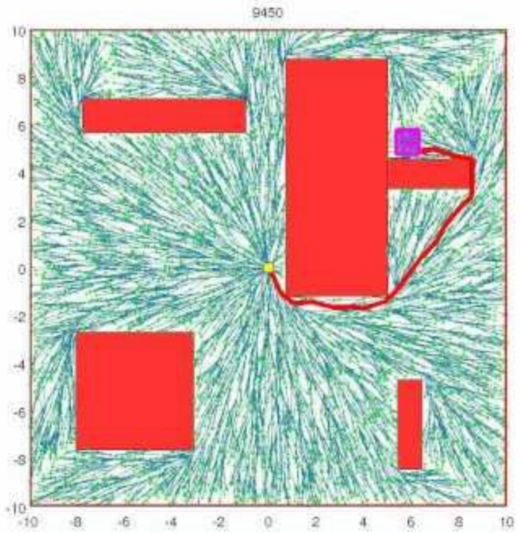
OMPL (Open Motion Planning Library) - https://ompl.kavrakilab.org

Path Planner: Global Planner

Docs: move_base - ROS Wiki

- Custom implementation based on OMPL
  - Code: `smb_path_planner/smb_ompl_planner`
- Basic version: RRT*
  - Probabilistically complete and optimal algorithm

RRT*



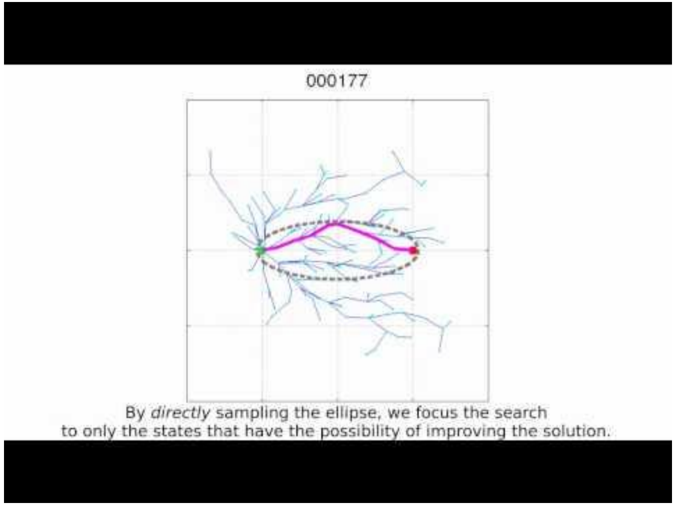
"Sampling-based Algorithms for Optimal Motion Planning", S. Karaman and E. Frazzoli, IJJR 2011

Path Planner: Global Planner

Docs: move_base - ROS Wiki

- Custom implementation based on OMPL
  - Code: `smb_path_planner/smb_ompl_planner`
- Basic version: RRT*
  - Probabilistically complete and optimal algorithm
- Possibility to swap solver from config file:
  - Informed RRT*
  - RRT#
  - PRM

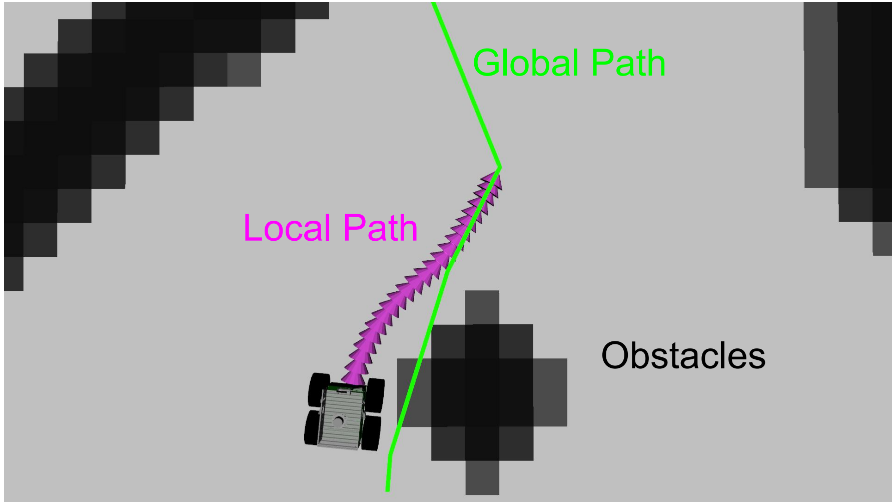
Informed RRT*



"Informed RRT: Optimal Incremental Path Planning Focused through an Admissible Ellipsoidal Heuristic"*, J.D. Gammell, IROS 2014

Path Planner: TEB Local Planner

- Compute locally optimal paths
  - Vehicle dynamics
  - Obstacle avoidance
- Pessimistic
  → unknown space = occupied
- Use Time-Elastic-Band (TEB) Local Planner
  - C. Rösmann et al., IROS 2017
  - Docs: teb_local_planner - ROS Wiki

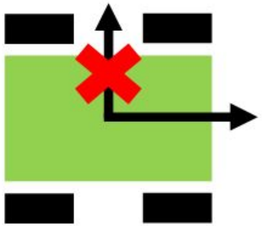


Path Planner: TEB Local Planner

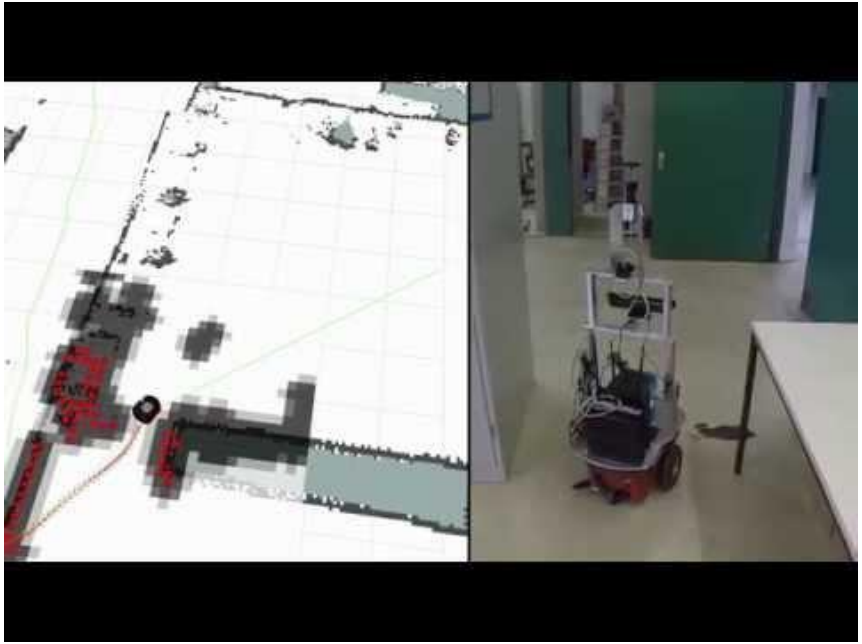
Docs: teb_local_planner - ROS Wiki
Link to TEB paper

- Online trajectory optimization
- Objective: reach goal in minimum time
  - Kinodynamic constraints (velocity, acceleration, …)
  - Non-holonomic kinematics

$$V_{robot}^{lateral} = 0$$



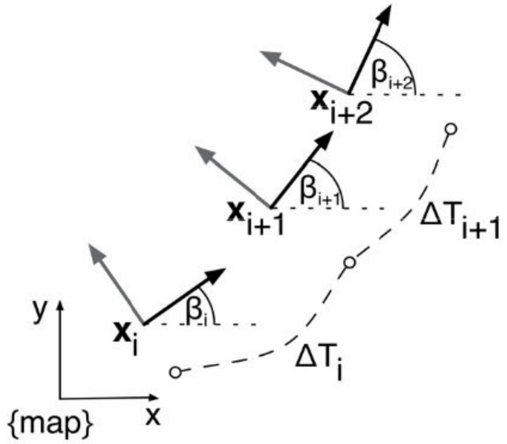
$$V_{robot} = V_{robot}^{forward}$$



Link to video

Path Planner: TEB Local Planner

Docs: teb_local_planner - ROS Wiki
Link to TEB paper



- Trajectory parametrized as a rubber band
  - Waypoints:

$$\mathbf{x}_i = (x_i, y_i, \beta_i)^T \in \mathbb{R}^2 \times S^1$$

  - Timing between waypoints:

$$\tau = \{\Delta T_i\}_{i=0\ldots n-1}$$

- Optimize cost function:

$$f(B) = \sum_k \gamma_k f_k(B)$$

Function to be optimized

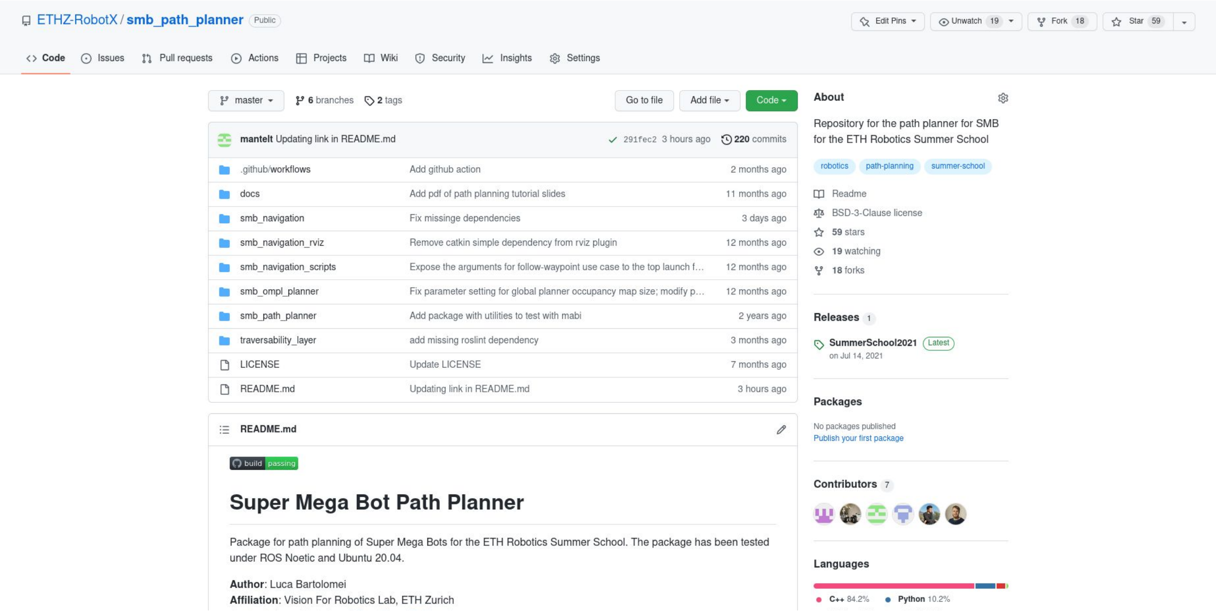
Waypoints and timing sequences

Weighted sum of
- Objectives (e.g. shortest path), and
- Soft constraints (e.g. kinematics, dynamics)

V4RL VISION FOR ROBOTICS LAB

Installation & Simulation Set-up

- Main webpage: https://github.com/ETHZ-RobotX/smb_path_planner



Installation & Simulation Set-up

- Main webpage: https://github.com/ETHZ-RobotX/smb_path_planner
- Simply follow the instructions to install the planner

Main Packages	Description
`smb_navigation`	Main package (utilities, launch and configuration files)
`smb_navigation_scripts`	Utility scripts (follow waypoints, point cloud processing)
`smb_ompl_planner`	Global planner based on OMPL library
`smb_navigation_rviz`	RViz plugin to select the navigation goal

Running in Simulation - basic usage

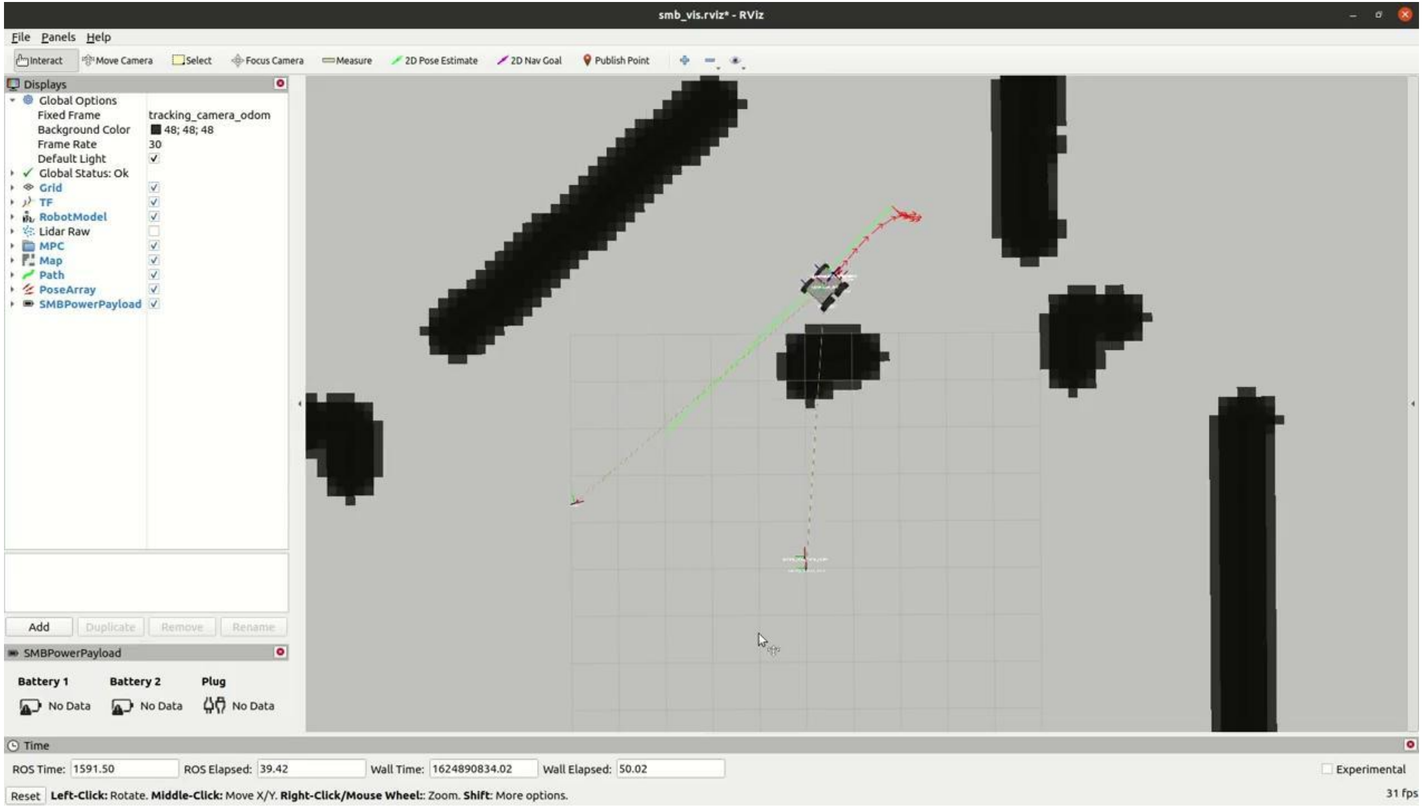
- Refer to the documentation

- Quick start:
  1. Start the simulation: `$ roslaunch smb_gazebo sim.launch`
     a. You should be able to see the SMB in RViz

  2. Start the planner:
     `$ roslaunch smb_navigation navigate2d_ompl.launch sim:=true global_frame:=tracking_camera_odom`
     a. You should see the occupancy map in RViz

  3. Send goal position using `“2D Nav Goal”` button in RViz

Running in Simulation - basic usage



VISION FOR ROBOTICS LAB

Running in Simulation - basic usage

- Refer to the documentation

- Run `rqt_reconfigure` to tune the planner online (remember to save the parameters!):

```
$ rosrun rqt_reconfigure rqt_reconfigure
```

- Play with the different global planners
  - Change OMPL planner by editing config file:
    `smb_navigation/config/ompl_global_planner.yaml`
  - Run `move_base` global planner (using A*):

```
$ roslaunch smb_navigation navigate2d.launch sim:=true global_frame:=tracking_camera_odom
```

4. Enjoy!

VISION FOR ROBOTICS LAB

Running in Simulation - advanced features

- Refer to the documentation for advanced features

- It is possible to specify...
  - ... a different odometry topic:
    `$ roslaunch smb_navigation navigate2d_ompl.launch` **`odom_topic:=/odom_new`**

  - ... different reference frames:
    `$ roslaunch smb_navigation navigate2d_ompl.launch` **`global_frame:=map_new robot_base_frame:=base_new`**

Running in Simulation - advanced features

- Refer to the documentation for advanced features
- It is possible to specify...
  - ... a different odometry topic:
    ```
    $ roslaunch smb_navigation navigate2d_ompl.launch  odom_topic:=/odom_new
    ```
  - ... different reference frames:
    ```
    $ roslaunch smb_navigation navigate2d_ompl.launch  global_frame:=map_new
    robot_base_frame:=base_new
    ```
- Use existing global maps for planning (e.g. from previous missions)
- Follow a set of waypoints

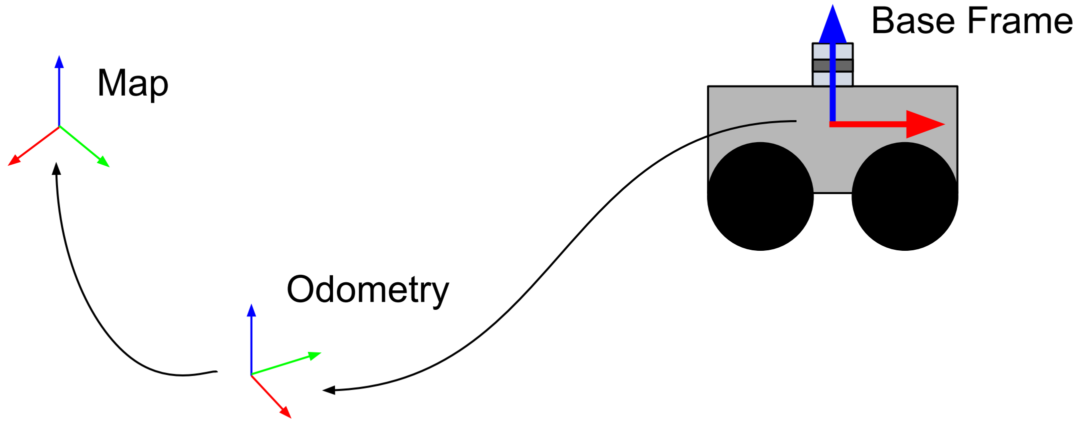
Running in Simulation - advanced features

- Refer to the documentation for advanced features
- It is possible to specify...
  - ... a different odometry topic:
    `roslaunch smb_navigation navigate2d_ompl.launch odom_topic:=/odom_new`
  - ... different reference frames:
    `roslaunch smb_navigation navigate2d_ompl.launch global_frame:=map_new robot_base_frame:=base_new`
- Use existing global maps for planning (e.g. from previous missions)
- Follow a set of waypoints

Running in Simulation - use existing global maps (doc)

- Global planning → static and globally consistent map
  - Finds the shortest path in the complete map (*Map* frame)
  - Uses TF connections to retrieve transformations (from *Base Frame* to *Map*)

- Local planning & control → *Odometry* frame
  - Use odometry information directly (drifting, but continuous estimates)



Running in Simulation - use existing global maps (doc)

- For this tutorial, we provide a map of the simulation environment
- Follow these steps:
  - Set the path to the global map in the launch file (already done for simulation)

master ▾ smb_path_planner / smb_navigation / launch / **navigate2d_ompl.launch** Go to file ···

lucaBartolomei Odometry topic is now passed as parameters to launch file; ··· Latest commit f50d7ac 6 hours ago **History**

2 contributors

65 lines (50 sloc) | 2.63 KB Raw Blame

```xml
<?xml version="1.0"?>

<launch>
  <!-- Arguments -->
  <arg name="sim"                default="false"/>
  <arg name="use_global_map"     default="false"/>
  <arg name="run_traversability" default="false"/>
  <arg name="follow_waypoints"   default="false"/>

  <arg name="global_frame"       default="tracking_camera_odom"/>
  <arg name="robot_base_frame"   default="base_link"/>

  <!-- TODO Set right map -->
  <arg name="global_map"         default="$(find smb_navigation)/data/simulation/map_sim.yaml"/>

  <!-- TODO Topics -->
  <arg name="odom_topic"         default="/base_odom"/>

  <!-- Mapping -->
```

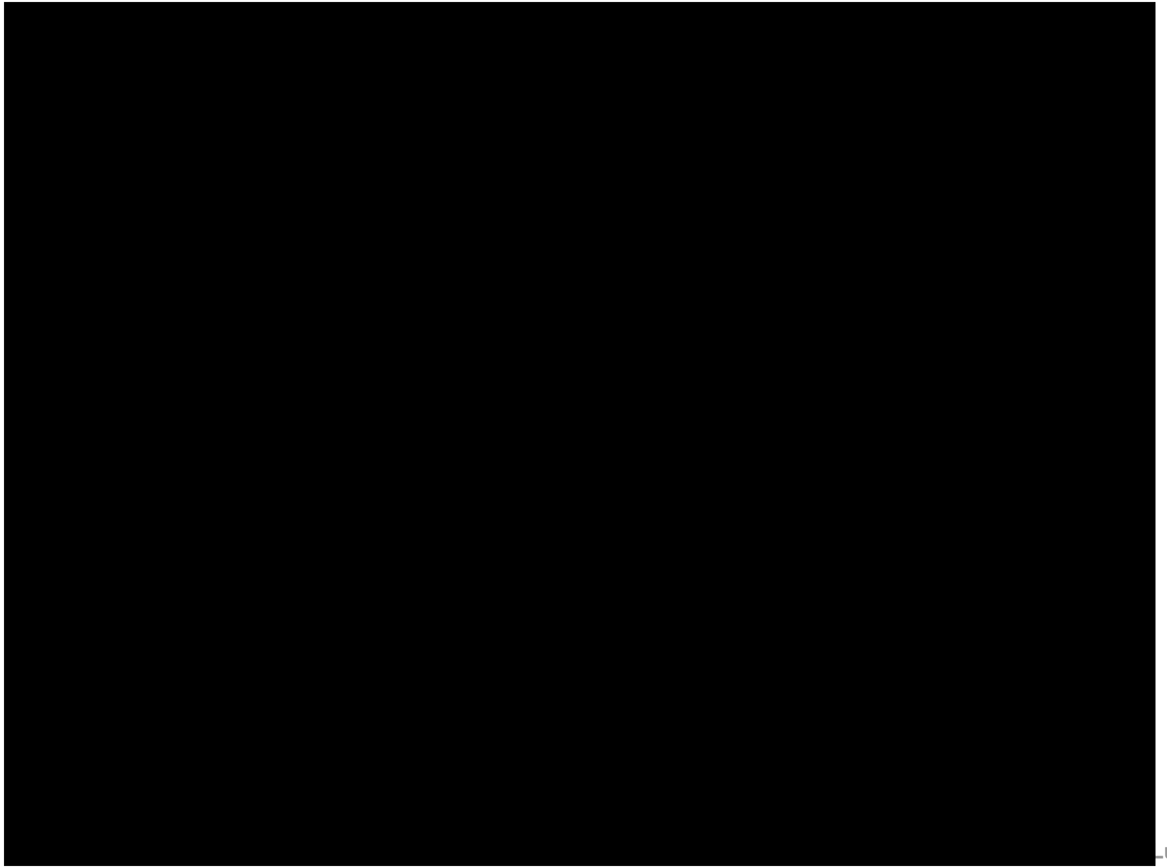
Running in Simulation - use existing global maps (doc)

- For this tutorial, we provide a map of the simulation environment
- Follow these steps:
  - Set the path to the global map in the launch file (already done for simulation)

  - Run the planner:
    `$ roslaunch smb_navigation navigate2d_ompl.launch sim:=true global_frame:=tracking_camera_odom` **`use_global_map:=true`**

- The global planner now uses a ***static*** **global map**
  - Use `rqt_reconfigure` to turn on the obstacle and inflation layers

Running in Simulation - use existing global maps (doc)



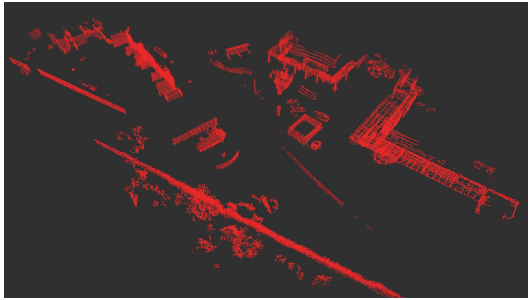
VISION FOR ROBOTICS LAB

Running in Simulation - create global maps (doc)

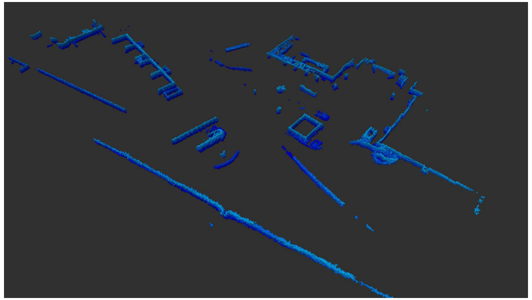
- But how do I create a global map (e.g. from SLAM)?

Running in Simulation - create global maps (doc)

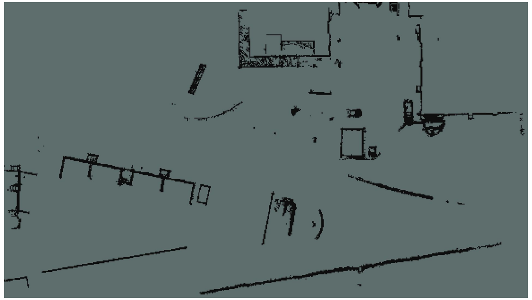
- But how do I create a global map (e.g. from SLAM)?
- These instructions show how to create an occupancy map from `*.pcd` files



Original `*.pcd` file
(3D map)



OctoMap
(3D map)



Occupancy Grid
(2D map)

Running in Simulation - create global maps (doc)

Can take several minutes of computation!

- If you have a `compslam_map.pcd` file created by `smb_slam`, run default script:
  - Start `roscore` on your machine
  - `$ cd smb_path_planner/smb_navigation/script`
  - `$ python3 pcd_to_grid_map_default_paths.py`

Manual work!

- Using *default parameters* (`resolution, z_min, z_max`) defined in `pcd_to_gridmap.sh`!
  - Inspect the intermediate results in RViz
- This will create a `*.yaml` and a `*.pgm` files in `smb_navigation/data/test`
  - Make sure the origin in the `*.yaml` file does not contain NaNs
    → Otherwise, replace them with zeros
  - Check that the path to `*.pgm` file in `*.yaml` file is correct (relative paths are ok)

Running in Simulation - create global maps (doc)

Can take several minutes of computation!

- If you want more control, use the script directly:
  - `$ cd smb_path_planner/smb_navigation/script`
  - `$ chmod +x pcd_to_gridmap.sh`
  - `$ ./pcd_to_gridmap.sh <input_file> <output_folder> <run_rviz>`

`True` or `False`

Manual work!

- Using *default parameters* (`resolution, z_min, z_max`) defined in `pcd_to_gridmap.sh`!
  - Inspect the intermediate results in RViz
- This will create a `*.yaml` and a `*.pgm` files in the specified output folder
  - Make sure the origin in the `*.yaml` file does not contain NaNs
    → Otherwise, replace them with zeros
  - Check that the path to `*.pgm` file in `*.yaml` file is correct (relative paths are ok)

Running in Simulation - create global maps (doc)

- `pcd_to_gridmap.sh` uses default parameters
  - `resolution` → resolution of the grid map
  - `z_min`
  - `z_max`

  Height range of the point cloud

- You will need to adjust these parameters to get a good result!

- **Method 1**: trial-and-error
  - Adjust the parameters and inspect results in RViz
  - Repeat until you get a reasonable result

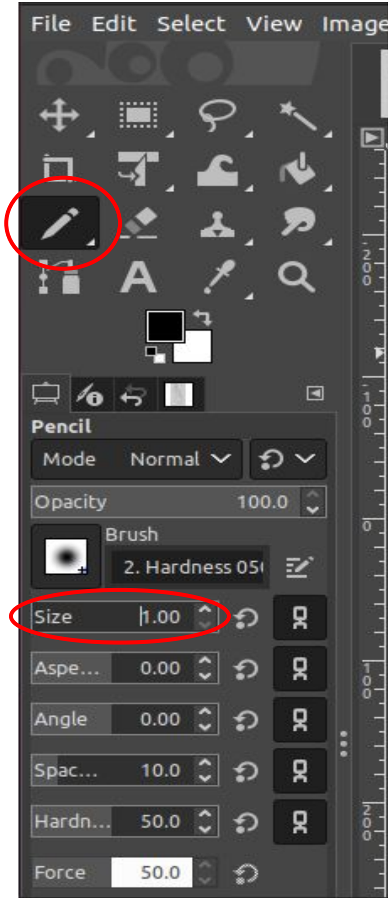
- **Method 2**: use image editing tools
  - Correct the image to remove artifacts

Running in Simulation - create global maps (doc)

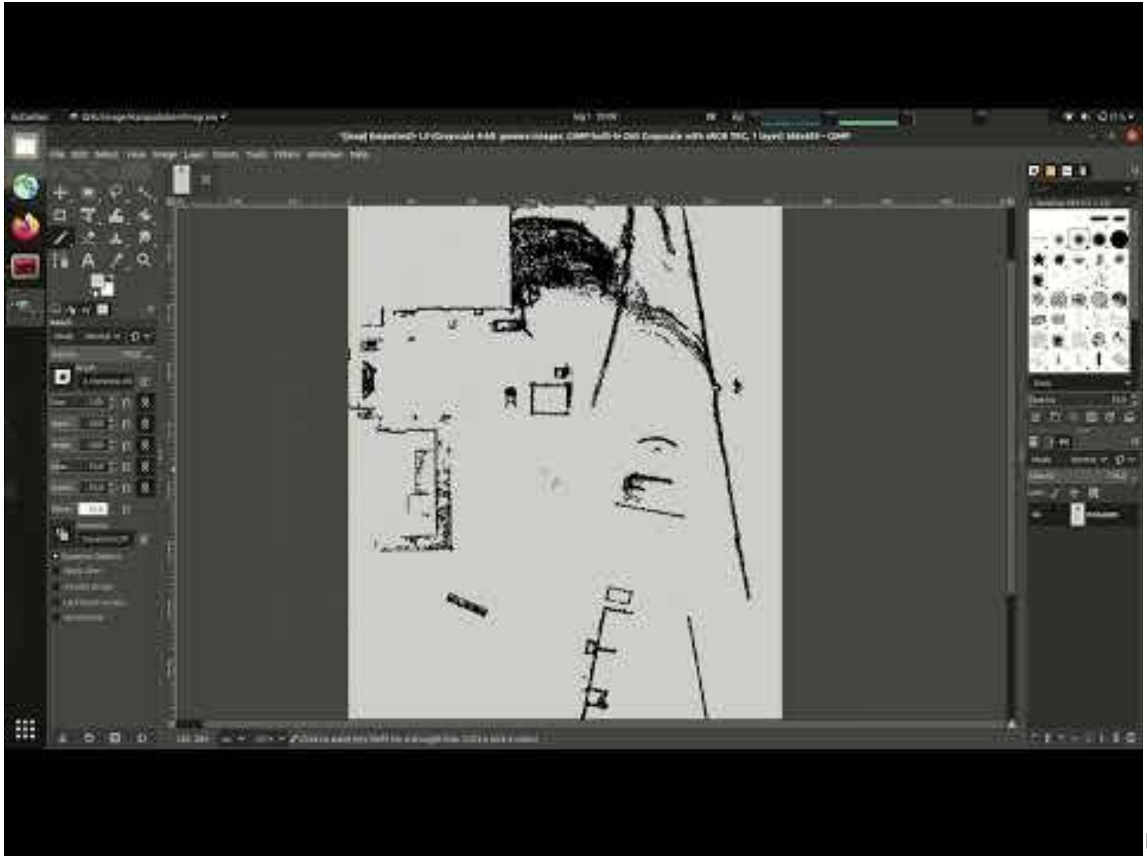
- **Method 2**: use image editing tools
  - Correct the image to remove artifacts

- Example with GIMP (install with `sudo apt install gimp`)

  1. Start GIMP and open the file `map.pmg`
  2. Select the pencil tool and choose proper size (e.g. 2)
  3. Select the right color and then you can:
     a. Remove artifacts
     b. Draw additional “fake” obstacles (e.g. borders)
  4. Save the new file:
     a. *File → Export As →* `.pgm` extension



Running in Simulation - create global maps (doc)



Running in Simulation - advanced features

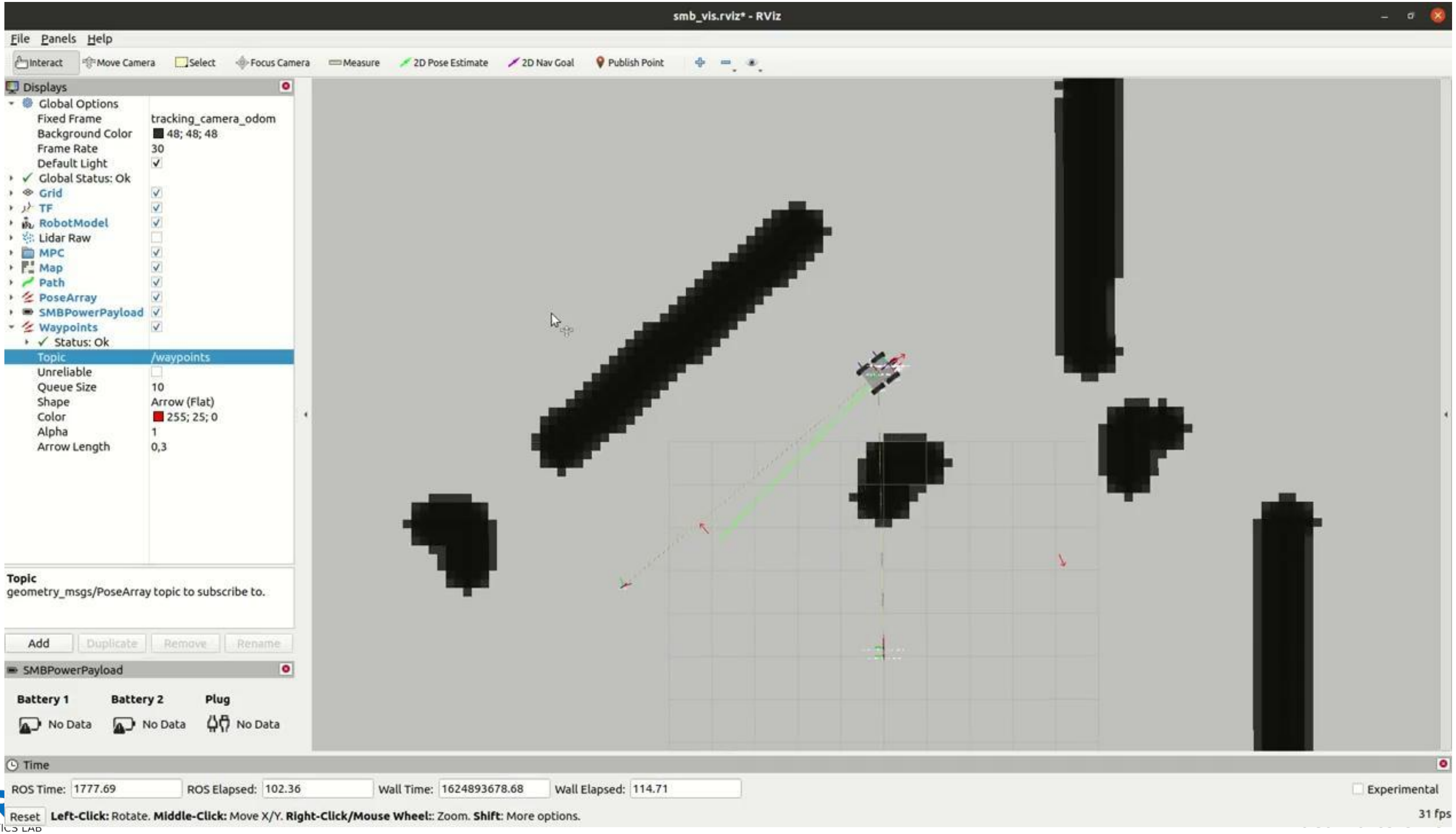
- Refer to the documentation for advanced features
- It is possible to specify...
  - ... a different odometry topic:
    `roslaunch smb_navigation navigate2d_ompl.launch odom_topic:=/odom_new`
  - ... different reference frames:
    `roslaunch smb_navigation navigate2d_ompl.launch global_frame:=map_new robot_base_frame:=base_new`
- Use existing global maps for planning (e.g. from previous missions)
- Follow a set of waypoints

Running in Simulation - follow waypoints (doc)

- Start the simulation and run the command:

```
$ roslaunch smb_navigation navigate2d_ompl.launch sim:=true
global_frame:=tracking_camera_odom  follow_waypoints:=true
```

Running in Simulation - follow waypoints (doc)



Running in Simulation - follow waypoints (doc)

- Start the simulation and run the command:
  `$ roslaunch smb_navigation navigate2d_ompl.launch sim:=true global_frame:=tracking_camera_odom` **`follow_waypoints:=true`**

- **Online**:
  - Start the simulation and the planner
  - Set sequence of waypoints in RViz (button “`2D Pose Estimate`”)
  - Call via terminal: `$ rostopic pub /path_ready std_msgs/Empty -1`
  - The waypoints will be stored in a file
    - Location specified in the launch file (parameter: `output_folder`)

- **Offline**:
  - Specify the input file in the launch file (folder and file name) - make sure it exists!
  - Start the simulation and the planner
  - Call via terminal: `$ rostopic pub /start_journey std_msgs/Empty -1`

Running on real SMB

All the advanced features tested in simulation can be used with the real robot as well!

- Refer to the documentation

1. Start the robot and the sensors
2. Launch the state estimation and control pipelines
   a. Make sure everything works correctly (e.g. move the robot around with joypad)
3. Start the planner:

```
$ roslaunch smb_navigation navigate2d_ompl.launch
```

4. Select a goal and start planning

Tutorial Complete!

- Follow the documentation and you should be fine
- Cheat sheet with all the most important commands

References: main configuration files

- Global Cost Map:
  smb_navigation/config/move_base_costmaps/global_costmap_params.yaml
- Local Cost Map:
  smb_navigation/config/move_base_costmaps/local_costmap_params.yaml
- Global Planner:
  smb_navigation/config/move_base_costmaps/ompl_global_planner.yaml
- Local Planner:
  smb_navigation/config/base_local_planner.yaml (sim / real)