Robotics Lab: Homework 4

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Here is the link to my public repo on github:
`https://github.com/TonyManz1/Robotics_Lab_HW.git`

We want to specify that all the participants of the group worked at each stage of the development of the project. In order to simplify the drafting of the report (as recommended by the professor) we have fairly divided the writing of the development of the various points.

Control a mobile robot to follow a trajectory

1. **Construct a gazebo world and spawn the mobile robot in a given pose**

   (a) Launch the Gazebo simulation and spawn the mobile robot in the world rl_racefield in the pose

   $$x = -3 \quad y = 5 \quad yaw = -90\,\text{deg}$$

   with respect to the map frame. The argument for the yaw in the call of spawn_model is Y.

Used commands to switch to the gmapping branch
$ cd catkin_ws/src/rl_fra2mo_description/
$ git checkout gmapping

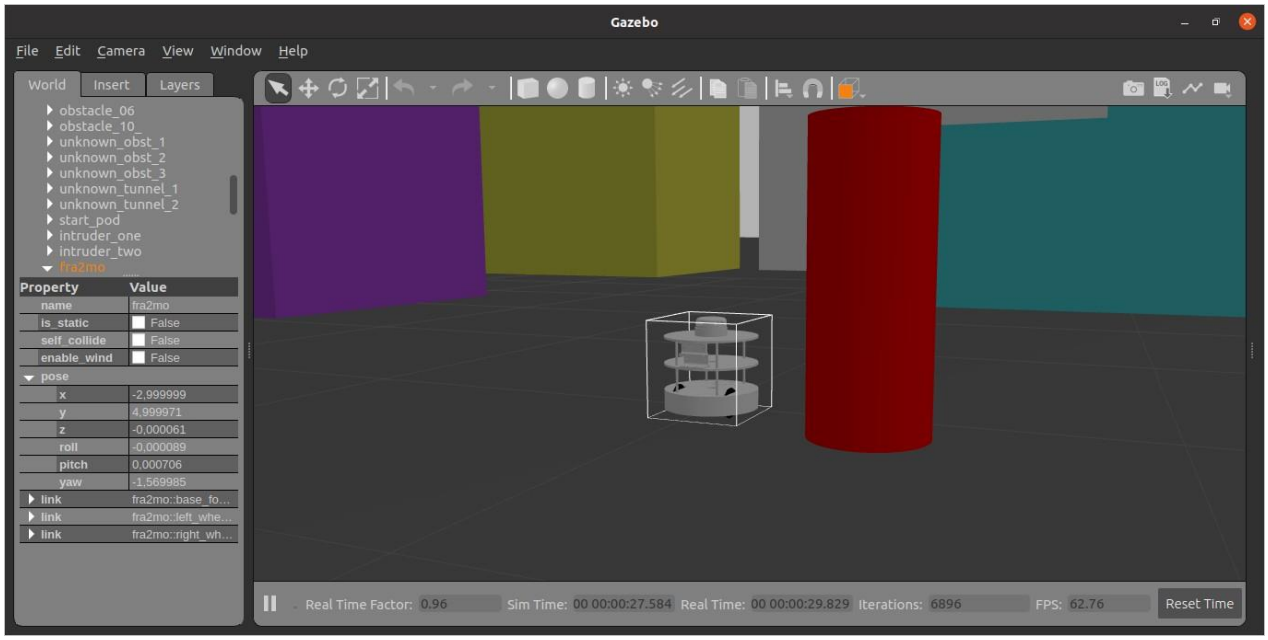
Due the fact, we have two branches on github (main and gmapping) firstly we had to use the command git checkout gmapping in order to switch to the gmapping branch.
After that we moved within the package "*rl_fra2mo_description*" and in particular we have modified the position's values and we added the yaw argument within the file "*spawn_fra2mo_gazebo.launch*" which is located inside the launch folder. What is made it's shown in the following figures:

```
4   <!-- these are the arguments you can pass this launch file, for example paused:=true -->
5   <arg name="paused" default="false"/>
6   <arg name="use_sim_time" default="true"/>
7   <arg name="gui" default="true"/>
8   <arg name="headless" default="false"/>
9   <arg name="debug" default="false"/>
10  <!-- Pose modified x=-3, y=5, yaw=-90° to satisfy the 1.a point-->
11  <arg name="x_pos" default="-3.0"/>
12  <arg name="y_pos" default="5.0"/>
13  <arg name="z_pos" default="0.0"/>
14  <arg name="yaw_or" default="-1.57"/>
15  <env name="GAZEBO_MODEL_PATH" value="$(find rl_racefield)/models:$(optenv GAZEBO_MODEL_PATH)"/>
```

```
31  <!-- Run a python script to the send a service call to gazebo_ros to spawn a URDF robot -->
32  <!-- Add yaw argument called Y -->
33  <node name="urdf_spawner" pkg="gazebo_ros" type="spawn_model" respawn="false" output="screen"
34  args="-urdf -model fra2mo -x $(arg x_pos) -y $(arg y_pos) -z $(arg z_pos) -Y $(arg yaw_or) -param robot_description"/>
```

Used commands to launch the Gazebo simulation
$ roslaunch fra2mo_2dnav fra2mo_nav_bringup.launch

As we can see from the the following picture the robot pose in the world rl_racefield has been implemented succesfully:


Gazebo
File Edit Camera View Window Help
World Insert Layers
obstacle_06
obstacle_10_
unknown_obst_1
unknown_obst_2
unknown_obst_3
unknown_tunnel_1
unknown_tunnel_2
start_pod
intruder_one
intruder_two
fra2mo
Property Value
name fra2mo
is_static False
self_collide False
enable_wind False
pose
x -2,999999
y 4,999971
z -0,000061
roll -0,000089
pitch 0,000706
yaw -1,569985
link fra2mo::base_fo...
link fra2mo::left_whe...
link fra2mo::right_wh...
Real Time Factor: 0.96
Sim Time: 00 00:00:27.584
Real Time: 00 00:00:29.829
Iterations: 6896
FPS: 62.76
Reset Time

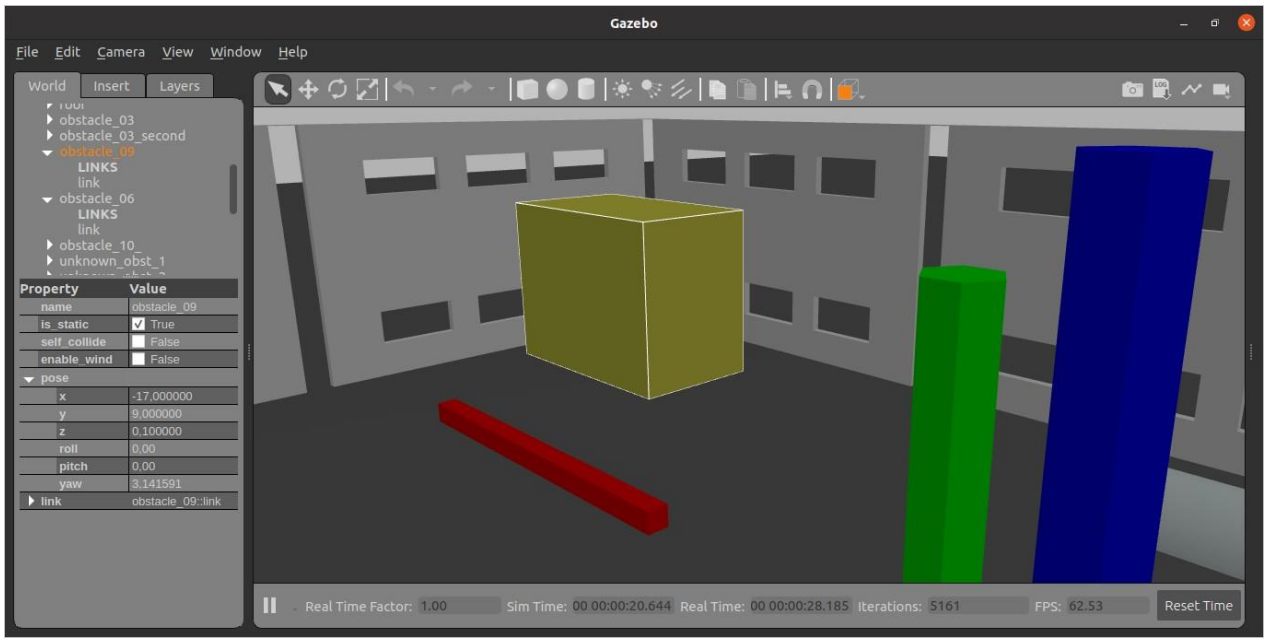
(b) Modify the world file of rl_racefield moving the obstacle 9 in position:

$$x = -17 \quad y = 9 \quad z = 0.1 \quad yaw = 3.14$$

In this section we have modified the file "*rl_race_field.world* " contained in the worlds folder of the rl_racefield package in such way to obtain the x, y, z positions and the yaw requested as in the following figure:

```
75    <include>
76      <name>obstacle_09</name>
77      <pose> -17 9 0.1 0 0 3.14159</pose>
78      <uri>model://obstacle_09</uri>
79    </include>
```

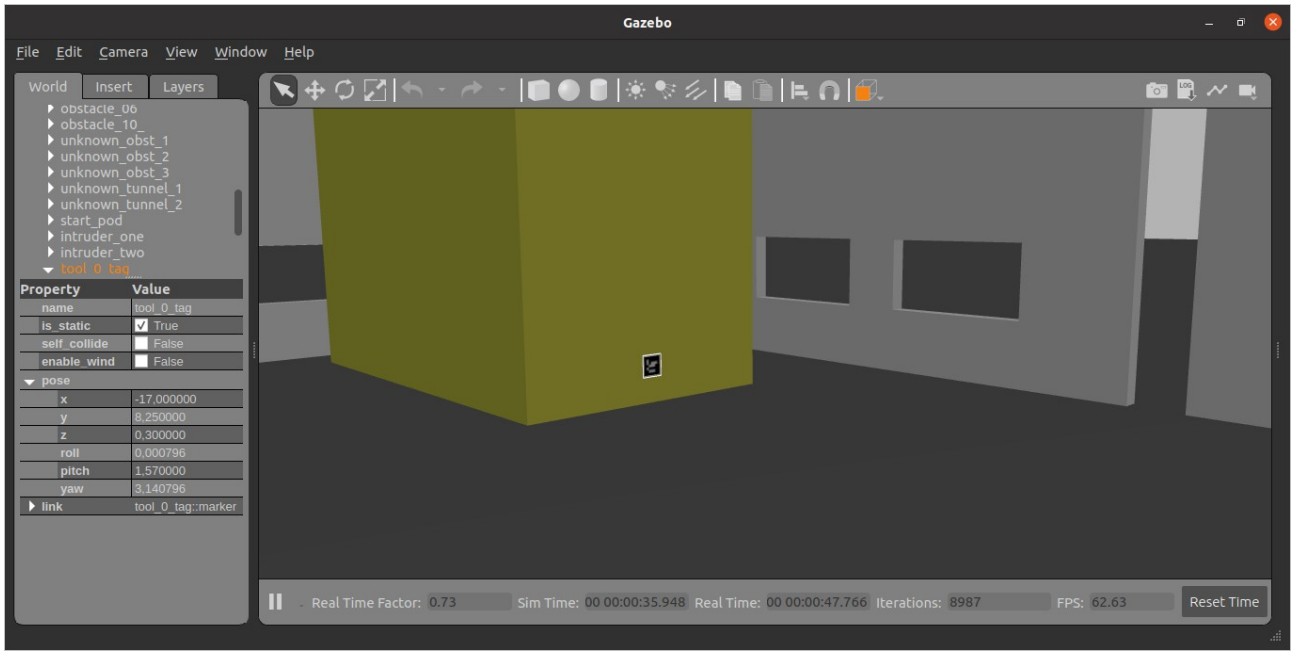
We can see in the following picture that the pose of the obstacle 9 in the world *rl_racefield* is the same of what we have developed in the code:



(c) Place the ArUco marker number 115 on obstacle 9 in an appropriate position, such that it is visible by the mobile robot's camera when it comes in the proximity of the object.

Within the folder models located inside the package *"rl_racefield"* we took the file *"marker_0.sdf"* and we have modified the names in an opportune way. Then we have renamed the folder in *"aruco115"* which contains a file sdf *"aruco115.sdf"*, the *"model.config"* file and the folder *"material"* with the relative *"scripts"* and *"textures"* folders. We have modified the folders renaming all the files with the prefix *"aruco115"* and then we added the image of the aruco marker 115 called *"aruco115.png"* that has been created through the link https://chev.me/arucogen/ given by the homework' trace. To insert this marker inside the world file we have modified the file *"rl_race_field.world"* , and in particular we have uncommented the rows of the code of the marker and we have modified the pose in such way to positioning the aruco marker on the obstacle 9, as it is shown in the following figures:

```
146   <!-- AR markers -->
147   <include>
148     <name>tool_0_tag</name>
149     <uri>model://aruco115</uri>
150     <pose>-17 8.25 0.3 0 1.57 3.14</pose>
151   </include>
```



Used commands

```
$ cd catkin_ws
$ roslaunch fra2mo_2dnav fra2mo_nav_bringup.launch
```

2. **Place static tf acting as goals and get their pose to enable an autonomous navigation task**

   (a) Insert 4 static tf acting as goals in the following poses with respect to the map frame:
   - Goal_1: *x*=-10 *y*=3 *yaw*=0 deg
   - Goal_2: *x*=-15 *y*=7 *yaw*=30 deg
   - Goal_3: *x*=-6 *y*=8 *yaw*=180 deg
   - Goal_4: *x*=-17,5 *y*=3 *yaw*=75 deg

   Follow the example provided in the launch file rl_fra2mo_description/launch/spawn_fra2mo_gazebo.launch of the simulation.

In this point we had to modify the file *"spawn_fra2mo_gazebo.launch"* in the launch folder within the package *"rl_fra2mo_description"* in order to set the desired pose specified by the goals.
To fulfill the goals it has been used the quaternion convention to define the orientation.
The quaternion is defined by 4 parameters (the first is the scalar part of the quaternion defined by the cosine of the angle divided by 2, while the last three are specified by the sine of the angle divided by 2).

$$\mathcal{Q} = \{\eta, \boldsymbol{\epsilon}\} \qquad \eta = \cos\frac{\vartheta}{2}$$

$$\boldsymbol{\epsilon} = \sin\frac{\vartheta}{2}\,\boldsymbol{r}$$

In the following figure we'll show how it has been implemented in code:

```
<!--Static tf publisher for goal1-->
<!-- Define publisher tf nodes for four goals (2a point) -->
<node pkg="tf" type="static_transform_publisher" name="goal_1_pub" args="-10 3 0 0 0 0 1 map goal1 100" />
<node pkg="tf" type="static_transform_publisher" name="goal_2_pub" args="-15 7 0 0 0 0.25882 0.96593 map goal2 100" />  <!--This is for 2a point -->
<node pkg="tf" type="static_transform_publisher" name="goal_3_pub" args="-6 8 0 0 0 1 0 map goal3 100" />
<node pkg="tf" type="static_transform_publisher" name="goal_4_pub" args="-17.5 3 0 0 0 0.60876 0.79335 map goal4 100" />
```

Where the first 3 arguments are relative to the position and the remaining ones are relative to the quaternion.

(b) Following the example code in fra2mo_2dnav/src/tf_nav.cpp, implement tf listeners to get target poses and print them to the terminal as debug.

In this point we have implemented the listeners to get the targets poses and then we have printed them to the terminal.

Firstly, we had to go inside the file *"tf_nav.cpp"* inside the folder *"src"* of the package *"fra2mo_2dnav"* and define the poses of the goals as shown in the following picture:

```
9       // Define pose of four goals (2b point)
10      _goal1_pos << 0.0, 0.0, 0.0;
11      _goal1_or << 0.0, 0.0, 0.0, 1.0;
12
13      _goal2_pos << 0.0, 0.0, 0.0;
14      _goal2_or << 0.0, 0.0, 0.0, 1.0;
15
16      _goal3_pos << 0.0, 0.0, 0.0;
17      _goal3_or << 0.0, 0.0, 0.0, 1.0;
18
19      _goal4_pos << 0.0, 0.0, 0.0;
20      _goal4_or << 0.0, 0.0, 0.0, 1.0;
```

Then in the same file we defined the listeners' functions and the debug print (due to space we show just one listener in the following photo):

```
83  // Goal listener functions (2b point)
84
85  void TF_NAV::goal_listener_1() {
86      ros::Rate r( 1 );
87      tf::TransformListener listener;
88      tf::StampedTransform transform;
89
90      while ( ros::ok() )
91      {
92          try
93          {
94              listener.waitForTransform( "map", "goal1", ros::Time( 0 ), ros::Duration( 10.0 ) );
95              listener.lookupTransform( "map", "goal1", ros::Time( 0 ), transform );
96          }
97          catch( tf::TransformException &ex )
98          {
99              ROS_ERROR("%s", ex.what());
100             r.sleep();
101             continue;
102         }
103
104         _goal1_pos << transform.getOrigin().x(), transform.getOrigin().y(), transform.getOrigin().z();
105         _goal1_or << transform.getRotation().w(),  transform.getRotation().x(), transform.getRotation().y(), transform.getRotation().z();
106
107         // // Debug Print
108         // ROS_INFO("Goal_1 Position: %f %f %f", _goal1_pos[0], _goal1_pos[1], _goal1_pos[2]);
109         // ROS_INFO("Goal_1 Orientation: %f %f %f %f", _goal1_or[0], _goal1_or[1], _goal1_or[2], _goal1_or[3]);
110
111         r.sleep();
112     }
113 }
114
```

Used commands

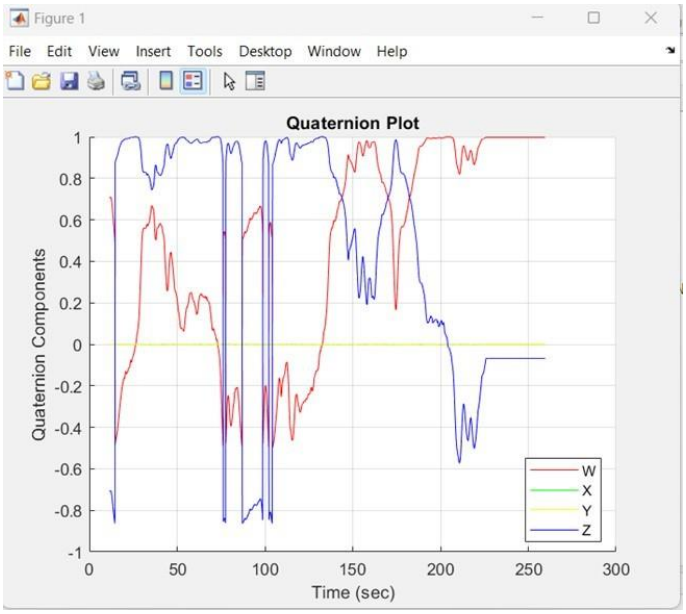
```
$ cd catkin_ws
$ roslaunch fra2mo_2dnav fra2mo_nav_bringup.launch
$ rosrun fra2mo_2dnav tf_nav
```

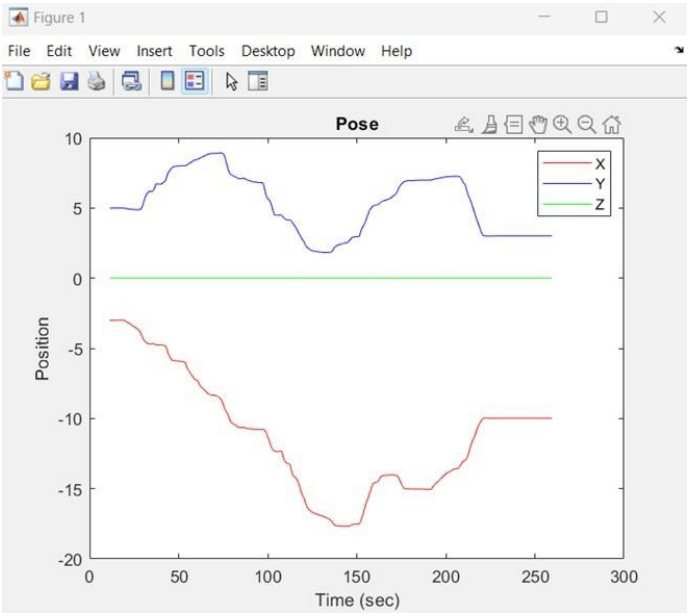
(c) Using move_base, send goals to the mobile platform in a given order. Go to the next one once the robot has arrived at the current goal. The order of the explored goals must be *Goal_3* → *Goal_4* → *Goal_2* → *Goal_1*. Use the Action Client communication protocol to get the feedback from move_base. Record a bagfile of the executed robot trajectory and plot it as a result.

In this point we had to send the goals to the robot in a certain order, in particular the sequence to follow is 3-4-2-1. To do that we went inside the file *"tf_nav.cpp"* and modified the function send_goal.
This function allows us to select between two different choices: send goal from TF or send home position goal. The first option that has been implemented brings the mobile robot to the desired points specified by the goals while the second one brings the robot to the home configuration. In the following picture we show the function that send the robot to the goal 3:

```
350         if ( cmd == 1) {
351             MoveBaseClient ac("move_base", true);
352 
353             while(!ac.waitForServer(ros::Duration(5.0))){
354             ROS_INFO("Waiting for the move_base action server to come up");
355             }
356             goal.target_pose.header.frame_id = "map";
357             goal.target_pose.header.stamp = ros::Time::now();
358 
359             // First goal of the sequence is Goal_3
360             goal.target_pose.pose.position.x = _goal3_pos[0];
361             goal.target_pose.pose.position.y = _goal3_pos[1];
362             goal.target_pose.pose.position.z = _goal3_pos[2];
363 
364             goal.target_pose.pose.orientation.w = _goal3_or[0];
365             goal.target_pose.pose.orientation.x = _goal3_or[1];
366             goal.target_pose.pose.orientation.y = _goal3_or[2];
367             goal.target_pose.pose.orientation.z = _goal3_or[3];
368 
369             ROS_INFO("Sending goal 3");
370             ac.sendGoal(goal);
371 
372             ac.waitForResult();
373 
374             if(ac.getState() == actionlib::SimpleClientGoalState::SUCCEEDED)
375             ROS_INFO("The mobile robot is in the pose of the Goal_3");
376 
377             else
378                 ROS_INFO("The base failed to move for some reason");
```

We have created a bag file called: *bag_2c.bag* and the results obtained on Matlab will be shown below. The first plot is the one relating to the quaternion and the second to the pose of the robot.





The Matlab file used to visualize the plots is shown below.

untitled.m

```
close,clear,clc

bag=rosbag('bag_2c.bag');
topic = '/fra2mo/pose';
pose= readMessages(select(bag, 'Topic', topic));

timestamps = cellfun(@(msg) double(msg.Header.Stamp.Sec) + double(msg.Header.Stamp.Nsec)/1e9, pose);
x = cellfun(@(msg) msg.Pose.Position.X, pose);
y = cellfun(@(msg) msg.Pose.Position.Y, pose);
z = cellfun(@(msg) msg.Pose.Position.Z, pose);

figure;
plot(timestamps, x,'r',timestamps, y,'b', timestamps, z,'g');
legend('X', 'Y', 'Z');
xlabel('Time (sec)');
ylabel('Position');
title('Pose');

% Access the orientation (quaternion) data in the messages and plot
orientation = cellfun(@(msg) msg.Pose.Orientation, pose);

% Extract quaternion components
quatW = cellfun(@(msg) msg.Pose.Orientation.W, pose);
quatX = cellfun(@(msg) msg.Pose.Orientation.X, pose);
quatY = cellfun(@(msg) msg.Pose.Orientation.Y, pose);
quatZ = cellfun(@(msg) msg.Pose.Orientation.Z, pose);

% Data plot
figure;
grid on;

% We have set the color order
colorOrder = [1 0 0; 0 1 0; 1 1 0; 0 0 1]; % Red, Green, Yellow, Blue
set(gca, 'ColorOrder', colorOrder, 'NextPlot', 'replacechildren');

% We plotted the data with the specified colors
plot(timestamps, quatW, timestamps, quatX, timestamps, quatY, timestamps, quatZ);

% We added legend, labels and title
legend('W', 'X', 'Y', 'Z', 'Location', 'Best');
xlabel('Time (sec)');
ylabel('Quaternion Components');
title('Quaternion Plot');

```

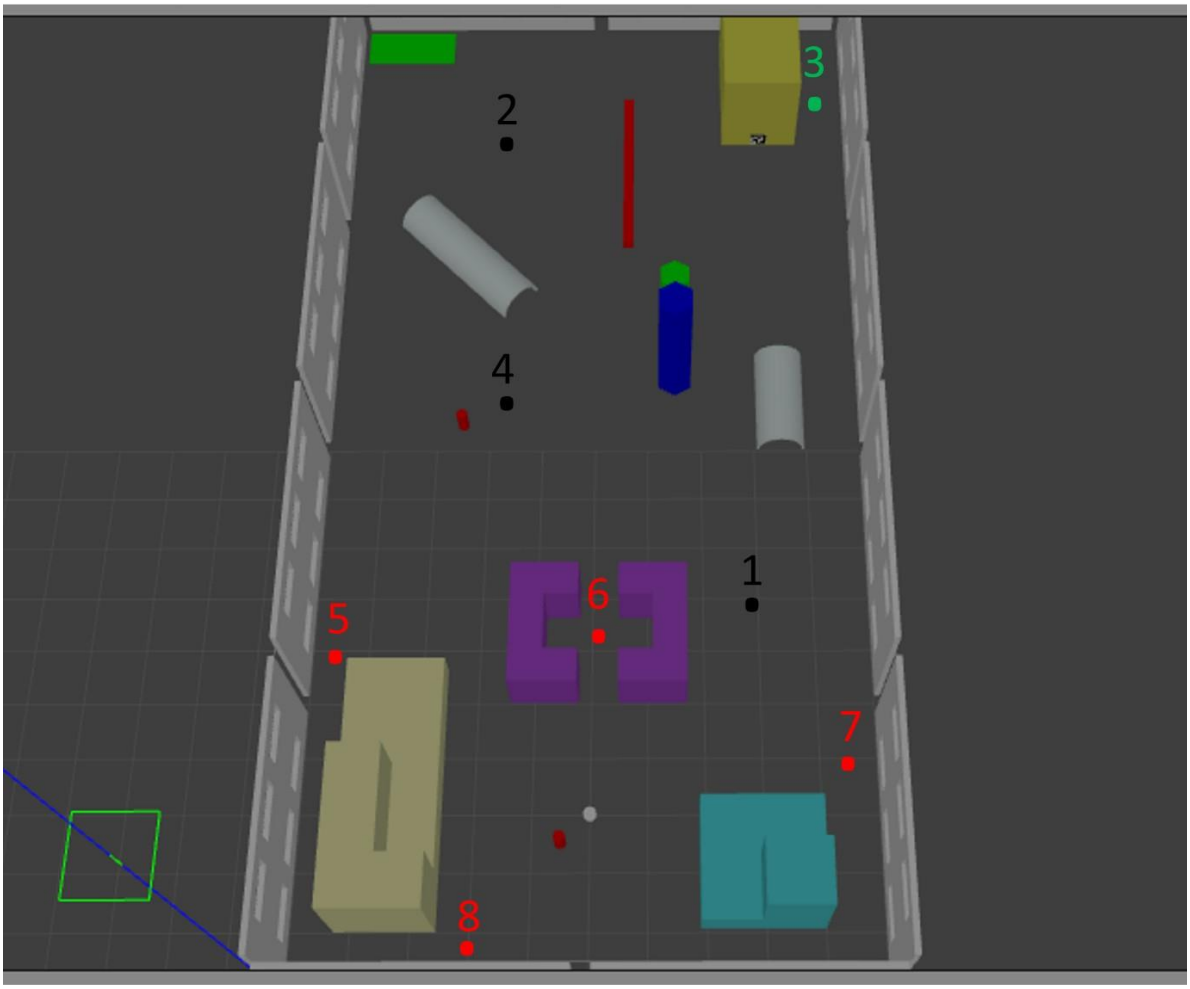
3. **Map the environment tuning the navigation stack's parameters**

    a) Modify, add, remove, or change pose, the previous goals to get a complete map of the environment

In this point we have created new goals to get a complete view of the map. What was made is shown in the following picture:

```
<!--Static tf publisher for goal1-->
<!-- Define publisher tf nodes for four goals (2a point) -->
<node pkg="tf" type="static_transform_publisher" name="goal_1_pub" args="-10 3 0 0 0 0 1 map goal1 100" />
<!-- <node pkg="tf" type="static_transform_publisher" name="goal_2_pub" args="-15 7 0 0 0 0.25882 0.96593 map goal2 100" />  This is for 2a point -->
<node pkg="tf" type="static_transform_publisher" name="goal_2_pub" args="-17.305 9.507 0 0 0 0.25882 0.96593 map goal2 100" /> <!-- This is for 3a point -->
<node pkg="tf" type="static_transform_publisher" name="goal_3_pub" args="-6 8 0 0 0 1 0 map goal3 100" />
<node pkg="tf" type="static_transform_publisher" name="goal_4_pub" args="-17.5 3 0 0 0 0.6088 0.7933 map goal4 100" />

<!-- Add publisher tf nodes for four goals in order to map all the environment (3a point) -->
<node pkg="tf" type="static_transform_publisher" name="goal_5_pub" args="-6.206 0.5 0 0 0 1 0 map goal5 100" />
<node pkg="tf" type="static_transform_publisher" name="goal_6_pub" args="-6.1293 5.1205 0 0 0 1 0 map goal6 100" />
<node pkg="tf" type="static_transform_publisher" name="goal_7_pub" args="-4.115 9.367 0 0 0 1 0 map goal7 100" />
<node pkg="tf" type="static_transform_publisher" name="goal_8_pub" args="-0.709 3.19 0 0 0 1 0 map goal8 100" />
```

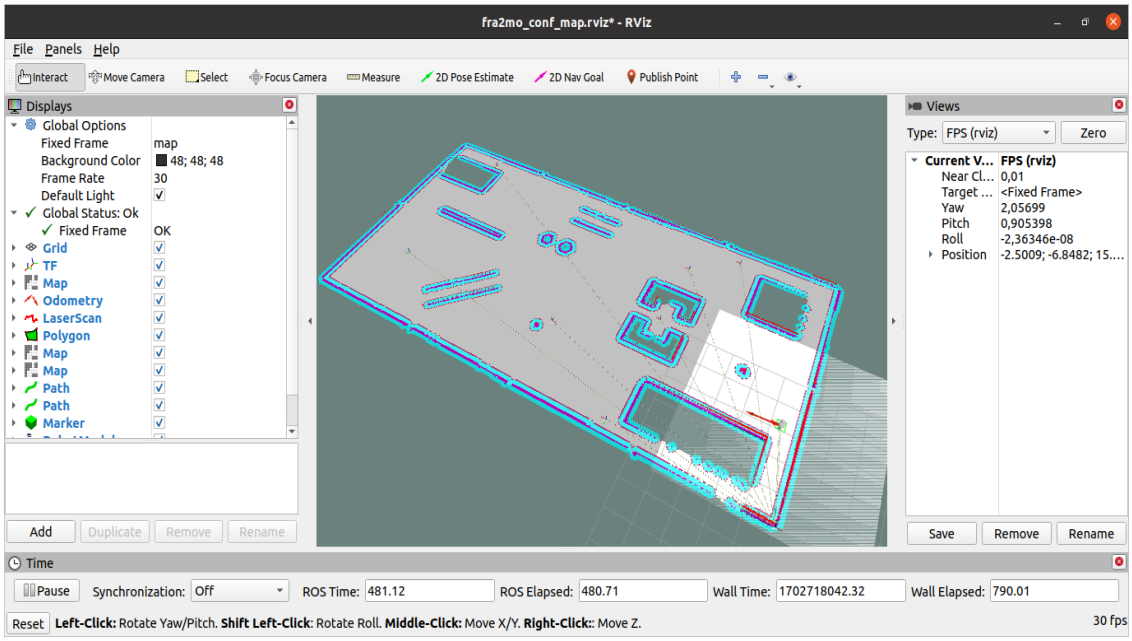
To have a better idea of what was made we show the gazebo map:



There is a caveat: the points in the photo above are not the goals but the sequence of motions. In particular, we added a goal through the two purple obstacle, one behind the azure obstacle, one behind the sand-colored one and the last one behind the obstacle 9 where it is located the aruco.
Note that we have also modified the code line relative to the goal 2 (point 3) in such way the robot could see better the obstacle 9. The last things to do were go inside the *"tf_nav.cpp"* and add orientation, position, send goals and listeners of the new goals, and finally we added all those stuffs inside the file *"tf_nav.h"*.
Used commands

```
$ cd catkin_ws
$ roslaunch fra2mo_2dnav fra2mo_nav_bringup.launch
$ rosrun fra2mo_2dnav tf_nav
```

To prove that all the map is scanned we provide also the rviz view:



b) Change the parameters of the planner and move_base (try at least 4 different configurations) and comment on the results you get in terms of robot trajectories. The parameters that need to be changed are:
   - In file teb_locl_planner_params.yaml: tune parameters related to the section about trajectory, robot, and obstacles.
   - In file local_costmap_params.yaml and global_costmap_params.yaml: change dimensions' values and update costmaps' frequency.
   - In file costmap_common_params.yaml: tune parameters related to the obstacle and raytrace ranges and footprint coherently as done in planner parameters.

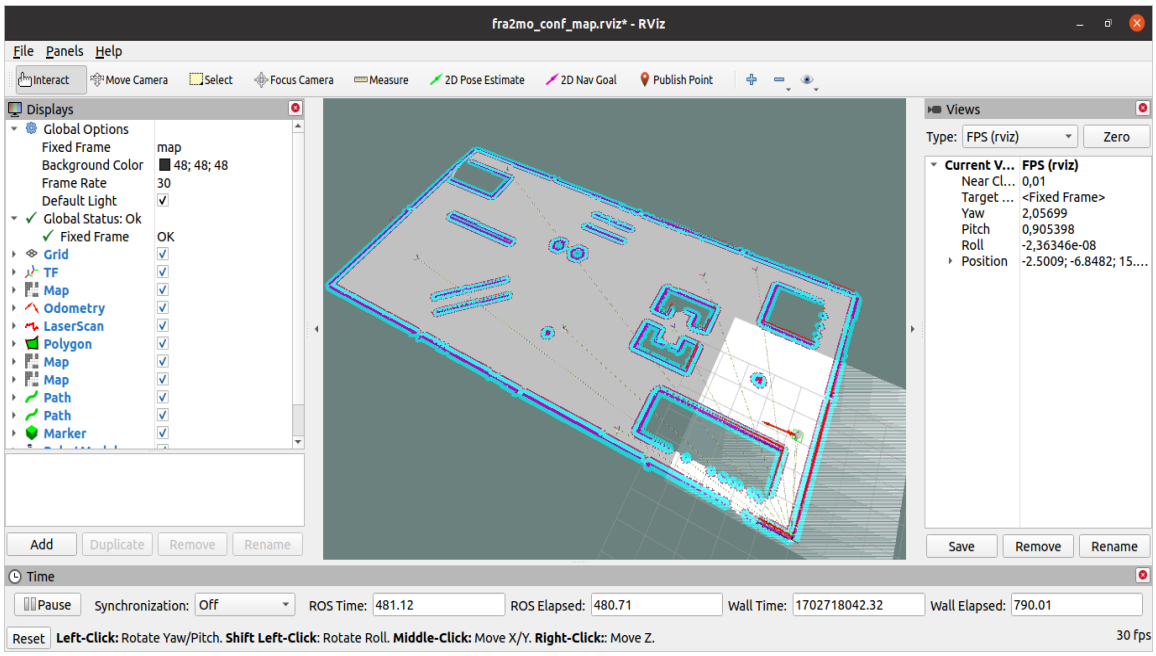
In this point we had to change some parameters of the planner and the move_base to test other configurations, this can be done inside the folder config of the package "*fra2mo_2dnav*".
Firstly we had modified the file "*teb_locl_planner_params.yaml*" , and in particular the minimum distance to the obstacle that we set to 0.2. With 0.2 the robot could reach all the points unless the one situated through the two purple obstacles, nevertheless it could scan what is inside.

```
40  # Obstacles
41
42  min_obstacle_dist: 0.1 # 0.2 # For 3b point we modified the minimum distance to obstacle at 0.2 value
43  include_costmap_obstacles: True
44  costmap_obstacles_behind_robot_dist: 1.0
45  obstacle_poses_affected: 20
46  costmap_converter_plugin: ""
47  costmap_converter_spin_thread: True
48  costmap_converter_rate: 5
49  inflation_dist: 0.1
50  include_dynamic_obstacles: false
```

Used commands

```
$ cd catkin_ws
$ roslaunch fra2mo_2dnav fra2mo_nav_bringup.launch
$ rosrun fra2mo_2dnav tf_nav
```

In the following picture it has been shown the map visualization in rviz with this change:



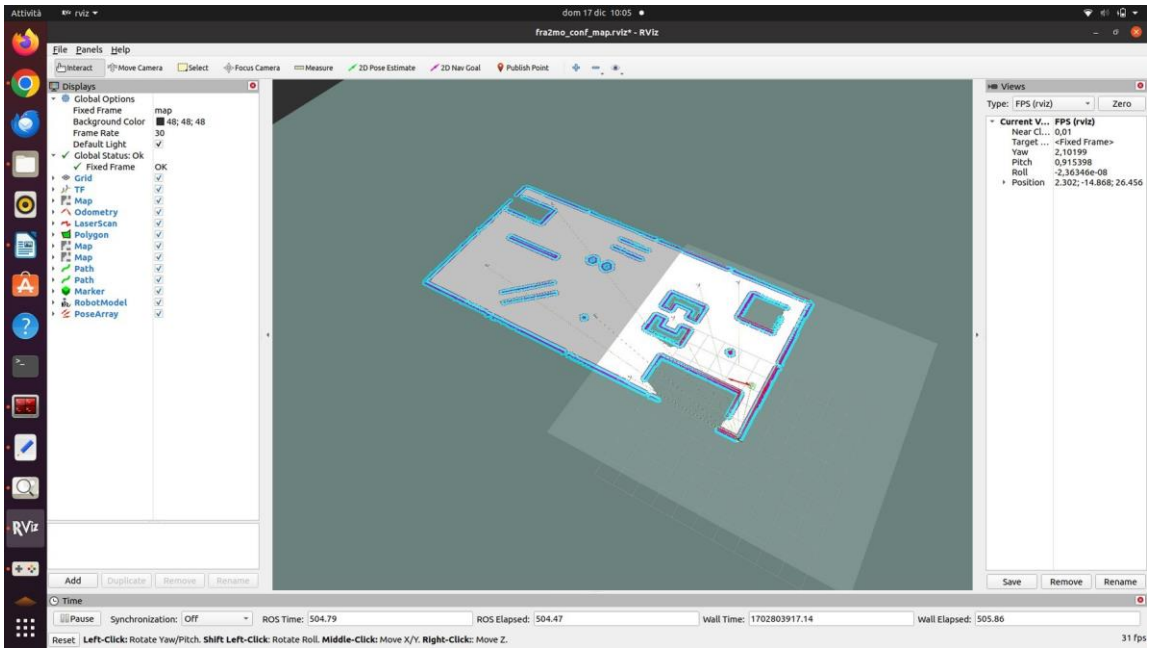
And then the same result but with the distance of 0.1:
In theory, even if we cannot appreciate it with the naked eyes, the minimum distance of the robot to the obstacle has been increased.
We have also tried to set the minimum distance equal to 0.3, but in this case the robot could not generate the trajectories to reach the points.
The second point demanded to change dimensions' values and update costmaps' frequency of the files *"local_costmap_params.yaml"* and *"global_costmap_params.yaml"*. So, in first, we had modified the update frequency and the publish frequency of the local_costmap; in particular, we set the first one equal to 6.0 and the second one equal to 11.0.

```
local_costmap:
  global_frame: map
  robot_base_frame: base_footprint
  update_frequency: 5.0 # 6.0 # For 3b point we modified the update_frequency at 6.0 value
  publish_frequency: 10.0 # 11.0 # For 3b point we modified the publish_frequency at 11.0 value
  static_map: false
```

The result of those changes is that the robot could not reach all the points of the map.
In second place we had modified the width (the number of cells along the x axis) and the height (the number of cells along the y axis) of the map representation setting both the parameters equal to 15.0.

```
local_costmap:
  global_frame: map
  robot_base_frame: base_footprint
  update_frequency: 5.0 # 6.0 # For 3b point we modified the update_frequency at 6.0 value
  publish_frequency: 10.0 # 11.0 # For 3b point we modified the publish_frequency at 11.0 value
  static_map: false
  rolling_window: true
  width: 7.0 # 15.0 # For 3b point we modified the width at 15.0 value
  height: 7.0 # 15.0 # For 3b point we modified the height at 15.0 value
  resolution: 0.03
```

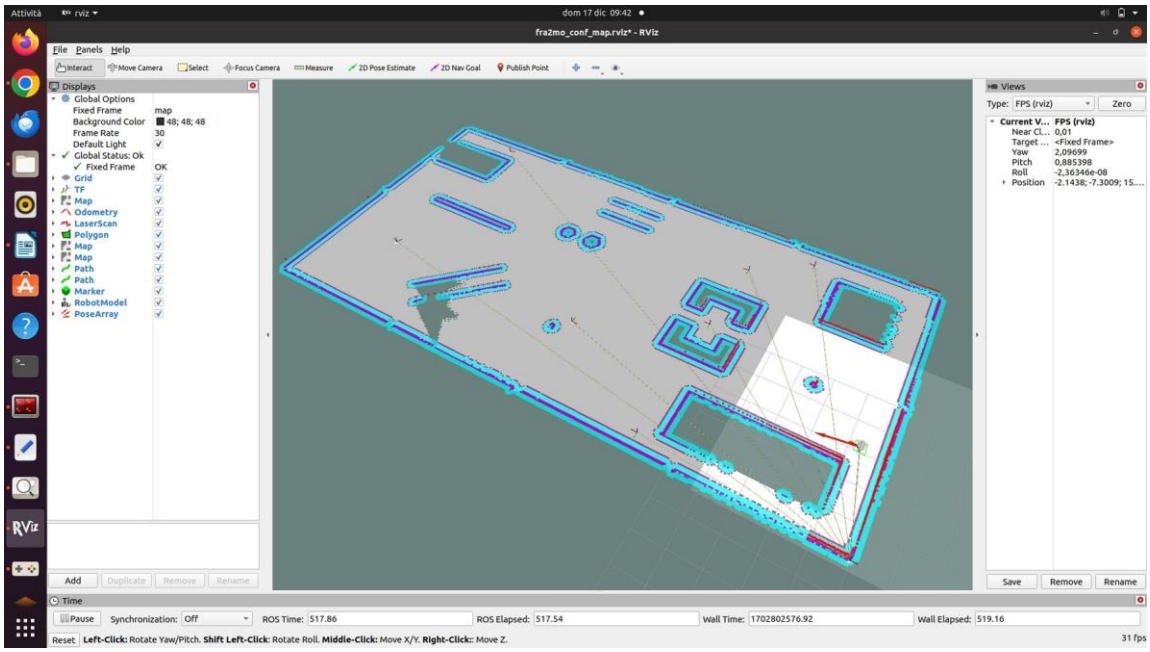
As expected, we can see a more detailed view of the map:



In global_costmap we have modified only the width and the height of the map.

```
global_costmap:
  global_frame: map
  robot_base_frame: base_footprint
  update_frequency: 5.0
  publish_frequency: 2.0
  #always_send_full_costmap: false #default is false
  rolling_window: false
  resolution: 0.05
  width: 30 # 60 # For 3b point we modified the width at 60 value
  height: 30 # 60 # For 3b point we modified the height at 60 value
  origin_x: -15
  origin_y: -15
```

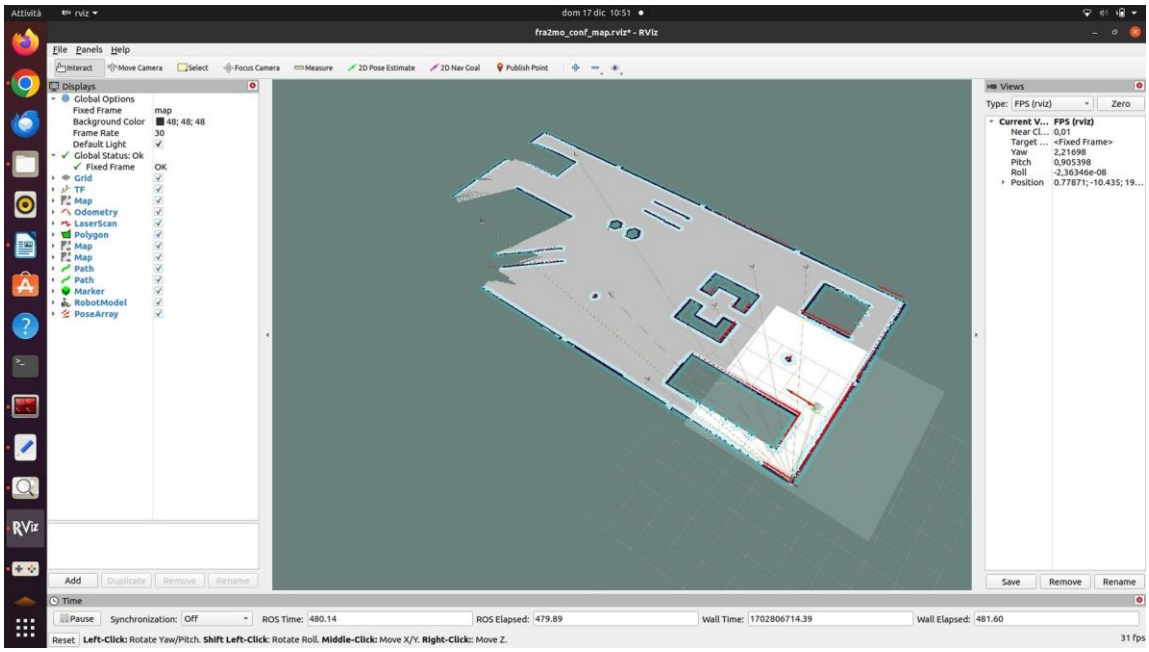
The results show us that the robot could not scan the entire map:



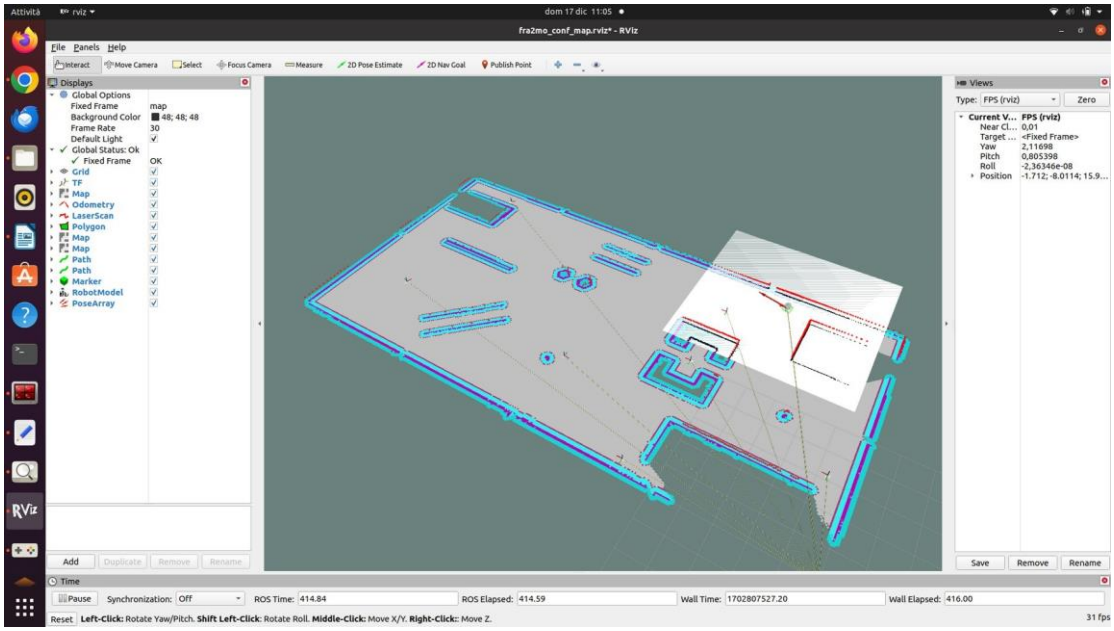
The last thing is to tune the parameters related to the obstacle and raytrace ranges and footprint coherently as done in planner parameters in the file *"costmap_common_params.yaml"*.
Increasing the value of the obstacle_range will change the maximum distance of the sensor scanning.

```
publish_voxel_map: false
transform_tolerance: 0.5
meter_scoring: true
obstacle_range: 7.0 # maximum range sensor reading that will result in an obstacle being put into the costmap # 8.0 # For 3b point we modified the obstacle_range at 8.0 value
raytrace_range: 8.0 # range to which we will raytrace freespace given a sensor reading # 9.0 # For 3b point we modified the raytarce_range at 9.0 value
footprint: [[0.15, -0.15], # 0.20, -0.20 # For 3b point we modified the first raw at 0.20, -0.20 value
            [-0.15, -0.15], # -0.20, -0.20 # For 3b point we modified the first raw at -0.20, -0.20 value
            [-0.15, 0.20], # -0.20, 0.25 # For 3b point we modified the first raw at -0.20, 0.25 value
            [0.15, 0.15]] # 0.20, 0.20 # For 3b point we modified the first raw at 0.20, 0.20 value
```

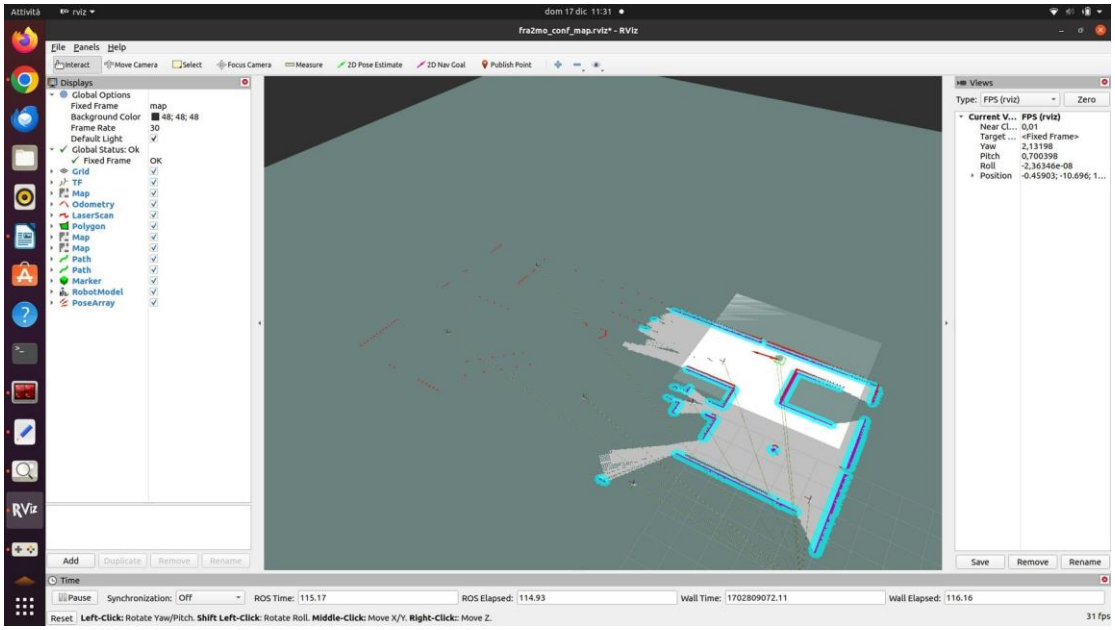
In first we have set the obstacle range equal to 8.0 but the robot was not able to navigate in several points.



Then we have raised the raytrace range to 9.0 from 8.0. Increasing the raytrace range may let the robot to have a more extended perception of the space.



The robot in the simulation shown above was not able to reach the goal 5,6 and 8.
As last thing we have modified the footprint of the robot but as we can see from the following picture, he could satisfy only one goal that is the sixth.



4. **Vision-based navigation of the mobile platform**

   a) Run ArUco ROS node using the robot camera: bring up the camera model and uncomment it in that fra2mo.xacro file of the mobile robot description rl_fra2mo_description. Remember to install the camera description pkg: sudo apt-get install ros-<DISTRO>-realsense2-description

To accomplish this point we went inside the file *"fra2mo.xacro"* in the folder *"urdf"* of the package *"rl_fra2mo_description"* and we have uncommented the code lines regarding the camera, as it is shown in the figure below:

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

<robot name="fra2mo" xmlns:xacro="http://ros.org/wiki/xacro">
  <xacro:include filename="$(find rl_fra2mo_description)/urdf/fra2mo_base_macro.xacro" />
  <xacro:include filename="$(find rl_fra2mo_description)/urdf/lidar_gazebo_macro.xacro" />
  <xacro:include filename="$(find rl_fra2mo_description)/urdf/d435_gazebo_macro.xacro" />


  <xacro:property name="LIDAR" value="True"/>
  <xacro:property name="DEPTH" value="True"/>

  <!-- Diff Drive Robot Base  -->
  <xacro:fra2mo_base />

  <!-- LIDAR Sensor -->
  <xacro:if value="${LIDAR}" >
    <xacro:lidar_gazebo_sensor parent="lidar_link" />
  </xacro:if>
  <!-- Uncomment if you want to add also a D435 camera -->
  <!-- RGBD Sensor -->
  <xacro:if value="${DEPTH}" >
    <xacro:d435_gazebo_sensor parent="d435_link" />
  </xacro:if>

</robot>
```

b) Implement a 2D navigation task following this logic
   - Send the robot in the proximity of obstacle 9.
   - Make the robot look for the ArUco marker. Once detected, retrieve its pose with respect to the map frame.
   - Set the following pose (relative to the ArUco marker pose) as next goal for the robot

$$x = x_m + 1, \quad y = y_m,$$

   where x_m , y_m are the marker coordinates.

To implement the first point of this task, it has been added to the file *"tf_nav.cpp"* another choice (command "3") when the node is running.
To bring the robot in front of the obstacle 9 we first have moved the robot to an intermediate point *"goal_4b_1"* and then to the final goal *"goal_4b"*. Inside the files *"tf_nav.h"* and *"tf_nav.cpp"* we have defined the poses of the goals and the listeners and inside the file *"spawn_fra2mo_gazebo. launch"*, those have been published, as shown in figure.

```
61  <!-- Add publisher tf node for goals in order to send the mobile robot in front of the Aruco marker (4b point) -->
62  <node pkg="tf" type="static_transform_publisher" name="goal_4b_pub" args="-15 7.8 0 0 0 1 0 map goal4b 100" />
63  <node pkg="tf" type="static_transform_publisher" name="goal_4b_1_pub" args="-7 8 0 0 0 1 0 map goal4b_1 100" />
```

The second point demanded to make the robot look for the ArUco marker, and once detected, the robot should retrieve its pose with respect to the map frame. To do that, we've added a vector *"aruco_pose"* that contains aruco position and orientation to the *"tf_nav.cpp"* file in *"fra2mo_2dnav"* package.
Then, we've added a *"aruco_pose_sub"* subscriber to the *"/aruco_single/pose"* topic and so recall *"arucoPoseCallback"* callback that writes on the aruco_pose and switches *"aruco_pose_available"* boolean parameter on true.

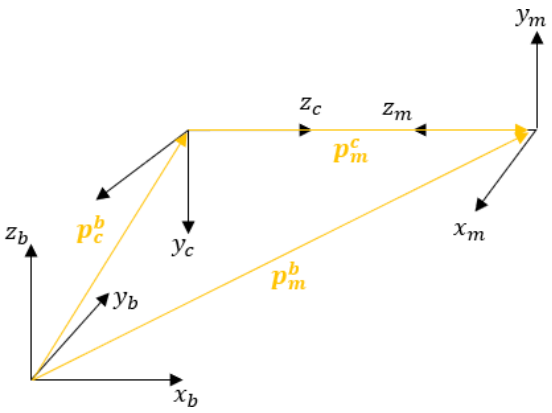
```
void arucoPoseCallback(const geometry_msgs::PoseStamped & msg)
{
    aruco_pose_available = true;
    aruco_pose.clear();
    aruco_pose.push_back(msg.pose.position.x);
    aruco_pose.push_back(msg.pose.position.y);
    aruco_pose.push_back(msg.pose.position.z);
    aruco_pose.push_back(msg.pose.orientation.x);
    aruco_pose.push_back(msg.pose.orientation.y);
    aruco_pose.push_back(msg.pose.orientation.z);
    aruco_pose.push_back(msg.pose.orientation.w);

}
```

In order to retrieve the marker pose in the map frame, we have added the *"tf_listener_aruco"* function. First of all, a listener has been defined to retrieve the camera_depth_optical_frame with respect to map frame. It has been chosen this frame because this one is where visual information are referred to.
Once the marker has been detected, its pose in the camera frame can be transformed in the map frame.

This reasoning has been implemented as shown below:

```
void TF_NAV::tf_listener_aruco() {
    ros::Rate r( 5 );
    tf::TransformListener listener;
    tf::StampedTransform transform;

    while ( ros::ok() ) {
        try {
            listener.waitForTransform( "map", "camera_depth_optical_frame", ros::Time(0), ros::Duration(10.0) );
            listener.lookupTransform( "map", "camera_depth_optical_frame", ros::Time(0), transform );
        }
        catch( tf::TransformException &ex ) {
            ROS_ERROR("%s", ex.what());
            r.sleep();
            continue;
        }

        _camera_pos << transform.getOrigin().x(), transform.getOrigin().y(), transform.getOrigin().z();
        _camera_or << transform.getRotation().w(),  transform.getRotation().x(), transform.getRotation().y(), transform.getRotation().z();

        if(aruco_pose_available) {
            KDL::Frame cam_T_object(KDL::Rotation::Quaternion(aruco_pose[3], aruco_pose[4], aruco_pose[5], aruco_pose[6]), KDL::Vector(aruco_pose[0], aruco_pose[1], aruco_pose[2]));
            KDL::Frame map_T_cam(KDL::Rotation::Quaternion(_camera_or[1], _camera_or[2], _camera_or[3], _camera_or[0]), KDL::Vector(_camera_pos[0], _camera_pos[1], _camera_pos[2]));
            KDL::Frame map_T_object(KDL::Rotation::Quaternion(_aruco_or[1], _aruco_or[2], _aruco_or[3], _aruco_or[0]), KDL::Vector(_aruco_pos[0], _aruco_pos[1], _aruco_pos[2]));

            map_T_object.p = map_T_cam.p + map_T_cam.M*cam_T_object.p;
            _aruco_pos = toEigen(map_T_object.p);

            map_T_object.M = map_T_cam.M*cam_T_object.M;
            double x,y,z,w;
            map_T_object.M.GetQuaternion(x,y,z,w);
            _aruco_or << x, y, z, w;

            std::cout<<"Aruco position wrt map frame:"<<std::endl<< _aruco_pos <<std::endl;
            //std::cout<<"Aruco quaternion wrt map frame:"<< _aruco_or <<std::endl;
            std::cout<<"Camera position wrt map frame:"<<std::endl<< toEigen(map_T_cam.p) <<std::endl;
            //std::cout<<"Aruco position wrt camera frame:"<< toEigen(cam_T_object.p) <<std::endl;
        }

        r.sleep();
    }

}
```

Frames configuration:



$$p_m^b = p_c^b + R_c^b p_m^c$$

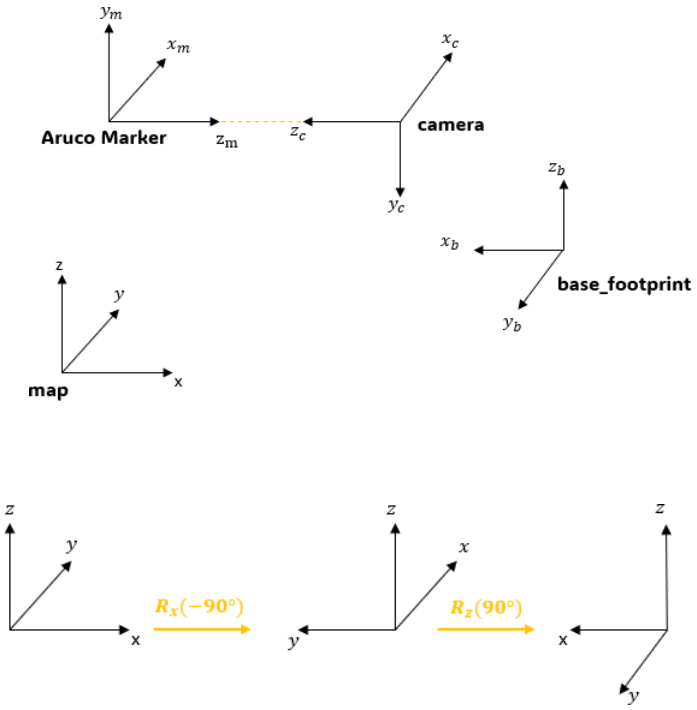
The last step is to send mobile robot in front of the Aruco with a pose relative at the aruco pose, and in particular it must be:

$y = y_m, x = x_m + 1$

This task has been implemented in the node *"tf_nav.cpp"* in the *"send_goal"* function in this way: when the mobile robot arrived at the *"goal4b"* goal, on the terminal is asked to insert the command "4" to bring the robot to the pose that has been defined above.
This task was implemented as follows:

- Knowing marker pose, the goal orientation can be assigned in a fixed way as x = 0, y = 0, z = 1, w = 0 (properly commented in the code below).

Alternatively, a more robust solution takes care also of the aruco orientation. First of all, to define the desired base_footprint frame, the Aruco Marker frame has been suitably rotated.



Due to approximation and measurement errors, it is not possible to directly extract quaternion reference, since it would end up having roll and pitch angles different from zero. To overcome this problem, a new rotation matrix has been defined retrieving its yaw angle, while setting roll and pitch to zero. At this point, the extracted quaternion reference is feasible for the robot. As shown below:

```
805             // When the mobile robot arrived in the goal4b it moves at this pose (x = x_m + 1 and y = y_m) when the user insert the command "4"
806
807             std::cout<<"\nInsert 4 to send Aruco goal"<<std::endl;
808             std::cin>>a_cmd;
809             if ( a_cmd == 4) {
810                 MoveBaseClient ac_a("move_base", true);
811                 while(!ac_a.waitForServer(ros::Duration(5.0))){
812                 ROS_INFO("Waiting for the move_base action server to come up");
813                 }
814                 goal.target_pose.header.frame_id = "map";
815                 goal.target_pose.header.stamp = ros::Time::now();
816
817                 goal.target_pose.pose.position.x = _aruco_pos[0] + 1;
818                 goal.target_pose.pose.position.y = _aruco_pos[1];
819                 goal.target_pose.pose.position.z = 0.0;
820 /*
821                 goal.target_pose.pose.orientation.w = 0.0;
822                 goal.target_pose.pose.orientation.x = 0.0;
823                 goal.target_pose.pose.orientation.y = 0.0;
824                 goal.target_pose.pose.orientation.z = 1.0;
825 */
826                 KDL::Rotation Ar_rot=KDL::Rotation::Quaternion(_aruco_or[1], _aruco_or[2], _aruco_or[3], _aruco_or[0]);
827                 KDL::Rotation Rb_des=Ar_rot*KDL::Rotation::RotX(-1.5708)*KDL::Rotation::RotZ(1.5708);
828                 double R,P,Y,x,y,z,w;
829                 Rb_des.GetRPY(R,P,Y);
830                 Rb_des=KDL::Rotation::RPY(0,0,Y);
831                 Rb_des.GetQuaternion(x,y,z,w);
832
833                 goal.target_pose.pose.orientation.w = w;
834                 goal.target_pose.pose.orientation.x = x;
835                 goal.target_pose.pose.orientation.y = y;
836                 goal.target_pose.pose.orientation.z = z;
837
838                 ROS_INFO("Sending goal aruco");
839                 ac_a.sendGoal(goal);
840
841                 ac_a.waitForResult();
842
843                 if(ac_a.getState() == actionlib::SimpleClientGoalState::SUCCEEDED)
844                     ROS_INFO("The mobile robot arrived in the TF aruco goal");
845                 else
```

Used commands

```
$ cd catkin_ws
$ roslaunch fra2mo_2dnav fra2mo_nav_bringup.launch
$ rosrun fra2mo_2dnav tf_nav
$ roslaunch aruco_ros usb_cam_aruco.launch camera:=/depth_camera/depth_camera markerId:=115
$ rqt_image_view
```

In the folder Simulations within github repository there are loaded the videos of the tests of this 4b point that has been implemented.

c) Publish the ArUco pose as TF following the example at [this link](#).

In order to implement this 4c point we added a new node "*tf_nav_4c.cpp*" in the package "*fra2mo_2dnav*" and so we added executable of this node in "*CMakeLists.txt*" file.
At the end of "*tf_listener_aruco*" function, the function "*position_aruco_pub*" is called and the latter publishes the aruco pose via "*_position_aruco_pub*" publisher on the topic "*aruco_frame/pose*".

```
10      _position_aruco_pub = _nh.advertise<geometry_msgs::PoseStamped>( "aruco_frame/pose", 1 );
```

We created a subscriber "*aruco_pose_sub_broadc"* that subscribes to "*aruco_frame/pose*" topic and it calls the "*poseCallback"* function that is shown in following figure.

```
910     ros::Subscriber aruco_pose_sub_broadc = n.subscribe("/aruco_frame/pose", 1, poseCallback);
```

```
67  // poseCallback function for 4c point (we got it from the website adviced in the pdf)
68  void poseCallback(const geometry_msgs::PoseStamped & msg) {
69      static tf::TransformBroadcaster br;
70      tf::Transform transform;
71      transform.setOrigin( tf::Vector3(msg.pose.position.x,msg.pose.position.y,msg.pose.position.z));
72      tf::Quaternion q(msg.pose.orientation.x,msg.pose.orientation.y,msg.pose.orientation.z,msg.pose.orientation.w);
73      transform.setRotation(q);
74      br.sendTransform(tf::StampedTransform(transform, ros::Time::now(), "map", "aruco_frame"));
75  }
```

Used commands

```
$ cd catkin_ws
$ roslaunch fra2mo_2dnav fra2mo_nav_bringup.launch
$ rosrun fra2mo_2dnav tf_nav_4c
$ roslaunch aruco_ros usb_cam_aruco.launch camera:=/depth_camera/depth_camera markerId:=115
$ rqt_image_view
```

In the folder Simulations within github repository there are loaded the videos of the tests of this 4c point that has been implemented.