TECHIN 516: Robotic Sensing And Mobility

Lab 6: Arm Kinematics in the Physical Robot

DATE: Feb 23rd. 2023

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1 Learning Objectives

1. Learn the difference between arm motions in task-space and configuration-space
2. Familiarize yourself with both forward and inverse kinematics in a robotic arm with 6 revolute joints.
3. Familiarize yourself with MoveIt! as a ROS component with a physical Kinova Arm gen3_lite.

2 Introducing the Kinova robotic arm as a physical platform

2.1 Connecting to the physical Kinova robotic arm

We have used the Kinova robotic arm in simulation in the previous lab. Today we will have the opportunity to familiarize ourselves with the actual physical robot.

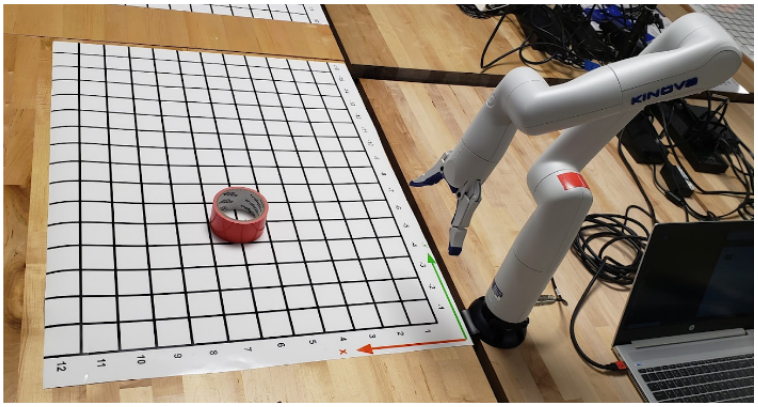


Figure 1: physical kinova arm.

Instructions:

1. Open your browser and type your assigned robot's IP address. This will open the Kinova Web App. The username is and the password are both "admin".

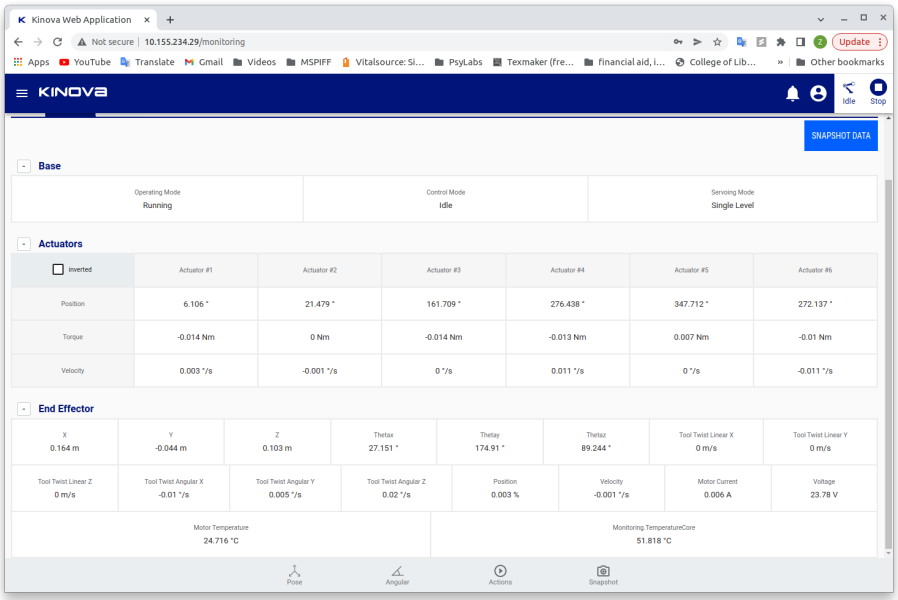


Figure 2: kinova web app.

2. In the Systems -> Monitoring you will see the current status of the robot's joints: joint angle values, pose of the end effector with respect to the base, velocities and efforts for each joint.

3. In the bottom panel there are two buttons: Pose and Angular. Each one of these, changes the position of the robot arm in a different working space: "Pose" changes the position and orientation of the end effector (task space), while "Angular" changes each joint angle value (configuration space).

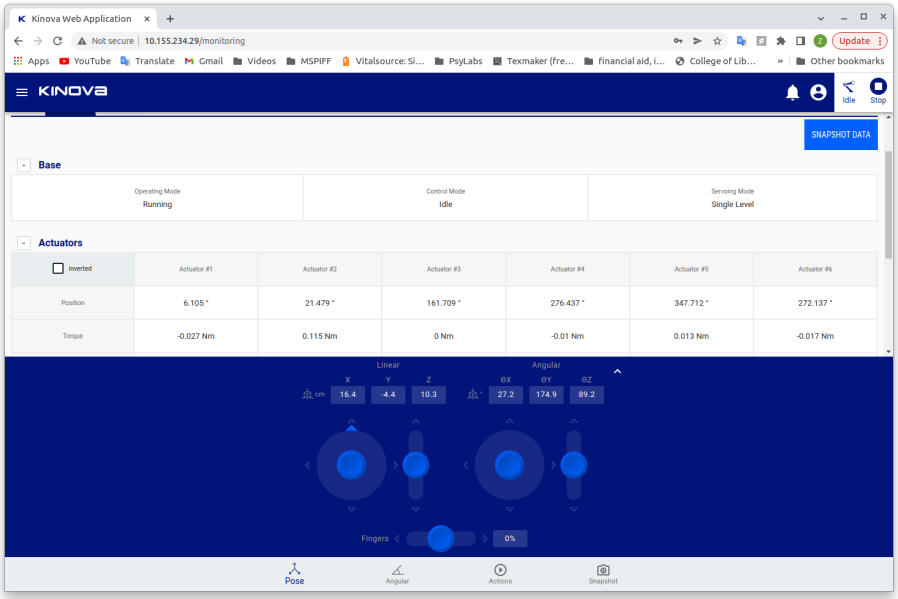


Figure 3: kinova web app - work space.

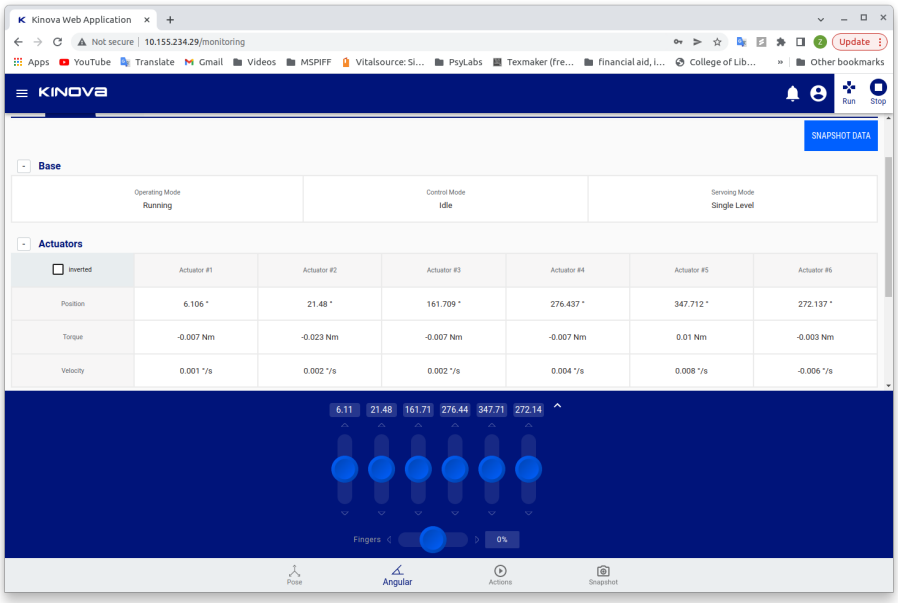


Figure 4: kinova web app - configuration space (joint space).

Note: Please be mindful as you use the UI's joysticks and keep speeds low and movements small, particularly when movements lead towards the table. Please pay close attention to the robot motion and stop the motion using emergency stop if necessary.

Deliverables:

1. Use the Pose tab on the bottom panel to move the robot's end effector towards the Grid quadrant x = 4, y = 6. Select a z pose value greater than 15cm. Close the gripper to 10%. You will have two camera views (one "over-the-shoulder" one "top"). Answering the following three questions:

   (a) Report the pose of the end effector (Position and Orientation with respect to the base).

Table 1: Pose information of end effector at grid $(4, 6)$

(a) Position

Linear	x	y	z
Position	20.2	-30.3	54.9

(b) Orientation

Angular	θx	θy	θz
Orientation	85.5	1.0	15.9

   (b) What is the corresponding set of joint angles that match this pose?

Table 2: Joint angles of end effector at grid $(4, 6)$

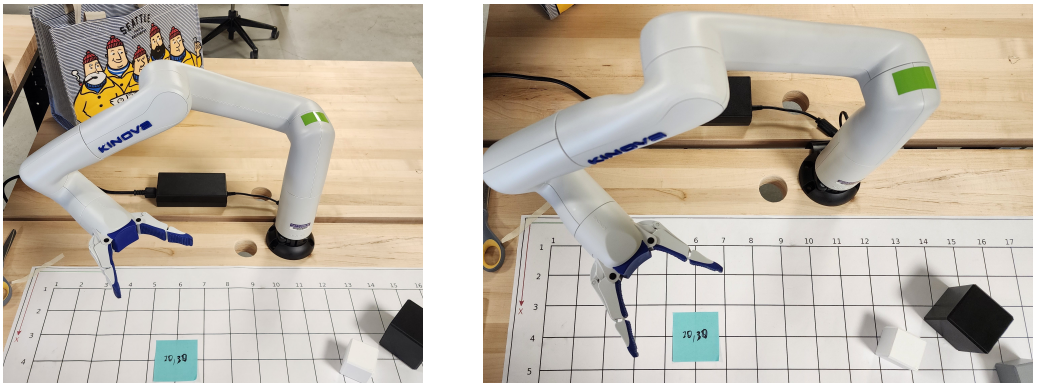
Joint	*1*	*2*	*3*	*4*	*5*	*6*
Angle	317	284	248	55	116	249

(c) The grid on the table is 5cm x 5cm per square. Determine the transformation between the end-effector's reference frame and the grid.

Answer: The origin of the arm w.r.t. the grid quadrant is $(0, 12)$. Based on the information that the grid location $(4, 6)$ translates to pose $(20, -30)$, and that the grid is 5×5, the formulae for transformation can be generalized as:

$$x_{\text{pose}} = 5 \times x_{\text{grid}} \quad (1) \qquad y_{\text{pose}} = 5 \times y_{\text{grid}} - 60 \quad (2)$$

2. Take a photo of your robot reaching the required pose.



(a) Front view (b) Bird view

Figure 5: Setting arm to reach custom goal state.

3. Switch to "Angular" on the bottom panel to move the robot to the following joint angle sets of values and report the robot's pose of the end effector from either the Pose tab or from the Monitoring overview by taking a screenshot. Also provide your best estimate of the location from the Grid quadrant.

(a) (17, 340, 134, 270, 338, 290) Gripper at 90%

Table 3: Pose information of end effector in custom state with grid estimate

Linear	x	y	z
Position	0.2	0.0	0.0

Angular	θx	θy	θz
Orientation	3.3	178.9	87.3

Linear	x	y
Grid	0.04	12.00

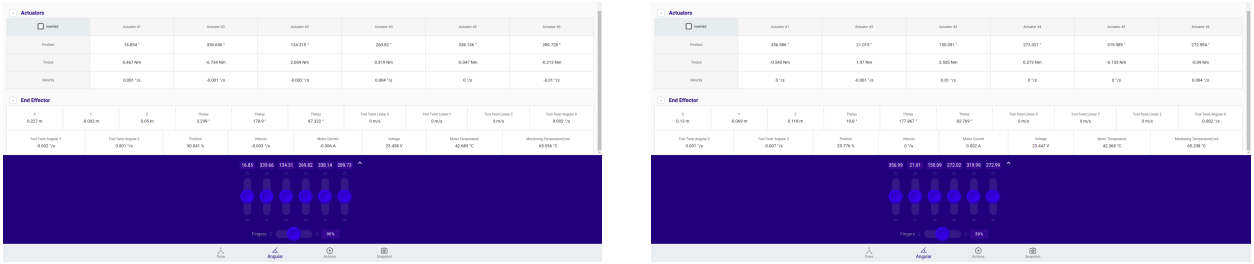
(b) (357, 21, 150, 272, 320, 273) Gripper at 30%

Table 4: Pose information of end effector in retract state with grid estimate

Linear	x	y	z
Position	0.1	-0.1	0.1

Angular	θx	θy	θz
Orientation	10.8	177.9	82.8

Linear	x	y
Grid	0.02	12.02



(a) Custom state (b) Retract state

Figure 6: Monitoring Pose of the end effector.

2.2 Spawning a Kinova robot arm using Kortex Driver

We will use the ros_kortex repository to work with the Kinova arm. In this metapackage, we will use the kortex_driver portion. Execute the following launch file that will bring up the gen3_lite controllers, MoveIt! Configurations and an RViZ window.

```
~$ roslaunch kortex_driver kortex_driver.launch arm:=gen3_lite ip_address:=
<IP OF ROBOT>
```

Note: Once the RViZ window has been opened, and the terminal should show two green messages (“You can start planning now!” and “The Kortex driver has been initialized correctly!”). At this point, you can add a MotionPlanning component in RviZ.

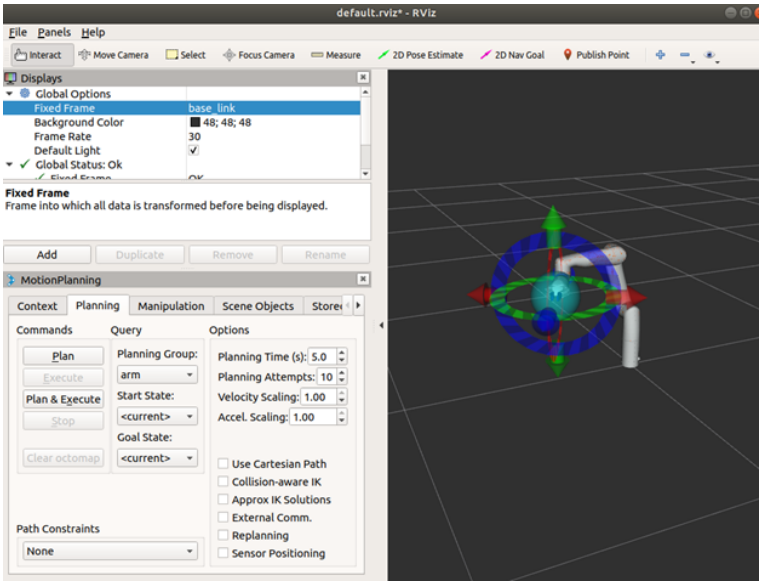


Figure 7: Kinova Rviz.

2.3 Using the Interactive Markers to change the robot’s pose based on the cartesian-space

Instructions:

1. You can use the different arrows and rings in the RViZ interactive marker, to change position and orientation of the robot's end-effector. As you use them, you will see an orange version of the robot arm with the proposed new position. Once you have reached a desired position, use the buttons "Plan" and "Execute" to make the robot in Gazebo match the new proposed position. Some useful tools for you to track the robot's motions are:

   ```
   ~$ rostopic echo -n 1 /my_gen3_lite/joint_states
   ```

   which publishes the values of the joints.

   ```
   ~$ rosrun tf tf_echo /base_link <END-EFFECTOR LINK>
   ```

   which outputs the pose of the robot's end-effector with respect to the base of the robot. You may also come to realize that there are other links on the robot's gripper that might report different values. You can use the following command to generate a PDF with the TF tree for the robot:

   ```
   ~$ rosrun tf view_frames
   ```

2. If you want to change the state of the gripper, you need to change the Planning Group from arm to gripper, and you can select a new position.

Deliverables:

1. What are the reported robot's joints values and end-effector pose (position and orientation w.r.t. the base, consider using both end_effector_link and tool_frame links) when you send the arm to the following positions:

   (a) Home

Table 5: Pose information of end effector in home state

(a) Position

Source	*x*	*y*	*z*
end_effector_link	0.37	0.08	0.45
tool_frame_link	0.44	0.19	0.45
Kinova Web App	0.44	0.19	0.45

(b) Orientation

Source	*x*	*y*	*z*	*w*
end_effector_link	-0.35	0.62	0.36	0.61
tool_frame_link	0.19	0.69	0.68	0.18

Table 6: Joint angles of end effector in home state

Source	*1*	*2*	*3*	*4*	*5*	*6*
joint_states	0.00	-0.28	1.31	0.00	-1.05	0.00
RViz	0	-16	75	0	-60	0
Kinova Web App	360	344	75	360	300	0

(b) Vertical

Table 7: Pose information of end effector in vertical state

(a) Position

Source	*x*	*y*	*z*
end_effector_link	0.06	-0.01	0.87
tool_frame_link	0.06	-0.01	1.00
Kinova Web App	0.06	-0.01	1.00

(b) Orientation

Source	*x*	*y*	*z*	*w*
end_effector_link	0.00	0.00	0.00	1
tool_frame_link	0.00	0.00	0.71	0.71

Table 8: Joint angles of end effector in vertical state

Source	*1*	*2*	*3*	*4*	*5*	*6*
joint_states	0.00	0.00	0.00	0.00	0.00	0.00
RViz	0	0	0	0	0	0
Kinova Web App	360	360	360	360	0	0

(c) Grid quadrant x = 4, y = 6. Note: Keep the z-pose value greater than 15cm to avoid hitting the ground.

Table 9: Pose information of end effector at grid $(4, 6)$

(a) Position

Source	*x*	*y*	*z*
end_effector_link	0.17	-0.18	0.54
tool_frame_link	0.20	-0.30	0.55
Kinova Web App	0.20	-0.30	0.55

(b) Orientation

Source	*x*	*y*	*z*	*w*
end_effector_link	0.40	0.55	0.45	0.58
tool_frame_link	0.67	0.10	0.10	0.73

Table 10: Joint angles of end effector at grid $(4, 6)$

Source	*1*	*2*	*3*	*4*	*5*	*6*
joint_states	-0.75	-1.33	-1.95	0.96	2.02	-1.94
RViz	-43	-76	-112	55	116	-111
Kinova Web App	317	284	248	55	116	249

(d) Compare the results reported by the Kinova Web App Monitoring against the reported values from tf_echo and joint_states for the 3 previous positions. Discuss any potential source for difference in the two sources. You can take screenshots to compare.

Answer: As can be seen in the tables above, there are differences and similarities between the values reported in Kinova and RViz/Terminal. The relationships between them can be found and summarized as:

i. For position values in Pose, the end_effector is different from, while tool_frame is the same as, the end effector position in Kinova GUI. Having different definitions of the end effector, RViz and Kinova report positions of distinct parts.
Specifically, end effector in Kinova refer to the *tool* at the end of the robot, in this case a gripper, that directly interacts with the environment; however, end effector in RViz is the same as joint_6 in joint_states, the last joint of the robot.

ii. For joint values, all of them display different yet the same results. The angle range of Kinova is the original $[0, 360]$, whereas that of the RViz is $[-180, 180]$.
Conversion from Kinova to RViz joint state isn't hard: when the angle is above $180°$, subtract 360 from it; when below, keep it as is. The joint positions returned by joint_states, on the other hand, are just the radian values converted from the degree values in RViz.

2.4 Using the Joints tab in MotionPlanning to change the robot's pose on the configuration-space

Instructions:

In the Motion Planning component, find the Joints tab. You will be able to change the values of the different joint angles. Explore the configuration space, determine which joints move in which direction when a positive or a negative angle is given to each joint.

Deliverables:

1. Use the same tools (tf_echo, joint_states, and the reported values in the Kinova Web App) described in the previous subsections to explore the values for the pose and the joint angles of the following sets:

   (a) (17, 340, 134, 270, 338, 290) Gripper at 90%

Table 11: Pose information of end effector in custom state

(a) Position

Source	*x*	*y*	*z*
end_effector_link	0.22	0.00	0.18
tool_frame_link	0.23	0.00	0.05
Kinova Web App	0.23	0.00	0.05

(b) Orientation

Source	*x*	*y*	*z*	*w*
end_effector_link	1.00	-0.02	0.04	-0.01
tool_frame_link	-0.69	0.72	-0.02	0.03

Table 12: Joint angles of end effector in custom state

Source	*1*	*2*	*3*	*4*	*5*	*6*
joint_states	0.30	-0.35	2.34	-1.57	-0.38	-1.22
RViz	17	-20	134	-90	-22	-70
Kinova Web App	17	340	134	270	338	290

(b) (357, 21, 150, 272, 320, 273) Gripper at 30%

Table 13: Pose information of end effector in retract state

(a) Position

Source	*x*	*y*	*z*
end_effector_link	0.11	-0.07	0.25
tool_frame_link	0.13	-0.07	0.12
Kinova Web App	0.13	-0.07	0.12

(b) Orientation

Source	*x*	*y*	*z*	*w*
end_effector_link	0.99	-0.06	0.10	-0.01
tool_frame_link	-0.66	0.75	-0.06	0.08

Table 14: Joint angles of end effector in vertical state

Source	*1*	*2*	*3*	*4*	*5*	*6*
joint_states	-0.05	0.37	2.62	-1.54	-0.70	-1.52
RViz	-3	21	150	-88	-40	-87
Kinova Web App	357	21	150	272	320	273

2. Describe any differences between using the Joints tab in RViZ and the Angular tab in the Kinova Web App. For example, What are the benefits or challenges of using one over the other?

   Answer: As stated in the last subsection, the angular values displayed in RViz, Kinova, and joint_states are the same in essence. The difference is that Kinova is the original full circular degree range of $[0, 360]$, while RViz converts it to $[-180, 180]$ with certain limits, and the degrees are expressed in radians in joint_states.
   Each way of expression has its own pros and cons:

   (a) Kinova stays true to the mathematical way of describing an angle, but can be confusing for users for being somewhat unintuitive.

   (b) RViz optimized it by modifying the range, as well as setting upper and lower limits. The sign indicates the direction, in which the joint moves; the limits prevent accidental collisions from happening. They all improve the usability of the arm, while inevitably increased the cost to learn.

(c) Terminal joint_states aren't designed for the users to navigate the joints in the arm, and can be somewhat enigmatic because of the different links and units. They, however, are great for logs and analyses of potential issues.

2.5 Pick up the cube

You can choose any methods you learned to finish the deliverables in this section.

Deliverables:

1. Take a video of the robot arm attempting to picking something(ideally a cube) up from your table. Aim the x-y location based on your Quadrant grid location x = 8, y = 3, z = (above the table constraint).(If x= 8, y = 3 is too far to get, then you can pick the point of your choice but you need to report which point you pick.) You can use your previously found transformation between the grid and the robot's axes.

   Google Drive link to the task of picking up the cube.

2. Select (and report) a percentage for the relative position of the gripper. Additionally, report the end_effector's pose.

Table 15: Pose information of end effector in pickup state

(a) End effector position

x	y	z
0.42	-0.45	0.01

(b) End effector orientation

θx	θy	θz
25.17	-177.28	78.75

(c) Gripper position

Upper	Lower
60%	80%

3 Introducing Planning Scene Objects in MoveIt! (Only simulation)

Instructions:

We will go through the steps of adding an object to our planning scene, which in turn will serve as a constraint when MotionPlanning is creating safe motions for the robot to reach different positions. Using the RViZ tab called Scene Objects, select a "Box" with dimensions 1m for all three axes (x, y, z).

Change the position values to the ones on the picture below (x= 0.55, y = ±0.45, z = -0.48) to set the scene object a little above the table level in the physical world. Tick the box next to Box_0 name (you may rename it), to attach the object to the base_link.

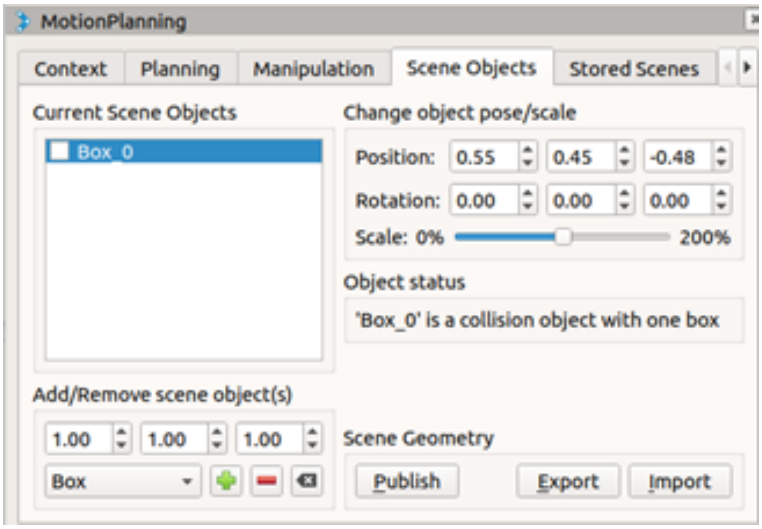


Figure 8: Kinova RViz

Finally, publish the changes made so the move_group instance saves the changes to include in planning stages.

Deliverables:
Use the interactive markers to move the gripper towards the planned scene object.

1. Describe what you see in terms of the pieces of robot changing colors.

   Answer: When the goal state has a potential collision with the scene object, the parts of the robot impacted will turn red. Mostly, the robot is divided by joints, so the changing color will apply to all the parts between two joints.

2. Hit the plan button (not execute) and report on any changes in the terminal or the status in the Planning tab.

   Answer: Upon hitting the button, the status in the Planning tab changes to 'Planning.' After 10 (or any times of your choosing) failed attempts, the status becomes 'Failed.' Generally, the planning is rather quick, but can be as thorough as possible.

4 Pick and Place task

Now that we have familiarized ourselves with the Kinova arm both in simulation and in the real world, we will expand our knowledge towards a common robotic arm task: pick and place.

Instructions: For this portion of the assignment, we will return to the simulated Kinova Arm.

```
~$ roslaunch kortex_gazebo spawn_kortex_robot.launch arm:=gen3_lite
```

In Gazebo, on the left panel's "Insert" tab, find the "Wooden cube 7.5cm" object and add it to the world on a position on the ground within the robot arm's workspace (space that can be reached by the arm). Add another planned scene object, to avoid hitting the ground with the robot's end effector. You can follow the same instructions from RViZ. The pick and place task can be summarized in the following steps:

1. Reach position above the center of the object to be picked with gripper oriented
2. Adjust gripper to open or semi-open state.
3. Decrease the end-effector's z-value position
4. Close gripper to grasp object.
5. Reach position above the desired location to place the object with gripper oriented.
6. Decrease the end-effector's z-value position
7. Open gripper to release object.
8. Increase the end-effector's z-value position to clear the object
9. Return to home position.

The goal of this section is to get familiar with this pick and place sequence and complete it step by step. To avoid errors during the executions, you are suggested to configure the program by running

```
$ rosrun rqt_reconfigure rqt_reconfigure
```

Set allowed_execution_duration_scaling to be 4 and uncheck the execution_duration_monitoring.

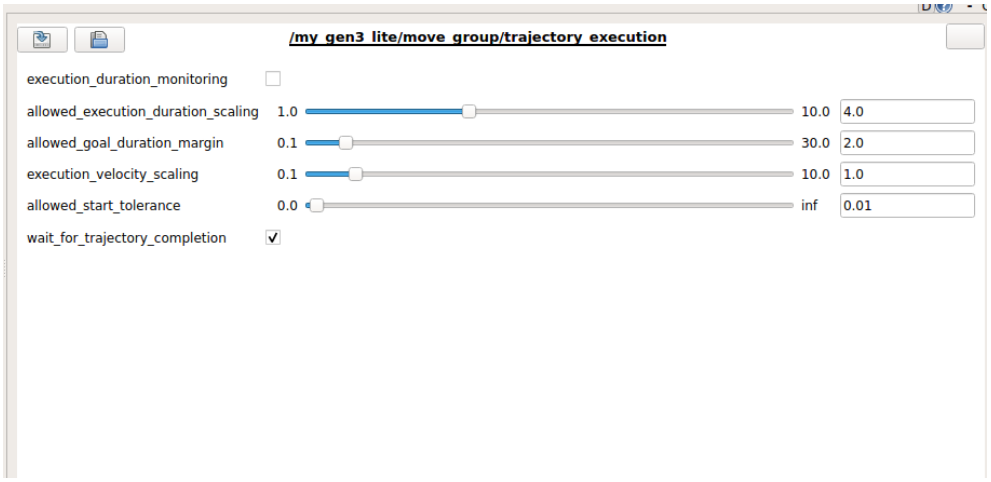


Figure 9: Configuration

Deliverables:

1. Attempt the pick and place steps through RViZ. Report values of interest used to complete the task:

   (a) Pose of the cube and desired placing location.

   Answer: The initial position of the cube is somewhere around $(0.25, 0.25, 0)$, and the end position is just a quadrant away, around $(0.25, -0.25, 0)$.

   (b) Selected height to approach object.

   Answer: The starting height of the arm is $0.25m$, and the lowered height to approach the object is around $0.06m$. Given the measurement of the cube is $7.5cm$, gripping height lower than $0.07m$ is likely safe.

   (c) Percentage of the gripper's open/close position.

   Answer: The open position of the gripper is 55%, default in the RViz setting. The close position for gripping, after trials and errors, is ideally 34%.

2. Record a video of the completed task.

   Google Drive link to the simulated task of picking and placing the cube

3. Discuss some of the challenges you faced to complete the task.

   Answer:

   (a) One of the biggest challenges I face is the separation of interfaces. RViz is the place to plan for the motion of the arm and gripper, while Gazebo is the place to preview movement of all the models. It's been hard to tell whether the arm is at the right place to pick up the object of interest.

   (b) Another challenge is the poor usability of RViz to navigate the arm. Directly setting the position parameters isn't allowed in the interface, and the only way is to use the interactive marker, which harms the accuracy of movement. Other actions, e.g. gripper percentages are also found out thru experiments.

   (c) Finding the right spot to grasp the object is no easy task. Misalignment of the gripper and object positions leads to unexpected collisions; inappropriate gripper percentage can possibly destroy the object by squeezing or dropping it; Holding the object with the back of the grippers is slippery and risky, etc.