Introduction

This report is for Pick & Place project for Robotics Software Engineer ND from Udacity.

It's going to states the steps of project and analysis used for the project.

First, it's going through the Kinematic Analysis where Dh parameters are derived from the URDF file of the Kuka KR210 robotic arm.

Then, it's going through the general homogenous matrix using the individual ones which developed by the DH parameters.

After the Forward Kinematics problem, the report will go through the Inverse Kinematics which will be solved the Kinematic Decoupling method due to the great characteristics of the KR210.

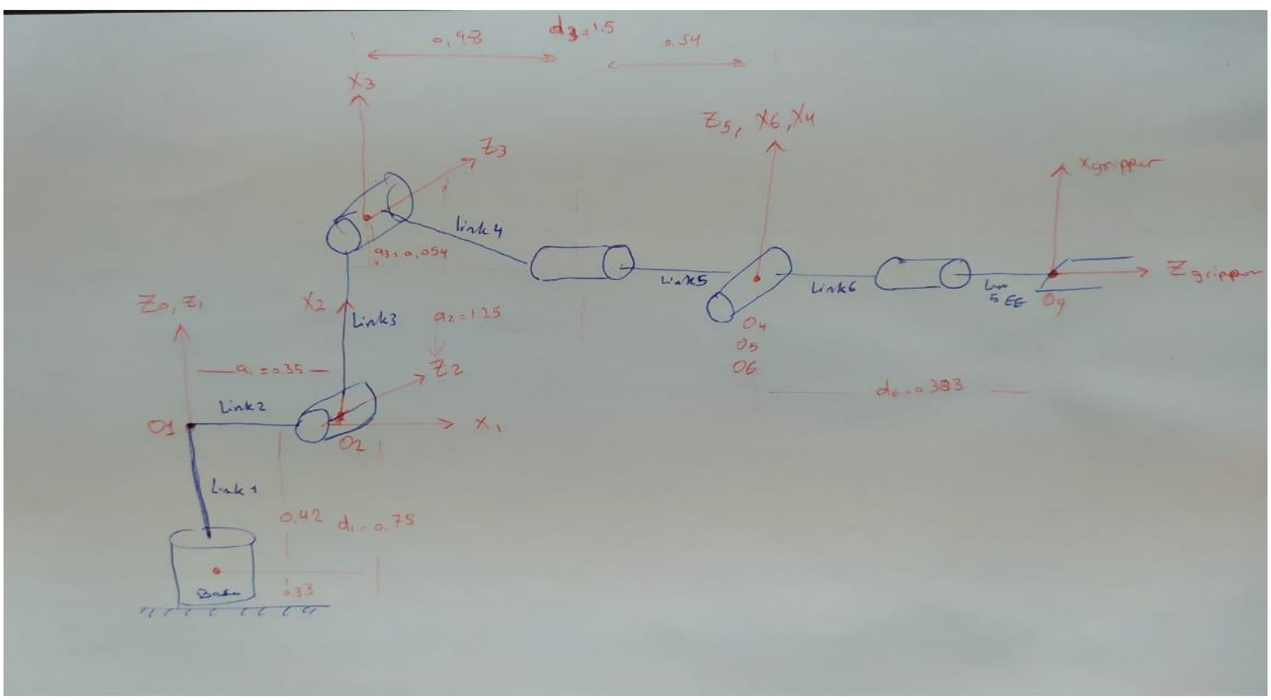
Finally, the implementation of the project using the simulation with gazebo and Rviz and the code developed to perform the Inverse Kinematics solutions.

1 Kinematics Analysis

1.1 Deriving DH parameters.

1.1.1 KR210 Frames Assignment

The following sketch is describing the frame assignment which will be used for getting the DH.



The URDF file helped to find the distances between the joints and links' relations.

DH Parameters.

The convention used to find the DH is “Craig” described as following:

$$a_i = \text{the distance from } \hat{Z}_i \text{ to } \hat{Z}_{i+1} \text{ measured along } \hat{X}_i;$$

$$\alpha_i = \text{the angle from } \hat{Z}_i \text{ to } \hat{Z}_{i+1} \text{ measured about } \hat{X}_i;$$

$$d_i = \text{the distance from } \hat{X}_{i-1} \text{ to } \hat{X}_i \text{ measured along } \hat{Z}_i; \text{ and}$$

$$\theta_i = \text{the angle from } \hat{X}_{i-1} \text{ to } \hat{X}_i \text{ measured about } \hat{Z}_i.$$

The following table is the DH parameters for KR210:

LINK	Alpha (i-1) (deg)	a(i-1)	d(i-1)	Theta(i-1)
0-1	0	0	0.75	q1
1-2	-90	0.35	0	q2 - 90
2-3	0	`1.25	0	q3
3-4	-90	-0.054	1.5	q4
4-5	90	0	0	q5
5-6	-90	0	0	q6
6-Gripper	0	0	0.303	q7

These parameters will be used to find the homogenous transform from the Base to Gripper (End Effector).

1.2 Generalized Homogenous Transform

DH parameters will be used as the following matrix to perform an individual HT from any frame

$$ {}^{i-1}_{\;\;i}T = R(x_{i-1}, \alpha_{i-1})\, T(x_{i-1}, a_{i-1})\, R(z_i, \theta_i)\, T(z_i, d_i) $$

$$ {}^{i-1}_{\;\;i}T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

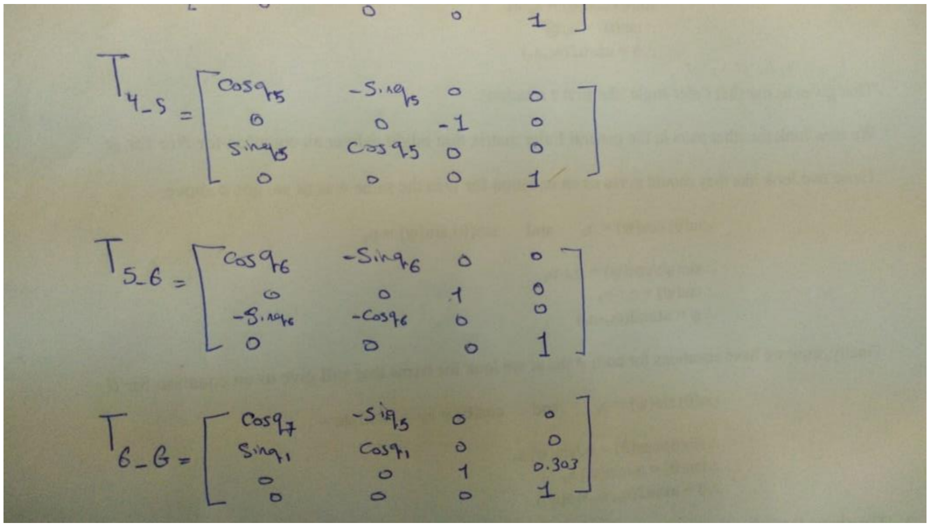
Then the individuals HT will be as following:

$$ T_{0-1} = \begin{bmatrix} \cos q_1 & -\sin q_1 & 0 & 0 \\ \sin q_1 & \cos q_1 & 0 & 0 \\ 0 & 0 & 1 & 0.75 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ T_{1-2} = \begin{bmatrix} \cos q_2 & -\sin q_2 & 0 & 0.35 \\ 0 & 0 & 1 & 0 \\ -\sin q_2 & -\cos q_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ T_{2-3} = \begin{bmatrix} \cos q_3 & -\sin q_3 & 0 & 1.25 \\ \sin q_3 & \cos q_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ T_{3-4} = \begin{bmatrix} \cos q_4 & -\sin q_4 & 0 & -0.054 \\ 0 & 0 & 1 & 1.5 \\ -\sin q_4 & -\cos q_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$



From these HTs we can develop the General HT from Base to the Gripper

T0_G = T0_1 x T1_2 x T2_3 x T3_4 x T4_5 x T5_6 x T6_G

After this step we consider a correction for the gripper frames in the URDF and simulator by performing a rotation about z-axis by 180 deg following by a rotation about y-axis by -90 deg "intrinsically"

T0_G=T0_G x Rot(Z,180) x Rot (Y, -90)

By this HT we can perform the Forward Kinematics of KR210

the code of this section will be found in " IK_server.py" line (50 :132).

1.3 Inverse Kinematics Problem.

Following the next the steps w can solve the KR210 IK problem.

We use the Kinematic decoupling method of robot because the robot has a Spherical Wrist.

1.3.1 Find the location of the WC relative to base.

Using the T0_G which derived in the previous section.

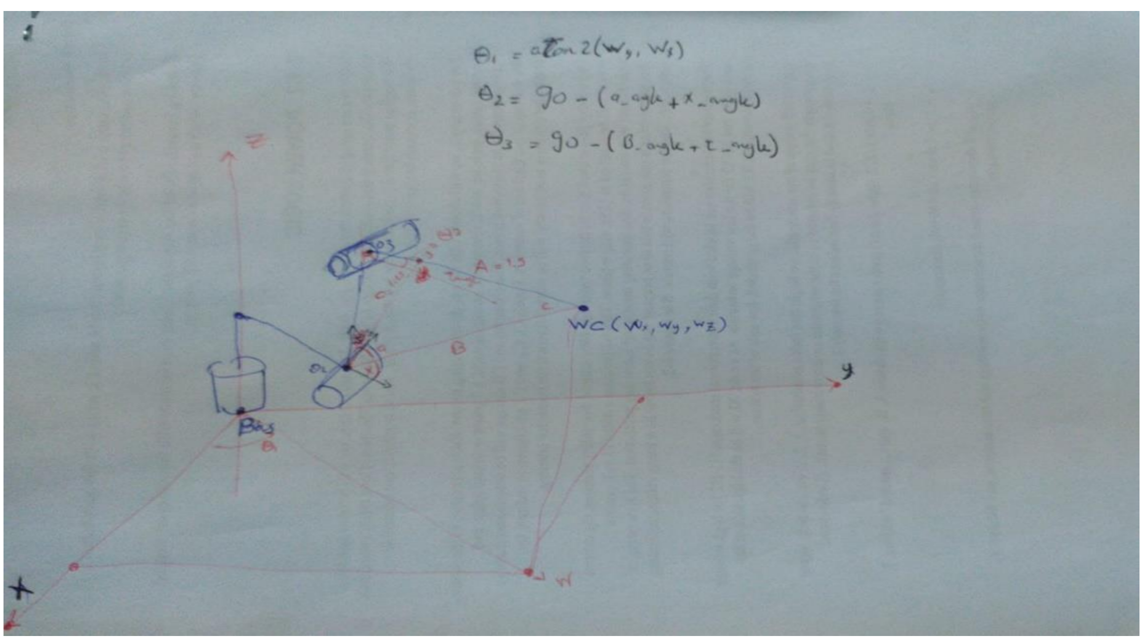
$$
{}_{EE}^{0}T = \left[\begin{array}{ccc:c} & {}_{6}^{0}R & & {}^{0}\boldsymbol{r}_{EE/0} \\ \hdashline 0 & 0 & 0 & 1 \end{array}\right] = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^{0}\boldsymbol{r}_{WC/0} = {}^{0}\boldsymbol{r}_{EE/0} - d \cdot {}_{6}^{0}R \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} - d \cdot {}_{6}^{0}R \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}
$$

Where d = 0.303 from DH parameters.

1.3.2 Find the first joint variables.

Using the End Effector position, we can find trigonometrically the Theta1,2,3



1.3.3 Finding Last three joint variables.

- Using the previous variables, we can calculate R0_3, by using the Individual HTs.
  And Extract the rotation part from the calculated HT.

T0_G = T0_1 x T1_2 x T2_3

- Then we can find Theta 4,5,6 by using Euler angles and the XYZ convention

$$ {}^{3}_{6}R = \left({}^{0}_{3}R\right)^{-1}\,{}^{0}_{6}R = \left({}^{0}_{3}R\right)^{T}\,{}^{0}_{6}R $$

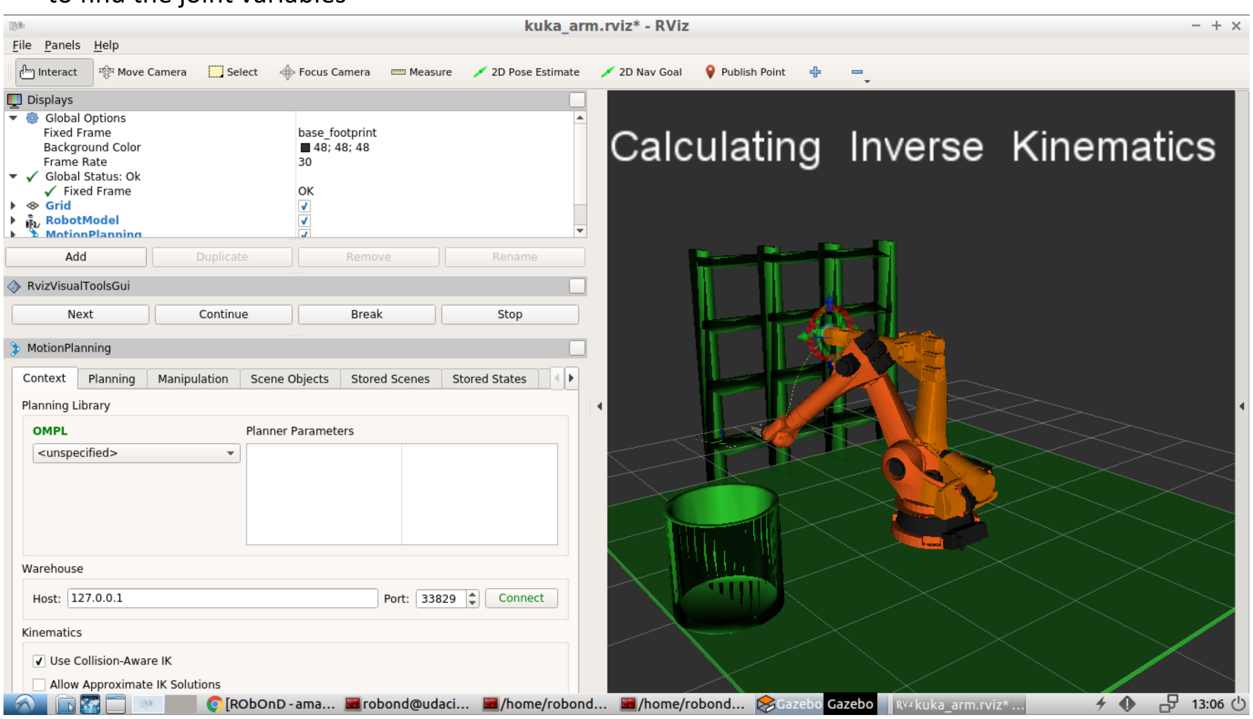
the code of this section will be found in " IK_server.py" line (178 : 237).

2 Project Implementation

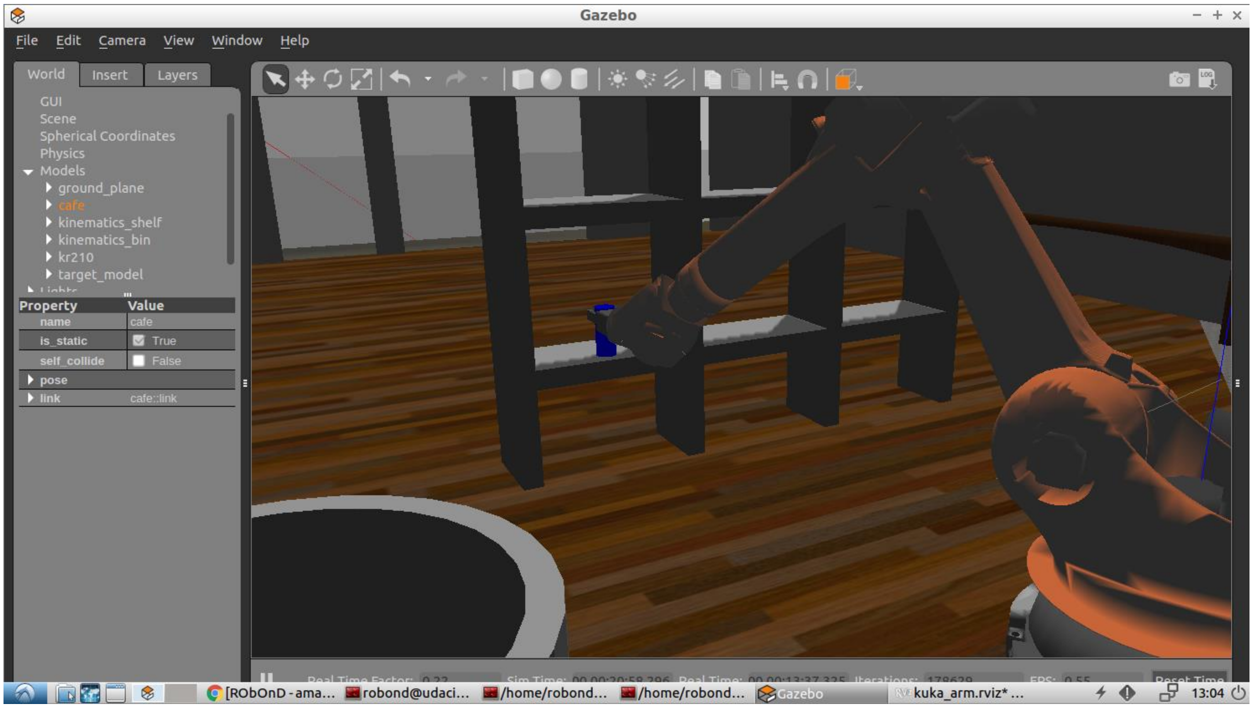
By using the GAZEBO and RViz and the code in IK_server.py, the Arm could perform the inverse kinematics.

The following images is from a trial for the IK problem.

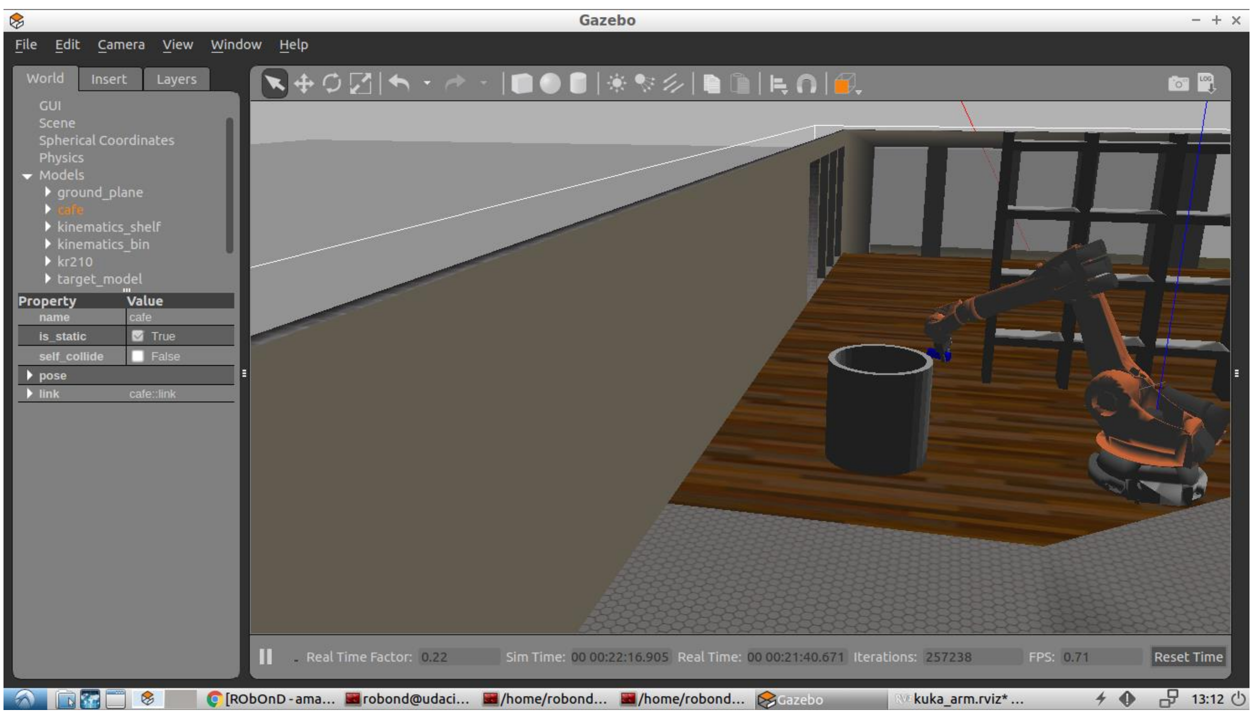
1- Calculating the inverse kinematics by sending a message request to IK_server.py with EE poses to find the joint variables



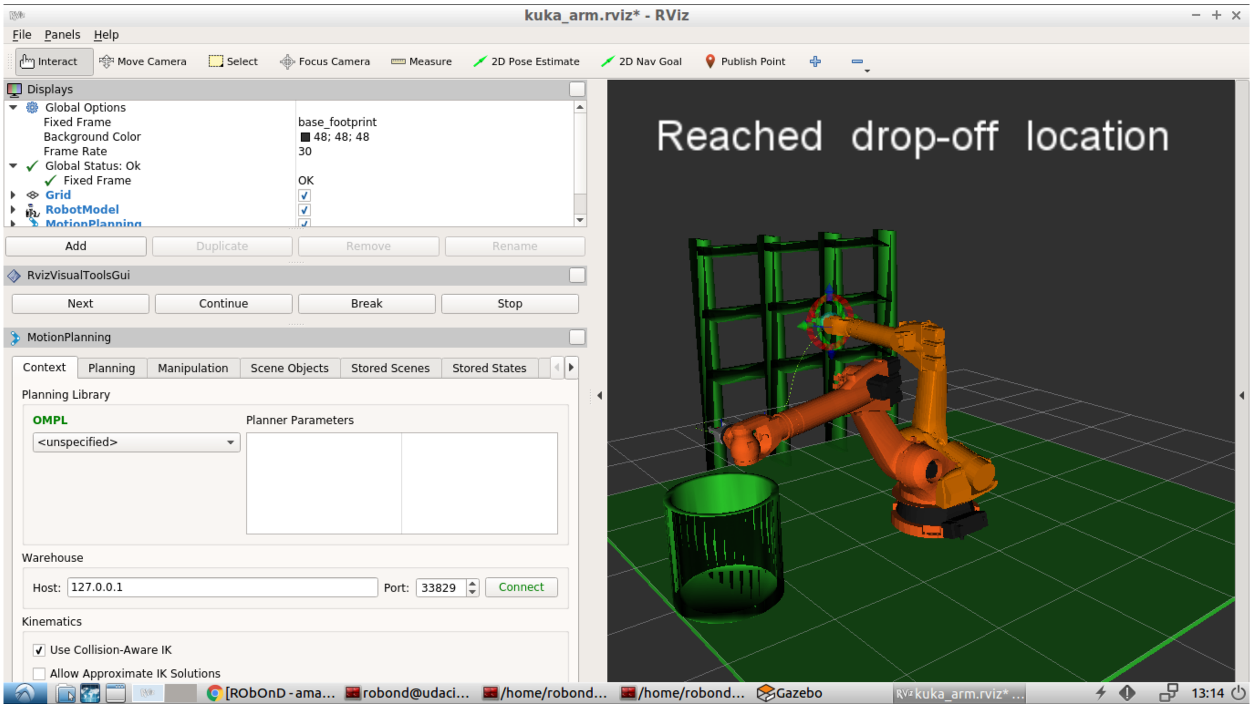
2- Go to the target and perform grasp action

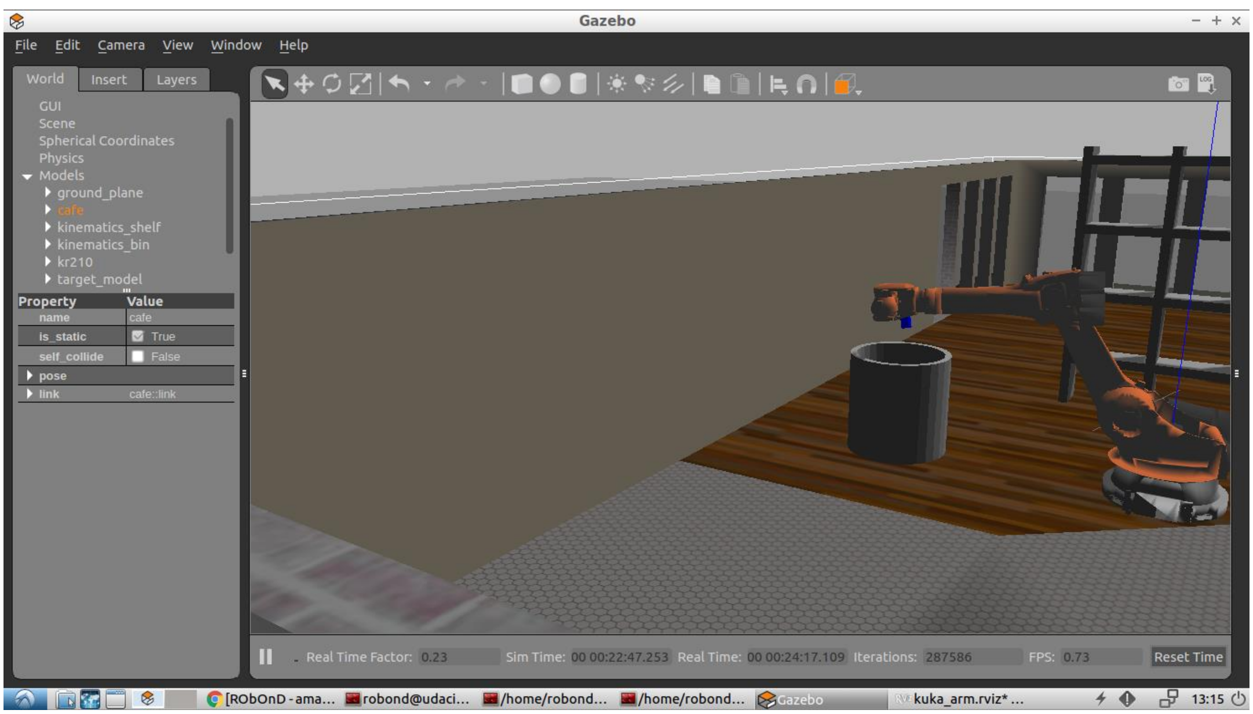


3- Calculate again the joint variables with new EE poses to go to the Bin and perfrom these varables



4- Finally, Drop Off the target





Summary

In this report, a case of KUKA KR210 robotic arm have been kinematically analyzed to solve both Forward and Inverse Kinematics.