Università degli Studi di Genova

CORSO DI LAUREA MAGISTRALE

Robotics Engineering

ROBOT DYNAMICS AND CONTROL

Assignment One Report

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DECLARATION

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ABSTRACT

This Report shows all the results for the exercise proposed as Robot Dynamics and Control first assignment, all the results are motivated with an explanation. Furthermore, the two exercises were simulated on MATLAB Simulink using Simscape for multibody package and for further approval of the simulated model a calculation were done to prove that the system is modeled in the correct way.

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I. Introduction

The assignment is composed of two robots in which one of the is Rotational Rotational (RR) and the other is Prismatic Rotational (PR). It is required to calculate the total forces and torque on each joint. Another approach was taken and instead of writing a MATLAB script the whole mechanisms was modeled on Simulink using Simscape for multibody package. This will ensure that all the results are more precise and near to the real world.

According to Simscape package: Simscape represents a system of mechanical components connected through multiple frame nodes. System can be used to organize complex hierarchies of nested blocks that are structured as needed.

How the system is modeled:

When the .XML file is exported from Inventor making sure all the material and the joints between each link is taken into consideration, MATLAB can export this file to a .slx file which is a Simulink representation for the mechanism, and from here the mechanism can be controlled, add another frame with reference to another using a translational block, add an external force or torque on any frame, choose to model the gravity or not and finally visualize the behavior of the mechanism.

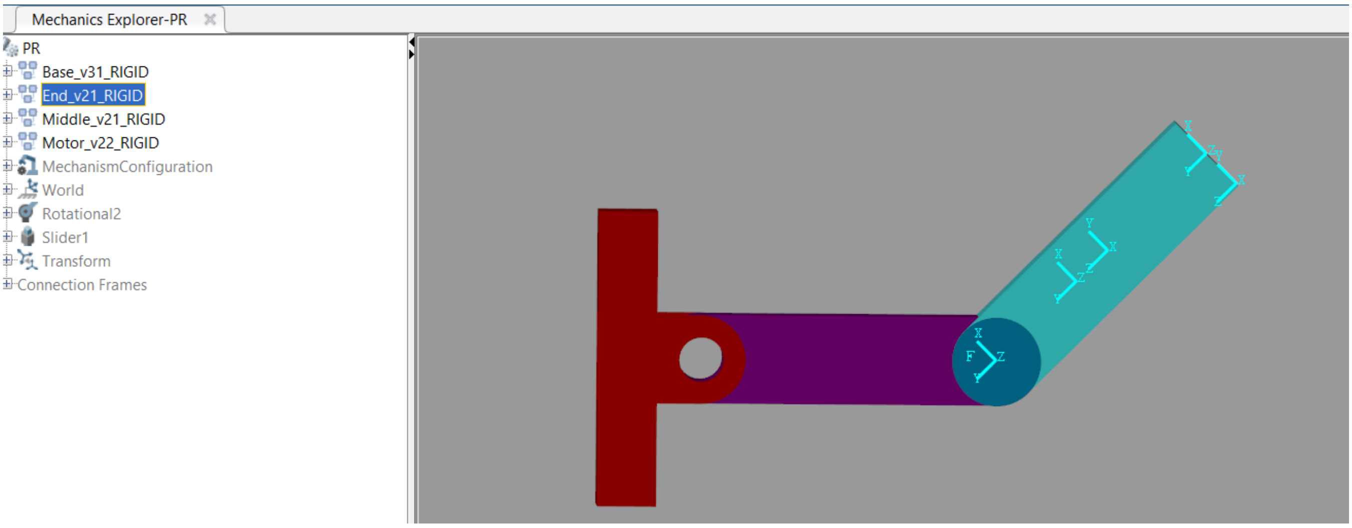

Figure 1: Frames on link 2

The pervious figure (1) shows the modeled mechanism with all the frames on the end effector link, note here there is a frame between the middle link and the end effector link also another frame on the Center of Mass of the link and two other frames each for points p2 and p1.

II. Case Study

1. Newtons Second law approach

Let’s consider a case study for one of the examples proposed in assignment so it can be compared to the results from the modeled system on Simulink.

First of all, the conditions are as follows:

$\theta_1 = \frac{\pi}{2}\, \theta_2 = -\frac{\pi}{2}$ g = [0, -9.81] acting on the COM of both links.

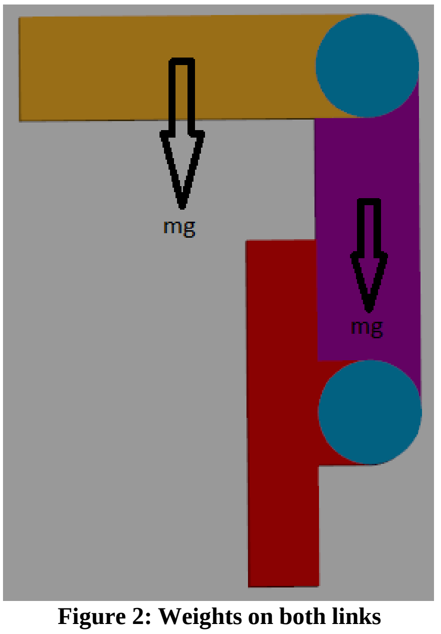

Figure 2: Weights on both links

For this case, there is no forces being applied to the system rather than weight of the mechanism its self-according to newton’s second law $F = ma$ where m is the mass of each link and a is the gravitational acceleration.

For link 2 (Calculating τ_2):

$$\tau_2 = m_2 g \times CoM_2$$

According to the RR_Datafile.m exported by MATLAB the mass of the second link is 872.6 kg and the Center of mass is 531.7 mm. Note here the mass of the link is huge as the material chosen is steel.

$$\therefore \tau_2 = 872.6 \times 9.81 \ \times 531.7 \ = \ 4{,}551 \ N.m$$

For link 1 (Calculating τ_1):

For this link the torque on its joint is simply the opposite direction of the one on joint to as the system is in static equilibrium so the motor in link 1 should cancel out the joint 2 torque.

$$\therefore \tau_1 = -\tau_2 = -4{,}551 \ N.m$$

2. Jacobian Transpose Approach

$$\boldsymbol{\tau_{eq} = J^T W}$$

Where:

$\boldsymbol{\tau_{eq}}$ is the vector of generalized actuator forces.

$\boldsymbol{W}$ represents a cartesian wrench (torque, force) applied to an arbitrary position on the robot body.

$\boldsymbol{J^T}$ is the transpose of the robot Jacobian.

As for simplicity and since it is known that the forces applied on the mechanism that result in the torque on each joint is the weight of link two, so let's take the transformation matrix to this point.

$${}^{CoM_2}_{0}T = \begin{bmatrix} \cos(\theta_1+\theta_2) & -\sin(\theta_1+\theta_2) & 0 & L_1\cos\theta_1 + CoM_2\cos(\theta_1+\theta_2) \\ \sin(\theta_1+\theta_2) & \cos(\theta_1+\theta_2) & 0 & L_1\sin\theta_1 + CoM_2\sin(\theta_1+\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

It is known that the mechanism can only do rotation around the Z-axis and transition on the x and y axis, so let's take the Jacobian simply as for only the linear Jacobian and neglect the angular Jacobian but only for that case.

$$J = \begin{bmatrix} -L_1\sin\theta_1 - CoM_2\sin(\theta_1+\theta_2) & -CoM_2\sin(\theta_1+\theta_2) \\ L_1\cos\theta_1 + CoM_2\cos(\theta_1+\theta_2) & CoM_2\cos(\theta_1+\theta_2) \end{bmatrix}$$

$$\therefore \tau_{eq} = \begin{bmatrix} -L_1\sin\theta_1 - CoM_2\sin(\theta_1+\theta_2) & L_1\cos\theta_1 + CoM_2\cos(\theta_1+\theta_2) \\ -CoM_2\sin(\theta_1+\theta_2) & CoM_2\cos(\theta_1+\theta_2) \end{bmatrix} \begin{bmatrix} 0 \\ -m_2 g \end{bmatrix}$$

$$\therefore \tau_{eq} = \begin{bmatrix} 4,551 \\ 4,551 \end{bmatrix}$$

Now for the same RR or PR robot the torques/ forces can be computed as follows:

$$\tau_1 = J_{c1}^T W_{c1} + J_{P3}^T W_{p3} + J_{c2/0}^T W_{c2/0} + J_{P1/0}^T W_{p1} + J_{P2/0}^T W_{p2/0}$$
$$\tau_2 = J_{c2}^T W_{c2} + J_{P1}^T W_{p1} + J_{P2}^T W_{p2}$$

$$\tau_{eq} = \tau_1 + \tau_2$$

3. Simulink Approach

As for the modeled mechanism on Simulink the gravity was taken into consideration and no external forces added on any point.

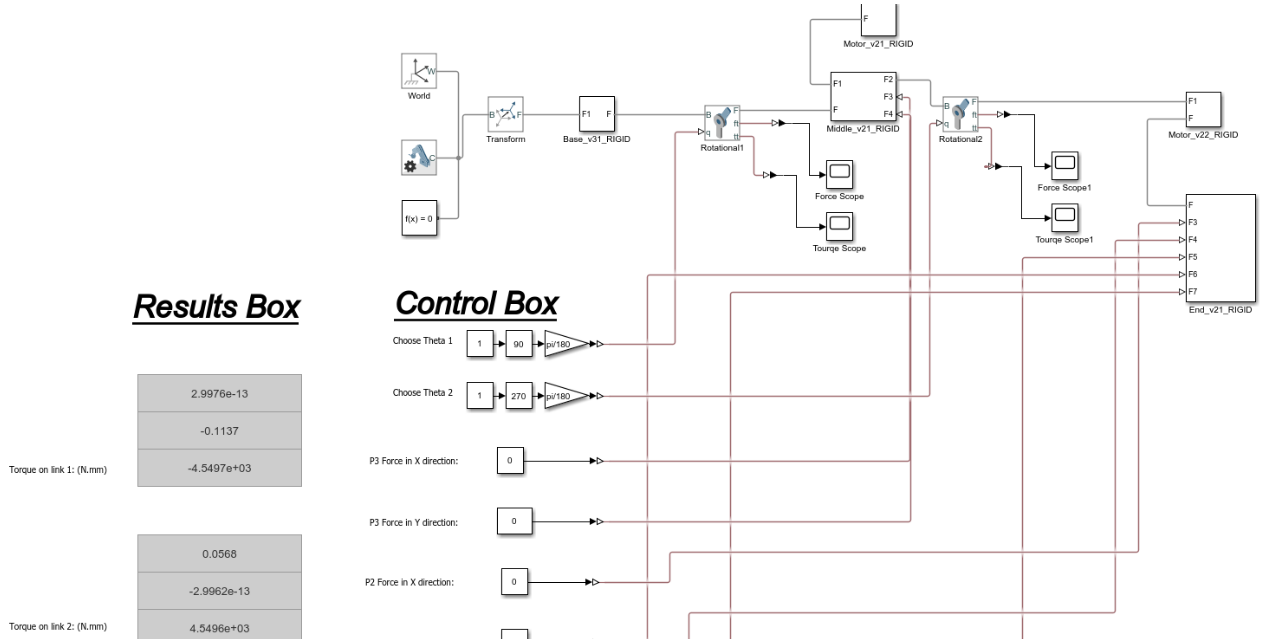

Figure 3: RR Robot Simulink model

It was found out that the torques on each joint are as follows: $\tau_1 = -\tau_2 = 4549.7\ N.m$

This is -0.028% error and this is because the approximations taken in the previous methods, also that the motor is neglected in pervious calculations, and yes it will not change the torque in this case but in other joints positions it would.

Moreover, the modeled mechanism on Simulink took into consideration the points in which external forces/ torques can be applied like (P1, P2 and P3) for both RR robot and PR robot. These points are from reference to the CoM of the mechanism. Furthermore, a small control box was designed to enter all the positions on of the joints and the values of external forces/ torques and therefore a small results box can show the τ_{eq}.

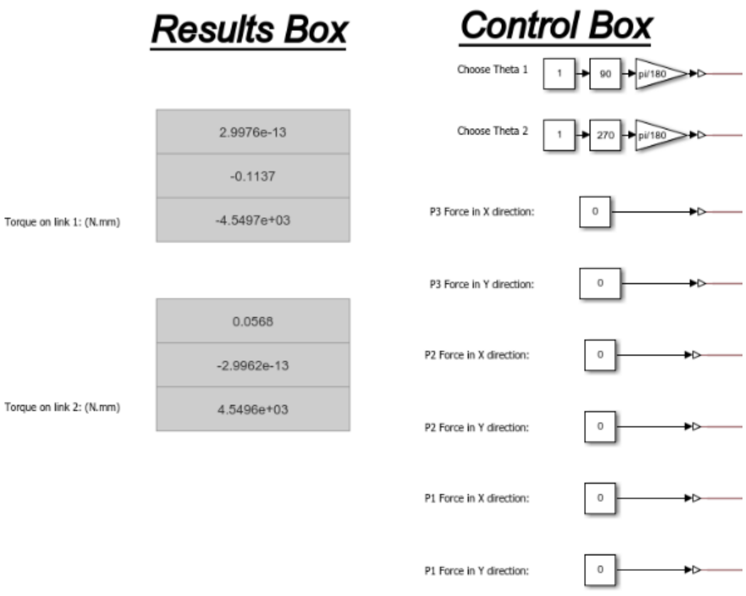

Figure 4: Control & Results box

4. Results

From the MATLAB Simulink all the cases for each exercise can be tested and find the τ_{eq}. The below tables show the result obtained for each exercise.

Exercise 1 – RR robot:

Table 1: RR Robot results

	1	2	3a	3b	4	5
$\boldsymbol{\theta_1}$ (degree)	90	0	30	30	30	30
$\boldsymbol{\theta_2}$ (degree)	-90	90	60	60	60	-60
Gravity 9.80665	Present	Present	No	No	No	Present
$\boldsymbol{P_{3x}}$ (N)	0	0	0	0	1.5	-0.4
$\boldsymbol{P_{3y}}$(N)	0	0	0	0	-0.3	1.2
$\boldsymbol{P_{2x}}$(N)	0	0	0	-0.7	0	1.2
$\boldsymbol{P_{2y}}$ (N)	0	0	0	-0.5	0	-0.2
$\boldsymbol{P_{1x}}$ (N)	0	0	-0.7	0	0	0
$\boldsymbol{P_{1y}}$ (N)	0	0	-0.5	0	0	0
$\boldsymbol{P_{1\tau}}$ (N.m)	0	0	0	0	1.2	0
$\boldsymbol{\tau_{1eq}}$ (N.m)	**-4548**	**13302**	**-0.617**	**-1.0152**	**0.93**	**11521**
$\boldsymbol{\tau_{2eq}}$ (N.m)	**4549**	**0**	**-0.7**	**0.2322**	**-1.2**	**-0.4125**

Exercise 2 – PR robot:

Table 2: PR Robot results

	1	2	3	4	5
$\boldsymbol{d}^*$(mm)	0	0	0	0	0
$\boldsymbol{\theta_2}$ (degree)	45	90	45	45	45
Gravity 9.80665Z	Present	Present	No	No	Present
$\boldsymbol{P_{3x}}$ (N)	0	0	0	0	0
$\boldsymbol{P_{3y}}$(N)	0	0	0	0	0
$\boldsymbol{P_{2x}}$(N)	0	0	0	-0.8	1.0
$\boldsymbol{P_{2y}}$ (N)	0	0	0	-0.2	-0.4
$\boldsymbol{P_{1x}}$ (N)	0	0	-0.8	0	0.5
$\boldsymbol{P_{1y}}$ (N)	0	0	-0.8	0	-0.6
$\boldsymbol{P_{1\tau}}$ (N.m)	0	0	0	0.5	0
$\boldsymbol{\tau_{1eq}}$ (N)	**0**	**0**	**-1.131371**	**0.8**	**-1.767767**
$\boldsymbol{\tau_{2eq}}$ (N.m)	**3217.1**	**4549.6**	**0.8**	**-0.018**	**3320.6**

III. Conclusion

In conclusion the modeled system showed the same expected results and furthermore the error percentages from the calculations and the Simulink model are -0.028% in advance to the Simulink model and this is a promising result.

It is also important to note that it was not possible to have a prismatic joint between the base and the first link so further modifications where made on the design which further changed the link mass and CoM for exercise two.

Moreover, all the results in table 1 and 2 are reasonable as for the simplicity of the system. Also, it was noted due to the high masses of the links $m_{link\ 1} = 789.7\ kg$, $m_{link\ 2} = 872.6\ kg\ and\ m_{motor} = 88.8\ kg$ in the cases of gravity present with an external force like exercise 1.5 and 2.5 the effect of the external forces was not noted in the results, This is because the forces applied are relatively very small to the masses of the mechanism.