University of Tehran
College of Engineering
School of Electrical and Computer Engineering (ECE)
School of Mechanical Engineering (ME)

Mechatronics & Robotics

Mini Project 2

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Deadline: 12 May 2024 (23 Ordibehesht), 23:59

This mini project is designed to address the kinematics and dynamics of robotic arms using MATLAB and Simscape environment. The given case study in this project is the known Scara robotic arm. In this project, the simulink file for the robotic arm and its physical parameters are given.

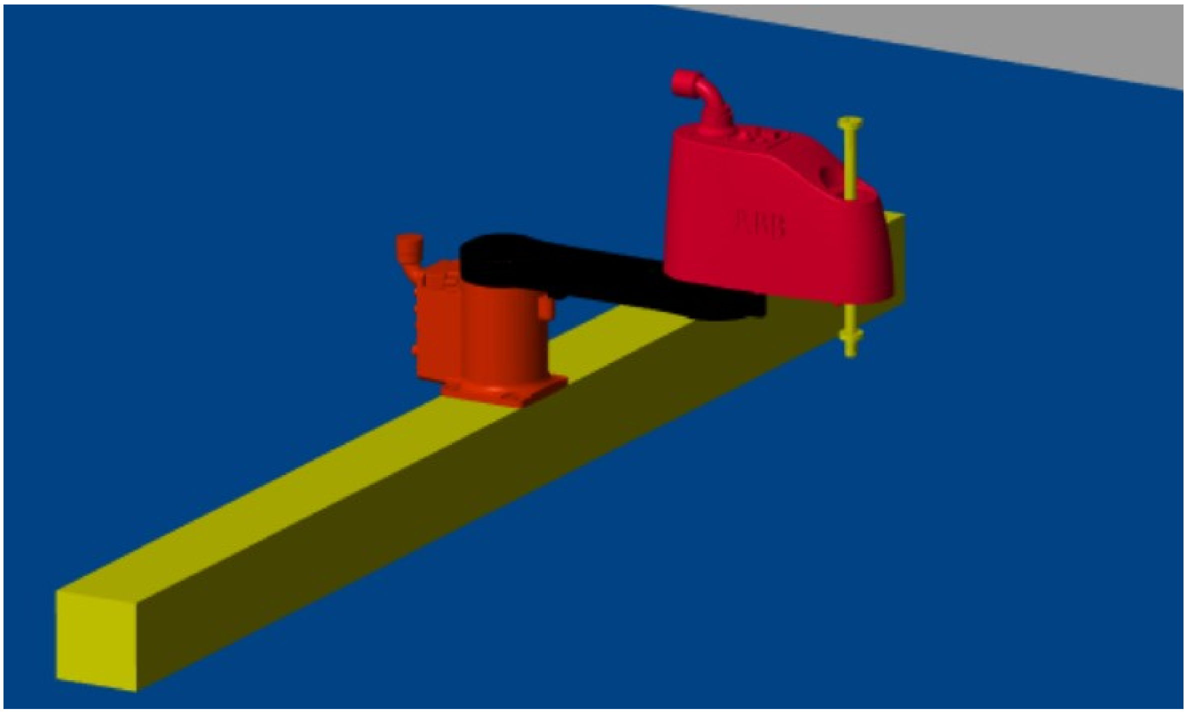


Figure 1: Scara Robotic Arm in Simscape Environment

List of Problems

Problem : Kinematic and Dynamic Modeling

In this problem, the goal is to obtain a kinematic model for the given robotic arm.

1. Obtain the Denavit-Hartenberg parameters for the arm and complete the Table. (The z-direction of DH axes should be the same as the z-direction of joints in the simulation model.) (10 Points)

i	a_i	b_i	α_i	θ_i	$q_i^{initial}$
1		b_1			
2			θ_2		
3			θ_3		
4		b_4			

2. Obtain the Forward Kinematics Problem for the robot and simplify it using MATLAB. (10 Points)
3. Using the previous item, obtain the Inverse Kinematics Problem. (10 Points)
4. Obtain the jacobian matrix for the manipulator. (10 Points)
5. Using the euler-lagrange method, obtain the dynamic model. (40 Points)
6. Verify the dynamic model using Simscape. (20 Points)

Robot dimensions are given as follows:

To obtain the dynamic model, the symbolic computations of MATLAB are helpful as well. You can also use the equations in the attached paper for further information on dynamic modeling. After obtaining the dynamic model, rewrite it as a matlabFunction, whose inputs are the joints position or rotation, and their first and second derivatives. The output is a 4-dimensional vector of forces and torques for the joints.

Note: To use the equations in the paper, the physical parameters of links must be written the DH frame.

$$[CoM]_{DH} = T[CoM]_{link}$$

$$[I]_{DH} = Q[I]_{link}Q^{-1}$$

where:

$$T = \begin{pmatrix} Q & b \\ 0 & 1 \end{pmatrix}$$

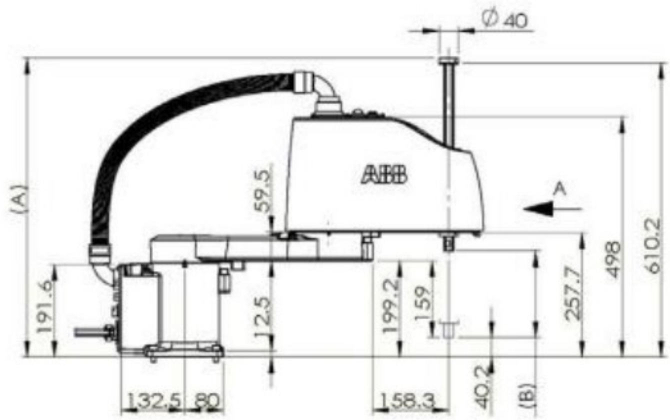


Figure 2: Robot Dimensions

To verify the model, use the simulation file given. First, run the `motions-for-simulink.m` file, then run the simulink model. Using the `plotting-results.m` file, plot the torques obtained from the dynamic model and simulation. Use a pick-and-place motion with the 4-5-6-7 interpolation.

Note: To use the simulink model, the STL files related to each link should be imported to the corresponding link's block in the file.

Note: Initial condition of the simulation model:

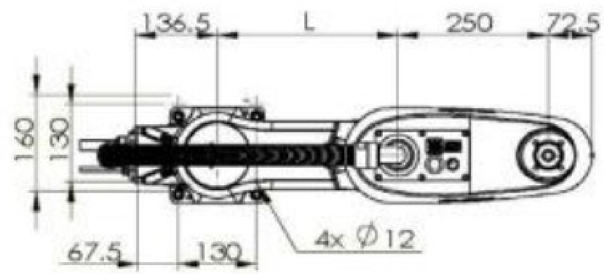
$$\theta_{sim}^{initial} = \begin{pmatrix} 0 & 0 & 0 & 0 \end{pmatrix}$$

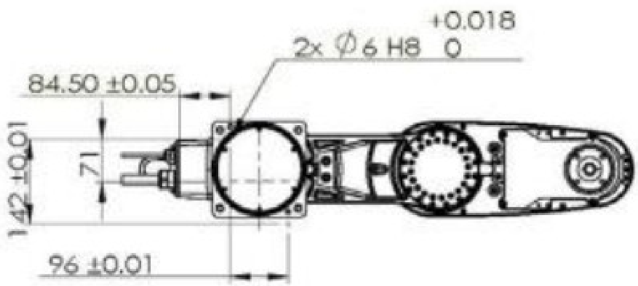
But in the dynamic model using DH parameters:

$$\theta_{model}^{initial} \neq \theta_{sim}^{initial} = \begin{pmatrix} 0 & 0 & 0 & 0 \end{pmatrix}$$

Also note that:

$$\theta_{final} = \theta_{initial} + \begin{pmatrix} 0.5 & \pi/3 & -\pi/6 & -0.05 \end{pmatrix}$$





Item	Description	Variant		
		IRB 910SC-3/0.45	IRB 910SC-3/0.55	IRB 910SC-3/0.65
L	Length of lower arm	200 mm	300 mm	400 mm
A	Maximum height	620 mm	620 mm	620 mm
B	Z stroke	180 mm	180 mm	180 mm

Figure 3: Robot Dimensions

Physical Parameters

$$mass_{link0} = 0.8kg$$

$$CoM_{link0} = \begin{pmatrix} 0 & 0 & 0 \end{pmatrix} m$$

$$I_{link0} = \begin{pmatrix} 0.44 & 0 & 0 \\ 0 & 0.003 & 0 \\ 0 & 0 & 0.44 \end{pmatrix} kg.m^2$$

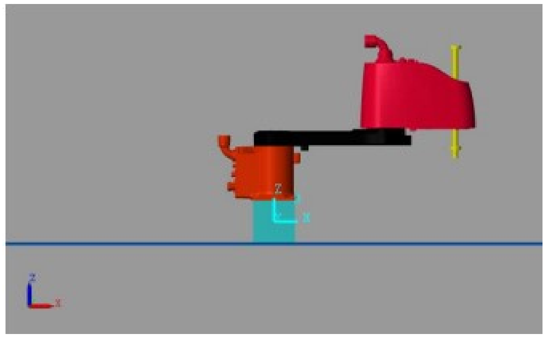


Figure 4: Link 0 Frame

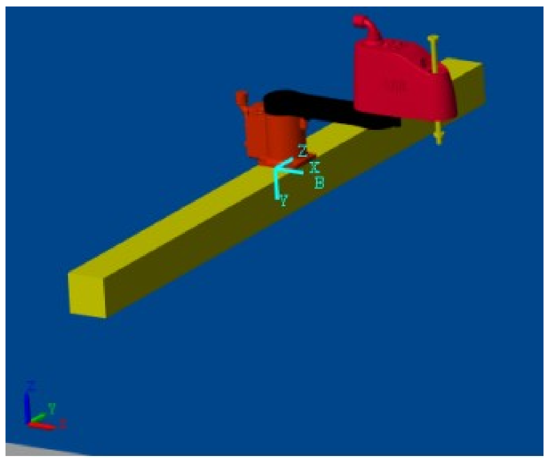


Figure 5: First Prismatic Joint Frame

$$mass_{link1} = 0.8kg$$

$$CoM_{link1} = \begin{pmatrix} 0.15 & 0.08 & 0.1 \end{pmatrix} m$$

$$I_{link1} = \begin{pmatrix} 2000 & 2 & 160 \\ 2 & 3000 & 1 \\ 160 & 1 & 2000 \end{pmatrix} \times 10^{-6} kg.m^2$$

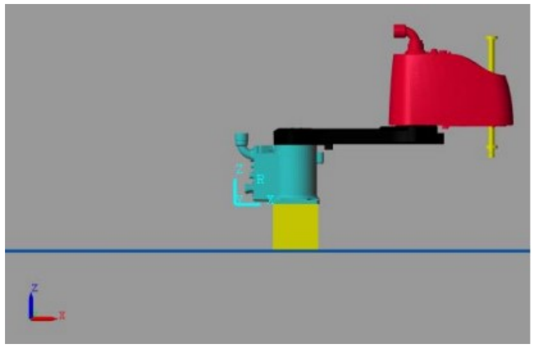


Figure 6: Link 1 Frame

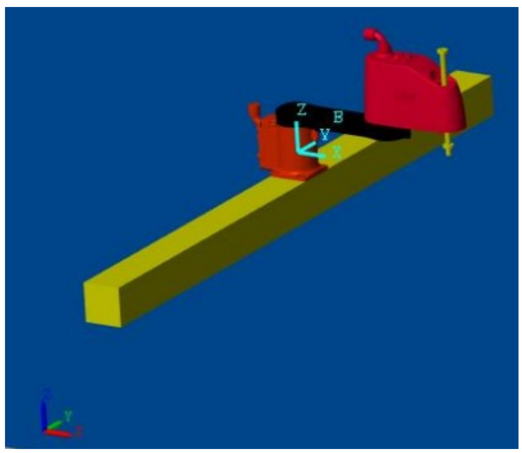


Figure 7: Second Rotational Joint Frame

$$mass_{link2} = 1.2kg$$

$$CoM_{link2} = \begin{pmatrix} 0.35 & 0.1 & 0.25 \end{pmatrix} m$$

$$I_{link2} = \begin{pmatrix} 1600 & -0.25 & -1200 \\ -0.25 & 30000 & 0.05 \\ -1200 & 0.05 & 30000 \end{pmatrix} \times 10^{-6} kg.m^2$$

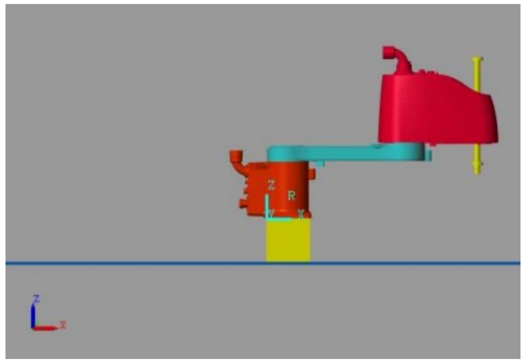


Figure 8: Link 2 Frame

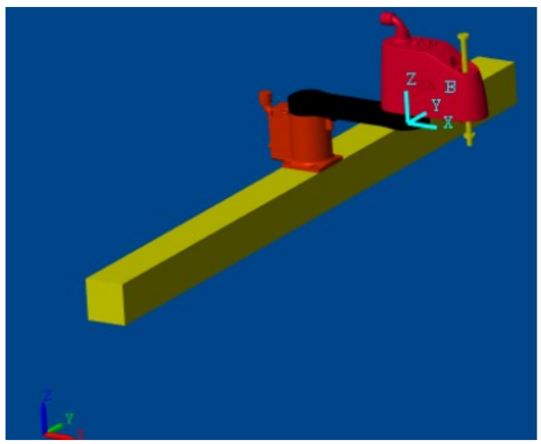


Figure 9: Third Rotational Joint Frame

$$mass_{link2} = 0.85kg$$

$$CoM_{link2} = \begin{pmatrix} 0.45 & 0.1 & 0.3 \end{pmatrix} m$$

$$I_{link2} = \begin{pmatrix} 6000 & -0.3 & 1300 \\ -0.3 & 15000 & -0.3 \\ 1300 & -0.3 & 12000 \end{pmatrix} \times 10^{-6} kg.m^2$$

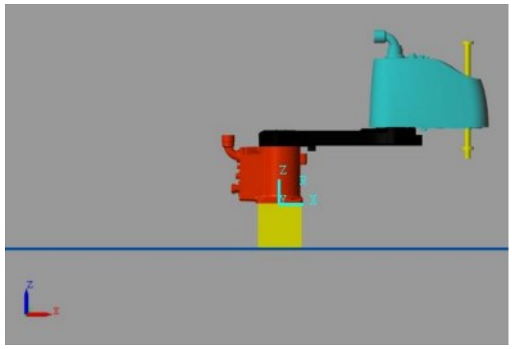


Figure 10: Link 3 Frame

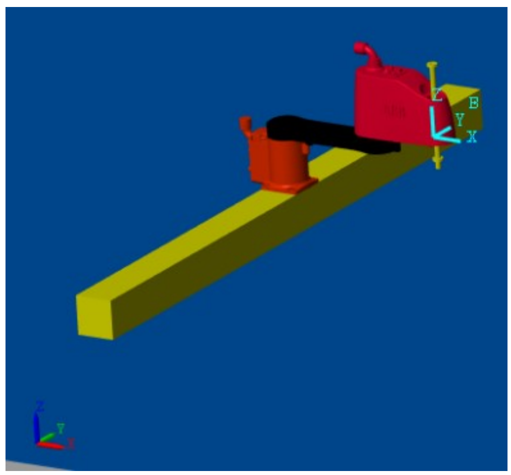


Figure 11: Fourth Prismatic Joint Frame

$$mass_{link2} = 0.15kg$$

$$CoM_{link2} = \begin{pmatrix} 0.65 & 0.02 & 0.4 \end{pmatrix} m$$

$$I_{link2} = \begin{pmatrix} 3000 & 0.07 & 0.04 \\ 0.07 & 3000 & 0.1 \\ 0.04 & 0.1 & 20 \end{pmatrix} \times 10^{-6} kg.m^2$$

Note: In the given pictures from joints, the frames shown are not necessarily the DH frames. The goal in these pictures was to show the z axis in the joint.

Note:

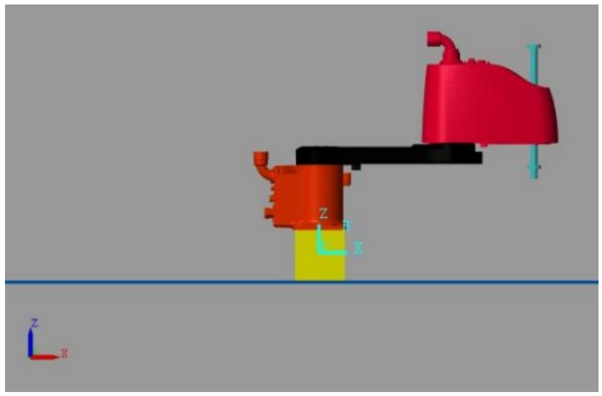


Figure 12: Link 4 Frame

$$\boldsymbol{Link_0} \xrightarrow{+\begin{bmatrix} 0 \\ 0 \\ 73.5mm \end{bmatrix} \text{ then } Rot_x(-90^\circ)} \boldsymbol{Joint_1} \xrightarrow{Rot_x(90^\circ) \text{ then } +\begin{bmatrix} -200mm \\ 0 \\ 0 \end{bmatrix}} \boldsymbol{Link_1}$$

$$\xrightarrow{+\begin{bmatrix} 200mm \\ 80mm \\ 78mm \end{bmatrix}} \boldsymbol{Joint_2} \xrightarrow{+\begin{bmatrix} -73mm \\ -83mm \\ -79mm \end{bmatrix}} \boldsymbol{Link_2} \xrightarrow{+\begin{bmatrix} 470mm \\ 90mm \\ 200mm \end{bmatrix}} \boldsymbol{Joint_3} \xrightarrow{+\begin{bmatrix} -400mm \\ -90mm \\ -200mm \end{bmatrix}} \boldsymbol{Link_3}$$

$$\xrightarrow{+\begin{bmatrix} 650mm \\ 70mm \\ 280mm \end{bmatrix}} \boldsymbol{Joint_4} \xrightarrow{+\begin{bmatrix} -650mm \\ 0 \\ -345mm \end{bmatrix}} \boldsymbol{Link_4}$$

Homework Guidelines and Instructions

- The deadline for sending this exercise will be until the end of May 12th.
- This time cannot be extended and you can use time grace if needed.
- This exercise is done by one person.
- If any similarity is observed in the work report or implementation codes, this will be considered as fraud for the parties.
- Using ready-made codes without mentioning the source and without changing them will constitute cheating and your practice score will be considered zero.
- If you do not follow the format of the work report, you will not be awarded the grade of the report.
- Handwritten exercise delivery is not acceptable.
- All pictures and tables used in the work report must have captions and numbers.
- A large part of your grade is related to the work report and problem solving process.
- Please upload the report, code file and other required attachments in the following format in the system: `HW1_[Lastname]_[StudentNumber].zip`
  For example, the: `HW1_Ezati_12345678.zip`
- If you have questions or doubts, you can contact the assistants through the following e-mail with the subject MP2_Mechatronics. Stay in touch educationally:
  - `SinaKazemi@ut.ac.ir` (Sina Kazemi)
  - `PNamazian@ut.ac.ir` (Parsa Namazian)
- Be happy and healthy