QArm Lab Procedure
Workspace Identification

Setup

1. It is recommended that you run this lab individually.
2. Launch MATLAB and browse to the working directory for Lab 2 – Workspace Identification.

Forward Kinematics

1. Open the ForwardKinematics.slx model via MATLAB. This will be used to implement and validate your forward kinematics formulation. The '<u>Task Space</u>' section will display the position and the orientation matrix of the end-effector frame with respect to the base frame corresponding to the static joint configurations described in the '<u>Joint Space</u>' section, as shown in Figure 1.

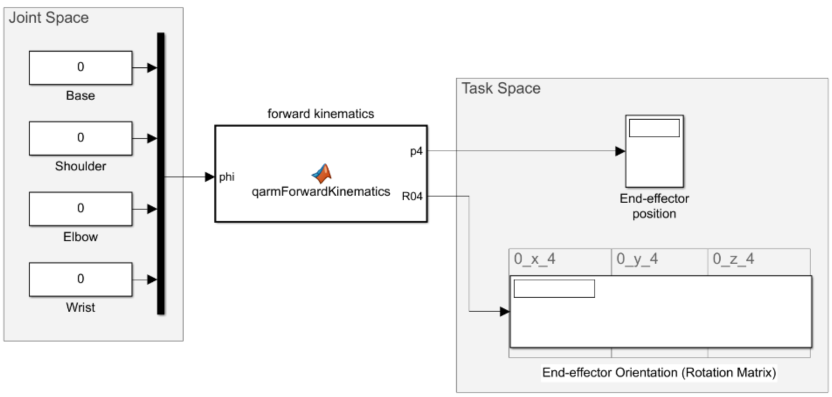

Figure 1: Forward Kinematics Simulink model.

2. Double-click the function labelled ***qarmForwadKinematics***. This MATLAB function is incomplete and must be completed before use.
3. Using the transformations from Table 1.2 in the Workspace Identification Concept Review, complete lines 20-24 and 27-30 in the ***qarmForwardKinematics*** function. Note that $l1$, $l2$ and $l3$ correspond to λ_1, λ_2 and λ_3. Also, change lines 33-37 to correctly convert joint angles from **phi** to **theta**.
4. Complete the DH Table below for the QArm manipulator based on the schematic in Figure 1 from the Workspace Identification Concept Review document.

i	a_i	α_i	d_i	θ_i
1				
2				
3				
4				

5. Use the DH table from step 4 to complete lines 42 to 45 in the ***qarmForwardKinematics*** function. Note that the ***quanser_arm_DH*** function call is described in line 41. Lastly, leave the theta parameter in lines 42 to 45 as $theta(i)$ where i corresponds to the correct index 1 to 4.
6. Before you proceed, you must complete the ***quanser_arm_DH*** function. You can find the function definition within ***qarmForwardKinematics*** at line 61. This function calculates and returns the

homogenous transform ${}^{i-1}T_i$ given the DH parameters a_i, α_i, d_i and θ_i as input parameters. Complete the correct definitions for $\mathrm{T\_R\_z}$, $\mathrm{T\_T\_z}$, $\mathrm{T\_T\_x}$, and $\mathrm{T\_R\_x}$ in terms of the inputs a, $alpha$, d and $theta$. Lastly, multiply the four individual transformations in the correct order to find the return transform T.

7. Now that you have completed ***quanser_arm_DH***, lines 42 to 45 will be functional. Complete lines 47, 48 and 49 to correctly calculate $\mathrm{T02}$, $\mathrm{T03}$ and $\mathrm{T04}$ in terms of $\mathrm{T01}$, $\mathrm{T12}$, $\mathrm{T23}$ and $\mathrm{T34}$. Note that TAB in MATLAB code corresponds to ${}^{A}T_{B}$.

8. Lastly, complete lines 54 and 57 to extract the correct elements of the $\mathrm{T04}$ transform.

9. Close ***qarmForwardKinematics***. Press the Run button to run your model. With the <u>Joint Space</u> set to $[0 \quad 0 \quad 0 \quad 0]^T$, the end-effector position and orientation in the <u>Task Space</u> section should display the following

$$p_4 = \begin{bmatrix} 0.45 \\ 0 \\ 0.49 \end{bmatrix}, \qquad {}^{0}R_4 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -1 & 0 \\ 1 & 0 & 0 \end{bmatrix} \tag{1}$$

Verify the position parameters from the schematic 1 in the Workspace Identification Concept Review.

Workspace Identification

1. Copy the ***qarmForwardKinematics*** function that you have completed. Ensure that you keep a copy of your files for future use. Close ForwardKinematics.slx and open WorkspaceIdentification.slx. Replace the ***qarmForwardKinematics*** function with the completed version.

2. With the QArm in the <u>rest</u> position, turn the power ON using the switch at the rear end of the platform. It should hold its position. Prior to running the model, open the model's Configuration Parameters and verify that they are configured as follows:

   a. Solver type: Fixed-step

   b. Solver: ode4 (Runge-Kutta)

   c. Fixed-step size (fundamental sample time): 500 Hz.

3. Ensure that the area around the manipulator is clear of any obstacles. Stay well outside the reach of the manipulator. Build and deploy the model using the Monitor & Tune action. Once started, the manipulator should remain at rest.

4. Hold the manipulator by hand and move it so as to capture workspace characteristics, such as extremes, joint limits, collision points, etc.

   Note: The arm is set to a PWM mode with 0 command. Although the back-emf in the actuators should provide resistance to motion, this dampens the response of the arm to your manipulation, making it safe to interact with the manipulator.

5. Move the manipulator back to the rest position and stop the model.

6. In MATLAB, right-click visualize_data.m and click run, which will spawn two plots.

   The first plot (Figure 1: QArm Workspace) provides a 3D plot of the end-effector trajectory. It draws the end-effector trajectory of the manipulator in 3D to help you visualize the end-effector motion and its extremes. Rotate the 3D plot using the tool at the top right of the plot. Take note of the workspace limits, and take screenshots of the X vs Y, Y vs Z, and X vs Z planes.

The second plot (Figure 2: End-effector Trajectory) displays the <u>Task Space</u> trajectories that the end-effector went through. Find the maximum x, y, and z ranges of the manipulator's end-effector. Take note of these extremes.

7. Do your figures match the provided workspace boundaries in the Workspace Identification Concept Review.

8. In the MATLAB Workspace, select the variables t, x, y, and z. Right-click and then select 'Save As…'. Save the data as **myData.mat** for future use.

9. Close all models

10. Turn OFF the power to the manipulator using the switch in the rear end of the base. Ensure that the manipulator is in the rest position.