QArm Lab Procedure
Singularity Identification

Setup

1. Launch Quanser Interactive Labs and load the QArm Workspace.
2. Launch MATLAB and browse to the working directory for Lab 7 – Singularity Identification.

Geometric Approach

In this approach you will place the manipulator in a series of singularity positions. For each position, the goal is to verify whether the singularity conditions described in the Concept Review holds true.

1. Open the Simulink model SingularityIdentification.slx (Figure 1).

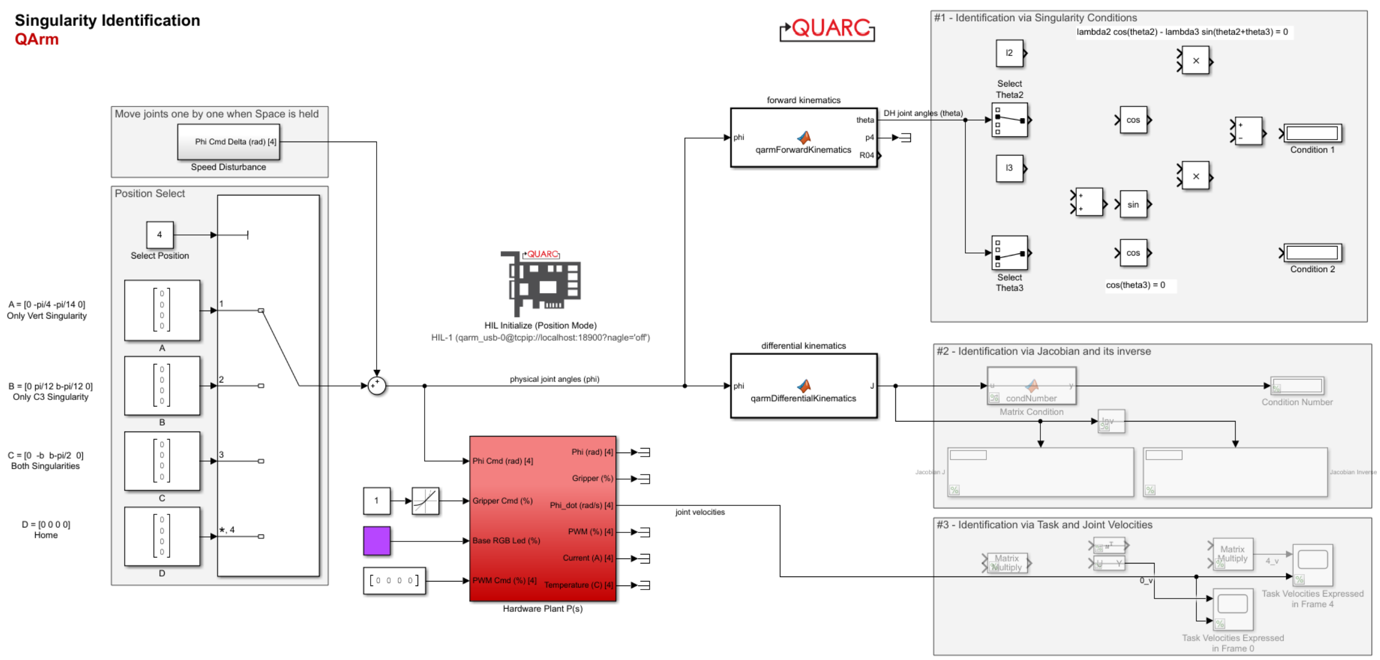

Figure 1 - Simulink model to explore the singularities of the QArm

2. Replace the forward kinematic and differential kinematic MATLAB function in the Simulink model with the same function that you developed in the previous labs.
3. Ensure the sections labeled #2 - Identification via Jacobian and its inverse and #3 - Identification via Task and Joint Velocities in the Simulink model are commented out as shown in Figure 2.1.
4. Using Equations 3 and 6 from the Concept Review, complete the section labeled #1 - Identification via Singularity Conditions in the Simulink model. Note that the constants l2 (λ_2) and l3 (λ_3) have already been defined for you and you can use these directly.
5. Run the model using the green Play button under the Simulation Tab of your model.
6. Set Select Position to 4. This will move the manipulator to the home position.

7. In the section labelled Position Select enter the suggested values given for vectors A, B, and C. Note that the constant beta (β) has also been defined for you and you can use these directly.

8. Set Select Position to 1. This will place the end-effector directly above the base without the manipulator being fully stretched out. If your earlier implementation of Equations 3 and 6 were correct you should observe a value close to zero shown in the display labelled Condition 1 and a non-zero value in the display labelled Condition 2. Otherwise, re-examine your Simulink code.

9. Set Select Position to 2 to fully stretch out the manipulator without the end-effector directly being above the base (the shoulder angle can be any value not close to 0). If your implementation of the Singularity Conditions 1 and 2 were correct, the display labelled Condition 2 should show a value close to 0 and Condition 1 should be non-zero.

10. Set Select Position to 3 to place the end-effector above the base with the arm fully stretched out. Verify that in this case, the values shown in Condition 1 and Condition 2 both show values close to 0 for the corresponding singular conditions.

11. Stop the model.

Mathematical Approach

In this approach you will examine the Jacobian and its invertibility to identify any joint configurations which will result in a singularity.

1. Uncomment the section labelled #2 - Identification via Jacobian and its inverse.

2. Run the model using the green Play button under the Simulation Tab of your model.

3. Set Select Position to 1. This will place the end-effector directly above the base without the manipulator being fully stretched out.

4. While the manipulator is in this position, examine the values and record the approximate values shown in the displays labelled Jacobian J, Jacobian Inverse, and Condition Number. Take notes on the column vectors that make up the Jacobian. Does the condition number relate to any element of the Jacobian's inverse?

5. Repeat the previous step for the remaining two positions (i.e. positions B and C). Make a note of your findings.

6. Stop the model.

Visual Approach

In this approach you will place the manipulator in a series of singularity positions. For each position, the goal is to observe if the end-effector loses movement along any of the task space X, Y, and Z axes when the manipulator's joints are actuated.

1. Uncomment the section labeled #3 - Identification via Task and Joint Velocities in the Simulink model.

2. Complete the section such that the scopes labelled Task Velocities Expressed in Frame 0 and Task Velocities Expressed in Frame 4 display the X, Y, Z components of the end-effector's velocity vector expressed in Frame 0 and Frame 4, respectively. *Hint: you can* use the rotation matrix *R04* to change the expression of a vector from frame 4 to frame 0, and the inverse of a rotation matrix is its transpose.

3. Run the model using the green Play button  under the Simulation Tab of your model.

4. Set Select Position to 1. This will place the end-effector directly above the base without the manipulator being fully stretched out.

5. Open the scopes labelled Task Velocities Expressed in Frame 0 and Task Velocities Expressed in Frame 4. With the arm in position A and with your cursor focus not actively in a Simulink scope or diagram (click anywhere else first), press and hold the space key on your keyboard to apply small velocity disturbances to joints 1, 2, 3, and 4 in succession. The scopes will display the applied velocity disturbances, as well as the X, Y, Z components of the end-effector's velocity when expressed in frames 0 and 4. Sample result shown in Figure 2.1 indicates that when all four of the joints have been actuated, the end-effector only moves along the X (red) and Z (green) axes when expressed in frame 0. In other words, movement along the Y axis is lost. Use Table 1, to record your results.

6. Repeat the previous step for the remaining two positions, i.e. setting Select Position to 2 and 3. Record your results in Table 1.

7. Stop the model.

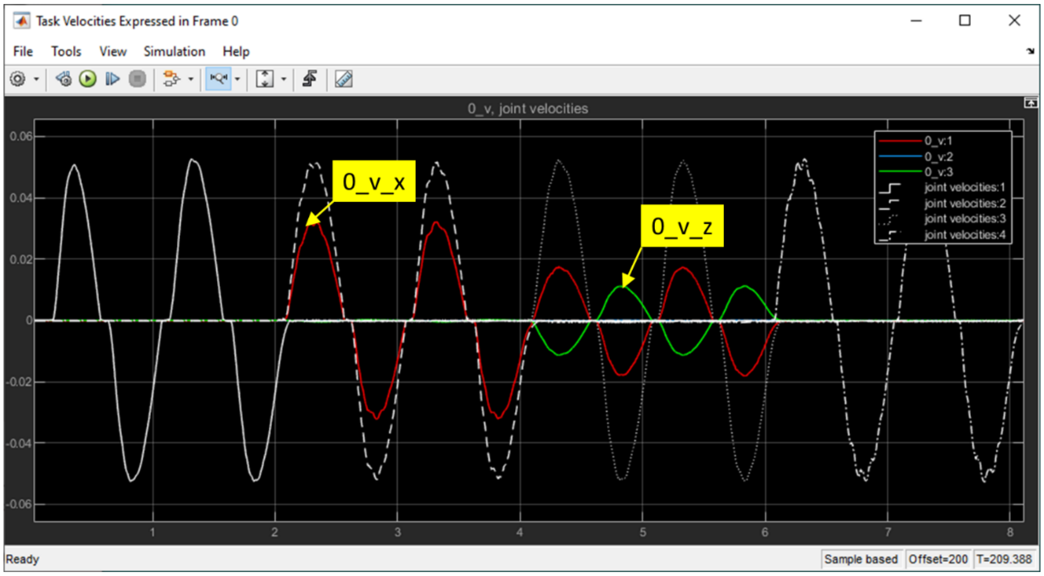

Figure 2 - Sample result for position A showing loss of velocity along the Y axis when expressed in frame 0

	Lost velocity components	
	Frame 0	Frame 4
Position A	0_v_y	
Position B		
Position C		
Position D		

Table 1 - Recorded loss of movement along X, Y, Z axes expressed in frames 0 and 4