Experiment Procedure
Robot Modelling, Identification, and Control

ICR - Implementation of an Impedance Controller for a 2-link robot arm

June 18, 2024

⚠ **IMPORTANT:** It is essential that you carry out the following steps before starting the experiment!

1.) Select "`Fixed-Step`" as the solver for your Simulink model with a variable Sample Time $T_s = 0.001$. You will select this later depending on the task. You can set this under "`Model Configuration Parameters`" in the upper bar.

2.) Avoid hardcoded values, i.e. only use variables within Simulink and define them outside in a central script which is called by the simulation via callback[1].

3.) Deactivate the check mark at "`Limit data points to...`" in Scopes in order not to lose any data points during longer simulation times.

4.) If you need to compare two systems, the easiest way is to copy the original system and make the changes to the copy. So you always have both versions available.

5.) For "`To Workspace`" blocks, select "`Array`" as the storage format, since they are the easiest to handle.

6.) If the function of a command is not clear, use MATLAB Help.

7.) Use the "`clear`" command in your main script to clean up your workspace before performing a task and avoid errors due to old data.

⚠ **IMPORTANT:** In Moodle you are provided with the MATLAB and Simulink files that you will need for the experiment. **Items marked with a ★ must be included in your experiment report**.

Experiment procedure

The goal of this experiment is for you to have an overview of how to implement an impedance controller and observe its performance. In all the tasks you are asked to discuss your observations, use figures to aid your answers.

T1 (**1p**) Implement gravity compensation for the given 2-link robot arm. Then add an external torque of [0.5 3.0] Nm (Step-Block) for 0.2 s to the robot arm (note that $\phi_{1,2_0} = 0$ rad).
★ **Observe how the angles behave and explain the behavior in your report.**

T2 (**6p**) Make three copies of the given arm so that you have three parallel systems in one model. In the following each system has to be controlled with an individual controller to the desired angles $\phi_{1_d} = 0.25$ rad, $\phi_{2_d} = 0.4$ rad (note that $\phi_{1,2_0} = 0$ rad). Try to reduce overshoots and oscillations as much as possible.
⚠ **IMPORTANT:** In this task we will deal with control on joint level only!

a) For the first system, implement an impedance control of form $F = K\Delta q$. In addition , make sure that the friction in the robot arm model is set to zero.
★ **Apply different values for the stiffness (same for both joints) and note your observations. Does enabling/disabling gravity compensation stabilize the system behavior?**

b) Control the second system with impedance control of form $F = K\Delta q$ and enabled friction in the robot arm, but without gravity compensation.
★ **How does the system behave? Include your observations in the report.**

c) Control the third system with enabled friction, impedance control of form $F = K\Delta q$ and gravity compensation. Improve the impedance control law to $F = K\Delta q + D\Delta\dot{q}$ with $\dot{q} = 0$.
★ **Find appropriate values for D and note your observations in the report.**

★ **Compare the different systems and explain the consequences/improvements in system behavior for the implementations and try to reason/explain why this might be.**

T3 (**6p**) Now the arm has to be controlled in Cartesian space, the corresponding coordinates are x, y and θ_2, see Fig. 1.

a) Implement the direct kinematics (the mapping of the joint angles to the Cartesian space) for the system, which converts the angles into Cartesian coordinates.

b) Implement the transposed Jacobian matrix, which transfers the forces and torques from Cartesian space back into joint space.
Hint: The Jacobian matrix is defined element by element as $J = \frac{\delta f_i}{\delta x_j}$, where f_i is the function of direct kinematics and x_j is the corresponding angles φ_j.
★ **Include in your report the expression for the Jacobian for the point on the robot that you want to control; in this case, the tip of the second link.**

c) Now implement an explicit Cartesian Impedance control of the form $F = K\Delta x + D\dot{x}$. Choose reasonable values for k_x, k_y, k_φ and the corresponding damping if needed. Try to regulate to this reference point
$\boldsymbol{x}_s = \begin{bmatrix} 0.9 & 0.9 & 1.5708 \end{bmatrix}^T$; in particular, minimize at least two of the errors.
Hint: The output of the Impedance Control are the reference Cartesian forces F_x, F_y and F_ϕ.
★ **What effect does small/high values for these gains have on the degrees of freedom?**
★ **Can you minimize all of the errors at the same time? Explain your observations.**

Parameters

Table 1: Parameters of the robot link

Parameter	Description	Value	Unit
m_1,m_2	Mass of the links	1	Kg
l_1,l_2	Lever arm of the link1/link2	1	m
τ_m	Commanded motor torque (i.e. input to the system)	variable	Nm

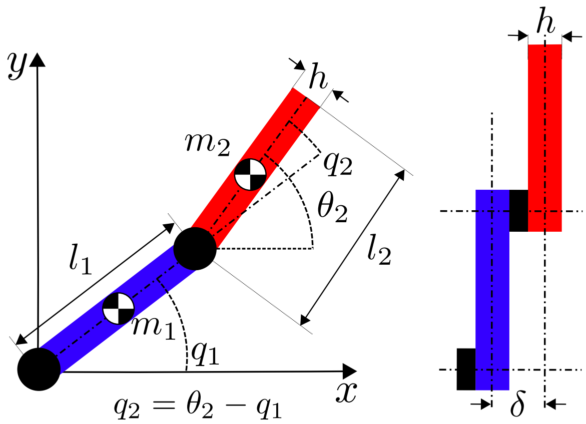

Figure 1: Sketch of the robot link