Control of industrial robots

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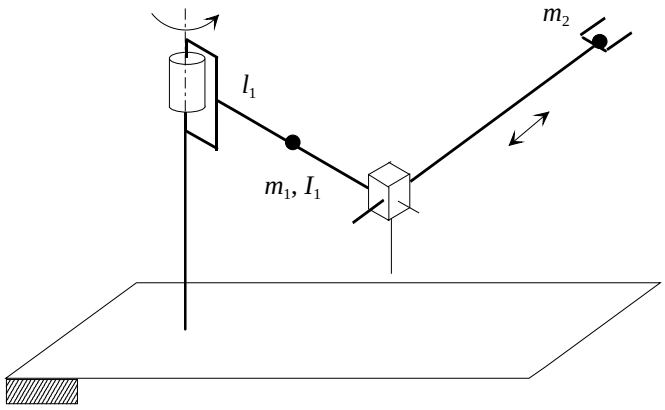
Warnings:

- This file consists of **8** pages (including cover). All the pages should be signed.
- During the exam you are not allowed to exit the room for any other reason than handing your work or withdrawing from the exam.
- You are not allowed to withdraw from the exam during the first 30 minutes.
- During the exam you are not allowed to consult books or any kind of notes.
- You are not allowed to use calculators with graphic display.
- Solutions and answers can be given **either in English or in Italian**.
- Solutions and answers must be given **exclusively in the reserved space**. Only in the case of corrections, or if the space is not sufficient, use the back of the front cover.
- The clarity and the order of the answers will be considered in the evaluation.
- At the end of the test you have to **hand this file only**. Every other sheet you may hand will not be taken into consideration.

Use this page ONLY in case of corrections or if the space reserved for some answers turned out to be insufficient

Exercise 1

Consider the manipulator sketched in the picture, where the mass of the second link is assumed to be concentrated at the end-effector:



1.1 Find the expression of the inertia matrix of the manipulator.

1.2 Write the dynamic model of this manipulator [1] .

1.3 Show that this model is linear with respect to a suitable set of dynamic parameters.

1.4 Assume that you want to identify the numerical values of such dynamic parameters through experiments. Describe an identification procedure and especially write down the formula that returns the estimates of the parameters, given the experimental data.

[1] The general expression of the Christoffel symbols is: $c_{ijk} = \frac{1}{2}\left(\frac{\partial b_{ij}}{\partial q_k} + \frac{\partial b_{ik}}{\partial q_j} - \frac{\partial b_{jk}}{\partial q_i} \right)$

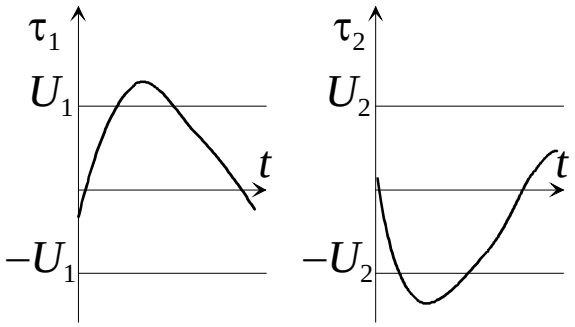
Exercise 2

2.1 Explain what is meant with kinematic scaling of a trajectory and write the general expression of a trajectory in the form (parameterized) which is used in such scaling.

2.2 Write the parametric form of a harmonic trajectory and find the expressions of the maximum velocity and maximum acceleration for such trajectory in terms of the positioning time T and the total displacement h.

2.3 Consider the design of a harmonic trajectory from $q_i = 20$ to $q_f = 60$, with $\dot{q}_{\max} = 10$, $\ddot{q}_{\max} = 20$. Find the minimum positioning time.

2.4 Assume now that for a 2 d.o.f. manipulator without gravitational load, a trajectory has been selected that requires torques at the joints whose profiles are sketched in the picture, where U_1 and U_2 are some torque bounds:



Explain what method can be used to modify the trajectory in such a way that the torques stay within the given bounds.

Exercise 3

3.1 Write the expression of a "PD plus gravity compensation" control law in joint space.

3.2 Write the expression of the Lyapunov function used to prove the stability property of such control scheme and explain why this Lyapunov function is positive definite.

3.3 Compute the derivative of the Lyapunov function along the trajectory of the system, when using the PD plus gravity compensation control law.

3.4 State exactly what is the theoretical result that can be achieved with the PD plus gravity compensation control law. Comment about the robustness of such result.

Exercise 4

Consider an interaction task of a manipulator, with a frictionless and rigid surface, as in this picture:

4.1 Assume a point contact and draw a contact frame directly on the picture. Based on this frame and neglecting angular velocities and moments, express the natural and the artificial constraints for this problem.

4.2 Write the expression of the selection matrix for this problem, explaining the meaning of such matrix.

4.3 Sketch the block diagram of a hybrid force/position control scheme.

4.4 Suppose now that along the force controlled direction an explicit force controller has to be designed. Determine the expression of such controller, taking a bandwidth of 25 rad/s.