Control of Industrial Robots

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july 23, 2024

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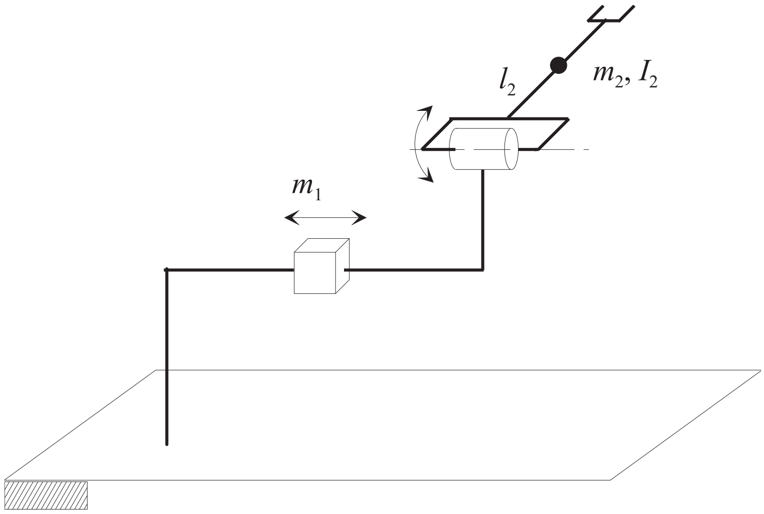
Warnings

- This file consists of **8** pages (including cover).
- 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.

EXERCISE 1

1. Consider the manipulator sketched in the picture:



Find the expression of the inertia matrix $\mathbf{B}(\mathbf{q})$ of the manipulator.

2. Write the complete dynamic model for this manipulator.

3. Consider the adoption of an inverse dynamics controller for this manipulator. Write the expressions of the two control variables.

4. Assume that the inverse dynamics controller assigns the same dynamics in closed loop to both joints of the manipulator. Compute the gains of the controller in such a way that one eigenvalue is in -10 and the other one is in -20.

EXERCISE 2

Consider a kinematically redundant manipulator.

1. Express the solution of the inverse kinematics in the form that includes a closed loop correction (kinematic control) and explain why this correction is used.

2. Write the expression of the dynamics of the error between desired task variables and the task variables computed by the algorithm. What are the requirements on the gain of the algorithm for this dynamics to be asymptotically stable?

3. Consider now the motion of the end effector along a linear path. Assigning to the natural coordinate s a cubic dependence on time, derive the expressions of the maximum speed and the maximum acceleration as functions of the displacement h and the positioning time T.

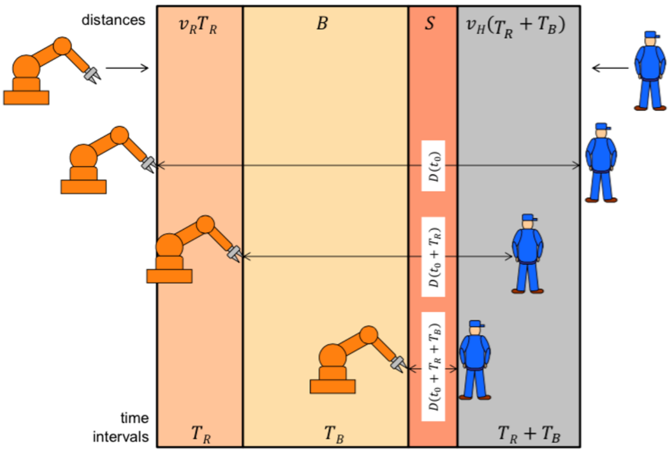
4. Assume that the length of the segment to cover is 0.6 m, the maximum linear velocity of the end effector is $1.2 m/s$ and the maximum linear acceleration $2 m/s^2$. Compute the minimum positioning time, adopting a cubic dependence on time.

EXERCISE 3

1. With reference to collaborative robotics, explain what are the general advantages in the use of cobots for small and medium enterprises.

2. One of the modes of interaction between human and robot allowed by the safety standards is the hand guiding. Explain what is the control system methodology that allows to hand guide an industrial robot. What variables need to be measured in order to implement such method?

3. Making reference to the following picture, write the inequality that has to be satisfied according to the speed and separation monitoring safety standard, explaining the meaning of the symbols used. What is a standard value assumed for the human velocity, in case it is not monitored?



4. Consider now a robot that is compliant with the power and force limiting safety standards. Making reference to the following picture, derive the expression of the maximum value of the relative velocity between robot and human requested by such standard.