Control of Industrial and Mobile Robots

Prof. Rocco, Bascetta

July 8, 2022

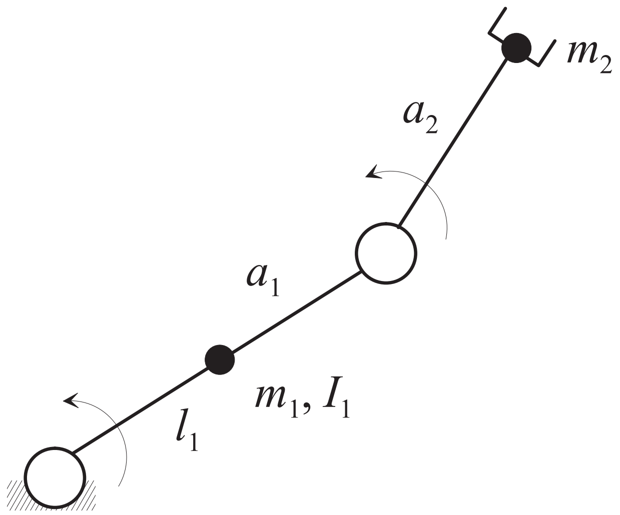
NAME:
UNIVERSITY ID NUMBER:
SIGNATURE: ____________________

Warnings

- This file consists of **10** 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

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



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

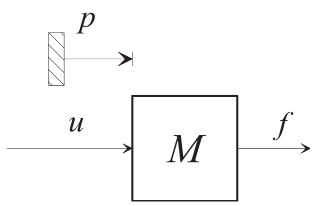
2. Find the expression of the gravitational torques for this specific manipulator.

3. For a generic manipulator, write the expression of the dynamic model in terms of a set of dynamic parameters.

4. Using the expression of the dynamic model in terms of a set of dynamic parameters, explain the process to identify such parameters.

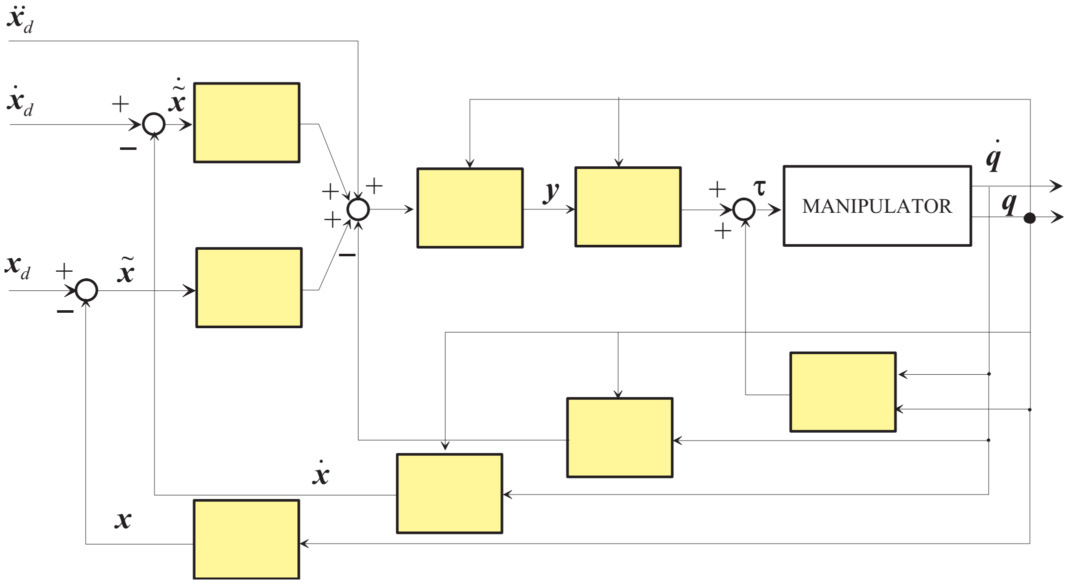
EXERCISE 2

1. Consider a single mass affected by an external force f and a control force u:



   Write the expression of an impedance control law that makes the system react to the external force f like a mass-spring-damper system, with all parameters assignable.

2. In order to extend the previous result to the whole manipulator, the inverse dynamics in operational space is used. A block diagram of the method is sketched in the following picture:



Write the correct expression for each of the empty blocks of the diagram.

3. Explain what is the result that can be ideally obtained with the inverse dynamics in operational space for a manipulator in free motion.

4. Assume now that a system of forces is applied at the end-effector. Explain whether and how the result of the inverse dynamics in operational space previously described changes.

EXERCISE 3

1. Consider tyre ground interaction modelling. Write the equations representing the linear model, the linear saturated model and the Fiala model. Explain all the variables/quantities that are used in these models.

2. Assuming the tyre has been modelled, from experimental data, using the Pacejka Magic Formula

$$F_y = 0.3F_z \sin\left(2 \arctan\left(5\alpha - \left(5\alpha - \arctan\left(5\alpha\right)\right)\right)\right)$$

   where $F_z = 1000\,\mathrm{N}$ and $\mu = 1$.
   Write the linear model, the linear saturated model, and the Fiala model for this tyre.

3. Which of the previous models (linear, linear saturated, Fiala) are suitable for simulation, and which for control system design? Clearly motivate the answer.

4. Write the equation of the friction circle, and explain how it is used in modelling tyre ground interaction.

EXERCISE 4

1. Write the definitions of *small-time local accessibility* and *small-time local controllability*.

2. Write the conditions that must be checked to verify if the kinematic model of a mobile robot is small-time locally accessible or small-time locally controllable.

3. Using an example, provide an intuitive interpretation of all the conditions introduced in the previous step.

4. Show how, applying the conditions introduced in the previous step, one can determine if the canonical simplified model is small-time locally accessible or small-time locally controllable.