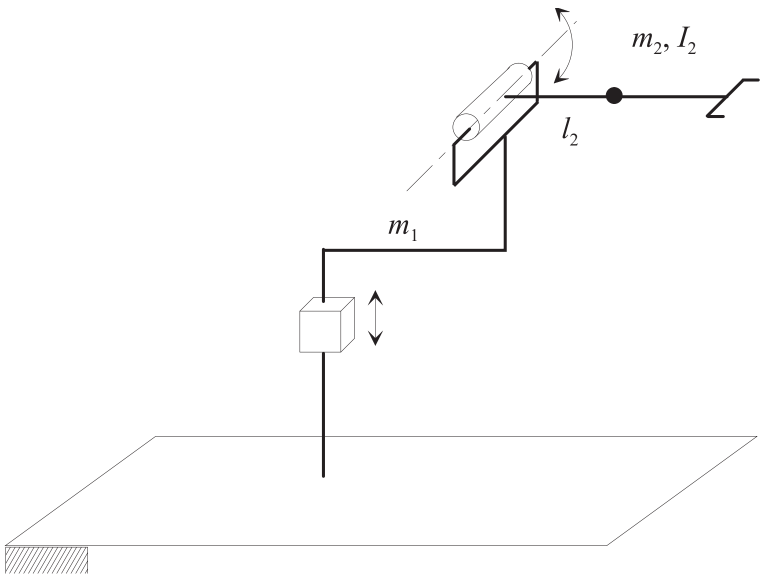
EXERCISE 1

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 expression of the kinetic energy for this specific manipulator.

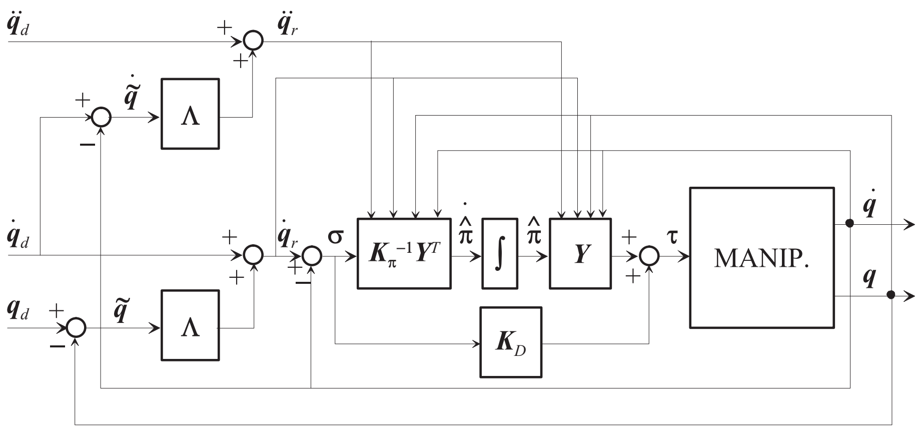
3. Explain what are the direct dynamics and the inverse dynamics for a manipulator.

4. Explain how the Newton-Euler method can be used in order to compute the *direct dynamics* of a manipulator.

EXERCISE 2

1. Explain what we mean with "adaptive" control.

2. Consider now this sketch of an adaptive controller:



Explain what the block denoted with **Y** stands for and what is the property of the dynamic model of the manipulator, related to **Y**, that is exploited in the adaptive control.

3. Explain what is the adaptation rule of the estimates of the parameters in the adaptive controller. Discuss the theoretical result that can be obtained with an adaptive controller.

4. Compare the adaptive controller with a robust one: when is it more appropriate to use one or the other one? Which one is a switching control law? What might be the problem of a switching controller?

EXERCISE 3

1. Consider a wheel rolling without slipping on the horizontal plane, keeping the sagittal plane in the vertical direction. Write the expression of the pure rolling constraint in the case of a fixed and a steerable wheel.

2. Are the previous constraints holonomic or nonholonomic? Motivate the answer using a mathematical proof.

3. Consider a single-track robot with front fixed wheel and rear steerable wheel. Assuming as configuration vector $\mathbf{q} = [x \; y \; \theta \; \phi]^T$, where $(x \; y \; \theta)$ is the robot pose and ϕ the steering angle, write the kinematic model of the robot without explicitly computing a base of Null $\left(A^T(\mathbf{q})\right)$.

EXERCISE 4

1. Consider a unicycle kinematic model. Assuming $z_1 = x$ and $z_2 = y$ as flat outputs, write the expression of the state and input variables as functions of the flat outputs and their derivatives.

2. How can the previous relations (flat representation of the unicycle kinematic model) be used to set up a trajectory tracking controller? Show a block diagram of the control system, including trajectory generation, controller and robot model.
   For each block specify the equations relating the inputs to the outputs. For trajectory generation consider a circle in the xy plane.

3. Illustrate the main pros and cons of the previous control solution with respect to a trajectory tracking controller based on feedback linearization.