UNIVERSITY OF OSLO

Faculty of Mathematics and Natural Sciences

Exam in **INF3480 – Introduction to Robotics**
Day of exam: **10th of June, 2014**
Exam hours: **14:30, 4 hours**
This examination paper consists of 4 page(s).
Appendices: **None**
Permitted materials:

- **Spong, Hutchinson and Vidyasagar, *Robot Modeling and Control*, 2005/2012**
- **Karl Rottman, Matematisk formelsamling (all editions)**
- **Appoved calculator**

Make sure that your copy of this examination paper is complete before answering.

Exercise 1 (20 %)

a) (5 %) Describe briefly how an Evolutionary Algorithms works.

b) (5 %) What is the principal difference between a serial and a parallel manipulators?

c) (5 %) Why is the Laplace transform useful when analyzing robot control systems? One reason is sufficient.

d) (5 %) What is the difference between industrial robots and mobile robots when it comes to proprioceptive and exteroceptive sensors?

Exercise 2 (45 %)

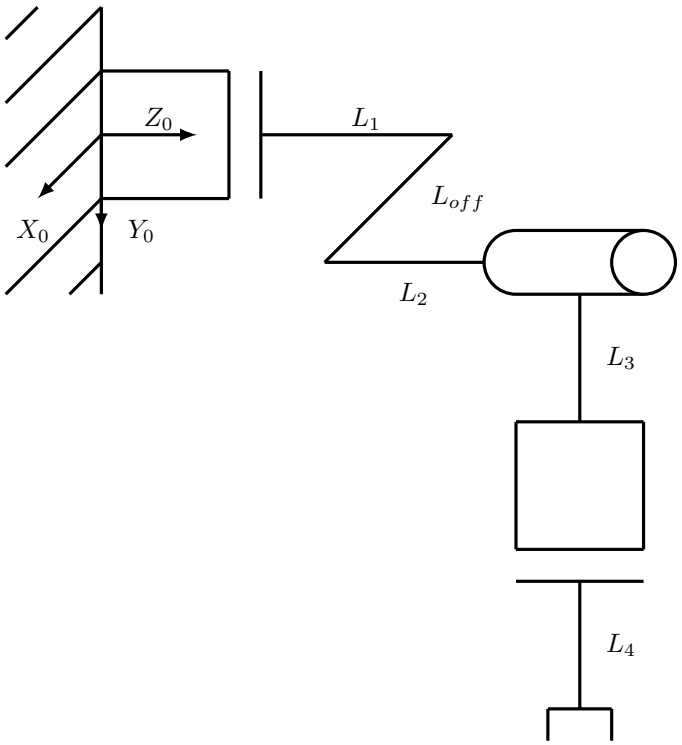

Figure 1:

a) (5 %) Robot manipulators are classified based on their joints. Classify the robot in Figure 1 and sketch the workspace of the robot.

b) (10 %) Assign coordinate frames on the robot in Figure 1 using Denavit-Hartenberg convention. Write the Denavit-Hartenberg parameters in a table.

c) (10 %) Derive the forward kinematics for the robot from the base coordinate system to the tool coordinate system at the tip of the robot.

d) (10 %) Derive the Jacobian for the robot.

e) (10 %) Derive the inverse kinematics for the robot.

Exercise 3 (15 %)

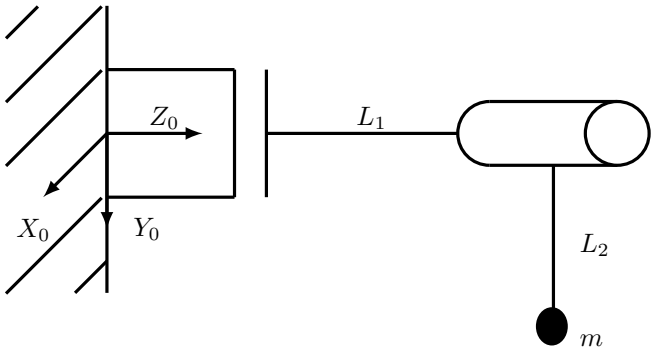

Figure 2:

Figure 2 shows a robot with two degrees of freedom. This is a simplification of the robot in exercise 2. Assume that the only mass is a point mass of m at the tool.

a) (7.5 %) Find the Lagrangian $\mathcal{L}$ of the robotic system in Figure 2.

b) (7.5 %) Derive the dynamic equations for the robot using the Euler-Lagrange formulation. Put the dynamic equation in the following form

$$\boldsymbol{M}(q)\ddot{q} + \boldsymbol{C}(q,\dot{q})\dot{q} + \boldsymbol{G}(q) = \boldsymbol{\tau} \tag{1}$$

Exercise 4 (20 %)

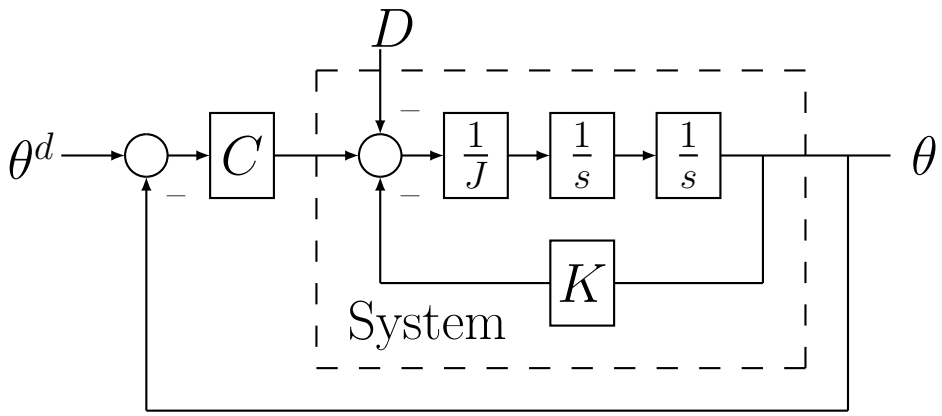

Figure 3:

Figure 3 shows a block diagram for the control of a robot.

a) (5 %) What is the name of the controller used in Figure 3.

b) (5 %) Find the Laplace equation for the robotic system excluding the controller (the system in dashed lines) from the block diagram in Figure 3. Then find the Laplace equation for the robotic system including the controller (the entire block diagram). Transform these two equations into dynamic equations in the time-domain.

c) (5 %) What is the steady-state error if both the disturbance D and the setpoint θ^d are impulse responses ($D = \frac{1}{s}D_c$ and $\theta^d = \frac{1}{s}T$)? Use the final value theorem provided below

$$\lim_{t\to\infty} \theta(t) = \lim_{s\to 0} s\theta(s) \tag{2}$$

d) (5 %) What controller would eliminate the steady-state error? Modify the block diagram to include this controller.