UNIVERSITY OF OSLO

Faculty of Mathematics and Natural Sciences

Exam in	**INF3480 – Introduction to Robotics**
Day of exam:	**11th of June, 2013**
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**
- **Karl Rottman, Matematisk formelsamling (all editions)**
- **Approved calculator**

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

Exercise 1 (20 %)

a) (5 %) What do we mean by singularity in robotics? How can you find the singularities of a given manipulator?

b) (5 %) Describe two main differences between robot manipulators and mobile robots.

c) (5 %) What is the *reality gap* in the context of Evolutionary Robotics?

d) (5 %) What are the three components of a PID-controller? What is the purpose of each of them?

Exercise 2 (50 %)

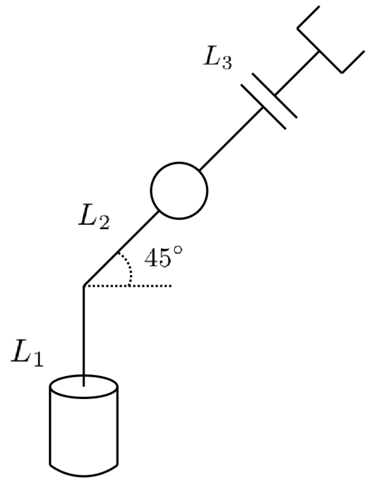

Figure 1:

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

b) (5 %) Derive the forward kinematics for the robot from the base coordinate system to the tool coordinate system at the tip of the robot.

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

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

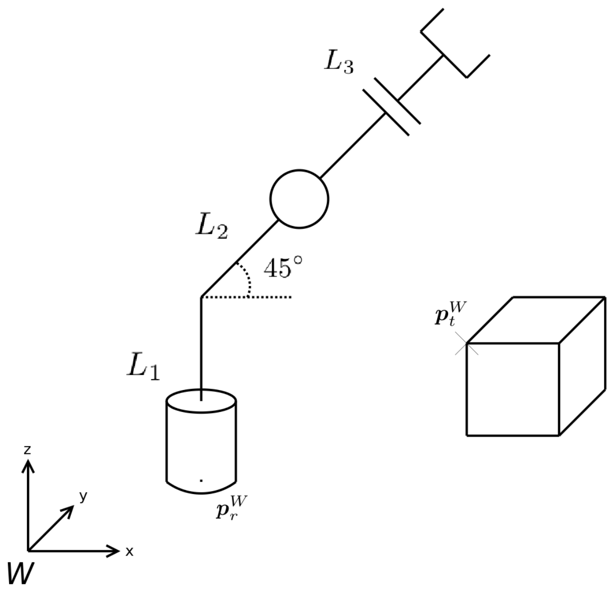

Figure 2:

A painting tool is attached to the robot. The environment where the robot should work is shown in Figure 2.

e) (7.5 %) The robot should start to paint an target object at point $\boldsymbol{p}_t^W$ in space (t for target). This point is in the World coordinate frame W. The robot is located at $\boldsymbol{p}_r^W$ (r for robot). Find the joint configuration that puts the tool tip at $\boldsymbol{p}_t^W$. Use the following values

$$L_1 = 30 \text{ cm} \qquad \boldsymbol{p}_r^W = [10, 15, 0] \text{ cm} \tag{1}$$
$$L_2 = 15 \text{ cm} \qquad \boldsymbol{p}_t^W = [60, 40, 20] \text{ cm} \tag{2}$$
$$L_3 = 10 \text{ cm} + q_3 \tag{3}$$
$$\tag{4}$$

f) (7.5 %) In which direction(s) in the tool frame is it impossible for the robot to exert force/torque if $\theta_1 = 0$? Use the relation $\boldsymbol{\tau} = \boldsymbol{J}^T \boldsymbol{F}$

Exercise 3 (30 %)

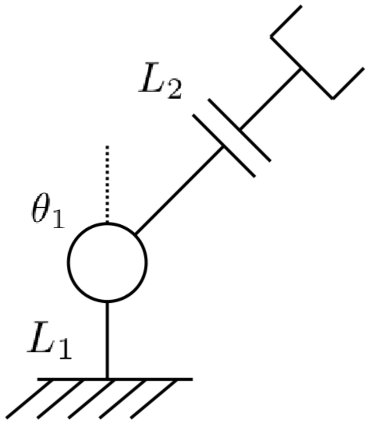

Figure 3:

Figure 3 shows a robot with two degrees of freedom. This 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 3.

b) (7.5 %) Derive the dynamic equations for the robot using the Euler-Lagrange formulation.

For the rest of the exercise we assume that L_2 is fixed and approximate $\sin\theta_1$ to θ_1 to get the dynamic equation on the following form

$$J\ddot{\theta} + b\dot{\theta} + k\theta = \tau$$

c) (7.5 %) Find the J, b and k and then transform the dynamic equation into the Laplace domain.

d) (7.5 %) Draw a closed-loop block diagram of the system using a PI-controller that has the desired angle θ_d as a setpoint.