UNIVERSITY OF OSLO

Faculty of Mathematics and Natural Sciences

Exam in **INF3480 – Introduction to Robotics**
Day of exam: **11. June, 2012**
Exam hours: **14:30, 4 hours**

This examination paper consists of 4 page(s).
Appendices: **None**

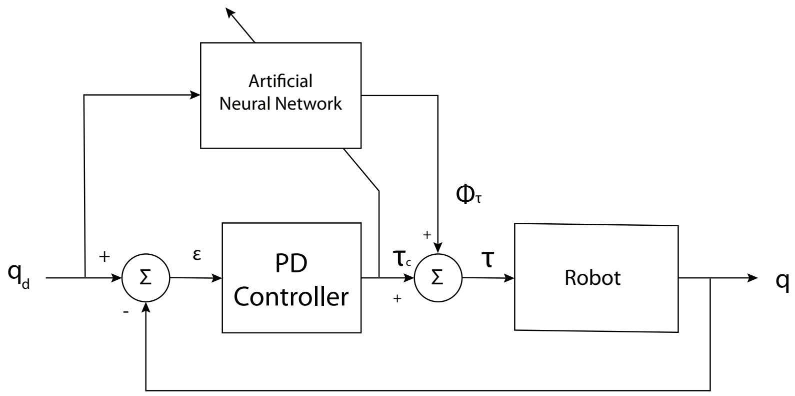
Permitted materials:

- **Spong, Hutchinson og Vidyasagar: Robot Modeling and Control, 2005.**
- **Karl Rottman: Matematisk Formelsamling (all editions) (collection of formulas)**
- **Approved calculator**

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

Exercise 1 (10 %)

a) What would be the reason for using an artificial neural network in a control loop like in the figure below?

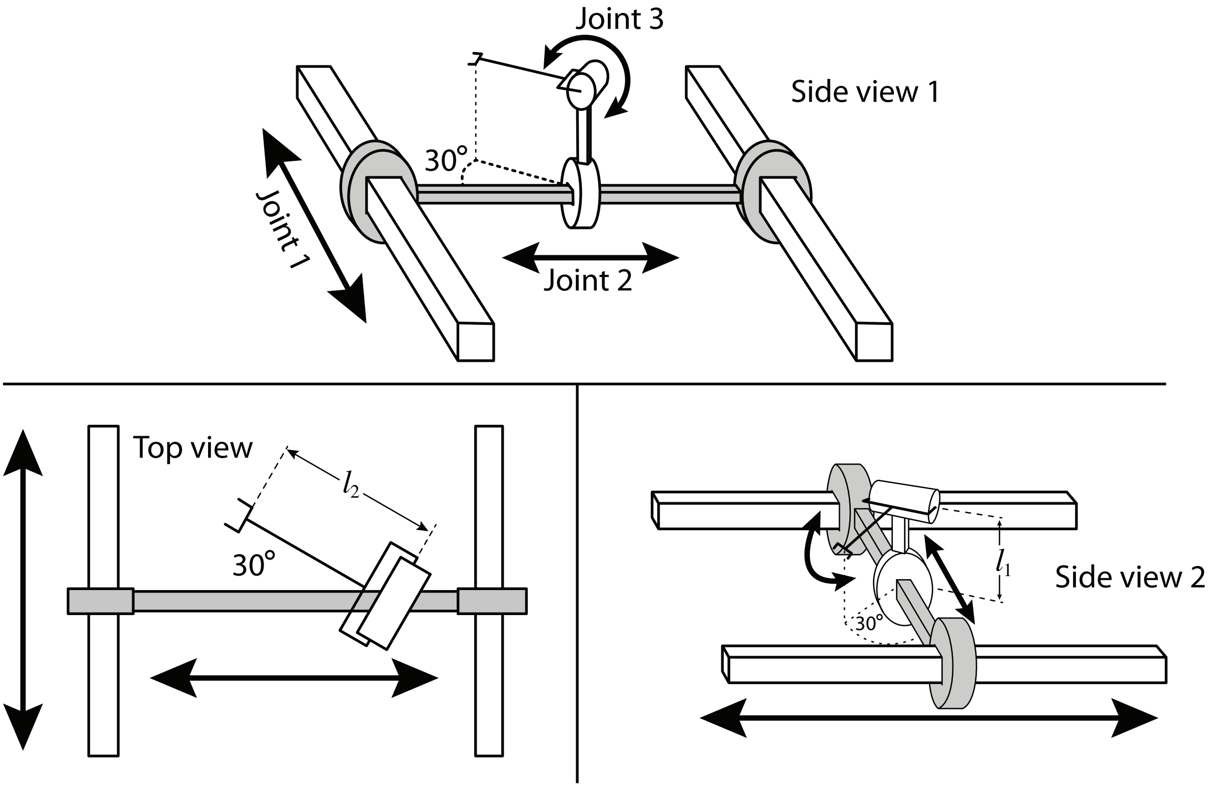


b) Which challenges do we face when working with mobile robots compared with stationary robot manipulators?

c) For what purposes would we want to use software like Robot Studio?

d) What is meant by a semiautonomous manipulator?
And what makes semiautonomous manipulators well suited for surgical applications?

Exercise 2 (60 %)



The robot above consists of three joints. The first and second joints are horizontal prismatic joints that are perpendicular to each other. The third joint is rotational, with a horizontal rotation axis. The rotation axis of joint 3 is located a distance l_1 above the axis of joint 2. The rotation axis of joint 3 is rotated by 30 degrees compared to the axis of joint 1. The tool is located a distance l_2 from the rotation axis of joint 3.

a) (5%) The joints on the robot are called Prismatic (P) and Rotaional (R) joints.

- Classify this robot using the P and R labels.
- Sketch the workspace of the robot

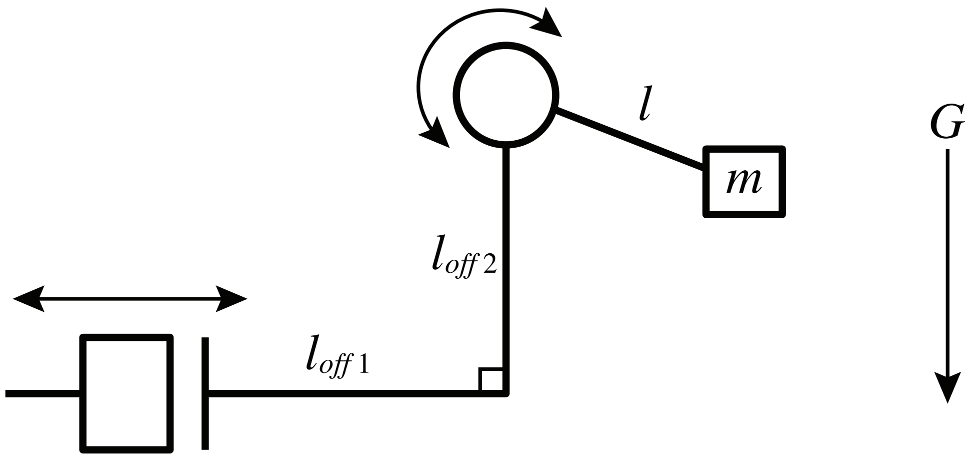
b) (15%) Use the Denavit-Hartenberg and place coordinate frames on the robot. Make a table with the Denavit-Hartenberg parameters.

c) (10%) Derive the forward kinematics for the robot

d) (15%) Derive the velocity kinematics (Jacobian) for the robot

e) (15%) Derive the inverse kinematics for the robot

Exercise 3 (30 %)



The robot above consists of a horizontal prismatic joint, followed by a horizontal offset l_{off1}, a vertical offset l_{off2}, a rotational joint, with horizontal rotation axis, perpendicular to the axis of joint 1 and to the offset. A mass m is located with centre of gravity at a length l from joint 2.

a) Derive the dynamics for the robot using the Euler-Lagrange formulation.

The dynamics of the robot contains a set of equations of motion.

b) Show how the equations of motion can be expressed in a matrix form like this:

$$\tau = D(q)\ddot{q} + C(q, \dot{q})\dot{q} + g(q)$$

In other words: Put content to the vectors and matrices D, C, and g.

For exercise 3c and 3d, ignore the translation joint, and look only at the rotational joint of the robot. The open-loop equation of motion for this robot is of the form:

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

where θ is the rotational variable. J is the moment of inertia about the axis of rotation.

c) Derive the Laplace transform of the equation of motion for this new 1DOF system, and make a closed-loop block diagram of the system with a PD controller.

d) Use the *final value theorem* to derive the steady state error e_{ss}. The tracking error is given by

$$E(s) = \Theta^d(s) - \Theta(s)$$

What would you do to remove the steady state error?