UNIVERSITY OF OSLO

Faculty of Mathematics and Natural Sciences

Exam in INF3480 – Introduction to Robotics
Day of exam: May 31st 2010
Exam hours: 3 hours
This examination paper consists of 5 page(s).
Appendices: none
Permitted materials:

- Mark W. Spong, Seth Hutchinson, M. Vidyasagar: Robot Modeling and Control
- K. Rottmann: "Matematisk formelsamling" (all editions)
- Approved calculator

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

You may submit your exam in either Norwegian or English.

1 (weight 15%)

a) Briefly explain the basics of a closed loop system with PID control. Sketch a diagram of a closed loop, and briefly explain the meaning of P, I and D (explain using words).

b) Briefly explain the concepts of how a genetic algorithm works. How can this be applied in a robot?

c) The DaVinci Teleoperation system for robotic surgery has a major lack. What is it and how can this be solved?

d) Name a few sensors or other input devices that are commonly used in mobile robots. Why are they needed?

2 (weight 30%)

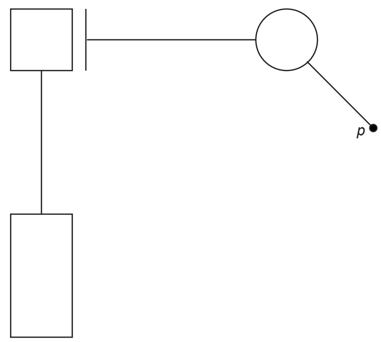

Figure 1: exercise 2

Figure 1 shows a three-link robot with link lengths L_1, L_2 and L_3. The first joint is revolute and rotates along the vertical axis. The second joint is prismatic and works perpendicularly to the rotation axis of joint 1. The third joint is revolute and rotates along the horizontal axis that is perpendicular to the working axis of joint 2 (as shown in the figure). The end effector is located at point p at the end of link 3.

a) Draw a sketch of the robot with attached coordinate frames according to the Denavit Hartenberg convention.

b) Define the table of Denavit Hartenberg parameters

c) Derive the forward kinematics of the robot

d) Derive the inverse position kinematics of the robot

e) Define the Jacobian of the manipulator and find the singular configurations

3 (weight 20%)

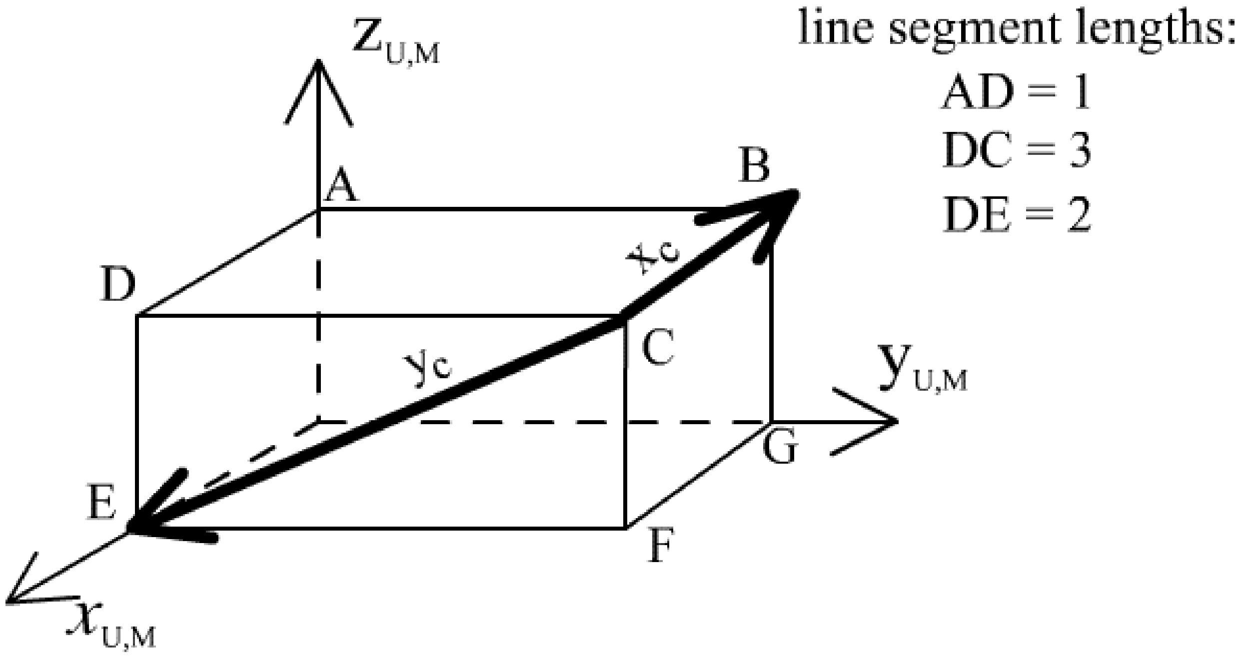

Figure 2: exercise 3

Frames M and C are attached rigidly to a cuboid as shown in Figure 2. Frame U is fixed and serves as the universe frame of reference. The cube undergoes the following motions (i) in the indicated sequence:

1. Rotation about the z axis of Frame C by 30^o, then
2. Translation by a vector (1,2,3) along Frame C, then
3. Rotation about the x axis of Frame M by 45^o, and then
4. Rotation about the y axis of Frame U by 60^o.

Let $T_{C_i}^U$ and $T_{M_i}^U$ be the 4×4 homogeneous transformation matrices that describe the position and orientation of Frames C and M, respectively, in U after motion i.

Show the equations of the successive transformations needed to find the following transformation matrices (do not perform the matrix multiplications):

a) $T_{C_1}^U$ b) $T_{C_2}^U$ c) $T_{C_3}^U$ d) $T_{C_4}^U$ e) $T_{M_4}^U$

4 (weight 15%)

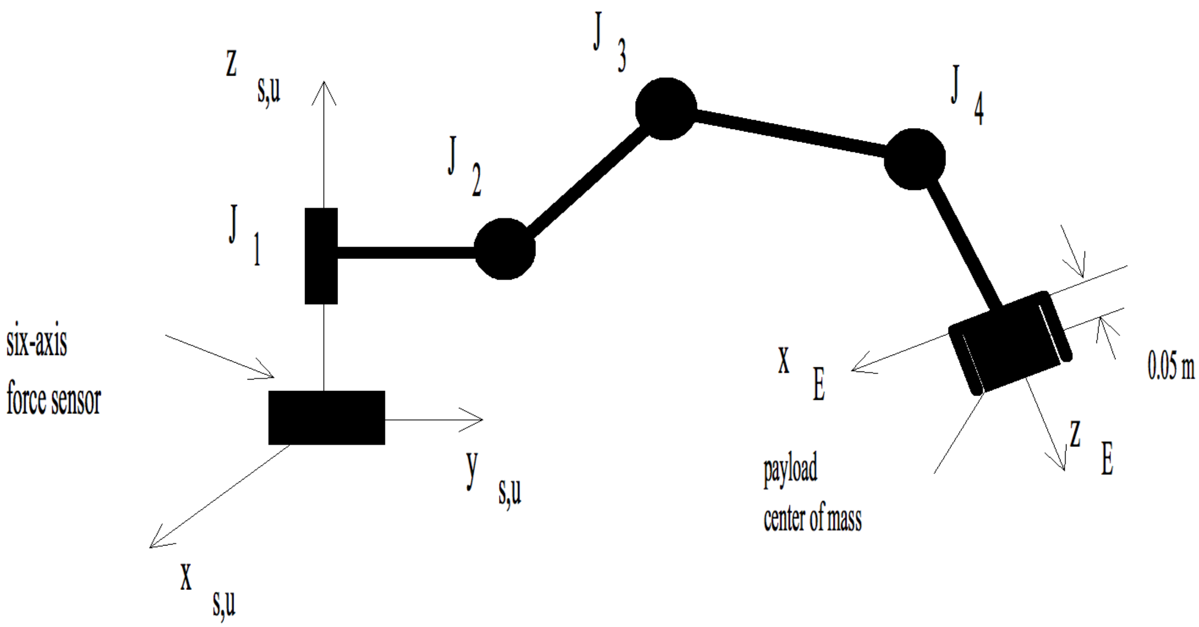

Figure 3: exercise 4

Figure 3 shows a 4-axis robot with all rotational joints. The first joint rotates about a vertical axis while the next three joints rotate about horizontal axes parallel to the xy plane of Frame U. Frame E is attached to the robot end-effector. A six axis force-torque sensor provides 3 force and 3 torque readings along and about the x, y, and z axes of the sensor frame S. Frame S is coincident to the fixed frame of reference U. At the following stationary configuration (does not correspond to the configuration in the figure):

$$T_E^U = \begin{pmatrix} R_E^U & p_E^U \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} 0.5 & 0 & 0 & 10 \\ 0.612 & 0.436 & -0.660 & 5 \\ -0.61 & 0.789 & -0.047 & 4 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

the robot end-effector is carrying a cubic ($0.1m$ cube) payload of $20kg$. Assume that the robot links are weightless. The gravitational force is pointing downward along the negative z axis direction of Frame U. The end-effector frame is at the base of the gripper. The center of mass of the payload is at its center and lies on the z axis located at $0.05m$ in positive z direction of the end-effector. The acceleration due to gravity is $9.8m/s^2$.

Calculate the six readings of the six-axis force-torque sensor.

5 (weight 20%)

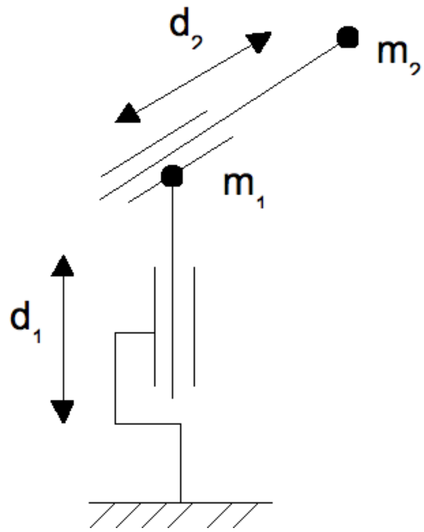

Figure 4: exercise 5

The two-link Cartesian arm has the link masses $m1$ and $m2$ concentrated at the distal ends as shown (Fig 4). The second joint axis makes an angle of 45^o with the first joint axis.

The Euler Lagrange equation is defined by:

$$\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_j} - \frac{\partial \mathcal{L}}{\partial q_j} = \tau_j$$

Here $\mathcal{L} = K - P$ where K is the kinetic energy and P is the potential energy

1. Derive the kinetic and potential energies of the links.
2. Formulate the Euler-Lagrange equations of the form $D(q)\ddot{q} + C(q, \dot{q})\dot{q} + G(q) = \tau$, where, $q = [d1, d2]^T, \tau = [f1, f2]^T$, $D(q)$ is the inertia matrix, $C(q, \dot{q})$ is the matrix defined by the so called Christoffel Symbols, and $G(q)$ represent the gravitational forces.