# Exam

January 15th, 2019
Västerås

# DVA414 – Industrial Robotics

**(Till tentamensvakten: engelsk information behövs)**

| | | |
|---|---|---|
| Teacher | Alessandro Papadopoulos, tel: 021-1073 23 | |
| Exam duration | 14:10-19:30 | |
| Help allowed | Calculator, language dictionary, ruler, and APPENDIX attached to this exam. | |
| Points | 60 p | |
| Grading | Swedish grades: | ECTS grades |
| | $< 30$p $\rightarrow$ failed | $< 30 \rightarrow$ failed |
| | $30-41$p $\rightarrow$ grade 3 | $30-34$p $\rightarrow$ D |
| | $42-53$p $\rightarrow$ grade 4 | $35-44$p $\rightarrow$ C |
| | $54-60$p $\rightarrow$ grade 5 | $45-54$p $\rightarrow$ B |
| | | $55-60$p $\rightarrow$ A |

**Instructions**

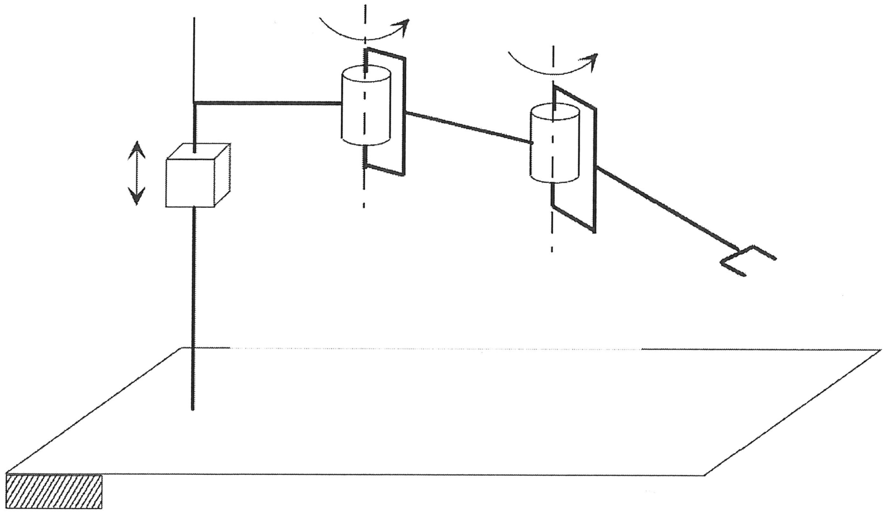
- Answers MUST be written in **English**.
- **Short and precise** answers are preferred. Do not write more than necessary. The clarity and the order of the answers will be considered in the evaluation.
- Use a **new sheet** for each of the assignments.
- If some assumptions are missing, or if you think the assumptions are unclear, **write down what do you assume** to solve the problem.
- Write **clearly**. If I cannot read it, you get zero points.
- During the exam you are not allowed to consult books or any kind of notes.

**Good luck!!!**

**Turn the page**

**EXERCISE 1 (DIRECT AND INVERSE KINEMATICS)** **10 POINTS**

Given the PRR robot below:



1. Place reference frames for each link according to the DH (Denavit-Hartenberg) convention
2. Write a table with the values of the DH parameters for each link
3. Compute the homogeneous transformation matrix that represents the manipulator forward kinematics
4. Outline the inverse kinematics problem (without addressing hand orientation)

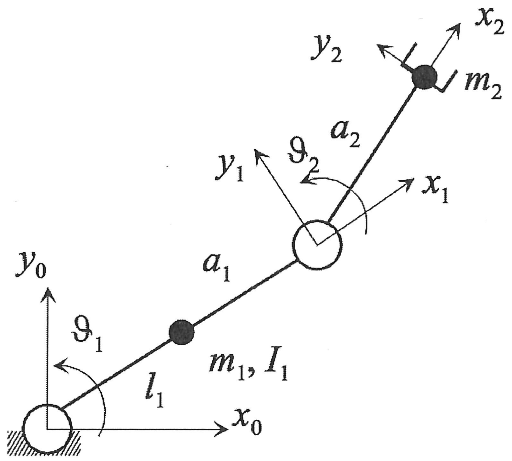
$$\left[\begin{array}{ccc|c} c & -cs & ss & ac \\ s & cc & -cs & as \\ 0 & s & c & d \\ 0 & 0 & 0 & 1 \end{array}\right]$$

**EXERCISE 2 (TRAJECTORY PLANNING)** **10 POINTS**

Compute a quintic trajectory which takes $q(t)$ from the initial value $q_i = 0$rad to the final value $q_f = 2$rad within 1s, with initial and final joint velocity equal to 0, and initial and final acceleration equal to 0. Plan another trajectory with the same requirements on initial and final positions and velocities, but using a trapezoidal velocity profile where the maximum speed is 3rad/s.

**EXERCISE 3 (DYNAMICS)** **10 POINTS**

Consider the planar manipulator in the vertical plane (gravity along the $y$ axis) sketched in the picture, where **the mass of the second link is assumed to be concentrated at the end-effector**.




**1.** Find the expression of the inertia matrix of the manipulator, knowing that

$$\mathbf{p}_1 = \begin{bmatrix} a_1 c_1 \\ a_1 s_1 \\ 0 \end{bmatrix}, \quad \mathbf{p}_2 = \begin{bmatrix} a_1 c_1 + a_2 c_{12} \\ a_1 s_1 + a_2 s_{12} \\ 0 \end{bmatrix}.$$

**2.** Find the expression of the gravitational torques for this specific manipulator.

## EXERCISE 4 (HOMOGENEOUS TRANSFORMATION) **10 POINTS**

1. Find a representation of the rotation $\mathbf{R}_3^0$ defined by the following ordered sequence of basic rotations:
   - **a.** Rotation Frame0 → Frame1, by $\theta$ about the current axis $x$, i.e., $\mathbf{x}_0$
   - **b.** Rotation Frame1 → Frame2, by $\phi$ about the **fixed** axis $z$, i.e., $\mathbf{z}_0$
   - **c.** Rotation Frame2 → Frame3, by $\alpha$ about the current axis $x$, i.e., $\mathbf{x}_2$
2. Write the expression of the unit vectors $\mathbf{x}_3^0$, $\mathbf{y}_3^0$, and $\mathbf{z}_3^0$, when $\theta = \frac{\pi}{2}$rad, $\phi = \frac{\pi}{3}$rad, and $\alpha = \frac{\pi}{6}$rad.

## Exercise 5 (Control) **10 points**

1. List the closed loop control control strategies in joint space.
2. Describe the motion control strategy "PD plus gravity compensation" in joint space, including
   a. The control law
   b. The control scheme
   c. Limitations of the control strategy

**EXERCISE 6 (MULTIPLE-CHOICE QUESTIONS)** **10 POINTS**

Respond to the following questions providing a brief and clear explanation for the selected answer. There is only one correct answer. If no explanation is provided, the answer will be considered wrong.

1. What is a robot?
   - **a.** A random device used to take over the world
   - **b.** A device powered by electricity doing things for a man kind
   - **c.** A machine programmed to carry out tasks
   - **d.** None of the above
2. The inverse kinematic problem
   - **a.** It is a completely defined algorithm
   - **b.** It is often solved with *ad hoc* methods
   - **c.** It is always available and used in industrial robots
   - **d.** It is computationally less difficult than the forward kinematic problem
3. The equation $T_n^0 = A_1^0 A_2^1 \cdots A_n^{n-1}$ represents
   - **a.** The equation to obtain the reference frame of the end-effector in the cartesian space
   - **b.** The solution of the inverse kinematics problem
   - **c.** The Denavit-Hartenberg equation
   - **d.** The computation of a generic rotation matrix
4. The Denavit-Hartenberg parameters
   - **a.** Are four constants
   - **b.** Their number depend on the type of joint
   - **c.** Cannot be equal to zero
   - **d.** None of the above
5. The forward kinematics
   - **a.** Expresses the values of the joint variables as a function of the position and orientation of the end-effector
   - **b.** Provides immediately the values of the end-effector orientation
   - **c.** Provides immediately the values of the end-effector position
   - **d.** Provides immediately the values of the end-effector position and orientation