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MICRO-450
Bases de la robotique

Date : 19 janvier 2017
Durée : 2 heures

Version A

Name ____________________________

First name ____________________________

SCIPER ____________________________

Signature :

Wait for the start before turning this page ! The document is printed two-sided for a total of 8 pages. DO NOT REMOVE THE CLIPS ! Additionally there is a separate sheet for the answers to multiple choice & true/false questions.

– Put your EPFL-Student ID card (Camipro) on the desk.

– Only allowed documents : The three two sided A4 sheets of personal notes

– Cell phones or calculators & other electronic equipment STRICTLY BANNED, leave them in your bag TURNED OFF, bags collected before start. FAILURE TO COMPLY (e.g. ringing phone) DISQUALIFIES.

– **Multiple choice questions** (unless otherwise stated) give **2 points** for the single correct answer.,
0 points for wrong, multiple or absent answer.

– True-False questions :
+1 point for correct answer
0 points for absent or wrong answer

– Use if possible pencil & eraser on the answer sheet (so you can correct), otherwise black or blue pen

– If we made some error in one of the questions, we may cancel this question.

– Write answers (« Questions libres ») directly on the exam sheets

– Mark choices as shown below on the separate answer sheet.

Exercice 1. True of false (15 pts, i.e. 1 for each question)

Please mark your answers on the separately given reply sheet Ⓥ for true or Ⓕ for false.

1.1 A serial robot is a structure consisting of a closed loop kinematic chain.

1.2 Generaly speaking, an angular robot is more precise than a cartesian robot.

1.3 Generaly speaking, a parallel robot has higher stiffness than a serial robot.

1.4 The purpose of the derivative gain of a PD controller is to cancel static error.

1.5 Proportional gain of a PD controller reduces static error.

1.6 The electomagnetic torque of a DC motor is always proportional to the input current of the the motor.

1.7 The « regulation factor » of a DC motor does not depend on the load.

1.8 The dynamic model of a robot links joint positions to joint torques.

1.9 The postion trajectory profile of a DC motor has no effect on the motor's energy losses.

1.10 The optimal reduction gear ratio, corresponding to the optimal adaptation of motor-(reduction-gear)-load, leads to minimum energy losses of the drive train.

1.11 The optimal reduction gear ratio, corresponding to the optimal adaptation of motor-(reduction-gear)-load, leads to maximum speed output of the drive-train.

1.12 A redundant robot has more degrees of freedom than motors.

1.13 The Jacobian matrix of a robot links applied forces at the end-effector to joint torques.

1.14 The Jacobian matrix of a robot links end-effector positions to joint positions.

1.15 The Jacobian matrix of a robot links end-effector positions to joint torques.

Exercice 2 (12 pts)

The actuator train of the 2nd joint of a SCARA robot consists of a motor and a reduction gear with the following specs :

Motor: J_m = **625** g cm^2,

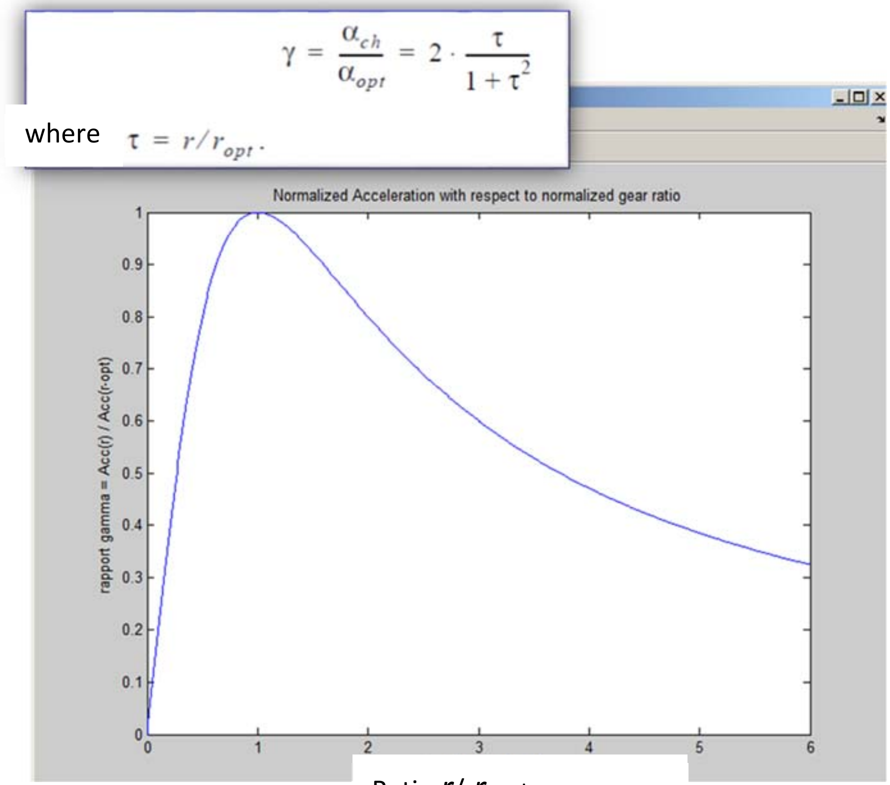
Reduction gear ratio : = **180**,

Robot arm inertia: J_{arm} = **0.1** kgm^2.

2.1 The optimal reduction gear ratio for this joint will be:

(A) 20 **(B) 40** **(C) 1600** **(D) 80**

The next figure gives the normalized acceletation ratio $\gamma(\tau)$ as function of normalized gear ratio τ:



Ratio $r/\ r$ opt

2.2 In percentage of the optimal acceleration, what will be the effective acceleration with the given reduction ratio as compared to the optimal case?

(A) ~ 25% **(B) ~ 35%** **(C) ~ 45%** **(D) ~ 55%**

2.3 In the design given above, an incremental encoder of 1000 periods, in quadrature, is used. The final best possible resolution at the load will be

(A) 0.09 ° **(B) 0.0005°** **(C) 0.002°** **(D) 0.008°**

2.4 The sampling rate of a controller is 2 kHz. The rotation speed ω is obtained through differentiation over a sampling period. The resolution of the rotation speed ω then will be:

(A) 4°/sec **(B) 1°/sec** **(C) 180 °/sec** **(D) 16°/sec**

2.5 The same robot should now be designed with a direct drive actuation. An absolute encoder of 20 bits is available. The angular resolution at the load will be

(A) ~(0.36×10^{-3}) ° **(B) ~(90×10^{-6}) °** **(C) ~(1.44×10^{-3}) °** **(D) ~(2×10^{-6}) °**

2.6 The sampling rate of the controller is now 1 kHz, the absolute encoder has 20 bits. The rotation speed ω is obtained through differentiation over a sampling period. The resolution of the rotation speed ω then will be:

(A) ~ 0.36°/sec **(B) ~ 1.44°/sec** **(C) ~(2×10^{-3}) °/sec** **(D) (90×10^{-3}) °/sec**

<u>Exercice 3 (18 pts)</u>

We aim to control the axes of a cartesian robot (3 translational degrees of freedom). The gravity vector is $\mathbf{g} = [0, 0, -g_0]^T$ dans le référentiel de base du robot ($g_0 = 9.8 m/s^2$).

3.a Give the forward kinematics and the Jacobian matrix for this robot (2.5 pt)

3.b The motors are torque controlled. Give the minimal (simplest possible) controller which would work for the position control for each of the three robot axes : **P , PI , PD or PID ? Explain for each of the three axes!** (3 pts)

3.c Give the control scheme (functional diagram) for the position control of any one (your choice) of the axes of question 3.b (2pts)

The axes of this device are driven by linear motors (direct actuation). The masses at each linear motor are m_X, m_y et m_Z. The viscous damping coefficients for each axis are kv_X, kv_y et kv_Z. Dry friction is neglected.

3.d Give the inverse kinematics of X (1 pt)

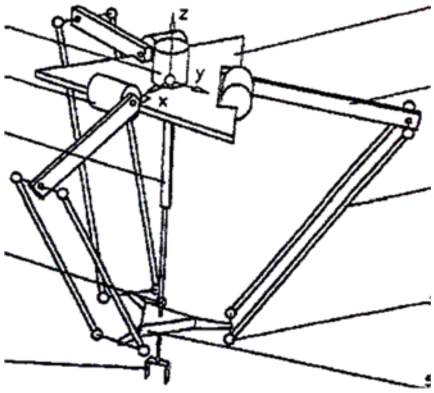
3.e Give the equation of the inverse dynamic model for the *Z* axis(2 pts)

3.f Give the generalized torque of the a-priori model for *X* and *Z* axis (3 pts)

3.g Give the controller functional diagram for the controler of question **(3.c)** including a generalized a priori couple. Give the total expression for the generalized couple of this controller (3 pts)

3.h Name three advantages of a control architecture with field bus (1.5 pts)

<u>Exercice 4 (15pts)</u>



The Delta 4 robot is a 4 degrees-of-freedom Delta robot for pick and place as shown to the right. The coordinate frame is {x, y, z} with the angles θx, θy et θz around these coordinate axes.

4.a Give vector [X] of the operational coordinates of this robot (1 pt)

X = [………. , …………, …………, …………..]

4.b Give the set [q] of the generalized robot coordinates and describe what they are (2 pts)

q = [………. , …………, …………, …………..]

4.c Give a 2-dimentional schematic for this robot kinematics allowing calculation of the mobilities of this robot (4 pts)

4.1 The equation **q**= $\phi(X)$ is:

(A) Forward kinematics
(B) Inverse kinematics
(C) Inverse Jacobian
(D) None of the above

4.2 How many kinematic loops in this structure (Delta 4) ?

(A) 3 **(B) 4** **(C) 5** **(D) 6**

4.3 The number of mobilities is:

(A) 4 **(B) 9** **(C) 10** **(D) 11**

4.4 The Delta-4 -:

(A) over constrained

(B) has internal mobilities

(C) is redundant

(D) None of the above

<u>Exercice 5 (10 pts)</u>

5.a Give three physical effects to avoid when aiming for high precision positioning of a robot (3 pts)

5.b Give four physical principles (from the lecture) used for micro actuation (4 réponses) (4 pts)

5.c Give three methods to obtain long motion range with microactuators

Exercice 6 (16 pts)

A rotation of 90° around *X*–axis is followed by a rotation of 90° around *Z*–axis. What are axis and angle of the composed motion ?

6.1 The axis of the composed motion is:

(B) [1, 1, 1]' **(B) [1,-1, 1]'** **(C) [1, 1, –1]'** **(D) [–1, 1, 1]'**

6.2 The rotation angle of the composed motion around this axis is:

(A) 90° **(B) 120°** **(C) 60°** **(D) –120°**

Same questions as 6.1 et 6.2 , but in inverse sequence (1st rotation of 90° around *Z*, then rotation of 90° around *X*

6.3 The axis of the composed motion is:

(A) [1,-1, 1]' **(B) [–1, –1, –1]'** **(C) [1, 1, –1]'** **(D) [–1, 1, 1]'**

6.4 The rotation angle of the composed motion around this axis is:

(A) 90° **(B) 120°** **(C) 60°** **(D) –120°**

6.5 Give the homgenous matrix corresponding to a translation of length 2 in direction of *Z* followed by a rotation of 60° around axis $[0, 1, 0]^T$ (A correct answer will give 4 pts)

$$\frac{1}{2}\begin{bmatrix} \sqrt{3} & 0 & 1 & 0 \\ 0 & 2 & 0 & 0 \\ -1 & 0 & \sqrt{3} & 4 \\ 0 & 0 & 0 & 2 \end{bmatrix} \quad \frac{1}{2}\begin{bmatrix} \sqrt{3} & 0 & 1 & 2 \\ 0 & 2 & 0 & 0 \\ -1 & 0 & \sqrt{3} & 2\sqrt{3} \\ 0 & 0 & 0 & 2 \end{bmatrix} \quad \frac{1}{2}\begin{bmatrix} 1 & 0 & \sqrt{3} & 0 \\ 0 & 2 & 0 & 0 \\ -\sqrt{3} & 0 & 1 & 4 \\ 0 & 0 & 0 & 2 \end{bmatrix} \quad \frac{1}{2}\begin{bmatrix} 1 & 0 & \sqrt{3} & 2\sqrt{3} \\ 0 & 2 & 0 & 0 \\ -\sqrt{3} & 0 & 1 & 2 \\ 0 & 0 & 0 & 2 \end{bmatrix}$$

(A) **(B)** **(C)** **(D)**

6.a Give the forward kinematics of the robot shown in the picture to the right (4 pts).
$\theta_3 = 0$ at the intersection of the axes