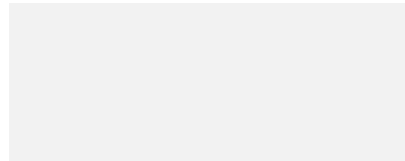


Date : 22 janvier 2020**Durée** : 2 heures

Version A

Nom _____
Prénom _____
SCIPER _____

Signature :



Wait for the test to start before turning the page. This document is printed on both sides and contains 12 pages. Do not unzip.

- Put your student card on the table.
- The only documents allowed are 3 double-sided A4 pages of personal notes.
- The use of a non-programmable scientific calculator is permitted.
- All electronic communication devices are forbidden during the test.
- For multiple-choice questions, the following points will be awarded:
+2 points if the answer is correct,
0 points if the question is not answered, if there are several crosses or if the answer is incorrect.
- For true-false questions, you will be awarded:
+1 point if the answer is correct,
0 point if the question is not answered, if there are several crosses or if the answer is incorrect.
- Depending on the exercise, the number of boxes to tick is greater than the number of questions. There is therefore no need to fill in unnecessary boxes.
- Use a pencil and erase neatly if necessary.
- If a question is incorrect, the teacher reserves the right to cancel it.
- Follow the instructions below to mark your choices on your answer sheet:

 oui | ja | sì | yes non | nein | non | no

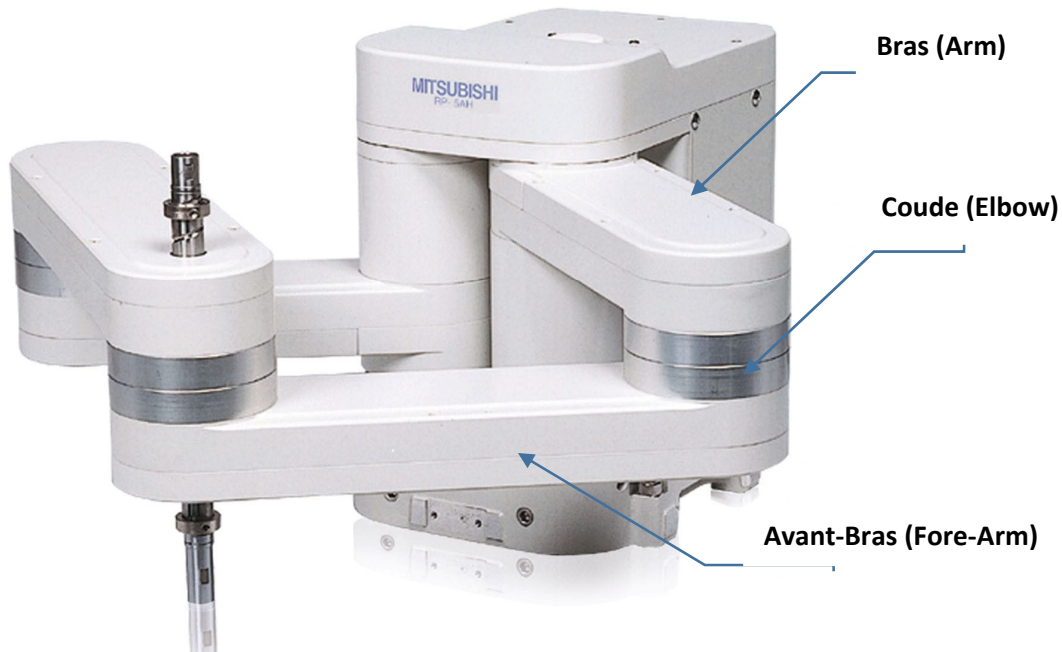
Exercise 1. Questions Vrai ou Faux (15 pts)

Please Choose V, for True or F, for False on your answer-sheet.

- 1.1 In general, a Cartesian robot is less precise than an angular robot.
- 1.2 In general, a parallel robot is more rigid than a serial robot.
- 1.3 The accuracy of a robot depends on its working position.
- 1.4 The maximum speed of a robot depends on its working position.
- 1.5 The higher is the factor of regulation of a DC motor, the better is the energy efficiency of the driven axis.
- 1.6 The optimal reduction ratio, corresponding to the optimal adaptation of a motor-reducer-load, maximizes the acceleration of the drive.
- 1.7 A redundant robot has more motors than degrees of freedom.
- 1.8 A redundant robot is a robot that has more sensors than motors.
- 1.9 The Jacobian matrix of a robot makes it possible to deduce positioning errors at the tool level as a function of positioning errors at the joints.
- 1.10 One of the advantages of a field bus is the reduction in wiring required for the implementation of the numerical controller.
- 1.11 In the case of a serial robot, the inverse geometrical model makes it possible to know the value of all the joints as a function of the position and the orientation of the **end effector**.
- 1.12 In the case of a parallel robot, the Inverse geometrical model makes it possible to know the value of all the joints as a function of the position and the orientation of the **end effector**.
- 1.13 The direct geometric model of a Cartesian serial robot has several possible postures.
- 1.14 At an applied voltage of 100V, a PZT material of 10 mm long will lengthen by 1.5 μm .
- 1.15 The STICK-SLIP control of a PZT material (using sawtooth control voltage) does not allow the implementation of larger movement strokes.

Description du Robot Mitsubishi

The company Mitsubishi Electric offers the following solution for SMD component placement operations. This robot has all the degrees of freedom necessary for the implementation of this type of application.



The rotary actuators of the first two segments are carried out using a Maxon EC Flat 45 motor and a reduction gear with a ratio $n = 25$.

The engine specifications are as follows:

Nominal torque: **128 mNm**.

Nominal speed: **4860 rpm**

Kc is the engine torque constant: **42 mNm / A**

Nominal voltage: **24 V**.

Moment of inertia of the rotor: **Jm = 180 g.cm²**



Specifications of other engines are not considered

Exercice 2 (Actionnement-Capteurs-Mobilité) (20 pts)

2.1 The nominal current of the considered DC motor is about :

(A) 3 A

(B) 0.33 A

(C) 2 A

(D) 0.5 A

2.2 The electromechanical efficiency of the DC motor is about :

(A) 70%

(B) 75%

(C) 80%

(D) 90%

2.3 Considering that the transmission gear ratio is 81%, the nominal torque at the side of the gear output is about:

- (A) 3.2 Nm (B) 2,6 Nm (C) 4 mNm (D) 18 mNm

2.4 An incremental encoder with 500 quadrature periods is set up at the side of the DC motor. What is the resolution at the side of each of the robot arms?

- (A) 0.018° (B) 0.0288° (C) 0.0072° (D) 0.072°

2.5 The length of each arm is 80 mm. What is the resolution at the elbow of each robot arm ?

- (A) 0.01 mm (B) 0.04 mm (C) 0.001 mm (D) 0.0004 mm

2.6 The equivalent absolute sensor to put at the side of the robot arm (output of the gear box) has to have the following minimal resolution :

- (A) 13 bits (B) 14 bits (C) 15 bits (D) 16 bits

2.7 The velocity is obtained through a numerical derivation. To improve the velocity resolution, it is required to :

- (A) Increase the sampling period
- (B) Reduce the sampling period,
- (C) Add a damper in series with the reductor.
- (D) None of the previous proposals.

2.8 The number of degrees of freedom of this robot is

- (A) 2 (B) 3 (C) 4 (D) 5

2.9 The kinematic mobility of this robot is :

- (A) 1 (B) 2 (C) 4 (D) 6

2.10 This robot :

- (A) is over-constrained
- (B) has internal mobility,
- (C) is a redundant robot.
- (D) None of the previous proposals.

Exercice 3 (Transmission – calcul d'inertie et accélérations) (14 pts)

We consider the following assumptions:

- The transmission will be considered as ideal (efficiency = 1).
- The moment of inertia of each arm around its axis of rotation is: $J_b = 69 \cdot 10^{-4} \text{ kg.m}^2$
- The mass of the arm is $M_b = 25 \text{ g}$ (center of mass in the middle of the arm).
- As a reminder, the length of the arm is $l_b = 80 \text{ mm}$.
- Considering the robot in the middle of its working volume, the total mass reported to each elbow (including the forearm and the end-effector), is approximated to $M_r = 100 \text{ g}$. This mass is assumed to be constant.

3.1 The moment of inertia of the motor reported to the load side (gear output) is about :

- (A) $224 \cdot 10^{-4} \text{ kgm}^2$ (B) $112 \cdot 10^{-4} \text{ kgm}^2$ (C) $0,29 \cdot 10^{-7} \text{ kgm}^2$ (D) $0,29 \cdot 10^{-8} \text{ kgm}^2$

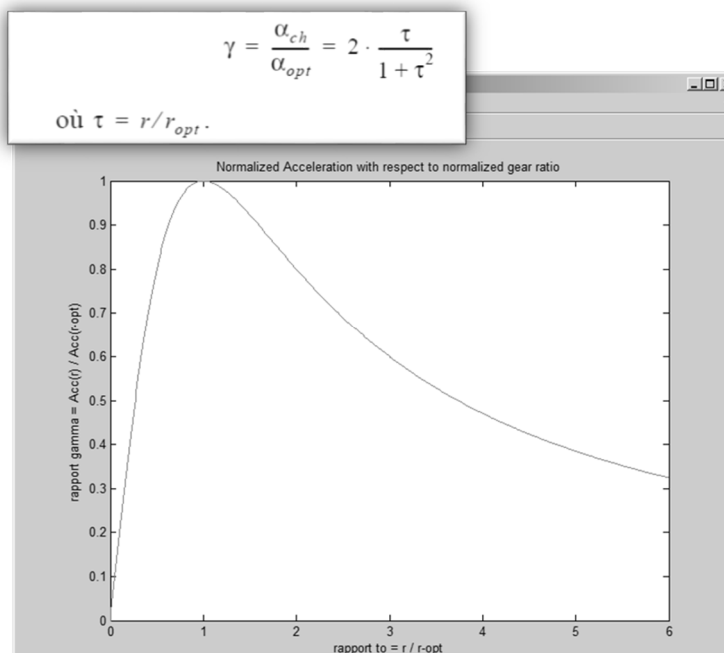
3.2 The total moment of inertia reported to the load side (gear output) is about :

- (A) $190 \cdot 10^{-4} \text{ kgm}^2$ (B) $305 \cdot 10^{-4} \text{ kgm}^2$ (C) $81 \cdot 10^{-4} \text{ kgm}^2$ (D) $85 \cdot 10^{-5} \text{ kgm}^2$

3.3 The optimal gear ratio associated to this transmission is approximately:

- (A) 5,5 (B) 20 (C) 25 (D) 400

The following figure represents the acceleration ratio curve $\gamma(\tau)$ as a function of the reduction ratio relative to the optimal ratio:



3.4 Relative to the optimal acceleration (if the reduction ratio is optimal), what is the admissible acceleration rate with the transmission used?

- (A) ~ 40% (B) ~ 20% (C) ~ 95% (D) ~ 100%

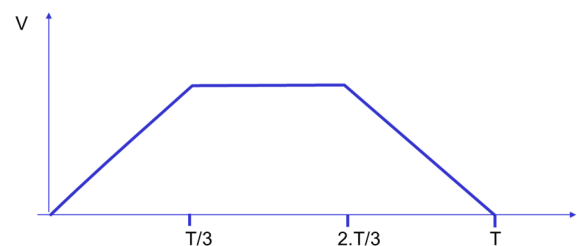
3.5 The optimal gear ration makes it possible to:

- (A) Maximize the speed at the load
(B) Maximize acceleration on the load
(C) Optimizing accuracy at the output.
(D) None of the previous proposals.

3.6 Assuming the used reduction ratio ($n=25$) and the transmission efficiency at 81%, the permissible nominal acceleration at the output of the reducer would be:

- (A) $25^\circ/\text{s}^2$ (B) $0.137^\circ/\text{s}^2$ (C) $137^\circ/\text{s}^2$ (D) $230^\circ/\text{s}^2$

We consider a trapezoidal velocity profile at $1/3$ of the time for acceleration, $1/3$ of the time at constant maximum speed and $1/3$ of the time for deceleration (figure opposite).



3.7 If γ_{mx} is the maximum acceleration associated with the previous profile. What is the corresponding RMS (quadratic mean) acceleration?

- (A) $\sqrt{1/3} \gamma_{mx}$ (B) $\sqrt{3/2} \gamma_{mx}$ (C) $\sqrt{2/3} \gamma_{mx}$ (D) γ_{mx}

Exercise 4 Modélisation dynamique (14 pts)

The robot's direct reference is **defined as shown**. The rotation is assumed to be positive counterclockwise. The articular translations have the same direction as the axes of the basic reference frame of the robot.

A positive current produces a joint force/moment in the positive direction of movement.

Kc and **Kf** are respectively the torque and force constants of the articular axes.

i is the motor current.

We will only consider **q1** and **q2**, the two articular coordinates of rotation of the first 2 segments (arms according to figure 1).

q1d and **q2d** are the desired joint positions



4.1 At unit efficiency (ideal transmission), considering the approximate configuration in the middle of the robot's working volume, the inverse dynamic model of axis 1 expressed relative to the output axis of the reducer (rotary axis q1) is given by:

$$(A) \Gamma_1 = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{q}_1 + M_b g \frac{l_b}{2} \sin(q_1) + M_r g l_b \sin(q_1)$$

$$(B) \Gamma_1 = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{\theta}_d + M_b g \frac{l_b}{2} \cos(q_{1d}) + M_r g l_b \cos(q_{1d})$$

$$(C) \Gamma_1 = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{q}_1$$

$$(D) \Gamma_1 = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{q}_{1d}$$

4.2 At unit efficiency (ideal transmission), the a priori dynamic model of axis 1 expressed relative to the output axis of the reducer (rotary axis q1) is given by:

$$(A) \Gamma_{1ap} = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{q}_1 + M_b g \frac{l_b}{2} \sin(q_1) + M_r g l_b \sin(q_1)$$

$$(B) \Gamma_{1ap} = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{\theta}_d + M_b g \frac{l_b}{2} \cos(q_{1d}) + M_r g l_b \cos(q_{1d})$$

$$(C) \Gamma_{1ap} = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{q}_1$$

$$(D) \Gamma_{1ap} = \{J_b + n^2 J_m + M_r l_b^2\} \ddot{q}_{1d}$$

4.3 The a priori dynamic model

- (A) Is useful for improving the positioning accuracy of a robot
- (B) Allows you to know the internal forces / torques at the level of each joint.
- (C) is used to project **generalized** joint forces to forces / torques at the tool.
- (D) Not useful for parallel robots.

4.4 In order to access the internal forces of interaction at each joint, the dynamic model should be developed using:

- (A) Newton Raphson's equation
- (B) The Jacobian matrix
- (C) The Newton-Euler method
- (D) The Lagrange method.

4.5 The Lagrange method discussed in class is valid for:

- (A) All types of robots
- (B) Only serial robots.
- (C) Only parallel robots.
- (D) Only for certain serial robots.

4.6 The Newton-Euler method discussed in class is valid for:

- (A) All types of robots**
- (B) Only serial robots.**
- (C) Only parallel robots.**
- (D) Only for certain serial robots.**

4.7 Regarding the development of the dynamic model of a robot, which of the following expressions is false

- (A) The Lagrange method gives the same result as the Newton-Euler method.**
- (B) For Cartesian robots, Newton's approach is sufficient.**
- (C) The Newton-Euler method makes it possible to obtain a more precise model.**
- (D) Lagrange's approach is more systematic than that of Newton-Euler**

Exercice 5 Contrôle en position (146 pts)

Please Choose ☒ V, for True or ☐ F, for False on your answer-sheet.

Important :

All the questions in this exercise assume control of the DC motor in “current mode”, without viscosity of the transmission and without friction.

5.1 In the absence of dry and viscous friction, the proportional controller is sufficient to control the position of the axis considered.

5.2 In the absence of dry and viscous friction, the integral action is never necessary for the control in position of the axis considered.

5.3 In the case of a translation axis, the contribution of the integrator is absolutely necessary for controlling the position of the axis considered.

5.4 The integrating action of a PID dampens the oscillations around the desired position.

5.5 The derivative action of a PID dampens the oscillations around the desired position.

5.6 All gains from a position PID controller are necessary for the implementation of a variable compliance.

5.7 The use of the dynamic **a priori** model in the controller makes it possible to reduce the dynamic position error.

5.8 The use of the dynamic **a priori** model is useless for the cancellation of the static deviation.

5.9 If we consider one of the rotary axes of the Mitsubishi robot of the exercise, the minimum controller for position control would be:

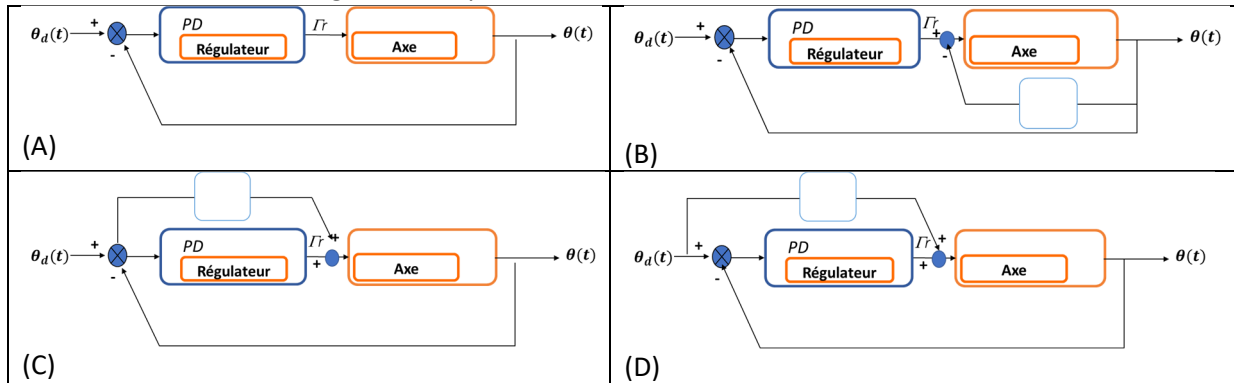
(A) P

(B) PI

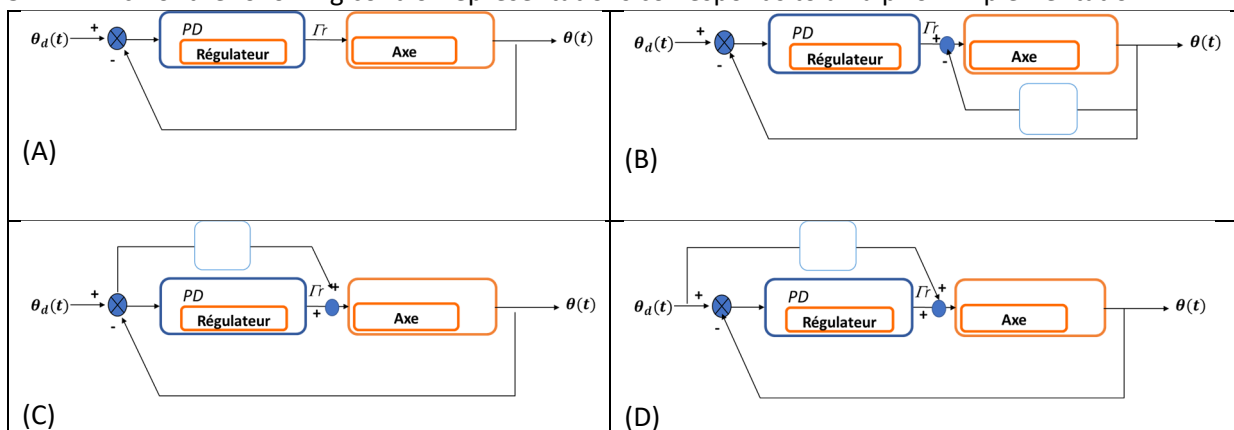
(C) PD

(D) PID

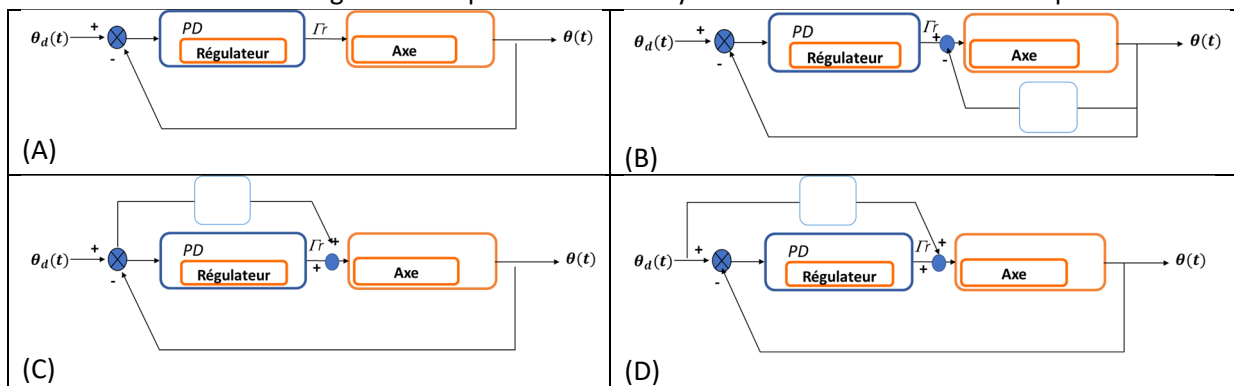
5.10. Which of the following control representations is false



5.11. Which of the following control representations corresponds to an a priori implementation:



5.12. Which of the following control representations may be associated to an exact compensation:



Exercise 6 (14 pts)

6.1 The mobility of a robot of a one degree of freedom linear axis carrying out a combined rough and precise movement is:

- (A) $m = 2$ (B) $m = 4$ (C) $m = 6$ (D) $m = 8$

6.2 The quaternion $\{\sqrt{3}/2, 1/2, -1/2, 1/2\}$ describes the following rotation:

- (A) 30° (B) 60° or -60° , depending on the direction of the axis
(C) -30° (D) is not a unitary quaternion

6.3 Which quaternion describes a rotation of 60° around the axis vector $[0, -1, 1]^T$

- (A) $[\sqrt{1}/2, -\sqrt{2}/2, -\sqrt{2}/4, \sqrt{2}/4]$ (B) $[-\sqrt{2}/4, 0, -\sqrt{2}/4, \sqrt{3}/2]$
(C) $[0, \sqrt{2}/4, -\sqrt{2}/4, \sqrt{3}/2]$ (D) $[\sqrt{3}/2, 0, -\sqrt{2}/4, \sqrt{2}/4]$

6.4 Which quaternion describes a rotation of 270° around X axis

- (A) $[-\sqrt{2}/2, \sqrt{2}/2, 0, 0]$ (B) $[-\sqrt{2}/2, 0, \sqrt{2}/2, 0]$
(C) $[\sqrt{3}/2, 0, 1/2, 0]$ (D) $[0, \sqrt{3}/2, 0, 1/2]$

6.5 Which quaternion describes the compound rotation of firstly 6.4.a) and secondly 6.4.c).

- (A) $[-\sqrt{6}/4, \sqrt{6}/4, -\sqrt{2}/4, -\sqrt{2}/4]$ (B) $[-\sqrt{2}/4, \sqrt{2}/4, -\sqrt{6}/4, \sqrt{6}/4]$
(C) $[-\sqrt{6}/4, \sqrt{2}/4, -\sqrt{6}/4, \sqrt{2}/4]$ (D) $[0, -1/\sqrt{2}, 0, 1/\sqrt{2}]$

6.6 Three of the following statements are wrong, only one is true. Select the correct statement:

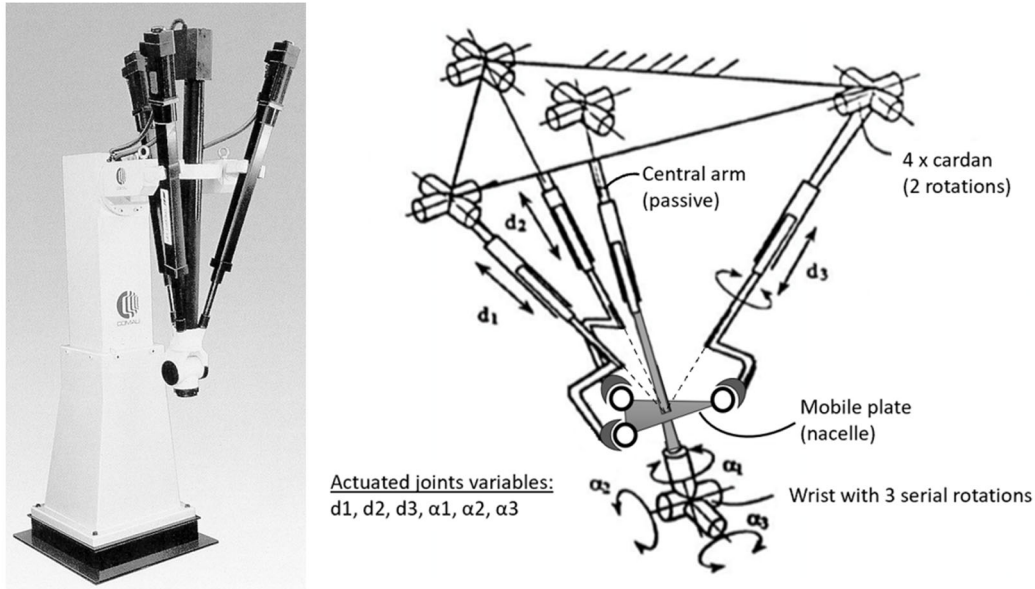
- (A) Quaternions have two real parts and two imaginary parts.
(B) The vector part within a quaternion, which describes the rotation axis, has to be unitary.
(C) Quaternion multiplication is always commutative.
(D) Quaternions represent a solution to the Gimbal Lock problem with the Euler Angle formulation.

6.7 Three of the following statements are true, only one is false. Select the wrong statement:

- (A) The direction cosine matrix indicates the orientation of a reference axis with respect to another.
(B) In robotics, the determinant of a rotation matrix is always < 1
(C) The trace of a 3D rotation matrix is equal to $1 + 2 \cos \theta$, (θ = angle), which is equivalent to the sum of its eigenvalues.
(D) The product of the orthonormal rotation matrices is not commutative.

Exercise 7 Kinematics (20 pts)

The *Tricept*, in its industrial version, is represented by the following figure:



7.1 The kinematics of this structure is of the type:

- (A) Serial (B) Parallel (C) Hybrid (D) Cartesian

7.2 What is the number of degrees of freedom of this platform?

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

7.3 This structure has neither hyper-guidance nor internal mobility. What is the mobility of this platform?

- (A) 3 (B) 6 (C) 0 (D) 12

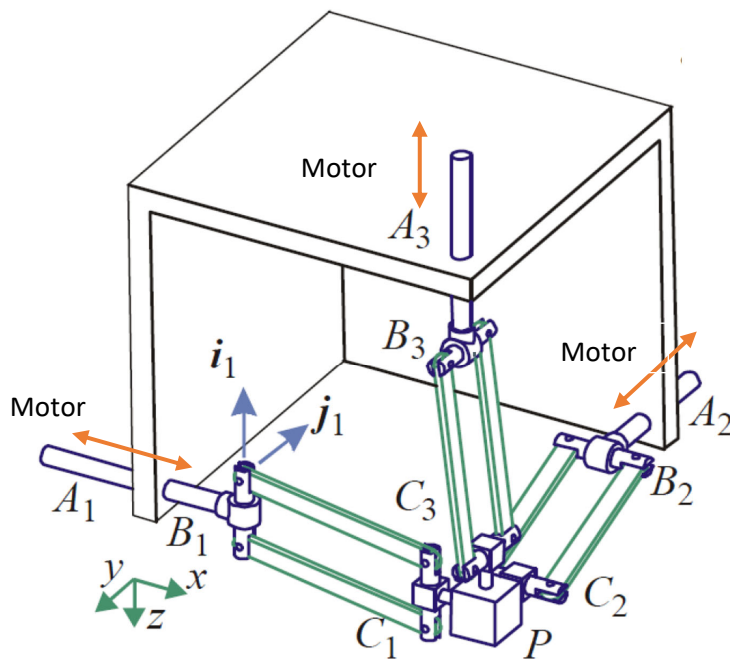
7.4 How many kinematic loops does this structure have?

- (A) 2 (B) 3 (C) 4 (D) 5

7.5 This structure has neither hyper-guidance nor internal mobility. Then, what is the type of attachment of each active arm (d_1, d_2, d_3) with the mobile plate (nacelle)?

- (A) pivot/hinge (B) cardan/universal joint (C) ball joint (D) blocked

Let's consider now the **Orthoglide** (ref. IRCCyN Lab). It is a variant of the orthogonal Delta. All passive joints are pivots.



The orthoglide from IRCCyN

7.6 What is the number of degrees of freedom of this configuration?

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

7.7 What is the mobility of this robot?

- (A) 3 (B) 6 (C) -9 (D) 0

7.8 This structure

- (A) is hyper-guided
 (B) has internal mobility
 (C) is a robot that combines aspects of parallel and serial kinematics
 (D) it doesn't relate to the above statements

7.9 Having the 3 driving axes of this structure vertically, the result structure will have:

- (A) a bigger mobility number.
 (B) a smaller mobility number.
 (C) an equal mobility number.
 (D) a smaller number of degrees of freedom.

7.10 In general, hyper-guidance makes the structure:

- (A) more rigid (B) faster (C) less rigid (D) easier to assemble