Zagazig University,Faculty of Engineering **Final Exam** **Date**: 04/02/2017
Academic Year: 2016/2017 **Exam Time**: 3 hours
Specialization: Computer & Systems Eng. **No. of Pages**: 6
Course Name: Robotics **No. of Questions**: 5
Course Name: CSE629/CSE514/CSE513 **Full Mark**: [70]
Examiner: Dr. **Mohammed Nour**

▷ Please **answer all questions**. Use **3** decimal digits approximation.

▷ Use your answer sheet as a draft for solutions. **Attach last exam page** to it.

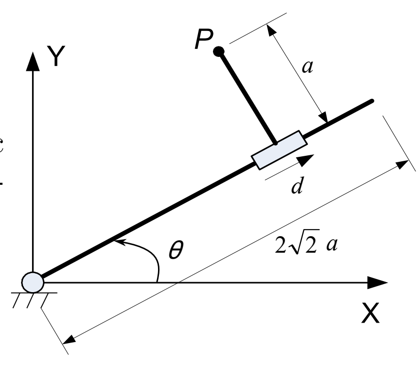
▷ Mark your answers for all questions in the table provided in the last page.

Question 1. [16 Marks] *(2 × 8)*

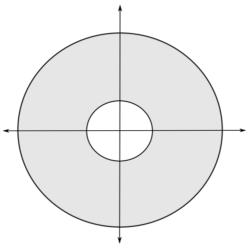
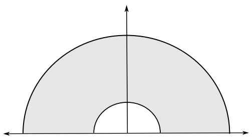
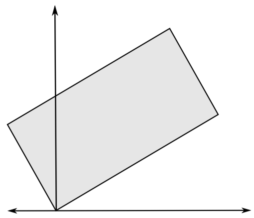
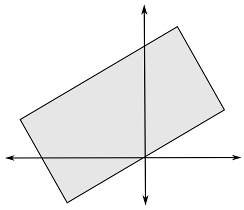
1. Which of the following terms refers to the rotational motion of a robot arm?
   a) swivel b) axle c) roll d) yaw
2. What is the name for the space inside which a robot unit operates?
   a) environment b) spatial base c) danger zone d) work envelop
3. Which of the following terms **is not** one of the five basic parts of a robot?
   a) peripheral tools b) end effectors c) controller d) sensor
4. The number of moveable joints in the base, the arm, and the end effectors of the robot determines ...... ?
   a) degrees of freedom b) operational limits c) flexibility d) cost
5. For a robot unit to be considered a functional industrial robot, typically, how many degrees of freedom would the robot have?
   a) three b) four c) six d) eight
6. . Which of the basic parts of a robot unit would include the computer circuitry that could be programmed to determine what the robot would do?
   a) controller b) arm c) end effector d) drive
7. End effectors can be classified into two categories which are...
   a) elbows and wrists b) grippers and end of arm tooling
   c) grippers and wrists d) end of arm tooling and elbows
8. The amount of weight that a robot can lift is called...
   a) tonnage b) payload c) dead lift d) horsepower

Question 2. [8 Marks] *(2 × 4)*

A 2-DOF planar manipulator has a rotational joint and a prismatic joint. The two links are perpendicular to each other and their dimensions are as indicated. P is the tip (end-effector) of the manipulator.



9. This manipulator workspace is sketched as:

a) 
b) 
c) 
d) 

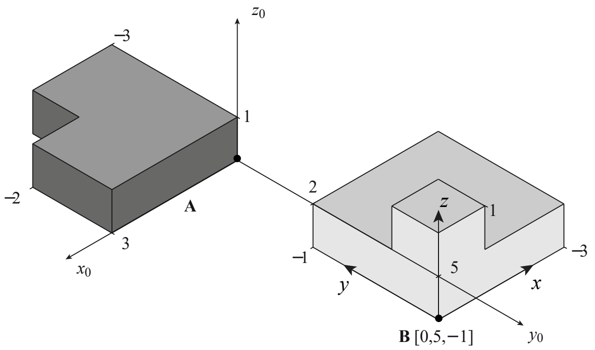
10. The dimensions of the workspace can be mathematically expressed as:

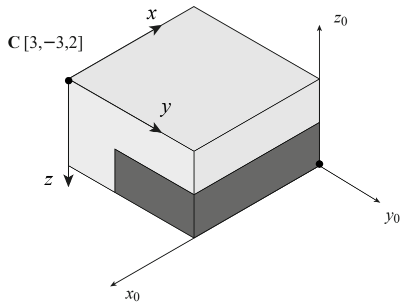
a) $x^2 + y^2 \leq 8\,a^2$ b) $x + y \leq a\cos\theta$

c) $a^2 \leq x^2 + y^2 \leq (3a)^2$ d) $x \leq 2\sqrt{2}\,a$ and $y \leq a$

Question 3. [10 Marks] *(2 + 2 + 1 + 1 + 2 + 2)*

Consider the pose of the objects A and B in space, as shown on the left. The goal is to displace object B into a new pose **C** on A, so that both objects are connected as shown on the right:





11. The homogeneous transformation matrix $\mathbf{H}_B^0$ to represent **B** w.r.t. frame 0 is:

a) $\begin{bmatrix} 1 & 0 & 0 & 3 \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 2 \\ 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ b) $\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 5 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ c) $\begin{bmatrix} 1 & 0 & 0 & 3 \\ 0 & -1 & 0 & 2 \\ 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ d) $\begin{bmatrix} 1 & 0 & 0 & -3 \\ 0 & -1 & 0 & 8 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

12. The homogeneous transformation matrix $\mathbf{H}_C^0$ to represent **C** w.r.t. frame 0 is:

a) $\begin{bmatrix} 1 & 0 & 0 & 3 \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 2 \\ 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ b) $\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 5 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ c) $\begin{bmatrix} 1 & 0 & 0 & 3 \\ 0 & -1 & 0 & 2 \\ 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ d) $\begin{bmatrix} 1 & 0 & 0 & -3 \\ 0 & -1 & 0 & 8 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

13. A sequence of transformations that reaches the desired pose is:

a) $\mathbf{C} = T(3,2,1)\,R_x\left(\frac{\pi}{2}\right)$ b) $\mathbf{C} = T(-3,0,-1)\,R_x\left(\frac{\pi}{2}\right)$

c) $\mathbf{C} = T(3,2,1)\,R_x(\pi)$ d) $\mathbf{C} = T(0,-5,1)\,R_x(\pi)$

Consider the following homogeneous transformation matrix **F** and rotation matrix **R**:

$$\mathbf{F} = \begin{bmatrix} x_1 & 0 & -1 & 5 \\ x_2 & 0 & 0 & 3 \\ x_3 & -1 & 0 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \mathbf{R} = \begin{bmatrix} x_1 & 0 & -1 \\ x_2 & 0 & 0 \\ x_3 & -1 & 0 \end{bmatrix}$$

14. We can split the transformation matrix **F** into:

    a) $\begin{bmatrix} 0 & -1 & 5 \\ 0 & 0 & 3 \\ -1 & 0 & 2 \end{bmatrix}$ and $\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$ b) $\begin{bmatrix} x_1 & 0 & -1 \\ x_2 & 0 & 0 \\ x_3 & -1 & 0 \end{bmatrix}$ and $\begin{bmatrix} 5 \\ 3 \\ 2 \end{bmatrix}$

    c) translation followed by a rotation d) both b) and c)

15. In the rotation matrix **R**:

    a) $Rank(\mathbf{R}) = 4$ b) $\mathbf{R}\mathbf{R}^T = \mathbf{I}$

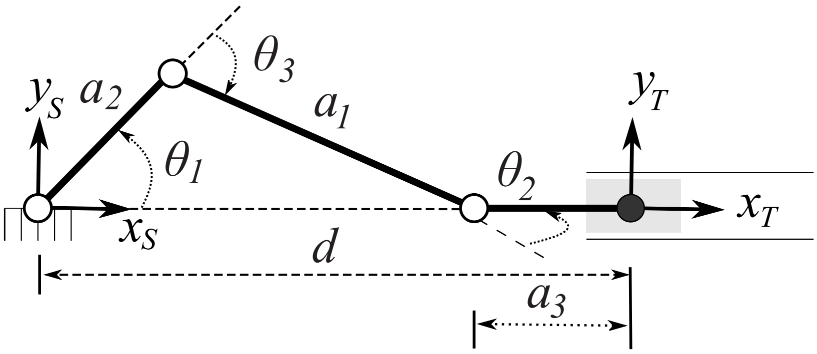
    c) dot product of any two columns is one d) cross product of any two rows is zero

16. In the rotation matrix **R**, values of x_1, x_2 and x_3 are calculated as:

    a) $1, 0, 0$ b) $0, 1, 0$ c) $0, 0, 1$ d) $1, 1, 1$

Question 4. [12 Marks] *(2 + 2 + 4 + 4)*

Consider the slider-crank mechanism shown below with θ_1 as **actuated** joint and $\{x_S, y_S\}$ is the base frame and $\{x_T, y_T\}$ is the tool frame:



17. This mechanism has ········· degrees of freedom.

    a) one b) two c) three d) four

18. Gruebler formula **can not** be used because:

    a) the mechanism moves in one dimension (in the x–axis direction) only.
    b) it is used with 2D parallel mechanisms.
    c) it is used with either 3D closed chains manipulators.
    d) it is applicable for inverse kinematics.

19. the manipulator forward kinematics (i.e. given θ_1 find $[x_T \quad y_T]^T$)

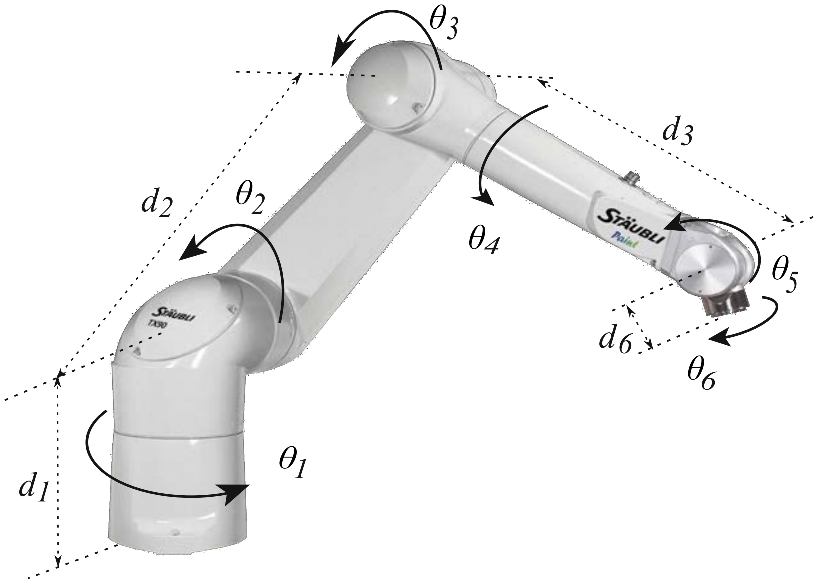
    a) $a_3 + \dfrac{a_2 \sin(\theta_1 + \theta_2)}{\sin\theta_1}$ b) $\dfrac{a_2 \sin(\theta_1 + \theta_2)}{\sin\theta_1}$ c) $a_2 \sin(\theta_1 + \theta_2)$ d) $d \sin(\theta_1)$

20. the manipulator inverse kinematics (i.e. given $[x_T \quad y_T]^T$ find θ_1)

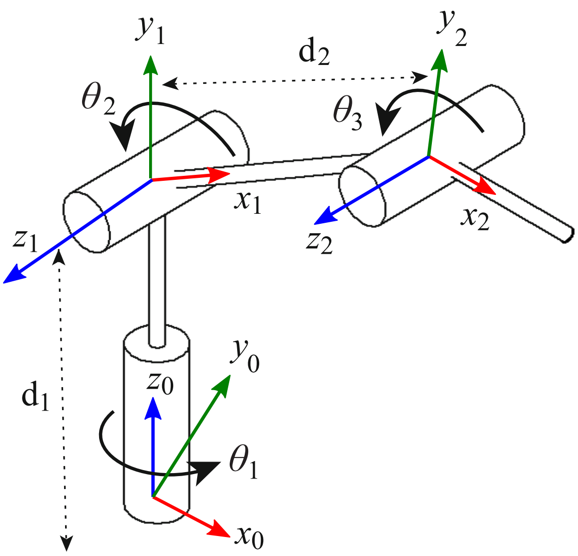
    a) $\cos(a^2 + a_2^2 - a_1^2)$ b) $a_2^2 + a^2 - 2\, a_2\, a \cos\theta_1$ c) $2\, a_2\, a \cos\theta_1$ d) $\arccos\left[\dfrac{a^2 + a_2^2 - a_1^2}{2a_2\, a}\right]$

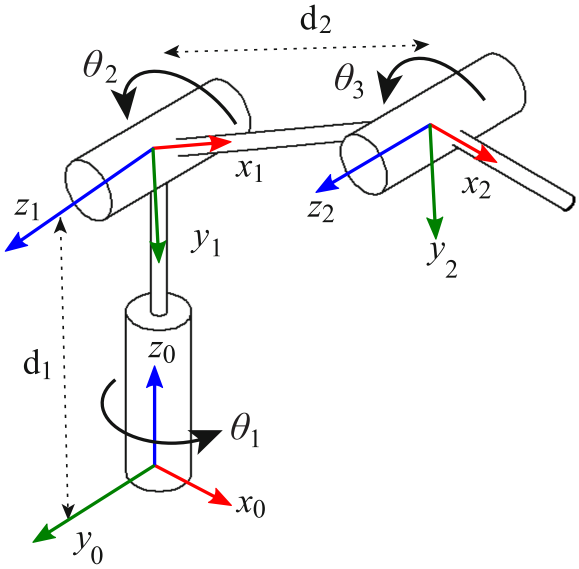
Question 5. [24 Marks] *(3 × 8)*

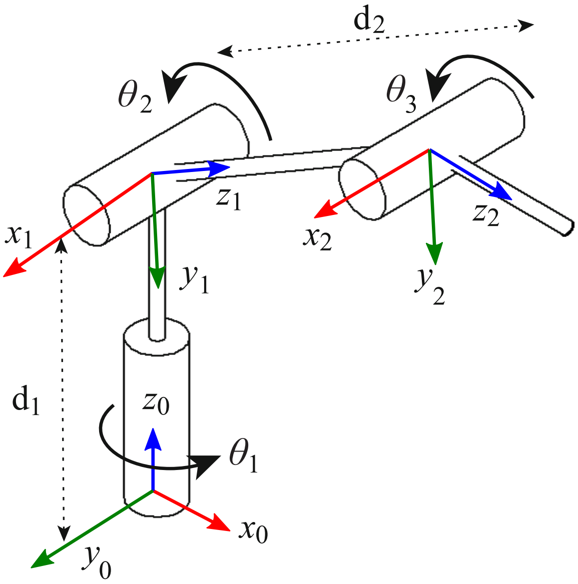
The Stäubli robot is an anthropomorphic robot with a spherical wrist as shown with its dimensions:

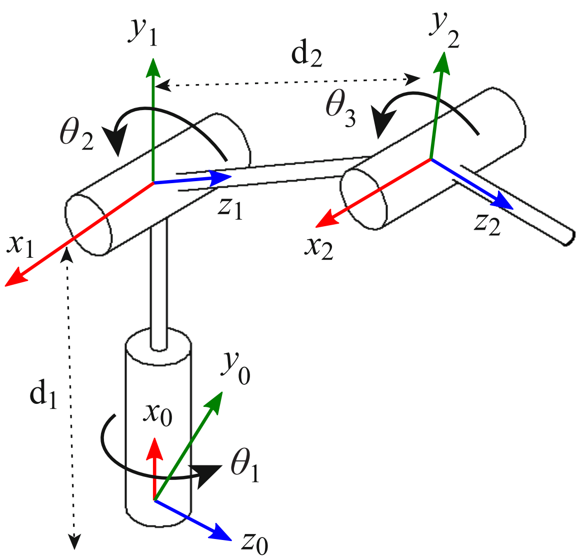


21. According to the DH conventions, we can assign frames to the first three joints as:

a)


b)


c)


d)


22. The DH parameters of the **spherical** wrist joints:

a)

Link	a_i	α_i	d_i	θ_i
4	0	-90	0	θ_4
5	0	90	0	θ_5
6	0	0	d_6	θ_6

b)

Link	a_i	α_i	d_i	θ_i
4	0	90	d_4	θ_4
5	0	90	0	θ_5
6	0	0	d_6	θ_6

c)

Link	a_i	α_i	d_i	θ_i
4	0	0	d_4	θ_4
5	0	0	0	θ_5
6	d_2	90	d_6	θ_6

d)

Link	a_i	α_i	d_i	θ_i
4	0	90	d_4	θ_4
5	0	-90	0	θ_5
6	0	0	d_6	θ_6

23. the homogeneous transformation matrices A_3 is found as:

a) $\begin{bmatrix} c_3 & 0 & s_3 & 0 \\ s_3 & 0 & -c_3 & 0 \\ 0 & 1 & 0 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ b) $\begin{bmatrix} c_3 & -s_3 & 0 & d_3\, c_3 \\ s_3 & c_3 & 0 & d_3\, s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ c) $\begin{bmatrix} c_3 & 0 & s_3 & 0 \\ s_3 & 0 & -c_3 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ d) $\begin{bmatrix} s_3 & 0 & c_3 & 0 \\ c_3 & 0 & -s_3 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Supplementary Material

Note: you *may* need some or none of these identities:

$$R_Z = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad R_Y = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}, \quad R_X = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}$$

$$A_i = \begin{bmatrix} \cos\theta_i & -\cos\alpha_i \sin\theta_i & \sin\alpha_i \sin\theta_i & a_i \cos\theta_i \\ \sin\theta_i & \cos\alpha_i \cos\theta_i & -\sin\alpha_i \cos\theta_i & a_i \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\cos(a \pm b) = \cos(a)\cos(b) \mp \sin(a)\sin(b)$$

$$\sin(a \pm b) = \sin(a)\cos(b) \pm \cos(a)\sin(b)$$

$$\sin(\theta) = -\sin(-\theta) = -\cos(\theta + 90°) = \cos(\theta - 90°)$$

$$\cos(\theta) = \cos(-\theta) = \sin(\theta + 90°) = -\sin(\theta - 90°)$$

$$\cos^2(\theta) + \sin^2(\theta) = 1$$

$$\textbf{if } \cos(\theta) = b, \textbf{ then } \theta = \operatorname{atan2}\left(\pm\sqrt{1-b^2}, b\right)$$

$$\textbf{if } \sin(\theta) = b, \textbf{ then } \theta = \operatorname{atan2}\left(b, \pm\sqrt{1-b^2}\right)$$

$$\textbf{if } a\cos(\theta) + b\sin(\theta) = c, \textbf{ then } \theta = \operatorname{atan2}(b, a) + \operatorname{atan2}\left(\pm\sqrt{a^2+b^2-c^2}, c\right)$$

$$\textbf{if } a\cos(\theta) - b\sin(\theta) = 0, \textbf{ then } \theta = \operatorname{atan2}(a, b) + \operatorname{atan2}(-a, -b)$$

For a triangle: $A^2 = B^2 + C^2 - 2BC\cos(a), \quad \frac{\sin(a)}{A} = \frac{\sin(b)}{B} = \frac{\sin(c)}{C}$

اسم الطالب :

التاريخ : / /

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رقم النموذج

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