Zagazig University,Faculty of Engineering **Midterm Exam** **Date**: 27/04/2017
Academic Year: 2016/2017 **Exam Time**: 75 Minutes
Specialization: Computer & Systems Eng. **No. of Pages**: 4
Course Name: Elective Course (5) **No. of Questions**: 3
Course Name: CSE4316:Robotics **Full Mark**: [40]
Examiner: Dr. **Mohammed Nour**

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

▷ Mark your **answers** for all questions **in the Answer Sheet** provided.

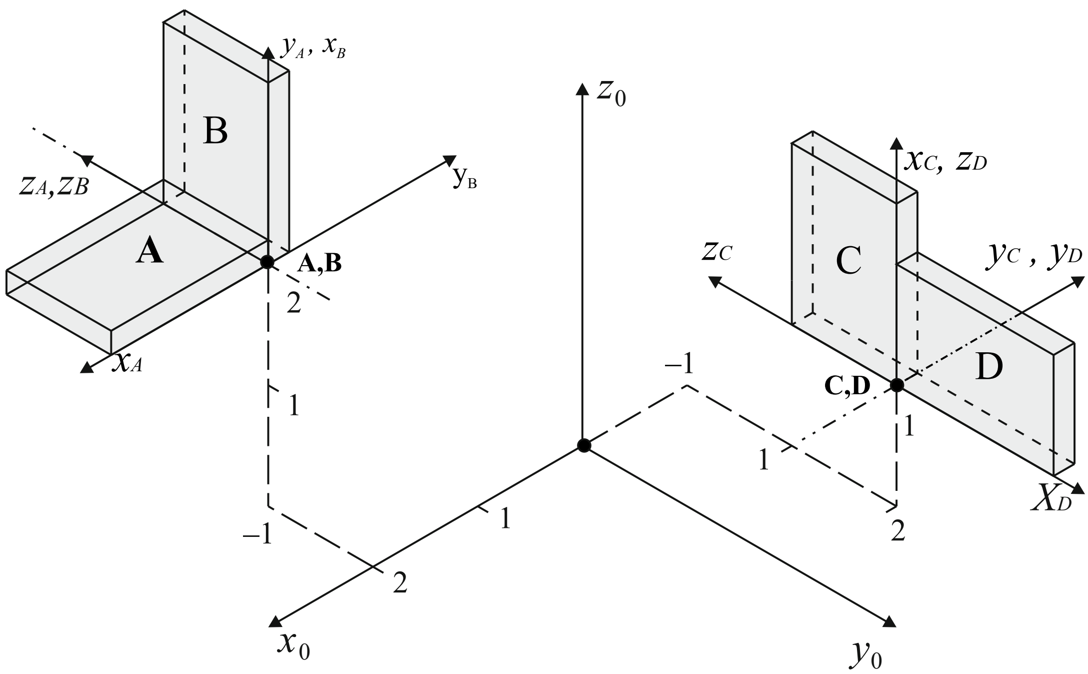
▷ In last page, some supplementary identities you *may* need.

Question 1. [10 Marks] (2 × 5)

1. Which of the following is **false** for a **parallel** manipulator
   a) it forms a closed-chain.
   b) Gruebler's formula may be applied to count its DOF
   c) its configuration space is always planar.
   d) it is two or more series chains connect the end–effector to the base.
2. Degrees of Freedom of manipulator are Number of
   a) position variables that have to be specified.
   b) configuration parameters minimally specified.
   c) of its joints.
   d) dimensions of its workspace.
3. One of the robot anthropomorphic characteristics is its
   a) mechanical arm
   b) degrees of freedom
   c) mobility as in rovers
   d) substitution for humans
4. A suitable robot configuration for high precision pick and place operations is ⋯
   a) SCARA
   b) Articulated-arm
   c) cylindrical
   d) Cartesian
5. The world reference frame is
   a) a universal fixed coordinate frame
   b) used to specify movements of each individual joint of the robot.
   c) specifies the movements of the robot tool–tip w.r.t hand frame.
   d) specifies the movements of work object w.r.t station frame.

Question 2. [15 Marks] (3 × 5)

Consider the pose of the objects A, B, C and D in space, as shown next:



6. The **relative** rotation matrix that displaces object A into the new pose **B** is:

a) $\begin{bmatrix}1&0&2\\0&1&-1\\0&0&1\end{bmatrix}$ b) $\begin{bmatrix}-1&0&2\\0&1&-1\\0&0&1\end{bmatrix}$ c) $\begin{bmatrix}0&-1&0\\1&0&0\\0&0&1\end{bmatrix}$ d) $\begin{bmatrix}0&1&0\\-1&0&0\\0&0&1\end{bmatrix}$

7. The **relative** transformation that displaces object B into the new pose **C** is:

a) $Trans(-1,3,-3)$ b) $Rot(y_B,90°)\,Trans(-1,2,1)$
c) $Trans(-1,2,1)$ d) $Rot(y_0,-90°)\,Trans(2,-1,1)$

8. The homogeneous transformation that relates frame A to frame 0 (i.e. H_A^0) is:

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

9. The homogeneous transformation that relates frame D to frame A (i.e. H_D^A) is:

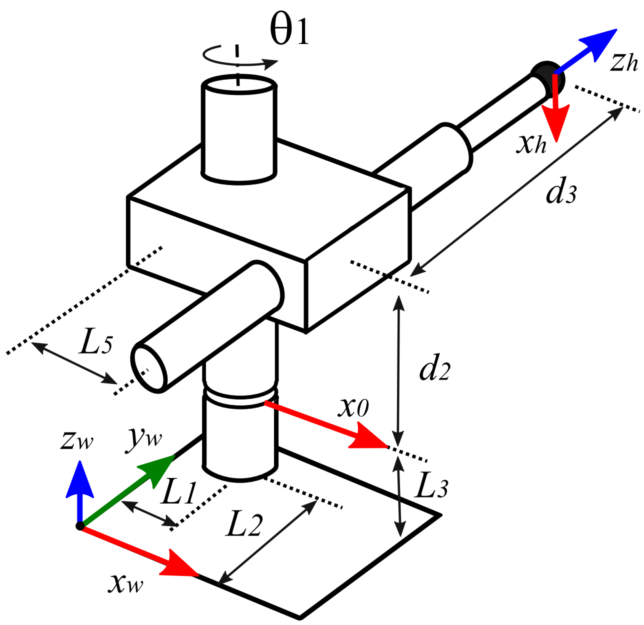
a) $\begin{bmatrix}1&1&0&-1\\0&-1&0&3\\0&0&1&-3\\0&0&0&1\end{bmatrix}$ b) $\begin{bmatrix}0&-1&0&-3\\0&0&1&-1\\-1&0&0&-3\\0&0&0&1\end{bmatrix}$ c) $\begin{bmatrix}1&0&0&3\\0&\frac{1}{\sqrt{2}}&\frac{-1}{\sqrt{2}}&2\\0&\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}&1\\0&0&0&1\end{bmatrix}$ d) $\begin{bmatrix}1&0&0&-3\\0&\frac{-1}{\sqrt{2}}&\frac{1}{\sqrt{2}}&-1\\0&\frac{1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

10. The frame transformation H_D^A can be expressed as:

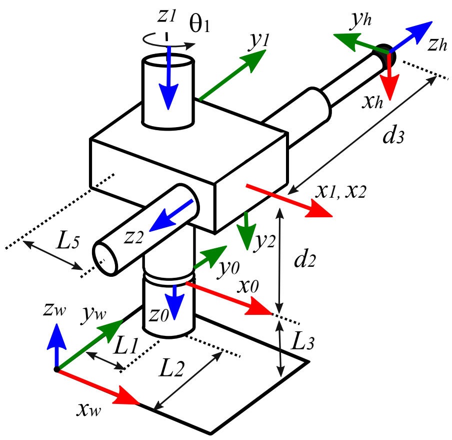
a) $\begin{bmatrix}0&-1&0&-1\\1&0&0&2\\0&0&1&1\\0&0&0&1\end{bmatrix}$ b) $\begin{bmatrix}1&0&0&-1\\0&1&0&2\\0&0&1&1\\0&0&0&1\end{bmatrix}$ c) $\begin{bmatrix}1&0&1&-1\\0&1&0&2\\-1&0&1&1\\0&0&0&1\end{bmatrix}$ d) $\begin{bmatrix}1&0&0&-1\\0&1&-1&2\\0&1&1&1\\0&0&0&1\end{bmatrix}$

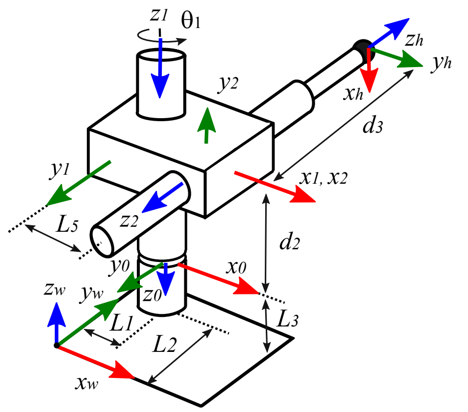
Question 3. [15 Marks] $(2+3+2+4+4)$

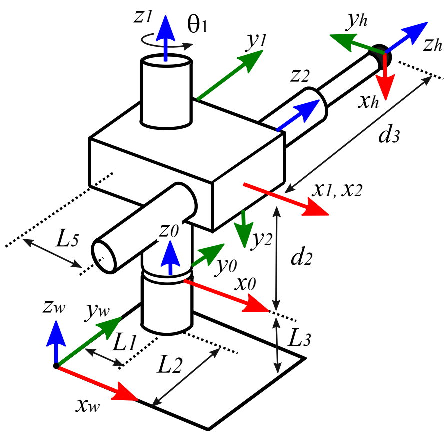
Consider the **R2P** robot manipulator mechanism shown next with $\{w\}$, $\{0\}$ and $\{h\}$ as the world, base and tool frame, respectively:

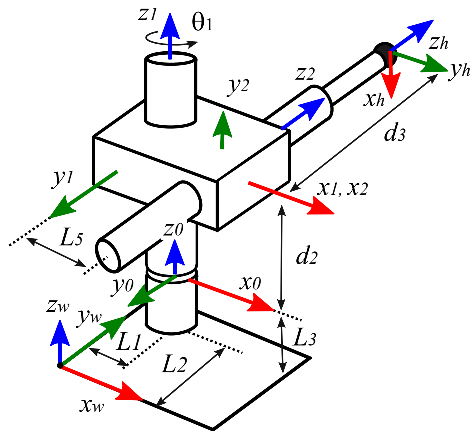


11. According to the DH conventions, we can assign frames to the joints as:

a) 

b) 

c) 

d) 

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

a)

Link	a_i	α_i	d_i	θ_i
1	L_2	0	0	θ_1^*
2	L_5	0	d_2^*	0
3	0	0	d_3^*	0

b)

Link	a_i	α_i	d_i	θ_i
1	0	0	0	θ_1^*
2	L_5	90	d_2^*	0
3	0	0	d_3^*	-90

c)

Link	a_i	α_i	d_i	θ_i
1	0	0	0	θ_1^*
2	0	0	d_2^*	90
3	L_3	0	d_3^*	0

d)

Link	a_i	α_i	d_i	θ_i
1	0	0	0	θ_1^*
2	L_5	-90	d_2^*	0
3	0	0	d_3^*	90

13. the homogeneous transformation matrix A_2 is found as:

a) $\begin{bmatrix} c_2 & -s_2 & 0 & 0 \\ s_2 & c_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ b) $\begin{bmatrix} 1 & 0 & 0 & L_5 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ c) $\begin{bmatrix} 0 & -1 & 0 & L_2 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ d) $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & -1 & L_3 \\ 0 & 1 & 1 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

14. The robot tool–tip coordinates can be expressed in the base frame using T_h^0 that is calculated as:

a) $\begin{bmatrix} 0 & -c_1 & -s_1 & -s_1 d_3 + c_1 L_3 \\ 0 & s_1 & c_1 & c_1 d_3 + s_1 L_3 \\ -1 & 0 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ b) $\begin{bmatrix} 0 & c_1 & s_1 & -s_1 d_3 + c_1 \\ 0 & -s_1 & -c_1 & c_1 d_3 + s_1 \\ 1 & 0 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

c) $\begin{bmatrix} 0 & s_1 & c_1 & c_1 d_3 + s_1 + L_1 \\ 0 & -c_1 & -s_1 & s_1 d_3 + c_1 + L_2 \\ -1 & 0 & 0 & d_2 + L_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ d) $\begin{bmatrix} 0 & -c_1 & -s_1 & -s_1 d_3 + c_1 L_5 \\ 0 & s_1 & c_1 & c_1 d_3 + s_1 L_5 \\ -1 & 0 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

15. At the configuration $\mathbf{q} = [0°, L_4, L_6]^T$, the hand **pose** at this configuration is calculated as:

a) $\begin{bmatrix} 0 & 1 & 0 & L_1 \\ 0 & 0 & -1 & L_6 \\ -1 & 0 & 0 & L_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ b) $\begin{bmatrix} 0 & 1 & 0 & L_3+L_4 \\ 0 & 0 & 1 & L_2+L_5 \\ 1 & 0 & 0 & L_1+L_6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ c) $\begin{bmatrix} 0 & -1 & 0 & L_3 \\ 0 & 0 & 1 & L_2 \\ -1 & 0 & 0 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ d) $\begin{bmatrix} 0 & -1 & 0 & L_5+L_1 \\ 0 & 0 & 1 & L_6+L_2 \\ -1 & 0 & 0 & L_4+L_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Supplementary Material

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

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

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

$$\cos(a \pm b) = \cos(a)\cos(b) \mp \sin(a)\sin(b) \qquad \sin(\theta) = -\sin(-\theta) = -\cos(\theta + 90°) = \cos(\theta - 90°)$$

$$\sin(a \pm b) = \sin(a)\cos(b) \pm \cos(a)\sin(b) \qquad \cos(\theta) = \cos(-\theta) = \sin(\theta + 90°) = -\sin(\theta - 90°)$$

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

if $\cos(\theta) = b$, **then** $\theta = \operatorname{atan2}\left(\pm\sqrt{1-b^2}, b\right)$ **For a triangle:** $A^2 = B^2 + C^2 - 2BC\cos(a)$, $\frac{\sin(a)}{A} = \frac{\sin(b)}{B} = \frac{\sin(c)}{C}$

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

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

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