Middle Technical University
Eng. Tech. College/Baghdad
Mechatronics Tech. Eng. Dept.
Final Exam
Date: 24/ 5/2018

الكلية التقنية الهندسية
TECHNICAL ENGINEERING COLLEGE
2017 / 2018

Subject : Robotics
Class : Fourth stage
Time : 3 Hours
Examiner : Dr. Basil

Note: Answer Four Questions only ---

Q1

25 Marks

(A)- *Answer three of the following:*

1- Define the following Robotics terms:
DOF ; End-effector ; Workspace ; Pose ; Link ; Dynamics ; Sensor.

2- List the main three robot power drive (actuator) systems with the positive and negative characteristics of each of them.

3- List the main four robot control methods with brief description.

4- Identify the manipulator singularities and mention four reasons for the importance of studying them.

(B)-

Drive the basic 2D rotation of an arbitrary point P(x, y) around the origin in matrix notation, **Figure (1)**.

Q2

25 Marks

(A)-

Consider the six-link Stanford manipulator of **Figure (2)**. The origins of the joints of first three links are indicated separately while for the last three joints of the spherical wrist intersect at the same point but they are shown separated for clarification.

1- Indicate the axes for each frame at the required joint.

2- Find the link parameters for each link.

3- Determine the transformation matrices **A1, A2, A3, A4, A5, A6** based on the DH-convention.

(B)-

Consider the three-link Cylindrical manipulator of **Figure (3)**. The origins of the joints are indicated.

1- Indicate the axes for each frame at the required joint.

2- Find the link parameters for each link.

3- Determine the transformation matrices **A1, A2, A3** based on the DH-convention.

4- Compute the forward kinematics equations T_3^0 .

Q3

25 Marks

(A)-

Consider the Elbow manipulator shown in **Figure (4)**. At certain pose at the end of the mounted end-effector, the orientation and position is given by the matrix ***H*** shown in **Figure** below. In the context of the Inverse Kinematics, calculate the following joint parameters to achieve the required pose:

1- All the possible values for Θ_1 with and without offset.
2- All the possible values for Θ_2 and Θ_3 with offset.

- Use : tool length **d6=5 cm**, offset **d = 10 cm , a2=37 cm, a3=35 cm**
- Note that the position vector values in ***H*** are indicated in centimeter unit.

$$H = \begin{bmatrix} 0.422 & -0.906 & 0.24 & 40 \\ 0.906 & 0.422 & 0.81 & 50 \\ -0.23 & 0.451 & 0.16 & 25 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(B)-

For the Spherical manipulator with six-degree of freedom, at certain pose of the end-effector, the orientation of the end-effector is given by the matrix $\boldsymbol{R_6^0}$ shown in **figure (a)** below. In the context of the Inverse Kinematics, calculate all possible values of the last three joint parameters (Θ_4 , Θ_5 , and Θ_6) to achieve this pose.

- Note that the derived rotation matrix for the Spherical manipulator for the first three-degree of freedom $\boldsymbol{R_3^0}$ **= A1 A2 A3** is given in **figure (b)** below.
- The general derived rotation matrix $\mathbf{R_6^3}$ for the spherical wrist is given in **figure (c)** below
- Use : Θ_1 **= 30°**, Θ_2 **= -20°**.

figure (a)

$$R = \begin{bmatrix} 0.3 & -0.91 & 0.26 \\ 0.9 & 0.36 & 0.22 \\ -0.29 & 0.17 & 0.94 \end{bmatrix}$$

$$R_3^0 = \begin{bmatrix} C1C2 & -S1 & C1S2 \\ S1C2 & C1 & S1S2 \\ -S2 & 0 & C2 \end{bmatrix}$$

figure (b)

$$R_6^3 = \begin{bmatrix} C_4C_5C_6 - S_4S_6 & -C_4C_5S_6 - S_4C_6 & C_4S_5 \\ S_4C_5C_6 + C_4S_6 & -S_4C_5S_6 + C_4C_6 & S_4S_5 \\ -S_5C_6 & S_5S_6 & C_5 \end{bmatrix}$$

figure (c)

Q4

25 Marks

(A)-

For the four link SCARA manipulator (RRPR) shown in **Figure (5)**, the transformation matrix **A** for each link is given below. Find the **6*4** Jacobian matrix of this robot.

$$A1 = \begin{bmatrix} c1 & -s1 & 0 & a1c1 \\ s1 & c1 & 0 & a1s1 \\ 0 & 0 & 1 & d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad A2 = \begin{bmatrix} c2 & s2 & 0 & a2c2 \\ s2 & -c2 & 0 & a2s2 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad A3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad A4 = \begin{bmatrix} c4 & -s4 & 0 & 0 \\ s4 & c4 & 0 & 0 \\ 0 & 0 & 1 & d4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(B)-

Investigate arm singularities from the given portion of the Jacobian of the SCARA robot **J11** shown below.

$$J11 = \begin{bmatrix} -a_1 s_1 - a_2 s_{12} & -a_2 s_{12} & 0 \\ a_1 c_1 + a_2 c_{12} & a_2 c_{12} & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

Q5

25 Marks

(A)-

The trajectory of a particular joint is specified as follows: Path points in degrees: **10, 35, 25**, and **10**. The duration of these three segments should be: **2, 1**, and **3** seconds, respectively. The magnitude of the default acceleration to use at all blend points is **50** degrees / second^2. Calculate all segment velocities, blend times, and linear times.

(B)-

The trajectory of a single-link rotary joint of a robot is to be specified over a path segment from Θ_o = **20** to Θ_f = **65** degrees in **5** seconds.

- Solve for the coefficients of one quantic polynomial with initial velocity and acceleration of **10, 30** respectively, and with final velocity and acceleration of **-7, -40** respectively.
- Find the equations of the position, velocity, and acceleration of this segment.

Sinusoidal functions you may need:

Sin (α + β) = sin α cos β + cos α sin β

Sin (α - β) = sin α cos β - cos α sin β

Cos (α + β) = cos α cos β - sin α sin β

Cos (α - β) = cos α cos β + sin α sin β

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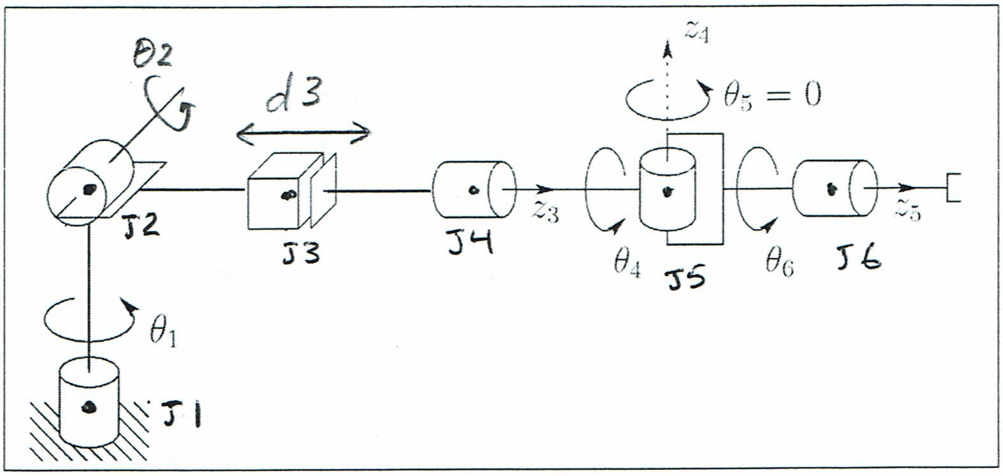

Figure 2

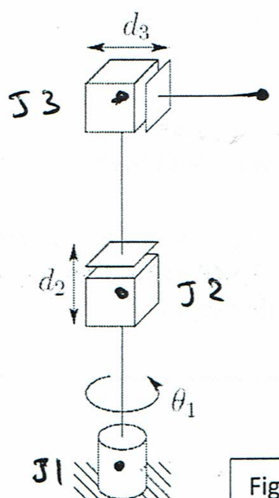

Figure 3

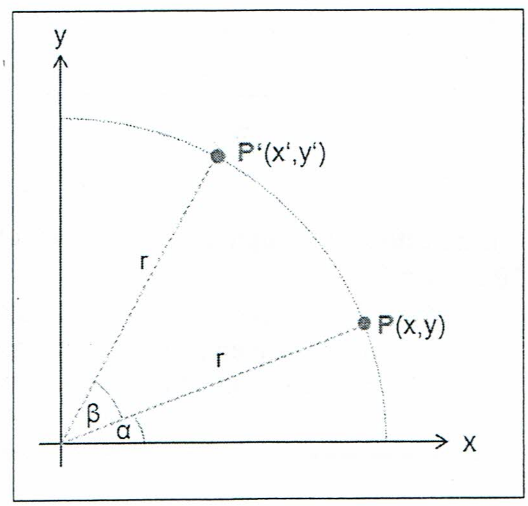

Figure 1

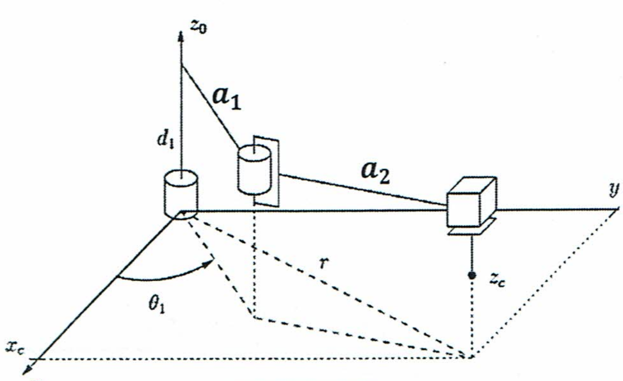

Figure 5

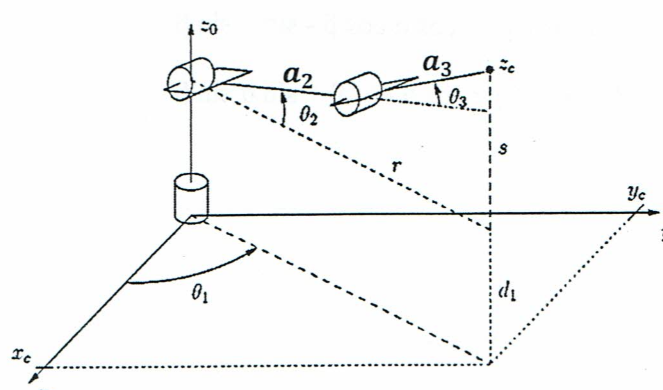

Figure 4