UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
(ONLINE)
SEMESTER II
SESSION 2019/2020

COURSE NAME	:	ROBOTICS SYSTEM
COURSE CODE	:	BEH 41703
PROGRAMME	:	BEJ
EXAMINATION DATE	:	JULY 2020
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS **OPEN BOOK EXAMINATION**

THIS QUESTION PAPER CONSISTS OF **SIX (6)** PAGES

Q1 *Consider the following Puma 560 robot arm with four rotary joints in* ***Figure Q1.***

(a) List **FOUR (4)** Denavit-Hartenberg rules to obtain Denavit-Hartenberg parameters

(4 marks)

(b) Evaluate the Denavit-Hartenberg parameters for the Puma 560 robot arm by applying the Denavit-Hartenberg rules.

(8 marks)

(c) Derive the forward kinematics matric H_0^4 for the Puma 560 robot arm

$$H_{i-1}^{i} = \begin{bmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i C\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i C\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(13 marks)

Q2 (a) Define the **FIVE (5)** differences between Forward Kinematic and Inverse Kinematic.

(5 marks)

(b) **Figure Q2** shows a spherical arm with two rotary joins and a prismatic join. The seven trigonometric equations and their solution are given in **Table Q2.** Analyse the inverse position (i.e. joint angles) of the spherical arm by using the seven trigonometric equations.

$$H_0^3 = \begin{bmatrix} -S\theta_1 & C\theta_1 C\theta_2 & C\theta_1 S\theta_2 & d_3 C\theta_1 S\theta_2 + d_2 S\theta_1 \\ C\theta_1 & S\theta_1 C\theta_2 & S\theta_1 S\theta_2 & d_3 S\theta_1 S\theta_2 - d_2 C\theta_1 \\ 0 & -S\theta_2 & -C\theta_2 & d_1 - d_3 C\theta_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(20 marks)

Q3 ***Figure Q3*** *shows a three-link RRR spatial manipulator with assigned frames and* link parameters as tabulated in following **Table Q3**.

(a) Derive the transformation matrix of H_0^3.

(8 marks)

$$H_{i-1}^{i} = \begin{bmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i C\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i C\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(b) Calculate the Jacobian of the linear velocities of the RRR manipulator.

(8 marks)

(c) Briefly discuss about the problem of singularities.

(2 marks)

(d) Analyze the singularities of the two simple two-link arm as shown in **Figure Q3**.

(6 marks)

Q4 The second joint of Stanford arm manipulator is required to move from an initial position of 20 degrees to a final position of 68 degrees in 4 seconds. Assume that the joint starts and finishes at zero velocity.

(a) Design the cubic polynomial that connects initial joint-angle position with desired final position.

(6 marks)

(b) Find the joint velocity and acceleration along the path.

(4 marks)

(c) Analyze the position, velocity and acceleration of this joint at intervals of one second and sketch their plots against time.

(15 marks)

-END OF QUESTIONS-

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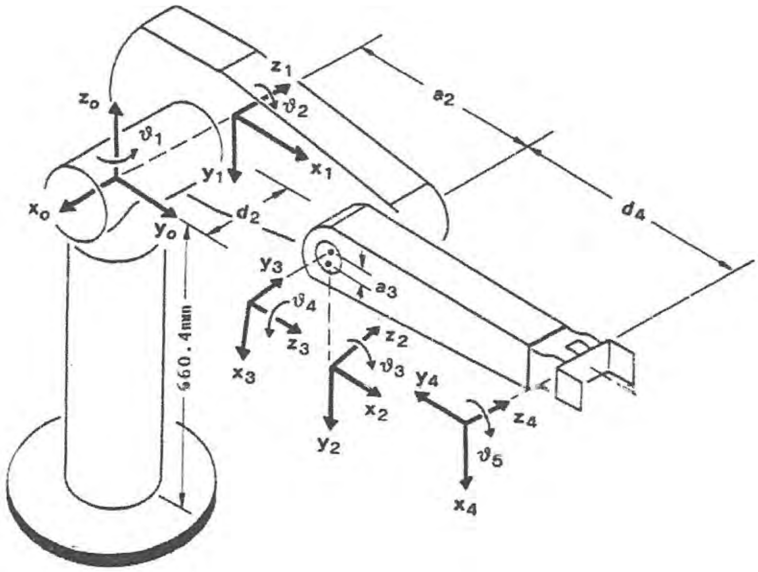

Figure Q1

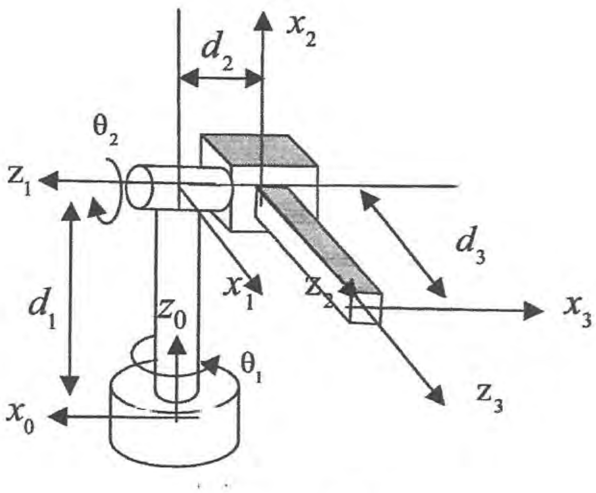

Figure Q2

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Table Q2

Equation	Solution
(a) $\sin\theta = a$	$\theta = Atan2\left(a, \pm\sqrt{1-a^2}\right)$
(b) $\cos\theta = b$	$\theta = Atan2\left(\pm\sqrt{1-b^2}, b\right)$
(c) $\begin{cases} \sin\theta = a \\ \cos\theta = b \end{cases}$	$\theta = Atan2\,(a, b)$
(d) $a\cos\theta - b\sin\theta = 0$	$\theta^{(1)} = Atan2(a, b)$ $\theta^{(2)} = Atan2(a, b) = \pi + \theta^{(1)}$
(e) $a\cos\theta + b\sin\theta = c$	$\theta^{(1)} = Atan2\left(c, \sqrt{a^2+b^2-c^2}\right) - Atan2\,(a, b)$ $\theta^{(2)} = Atan2\left(c, -\sqrt{a^2+b^2-c^2}\right) - Atan2\,(a, b)$
(f) $\begin{cases} a\cos\theta - b\sin\theta = c \\ a\sin\theta + b\cos\theta = d \end{cases}$	$\theta = Atan2\,(ad-bc, ac+bd)$
(g) $\begin{cases} \sin\alpha\sin\beta = a \\ \cos\alpha\sin\beta = b \\ \cos\beta = c \end{cases}$	$\begin{cases} \alpha^{(1)} = Atan2\,(a, b) \\ \beta^{(1)} = Atan2\left(\sqrt{a^2+b^2}, c\right) \end{cases}$ $\begin{cases} \alpha^{(2)} = Atan2\,(-a, -b) = \pi + \alpha^{(1)} \\ \beta^{(2)} = Atan2\left(-\sqrt{a^2+b^2}, c\right) \end{cases}$

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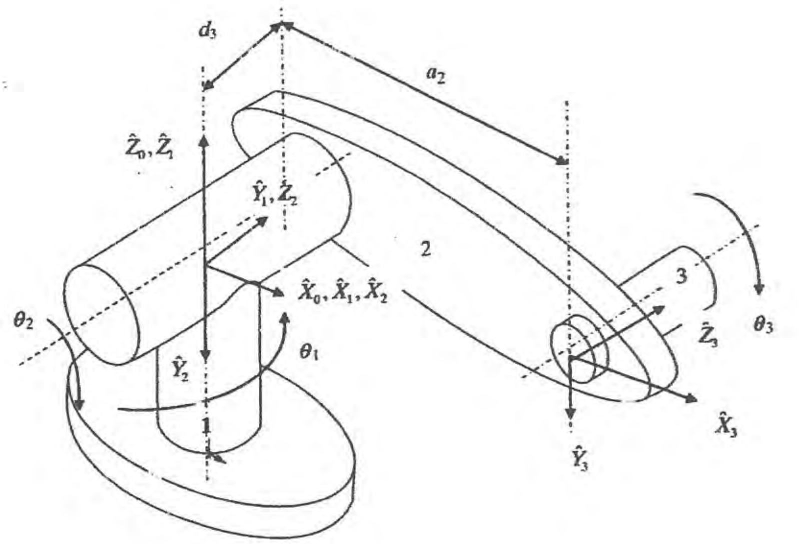

Figure Q3

Table Q3 Three-link RRR spatial manipulator link parameters

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	-90°	0	0	θ_2
3	0	a_2	d_3	θ_3