Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2018/2019

COURSE NAME	:	ROBOTIC SYSTEMS
COURSE CODE	:	BEH 41703
PROGRAMME CODE	:	BEJ
EXAMINATION DATE	:	DECEMBER 2018 / JANUARY 2019
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

THIS QUESTION PAPER CONSISTS OF **EIGHT (8)** PAGES

Q1 Consider the robot shown in **Figure Q1** with two rotary joints and a prismatic joint.

(a) Assign coordinate frames to the robot arm using the D-H algorithm.

(5 marks)

(b) Obtain a table of the D-H parameters of the robot.

(5 marks)

(c) Construct the transformation matrices H_0^1, H_1^2 and H_2^3 by using the D-H matrix as given below:

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

(5 marks)

(d) Produce the forward kinematics matric H_0^3.

(5 marks)

Q2 (a) Define the differences between forward kinematics with inverse kinematics

(4 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 (joint angles) of $\boldsymbol{\theta_1}$ and $\boldsymbol{d_3}$ by using the D-H matrix as given below:

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

(16 marks)

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

Table Q3 Three-link RRR spatial manipulator link parameters

i	α_i	a_i	d_i	θ_i
1	0	0	0	θ_1
2	-90°	0	0	θ_2
3	0	a_2	d_3	θ_3

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

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

(6 marks)

(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(d)**.

(4 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.

(2 marks)

(c) Calculate the position, velocity and acceleration of this joint at intervals of 1 second and sketch their plots against time.

(12 marks)

Q5 Consider the point masses m_1 and m_2 at the distal end of links of the θ-r robot manipulator with a rotary joint and a prismatic join shown in **Figure Q5**.

(a) Identify the Cartesian coordinates of the point masses m_1 and m_2.

(2 marks)

(b) Calculate the velocities of the point masses m_1 and m_2.

(3 marks)

(c) Analyze the total potential energy of the manipulator.

(6 marks)

(d) Find the Lagrangian function of the θ-r robot manipulator by using $L = K(q, \dot{q}) - P(q)$.

(2 marks)

(e) Derive the differential equations of motion of the θ-r robot manipulator by applying the following function:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) - \frac{\partial L}{\partial q_1} = \tau_1$$

where

$K(q, \dot{q})$ is the total kinetic energy

$P(q)$ is the total potential energy store in the system

τ_1 is the external torque/force

(7 marks)

-END OF QUESTION-

FINAL EXAMINATION

SEMESTER/SESSION	: SEM I / 2018/2019	PROGRAMME	: BEJ
COURSE	: ROBOTIC SYSTEMS	COURSE CODE	: BEH41703

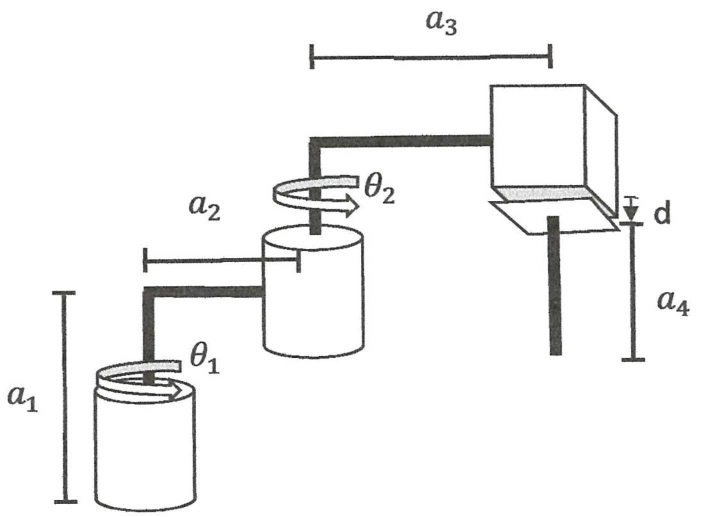

FIGURE Q1

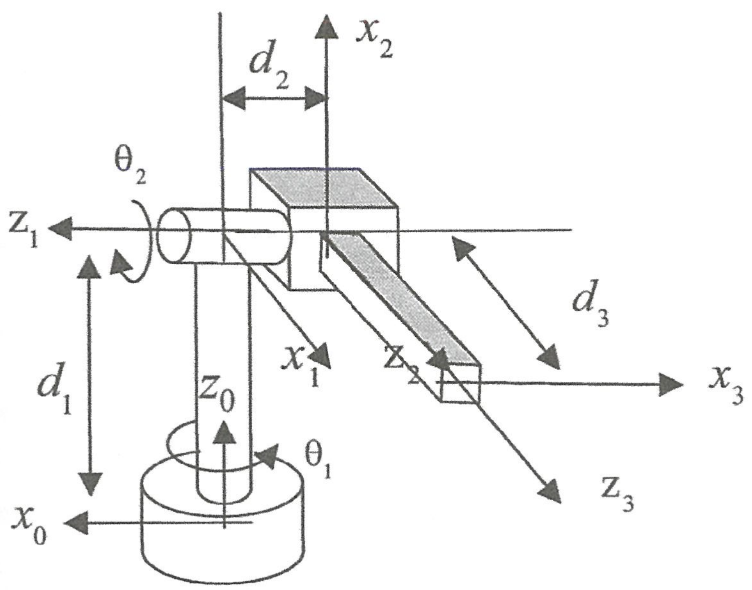

FIGURE Q2

FINAL EXAMINATION

SEMESTER/SESSION : SEM I / 2018/2019 PROGRAMME : BEJ
COURSE : ROBOTIC SYSTEMS COURSE CODE : BEH41703

TABLE Q2

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

FINAL EXAMINATION

SEMESTER/SESSION	: SEM I / 2018/2019	PROGRAMME	: BEJ
COURSE	: ROBOTIC SYSTEMS	COURSE CODE	: BEH41703

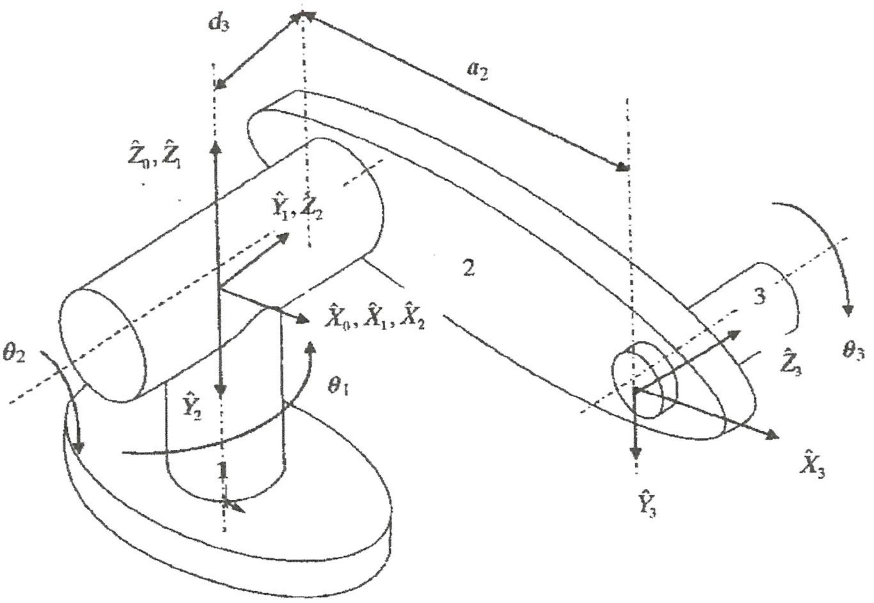

FIGURE Q3

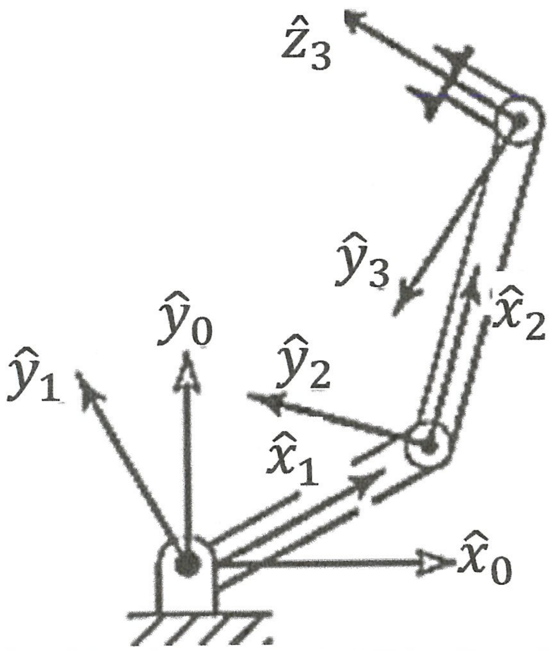

FIGURE Q3(d)

FINAL EXAMINATION

SEMESTER/SESSION : SEM I / 2018/2019 PROGRAMME : BEJ
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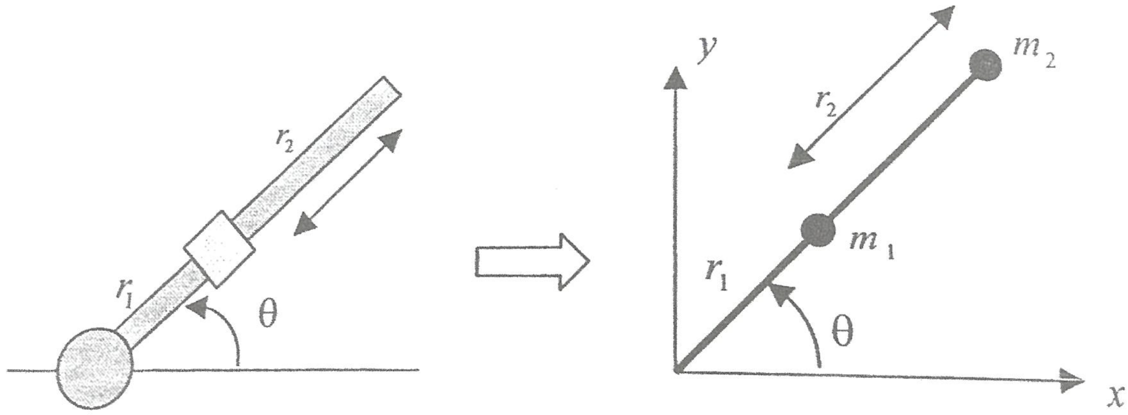

FIGURE Q5