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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2016/2017

COURSE NAME	:	ROBOTIC SYSTEMS
COURSE CODE	:	BEH 41703
PROGRAMME	:	BEJ
EXAMINATION DATE	:	DECEMBER 2016/JANUARY 2017
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

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

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Q1 **Figure Q1** shows a three-link articulated robot arm. The seven trigonometric and their solutions are given in **Table Q1**. The forward kinematic solution is given as below. Formulate the inverse position of the articulated arm from this forward kinematic, H_3^0.

$$H_0^3 = H_0^1 H_1^2 H_2^3 = \begin{bmatrix} C_1C_{23} & -C_1S_{23} & S_1 & C_1(eC_2+fC_{23}) \\ S_1C_{23} & -S_1S_{23} & -C_1 & S_1(eC_2+fC_{23}) \\ S_{23} & C_{23} & 0 & eS_2+fS_{23}+d \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(20 marks)

Q2 (a) Explain the motion kinematics and its usage.

(2 marks)

(b) Briefly discuss on how to avoid the problem of singularity.

(3 marks)

(c) **Figure Q2(c)** shows a spherical wrist with three rotary joints, where the joint z_4 , z_5 and z_6 at one point. By applying the transformation matrix and arm parameters as in **Table Q2(c),** solve the following Jacobian matrix.

Transformation matrix

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

Jacobian matrix

$$\begin{bmatrix} v_x \\ v_y \\ v_z \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial q_1} & \frac{\partial f_1}{\partial q_2} & \frac{\partial f_1}{\partial q_3} \\ \frac{\partial f_2}{\partial q_1} & \frac{\partial f_2}{\partial q_2} & \frac{\partial f_2}{\partial q_3} \\ \frac{\partial f_3}{\partial q_1} & \frac{\partial f_3}{\partial q_2} & \frac{\partial f_3}{\partial q_3} \\ \eta_1 R^0_{3(3col)} & \eta_2 R^1_{3(3col)} & \eta_3 R^2_{3(3col)} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_4 \\ \dot{q}_5 \\ \dot{q}_6 \end{bmatrix}$$

(15 marks)

Q3 (a) Define the usage of the dynamics equations.

(2 marks)

(b) **Figure Q3(b)** shows a robot manipulator with two revolute joints. The link lengths are l_1 and l_2 and the link masses, m_1 and m_2. Evaluate the differential equations of motion of the manipulator by applying the Lagrange function as follows:

$$L = K(q,\dot{q}) - P(q)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_1}\right) - \frac{\partial L}{\partial q_1} = \tau_1$$

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

$$\begin{bmatrix} v_x \\ v_y \\ v_z \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial q_1} & \frac{\partial f_1}{\partial q_2} & \frac{\partial f_1}{\partial q_3} \\ \frac{\partial f_2}{\partial q_1} & \frac{\partial f_2}{\partial q_2} & \frac{\partial f_2}{\partial q_3} \\ \frac{\partial f_3}{\partial q_1} & \frac{\partial f_3}{\partial q_2} & \frac{\partial f_3}{\partial q_3} \\ \eta_1 R^0_{3(3col)} & \eta_2 R^1_{3(3col)} & \eta_3 R^2_{3(3col)} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_4 \\ \dot{q}_5 \\ \dot{q}_6 \end{bmatrix}$$

(18 marks)

Q4 (a) Consider a single - link robot manipulator with a rotary joint. Design its trajectory with following two cubic segments. The first segment connects the initial angular position of θ(0)=30° to the via point θ(1)=5°, and the second segment connects the via point θ(1)=5° to the final angular position θ(2)=90°. The designed trajectory should have zero initial velocity and zero final velocity. Also, at the via point θ(1)=5°, the trajectory should have continuous velocity and acceleration.

(16 marks)

(b) Explain why, it is necessary to specify the via points in designing the trajectory in some situations.

(2 marks)

(c) Discuss the advantage of LSPB (Linear segment with two parabolic blends) in term of velocity and acceleration trajectory compared to normal trajectory.

(2 marks)

Q5 Consider a single- link robot manipulator with a rotary joint as shown in **Figure Q5**. The differential equation of the single link robot manipulator is given by

$$\left(I_m + \frac{I_l}{n^2}\right)\ddot{\theta}_m + \left(B_m + \frac{B_l}{n^2}\right)\dot{\theta} + \frac{mgl}{n}\sin\left(\frac{\theta_m}{n}\right) = u$$

(a) Formulate the linear equation of differential equation with some assumptions.

(5 marks)

(b) Obtain the Laplace equation of the transfer function of $\frac{\theta_m(s)}{U(s)}$ based on linearized equation in **Q5(a)**.

(4 marks)

(c) Draw a block diagram and label of the complete system with PD controller. Hint: PD controller = K_p+K_ds.

(5 marks)

(d) Design the PD controller with stable values of K_p dan K_d. Hint : Characteristic Equation =1+G(s)H(s)=0.

(6 marks)

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- END OF QUESTIONS -

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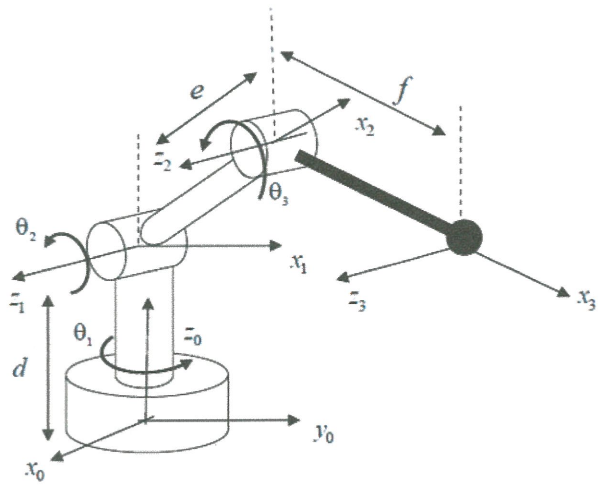

Figure Q1

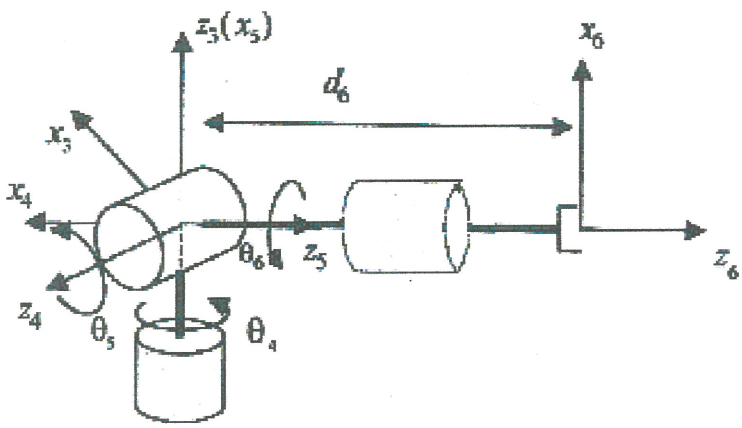

Figure Q2(c)

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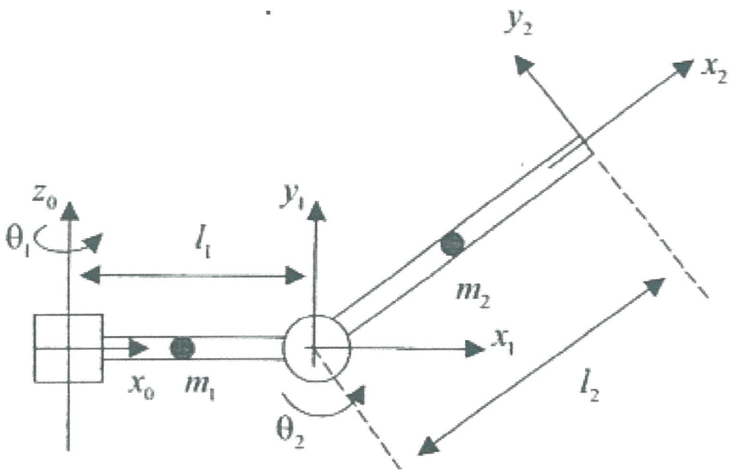

Figure Q3(b)

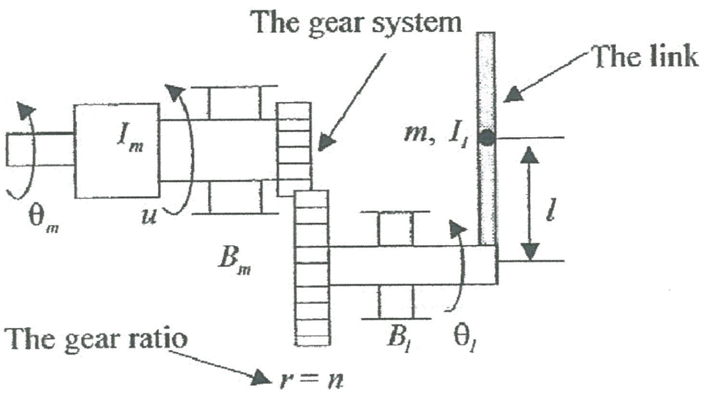

Figure Q5

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TABLE Q1

Equation(s)	Solution(s)
(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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TABLE Q2(c)

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