UTHM
Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2015/2016

COURSE NAME	:	ROBOTIC SYSTEMS
COURSE CODE	:	BEH41703
PROGRAMME	:	BACHELOR OF ELECTRONIC ENGINEERING WITH HONOURS
EXAMINATION DATE	:	DECEMBER 2015 / JANUARY 2016
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

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

Q1 (a) With the block diagrams, compare the usage of forward kinematics and inverse kinematics in relation to robotic manipulators.

(4 marks)

(b) Differentiate the usage of major axes and minor axes with regards to kinematics study.

(4 marks)

(c) Discuss **THREE** (3) type of the sensor and the applications of sensors in the robotic systems.

(7 marks)

(d) Discuss the reasons why the inverse kinematic problem for robotic system is one of the most difficult to be solved.

(5 marks)

Q2 **Figure Q2** shows a three-link articulated robot arm with three revolute joints. The seven trigonometric equations and their solutions are given in Table **Q2.** The forward kinematic solution is given as below. Analyze the inverse position of the ariculated arm from this forward kinematic, H_0^{3}.

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

(20 marks)

Q3 (a) Explain the Jacobian matrix with its application.

(2 marks)

(b) Discuss about the problem of singularity. (3 marks)

(c) **Figure Q3(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 **Q3(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)

Q4 (a) List **TWO** (2) main reasons to use the dynamics equations.

(2 marks)

(b) **Figure Q4(b)** shows a two-link robot manipulator. The link lengths are l_1 and l_2 and the link masses are m_1 and m_2 respectively. Evaluate the differential equations of motion of the θ–*r* 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

(18 marks)

Q5 Consider a single- link robot manipulator with a rotary joint as shown in **Figure Q5**. The deferential equation of the above single link robot manipulator 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) Linearized the differential equation with some assumptions (5 marks)

(b) Based on linearized equation transform to the Laplace equation to formulate the transfer function of $(\theta_m(s))/(U(s))$. (4 marks)

(c) Draw a block diagram and label of the complete system with PI controller. (Hint: The transfer function of a PI controller $G(s) = K_P + K_i/s$) (5 marks)

(d) Obtain the transfer function PI controller with stable values of K_P and K_i (Hint : Characteristic Equation, 1+G(s)H(s)=0). (6 marks)

- END OF QUESTION -

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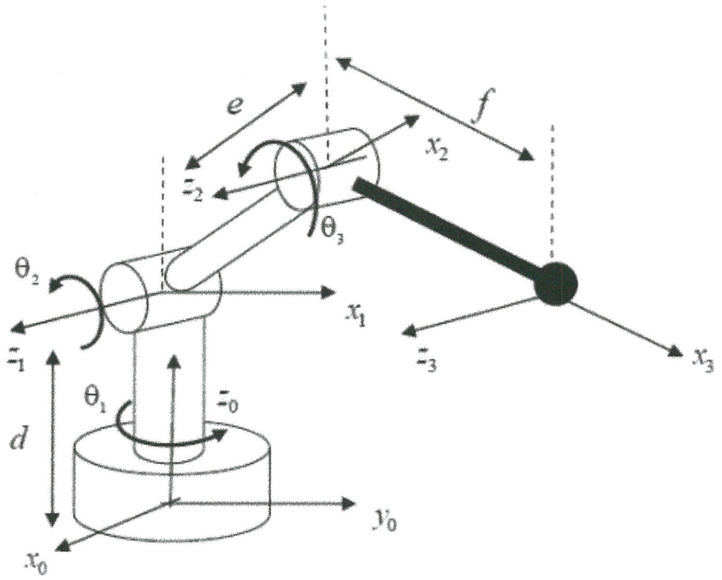

FIGURE Q2

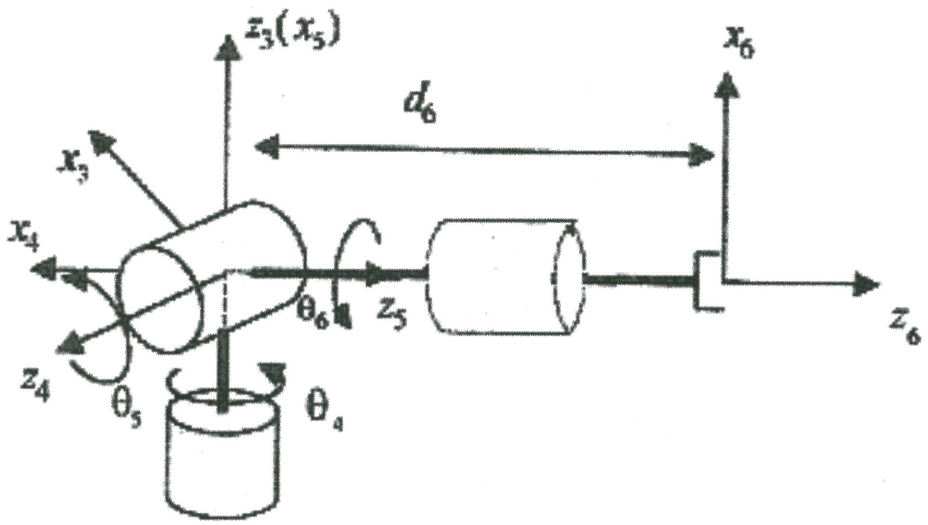

FIGURE Q3(c)

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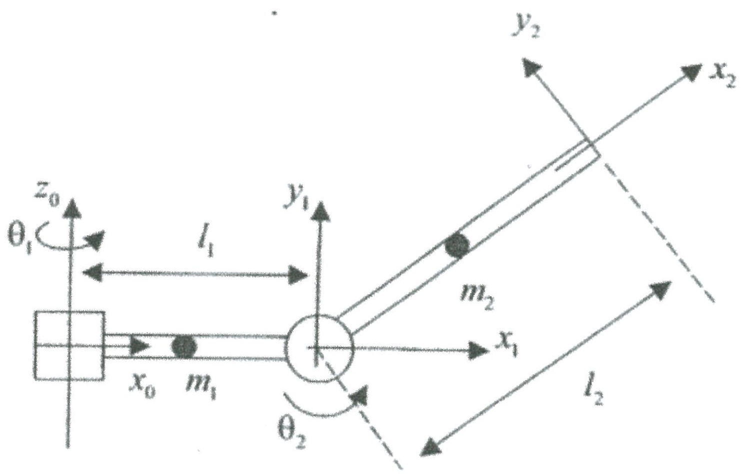

FIGURE Q4(b)

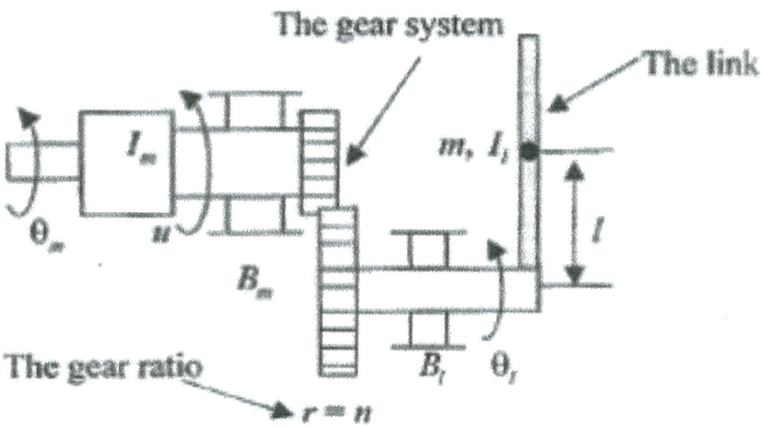

FIGURE Q5

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TABLE Q2

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 Q3(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