Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2014/2015

COURSE NAME	:	ROBOTIC SYSTEMS
COURSE CODE	:	BEH 41703
PROGRAMME	:	4 BEJ
EXAMINATION DATE	:	DECEMBER 2014 / JANUARY 2015
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

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

Q1 (a) With the help of a block diagram, 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) (i) List three (3) applications of robotic systems.
(ii) For each application discuss which type of the manipulator that would be best suited and least suited.
(iii) Clarify your choices in each case.

(7 marks)

(d) Construct a block diagram of a closed loop position control system of robot completed with labels and briefly define each part. The block diagram should indicate the block of kinematics, dynamics, trajectory, control system and type of sensors.

(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. Obtain and 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 and list its applications.

(2 marks)

(b) Briefly 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 dynamic 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 (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 the $\theta(0)=20°$ to the via point $\theta(1)=5°$, and the second segment connects the via point $\theta(1)=5°$ to the final angular position $\theta(2)=70°$. The designed trajectory should have zero initial velocity and zero final velocity. Also, at the via point $\theta(1)=5°$, the trajectory should have continuous velocity and acceleration.

(16 marks)

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

(2 marks)

(c) Disscuss the reasons that LSPB (Linear segment with two parabolic blends) trajectory is much better in term of velocity and acceleration trajectory compared to normal trajectory.

(2 marks)

- END OF QUESTION -

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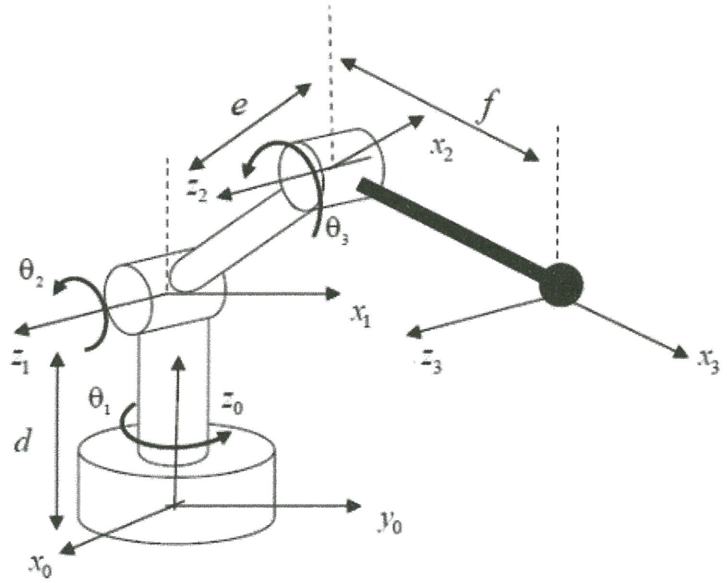

FIGURE Q2

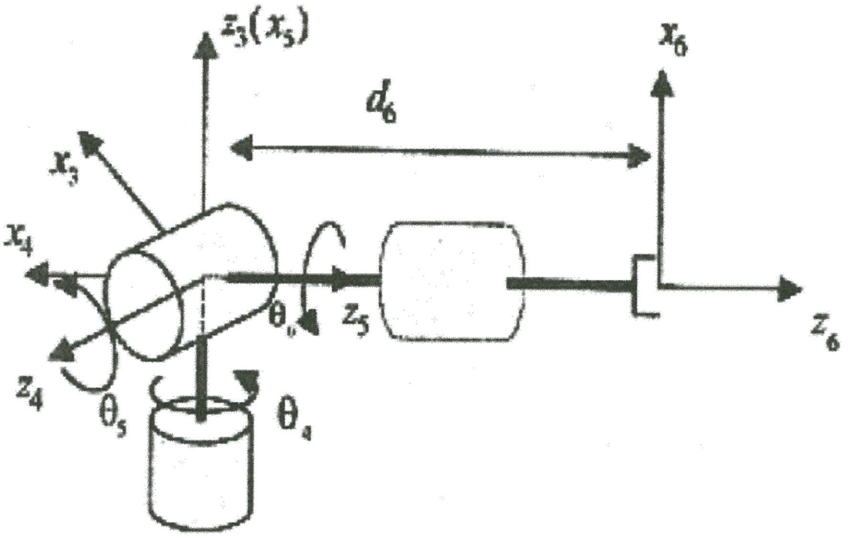

FIGURE Q3(c)

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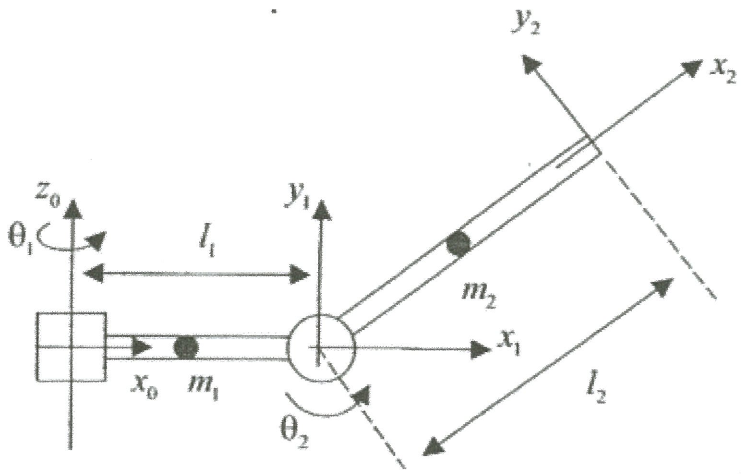

FIGURE Q4(b)

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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) $a\cos\theta + b\sin\theta = c$	$\theta^{(1)} = A\tan2\left(c,\ \sqrt{a^2+b^2-c^2}\right) - A\tan2\ (a,\ b)$ $\theta^{(2)} = A\tan2\left(c,\ -\sqrt{a^2+b^2-c^2}\right) - A\tan2\ (a,\ b)$
(f) $\begin{cases}a\cos\theta - b\sin\theta = c \\ a\sin\theta + b\cos\theta = d\end{cases}$	$\theta = A\tan2\ (ad - bc,\ ac + bd)$
(g) $\begin{cases}\sin\alpha\sin\beta = a \\ \cos\alpha\sin\beta = b \\ \cos\beta = c\end{cases}$	$\begin{cases}\alpha^{(1)} = A\tan2\ (a,\ b) \\ \beta^{(1)} = A\tan2\left(\sqrt{a^2+b^2},\ c\right)\end{cases}$ $\begin{cases}\alpha^{(2)} = A\tan2\ (-a,\ -b) = \pi + \alpha^{(1)} \\ \beta^{(2)} = A\tan2\left(-\sqrt{a^2+b^2},\ c\right)\end{cases}$

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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