UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER 1
SESSION 2013/2014

COURSE NAME	:	ROBOTIC SYSTEMS
COURSE CODE	:	BEH 41703
PROGRAMME	:	BEJ
EXAMINATION DATE	:	JANUARY 2014
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 kinematic and inverse kinematic in relation to robotic manipulators.

(5 marks)

(b) With the help of appropriate figures, explain three (3) reasons why the inverse kinematic problem for robotic system is one of the most difficult to solve.

(5 marks)

(c) Explain the degree of freedom means and draw a simple 3 DOF articulated robot arm.

(5 marks)

(d) Explain the work envelope and draw the outline of the work envelope for the articulated robot that you drew in **Q1(c)**.

(5 marks)

Q2 Figure **Q2** shows a cylindrical arm with two prismatic joints and a rotary joint. The seven trigonometric equations and their solutions are given in Table **Q2**. The forward kinematic solution is given as below.

$$H_0^3 = \begin{bmatrix} C_2 & 0 & -S_2 & -d_3S_2 + a_2C_2 \\ S_2 & 0 & C_2 & d_3C_2 + a_2S_2 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(a) Obtain the inverse position of the cylindrical arm from this forward kinematic, H_0^{3}.

(18 marks)

(b) Analyze which is the correct angle and distance.

(2 marks)

Q3 (a) Explain the Jacobian matrix. List its applications?

(2 marks)

(b) Briefly discuss about the problem of singularities.

(3 marks)

(c) Figure **Q3(c)** shows a spherical arm with two rotary joints and a prismatic joint. By applying the transformation matrix and arm parameters as in Table **Q3(c)**, solve the Jacobian matrix.

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

(15 marks)

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

(2 marks)

(b) Figure **Q4(b)** shows a *θ-r* robot manipulator with a revolute joint and a prismatic joint. Consider the point masses, m_1 and m_2 at the distal end of links. 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

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

(18 marks)

Q5 (a) Consider a single- link robot anipulator with a rotary joint. Design its trajectory with following two cubic segments. The first segment connects the initial angular position the $\theta(0)=10^{\circ}$ to the via point $\theta(1)=5^{\circ}$, and the second segment connects the via point $\theta(1)=5^{\circ}$ to the final angular position $\theta(2)=50^{\circ}$. The designed trajectory should have zero initial velocity and zero final velocity. Also, at the via point $\theta(1)=5^{\circ}$, the trajectory should have continous velocity and acceleration.

(16 marks)

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

(2 marks)

(c) Disscuss why 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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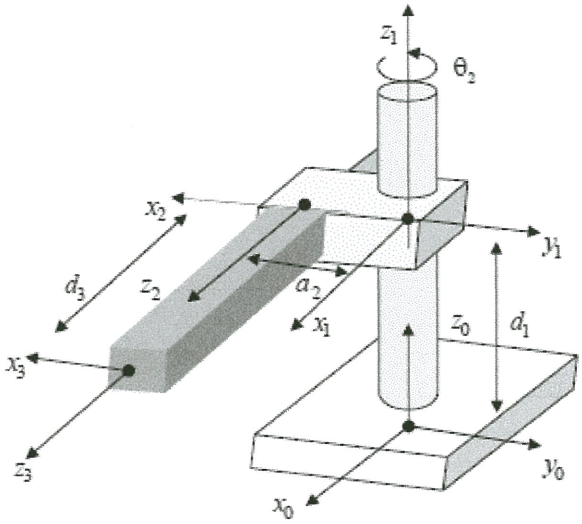

FIGURE Q2

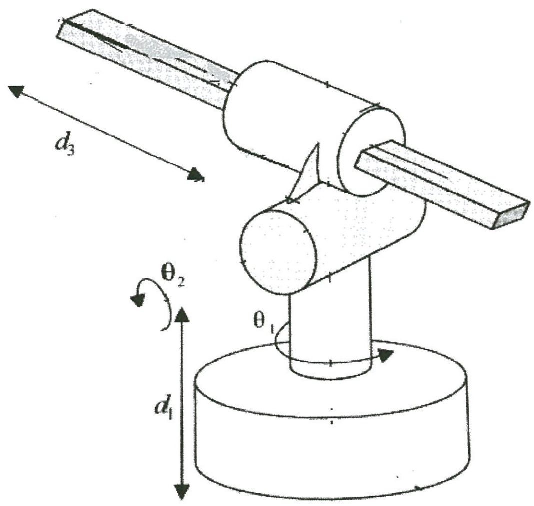

FIGURE Q3(c)

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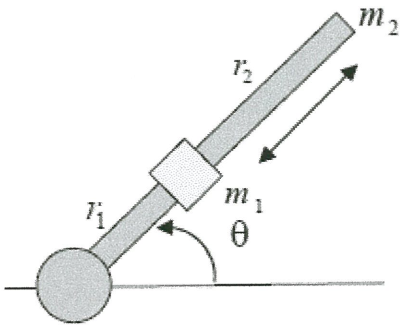

FIGURE Q4(b)

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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) $a\cos\theta + b\sin\theta = c$	$\theta^{(1)} = Atan2\left(c,\ \sqrt{a^2+b^2-c^2}\right) - Atan2\ (a,\ b)$ $\theta^{(2)} = Atan2\left(c,\ -\sqrt{a^2+b^2-c^2}\right) - Atan2\ (a,\ b)$
(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	d_i	a_i	α_i
1	θ_1	d_1	0	-90°
2	θ_2	0	a_2	-90°
3	0°	d_3	0	0°