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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

**FINAL EXAMINATION
SEMESTER 1
SESSION 2011/2012**

COURSE : INTELLIGENT ROBOT
COURSE CODE : BEM 4223
PROGRAMME : BACHELOR OF ELECTRICAL
ENGINEERING WITH HONOURS
EXAMINATION DATE : JANUARY 2012
DURATION : 3 HOURS
INSTRUCTION : ANSWER **FOUR (4)** QUESTIONS ONLY

THIS PAPER CONSISTS OF SIX (6) PAGES

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- Q1.** (a) What is the definition of an intelligent robot? (4 marks)
- (b) The robots can be classified according to the types of task, control, configuration and mobility. Briefly describe the different classes robots based on type of configuration classification. (10 marks)
- (c) Briefly describe three (3) applications of robotic systems and discuss the advantages of using robot in industrial processes? (7 marks)
- (d) Construct a block diagram of closed loop control system of robot with complete label of each part. The block diagram should indicate the block of kinematics, dynamics, trajectory, control system and sensor. (4 marks)
- Q2.** (a) With the help of block diagram, explain what is meant by forward kinematic and inverse kinematic in relation to robotic manipulators? (3 marks)
- (b) List three (3) reasons why the inverse kinematic problem for robotic system is one of the most difficult to solve. (3 marks)
- (c) Figure Q2(c) shows an articulated robot arm.
- (i) Assign coordinate frames of the robot arm using the Denavit-Hartenberg algorithm
- (ii) Obtain a table of the arm parameters.
- (iii) With the help of Denavit-Hartenberg transformation matrix, obtain the transformation matrices H_0^1, H_1^2 and H_2^3 .
- $$H_{i-1}^i = \begin{bmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i C\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i C\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
- (iv) Compute the forward kinematic of the robot manipulator to determine the position and orientation of the robot hand relative to the robot base frame. (19 marks)

- Q3.** Figure Q3 shows a cylindrical arm with two prismatic joints and a rotary joint. Table Q3 shows the arm parameters. The forward kinematic solution is given as below. Compute the inverse kinematics solution for this robot.

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

(25 marks)

- Q4.** (a) List two (2) main reasons to use the dynamics equations? (3 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. Derive the differential equations of motion of the θ - r manipulator using the Lagrange equations. (22 marks)

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

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

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

- Q5.** Consider a single-link robot manipulator with a rotary joint. Design a trajectory with following two cubic segments: The first segment connects the initial angular position $\theta(0)=10^\circ$ 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 continuous velocity and acceleration.

(25 marks)

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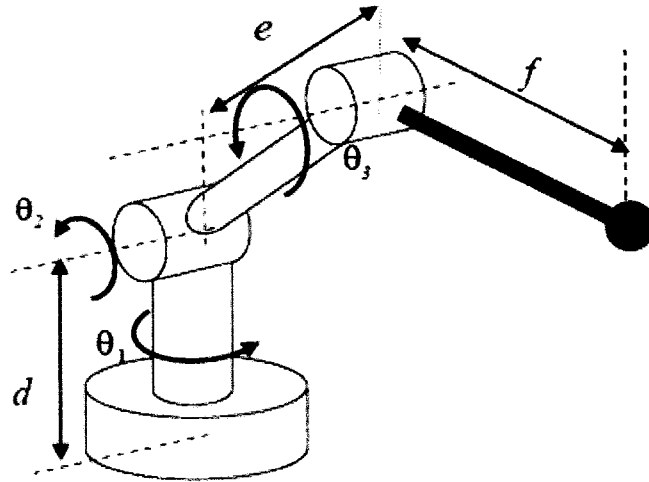


Figure Q2(c)

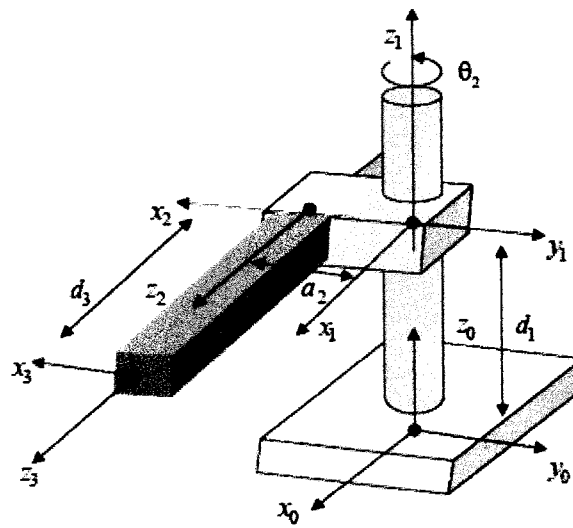


Figure Q3

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Table Q3

Axis	θ_i	a_i	α_i	d_i
1	0^0	0	0^0	d_1
2	θ_2	a_2	-90^0	0
3	0^0	0	0^0	d_3

Table : Seven trigonometric equations and their solution

Equation(s)	Solution(s)
(a) $\sin \theta = a$	$\theta = \text{Atan 2} \left(a, \pm\sqrt{1-a^2} \right)$
(b) $\cos \theta = b$	$\theta = \text{Atan 2} \left(\pm\sqrt{1-b^2}, b \right)$
(c) $\begin{cases} \sin \theta = a \\ \cos \theta = b \end{cases}$	$\theta = \text{Atan 2} (a, b)$
(d) $a \cos \theta - b \sin \theta = 0$	$\theta^{(1)} = \text{Atan 2}(a, b)$ $\theta^{(2)} = \text{Atan 2}(-a, -b) = \pi + \theta^{(1)}$
(e) $a \cos \theta + b \sin \theta = c$	$\theta^{(1)} = \text{Atan 2} \left(c, \sqrt{a^2 + b^2 - c^2} \right)$ $-\text{Atan 2} (a, b)$ $\theta^{(2)} = \text{Atan 2} \left(c, -\sqrt{a^2 + b^2 - c^2} \right)$ $-\text{Atan 2} (a, b)$
(f) $\begin{cases} a \cos \theta - b \sin \theta = c \\ a \sin \theta + b \cos \theta = d \end{cases}$	$\theta = \text{Atan 2} (ad - bc, ac + bd)$
(g) $\begin{cases} \sin \alpha \sin \beta = a \\ \cos \alpha \sin \beta = b \\ \cos \beta = c \end{cases}$	$\begin{cases} \alpha^{(1)} = \text{Atan 2} (a, b) \\ \beta^{(1)} = \text{Atan 2} \left(\sqrt{a^2 + b^2}, c \right) \end{cases}$ $\begin{cases} \alpha^{(2)} = \text{Atan 2} (-a, -b) = \pi + \alpha^{(1)} \\ \beta^{(2)} = \text{Atan 2} \left(-\sqrt{a^2 + b^2}, c \right) \end{cases}$

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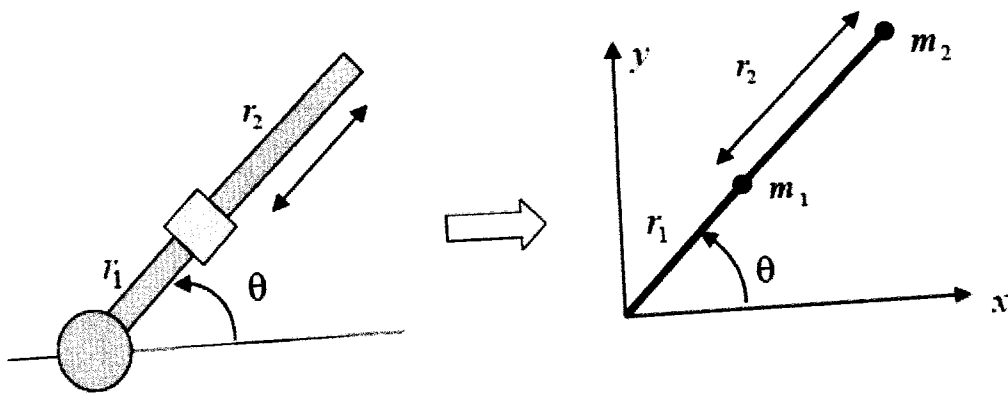


Figure Q4