Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2016/2017

COURSE	:	ROBOTIC SYSTEMS
COURSE CODE	:	BEH41703
PROGRAMME	:	BEJ
EXAMINATION DATE	:	JUNE 2017
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **ALL** QUESTIONS

THIS PAPER CONSISTS OF **SIX (6)** PAGES

Q1 Consider the following cylindrical robot arm with one rotary joint and two prismatic joints in **Figure Q1**

(a) Assign coordinate frames to the robot arm using the D-H algorithm.

(5 marks)

(b) Obtain a table of the D-H parameters of the robot.

(5 marks)

(c) Obtain the transformation matrices H_0^1, H_1^2 and H_2^3 by using the D-H matrix as given below:

$$H_{i-1}^{i} = \begin{bmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i C\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i S\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(5 marks)

(d) Obtain the forward kinematics matrix H_0^3.

(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. Analyse the inverse position (joint angles) of the articulated arm from this forward kinematic, H_0^3.

$$H_0^3 = \begin{bmatrix} C_2 & 0 & -S_2 & -d_3 S_2 + a_2 C_2 \\ S_2 & 0 & C_2 & d_3 C_2 + a_2 S_2 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(20 marks)

Q3 (a) Briefly discuss about the problem of singularity.

(3 marks)

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

$$H_{i-1}^{i} = \begin{bmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i C\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i S\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Jacobian matrix

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

(17 marks)

Q4 (a) From the perspective of robotics, list two (2) main reasons for using dynamics equations for robot modelling.

(2 marks)

(b) The links of an RP manipulator, shown in **Figure Q4**, have the following inertial tensors (relative to the frame with its origin positioned at the center or rotation θ_1, with θ_1 being the rotation around z-axis):

$$^{o}I_1 = \begin{bmatrix} I_{xx1} & 0 & 0 \\ 0 & I_{yy1} & 0 \\ 0 & 0 & I_{zz1} \end{bmatrix}$$

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$$^{o}I_2 = \begin{bmatrix} I_{xx2} & 0 & 0 \\ 0 & I_{yy2} & 0 \\ 0 & 0 & I_{zz2} \end{bmatrix}$$

and total mass of m_1 and m_2. As shown in the Figure, the center of mass of link-1 is located at a distance of l_1 from the joint-1 axis, and the center of mass of link-2 is at a variable distance of d_2 from the joint-1 axis. Use Lagrangian dynamics to determine the equation of motion for the manipulator.

(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

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

(a) Linearize the above differential equation with some assumptions.

(5 marks)

(b) Transform the linearized equation to the Laplace equation to formulate the transfer function $\Theta_m(s)/U(s)$

(4 marks)

(c) Draw the block diagram and label of the complete system with a PD controller. [Hint: The transfer function of a PD controller $G(s) = K_P + K_D s$)]

(5 marks)

(d) Obtain the transfer function for the PD controller with stable values of K_P and K_D [Hint: find out the *characteristic equation* of the closed loop system].

(6 marks)

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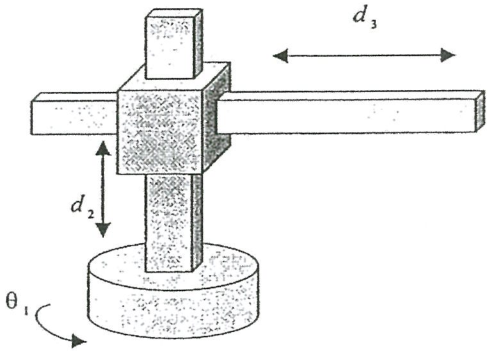

Figure Q1

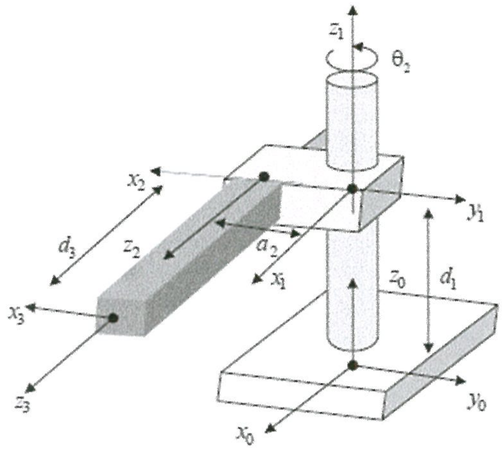

Figure Q2

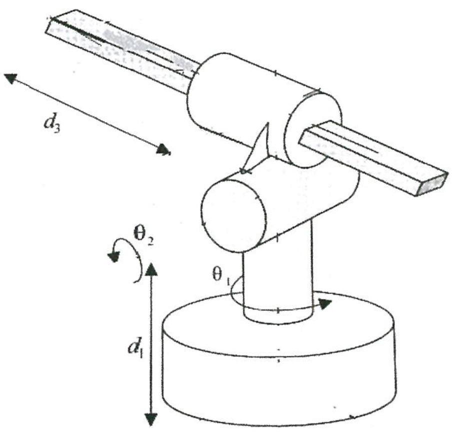

Figure Q3(b)

Table Q3 (b)

Link	θ_i	a_i	α_i	d_i
1	θ_1	0	-90°	d_1
2	θ_2	a_2	-90°	0
3	0	0	0	d_3

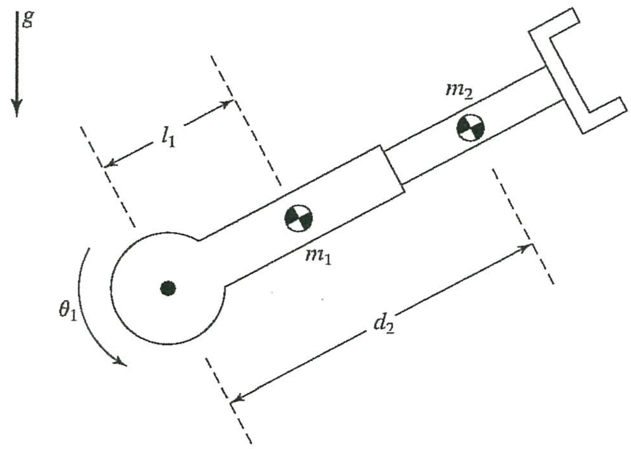

Figure Q4

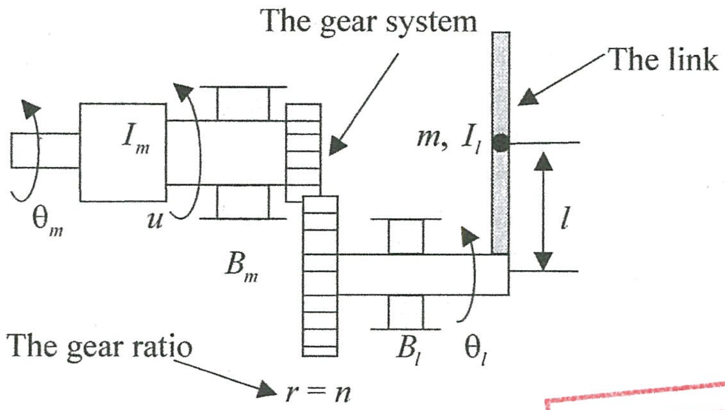

Figure Q5