Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2021/2022

COURSE NAME	:	ROBOTIC SYSTEMS
COURSE CODE	:	BEJ 44203 / BEH 41703
PROGRAMMECODE	:	BEJ
EXAMINATION DATE	:	JULY 2022
DURATION	:	3 HOURS
INSTRUCTION		1. ANSWER ALL QUESTIONS 2. THIS FINAL EXAMINATION IS AN **ONLINE** ASSESSMENT AND CONDUCTED VIA **OPEN BOOK**.

THIS QUESTION PAPER CONSISTS OF **FOUR (4)** PAGES

Q1 (a) List out factors that might affect the repeatability and accuracy of a manipulator.

(2 marks)

(b) The corresponding arm parameters and the forward kinematics matrix for a spherical arm with two rotary joints and prismatic joints as follows:

$$H_0^3 = \begin{bmatrix} -S_1 & C_1C_2 & C_1S_2 & d_3C_1S_2 + d_2S_1 \\ C_1 & S_1C_2 & S_1S_2 & d_1S_1S_2 - d_2C_1 \\ 0 & S_2 & -C_2 & d_1 - d_3C_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(i) Derive the position vector of the tip of the arm

(2 marks)

(ii) Obtain the solution of θ_1 and d_3.

(8 marks)

(c) **Figure Q1(c)** shows a three-link planar arm with three rotary joints.

(i) Derive the Jacobian for the three-link arm. The transformation matrices are obtained using DH rules as follows:

$$H_0^3 = \begin{bmatrix} C_1C_{23} & -C_1S_{23} & S_1 & L_1C_2 + L_2C_1C_2 \\ S_1C_{23} & -S_1S_{23} & -C_1 & L_1S_1 + L_2S_1C_2 \\ S_{23} & C_{23} & 0 & L_2S_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(10 marks)

(ii) Suggest a set of joint angles for which the arm is at a workspace-boundary singularity and sketch your answer.

(3 marks)

Q2 (a) A single-link robot with a rotary joint is motionless at $\theta = -5°$. It is desired to move the joint in a smooth manner to $\theta = 80°$ in 4 seconds. The initial velocity and final velocity are zero.

(i) Design a cubic trajectory to accomplish this motion and bring the arm to the rest at the goal.

(10 marks)

(ii) Plot the position, velocity, and acceleration of the joint as the function of time.

(3 marks)

(b) Solve for the coefficients of two-segments of continuous velocity and acceleration spline with initial angle is $\theta_0 = 5^o$. The via point is $\theta_v = 15^o$, and the goal point is $\theta_g = 40^o$. The designated trajectory should have zero initial velocity and zero final velocity. Each segment lasts 1.0 seconds.

The first cubic $(0 \leq t \leq 1)$ is

$$\theta(t) = a_{10} + a_{11}t + a_{12}t^2 + a_{13}t^3$$

and the second cubic $(1 \leq t \leq 2)$ is

$$\theta(t) = a_{20} + a_{21}(t-1) + a_{22}(t-1)^2 + a_{23}(t-1)^3$$

(12 marks)

Q3 Consider the point masses at distal ends of link of the following two-link manipulator as shown in **Figure Q3**. The link lengths are described by l_1 and l_2.

(a) Find the Cartesian coordinates of the point masses m_1 and m_2.

(4 marks)

(b) Calculate the velocities of the point masses m_1 and m_2.

(7 marks)

(c) Analyse the total kinetic and potential energy of the manipulator.

(6 marks)

(d) Evaluate the differential equation of T_{θ_1} for the first link of the manipulator.

(8 marks)

Q4 (a) Identify the natural and artificial constraints for the task of closing a hinged door with manipulator. Make any reasonable assumptions needed and show your definition of {C} in sketch.

(14 marks)

(b) Discuss **ONE (1)** example of the application of hybrid position/force controller in robot manipulator operation.

(3 marks)

(c) Draw a block diagram of a hybrid position/force controller for the application in **Q4(b)**. Please write down all related parameters and variables in your diagram.

(8 marks)

-END OF QUESTIONS –

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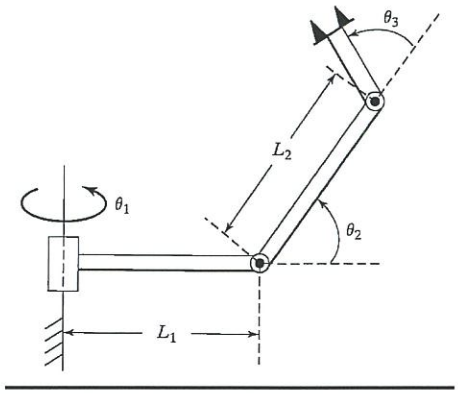

Figure Q1(c)

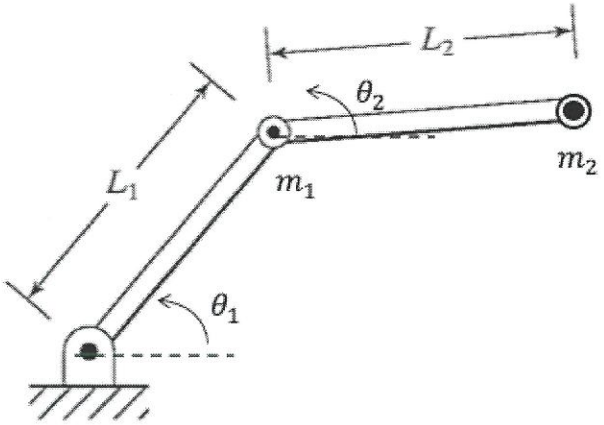

Figure Q3