

**UNIVERSITY COLLEGE TATI (UCTATI)****FINAL EXAMINATION QUESTION BOOKLET**

COURSE CODE	: BMT 4023
COURSE	: INDUSTRIAL ROBOTIC AND APPLICATION
SEMESTER/SESSION	: 1 – 2024/2025
DURATION	: 3 HOURS

Instructions:

1. This booklet contains **4** questions. Answer all questions.
2. All answers should be written in answer booklet.
3. Write legibly and draw sketches wherever required.
4. If in doubt, raise your hands and ask the invigilator.

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO

THIS BOOKLET CONTAINS 10 PRINTED PAGES INCLUDING COVER PAGE

QUESTION 1

- a) Describe the definition of industrial robot according to the Robot Institute of America (RIA). (4 marks)
- b) State the **three (3)** laws of robotic. (3 marks)
- c) Describe the following terms of robotic arm specifications:
- i. Degree of freedom (1 mark)
 - ii. Working envelope (1 mark)
 - iii. Accuracy (2 marks)
- d) The on-line programming method for a robotic arm can be done either using powered leadthrough or manual leadthrough. Describe the differences between powered leadthrough and manual leadthrough. (4 marks)
- e) Robot wrist refers to the joints in the kinematic chain between the robot arm and the end effector. Identify the wrist motions that able it to move. (3 marks)
- f) Describe the meaning of flexible manufacturing system (FMS). (4 marks)
- g) State the **four (4)** components of an FMS. (4 marks)
- h) Describe the following benefits of FMS:
- i. Lower manufacturing lead times (3 marks)
 - ii. Opportunity for unattended production (3 marks)
- i) In computer integrated manufacturing (CIM), there are 15 key processes for product definition, manufacturing and customer support as shown in **Table 1**.
- i. Identify any **two (2)** processes involve in product definition. (2 marks)
 - ii. Identify any **two (2)** processes involve for manufacturing. (2 marks)

INDUSTRIAL ROBOTIC AND APPLICATION (BMT 4023)

Table 1

15 key processes	
Business definition	Global organization
Resource planning	System design
Sales and promotion	Operations planning
Assembly and test	Customer services
Component design	Component fabrication
Life cycle transitions	Documentation and release
Material management	Distribution
Continuous improvement	

QUESTION 2

a) Point A with coordinate of (1, -1, 0) is located in the xyz axis. Point A is applied with the following transformations:

- Rotate 90° about the z axis,
- Then rotate it 90° about the x axis,
- Then translate 3 unit along x axis and 6 unit along y axis,
- Finally rotate it 90° about the y axis

- i. Write the transformation equation by applying post-multiply order. (2 marks)
- ii. Compute the transformation matrix based on the equation obtained in (i). (6 marks)
- iii. Express the new coordinate for point A. (3 marks)

b) Given a transformation matrix F:

$$F = \begin{bmatrix} 0 & 0 & 1 & 4 \\ 1 & 0 & 0 & 7 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Calculate the inverse of this transformation matrix F.

(7 marks)

QUESTION 3

Figure 1 illustrates the link coordinate systems for a two-link planar robot arm with z axes are pointing out of the page. From the link coordinate systems, the DH parameters for the robot arm were obtained as in **Table 2**. The transformation matrix of T_0^1 and T_1^2 are given as follow:

$$T_0^1 = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & L1\cos\theta_1 \\ \sin\theta_1 & \cos\theta_1 & 0 & L1\sin\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_1^2 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & L2\cos\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & L2\sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Describe the rotation and translation movement involved in obtaining the transformation matrix T_0^1 (4 marks)
- Describe the rotation and translation movement involved in obtaining the transformation matrix T_1^2 (4 marks)
- Calculate the complete transformation matrix T_0^2 (14 marks)
- Based on the answer obtained in c), determine the coordinate of the robot end effector if:

$$\theta_1 = 45^\circ$$

$$\theta_2 = 60^\circ$$

$$L_1 = 2$$

$$L_2 = 2$$

(6 marks)

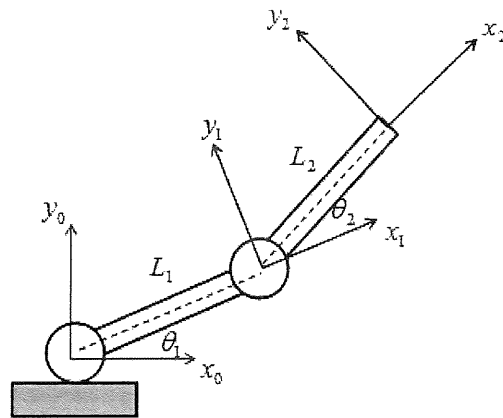


Figure 1

Table 2

Link	a_i	α_i	d_i	θ_i
1	L_1	0	0	θ_1
2	L_2	0	0	θ_2

QUESTION 4

A single link robot with a rotary joint is motionless at $\theta = 15^\circ$. It is desired to move the joint in a smooth manner to $\theta = 75^\circ$ in 3 seconds.

- a) Calculate the coefficients of a cubic polynomial trajectory that accomplishes this motion and brings the robot link to rest at the destination. (10 marks)
- b) Sketch the graph of position as a function of time. (4 marks)
- c) Sketch the graph of velocity as a function of time. (4 marks)

----- END OF QUESTION -----

FORMULAS**Rotation matrices:**

$$R_{x,\theta} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta \\ 0 & \sin \theta & \cos \theta \end{bmatrix}$$

$$R_{y,\theta} = \begin{bmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{bmatrix}$$

$$R_{z,\theta} = \begin{bmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Homogeneous rotation matrices:

$$T_{x,\theta} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta & 0 \\ 0 & \sin \theta & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{y,\theta} = \begin{bmatrix} \cos \theta & 0 & \sin \theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \theta & 0 & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_{z,\theta} = \begin{bmatrix} \cos \theta & -\sin \theta & 0 & 0 \\ \sin \theta & \cos \theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Homogeneous translation matrices:

$$T_{trans} = \begin{bmatrix} 1 & 0 & 0 & dx \\ 0 & 1 & 0 & dy \\ 0 & 0 & 1 & dz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

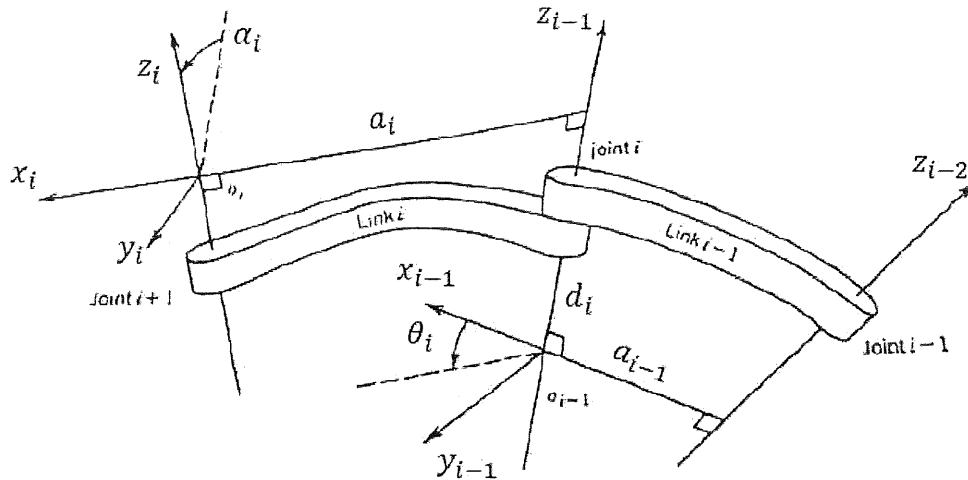
Homogeneous transformation matrix:

$$T = \begin{bmatrix} R_{3 \times 3} & p_{3 \times 1} \\ f_{1 \times 3} & 1 \times 1 \end{bmatrix} = \begin{bmatrix} n_x & s_x & a_x & dx \\ n_y & s_y & a_y & dy \\ n_z & s_z & a_z & dz \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} n & s & a & p \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Inverse of homogeneous transformation matrix:

$$T^{-1} = \begin{bmatrix} n_x & n_y & n_z & -n^T P \\ s_x & s_y & s_z & -s^T P \\ a_x & a_y & a_z & -a^T P \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The Denavit-Hartenberg frame representation:



Summary of the DH parameters:

- θ_i Joint angle ➡ Angle from x_{i-1} and x_i measured about z_{i-1}
- d_i Link offset ➡ Distance from x_{i-1} and x_i measured along z_{i-1}
- a_i Link length ➡ Distance from z_{i-1} and z_i measured along x_i
- α_i Link twist ➡ Angle from z_{i-1} and z_i measured about x_i

Trigonometry formulas:

$$\begin{aligned} \sin(A + B) &= \sin A \cos B + \cos A \sin B \\ \sin(A - B) &= \sin A \cos B - \cos A \sin B \\ \cos(A + B) &= \cos A \cos B - \sin A \sin B \\ \cos(A - B) &= \cos A \cos B + \sin A \sin B \end{aligned}$$

Cubic polynomial:

$$\theta(t) = a_0 + a_1t + a_2t^2 + a_3t^3$$