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FINAL EXAMINATION QUESTION BOOKLET

COURSE CODE	:	BMT 4023
COURSE	:	INDUSTRIAL ROBOTIC AND APPLICATION
SEMESTER / SESSION	:	02 - 2023/2024
DURATION	:	3 HOURS

Instructions:

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

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

THIS BOOKLET CONTAINS 7 PRINTED PAGES INCLUDING COVER PAGE

QUESTION 1

a) Robots are considered a key element in many fields and applications. List THREE (3) laws of robotics. (3 marks)

b) End effectors are devices attached to the wrist of a manipulator. List FIVE (5) end effectors commonly found in the industry. (5 marks)

c) A special spraying robot has been designed, as shown in Figure 1.

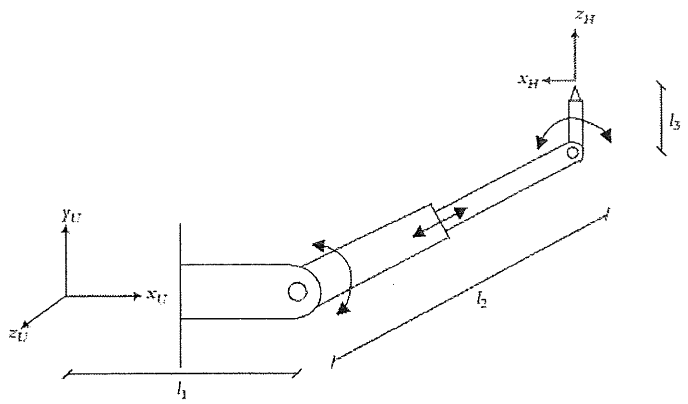

Figure 1

i) Find the degree of freedom of this robot. (1 mark)

ii) Name the joints that contribute to the degree of freedom of this robot. (2 marks)

d) One method of classifying a robot is by the geometric configuration of its work envelope. List FOUR (4) major configurations of industrial robot manipulators. (4 marks)

e) Various ways exist to classify industrial robots based on their motion control methods. List FOUR (4) industrial robot categories. (4 marks)

f) A robot uses several coordinate systems, each suitable for specific types of jogging or programming. State the differences in the Jogging operation in the base coordinate system (BCS) and tool coordinate system (TCS). (4 marks)

g) Based on the robot ABB teach pendant programming, write instructions to move the ABB robot with the tool, *Tool0* non-linearly to the robot position, *Target1* with velocity data *v1000*, and zone data *z50*. (2 marks)

QUESTION 2

a) Define the forward kinematics of manipulators. (2 marks)

b) Define the inverse kinematics of manipulators. (2 marks)

c) A 4 x 4 homogeneous transformation matrix T can be represented as: (5 marks)

$$T = \begin{bmatrix} R & p \\ 0 & 1 \end{bmatrix}$$

where R is a 3 x 3 rotation matrix, p is a 3-element column vector 0 is a 3-element row vector. Express the inverse of T in terms of R and p.

d) Find the inverse of the following homogeneous transformation matrix B. (6 marks)

$$B = \begin{bmatrix} 0 & 0 & 1 & 7 \\ 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 10 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

e) Two coordinate frames, A and B, are shown in Figure 2. Write the 4 x 4 homogeneous transformation matrices B^A which represents frame B relative to frame A. (10 marks)

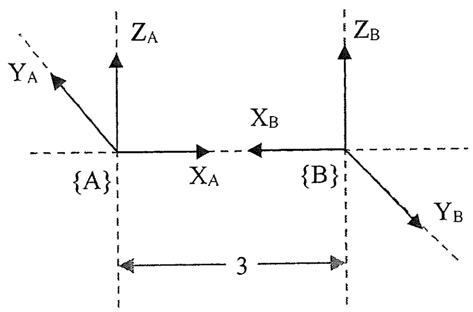

Figure 2

QUESTION 3

a) For the given three-link PRR manipulator shown in Figure 3:

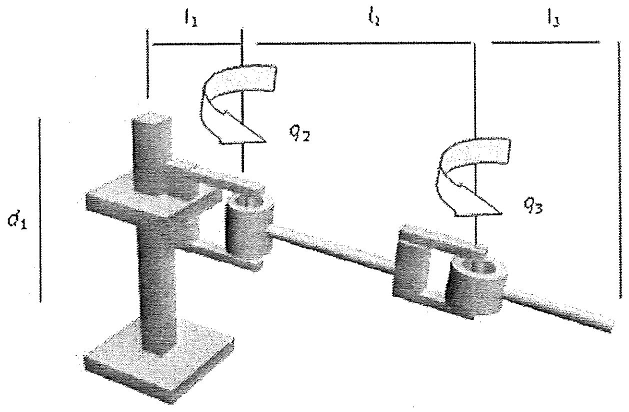

Figure 3

i) Assign link frames {0} through {3} for the manipulator—i.e. sketch the coordinate axes of each frame. (6 marks)

ii) Fill out the Denavit-Hartenberg parameters table for this manipulator. (6 marks)

Link	θ	d	a	α
1				
2				
3				

iii) Write all the arm matrices, A. (6 marks)

iv) Derive the forward kinematics for this manipulator—that is, find the T_H^0 (hand frame relative to base frame) in terms of the A matrices. (12 marks)

QUESTION 4

a) Safeguarding devices are essential to ensuring the safety of personnel working with or around machinery and equipment. List THREE (3) of these devices. (3 marks)

b) Robot accidents do not occur under normal operating conditions. Describe THREE (3) occasions of robot accidents. (3 marks)

c) Define Computer Integrated Manufacturing (CIM) term referring to the Computer and Automated Systems Association (CASA) and Society of Manufacturing Engineers (SME). (3 marks)

d) Computer Integrated Manufacturing (CIM) offers several benefits to manufacturing organizations. Give FOUR (4) benefits of CIM. (4 marks)

e) Define a Flexible Manufacturing System (FMS). (3 marks)

f) A Flexible Manufacturing System (FMS) consists of several interconnected components that create a flexible and efficient manufacturing environment. List FOUR (4) key components typically found in an FMS. (4 marks)

----------------End of Questions--------------

FORMULA SHEET

Homogeneous Transformation Matrix

$$T = \begin{bmatrix} R_{3x3} & p_{3x1} \\ f_{1x3} & 1x1 \end{bmatrix} =$$

Rotation matrix	Position vector
Perspective transformation	Scaling

$$T = \begin{bmatrix} R_{3x3} & p_{3x1} \\ f_{1x3} & 1x1 \end{bmatrix} = \begin{bmatrix} n_x & s_x & a_x & dx \\ n_y & s_y & a_y & dy \\ n_z & s_z & a_z & dz \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} n\,s\,a\,p \\ 0\,0\,0\,1 \end{bmatrix}$$

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

Homogeneous Translation Matrix

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

Homogeneous Rotation Matrix

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

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

Arm Matrix

$$A_i = \begin{bmatrix} \cos\theta_i & -\cos\alpha_i \sin\theta_i & \sin\alpha_i \sin\theta_i & a_i \cos\theta_i \\ \sin\theta_i & \cos\alpha_i \cos\theta_i & -\sin\alpha_i \cos\theta_i & a_i \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\sin(\alpha \mp \beta) = \sin\alpha \cos\beta \mp \sin\beta \cos\alpha$$

$$\cos(\alpha \mp \beta) = \cos\alpha \cos\beta \pm \sin\beta \sin\alpha$$