NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING

DEPARTMENT OF INDUSTRIAL AND MANUFACTURING ENGINEERING

MASTER OF ENGINEERING DEGREE IN MANUFACTURING ENGINEERING/SYSTEMS AND OPERATIONS MANAGEMENT

AUTOMATION & ROBOTICS

TIE 6220

Stage 2 Examination Question Paper

March 2025

This examination paper consists of **6** printed pages

Time Allowed: 3 hours

Total Marks: 100

Special Requirements: Nil

Examiner's Name: G Kanyemba

INSTRUCTIONS AND INFORMATION TO CANDIDATE

1. This paper contains seven (7) questions.
2. Answer **all** questions in **Section A** which carries **40 marks**.
3. Answer any other **three (3)** questions in **Section B**, each carries **20 marks**.
4. Use of calculators is permissible.

SECTION A: Answer all questions from this section (40 marks)

Question 1

(a) Describe the use of Remote Centre Compliance in robot grippers design as a way of avoiding jamming for insertion operations with tight clearances. [4]

(b) Consider the three-link planar manipulator shown in Fig. Q1. Derive the forward kinematics for the manipulator. [8]

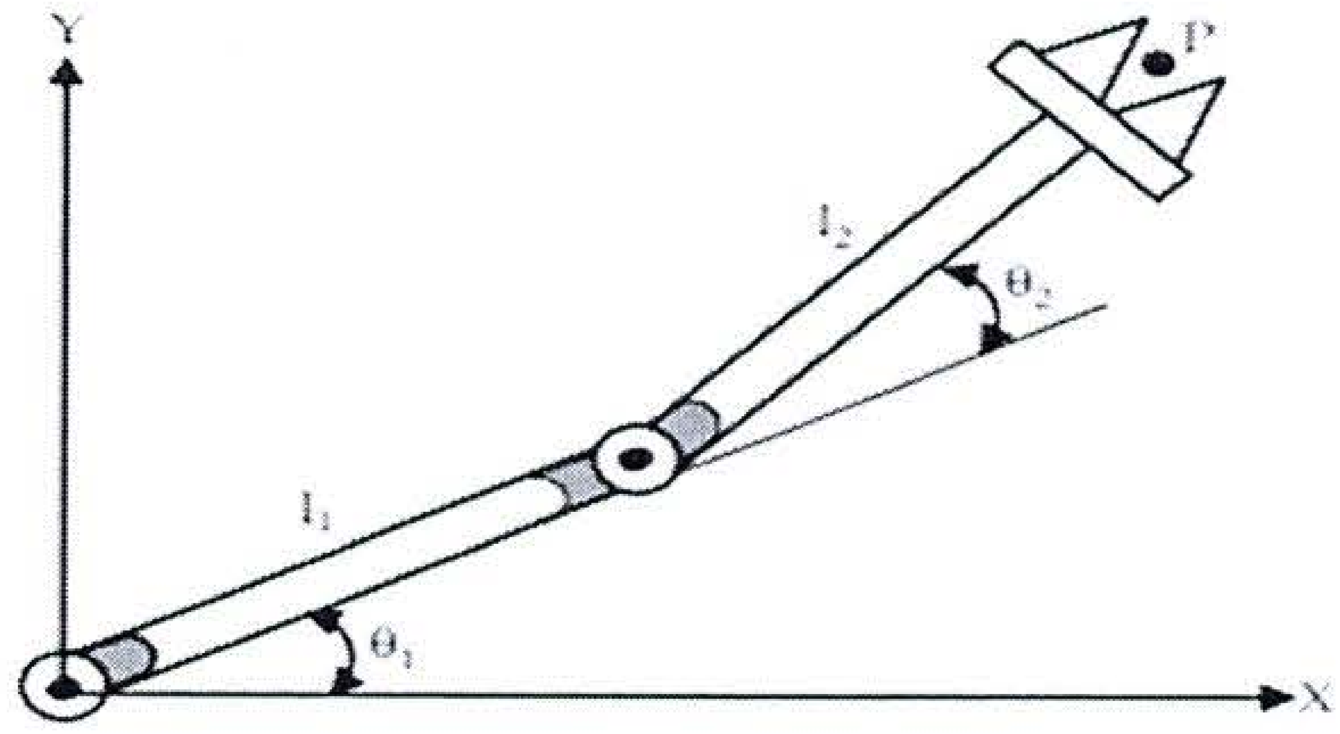

Fig. Q1: Robotic arm

Question 2

A point **P** (7, 3, 2) is attached to a frame (**η , o, a**) and is subjected to transformations described as follows:

1. Rotation by 45^o about the y-axis
2. Then rotation by 90^o about the z axis,
3. And followed by a translation of [3, -2, 5]

Find the coordinates of the point relative to the fixed frame at the conclusion of the transformation. [12]

Question 3

A Laser Engraver Printer uses a laser beam to engrave on metal and wooden materials from a computer program. The laser is positioned by a control input, r(t), so that we have.

$$Y(s) = \frac{5(s+100)}{s^2+60s+500}R(s)$$

The input $r(t)$ represents the desired position of the laser beam.

(a) If $r(t)$ is unit step input, find the output of the laser beam. [14]

(b) What is the final value of $y(t)$? [2]

SECTION B: Answer any three (3) questions from this section.

Question 4

(a) The USA principle is a common sense approach to achieve automation. With the use of an appropriate automation project example in a manufacturing setup, explain the USA principle and how it can be applied to the project. [12]

(b) Discuss implementation issues of robots in an assembly environment. [8]

Question 5

An industrial robot has a transfer function given by the following by the expression:

$$G_R = \frac{1}{Js+1}$$

A controller, which has a gain K, is connected to the robot in series (cascade)

(a) Draw the open-loop representation (block diagram) of this arrangement. [2]

(b) Determine the combined transfer function of the system. [2]

(c) The loop is then closed by a feedback loop with a transfer function H(s) = 1.

  (i) Draw the closed-loop representation (block diagram) of the arrangement. [2]

  (ii) Determine the closed-loop transfer function of the system. [4]

(d) For K = 10 and a time constant of 0.7 seconds, find the value of θ, the output (position) angle of the robot if the step input is a torque of 20 Nm , after 3 seconds.
(Assume *that the initial conditions are all zero*.) [10]

Question 6

(a) Discuss in detail various methods available for the analysis of robot economics. [8]

(a) A robot used for machine loading is priced at $46 000.00. The special gripper required for it costs $5 000.00 and the sensors cost $1 000.00. The feeder costs $30 000.00. There are no layout charges. The robot will replace one operator whose rate is $16.00 per hour including fringe benefits. The operator works 250 days a year, 8 hours a day. No production increase or quality improvements are anticipated.
What is the payback period for: -

  (i) one-shift and [6]

  (ii) two-shift operation? [6]

Question 7

(a) Explain the *work envelope concept* giving reference to an articulated robot. [4]

(b) Distinguish between servo control and non-servo control of robots? [4]

(c) Describe the following teaching methods for robots

(i) Lead Through, [3]

(ii) Offline Programming, [3]

d) With the aid of diagrams and examples of areas of application, describe the rectangular robot joint configurations. Indicate the directions of movement about and along the axes and the number of degrees of freedom.

[6]

End of examination question paper

APPENDIX A: ROTATIONAL AND TRANSLATIONAL MATRICES

Rotation

There are three types of rotation – for the three axes. Here a shorthand for the trigonometric functions sine and cosine will be adopted as $s\theta \equiv \sin\theta;\ c\theta \equiv \cos\theta$

(a) About the X axis

$$Rot(x,\theta) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c\theta & -s\theta & 0 \\ 0 & s\theta & c\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(b) About Y

$$Rot(y,\theta) = \begin{bmatrix} c\theta & 0 & s\theta & 0 \\ 0 & 1 & 0 & 0 \\ -s\theta & 0 & c\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(c) About Z

$$Rot(z,\theta) = \begin{bmatrix} c\theta & -s\theta & 0 & 0 \\ s\theta & c\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Translation

Suppose the end-effector is translated by e units in x, f units in y and g units in z. Then

$$A = Trans(e, f, g) = \begin{bmatrix} 1 & 0 & 0 & e \\ 0 & 1 & 0 & f \\ 0 & 0 & 1 & g \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

APPENDIX B: COMMON LAPLACE TRANSFORM PAIRS

	Time function $f(t)$	*Laplace transform* $\mathscr{L}[f(t)] = F(s)$
1	unit impulse $\delta(t)$	1
2	unit step 1	$1/s$
3	unit ramp t	$1/s^2$
4	t^n	$\dfrac{n!}{s^{n+1}}$
5	e^{-at}	$\dfrac{1}{(s+a)}$
6	$1 - e^{-at}$	$\dfrac{a}{s(s+a)}$
7	$\sin \omega t$	$\dfrac{\omega}{s^2+\omega^2}$
8	$\cos \omega t$	$\dfrac{s}{s^2+\omega^2}$
9	$e^{-at} \sin \omega t$	$\dfrac{\omega}{(s+a)^2+\omega^2}$
10	$e^{-at}(\cos \omega t - \frac{a}{\omega} \sin \omega t)$	$\dfrac{s}{(s+a)^2+\omega^2}$

(c) Constant multiplication

$$\mathscr{L}[af(t)] = aF(s)$$

(d) Real shift theorem

$$\mathscr{L}[f(t-T)] = e^{-Ts}F(s) \quad \text{for} \quad T \geq 0$$

(e) Convolution integral

$$\int_0^t f_1(\tau)f_2(t-\tau)\mathrm{d}\tau = F_1(s)F_2(s)$$

(f) Initial value theorem

$$f(0) = \lim_{t \to 0} [f(t)] = \lim_{s \to \infty} [sF(s)]$$

(g) Final value theorem

$$f(\infty) = \lim_{t \to \infty} [f(t)] = \lim_{s \to 0} [sF(s)]$$

