Ref. No.: Ex/ME/T/424O/2019

B.E. MECHANICAL ENGINEERING FOURTH YEAR SECOND SEMESTER – 2019

Subject: ROBOTICS

Time: 3 hours **Full Marks: 100**

Answer any five questions

1. (a) What are the missing elements in the frame represented by the transformation matrix T_1? After writing the missing elements state the significance of the terms of the matrix. (2+3)

$$T_1 = \begin{bmatrix} ? & 0 & ? & 5 \\ 0 & 1 & 0 & 10 \\ -0.707 & 0 & ? & 20 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(b) If the above frame T_1 moves 10 units along the x-axis, 5 units along the y-axis and -5 units along z-axis, what will be the new location of the frame? 2

(c) A point $P = [10,5,15]^T$ is attached to a frame T_2 and is subjected to the transformation as described below. Find the coordinates of the point P relative to the reference frame T_1 after all the movements.

(i) rotation of 90^0 about z_1-axis;

(ii) rotation of 90^0 about y_2-axis;

(iii) translation of [5, 15, -20] along axes of frame T_2. 3

(d) If F_1 and F_2 are two transformation matrices state the significance of the values of the diagonal terms. (2+2)

$$F_1 = \begin{bmatrix} 5 & 0 & 0 & 0 \\ 0 & 10 & 0 & 0 \\ 0 & 0 & 15 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad F_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 10 \end{bmatrix}$$

(e) With respect to two consecutive joints connected by a link of a robotic manipulator explain D-H algorithm. 6

2. A 4-DOF robotic manipulator is shown in the Fig Q2. Using D-H algorithm determine the forward kinematic model in the form of overall transformation matrix from base to point P.

Assume $l_1 = 20, l_2 = 30, l_3 = 25, l_4 = 28, \theta_1 = 45^0, \theta_2 = 60^0, \theta_3 = 30^0, d = 20$ 20

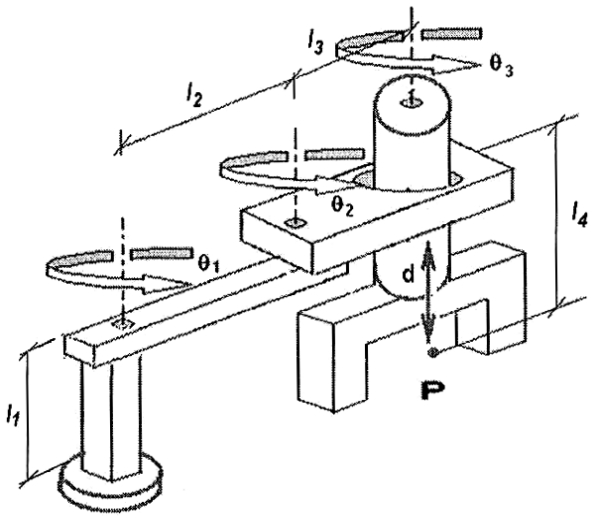

Fig. Q2

3. The Fig. Q3 shows an *R-P-P-P* manipulator where the joint parameters are $q = [\theta, d_1, d_2, d_3]^T$. The point P on the end-effector assumes the position and orientation with respect to the base coordinates are known and are represented by the following matrix

$$T = \begin{bmatrix} n_x & o_x & a_x & d_x \\ n_y & o_y & a_y & d_y \\ n_z & o_z & a_z & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Find T_4^0 and by inverse kinematics establish the equations for determining the joint parameters. 20

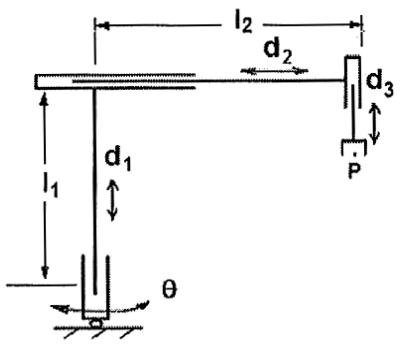

Fig. Q3

4. (a) In connection with robot programming language VAL II state the significance of the following commands:

(i) MOVE A1, (ii) MOVES A1, (iii) MOVE A1 VIA A2, (iv) OPEN, (v) OPENI, (vi) SIGNAL 5 ON, (vii) SPEED 80 and (viii) CLOSE 5.0 LB.

(b) A joint space trajectory is to be designed for a robot by 5^{th} order polynomial. Given that a joint should be allowed to go from an initial angle of 0^0 to a final angle of 75^0 in 3 seconds, both the initial and final velocities being zero and initial and final accelerations and retardations being 10 deg/sec^2. Find the equations of position, velocity and acceleration. Also draw the position, velocity and acceleration curves. (8+12)

5. (a) In connection with fuzzy based control define the following:

(i) fuzzy value & crisp value, (ii) fuzzy set & membership function and (iii) fuzzification & defuzzification.

(b) Design a fuzzy logic system for the motion of the gripper of a robot used for lifting objects. Inputs will be size of object and lifting speed and output will be gripping force. Sizes are: extra large, large, moderate and small; Speeds are: fast, normal and slow; forces are: high, medium and little. Size ranges from 20 cm^3- 100 cm^3; speed from 10 cm/s- 50 cm/s and force from 10 kg-30 kg. Create fuzzy sets for inputs and outputs and develop rule-base. Also show rules graphically. (6+14)

6. (a) Find the effect of differential rotation of 0.05 radian about the y-axis and 0.1 radian about the z-axis followed by a differential translation of $[0.05, 0.1, 0.25]$ on the frame {F}. Find the location and the orientation of the frame {F} after the move.

$$F = \begin{bmatrix} 0 & 0 & 1 & 20 \\ 1 & 0 & 0 & 10 \\ 0 & 1 & 0 & 25 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(b) Prove that for a multi-dof robot arm $U_{ij} = A_1 A_2 A_3 \ldots Q_j A_j \ldots A_i \qquad j \le i.$

(c) Using this equation and from the expression of T_4^0 of question3 find the expressions for U_{43}, U_{42} and U_{431}. (6+5+9)

7. Write notes on the following (any four): (4x5)

(i) forward kinematics, (ii) robotic actuators, (iii) robot sensors, (iv) SCARA robot, (v) multiple solutions in inverse kinematics.