Reg. No.

MANIPAL INSTITUTE OF TECHNOLOGY
MANIPAL
(A constituent unit of MAHE, Manipal)

SEVENTH SEMESTER B.TECH. (INSTRUMENTATION AND CONTROL ENGG.)

END SEMESTER DEGREE EXAMINATIONS, DECEMBER – 2020

SUBJECT: Robotic Systems and Control [ICE 4030] [Elective]

26-12-2020

TIME: 3 HOURS MAX. MARKS: 50

Instructions to candidates :*Answer ALL questions and missing data may be suitably assumed.*

1A. Figure Q1A shows the initial position of a cube with one of its corner marked as 'H' at origin 'O' and the edges of length ℓ = 1 unit. Assume both UVW and XYZ frames initially share the same origin O. Draw neat diagrams illustrating the corresponding positions of the cube with its all corners marked on it, while carrying out each of the following sequences of transformation (in order).

(a) Rotation about V axis by 90^0

(b) Translation of pt. H by $[2, 0, 3]^T$ w.r.t OXYZ frame

(c) Rotation about –Y axis by 90^0

Also, verify the result using matrix method.

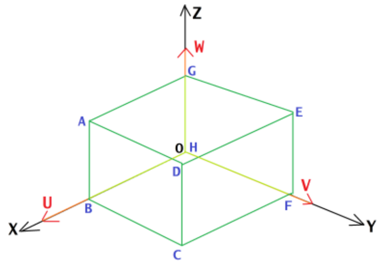

Fig Q 1A

1B. A delta robot system is as shown in Fig. Q1B(i). Here, $\overline{R}$ corresponds to active joints (i.e. joints with actuators) and R as the passive joints. As in figure Fig. Q1B(ii), each set of 3 passive joints are connected by a common link. Determine the effective degrees of freedom for the mechanism.

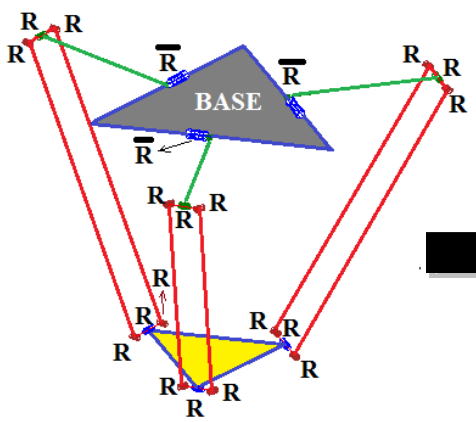

Fig. Q1B(i)

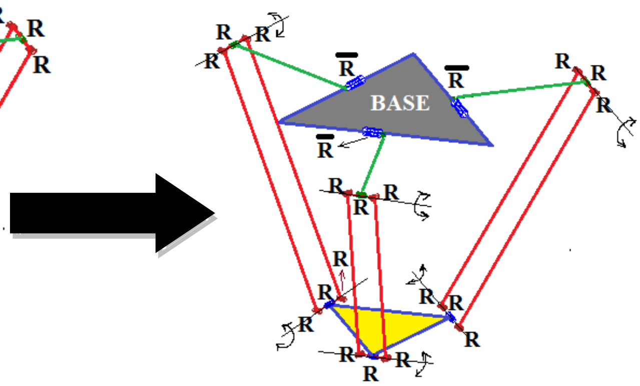

Fig. Q1B(ii)

1C. The end-point of a link of a manipulator, P is given as $^{3}p = [5, 15, 10]^T$ w.r.t a frame {3}. Compute the position of the point P w.r.t. another frame {1}, if the transformations of frame {2} to frames {1} and {3} are respectively given by:

$$ {}^{1}T_{2} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.5 & 0.867 & 0 \\ 0 & -0.867 & 0.5 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{ and } {}^{3}T_{2} = \begin{bmatrix} 1 & 0 & 0 & 10 \\ 0 & 1 & 0 & -5 \\ 0 & 0 & 1 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(5+3+2)

2A. With a relevant schematic diagram, give a brief description on Stiffness Control scheme.

2B. Obtain the spatial coordinates of end-effector 'E' for the robot wrist w.r.t its base frame {3}, as shown in Figure Q2B.

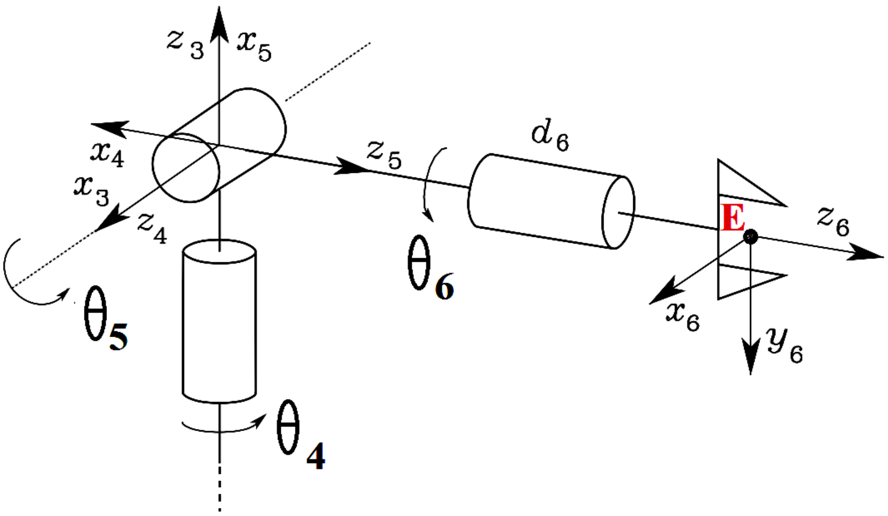

Figure Q2B

2C. Design a fifth order polynomial trajectory profile for a given joint, given the following kinematic and time constraints:

$$ t_i = 0s,\ t_f = 5s, $$

$$ x_i = 5cm, x_f = 8cm, $$

$$ \dot{x}_i = \dot{x}_f = 0\ cm.s^{-1}, $$

$$ |\ddot{x}_i| = |\ddot{x}_f| = 2\ cm \cdot s^{-2} $$

2D. Determine the differential transformation matrix (ΔT), given the Jacobian matrix (J) and differential joint motion matrix (δq) as follows:

$$ J = \begin{bmatrix} 2 & 0 & 0 & 0 & 1 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad \delta q = [0 \quad 0.1 \quad -0.1 \quad 0 \quad 0 \quad 0.2]^T $$

(2+3+3+2)

3A. Given the following link transformation matrices that relate the end-effector frame {4} of a given manipulator to its base frame {0}. Using algebraic method, determine the joint space q = [θ_1 θ_2 θ_3]^T corresponding to the actual end-effector coordinates [1, 1.1, 1.2]^T (in m). Given: ℓ_1 = 1m, ℓ_2 = 1.05m, ℓ_3 = 0.89m.

$$^0T_1 = \begin{bmatrix} \cos\theta_1 & 0 & \sin\theta_1 & 0 \\ \sin\theta_1 & 0 & -\cos\theta_1 & 0 \\ 0 & 1 & 0 & l_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad ^1T_2 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & l_2\cos\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & l_2\sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^2T_3 = \begin{bmatrix} \cos\theta_3 & 0 & \sin\theta_3 & 0 \\ \sin\theta_3 & 0 & -\cos\theta_3 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad ^3T_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3B. Determine the kinematic singularity configurations of an RPR arm, whose DH parameters are given as follows:

θ	**d**	**a**	**α**
θ_1	--	--	-90^0
--	d_2	--	--
θ_3	--	L_3	90^0

(5+5)

4A. Calculate the linear and angular velocities of end-effector for the manipulator (w.r.t. the base frame) shown in Fig.Q4A.

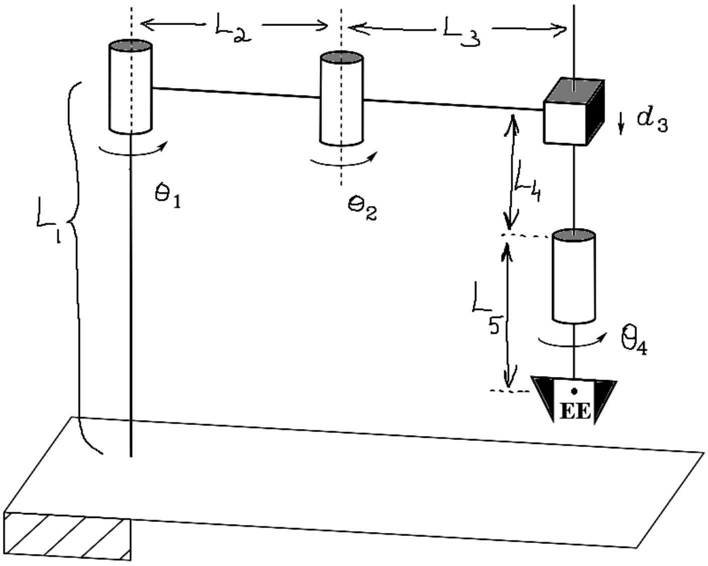

Fig.Q4A

4B. Derive the dynamic model of a 2dof planar R||R arm using Euler-Lagrangian algorithm. Here, assume that the mass of each link is a point-mass located at the centre of mass of the link, and the links are assumed to be rigid, slender structures. Given MoI of link 'i', $I = \frac{1}{12} m_i L_i^2$.

(5+5)

5A. The DH table for a non-planar manipulator is given as follows. It is desired to move the end-effector of the manipulator from point. A (9, 4, 1) to point B (5, 3, 4). Determine the joints angles corresponding to these given Cartesian points. Let $L_1=L_2=1$.

θ	**d**	**a**	**α**
θ_1	--	L_1	90^0
θ_2	--	--	-90^0
--	d_3	L_3	--

5B. Design a *trapezoidal velocity* trajectory profile for a given joint, given the following kinematic constraints:

$$t_i = 0s,\ t_f = 10s,$$
$$\theta_i = 30^0, \theta_f = 60^0,$$
$$\dot{\theta}_i = \dot{\theta}_f = 0 \text{ deg.}s^{-1}$$

(7+3)

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ANNEXURE:

$$^{i}T_{i+1} = \begin{bmatrix} C_{\theta_i} & -S_{\theta_i}C_{\alpha_i} & S_{\theta_i}S_{\alpha_i} & a_iC_{\theta_i} \\ S_{\theta_i} & C_{\theta_i}C_{\alpha_i} & -C_{\theta_i}S_{\alpha_i} & a_iS_{\theta_i} \\ 0 & S_{\alpha_i} & C_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$