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, JANUARY - 2021**

**SUBJECT: ROBOTIC SYSTEM AND CONTROL [ICE 4030]**

27-01-2021

TIME: 3 HOURS MAX. MARKS: 50

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

1A. Assume that a quad-pod robot is standing on a given plane. The sagittal cross-section of the robot is shown in Fig.Q1A. With this configuration of the gaits (i.e. 'robot legs'), determine the effective degrees of freedom.

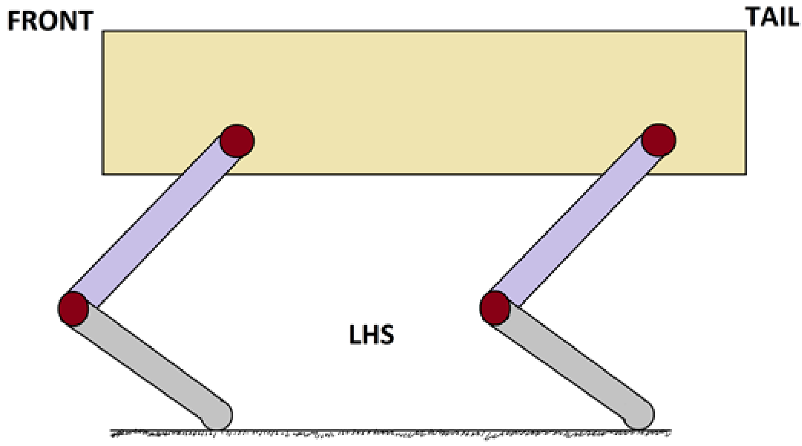


Fig.Q1A

1B. Determine the end-effector position (E) of a given manipulator shown in Fig. Q1B using geometrical approach only.

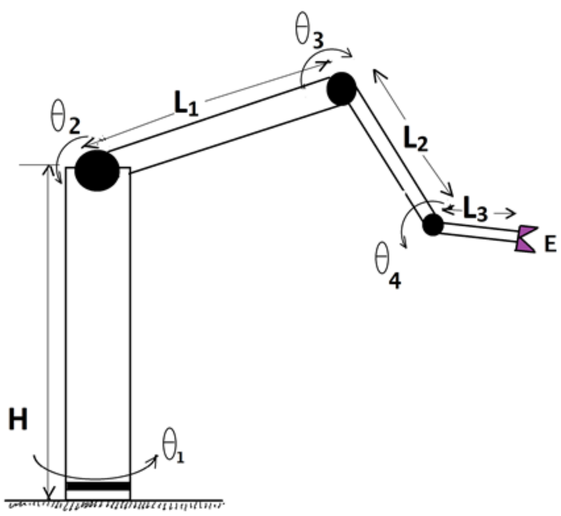


Fig.Q1B

1C. For Q1B, design a joint space trajectory planning for the third joint (from Base) by considering a linear function with parabolic blends. Assume all units in radians and time in seconds:

$$\theta_i = 0.872 \quad \dot{\theta}_i = 0 \quad t_i = 0$$

$$\theta_f = 1.047 \quad \dot{\theta}_f = 0 \quad t_f = 10$$

(2+3+5)

2A. Is it important while choosing frame assignment for an *n*-DOF manipulator that gives a maximum number of *zero* joint-link parameters? Justify your answer.

2B. A 6DOF humanoid arm is employed to drill a hole on a given object. A camera is placed on the fifth revoluting joint of the robot arm. Assume only the following homogeneous transformation matrices to be available. Using these matrices, determine the homogeneous transformation matrix, ${}^{D}T_{obj}$, that connects the coordinate frame of the drill-tip to that of the given object.

| | | |
|---|---|---|
| ${}^{5}\mathbf{T}_{6}$ | : | Joint-5 frame to Joint 6 frame |
| ${}^{6}\mathbf{T}_{E}$ | : | Joint-6 frame to End-effector frame |
| ${}^{E}\mathbf{T}_{D}$ | : | End-effector frame to Drill-Tip frame |
| ${}^{5}\mathbf{T}_{Cam}$ | : | Joint-5 frame to Camera frame |
| ${}^{Cam}\mathbf{T}_{Obj}$ | : | Camera frame to Object frame |

2C. For the manipulator given in Q1B, determine the rotation-matrix using DH method for the end-effector ‘E’.

(2+3+5)

3A. For the *ball-and-plate* mechanism shown in Fig.Q3A, calculate the overall degrees of freedom of the ball:

(i) At the point of contact of the ball and plate

(ii) With respect to the base/ground

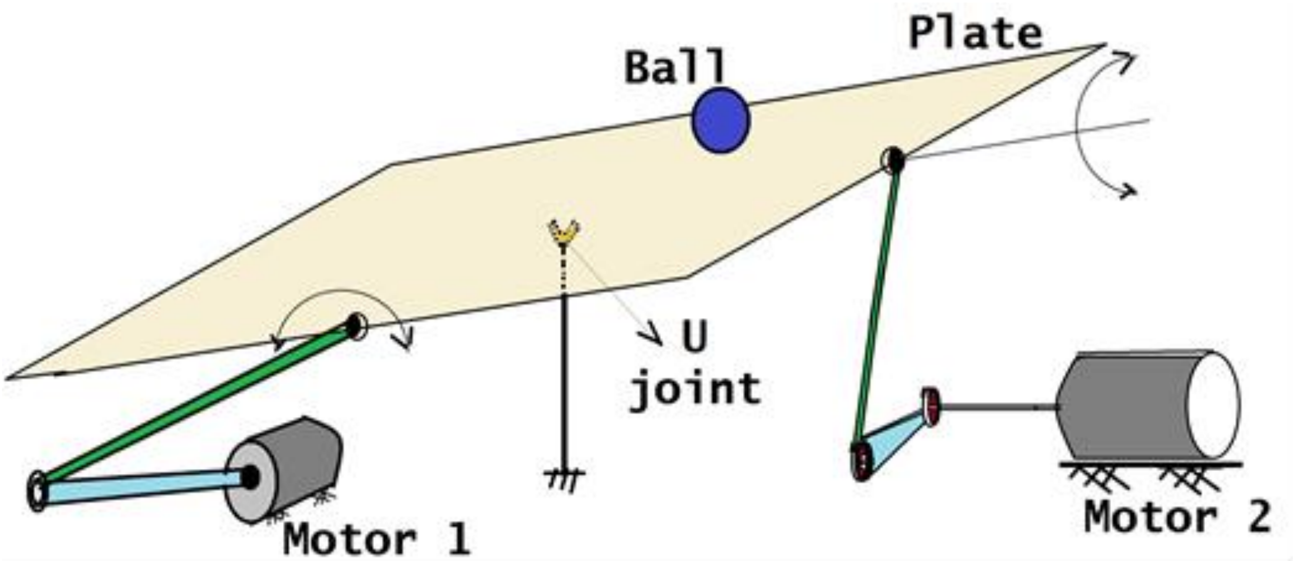


Fig.Q3A

3B. The Differential Operator $\Delta$ and the Jacobian matrix for a given 3-DOF manipulator are as follows.

$$\triangle = \begin{bmatrix} 0 & -1 & 0 & 0.1 \\ 1 & 0 & 0 & -0.2 \\ 0 & 0 & 0 & 0.3 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad J = \begin{bmatrix} 0 & 0.5 & -0.366 \\ 0 & -0.866 & -0.2113 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & -0.9063 \end{bmatrix}$$

Determine the differential joint motion matrix, $\delta q = [\delta\theta_1 \quad \delta\theta_2 \quad \delta\theta_3]^T$.

3C. Obtain the inverse kinematic solution for the manipulator as shown in Fig.Q3C.

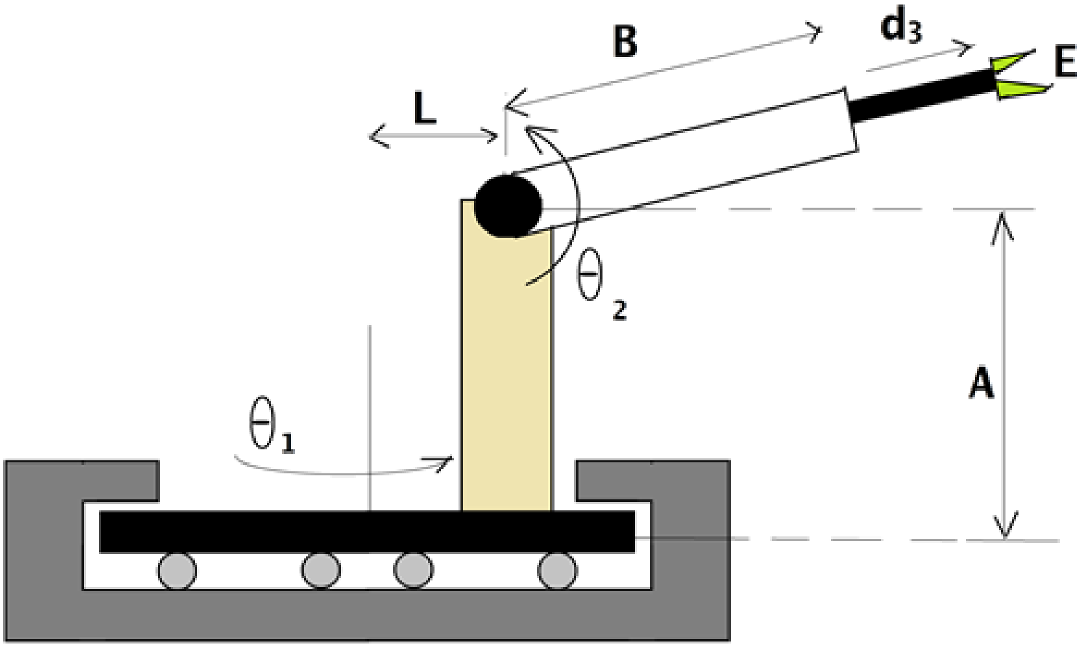


Fig.Q3C

(2+3+5)

4A. For the manipulator given in Q3C, determine Jacobian and also the joint configurations that may lead to kinematic singularity.

4B. For the manipulator given in Q1B, determine the expressions of both linear and angular velocities of the last joint (i.e. immediate to the end-effector).

(5+5)

5A. Design a fifth order polynomial trajectory for the first joint of a cylindrical manipulator, assuming the following conditions:

$$\theta_i = 0 \qquad \dot{\theta}_i = 0 \qquad t_i = 0$$

$$\theta_f = 0.785 \qquad \dot{\theta}_f = 0 \qquad t_f = 10 \qquad |\ddot{\theta}| = 1.571$$

$${}^0T_e = \begin{bmatrix} C_1 & 0 & -S_1 & -d_3S_1 \\ S_1 & 0 & -C_1 & d_3C_1 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_i = \begin{bmatrix} 0 & 0 & 1 & -25 \\ 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 50 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_f = \begin{bmatrix} 0.5 & 0 & 0.867 & 26.01 \\ -0.867 & 0 & -0.5 & 15 \\ 0 & -1 & 0 & 200 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$T_i$ : Initial position of End-effector

$T_f$ : Final Position of End-effector

5B. Using Euler-Lagrangean algorithm, determine the dynamic equations for the given manipulator, whose transformation matrices and inertial tensor matrices corresponding to each link are as follows:

$$ {}^{0}T_1 = \begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}^{1}T_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ I_1 = \begin{bmatrix} I_{x_1} & 0 & 0 & 0 \\ 0 & I_{y_1} & 0 & 0 \\ 0 & 0 & I_{z_1} & 0 \\ 0 & 0 & 0 & 500 \end{bmatrix} \qquad I_2 = \begin{bmatrix} I_{x_2} & 0 & 0 & 0 \\ 0 & I_{y_2} & 0 & 0 \\ 0 & 0 & I_{z_2} & 0 \\ 0 & 0 & 0 & 100 \end{bmatrix} $$

(5+5)

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