Reg. No.										

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

V SEMESTER B.TECH. (MECHATRONICS ENGINEERING)

END SEMESTER EXAMINATION, DEC. 2019

SUBJECT: MECHANICS OF ROBOTIC SYSTEM [MTE 3102]

(21/12/2019)

Time: 3 Hours MAX. MARKS: 50

Instructions to Candidates:

- Answer **ALL** the questions.
- Data not provided may be suitably assumed

1A. State the joint specification and work volume of the following robot configuration: **03** **CO1**

(i) Polar Configuration
(ii) Cylindrical Configuration
(iii) Joint-arm Configuration

1B. Define the following : **02** **CO1**

(i) Accuracy (ii) Repeatability

1C. A robotic work cell has a camera with in the setup. The origin of the six joint robot fixed to a base can be seen by the camera. A cube placed on the work cell table is also seen by the camera. The Homogeneous transformation Matrix $H1$ maps the camera with cube centre. The origin of the base coordinate system as seen from the camera is represented by the homogeneous transformation system $H2$. **05** **CO2**

$$H1 = \begin{bmatrix} 0 & 1 & 0 & 2 \\ 1 & 0 & 0 & 8 \\ 0 & 0 & -1 & 7 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad H2 = \begin{bmatrix} 1 & 0 & 0 & -8 \\ 0 & -1 & 0 & 15 \\ 0 & 0 & -1 & 6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(i) What is the position and orientation of the cube with respect to the base coordinate system?

(ii) After the system has been setup someone rotates the camera 90^0 about Z-axis of the camera. What is the position and orientation of the camera with respect to robots base coordinate system?

(iii) The same person rotated the object by 90^0 about the X-axis and translated 5 units' distance along the rotated Y-axis. What is the position and orientation of the object with respect to the robot base coordinate system?

2A. Determine the frame assignment, D-H table and transformation matrix ${}^{0}\boldsymbol{T}_3$ of 3-DoF articulated arm robot shown in Fig. Q2A using D-H convention. **05** **CO3**

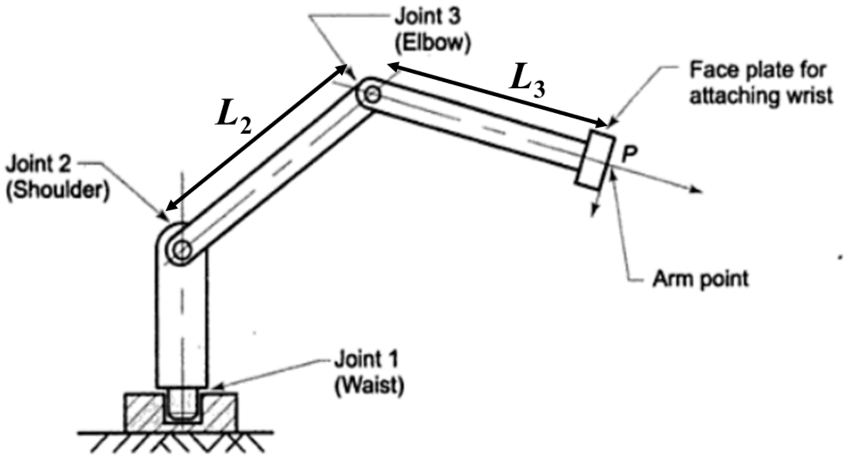

Fig. Q2A

2B. Determine the joint variables of the 4-DOF RPPR manipulator, given transformation matrix which is presented below **05** **CO3**

$$ {}^{0}T_1(\theta_1) = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}^{1}\boldsymbol{T}_2(d_2) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{2}\boldsymbol{T}_3(d_3) = \begin{bmatrix} 1 & 0 & 0 & 5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}^{3}\boldsymbol{T}_4(\theta_4) = \begin{bmatrix} C_4 & -S_4 & 0 & 0 \\ S_4 & C_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ \boldsymbol{T}_E = \begin{bmatrix} -0.250 & 0.433 & -0.866 & -89.10 \\ 0.433 & -0.750 & -0.500 & -45.67 \\ -0.866 & -0.500 & 0.000 & 50.00 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Where, $\text{Cos}(\theta_1) = C_1$ $\text{Sin}(\theta_1) = S_1$
$\text{Cos}(\theta_4) = C_4$ $\text{Sin}(\theta_4) = S_4$

3A.	Determine the new location of the hand after the differential motion. If hand frame of 2RPP2R manipulator, its numerical Jacobian (J) for this instance, and a set of differential motions are given.	**05**	**CO3**

$$Transformation\ Matrix\ (Te) = \begin{bmatrix} 1 & 0 & 1 & 4 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & -1 & 6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$Jacobian\ Matrix\ J = \begin{bmatrix} 2 & 0 & 0 & 0 & 0 & 0 \\ 3 & 0 & 3 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ -1 & 5 & 0 & 1 & -4 & 0 \\ 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 1 & -2 & 0 & 0 & 1 \end{bmatrix}$$

$$Differential\ Motion\ matrices\ [D] = \begin{bmatrix} d\theta 1 \\ d\theta 2 \\ ds1 \\ ds2 \\ d\theta 5 \\ d\theta 4 \end{bmatrix} = \begin{bmatrix} 0.1 \\ -0.2 \\ 0.04 \\ 0.07 \\ 0.3 \\ 0.5 \end{bmatrix}$$

3B.	A camera is attached to the hand frame T_H of a robot. The corresponding inverse jacobian (J^{-1}) of the robot at this location is also shown. The robot makes a differential motion described as $D = [\ 0.05\ \ 0\ \ -0.1\ \ 0\ \ 0.1\ \ 0.03\ ]^T$; Find:	**04**	**CO3**

(i) Which joints must make a differential motion, and by how much, in order to create the indicated differential motions.
(ii) The change in the hand frame.
(iii) The new location of the camera after the differential motion.
(iv) How much the differential motions should have been instead, if measured relative to Frame T_H, to move the robot to the same new location as in part (iii) above.

$$T_H = \begin{bmatrix} 0 & 1 & 0 & 3 \\ 1 & 0 & 0 & 2 \\ 0 & 0 & -1 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad J^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & -1 & 0 & 0 & 0 \\ 0 & -0.2 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

3C.	Define Degree of Freedom? What is maximum degree of freedom of a body resting in a plane?	**01**	**CO1**
4.	Develop equations of motions of 2-DOF manipulator shown in Fig.Q4 using Lagrangian method, The center of mass for each link is at the center of the link. The moment of inertia are I_1 and I_2. Calculate:		**CO4**
	(i) The kinetic and potential energy of link 1 and 2.	**06**	

(ii) The torque of joint 2. **04**

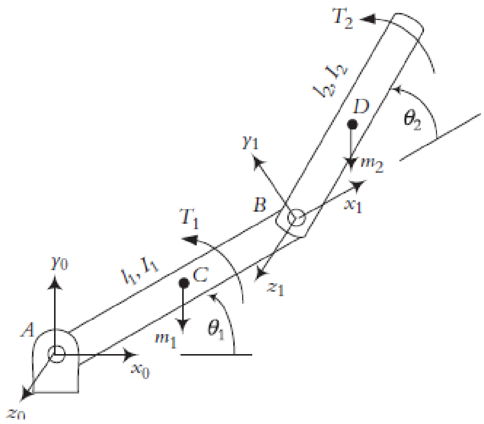

Fig. Q4

5A. Define the following : **05** **CO5**

(i) Path
(ii) Trajectory
(iii) Joint space trajectory planning
(iv) Knot Points
(v) Spline

5B. Using a third-order polynomial, calculate the joint angle at 1, 2, and 4 seconds, if the first joint of a 6-axis robot go from initial angle of 30^0 to a final angle of 75^0 in 5 seconds. **05** **CO5**