Reg. No.										

MANIPAL INSTITUTE OF TECHNOLOGY

MANIPAL

A Constituent Institution of Manipal University

V SEMESTER B.TECH. (MECHATRONICS ENGINEERING)

END SEMESTER EXAMINATIONS, DEC 2016/JAN 2107

SUBJECT: MECHANICS OF ROBOT SYSTEMS [MTE 3102]

REVISED CREDIT SYSTEM

Time: 3 Hours MAX. MARKS: 50

Instructions to Candidates:

- Answer **ALL** the questions.
- Missing data may be suitable assumed or referred in Appendix.

1A. A six joint robotic manipulator equipped with a digital TV camera is capable of continuously monitoring the position and the orientation of an object. The position and the orientation of the object with respect to the camera is expressed by a matrix [T1], the origin of the robot base coordinate with respect to the camera is given by [T2], and the position and the orientation of the gripper with respect to the base coordinate frame is given by [T3]. **4**

$$[T1]=\begin{bmatrix}0 & 1 & 0 & 5\\ 1 & 0 & 0 & 6\\ 0 & 0 & -1 & 10\\ 0 & 0 & 0 & 1\end{bmatrix}\quad [T2]=\begin{bmatrix}1 & 0 & 0 & -20\\ 0 & -1 & 0 & 10\\ 0 & 0 & -1 & 12\\ 0 & 0 & 0 & 1\end{bmatrix}\quad [T3]=\begin{bmatrix}1 & 0 & 0 & 8\\ 0 & 1 & 0 & 6\\ 0 & 0 & 1 & 6\\ 0 & 0 & 0 & 1\end{bmatrix}$$

Determine

i. The position and the orientation of the object with respect to the base coordinate.

ii. The position and the orientation of the object with respect to gripper.

1B. The hand frame of a robot with five degree of freedom its numerical jacobian for this instance, and a set of differential motion are given. The robot has a 2RP2R configuration. Find the new location of the hand after the differential motion **2**

$$T_6 = \begin{bmatrix} 1 & 0 & 0.1 & 5 \\ 0 & 0 & -1 & 3 \\ 0 & 1 & 0 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad J = \begin{bmatrix} 3 & 0 & 0 & 0 & 0 \\ -2 & 0 & 1 & 0 & 0 \\ 0 & 4 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ -1 & 0 & 0 & 0 & 1 \end{bmatrix}, \quad \begin{bmatrix} d\theta_1 \\ d\theta_2 \\ ds_1 \\ d\theta_4 \\ d\theta_5 \end{bmatrix} = \begin{bmatrix} 0.1 \\ -0.1 \\ 0.05 \\ 0.1 \\ 0 \end{bmatrix}$$

1C. Discuss the following robot specifications: **4**

a) Speed of Motion

b) Spatial Resolution

c) Repeatability

d) Accuracy

2A. A two degree of freedom robot manipulator is shown in figure Q.2A. Given that the length of each link is 1 unit. Establish link co-ordinate frame and the kinematic parameters. Find ${}^0A_1$ and ${}^1A_2$. Arrive at the inverse kinematic solution to this problem. **5**

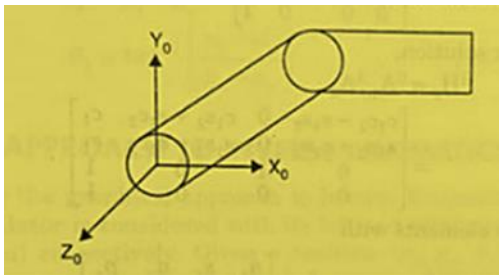

Figure Q.2A

$$[T_E] = \begin{bmatrix} n_x & s_x & a_x & p_x \\ n_y & s_y & a_y & p_y \\ n_z & s_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2B. Determine the homogeneous transformation matrix to represent the following sequence of operations. **3**

a) Rotation of 60˚ OX axis.

b) Translation of 4 units along OX axis.

c) Translation of -6units along OC axis.

d) Rotation of 30˚ about OB axis.

2C. Differentiate between: **2**

1. Joint space Trajectory and Cartesian Space Trajectory

2. Reachable Workspace and Dexterous Workspace

3A. Find the inverse kinematics of RPY wrist of 3 DOF, The transformation matrix **4**

is $^{0}T_{1}=\begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ $^{1}T_{2}=\begin{bmatrix} -S_2 & 0 & C_2 & 0 \\ C_2 & 0 & S_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ $^{2}T_{3}=\begin{bmatrix} C_3 & -S_3 & 0 & 0 \\ S_3 & C_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Determine the solution for the three joint variables for a given end-effector orientation matrix T_E. *(Table 1 for reference)*

$$T_E=\begin{bmatrix} n_x & o_x & a_x & 0 \\ n_y & o_y & a_y & 0 \\ n_z & o_y & a_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3B. Derive the equations of motion for the two link mechanism with distributed mass as shown in figure Q.3B. **6**

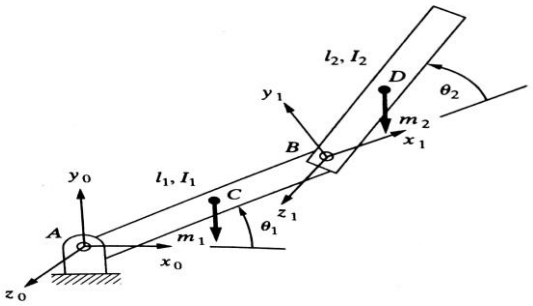

Figure Q.3B

Also define the various terms involved.

4A. **10**

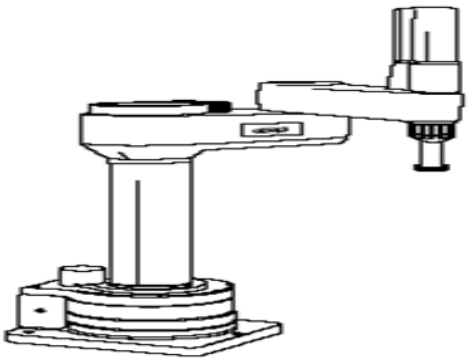

Figure Q.4A

$$T_E=\begin{bmatrix} n_x & o_x & a_x & 0 \\ n_y & o_y & a_y & 0 \\ n_z & o_y & a_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

For a SCARA robot as shown in figure Q.4A, determine the joint displacement

for known position and orientation of the end of the arm point.

5A. **5**

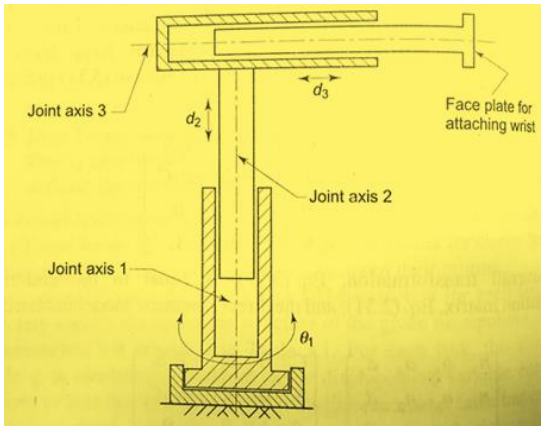

Figure Q.5A

Define the various terms of D-H table. Formulate the forward kinematics model of the three degree of freedom (RPP) manipulator shown in figure Q.5A.

5B. A fifth order polynomial is to be used to control the motions of the joints of a robot in joint. Find the coefficients of the fifth order polynomial that allow a joint to go from 0º to 120º in 5 seconds, while the initial and final velocities are zero the initial acceleration and deceleration are 10 degrees/sec^2 **3**

5C. With neat sketch, explain the different configurations of robot (with work volume, joint notation scheme). **2**

Appendix

	Equations	Solutions
1	$a\sin\theta + b\cos\theta = c$	$\theta = A\tan 2(a,b) \mp A\tan 2\left(\sqrt{a^2+b^2-c^2}, c\right)$
2	$a\sin\theta + b\cos\theta = 0$	$\theta = A\tan 2(-b, a)$ or $\theta = A\tan 2(b, -a)$
3	$\cos\theta = a$ and $\sin\theta = b$	$\theta = A\tan 2(b, a)$
4	$\cos\theta = a$	$\theta = A\tan 2\left(\mp\sqrt{1-a^2}, a\right)$
5	$\sin\theta = a$	$\theta = A\tan 2\left(a, \mp\sqrt{1-a^2}\right)$

$$A_{n+1} = \begin{bmatrix} C\theta_{n+1} & -S\theta_{n+1}C\alpha_{n+1} & S\theta_{n+1}S\alpha_{n+1} & a_{n+1}C\theta_{n+1} \\ S\theta_{n+1} & C\theta_{n+1}C\alpha_{n+1} & -C\theta_{n+1}S\alpha_{n+1} & a_{n+1}S\theta_{n+1} \\ 0 & S\alpha_{n+1} & C\alpha_{n+1} & d_{n+1} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$