BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI
HYDERABAD CAMPUS
Second Semester (2022-23)
BITS F441: Robotics

Comprehensive Exam **26th December 2022**

Time: 2.00 PM – 5.00 PM **Closed Book** **Max. Marks: 80**

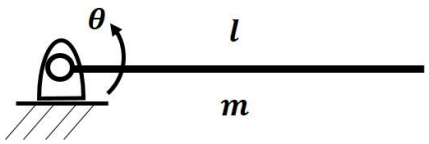
Answer the following:

Use the following Link Joint Transformation matrix if needed

$$(i-1)T_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Q1. a) Define Lagrange and Write Lagrangian equation. **2 M**

Considering a single link of length $0.35\,m$ and mass $0.25\,Kg$ as shown, determine the kinetic and potential energies of the system. **4 M**

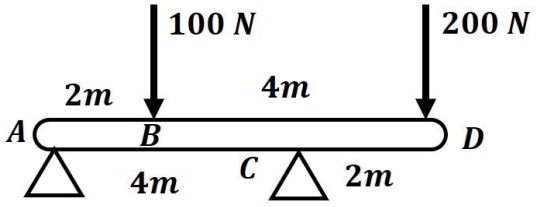


Hence determine the Lagrangian of the system. **1 M**

Draw a suitable diagram. **1 M**

Using Lagrangian equation determine the torque acting at the joint. **2 M**

Q1. b) Using Principle of Virtual work determine the reaction at support C . Draw a suitable diagram. **5 M**



Q2. For a three degree of freedom manipulator link transformation matrices for the three links are given below, determine $[0T_2]$ and $[0T_3]$ **2 M + 2 M**

$$[0T_1] = \begin{bmatrix} C_1 & 0 & S_1 & 0.2C_1 \\ S_1 & 0 & -C_1 & 0.2S_1 \\ 0 & 1 & 0 & 0.4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad [1T_2] = \begin{bmatrix} -S_2 & -C_2 & 0 & 0 \\ C_2 & -S_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[2T_3] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

What are the types of joints used? **1 M**

Write the expression for Jacobian of a revolute joint, $[J_i]$. **1 M**

What is the relation for $[0P_{i-1}]$ **1 M**

Write the expression for $[i-1P_n]$ for a revolute joint **1 M**

Determine the Jacobian for the first joint **3 M**

Determine the Jacobian for the second joint **3 M**

Determine the Jacobian for the third joint **2 M**

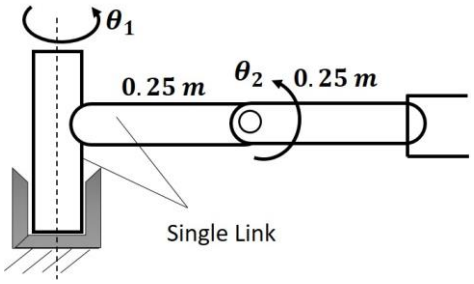
Taking $\theta_1 = 30^0$, $d_2 = 0.45\,m$ and $d_3 = 0.4\,m$ Or $\theta_1 = 30^0$, $\theta_2 = 45^0$ and $\theta_3 = 40^0$ or $\theta_1 = 30^0$, $\theta_2 = 45^0$ and $d_3 = 0.4\,m$, whichever is appropriate determine the Jacobian of the manipulator, (Separate Jacobian for each joint). Substitute the numericals at the end after writing the manipulator Jacobian**.** **2 M**

Taking End effector force vector as $[\mathcal{F}] = [10 \quad 25 \quad 0 \quad 10 \quad 20 \quad 0]^T$, , determine the Joint torque matrix, $[\tau]$. **2 M**

Q3. Using a trajectory smooth to the order C^2 determine the time history of position and velocity and acceleration of the first joint in R-R-P manipulator as it starts moving and reaching the goal point via one via point as for the following data. **10 M**

Joint 1	Via Point	Goal point
t seconds	4	4
θ degrees	24	60
$\dot{\theta}$ degrees/s	32	60

Q4. For a 2 degree of freedom RR manipulator shown in figure, assign frames and determine the link joint parameters for each link. **2 M**



Determine the transformation matrices for the 2 links, $[0T_1]$ and $[1T_2]$. **4 M**

Thereby determine the overall manipulator transformation matrix. **2 M**

Write the expression for the linear velocity of link (i) with respect to $\{0\}$. **1 M**

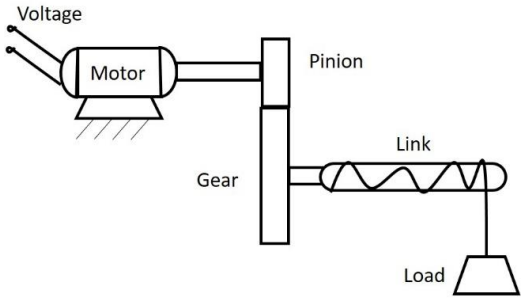
Write the expression for the angular velocity of link (i) with respect to $\{0\}$. **1 M**

Determine the linear and angular velocities of the link (1). **2 M + 2 M**

Determine the linear and angular velocities of the link (2). **2 M + 2 M**

Hence write the overall manipulator Velocity matrix. **2 M**

Q5 a. A link is driven by a gear train which is supplied with power by an electric motor as shown in figure below. When $one\ volt$ supply is given to motor, motor shaft rotates at $120rpm$. Pinion speed is 2.5 times the gear speed. As the link is rotated at $0.5\ rpm$ the load attached to the link moves by $8\ cm\ per\ minute$. Determine the gain for each element of the system. Draw a block diagram for the system and find the overall transfer function. If the load moves at $76.8\ m/min$, what is the supply voltage? **12 M**



Q5b. What is the load applied on the link, if the change in resistance of strain gauge of resistance $100\ \Omega$ is found to be $0.2\ \Omega$? Take Modulus of Elasticity of the link material as $200\ GPa$ and area of cross section is $7.5 * 10^{-6}\ m^2$. **3 M**

All The Best