Birla Institute of Technology & Science, Pilani
First Semester 2023-24 (Comprehensive Examination - Regular)

ME G511 (M&R) Total Marks: 40
Date: 15/12/2023 AN Duration 3 hrs

Close Book test (1 hour) **[Max. Marks 15]**

Each symbol represents its usual meaning. If you think data is missing in any of the problems, you may assume it and specify clearly in the answer sheet. You will be **suitably awarded** for the correct steps. The answers should be crisp and pointed.

Question 1. Each question carries 2 marks **[10]**

Q1 There is a 2R planar robotic manipulator with link length 1 unit each. Determine the velocities at the end effector as each joints move

Q2. Is it possible to generate T matrix by a set of four DH parameters (α, a, d, θ)? Provide these values. The 4×4 matrix is given below.

$$T=\begin{bmatrix} -0.7071 & 0.5 & -0.5 & -1 \\ -0.7071 & -0.5 & 0.5 & -1 \\ 0 & 0.7071 & 0.7071 & -0.7071 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Q3. Consider the 2-DOF VV arm shown in Fig.1. Assign Frames and obtain DH link and joint parameters.

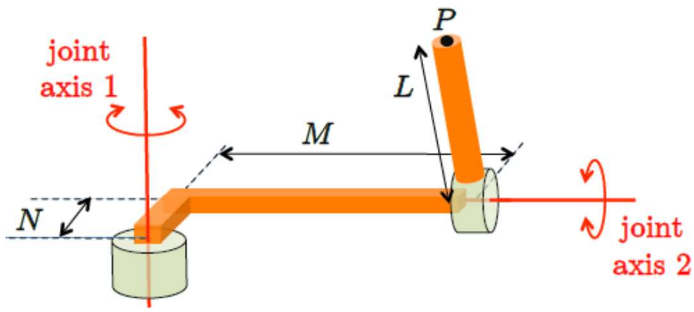

Fig.1

Q4. An incomplete time varying rotation matrix from frame 0 to frame 1 is given below. Determine the expression of a(t), b(t), c(t), d(t) and k(t) in a consistent way.

$$
{}^{0}R_{1} = \begin{bmatrix} \cos t & a(t) & b(t) \\ \sin t & \frac{k(t)}{\sqrt{2}}\cos t & c(t) \\ 0 & -\frac{k(t)}{\sqrt{2}}\sin t & d(t) \end{bmatrix}
$$

Q5. The DH parameters of a 2-DOF arm is given in table:

Link	αi	ai	di	Θi
1	π/2	0	0	q_1
2	0	0	q_2	0

The two joints have a range limitation: $|q_1| \leq 120^0 \, and \, |q_2| \leq 2 \, [m]$.
Determine all feasible inverse kinematics solutions. If the origin of frame {2} needs to be placed at (-1,1) [m].

Q6. Each question carries 0.5 mark. (Justify if required) **[5]**

(a) Show the block diagram to indicate how multi joint industrial manipulators are controlled.

(b) A 3-DOF Gantry-type robot has multiple inverse kinematic solution in its workspace.

(c) Discuss the major differences between LE and NE approach for dynamic models

(d) A planar manipulator with n ≥ 3 revolute joints has up to n inverse solutions for a positioning task.

(e) State the formula linking joint torque with the generalized force acting at EE when the robot is in static equilibrium.

(f) Is it true that if a closed-form inverse solution is not known in advance, then a numerical method cannot provide a solution?

(g) Is it true that a robot with twist angles αi different from 0, ±π/2, or ±π has no closed-form inverse solution?

(h) Why joints of robot following cubic trajectory will have jerkier motion compared to the joints following quantic trajectory?

(i) Is Freudenstien’s equation for 4 bar mechanism scale-dependent?

(j) If the $\omega = \begin{bmatrix} -1 & 0.5 & \sqrt{3}/2 \end{bmatrix}^T$ and $R = [0 \quad 1 \quad 0; 0.5 \quad 0 \quad \sqrt{3}/2; \sqrt{3}/2 \quad 0 \quad -0.5]$. Then what is $\dot{R}$

Important Formula

$$
{}^{i-1}\mathbf{T}_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
R_3 + R_2 C_4 - R_1 C_2 = \cos(\theta_2 - \theta_4)
$$

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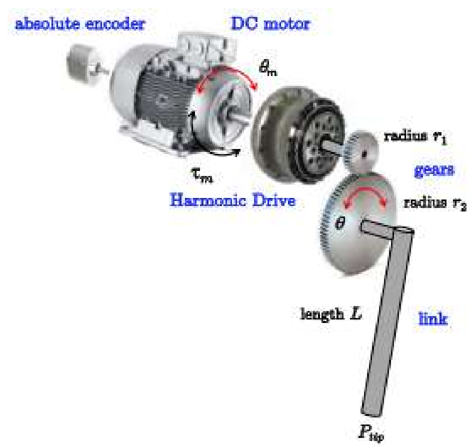
OPEN BOOK [2hrs] **[Max. Marks 25]**

Each symbol represents its usual meaning. If you think data is missing in any of the problems, you may assume it and specify clearly in the answer sheet.

Q1. Using velocity analysis of four bar mechanism, obtain the solutions of ω_3 and ω_4. Assume a, b, c, and d, are link lengths and $\theta_1, \theta_2, \theta_3,\ and\ \theta_4$ are corresponding angles made by links. **[6]**

Q2. DC motor is used to move a link of length L = 0.7[m], as shown in Fig. The motor mounts on its axis an absolute encoder and uses as transmission elements a Harmonic Drive having a flexspline with NFS=160 teeth and a gear with two toothed wheels of radius r_1=2 and r_2=4[cm], respectively. If the motor inertia is $J_m = 1.2 \times \cdot 10^{-4}$ [kgm2], determine the link inertia J_l around the axis at its base which minimizes the motor torque τ_m needed for a desired link acceleration. What is then the value of τm (in [Nm]) for acceleration = 7 [rad/s2]? [4]



Q3. Perform static analysis of 2-R planar manipulator, with length and mass $l_1, l_2, m_1, and\ m_2$ respectively. Determine $f_{i-1,i}\ and\ N_{i-1,i}$ and Torque at the joints when the end effector system applies following forces and moments to the environment $F = [2N \quad 2N \quad 0 \quad 0 \quad 0 \quad 1N.m]$ **[6]**

Q4. Derive the dynamic model using the Lagrange Euler method (Matrix approach) for a 1-R, manipulator lifting a payload W at its end-effector. Assuming that the link has length L and link mass M at the CG.

(A) Determine kinematic model, where the link has a twist angle of α

(B) Inertia Tensor matrix, $d_{ij}, M_{ij}, H_i\ and\ G_i$ values. (Assume that the Link is a slender member)

(C) Determine the Torque required to change the configuration of the link for 0 to 80 degrees in 2 sec, using quintic trajectory (Show Joint Torque at 0.25 sec, 0.5 sec, 1 sec, and 2 sec). Assume that the Payload is 1 Kg and Link length and weight are 1 m and 3 Kg respectively. **[1+4+4]**

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