BITS Pilani K.K. Birla Goa Campus
Mid-semester Examination
First Semester 2022-2023

ME G511- Mechanisms & Robotics

Date: 05/11/2022
Time: 11:30 AM – 01:00 PM

Total marks: 60
No. of questions: 3

Note:

- *The exam is open-book. Students are allowed to carry 1 textbook, 1 notebook and bound/stapled printouts of lecture slides. Loose sheets are not allowed in the exam hall.*
- *All variables, constants, and annotations carry the same meaning mentioned in the class.*
- *If necessary, make reasonable assumptions for solving the problems and state them clearly in the answer sheet.*

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1. Figure 1 shows a gantry type PRR robot with coordinate frames attached to the links. Transformation matrices for the frames are given below.

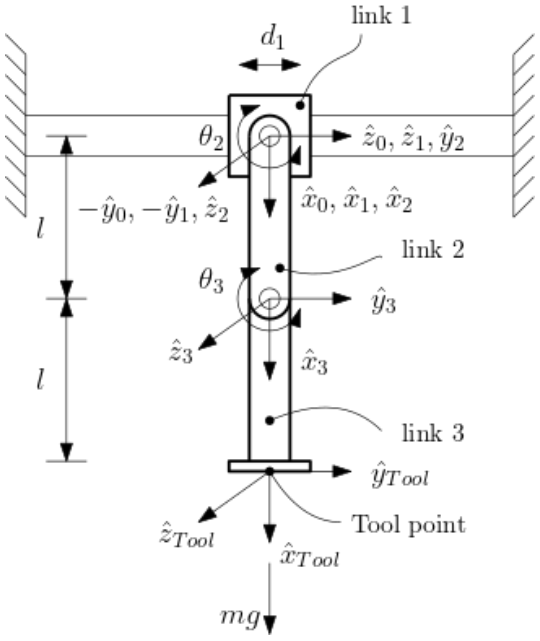

Figure 1: PRR robot for Qn. 1

$$ {}^0[T]_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \; {}^1[T]_2 = \begin{bmatrix} C_2 & -S_2 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ S_2 & C_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \; {}^2[T]_3 = \begin{bmatrix} C_3 & -S_3 & 0 & l \\ S_3 & C_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \; {}^3[T]_{Tool} = \begin{bmatrix} 1 & 0 & 0 & l \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(a) (10 marks) Calculate the linear velocity ${}^i\mathbf{v}_i$ and angular velocity ${}^i\omega_i$ where $i = \{1, 2, 3, Tool\}$

(b) (10 marks) Find the manipulator Jacobian matrix, ${}^0[J(\mathbf{q})]_{Tool}$

(c) (5 marks) Calculate the static forces/torques required at the links for holding a mass m at the tool point.

(d) (5 marks) Write the Jacobian submatrix , ${}^0[J'(\mathbf{q})]_{Tool}$ such that $[{}^0\dot{x}_{Tool}, {}^0\dot{z}_{Tool}, {}^0\omega_{y_{Tool}}]^T = {}^0[J'(\mathbf{q})]_{Tool}\dot{\mathbf{q}}$. Find the singular configuration(s) of the robot by analysing ${}^0[J'(\mathbf{q}]_{Tool}$

(P.T.O.)

2. The RPRR robot shown in Figure 2 is in home position.

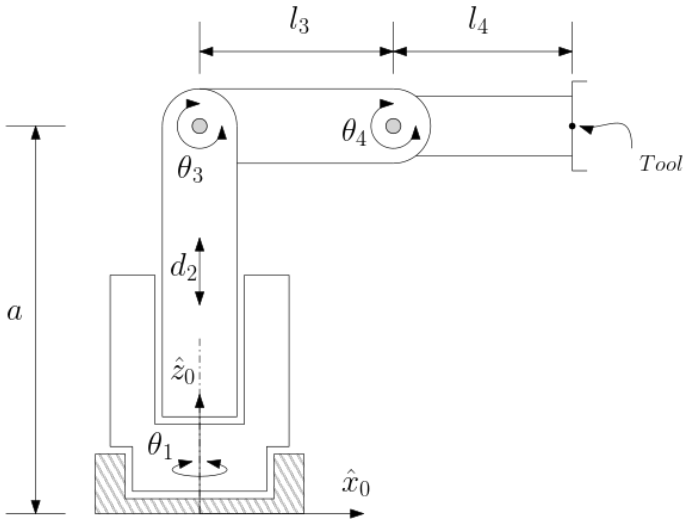

Figure 2: RPRR robot for Qn. 2

(a) (10 marks) Draw the link-coordinate diagram and populate the DH table.

(b) (10 marks) Find the transformation matrix ${}^0[T]_{Tool}$ in terms of joint variables and constants.

3. (10 marks) One of the joints in an industrial robot is directly driven by a DC servo motor with position control(as shown in Figure 3). The robot attains singular configuration if the joint angle θ is at 63°. To avoid singularity, the user always prescribes the value of joint rotation to be less than or equal to 60°. If the closed loop transfer function of the DC motor position controller is $\frac{\theta}{\theta_d} = \frac{225}{s^2 + Ks + 225}$, what should be the *minimum* value of controller gain K to ensure that the singular configuration is always avoided for a step input?

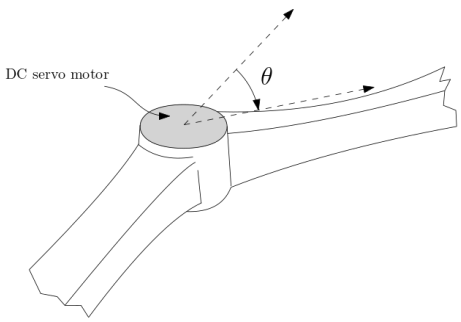

Figure 3: Figure for Qn. 3

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