PP2

TECHNICAL UNIVERSITY OF MOMBASA

School of Engineering & Technology

Department of Electrical & Electronic Engineering

UNIVERSITY EXAMINATION FOR:

BACHELOR OF SCIENCE (ELECTRICAL & ELECTRONIC ENGINEERING)

EEE 4518: ROBOTIC SYSTEMS MODELLING

END OF SEMESTER EXAMINATION

SERIES: MARCH 2025

TIME: 2 HOURS

DATE: MARCH 2025

Instructions to Candidates

You should have the following for this examination

-Answer Booklet, examination pass and student ID

This paper consists of FIVE questions. Attempt Question **ONE** and any other **Two** Questions.

Do not write on the question paper.

Question ONE

(a) Figure Q1a is a manipulator with linear, second order dynamic model given as:

$$\tau = I\ddot{\theta}_o + B\dot{\theta}_o$$

Where *I* is a total inertia and B is effective friction. The actuator gain is Km in Nms/rad. The manipulator is required to follow the desired trajectory defined by:

$$\left[\ddot{\theta}_d \quad \dot{\theta}_d \quad \theta_d\right].$$

A model-based control is deployed for the dynamic control of the manipulator. Determine the error dynamics of the system and the condition for critically damped response of the system.

[12 marks]

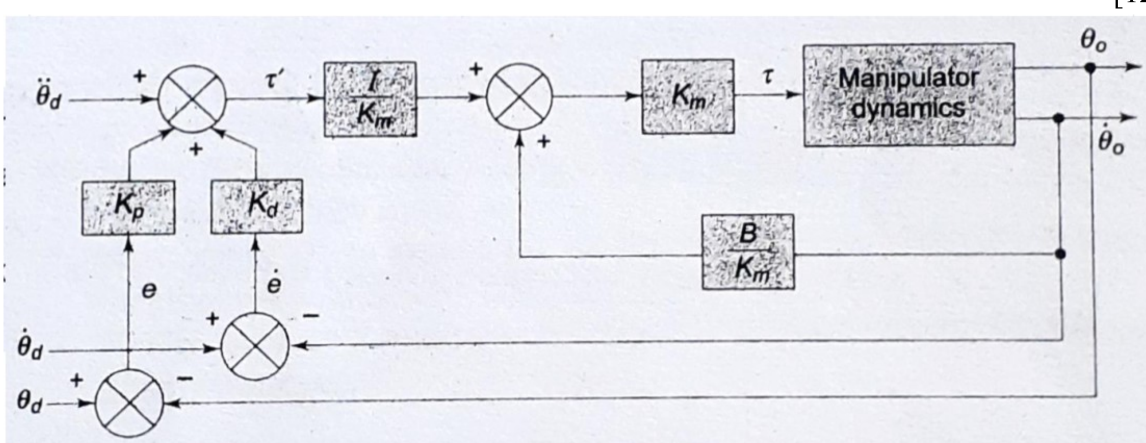

Figure Q1a

(b) (i) Briefly explain the procedure to followed when faced with a new mechanism, in order to properly attach the link frames using the **Denavit—Hartenberg's** convention:

(ii) Figure Q1b is a three-link planar arm. Assign link frames to the mechanism and give the Denavit —Hardenberg parameters. [11 marks]

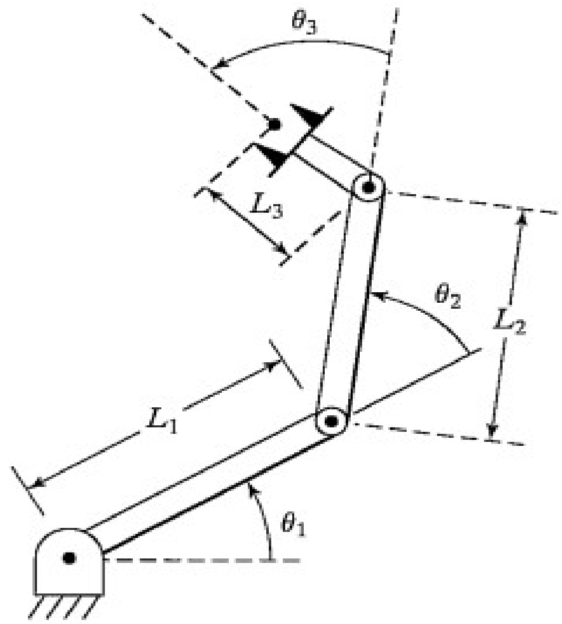

Figure Q1b

(d) Calculate the homogeneous transformation matrix for the following transform sequence that describes frame {1} with respect to the reference frame:

T = Trans (4, -3,7) Rot (x, -60) Rot(y,45) Rot (z, 90)

[7 marks]

Question TWO

(a) Explain the following as applied in robotics

(i) forward kinematics

(ii) inverse kinematics

[4 marks]

(b) In Figure Q2b are given the kinematics for a two-link planar RR arm, with τ_1, and τ_2 torques supplied by the actuators. The assumption is that the link masses are concentrated at the ends of the links. The joint variable and the generalized force vector are given as:

$$q=[\theta_1 \ \ \theta_2]^T$$

$$\tau = [\tau_1 \quad \tau_2]^T$$

For links 1 and 2, determine

(i) the kinetic energy

(ii) the potential energy

[10 marks]

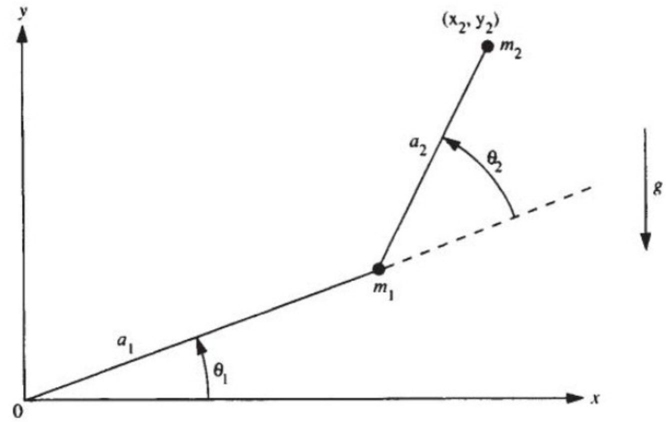

Figure Q2b

(c) The second joint of a SCARA manipulator is required to move from $\theta_2 = 30^o$ to 150^o in 5 seconds.

(i) deter the cubic polynomial to generate the smooth trajectory for the joint

(ii) determine the maximum velocity and acceleration for this trajectory

[6 marks]

Question THREE

a) In figure Q3a is 3-DOF manipulator, vector $\boldsymbol{q} = [90^o\ -45^o\ 100\text{mm}]^T$ with x_1 =50 mm and x_2 = 40mm. Obtain the position and orientation of tool point *P*.

[10 marks]

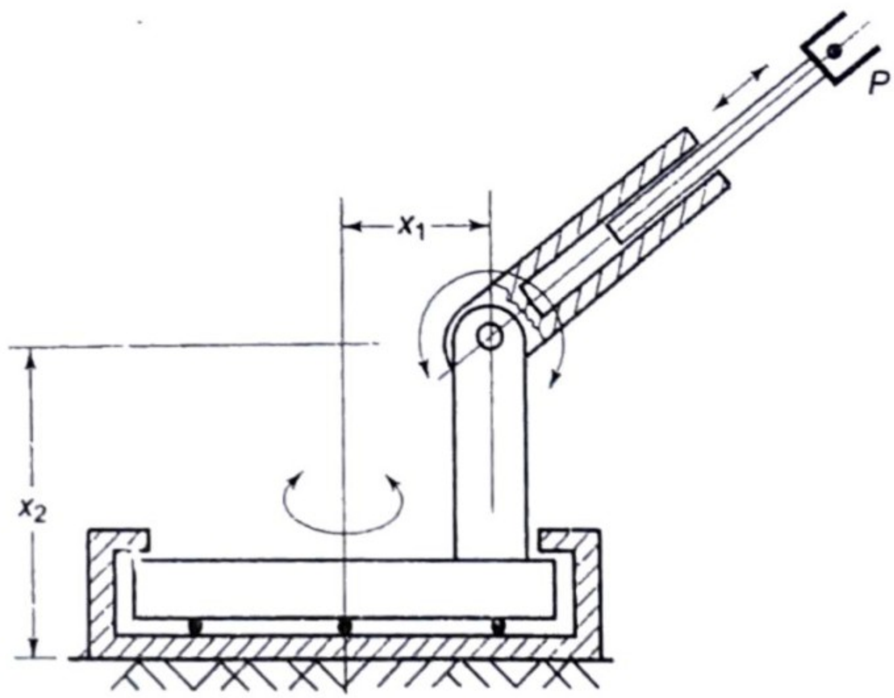

Figure Q3a

b) Figure Q3b is a two-link manipulator with rotational joints. Determine the velocity of the tip of the arm as a function of the joint rates giving your answer in two forms

i) in terms of frame {3}

ii) in terms of frame {0}

[10 marks]

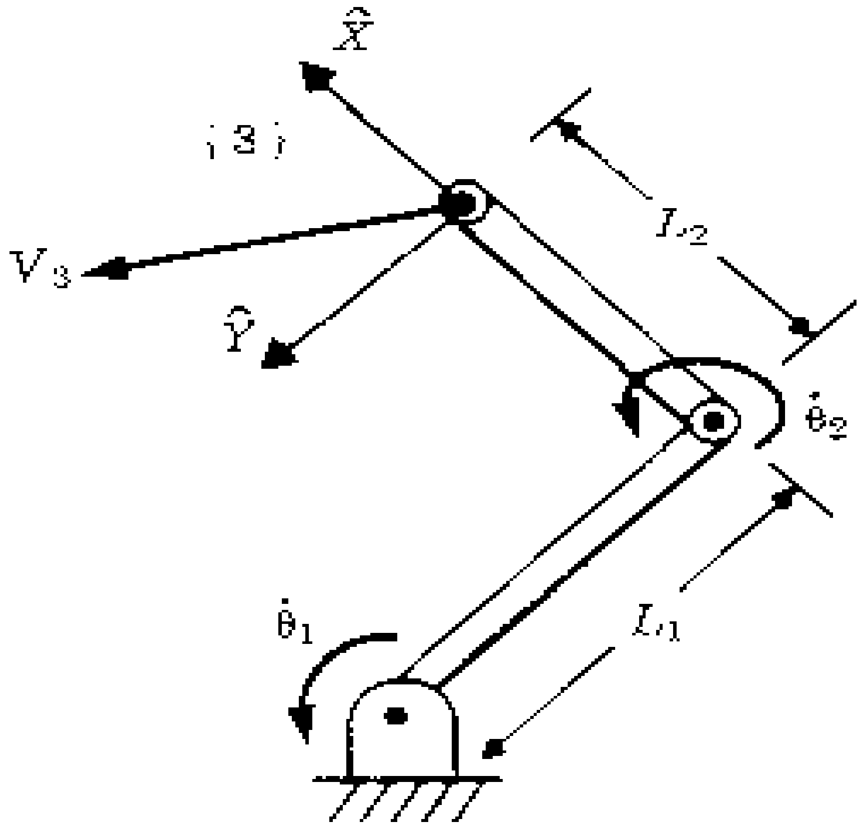

Figure Q3b

Question FOUR

(**a**) Explain the term following as applied to robotics

- (i) Manipulator structure
- (ii) Open kinematic chain
- (iii) Closed kinematic chain
- (iv) Mapping

[4 marks]

(**b**) Frame {2} is rotated with respect to Frame {1} about the x-axis by an angle of 60°. The position of origin of Frame {2}as seen from frame {1} is ${}^{1}D_2 = [7.0\ 5.0\ 7.0]^T$

- (i) Obtain the transformation matrix ${}^{1}T_2$which describes Frame {2} relative to frame {1}
- (ii) Find the description of point P in frame {1} given that ${}^{2}P = [2.0\ 4.0\ 6.0]^T$

[8 marks]

c) To study the effects of joint flexibility, a single armature-controlled dc motor coupled to a load through a shaft that has significant flexibility. The electrical and mechanical subsystems are shown in Figure Q4c, determine the mathematical model.

[8 marks]

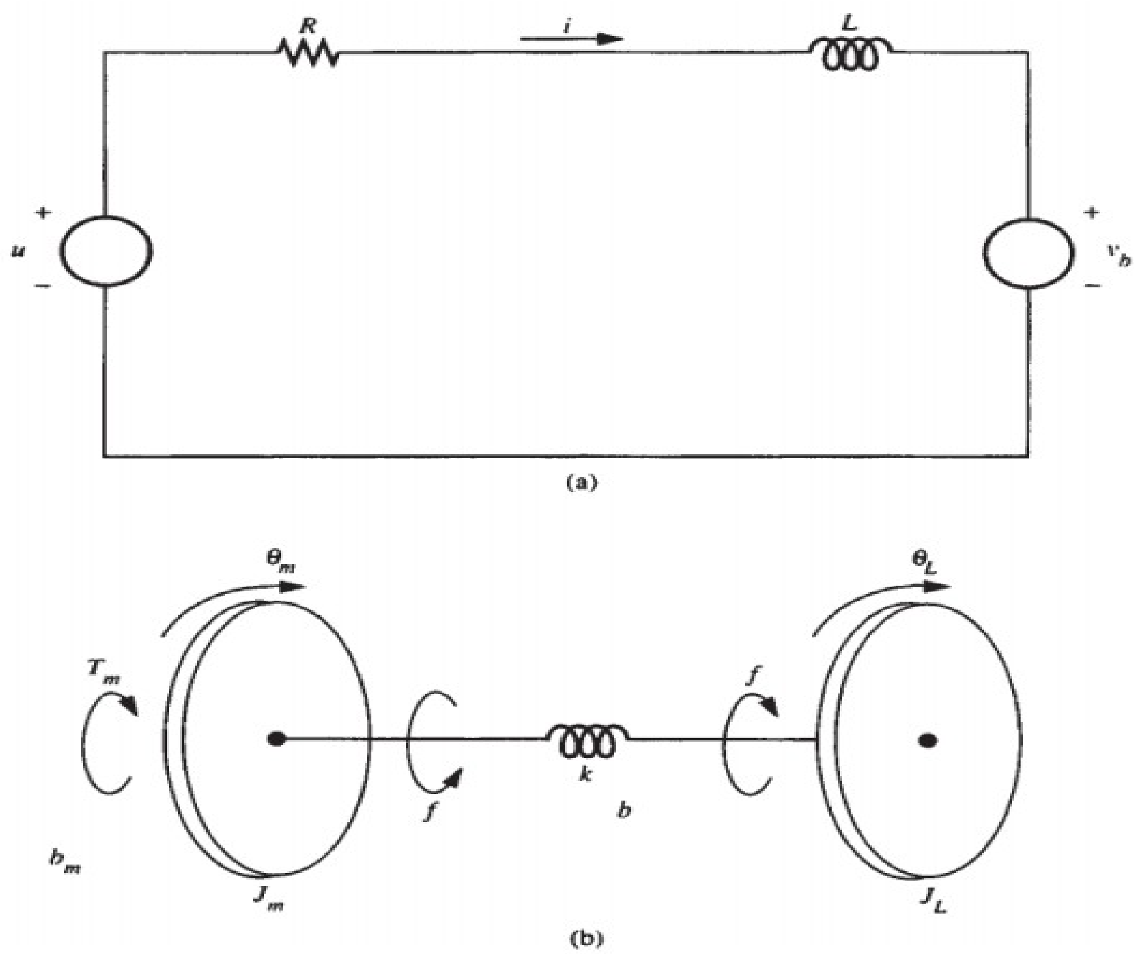

Figure Q4c

Question FIVE

(a) Describe the transformation from frame {R} to frame {Q} in Figure Q5a

[6 marks]

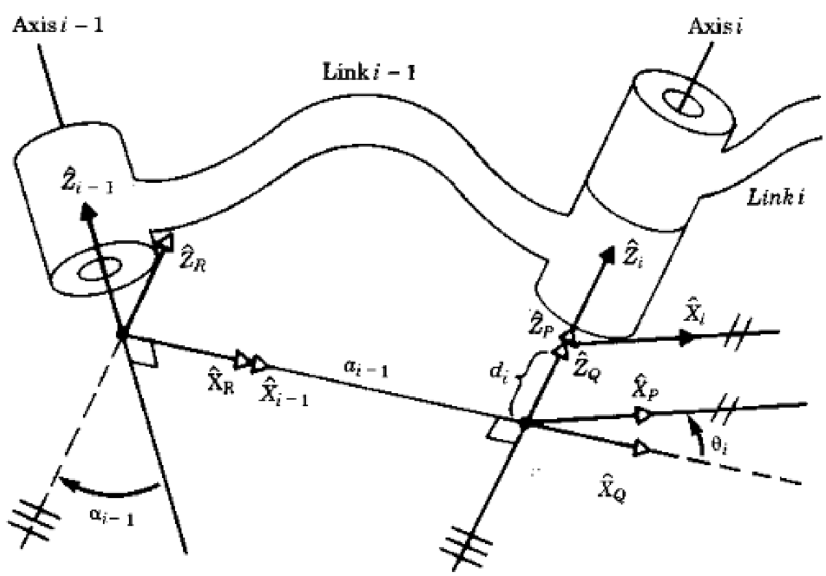

Figure Q5a

(b) Figure Q5b is a rotational system with a rotational mass at the end of a shaft. The input, a torque τ, is applied to the disk with a moment of inertia I about the axis of shaft, which is fixe at the end. The torsional stiffness of the is K and the bearing friction constant is B. Determine the condition for the system to be critically damped

[14 marks]

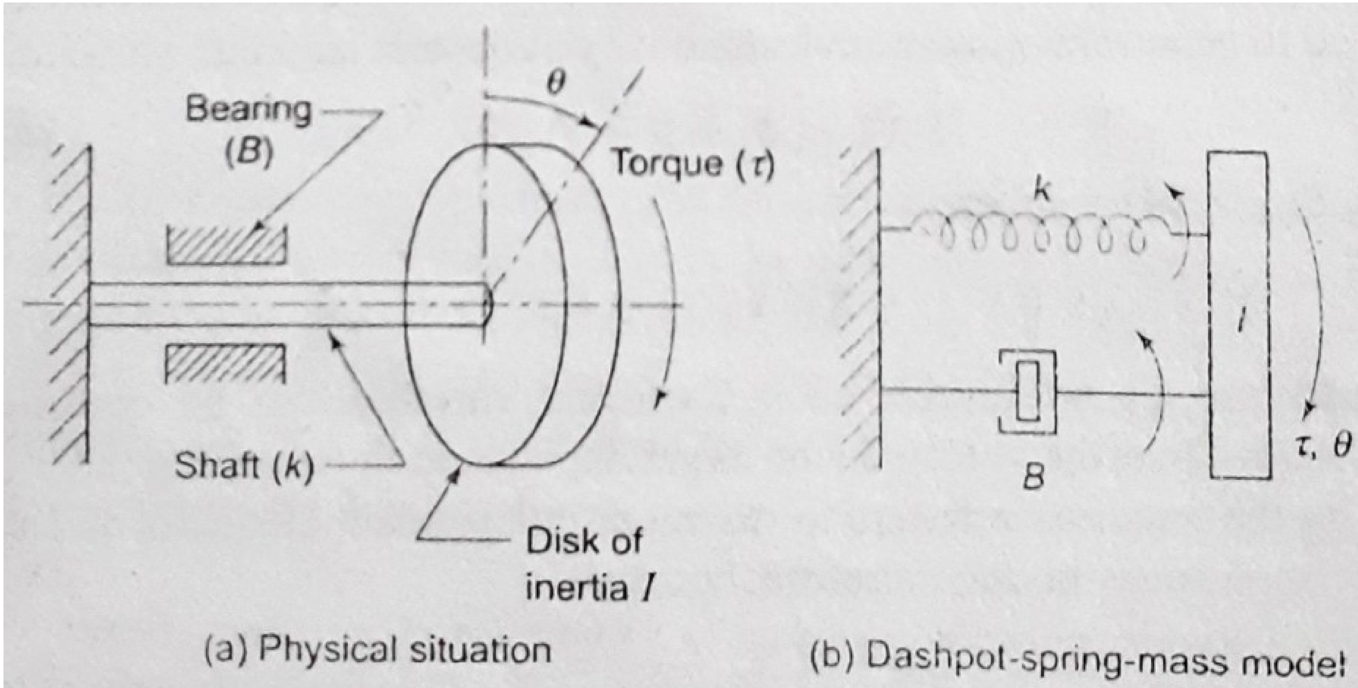

Figure Q5b