UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 6 Examination in Engineering: January 2022

Module Number: ME6213 **Module Name: Robot Manipulator Kinematics**

[Three Hours]

[Answer **all questions**, each question carries **12** marks]

Clearly state all the assumptions that you may make.

To get full marks, make sure that you have answered with correct SI units and standard notations.

Q1. Robot manipulators are important part of modern industrial systems.

a) (i) Briefly describe five industrial applications of robot manipulators.

(ii) Select one of the applications from above (i) and prepare five main specifications to select a suitable robot manipulator for the application.

[5 Marks]

b) (i) Explain the terms "redundancy" and "degree of redundancy" with reference to robot manipulators.

(ii) Compare and contrast redundant robot manipulator vs. non-redundant robot manipulator taking suitable examples or applications.

[5 Marks]

c) If you are an automation engineer assigned to design an application of product assembly to replace a few manual laborers with a robot manipulator. Explain how do you compare manual laborers vs. robot in terms of quality of the work performed and production rate.

[2 Marks]

Q2 Coordinate frame {B} is free to translate and rotate with respect to fixed coordinate frame {A}.

a) Represent {A} and {B} using the Cartesian coordinate system with the origins O and B_{ORG}. Using suitable sketches and dot products of unit vectors along the axes (X_A, Y_A, Z_A) and (X_B, Y_B, Z_B), obtain the ${}^{A}_{B}R$ and ${}^{B}_{A}R$ rotation matrixes.

[2.5 Marks]

b) Show that two rotation matrixes are orthonormal.

[2.5 Marks]

c) Write down ${}^{A}_{B}T$ and ${}^{B}_{A}T$ homogeneous transformation matrixes using position vector of B_{ORG}.

[2 Marks]

d) Show that homogeneous transformation matrixes are orthogonal but not orthonormal.

[2.5 Marks]

e) Given that coordinates of a point in {B} as $D \equiv [2 \quad 1 \quad -4]$ and $B_{ORG} \equiv [1 \quad -1 \quad 0]$, obtain position vector of D with respect to {A}.

[2.5 Marks]

Q3 a) The *Denavit–Hartenberg* (D-H) parameters are the four parameters for attaching reference frames to the links and joints of a spatial kinematic chain, or robot manipulator.

i) Draw a suitable sketch taking two consecutive joint axes as i and $i-1$, and state four D-H parameters clearly.

ii) Determine $R_X(\alpha_{i-1})$, $D_X(a_{i-1})$, $R_Z(\theta_i)$, and $D_Z(d_i)$ in usual notations.

iii) Hence show that

$$ {}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i . \cos\alpha_{i-1} & \cos\theta_i . \cos\alpha_{i-1} & -\sin\alpha_{i-1} & -\sin\alpha_{i-1} . d_i \\ \sin\theta_i . \sin\alpha_{i-1} & \cos\theta_i . \sin\alpha_{i-1} & \cos\alpha_{i-1} & \cos\alpha_{i-1} . d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

[7 Marks]

b) Figure Q3(b) shows a manipulator with two rotary joints and one prismatic joint.

i) Sketch the robot skeleton diagram.

ii) Assign three coordinate frames to the robot.

iii) Copy table Q3(b) to your answer script and fill the D-H parameters.

iv) Hence obtain the ${}^{0}_{3}T$ where {0} represents the base fixed frame.

[5 Marks]

Q4 a) Briefly explain following terms using suitable examples.

i) Dexterous workspace

ii) Reachable workspace

iii) Robot inverse kinematics

[4.5 Marks]

b) Figure Q4(a) shows the 2D top view, and side view schematics of the 4-DOF MICO robot manipulator.

i) Derive a condition to 4-DoF MICO manipulator to have a reachable workspace.

ii) Given that $L_0 + L_1 = 27.55m$, $L_2 = 29mm$, $L_3 = 12.33m$ and $L_4 = 16mm$. Solve the inverse kinematics of the robot when $(0.1, 0.1, 0.5)m$.

[6 Marks]

c) Using a suitable sketch explain the function of a robot wrist assembly.

[1.5 Marks]

Q5 a) Consider a two link RR robot manipulator (Figure Q5(a)) with link length a_1 and a_2 . It is moving its end effector along the X_0 axis at $1m/s$ constant speed.

(i) Derive the Jacobian (J) for the above manipulator and hence obtain the relationship between the end effector linear velocity $\begin{bmatrix}\dot{x}_2\\ \dot{y}_2\end{bmatrix}$ and joint velocities $\begin{bmatrix}\dot{\theta}_1\\ \dot{\theta}_2\end{bmatrix}$.

(ii) Briefly describe the condition called singularity.

(ii) Where are the singularities of the RR robot above Q5(a)?

[5 Marks]

c) Assume you are a robotics engineer of a company where various types of robot manipulators are designed, built, tested, installed and perform maintenance. The company asked you to make a proposal for one of its clients who wants to develop a robot to cook "plain hoppers". The main steps and conditions that maintained for the cooking process are listed below.

- Required mixture according to the recipe is provided in an open container or can be arranged as you wish.
- Drops of oil should be applied to the pan

- When the pan is heated to a certain temperature, a certain amount of mixture poured to the pan
- The pan (transparent) should be covered by a lid
- After the hopper is cooked properly, (identify based on the colour) it should be removed from the pan carefully.
- The above process should be repeated.

i) List the tasks needed to be performed by your robot and propose/ design a suitable robot to perform above operation. Your design should include;
   - Robot type
   - Number of links and joint types
   - Number of DoF
   - Gripper design
   - List of all the conditions maintain and any mechanism to support the operations of the robot.

ii) List suitable sensors to perform above task accurately and to produce well cocked hopers (based on the above requirements).

iii) Identify suitable actuators for the whole automated system.

iv) Sketch all the reference frames required by your robot to perform the task.

[7 Marks]

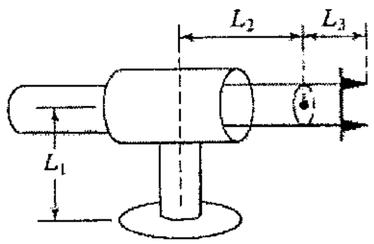
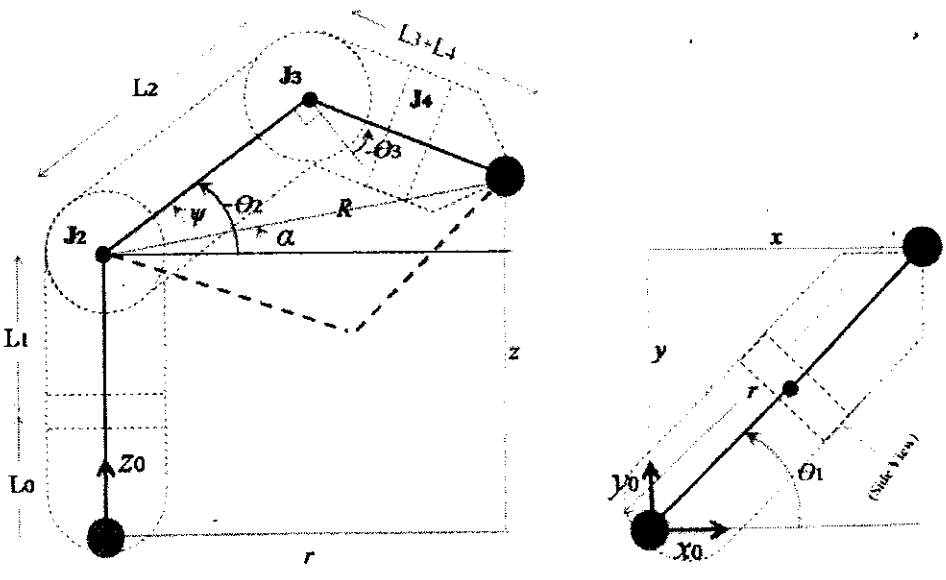


Figure Q3(b)

Joint (i)	α_{i-1} (*alpha*)	a_{i-1}	d_i	θ_i

Table Q3(b)



Side View **Top View**

Figure Q4(b)

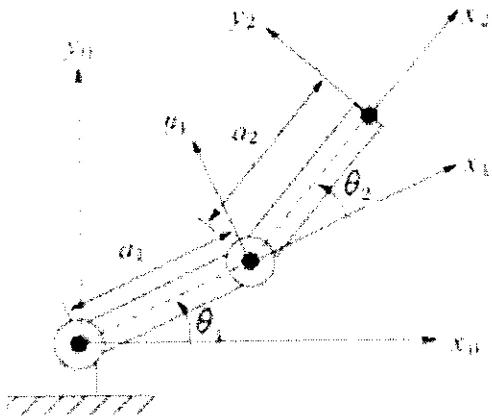


Figure Q5(a)