UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: December 2018

Module Number: ME 8214 **Module Name: Robot Manipulator Dynamics**

[Three Hours]

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

Q1. a) The GMF S-400 (GMF Robotics Corporation, USA) is a six-axis articulated arm, electric servo driven robot as shown in Figure Q1(a). All six axis motions are controlled simultaneously. Joint angle description is given in Table Q1(a).

(i) Sketch the kinematic structure of the above robot manipulator using arbitrary length parameters and position the axes system for each joint by using the standard terminology.

[2 Marks]

(ii) Sketch the robot workspace (top view and side view).

[2 Marks]

b) Define the terms "Redundancy" and "degree of redundancy" related to robotic manipulators.

[2 Marks]

c) List five industrial applications of a robot manipulator and prepare list of arbitrary specifications for one of such application.

[4 Marks]

Q2. $\{A\}$ and $\{B\}$ are two coordinate frames representing a fixed axis system and a moving rigid body frame, respectively as shown in Figure Q2. $R_x(\gamma), R_y(\beta)$ and $R_z(\alpha)$ are representing the basic rotational matrices with usual notation.

a) Derive $R_x(\gamma), R_y(\beta)$ and $R_z(\alpha)$ using scalar products of vector components method.

[4 Marks]

b) Show that rotational matrices (${}^A_BR, {}^B_AR$) are orthonormal; but homogeneous transformation matrices (${}^A_BT, {}^B_AT$) are not.

[4 Marks]

c) Given that

$$ {}^A_BT = \begin{pmatrix} 0.707 & -0.707 & 0 & -2 \\ 0.707 & 0.707 & 0 & 4 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & 1 \end{pmatrix}, $$

obtain ${}^B_AT$ without using inverse matrix transformation.

[2 Marks]

Q3. a) An RPR serial link robot manipulator is shown in Figure Q3(a). Angle between OA and AB is fixed to 90 degrees. If length of the first link (OA) and the last link are l_1 and l_2, respectively and displacement of link 2 is d,

(continue to next page...)

(i) obtain the coordinates of the end-effector position is $\binom{x_e}{y_e}$ and orientation is $\emptyset_e$ using the geometrical parameters and joint displacements.

[1.5 Marks]

(ii) Sketch the schematic of this manipulator, with the axes of frames {0} to {3} labeled. Then, obtain the *Denavit–Hartenberg* (D-H) parameters for this manipulator in the form of a table:

Joint (i)	a_{i-1}	α_{i-1}	d_i	θ_i
1				
2				
3				

[4 Marks]

(iii) Derive the forward kinematics (i.e. ${}^0_3T$) for the manipulator using D-H parameters obtained above.

[2.5 Marks]

(iv) Derive the inverse kinematics of the manipulator showing joint variables in terms of end effector position

[2 Marks]

Q4. By referring the serial PR robot manipulator shown in Figure Q4, answer to following questions.

a) Write down the *Denavit–Hartenberg* (D-H) parameters for the manipulator.

[2 Marks]

b) Determine the origin of frame {3} expressed in terms of frame {0}.

[2 Marks]

c) Derive the inverse kinematics of the manipulator showing joint variables in terms of end effector position.

[2 Marks]

d) Determine the Jacobian (2x2 matrix) that relates the joint velocities to the linear velocity of end-effector ($origin\ of$ {3}).

[2 Marks]

e) For what joint values of this manipulator at a singularity? What motion is restricted at that singularity? Briefly explain the reasons.

[2 Marks]

Q5. a) For the serial manipulator shown in Figure Q5(a),

(i) show that the end effector's velocity ($\dot{x}$) can be derived as $\dot{x} = J_1\dot{q}_1 + J_2\dot{q}_2$ where q_1 and q_2 are generalized coordinates and J_1, J_2 are related Jacobian matrices.

[2 Marks]

(ii) Hence, obtain the condition(s) for singularity of the manipulator motion and explain the physical interpretation of the arm in a singularity configuration by sketching the singularity positions and describing the resulting limitations of its movements.

[3 Marks]

b) The schematic of the *Kinova Mico* 4 DoF robot arm is shown in Figure Q5(b). Using the parameters given in the side view and top views of the robot arm;

(i) Derive the forward kinematics showing the cartesian coordinates of the origin of 4th joint in terms of joint angles.

[3 Marks]

(continue to next page...)

(ii) Obtain the Jacobian showing the relationship between linear velocity of the origin of the 4th joint in terms of joint velocities. Explain how to obtain the singularity configurations of the arm.

[2 Marks]

Q6. a) A Five bar link planer robot arm / mechanism is shown in Figure Q6(a).

(i) If the desired end-effector position is $(x_e, y_e)'$;, determine joint angles: θ_1 and θ_2.

[1 Mark]

(ii) Obtain the position of the joint 5 i.e. $(x_A, y_A)'$ using θ_1 and θ_2 above.

[1 Mark]

(iii) Given $(x_A, y_A)'$, determine the joint angles: θ_3 and θ_4.

[1 Mark]

(iii) Using the results of (i), (ii) and (iii) above, derive the relationship between $(x_e, y_e)'$ and independent variables θ_1 and θ_3.

[2 Marks]

b) In the context of robotics, trajectory refers to the time history of the position, velocity and acceleration for each degree of freedom of the robot manipulator either in the Joint space or Cartesian space. Answer following questions regarding the trajectory planning of 4 DoF revolute joints robot manipulator.

(i) What are the basic motion constraints to be satisfied in order to achieve the desired smooth motion between any consecutive way points (X_0 and X_1) of a path described by a cubic polynomial ?

[2 Marks]

(ii) How the path polynomial is extended; if the minimum jerk during the operation also to be considered? Explain capabilities of such path compared to the cubic polynomial described in above (i).

[1 Mark]

(iii) Compare and contrast trajectory planning in the operational space vs. the joint space.

[2 Marks]

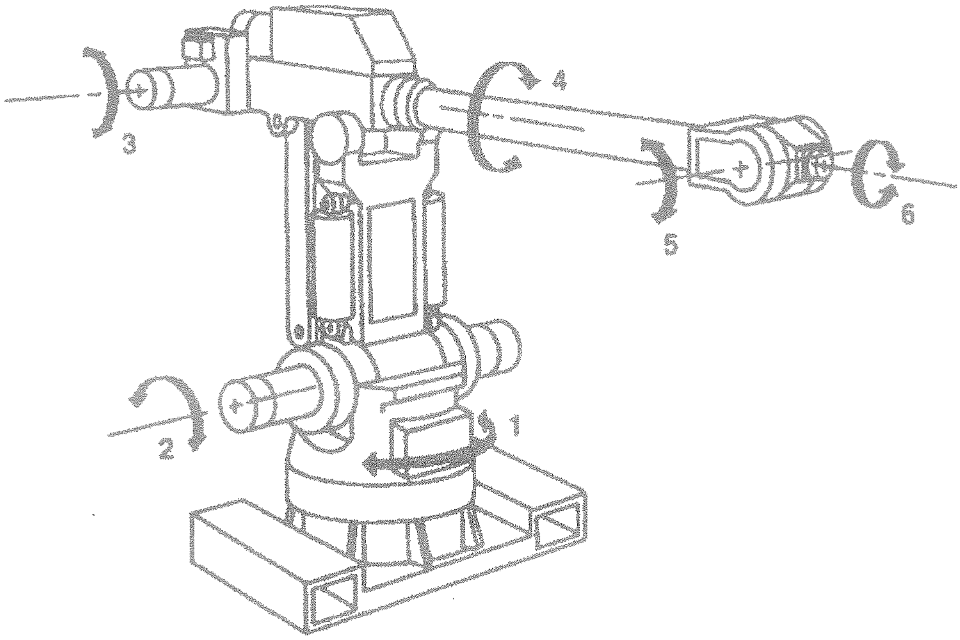

Figure Q1(a): GMF S-400 robot arm

Axis	Description	Range
1	Base rotation	-150° ~ 150°
2	Wrist bend	0° ~ 105°
3	Shoulder bend	0° ~ 120°
4	Arm roll	360°
5	Wrist pitch	0° ~ 240°
6	Wrist roll	360°

Table Q1(a): GMF S-400 axis rotation

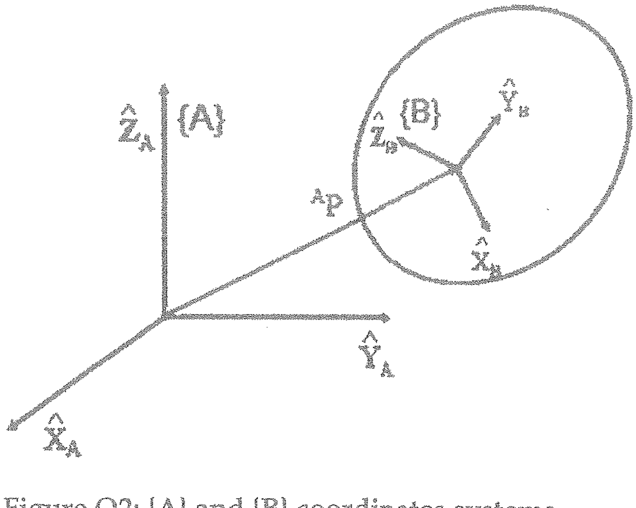

Figure Q2: {A} and {B} coordinates systems

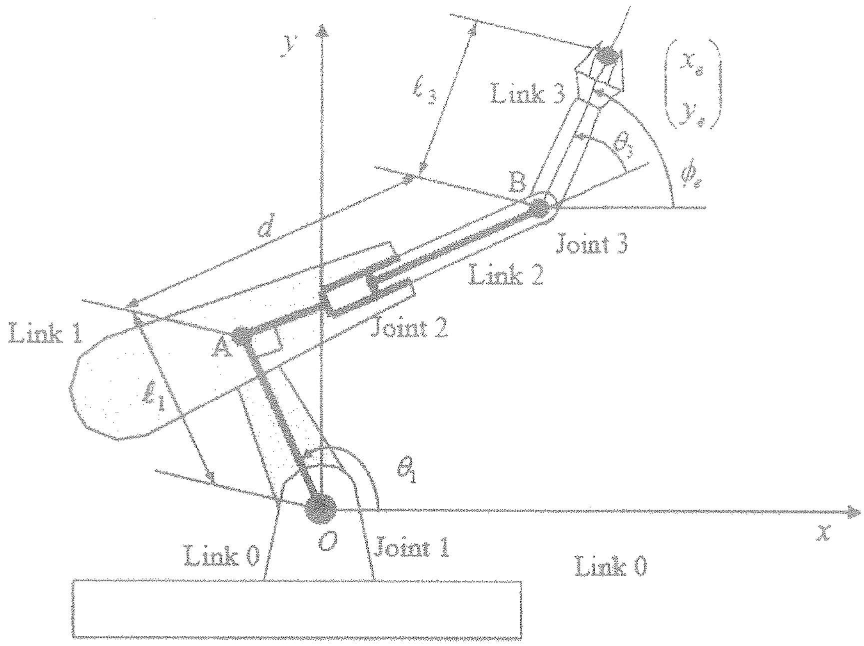

Figure Q3(a): RPR serial link robot manipulator

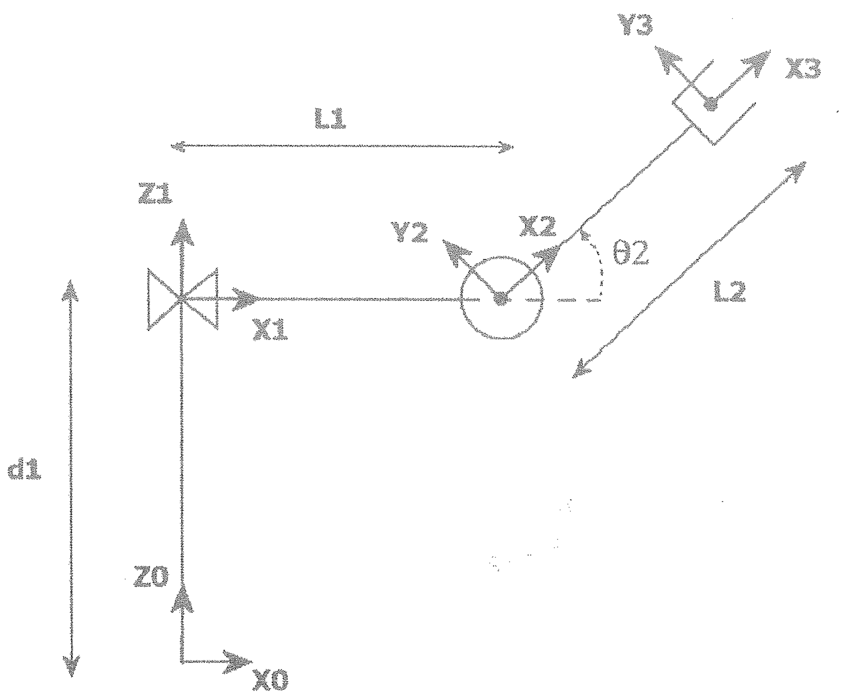

Figure Q4: PR robot manipulator

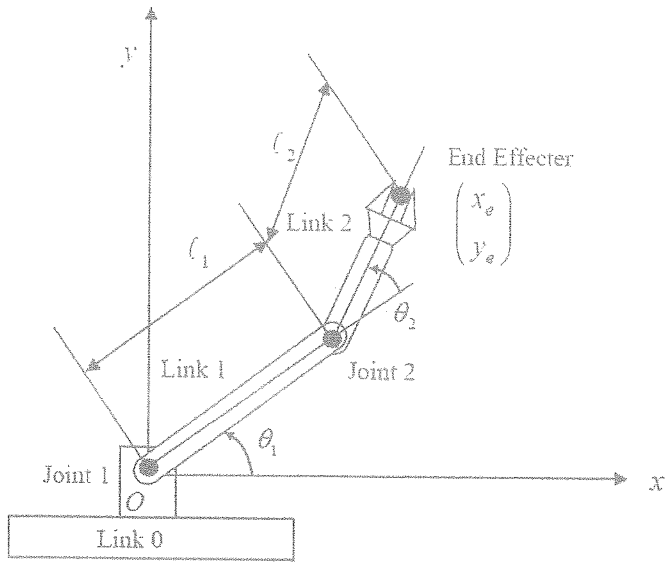

Figure Q5(a): Serial manipulator

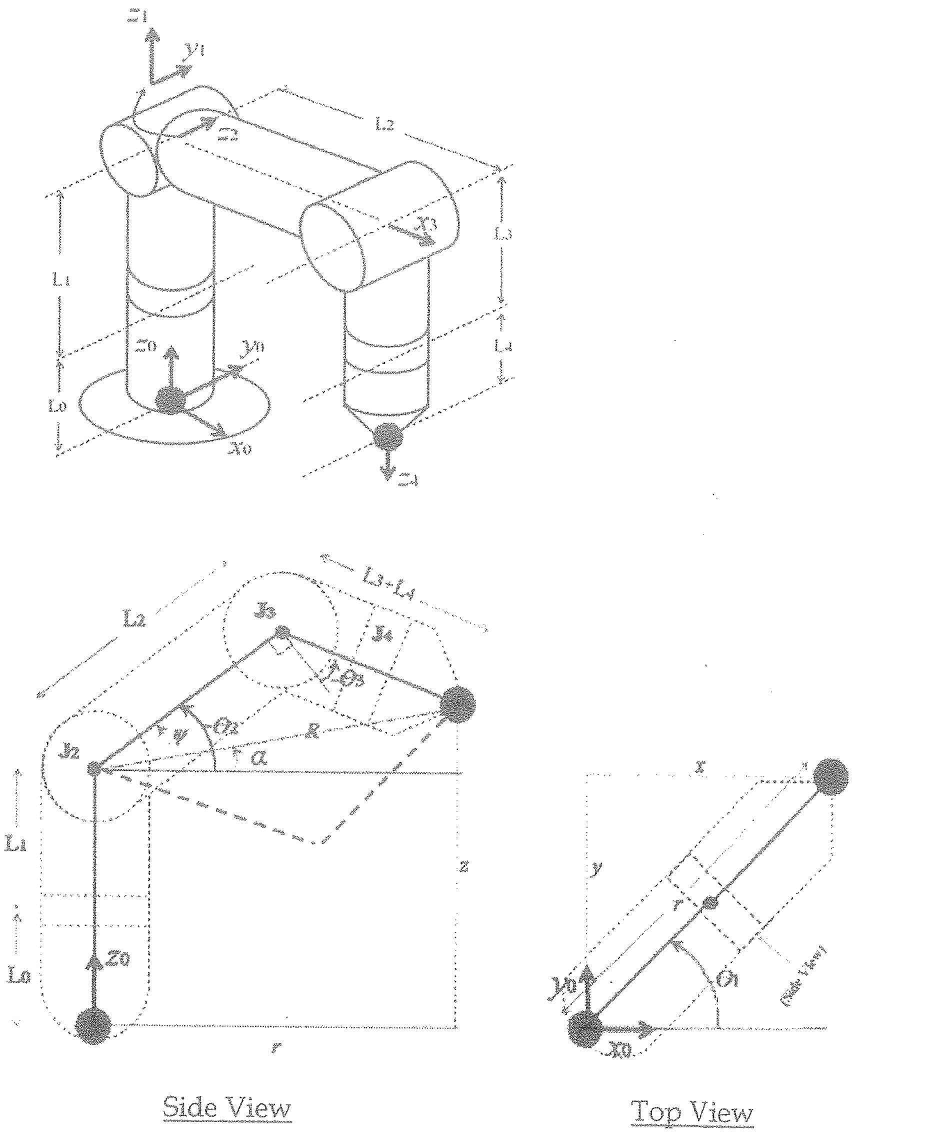

Figure Q5(b): *Kinova Mico* 4 DoF robot arm

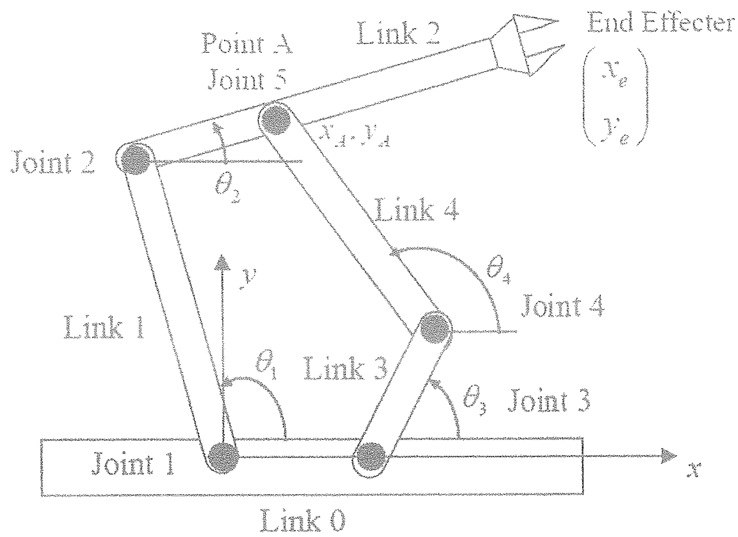

Figure Q6(a): Five bar link planer robot arm