The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Mechanical Engineering

Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	**: DMX7303 Control of Robotic Manipulators**
Academic Year	: 2020/21
Date	: 18th January 2022
Time	: 09:30-12:30 hrs.
Duration	**: 3 hours**

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Seven (8)** questions in **Six (6)** pages.
3. Answer any **Five (5)** questions only. All questions carry equal marks.
4. Answer for each question should commence from a new page.
5. This is a Closed Book Test (CBT).
6. Answers should be in clear handwriting.
7. Do not use Red colour pen.

Question 01

(a) Robotic manipulators are an indispensable tool in modern factory environments. Discuss briefly the reasons as to why robotic manipulators are widely used in the factory environment. *(05 Marks)*

(b) List out five factors in which robots may not be desirable. You may take examples to elaborate on your answer. *(05 Marks)*

(c) Robots, especially industrial robotic manipulators are considered to be dangerous if not handled in a proper manner. What are the safety precautions that are usually incorporated into robotic manipulators and precautions that are taken from the user side, in order to make the robotic working environment safe? *(05 marks)*

(d) Before designing a robotic manipulator for a particular application, discuss the importance of studying the dynamics of the robotic manipulator.

(*05 marks*)

Question 02

(a) Robot manipulators are often categorized into four, based on their geometrical configurations. Briefly describe these configurations and discuss the pros and cons of each of these. (*08 marks*)

(b) The majority of manipulators used in industry are driven by actuators that supply a force or torque that will cause the link to move in the desired trajectory and a control algorithm will calculate the desired force/torque. Such a system is typically described as the position control system of the robot manipulator. What is the primary concern of such a system and what measures have been taken in order to face such concerns? Explain.

(*06 marks*)

(c) Briefly explain force control and hybrid control with respect to control of robotic manipulators. (*06 marks*)

Question 03

(a) Obtain expressions for the three fundamental rotation matrices $\mathbf{R}(\theta)$ for the rotation about the principal axes. [*Note: It will be sufficient for you to derive for a rotation about one principal and the other be deduced*] Hence show that the sequence of rotation matters since a different sequence in rotation with the same angle does not correspond to the same orientation of the rotated frames. (*06 marks*)

(b) Two frames {1} and {2} are initially coincident with each other (both frame and origin). Frame {1} is considered to be fixed and frame {2} is considered to be the moving frame. Let {1} = {x'y'z'} and {2}= {x"y"z"}. Now a series of rotations are carried out on frame {2} with respect to frame {1}. First frame {2} is rotated about the x' axis by 60^0 followed by a rotation about y' axis by 45^0 and finally a rotation about x' axis by 30^0. Obtain the equivalent rotation matrix ${}^1\mathbf{R}_2$. (*07 marks*)

(c) Show that the same equivalent rotation matrix ${}^1\mathbf{R}_2$ as found in part (b) could be obtained by performing the same rotations about a moved x'y'z' axes of the moving frame but in the reverse order. (*07 marks*)

Question 04

(a) Obtain an expression for inverting a homogeneous transform. *(08 marks)*

(b) Using the expression obtained in part (a) or otherwise, find the homogeneous transformation matrix ${}^{v}\mathbf{T}_{w}$ provided that

$$ {}^{v}\mathbf{T}_{u} = \begin{bmatrix} 0.866 & -0.500 & 0 & 5 \\ 0.500 & 0.866 & 0 & -2 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix}, $$

$$ {}^{w}\mathbf{T}_{u} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.866 & -0.500 & 5 \\ 0 & 0.500 & 0.866 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Where u,v and w are frames $\{u\}$, $\{v\}$ and $\{w\}$ respectively. (12 marks)

Question 05

(a) What is a kinematic diagram with respect to a robotic manipulator? *(02 marks)*

(b) Figure 01 represents a robot manipulator commonly used in the industry known as Selective Compliance Assembly Robot Arm or SCARA.

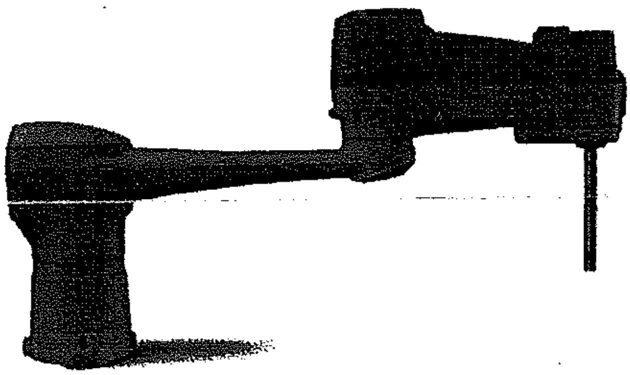

Figure 01

For the above SCARA robot shown in Figure 01,

(i) Draw the kinematic diagram and assign frames according to the Denavit Hartenberg (DH) convention. *(06 marks)*

(ii) Create the DH parameter table and find the DH parameters, θ, α, r and d. *(06 marks)*

(iii) Using the values of parameters in the DH table find the homogeneous transformation of the end effector with respect to the base frame.

(06 marks)

(Note: You may use the standard transformation matrix shown by equation 01 in order to find the homogenous transformation matrix)

$$^{n-1}\mathbf{T}_n = \begin{bmatrix} C(\theta_n) & -S(\theta_n)C(\alpha_n) & S(\theta_n)S(\alpha_n) & r_nC(\theta_n) \\ S(\theta_n) & C(\theta_n)C(\alpha_n) & -C(\theta_n)S(\alpha_n) & r_nS(\theta_n) \\ 0 & S(\alpha_n) & C(\alpha_n) & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix} ----(Equation\,01)$$

Question 06

(a) What is meant by an inverse kinematic problem in relation to a robotic manipulator?

(02 marks)

(b) Unlike in the case of forward kinematics, inverse kinematics may have multiple solutions. Give reasons for having multiple solutions for inverse kinematic problems. *(04 marks)*

(c) What does singularity mean in relation to inverse kinematics? *(04 marks)*

(d) Figure 02 represents a kinematic diagram for a 2 degree of freedom manipulator. Find the inverse kinematic equations. *(10 marks)*

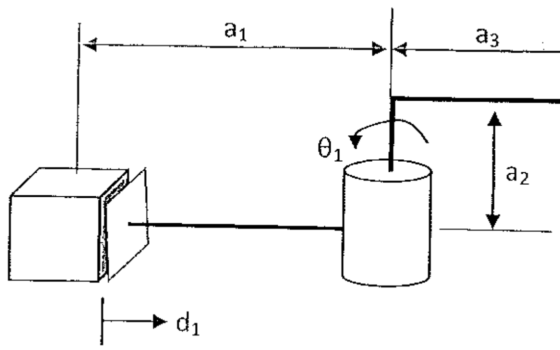

Figure 02

Question 07

The dynamics of a simple manipulator can be found by a scalar function called the Lagrangian (L), which is the difference between the kinetic energy (K) and the potential energy (P) of the manipulator system. That is, L= K – P.

Figure 3 represents a planar simplified version of a two degree of freedom manipulator. For the manipulator the coordinate frames are {0}and {1}, joint variables are θ_1 and θ_2 , link lengths are L_1 and L_2 and the masses are m_1 and m_2 respectively. It is also assumed that the masses of the links are acting as point masses at the center of each link and the links are thin. The linear and angular velocities of the links are v_1,v_2 $\dot{\theta}_1$ and $\dot{\theta}_2$ respectively. Find the dynamic model for the manipulator system represented by figure 3 based on the Lagrangian. State any assumptions you make.

(20 marks)

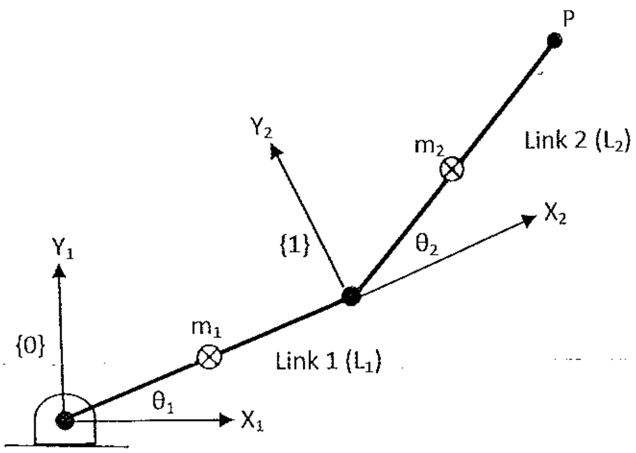

Figure 3

Question 08

(a) Explain the following terns in relation to trajectory planning.

(i) A path

(ii) A trajectory

(iii) Via points

(iv) Trajectory generation

(04 marks)

(b) Distinguish between joint space trajectory planning vs Cartesian space trajectory planning. *(04 marks)*

(c) A one degree robot manipulator having a rotary joint is to move from 95^0 to 185^0 within 3 seconds. Determine the coefficients of the cubic polynomial that will ensure a smooth trajectory for the above mentioned conditions. Plot the position, velocity and acceleration for the above trajectory.

(12 marks)

End