



Instructions to candidates.

Duration: Two (02) hours

Number of questions: Four (04) essay questions

Mark allocation: 100 mark

Answer all questions.

1.

- a. Derive the compound transformation equation given below.

$${}^A_ZT = {}^A_BT {}^B_CT {}^C_DT \dots {}^W_XT {}^X_YT {}^Y_ZT \quad (3 \text{ mark})$$

- b. Determine the new position of an end effector of a robot after the following operations are carried out sequentially.

- i. Rotation of 90° about Z axis.
- ii. Translation of 7 units along Y direction.
- iii. rotation of 60° about Y axis.

Current position vector of the end effector is $4i+7j-3k$ (i, j , and k denote their usual notations)
(5 mark)

- c. A planer robotic manipulator consists of four revolute joints. Answer following questions, stating your assumptions (if any).

- i. Derive the forward kinematic equation for the above manipulator using the D-H parameter method. (5 mark)
- ii. Using the kinematic equations obtained in the above part (i) find the Jacobian matrix for the manipulator. (3 mark)

- d. Your company higher management ask you to develop an underwater robot to explore ocean surface.

- i. State two actuators and two sensors for the robot. (3 mark)
- ii. Provide the special advantages of the sensors mentioned above for the particular application. (3 mark)
- iii. What are the additional factors you have to consider when selecting; actuators and sensors for the above robot separately. (3 mark)

2. Figure 01 shows an industrial robot with six revolute joints. Joint rotations of the robot are indicated in arrows.



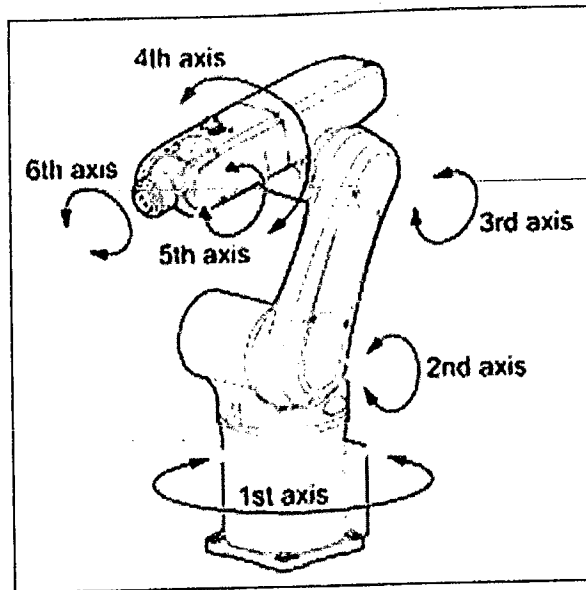


Figure 01: 6DoF industrial robot

- a. State four **main** specifications that should be included in the tender (purchasing) documents prepared to purchase a robot. Briefly explain two main specifications. (5 mark)
 - b. Using your own sketch assign frames for the robot to find Denavit-Hartenberg (D-H) parameters. (3 mark)
 - c. Construct the Denavit-Hartenberg (D-H) parameter table for the robot defining required link geometries and joint angles. Explain the assumptions you made. (14 mark)
 - d. Find first two transformation matrices applied from base to end-effector of the robot using the given D-H matrix. (3 mark)
- 3.
- a. State the importance of the gravity and the friction terms in the dynamic equation of motion for a robotic manipulator. (2 mark)
 - b. State the Euler-Lagrangian equation for external torque on a given rotational joint. (2 mark)
 - c. Derive the Jacobian matrix for a planar P-2R manipulator using the notation given in Figure 02. Express your answer in the usual matrix notation. (6 mark)

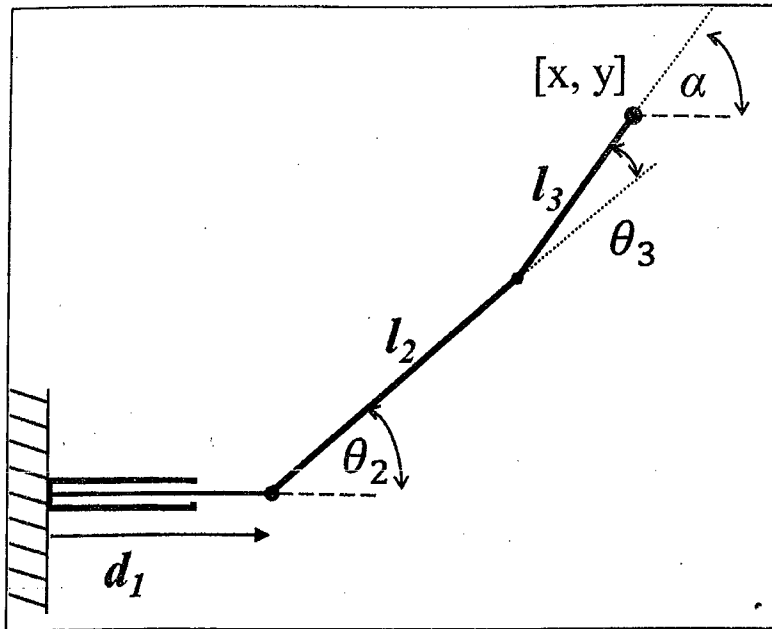


Figure 02

- d. Write a short note in point form explaining **ONE** of the following robot dynamics algorithms.
- i. Recursive Newton-Euler algorithm (RNEA)
 - ii. Articulated-body algorithm (ABA)
 - iii. Composite-rigid-body algorithm (CRBA) (3 mark)
- e. Briefly, explain why linear control techniques are approximate methods of manipulator control. (4 mark)
- f. Briefly, explain **ONE** of the following two terms used with respect to robot manipulators.
- i. Computed-torque control
 - ii. Manipulator compliance (3 mark)

- 4.
- a. List four types of land based mobile robots. (2 mark)
 - b. State the three fundamental problems faced by a mobile robot. (3 mark)
 - c. State two advantages of wheeled robots over other types of locomotion. (2 mark)
 - d. Briefly explain, using sketches or otherwise, the maneuverability of the following two types of mobile robot platforms. (4 mark)
 - i. Omni-steer robot.
 - ii. Two-steer robot.



- e. Using examples, briefly explain the difference between holonomic and non-holonomic configurations of mobile robots. (4 mark)
- f. Figure 03 shows a Hilare type mobile robot which has a linear velocity of v and angular velocity of ω . V_L and V_R are the left and right wheel velocities respectively. Both wheels have equal diameter of $2R$. Derive the relationship between V_L , V_R , and v , ω in the following matrix format.

$$\begin{bmatrix} V_R \\ V_L \end{bmatrix} = [A] \begin{bmatrix} v \\ \omega \end{bmatrix} \quad (6 \text{ mark})$$

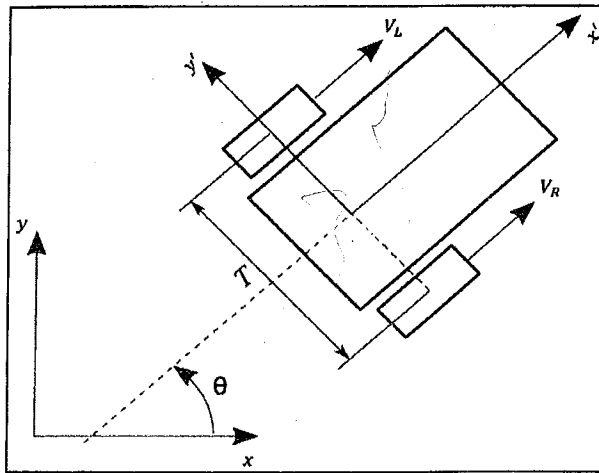


Figure 03

- g. State, what is meant by 'Proprioceptive' sensors and 'Exteroceptive' sensors. (2 mark)
- h. Identify two exteroceptive sensors required in a self-driving car. (4 mark)
- i. List three robot localization methods and briefly explain one of those methods. (3 mark)