1. **What are the various ways of representing orientation of a robot?**
   - ❖ Direct Cosine representation
   - ❖ Fixed – axes rotations
   - ❖ Euler – angles representation
   - ❖ Single and double – axes rotations
   - ❖ Euler parameters etc.
2. **What is a Homogenous Transformation Matrix (HTM)? (Or) What is the significance of HTM?**

Homogeneous Transformation Matrix (HTM) is a 4 x 4 matrix which is very useful when both translation and rotation need to be performed. It describes both the position and orientation of a frame w.r.to another frame.

3. **Write the HTM for rotation of a frame about x axis.**

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

4. **Write the HTM for rotation of a frame about y axis.**

$$H = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

5. **Write the HTM for rotation of a frame about z axis.**

$$H = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

6. **Write the HTM for translation of a, b and c units in x, y and z axis respectively.**

$$H = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

7. **List the D – H parameters.**

The D – H parameters used are:

- ✓ Link Length a_i
- ✓ Link twist α_i
- ✓ Joint distance d_i and
- ✓ Joint angle θ_i

8. **What is direct kinematics?**

The direct kinematic model gives the position and orientation of the end effector as a function of the joint variables. i.e. using direct kinematics, we can find the position and orientation of end effector for any given joint angle and joint distance.

9. What is inverse kinematics?

The inverse kinematic model gives the joint variables as a function of position and orientation of end effector. i.e. using inverse kinematics, we can find the joint variables (joint distance and joint angle) required to achieve given position and orientation.

10. What is the drawback of D-H notation?

One major drawback of D – H notation is that it considers the transformations (rotation or translation) only in the *x* and *z* axes. The transformations in *y* axis are not considered in D – H notation.

11. What is the reason for multiple solutions of inverse kinematic problem?

The reasons for getting multiple solutions are:

- ✓ Parallel axes of revolute joints
- ✓ Existence of trigonometric functions in equations
- ✓ Presence of non-zero joint – link parameters and the range of joint motions allowed
- ✓ Degrees of freedom

12. What is kinematically redundant manipulator?

A manipulator with more DOF than necessary is called ***kinematically redundant manipulator***. The SCARA configuration is an example of redundant manipulator. It has one redundant DOF in the horizontal direction. The redundant manipulator has added flexibility, which can be useful in avoiding obstacles or reaching inaccessible locations

13. What are the techniques for solving inverse kinematic problem?

The approaches for determining the solution of inverse kinematic problem are:

- ❖ Closed form solutions
- ❖ Numerical solutions

In closed form solution, joint displacements are determined as functions of the position and orientation of the end effector. They are based on analytical algebra or kinematic approach, giving expression determining joint displacements. Closed form solutions may not be possible for all kinds of structures.

In numerical method approach, iterative algorithms such as Newton – Raphson method are used. Numerical methods are computationally complex and slower compared to closed form methods. Moreover this method doesn't guarantee convergence to correct solution.

14. Give the Expression for Transformation matric for movement from the frame i – 1 to i.

$$ {}^{i-1}T_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ where, C\theta_i = \cos\theta_i, S\theta_i = \sin\theta_i, C\alpha_i = \cos\alpha_i \ and \ S\alpha_i = \sin\alpha_i $$

15. State Inverse Kinematic Problem.

The inverse kinematic problem is stated as: "*The determination of all possible and feasible set of joint variables which would achieve the specified position and orientation of the manipulator's end effector with respect to the base frame*."

16. How is Reachable workspace different from Dexterous Workspace?

The region that can be reached by the origin of the end effector frame with at least one orientation is called the ***Reachable workspace*** (RWS).

The space where the end effector can reach every point from all orientation is called the ***Dexterous workspace*** (DWS). The DWS is either smaller or same as RWS.

17. Why is Inverse Kinematic problem considered to be complex?

- Inverse kinematics is complex because the solution is to be found for nonlinear simultaneous equations involving transcendental (harmonic sine and cosine) functions.
- The number of simultaneous equations is also generally more than the number of unknowns, making some equations mutually dependent.
- These conditions lead to possibility of many solutions (multiple solutions) or non – existence of any solution for given end effector position and orientation.

18. Point out the conditions under which no solution exists for Inverse Kinematic Problem.

- If the desired point ***P*** lies outside the RWS, then no solution exists.
- Even if ***P*** is within the RWS, not all orientations are realizable unless ***P*** lies within the DWS.
- If the wrist has less than 3 DOF to orient the end effector, then certain classes of orientations are not realizable.