Q1)

- Singularities represent configurations of a robot where it loses one or more degrees of freedom, making certain directions of motion unattainable. Near singularities there will not exist a unique solution to the inverse kinematics problem. In such cases there may be no or infinitely many solutions.

- To determine if a robot is in a singular configuration, we can compute the determinat of the Jacobian. If it is zero, the robot is in a singular configuration.

- To detect if a particular configuration is close to being singular, we can look at magnitude of determinant. If its very close to zero, the robot is near singular config.

Q5)

DH- Parameters :

Link	d_i	a_i	α_i	θ_i
1	d_1	0	q_0	0
2	d_2	0	q_0	0
3	d_3	0	0	0

$$A_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & d_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} 0 & 0 & 1 & d_3 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_0^3 = \begin{bmatrix} 0 & 0 & 1 & d_3 \\ 1 & 0 & 0 & d_2 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} //$$

$P_x = d_3$

$\Rightarrow P_y = d_2$

$P_z = d_1$

DH parameters:

link	d_i	a_i	α_i	θ_i
1	d_1	0	$\pi/2$	θ_1
2	d_2	0	0	θ_2
3	d_3	0	0	θ_3
4	0	0	$-\pi/2$	θ_4
5	0	0	$\pi/2$	θ_5
6	d_6	0	0	θ_6

$$A_1 = \begin{bmatrix} C_1 & 0 & -S_1 & 0 \\ S_1 & 0 & C_1 & 0 \\ 0 & -1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} C_2 & 0 & S_2 & 0 \\ S_2 & 0 & -C_2 & d_2 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & d_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_4 = \begin{bmatrix} C_4 & 0 & -S_4 & 0 \\ S_4 & 0 & C_4 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_5 = \begin{bmatrix} C_5 & 0 & -S_5 & 0 \\ S_5 & 0 & C_5 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_6 = \begin{bmatrix} C_6 & -S_6 & 0 & 0 \\ S_6 & C_6 & 0 & 0 \\ 0 & 0 & 1 & d_6 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Q1)

- Direct drive config: In this the motors are directly mounted at the joints of manipulator.
  Advantages: • Fewer components
  • Faster response

- Remotely driven config. In this the motors are located away from the joints at some fixed location. The motion is transmitted via belts or shafts.
  Advantages: • Reduced inertia
  • Variety in motor selection

- 5-Bar Parallelogram Arrangement: This is a special config. where the arm is designed in such a way that it maintains a constant orientation relative to base.
  Advantages: • Constant orientation.

Q2) Given D(q) inertia matrix and V(q) (the potential energy) the steps to get eqn of motion are:

- Gravity terms:
  G(q)
  ↳ $g_i = \frac{\partial V(q)}{\partial q_i}$

- Coriolis & Centrifugal terms:

$$C(q,\dot{q}) \qquad c_{ij} = \sum_{k=1}^{n} \Gamma_{ijk}\,\dot{q}_k$$

(Γ_{ijk}: Christoffel symbols)

where n is the no. of joints

&

$$\Gamma_{ijk} = \frac{1}{2}\left(\frac{\partial D_{ij}}{\partial q_k} + \frac{\partial D_{ik}}{\partial q_j} - \frac{\partial D_{jk}}{\partial q_i}\right)$$

∴ Equation of motion:

$$D(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) = \tau \;//$$

Q.18)

DH Parameters for 3D printer:

link	d_i	a_i	α_i	θ_i
1	d_1	0	90°	0
2	d_2	0	90°	0
3	d_3	0	0	0

//

Q.19)

Inverse kinematics:

$d_1 = P_z$

$d_2 = P_y$

$d_3 = P_x$