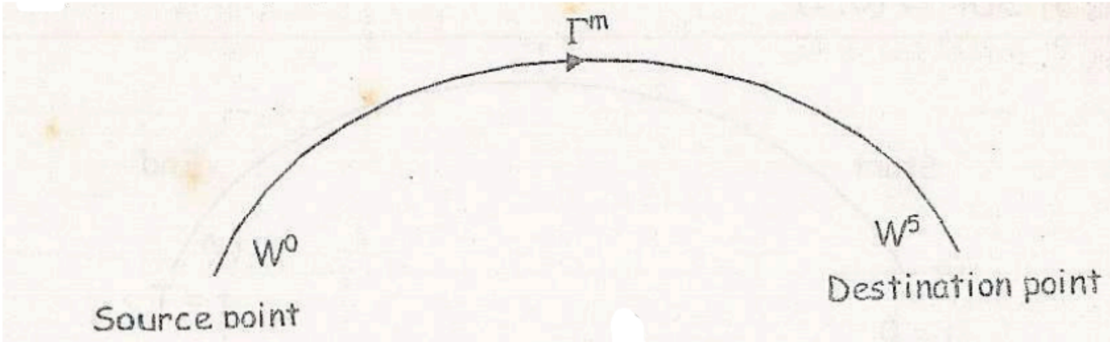
Syllabus for UT-2

1. Numerical example on trajectory planning
2. Theory questions on trajectory, task & motion planning as discussed in lab

1. **Define the terms path & trajectory with neat sketches wherever necessary. Explain the difference between them.**

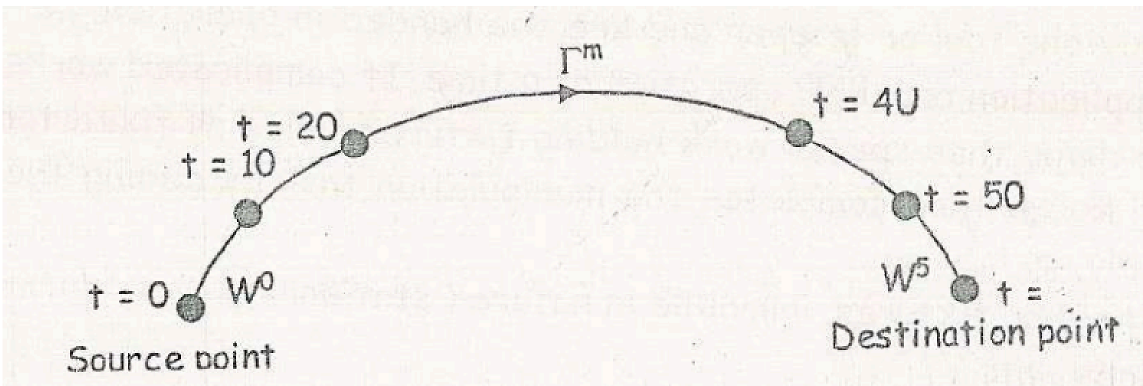
Path:

- **path is a route which is taken by the robot to move from source (pick point) to destination (place point).**
- Equation for path w(q) = Represented by $3^{rd}/4^{th}/5^{th}$ order.
- It is purely spacial information.
- It does not depend on velocity and time.
- It is used in path planning algorithms.
- Example - Path between two points on a map.



Trajectory:

- **Trajectory is a path with time information.**
- if we specify times at which the robotic end effector should be at various points along the path, then the path is converted into Trajectory.
- It is both spatial and temporal information.
- It depends velocity and time.
- It is used in motion planning algorithms
- Example - Trajectory of a robotic arm during assembly task



Path	Trajectory
Path is a route which is taken by the robot to move from source to destination.	Trajectory is a path with time information
It does not depends velocity and time	It depends velocity and time
It is used in path planning algorithms	It is used in motion planning algorithms
It is spacial information	It is both spatial and temporal information

Example - Path between two points on a map	Example - Trajectory of a robot arm during assembly task

2. **Define & explain in detail the speed distribution function (SDF) with a neat sketch.**

In robotics, the Speed Distribution Function (SDF) is a concept used to represent the probability distribution of speeds for different parts of a robot's manipulator or system. It's a fundamental concept in motion planning and control, providing insight into how velocities are distributed across the robot's joints or end-effector.

Definition: The Speed Distribution Function (SDF) is a mathematical function that describes the probability distribution of velocities within a robotic system. It provides information on how likely different velocities are to occur in various parts of the robot's workspace or along its trajectory.
Components of the SDF:
a. Joint Space: In joint space, the SDF describes the probability distribution of velocities across the robot's individual joints. It indicates how likely it is for each joint to move at a certain velocity.
b. Task Space: In task space, the SDF describes the distribution of velocities for the robot's end-effector or tool center point (TCP). It shows the likelihood of the end-effector moving at different speeds in different directions.
Purpose:
a. Motion Planning: By understanding the SDF, roboticists can plan motions that optimize certain criteria, such as minimizing energy consumption, maximizing speed, or avoiding obstacles. Motion planning algorithms often take the SDF into account to generate smooth and efficient trajectories.
b. Control: Controllers use the SDF to regulate the robot's motion and ensure that it follows desired trajectories accurately and safely. Feedback control systems adjust the robot's velocities based on deviations from the desired SDF, helping to maintain stability and precision.
Factors Affecting the SDF:
a. Robot Design: The mechanical structure of the robot, including the types of joints and actuators used, influences the shape of the SDF. Robots with different kinematic configurations will have different SDFs.
b. Task Requirements: The specific tasks that the robot is designed to perform also affect the SDF. For example, tasks requiring high-speed movements may result in a different SDF compared to tasks requiring precise, slow movements.
c. Environment: External factors such as friction, inertia, and the presence of obstacles can influence the SDF by affecting the dynamics of the robot's motion.
Representation: The SDF is often represented either as a continuous probability density function (PDF) or discretized into a histogram, depending on the complexity of the system and the requirements of the application.
Optimization: In some cases, roboticists may seek to optimize the SDF to improve certain aspects of the robot's performance, such as maximizing speed while minimizing energy consumption or reducing wear and tear on mechanical components.
In summary, the Speed Distribution Function (SDF) is a crucial concept in robotics, providing insights into how velocities are distributed within a robotic system and guiding motion planning and control algorithms to achieve desired performance criteria.

3. **Write a detailed note on pick & place operations with neat sketches. Define the following terms:**
    - (a) Pick Point
    - (b) Pick Off Point
    - (c) Set Down Point
    - (d) Place Point

Pick and Place operation: (Four-point pick and place trajectory)

- The main function of robotic manipulator is to pick up an object from a particular place and place it at another particular place in desired position and orientation.
- The taken by the robot to pick and place an object is known as four-point pick and place trajectory.

Pick and place operations:

1. Pick Point:

- **the point from where the object has to be pick up is known as pick point.**
- it is the 1st operation of pick and place operation.
- it represents the initial position and orientation of the object.
- The pick point is always the center of gravity of an object.
- Gross motion is used from initial position to pick point.
- matrix:

$$R^{Pick}_{Base} = \left[\begin{array}{c|c} R^{Pick} & p^{Pick} \\ \hline 000 & 1 \end{array}\right]$$

2. Lift off Point:

- **it is the point from where the robot actually starts moving before picking up the object.**
- it is the 2nd operation of pick and place operation.
- This point is just above pick point by distance u.
- Fine motion is used from pick point to lift off point.
- Matrix:

$$T^{Lift}_{Base} = \left[\begin{array}{c|c} R^{Pick} & p^{Pick} - uR^{Pick;3}_{i} \\ \hline 000 & 1 \end{array}\right]$$

3. Set Down Point:

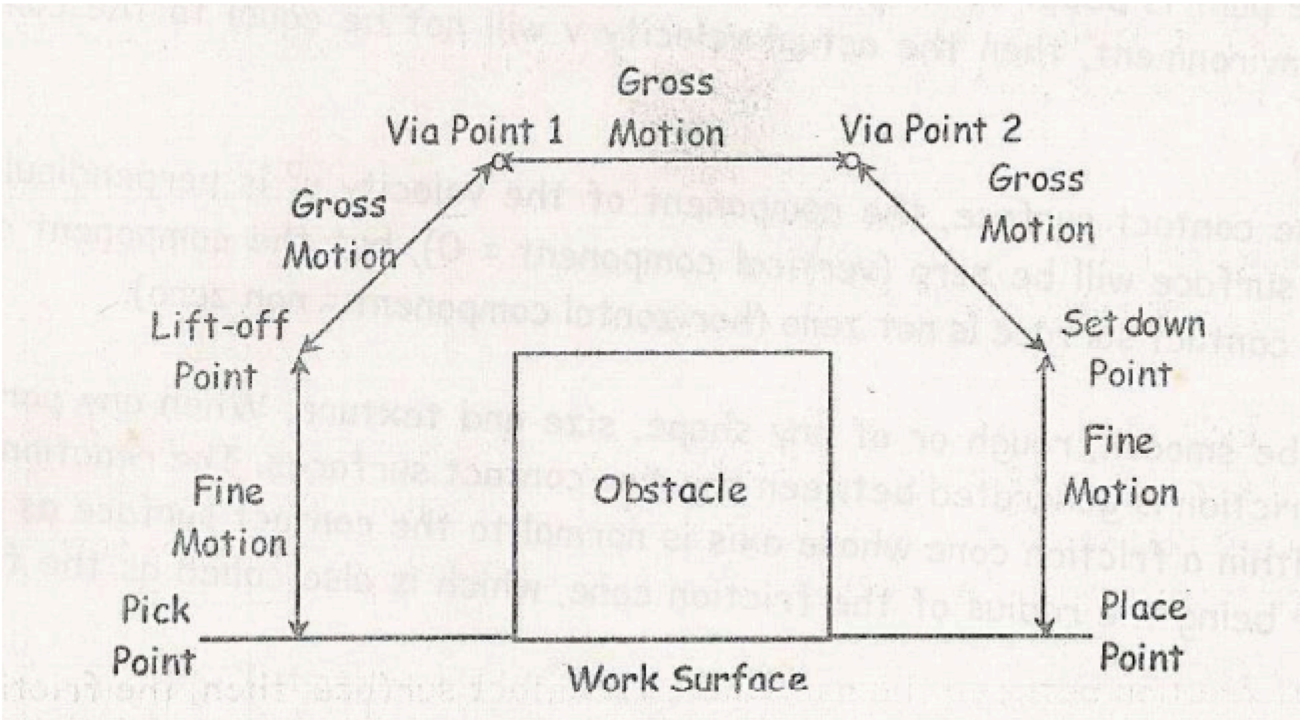
- **it is the point from where the robot actually starts moving before placing the object on the work surface.**
- it is the 3rd operation of pick and place operation.
- This Point is just above place point by distance u.
- Gross motion is used from Lift off Point to Set Down Point.
- Matrix:

$$T_{Base}^{Setdown} = \left[\begin{array}{c|c} R^{Place} & P^{Place} - \nu R^{Place} i^3 \\ \hline 000 & 1 \end{array}\right]$$

4. Place Point:

- **the point at which the object has to be placed is known as place point**
- it is the 4^{th} operation of pick and place operation.
- it represents the final position and orientation of the object.
- Fine motion is used from Set Down Point to Place point.
- Matrix:

$$T_{Base}^{Place} = \left[\begin{array}{c|c} R^{Place} & P^{Place} \\ \hline 000 & 1 \end{array}\right]$$



A Minimal Four Point Pick and Place Trajectory

4. **With a neat sketch, write a note on 'grasp planning.'**

Grasp Motion Planning:

- **Grasp Motion planning is the process of identifying and selecting suitable grasp configuration for the robotic end-effector to manipulate the object**.
- It is important because it determines whether the robot can successfully pick up and move the object without causing any damage.
- 3 main considerations while selecting a suitable grasp configuration for an object:

1. Safe Grasp Configuration: (Safety)

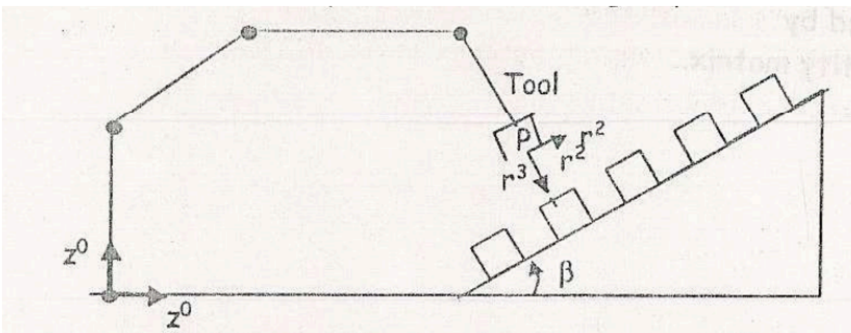
- **A safe grasp configuration means that the robot should not come in contact with other parts of the payload.**
- The object should not come in contact with any obstacle.
- The robot should be safe at initial and final grasp configuration.

0. Reachable Grasp Configuration: (Reachability)

- **A reachable grasp configuration means that the robot should be able to reach the initial grasp position and when the object is in the hand, the robot should be able to find a collision – free path to the final grasp position.**
- Grabbing the object from the top works fine, but while placing it in an inverted fashion might create a problem because the robot collides with the work surface. Therefore, this method is not feasible.
- To solve this problem, the tool can grasp the object from the sides, then perform a roll operation of the tool in either clockwise or anticlockwise direction and then place it on the work surface.

0. Secured or Stable Grasp Configuration: (Stability or Security)

- **Stable or secured grasp configuration means that the object should not slip, move or fall down during the part transfer or during the mating operations.**
- When the object is in the hand of end-effector, the gripping force should be such that the object should not fall, slip, rotate or slide from the fingers of the end-effector.

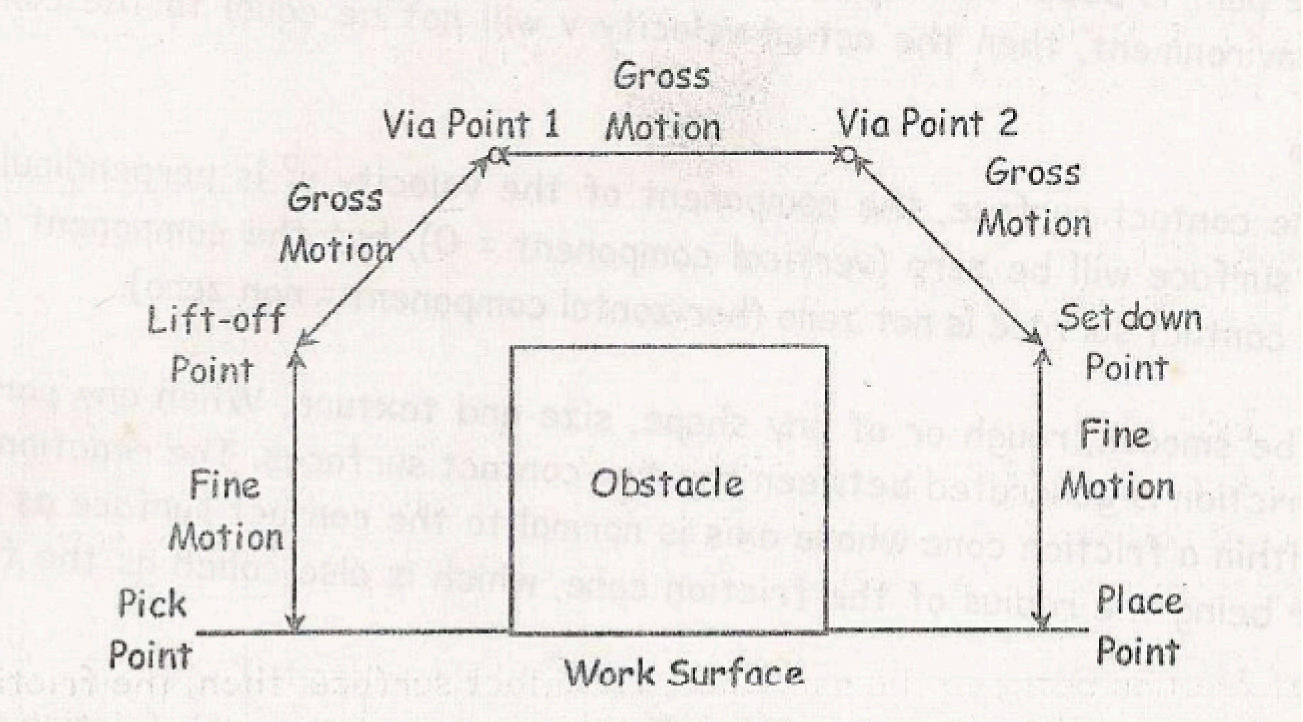


A gravity Part Feeder Showing that how parts are Grasped

5. **Explain fine motion planning with a neat sketch.**

- **Fine motion planning is the process of planning of precise movements of the robot to achieve a desired task.**
- Fine motion is the motion in which an object comes in physical contact with the surrounding environment of the robot.
- Various forces act on the part during the fine motion planning which includes frictional force, gravitational force, and the force with which it is moving.
- These forces can be controlled using advanced modelling and control techniques.
- Techniques for obtaining fine motion planning are:

    1. Impedance control technique
    2. Generalized damper approach
    3. Slow movement during picking and placing the object.
    4. Guarded motion
    5. Compliant motion



A Minimal Four Point Pick and Place Trajectory

6. **For the given motion planning problem in the above experiment, systematically calculate all parameters & mention the mathematical expression for the straight line (linear) trajectory with parabolic blends.**

7. **Describe the following methods of robot programming in detail:**
    - (a) Powered lead through method
    - (b) Manual lead through mode
    - (c) Textual mode of programming language
    - (d) Task level programming

Answer:

Task Level Programming:

- Programming of a robot means to teach it how to do a particular task efficiently.

Methods of Programming:

1. **Powered Lead Through Method:**
    - In the powered -lead through mode, a small control unit called as a teach pendant is used.
    - Using the teach pendant, each axis of the robot is moved manually, until the combination of all the axial positions comes the desired position.
    - The operator uses a series of push buttons on a teach pendant to give commands.
    - All these operations are stored in memory while teaching the robot to do a particular task which is later used to perform the specified task.
    - **Disadvantages**:
        - It is time consuming as it requires a human operator to program the robot.
        - Robot might go out of service during the teaching period.
        - It cannot be used for continuous motions because it is difficult to use the teach pendant to perform complex geometric motions.
        - It cannot be used with external sensors such as camera to get adaptable with the surrounding environment.
        - objects that are manipulated should be presented to the robot at the same position and orientation every time.

2. **Manual Lead through Mode of Programming:**
    - In this method, the programmer physically grasps the robotic arm & the end – effector and manually leads it through the desired path at the required speed, while simultaneously recording the continuous position of each axis.
    - The manual lead through method is generally used for the Continuous Path (CP) robots.
    - It is also known as walk through method.

3. **Textual Method of Programming:**
    - In this method, the programmer instructs the robot to do certain task in English like commands.

- The programmer is not concerned about the motion of the individual joints, because it is calculated by a language processor like a compiler or interpreter.

Offline Programming:

- In an offline programming, the programmer writes the program for the robot and then tests that program offline.
- Once the program is executed successfully offline, then the programmer tests the program on the robot.
- **Disadvantages** of the Off-line programming:
    - Offline programming requires 32 bit computers to simulate robot movements graphically. It also requires a software package.
    - Offline programming creates positional errors that are caused by the deflection of the manipulator links.
    - The programmer has to specify details like manipulation task, layout of the parts, movement attribute such as speed, acceleration, force, etc.

0. Task Level Programming Languages:

- In this method, the programmer has to describe the task in a high -level language which is known as the task specification.
- The task specification is given as the input to the task planner.
- The task planner then uses a database called the world model to characterize the robot & its environment.
- The task specification is divided into a sequence of sub-tasks by the task decomposer. The subtasks are then passed through the sub-planner which generates an output.
- The task planner produces an output as a detailed set of instructions which is called the robot program.

8. **What are workspace fixtures? Write short notes on the following (with neat sketches as applicable):**
   - (a) Part Feeders
   - (b) Conveyors
   - (c) Carousels
   - (d) Fixed Tools

Answer:

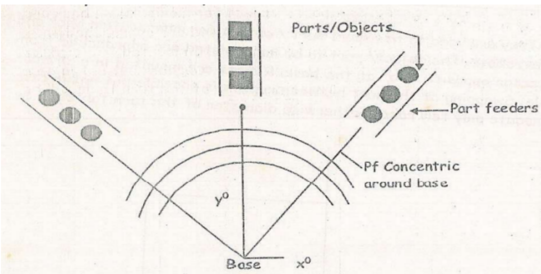
Workspace fixtures:

- Workspace fixtures are accessories of the robot.
- It forms a part of the robot to perform a particular task.

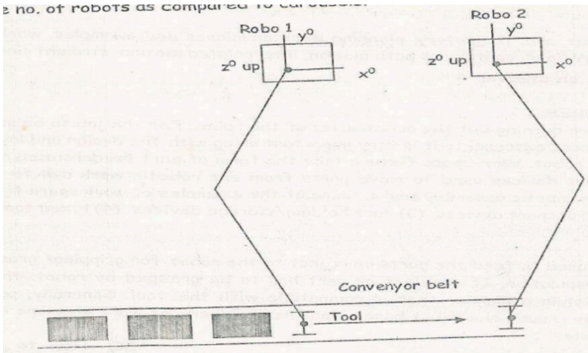
  Work space fixtures used in the robot are:

1. **Part feeders:**

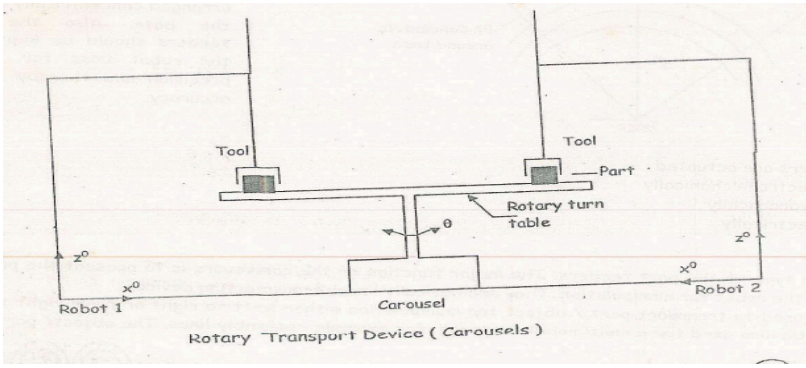
- Part feeder are used to feed a part or an object to the robot for manipulation like griping/grasping/picking.
- In order to grasp the object, it must be presented to the robot in such a way which is compatible with the tool.
- It is arranged in a concentric manner around the robot base.
- It can be activated electrically, electromechanically and hydraulically.



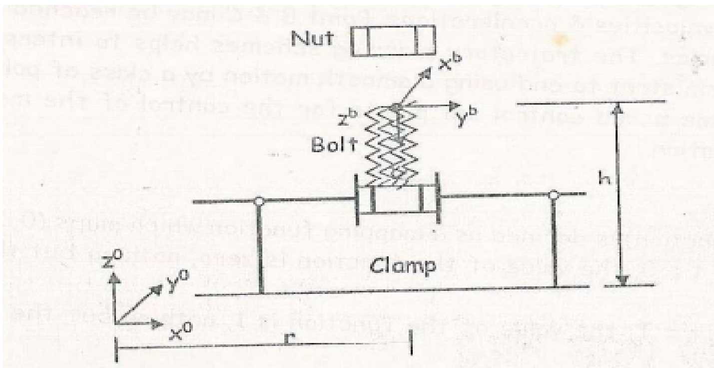
2. **Conveyors:**
   - **They are linear transport device.**
   - They can transport the object in either from left to right or right to left manner.
   - They are used for multi robot work cell.
   - **Advantage**: it can accommodate more no. of robots as compared to carousels.
   - **Disadvantage**: part or object cannot be swapped between two robots.



3. **Carousels:**
   - **They are rotary transport device.**
   - They transport object for manipulation back and forth between two or more robots.
   - Robots are mounted in a circular fashion around the rotary turn table.
   - **Advantage**: part can be swapped between two robots.
   - **Disadvantage**: it can accommodate only few robots.



4. **Fixed Tool:**
   - **Fixed Tool are used to hold a sub-part in exact position and orientation.**
   - Most of the robots are one-handed and have only one tool for operation. If any complicated task needs to be done (like putting a nut onto a bolt), then fixed tools are used to secure the sub part.
   - It is fixed and cannot move by itself.
   - Examples: jigs, clamps etc.



9. **Write a short note on continuous path motion & interpolated motion. Explain the different methods of splitting a trajectory.**

Answer:

Continuous path motion: (CP)

- In continuous path motion, the path is specified by the user, after which the robot moves continuously in CP motion.
- This motion is performed by continuous path robots.
- When the robot end-effector moves along the path, care has to be taken to see that each & every joint angle is controlled. Otherwise, the robot tool will not move along the path.
- When the robot tool performs the tasks, at that time each & every axes moves at different velocities which is controlled by a computer.

Interpolated motion:

- In interpolated path motion, the user specifies the start point, end point & the via points instead of specifying the path.
- Then, a trajectory planning software is used to interpolate between the knot points & via points to generate a smooth trajectory T passing through all knot points.
- It is done by using continuous path motion control technique.

Different methods of splitting a trajectory:

1. **4 - 3 - 4 Trajectory:**
    - In 1st segment, from pick point to lift off point is defined by 4th degree polynomial.
    - In 2nd segment, from lift off point to set down point is defined by 3rd degree polynomial.
    - In 3rd segment, from set down point to place point is defined by the 4th degree polynomial.
2. **3 – 5 - 3 Trajectory:**
    - In 1st segment, from pick point to lift off point is defined by 3rd degree polynomial.
    - In 2nd segment, from lift off point to set down point is defined by 5th degree polynomial.
    - In 3rd segment, from set down point to place point is defined by the 3rd degree polynomial.
2. **Cubic Trajectory (3 – 3 – 3 - 3 - 3):**
    - In this, each segment is defined by a 3rd degree polynomial.

10. Describe interpolated motion with parabolic blends giving neat sketches as applicable.

Interpolated motion with parabolic blends:

- In interpolated path motion, when the robot passes through the knot points, the velocity changes abruptly.
- This results in a jerky robotic motion which could burn out the drive circuit or damage the gear.
- In order to solve this problem, we introduce a parabolic curve or blend which smoothly connects the adjacent linear segments, resulting into a smooth path.
- A parabolic blend consists of three segments: acceleration segment, deceleration segment & constant velocity segment.
- In acceleration and deceleration segments, the velocity of the robot changes when it passes through the parabolic curve.
- In constant velocity segment, the velocity of the robot remains constant when it passes through the linear segments.