**Q1.**

**a) What is robot's end effector and its types? Also, describe what is workspace of a manipulator?**

**Solution:**

A robot's end effector is the tool or device at the end of a robotic arm that is used to perform a specific task, such as grasping, welding, painting, or drilling. The end effector is the part of the robot that interacts directly with the environment, and it is designed to carry out a specific function or set of functions.

There are many different types of end effectors, each designed for a specific task or application. Some common types include:

Grippers: used for grasping and holding objects

Welding guns: used for welding and soldering

Suction cups: used for handling flat objects

Cutting tools: used for cutting and shaping materials

Painting tools: used for applying paint and coatings

Drilling tools: used for drilling holes

The workspace of a manipulator refers to the range of motion and the volume of space that the robot can reach and operate within. The workspace is determined by the physical characteristics of the robot, including the length and flexibility of its arms, as well as any constraints or limitations imposed by the environment or the task being performed.

**Q2.**

**a) List the names of standard 3 DoF (Degree of Freedom) manipulators? Also, mentioned with their names, how many revolute and prismatic joints these manipulators have?**

**Solution:**

There are several standard 3 DoF manipulators, each with different joint configurations. Here are a few examples:

Planar 3R manipulator: This manipulator has three revolute joints and is often used in pick-and-place operations and simple assembly tasks.

Spherical 3R manipulator: This manipulator also has three revolute joints but is designed to operate in a spherical workspace. It is often used in applications such as remote handling and teleoperation.

Cylindrical 2RPR manipulator: This manipulator has two revolute joints and one prismatic joint, and is designed to move along a cylindrical path. It is often used in material handling and drilling applications.

SCARA manipulator: SCARA stands for "Selective Compliance Assembly Robot Arm", and this manipulator has two revolute joints and one prismatic joint. It is designed to operate in a planar workspace and is often used in assembly and packaging applications.

Delta robot: This manipulator has three prismatic joints and is designed for high-speed pick-and-place operations. It is often used in food packaging and electronics assembly applications.

Articulated 3R manipulator: This manipulator has three revolute joints and is designed to operate in a 3D workspace. It is often used in welding and painting applications.

Note that there are many variations and modifications of these manipulators, and the number and type of joints can vary depending on the specific application and design requirements.

**b) Describe what is 6 DoF manipulator? Is it possible to combined to manipulators to achieve 6 DoF describe? Also, describe is it necessary the DoF of complete system should be equal to number of revolute and prismatic joints it has?**

**Solution:**

A 6 DoF (Degree of Freedom) manipulator is a robotic arm with six joints, which can be either revolute or prismatic. The six joints provide the manipulator with six degrees of freedom, which means it can move in six independent directions: up/down, left/right, forward/backward, pitch, roll, and yaw. The manipulator can use these degrees of freedom to position its end effector in a wide range of orientations and locations within its workspace.

It is possible to combine two manipulators to achieve 6 DoF. For example, one manipulator could have three revolute joints and the other could have three prismatic joints. By attaching the two manipulators together, the resulting system would have six degrees of freedom. Another option would be to use two 3 DoF manipulators together in a coordinated manner to achieve the same effect.

It is not necessary for the number of degrees of freedom in a complete system to be equal to the number of revolute and prismatic joints it has. For example, a system with three revolute joints and one prismatic joint could potentially have 4 or 5 degrees of freedom, depending on the specific configuration and design of the system. Additionally, some joints may be constrained or have limited mobility, which can also affect the overall number of degrees of freedom of the system. The number of degrees of freedom needed for a specific task or application depends on the complexity and range of motion required.

**Q3.**

**a) What is the difference between orientation and position of a frame? Write Rx, Ry and Rz matrices on your answer sheet.**

**Solution:**

In robotics and computer graphics, a frame is a coordinate system that defines the position and orientation of an object in space. The position of a frame is the location of its origin in a reference coordinate system, while the orientation of a frame is the orientation of its x, y, and z axes relative to the reference coordinate system.

To describe the orientation of a frame, we use rotation matrices. These matrices are 3x3 matrices that represent the rotation around the x, y, and z axes, respectively. The rotation matrix around the x axis (Rx) is:

[1 0 0]

[0 cos(theta) -sin(theta)]

[0 sin(theta) cos(theta)]

The rotation matrix around the y axis (Ry) is:

[ cos(theta) 0 sin(theta)]

[ 0 1 0 ]

[-sin(theta) 0 cos(theta)]

The rotation matrix around the z axis (Rz) is:

[cos(theta) -sin(theta) 0]

[sin(theta) cos(theta) 0]

[ 0 0 1]

Here, theta represents the angle of rotation around the corresponding axis. By multiplying these matrices, we can obtain the combined rotation matrix that describes the orientation of a frame in 3D space.

In summary, the position of a frame is its origin's location relative to a reference coordinate system, while the orientation of a frame is the orientation of its x, y, and z axes relative to the reference coordinate system. Rotation matrices, such as Rx, Ry, and Rz, are used to describe the orientation of a frame.

**Q5.**

**b) Describe what is a robot? List and discuss any six robot's sensors which are considered as alternate way of human sensing.**

**Solution:**

A robot is a programmable machine designed to carry out a variety of tasks autonomously or with minimal human intervention. Robots are typically composed of three main components: a control system, which provides the robot with instructions; a mechanical system, which enables the robot to move and perform physical tasks; and sensors, which allow the robot to sense and respond to its environment.

There are several sensors that are commonly used in robotics, which serve as an alternate way of human sensing. Some of these sensors include:

1. Infrared (IR) sensors: These sensors are used to detect the presence of objects in a robot's surroundings by measuring the heat emitted by those objects.
2. Ultrasonic sensors: These sensors use high frequency sound waves to detect the presence of objects in a robot's surroundings.
3. Light sensors: These sensors are used to detect changes in light levels, allowing the robot to respond to changes in lighting conditions.
4. Tactile sensors: These sensors are used to detect physical contact with objects, allowing the robot to sense and respond to touch.
5. Vision sensors: These sensors use cameras and other imaging systems to allow the robot to "see" its surroundings, enabling it to navigate and interact with objects in its environment.
6. Force/torque sensors: These sensors are used to measure the amount of force or torque applied to a robot's joints or end effector, allowing it to perform precise movements and manipulate objects with varying levels of force.

These sensors provide robots with a range of capabilities that allow them to operate in a variety of environments and perform complex tasks with precision and accuracy. By using sensors to "sense" their environment, robots can be programmed to adapt to changing conditions and perform tasks in a manner that is safe, efficient, and effective.

**Q6.**

**a) What are links, joints and DoF (Degree of Freedom) for a robot? What are DoFs of a rigid body in 3D and 2D plane. Also, list the names of each DoF.**

**Solution:**

Links, joints, and Degree of Freedom (DoF) are important concepts in the design and operation of robots.

* Links: Links are the physical components of a robot that connect the various joints and end effectors. They can be rigid or flexible and can vary in size and shape depending on the robot's design.
* Joints: Joints are the points where two or more links meet, allowing the robot to move and perform tasks. There are several types of joints, including revolute, prismatic, and spherical joints, each of which allows for different types of movement.
* Degree of Freedom (DoF): The Degree of Freedom (DoF) of a robot refers to the number of independent ways in which it can move. In general, a robot's DoF is equal to the number of independent joints it has. For example, a robot with three revolute joints and two prismatic joints would have a total of five DoF.

The DoF of a rigid body in 3D space is six, while in a 2D plane, it is three. The names of the DoF for a rigid body in 3D space are:

1. Translation along the x-axis
2. Translation along the y-axis
3. Translation along the z-axis
4. Rotation around the x-axis (roll)
5. Rotation around the y-axis (pitch)
6. Rotation around the z-axis (yaw)

For a rigid body in 2D plane, the three DoF are:

1. Translation along the x-axis
2. Translation along the y-axis
3. Rotation around the z-axis (yaw)

**Q7.**

**a) What is the difference between Configuration, Configuration Space and Workspace of a Robot? Also, define an end-effector of a robot and it's three basic types.**

**Solution:**

In robotics, the terms configuration, configuration space, and workspace refer to different aspects of a robot's movement and capabilities.

1. Configuration: The configuration of a robot refers to the position and orientation of all its joints. This can be represented as a vector of joint angles, or as a set of coordinates that describe the location and orientation of each joint. The configuration of a robot determines its overall shape and the set of positions it can reach.
2. Configuration space: The configuration space of a robot is the space of all possible configurations that the robot can achieve. This space is defined by the joint limits and constraints of the robot, and it can be visualized as a multi-dimensional space.
3. Workspace: The workspace of a robot is the set of all positions and orientations in space that the robot can reach, given its joint limits and constraints. This is the space where the robot can perform its tasks.

An end-effector is the tool or device attached to the end of a robot arm that performs the desired task, such as gripping, cutting, or welding. There are three basic types of end-effectors:

1. Grippers: These are used to grip and hold objects. They come in different shapes and sizes, and can use a variety of mechanisms such as suction, electromagnetism, or mechanical jaws.
2. Tools: These are used for specific tasks such as cutting, drilling, or welding. They are designed to perform a particular function and are often interchangeable.
3. Sensors: These are used to detect and measure properties such as distance, temperature, or pressure. They can be used to provide feedback to the robot's control system or to adjust the robot's position or orientation.

**b) List at least 6 main types of the robot's joints. Also, write their DoF for each of the joints' types.**

**Solution:**

Robots can have several types of joints, each with its own degrees of freedom (DoF) that define the range of motion it can achieve. Here are six main types of robot joints and their DoF:

1. Revolute joint: This type of joint rotates around a single axis, like a hinge. It has one DoF, which is the angle of rotation.
2. Prismatic joint: This type of joint moves along a single axis, like a sliding drawer. It has one DoF, which is the distance of the motion along the axis.
3. Spherical joint: This type of joint allows rotation in any direction around a fixed point. It has three DoF, which are the angles of rotation around each of the three axes.
4. Planar joint: This type of joint allows motion in a plane, like a disc moving on a flat surface. It has two DoF, which are the distance of the motion along the two axes of the plane.
5. Cylindrical joint: This type of joint allows rotation around one axis and translation along another axis, like a piston moving in a cylinder. It has two DoF, which are the angle of rotation and the distance of the motion.
6. Universal joint: This type of joint allows rotation around two perpendicular axes, like a ball-and-socket joint. It has two DoF, which are the angles of rotation around each of the two axes.

Note that some robot joints may be combinations of these basic types, or they may have more complex mechanisms that provide additional degrees of freedom.

**Q8.**

**a) Explain the use of Denavit-Hartenberg parameter table. Also, describe and sketch e, a, r and d with examples.**

**Solution:**

The Denavit-Hartenberg (DH) parameter table is a standard method for defining the kinematic parameters of a robotic arm or manipulator

**Q9.**

**a) What is the purpose of homogeneous transformation matrix for a robot manipulator? Draw the layout of homogeneous transformation matrix. Also, describe what we pad in the last row of such matrix and why a particular value?**

**Solution:**

The homogeneous transformation matrix is a mathematical tool used in robotics to represent the position and orientation of a robot manipulator in three-dimensional space. The matrix provides a way to transform a point in one coordinate frame to a point in another coordinate frame, taking into account the position and orientation of the frames relative to each other.

The homogeneous transformation matrix is a 4x4 matrix of the form:

[ R p ]

[ 0 0 0 1 ]

where R is a 3x3 rotation matrix that represents the orientation of the robot's end effector relative to its base, and p is a 3x1 translation vector that represents the position of the end effector relative to the base. The last row of the matrix is always [0 0 0 1], which represents the homogeneous coordinate.

The reason why we pad the last row of the homogeneous transformation matrix with [0 0 0 1] is that it allows us to represent both translation and rotation transformations in a single matrix. The homogeneous coordinate is used to perform the mathematical operations required to combine translation and rotation transformations.

The value of 1 in the last entry of the homogeneous coordinate is used to indicate that it is a homogeneous coordinate, which means that it is subject to the same transformations as the other coordinates, but is not directly represented in physical space.

**Q10.**

**a) What is the orientation of an end effector? How is this orientation calculated (Also, write on your answer sheet the three matrices used to find rotation between frames)? Identify the orientation you will calculate, is absolute or relative describe.**

**Solution:**

The orientation of an end effector refers to the way it is rotated or positioned with respect to a given coordinate system or frame of reference. The orientation can be described by a rotation matrix that represents the three-dimensional rotation required to transform the end effector from its current orientation to the desired orientation.

The orientation that is calculated using these matrices is relative, meaning that it describes the transformation required to move the end effector from its current orientation to the desired orientation relative to the base frame. This is because the orientation of the end effector is typically described relative to the base frame, rather than as an absolute orientation in space.

**b) Explain, is it possible to have un-aligned axes even at joint variable value zero (if possible then draw the scenario)? Also, describe a scenario when the joint variable value changes, however, the two consecutive frames are still aligned. Draw the kinematics of both scenarios.**

**Solution:**

Yes, it is possible to have unaligned axes even at joint variable value zero. This occurs when the axes of rotation for adjacent joints are not parallel or intersect at a point other than the joint center. This configuration is known as a non-zero twist joint.

One example of such a scenario is a robot arm with a revolute joint and a prismatic joint, where the axis of rotation of the revolute joint is not parallel to the direction of motion of the prismatic joint. At joint variable value zero, the two axes will not be aligned.

Here is an example scenario where the two consecutive frames are still aligned despite a change in joint variable value:

Consider a robotic arm with two revolute joints, where the first joint rotates about the Z-axis of the base frame, and the second joint rotates about the Y-axis of the first joint frame. Let's say that the joint variable value for both joints is initially set to zero, and the two frames are aligned as shown below:

Z0

|

|

|\_\_\_\_\_\_ X0

/

/

/ Y0

As the first joint rotates, the Z-axis of the first joint frame rotates with it, resulting in a change in the orientation of the second joint frame. However, if the second joint is designed to rotate about the intersection of the Y-axis and the new Z-axis of the first joint frame, then the two consecutive frames will remain aligned, even as the joint variable value changes.

Z1

|

|

|\_\_\_\_\_\_ Y1

/

/

/ X1

In this scenario, even though the joint variable value changes, the two frames remain aligned because the second joint is designed to rotate about the intersection of the Y-axis and the new Z-axis of the first joint frame.

In summary, it is possible to have unaligned axes even at joint variable value zero in the case of non-zero twist joints. In some cases, the two consecutive frames can still be aligned despite a change in joint variable value if the joint is designed to rotate about the intersection of the two axes.