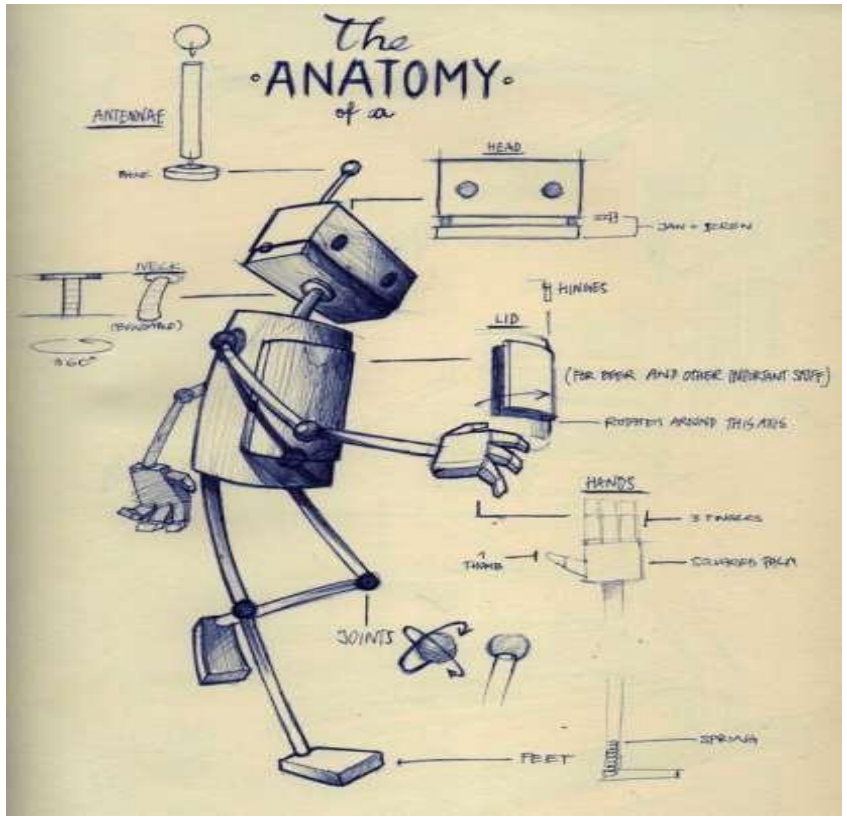
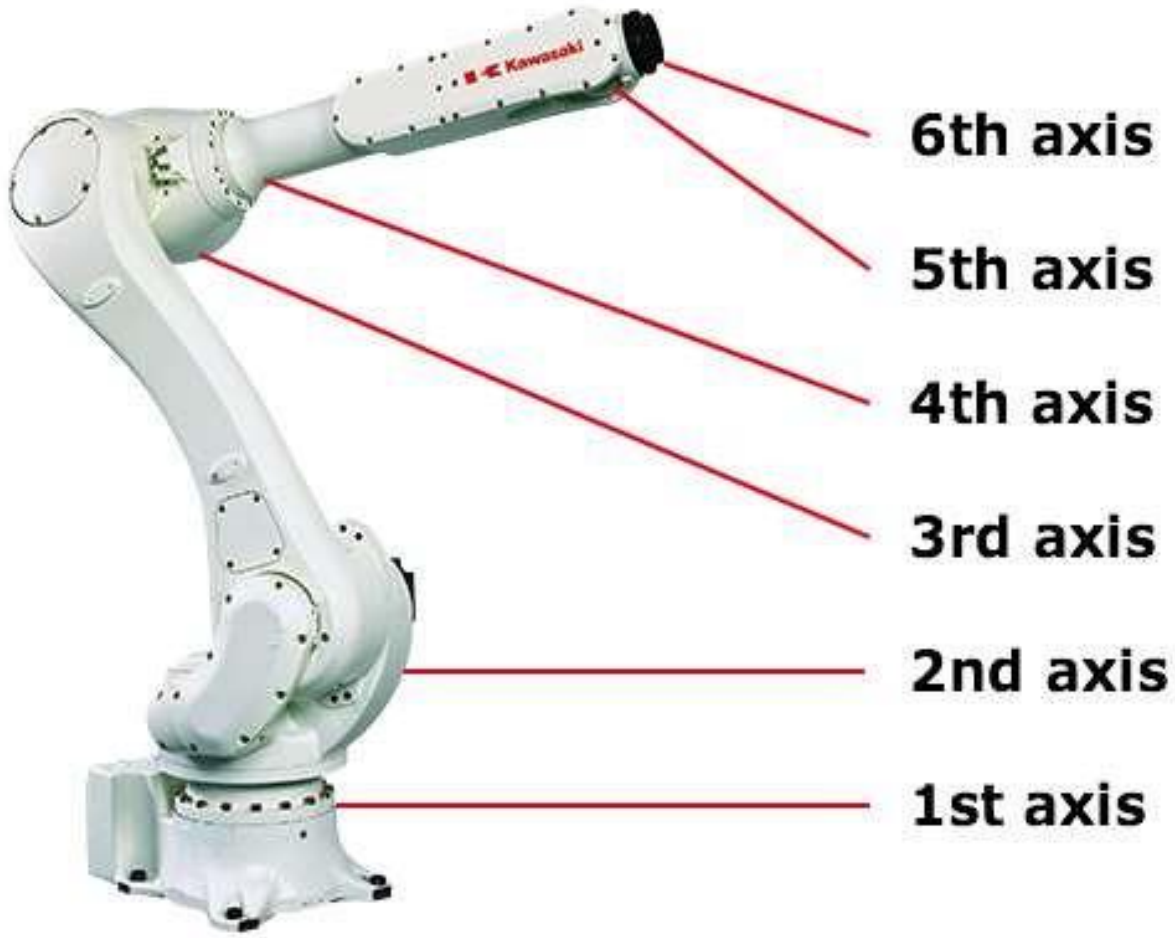
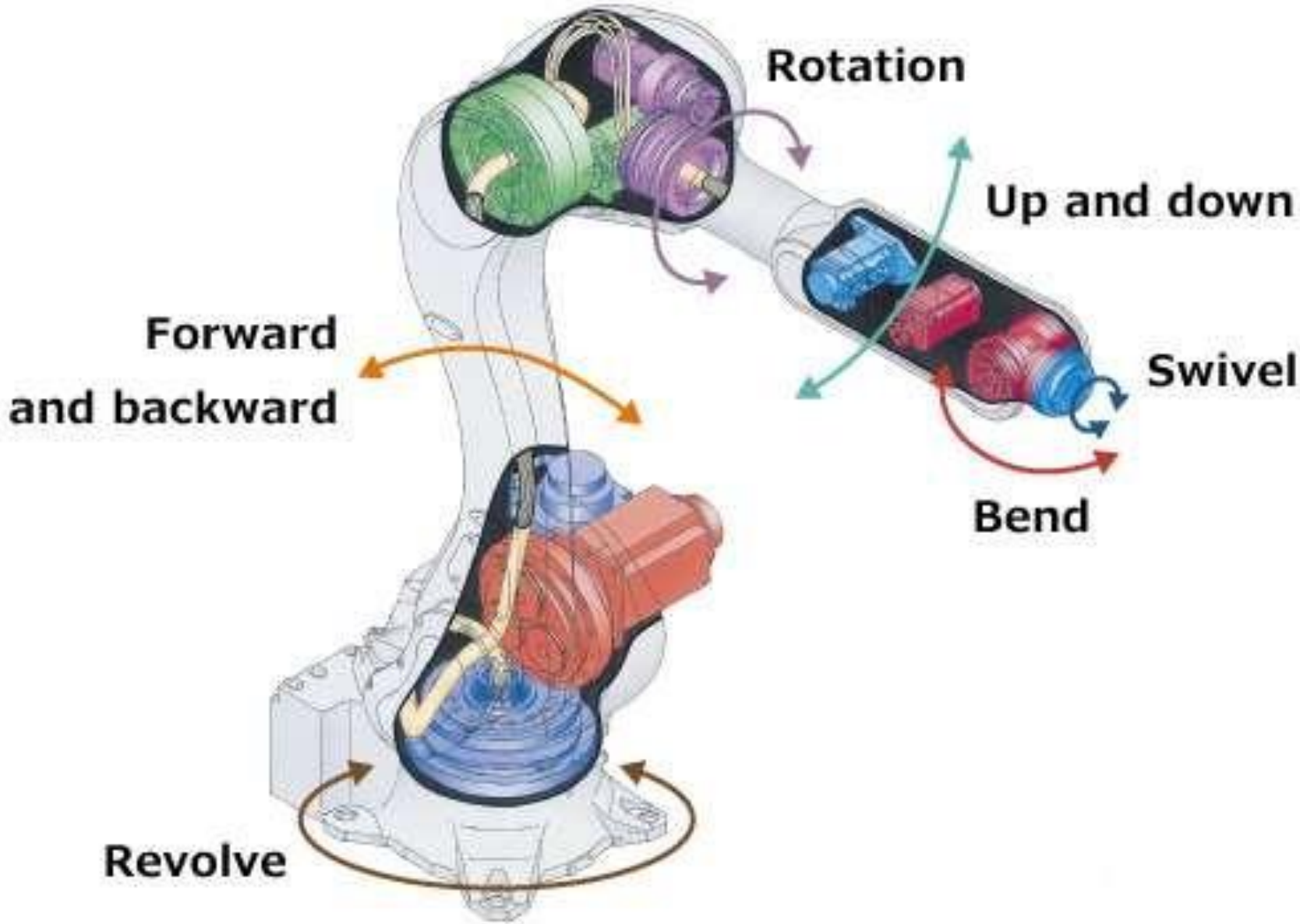
Subject: Skill Enhancement Elective – III - Introduction to Robotics
Semester: IVth Sem ETC
Name of the Faculty: Mr. Ashish Katore

Fundamentals of Robotics & Applications

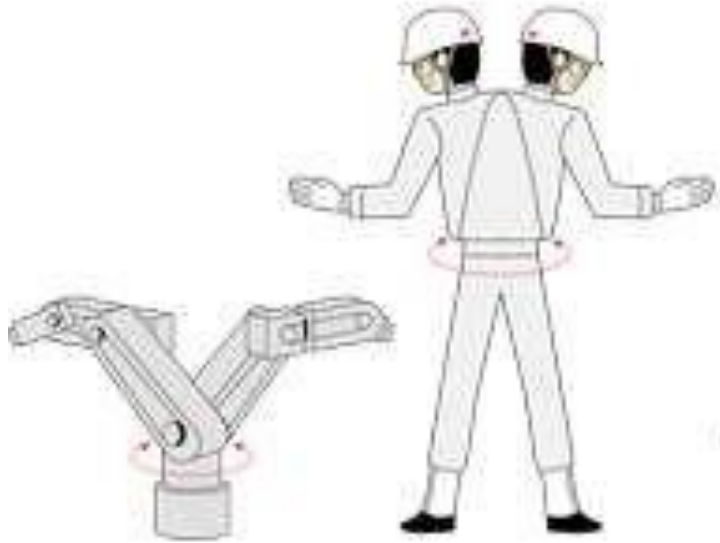
MODULE 2: Robot Anatomy And Motion Analysis



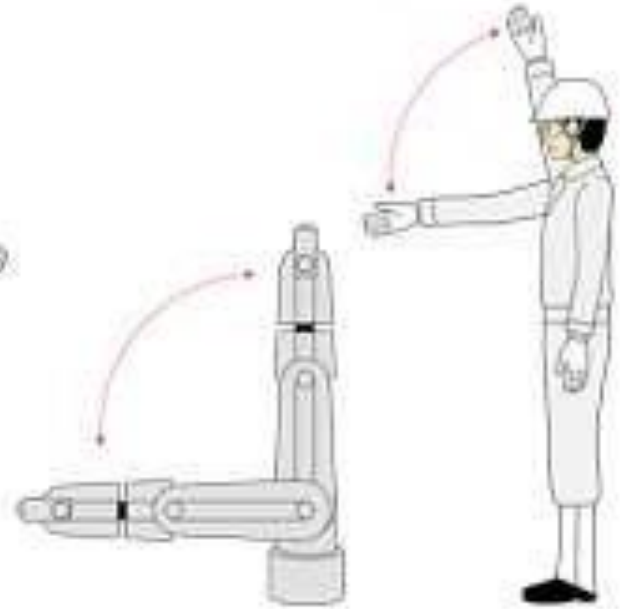



Rotation
Up and down
Swivel
Bend
Forward
and backward
Revolve

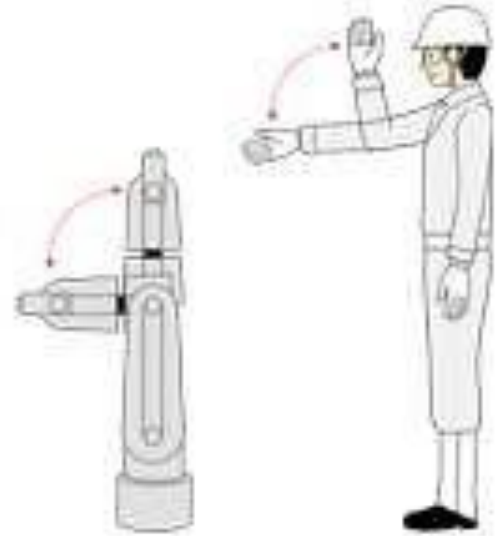
1st axis: Waist



2nd axis: Shoulder



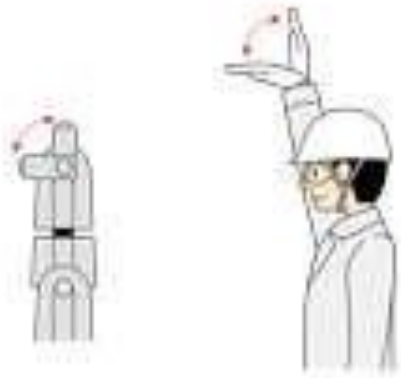
3rd axis: Elbow



4th axis: Wrist (Rotating)



5th axis: Wrist (Bending)



6th axis: Fingertip



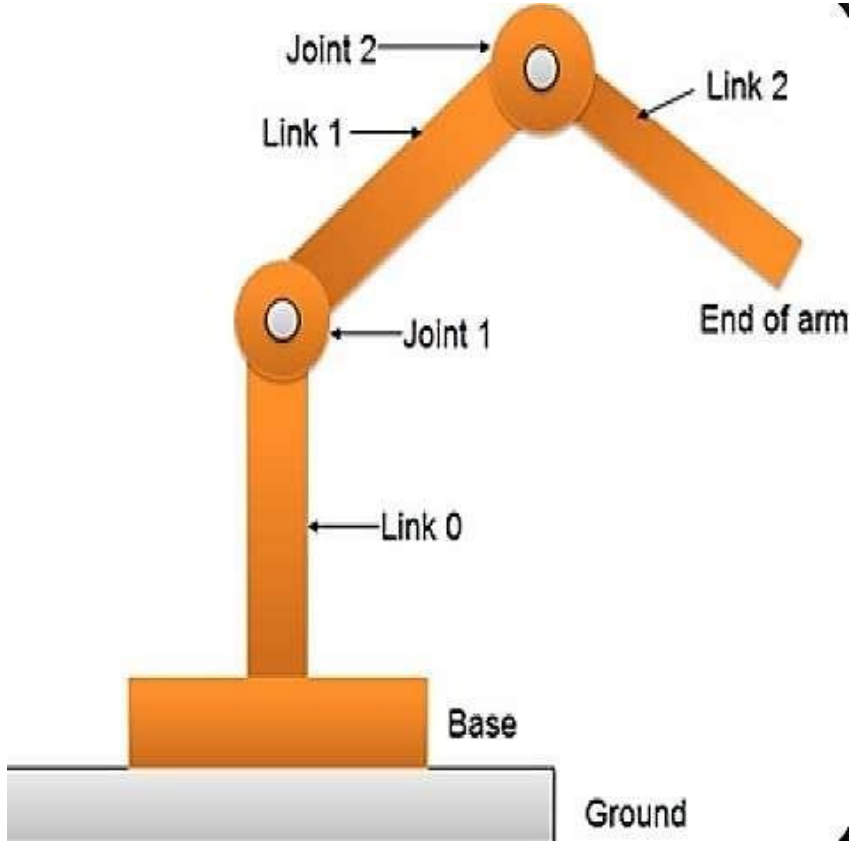
MODULE 2: Robot Anatomy And Motion Analysis

Content

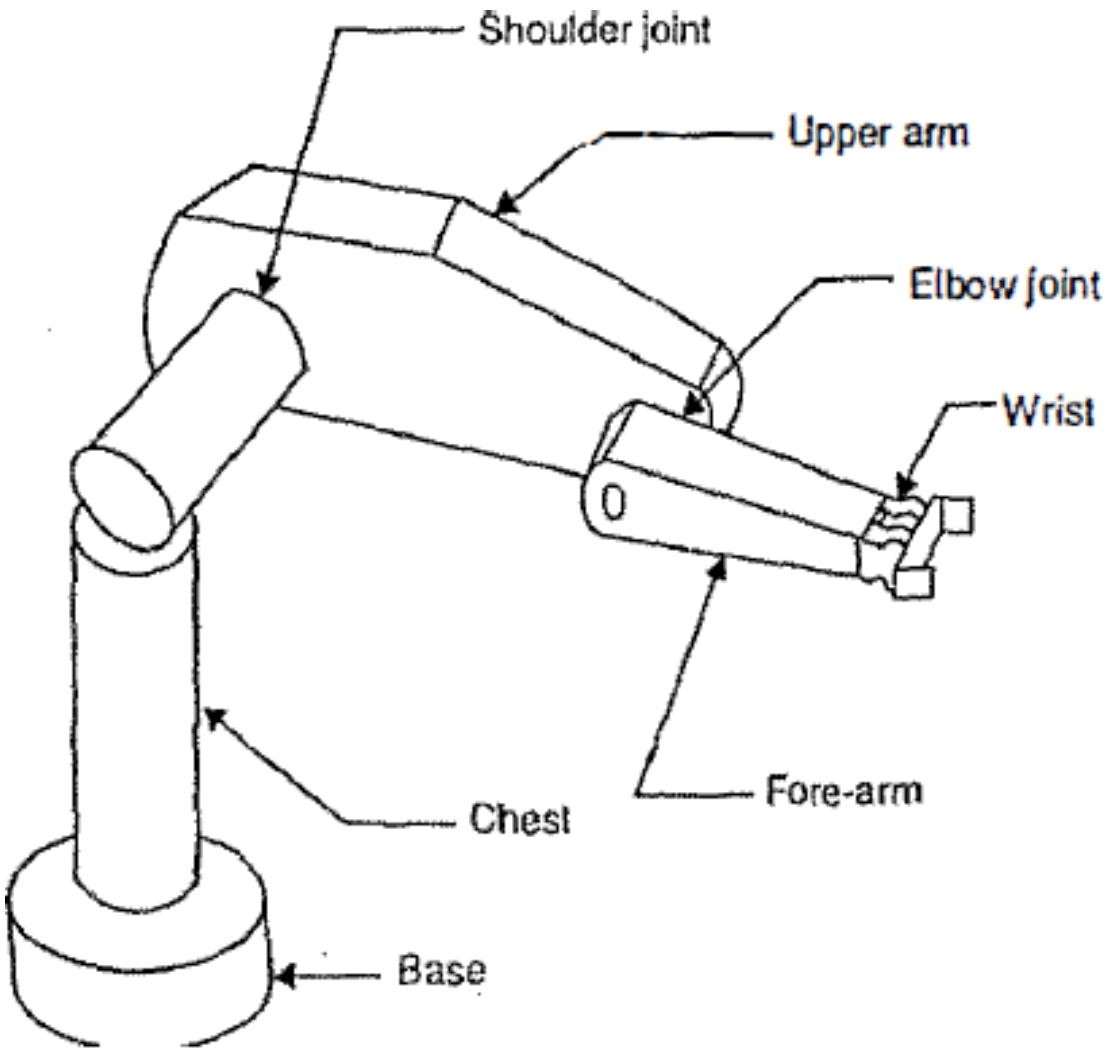
- Anatomy of a Robot, Robot configurations: polar, cylindrical, Cartesian, and jointed arm configurations.
- Robot links and joints, Degrees of freedom: types of movements, vertical, radial and rotational traverse, roll, pitch and yaw, Work volume/envelope,
- Robot kinematics: Introduction to direct and inverse kinematics, transformations and rotation matrix

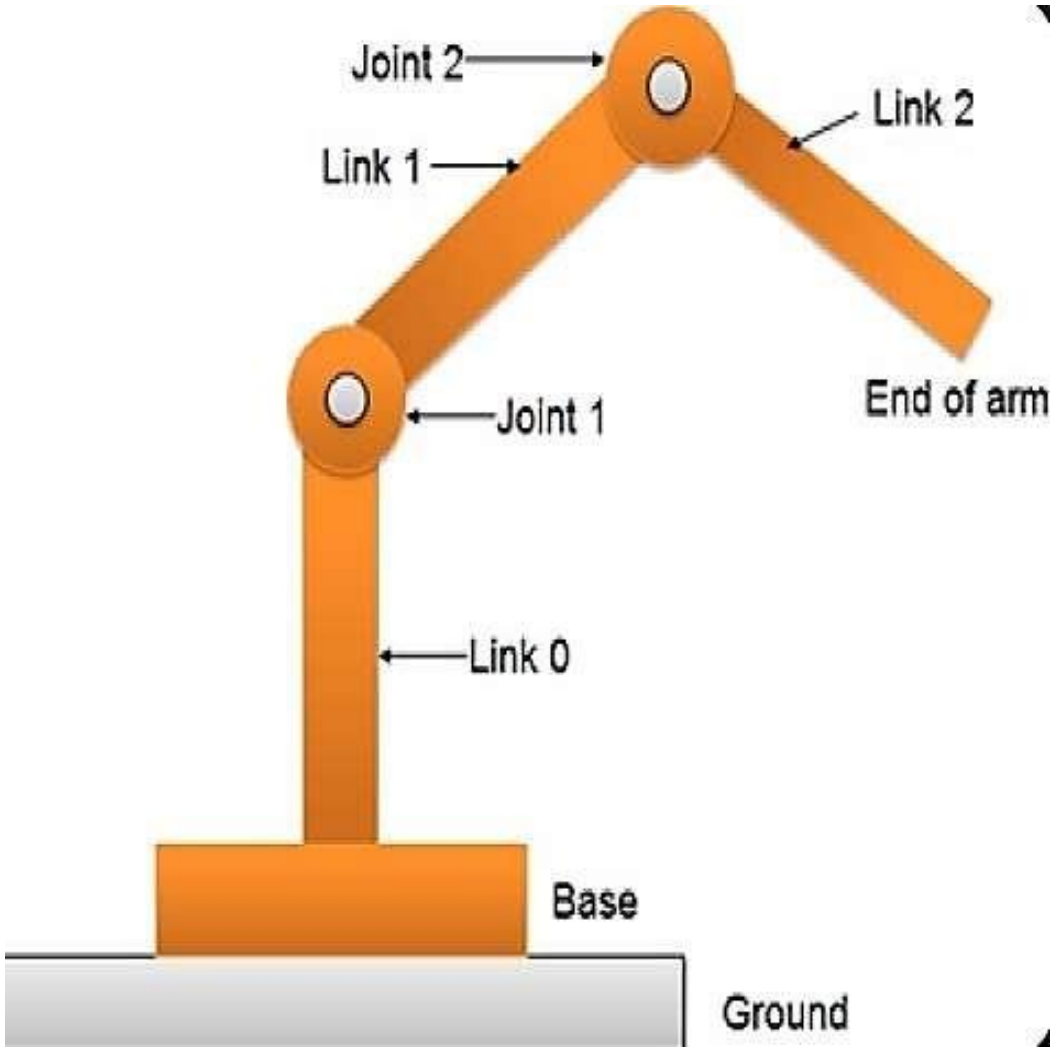
Anatomy of a Robot

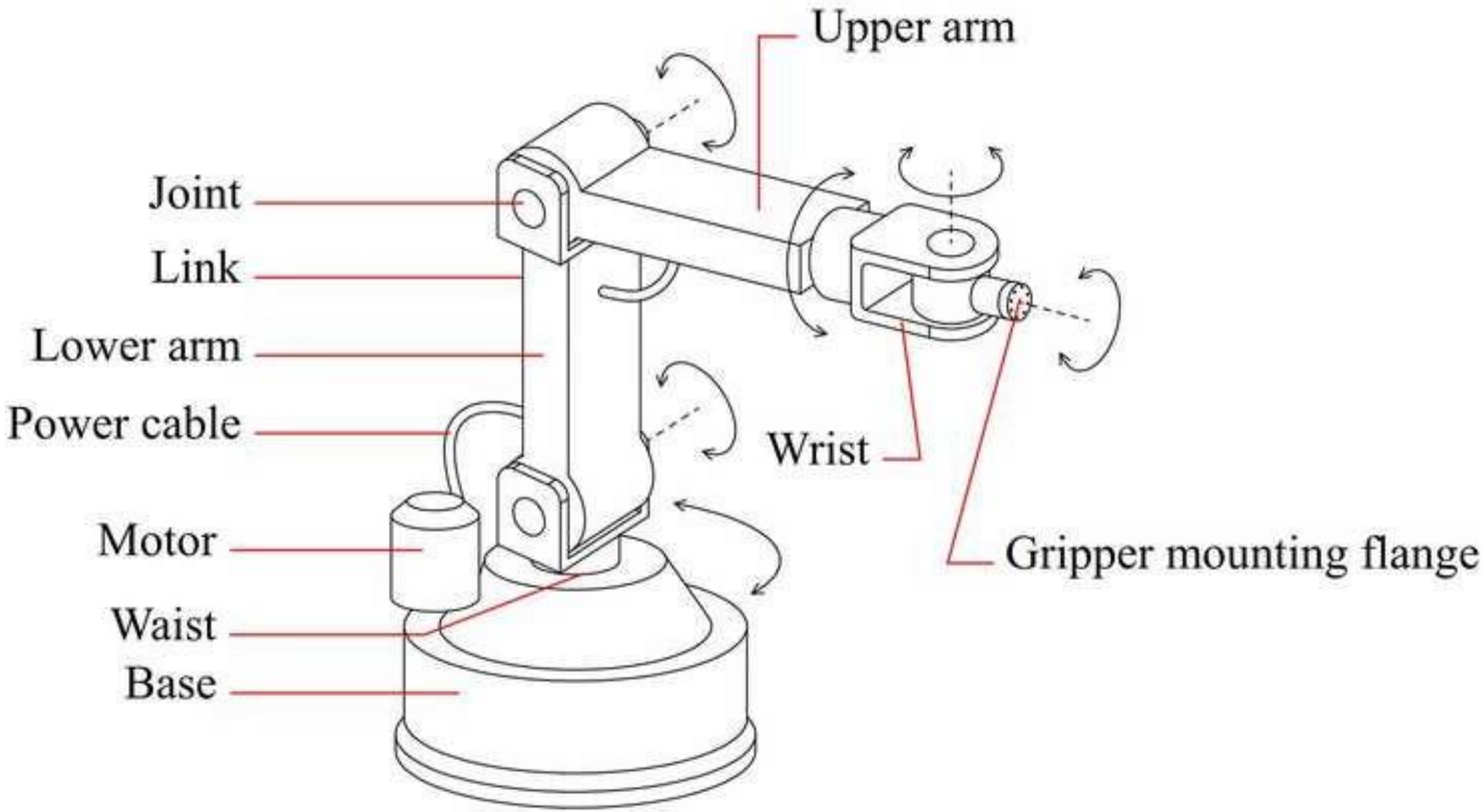
- Robot anatomy is concerned with the physical construction of the body, arm and wrist
- Most robots used in plants are mounted on a base and fastened to the floor.
- The body is attached to the base, and the arm assembly is attached to the body.
- At the end of the arm, carries the wrist.
- Wrist allows it to be oriented in a variety of positions.
- Relative movements between the links are provided by a series of joints
- The robot's wrist receives a hand or a tool called the "end effector
- The end effector is not considered as part of the robot's anatomy



Anatomy of a Robot






Upper arm
Joint
Link
Lower arm
Power cable
Wrist
Motor
Gripper mounting flange
Waist
Base

Robot Configurations

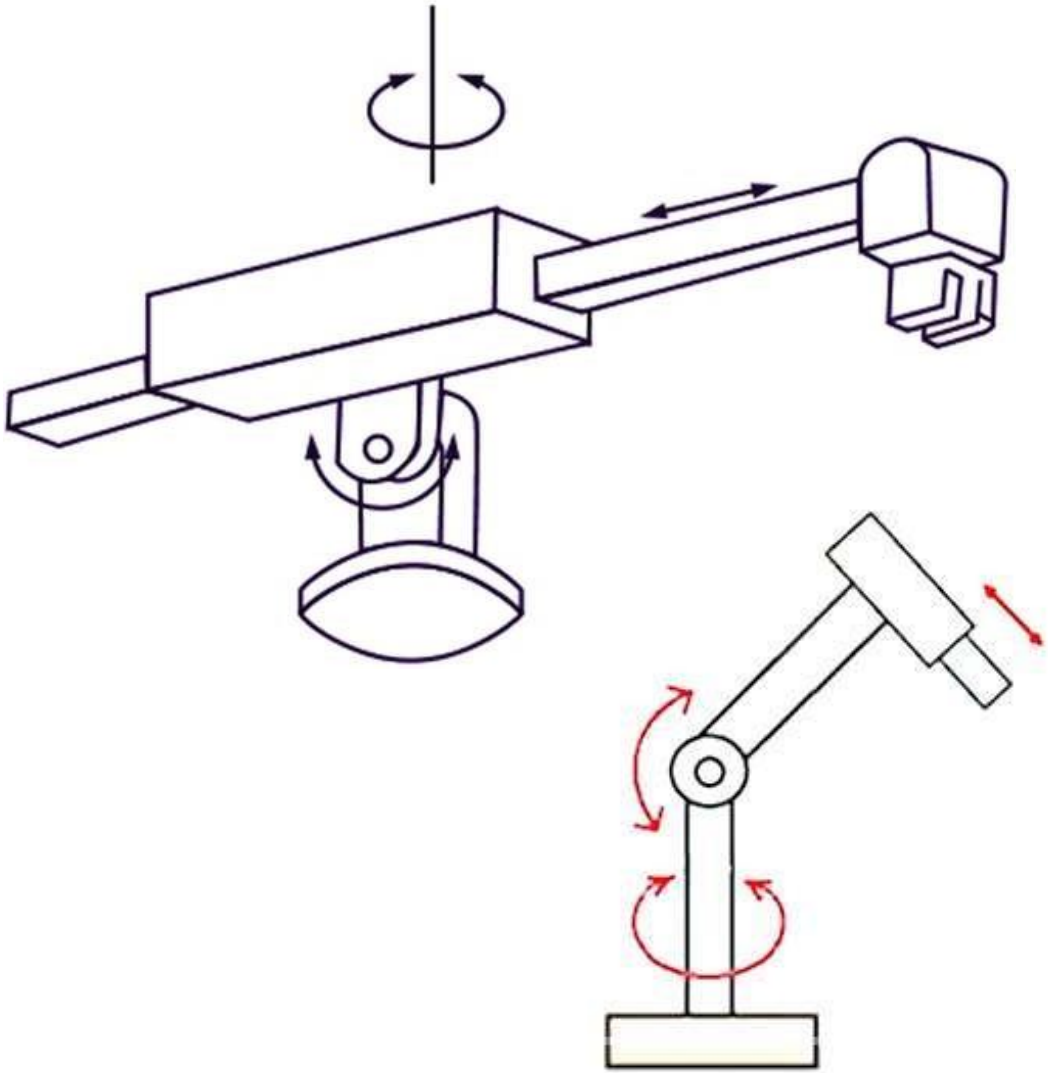
Physical configuration

Today's commercially available robots possess four basic configurations;

1. Polar Configuration
2. Cylindrical configuration
3. Cartesian coordinate configuration
4. Jointed arm robots

Robot Configurations

1. Polar / Spherical Configuration (P2R)



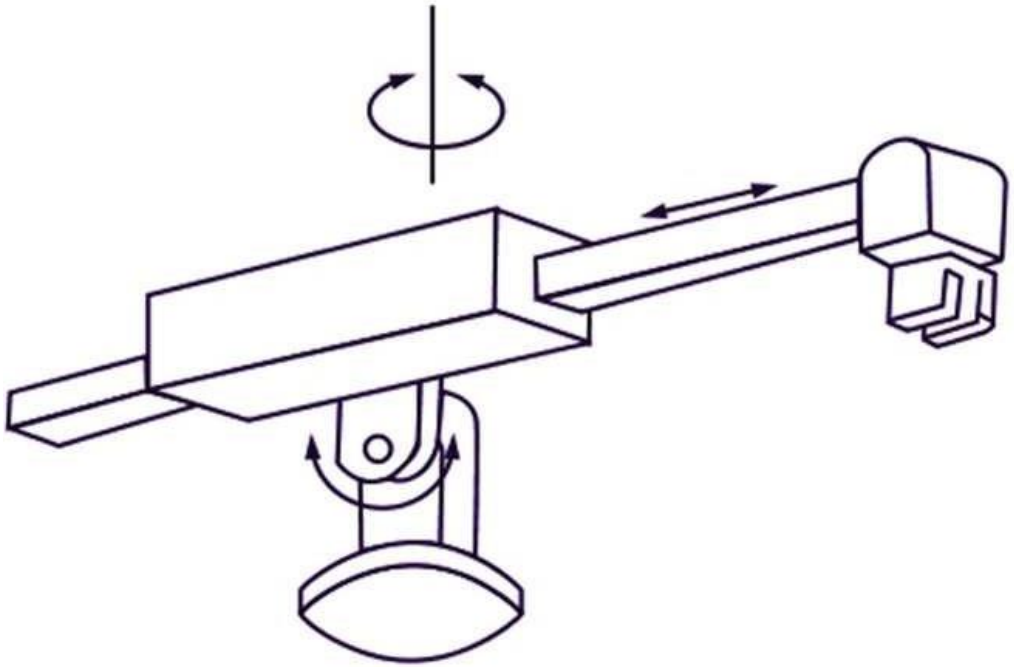
- This combination allows the robot to operate in a spherical work volume.

The robot arm has following movements.

1. **Linear movement**: allows the arm to extend and retract because of one linear joint.
2. Rotary movement: occurs around an axis (vertical) perpendicular to the base because of one twisting joint.
3. Vertical lift of the arm about the pivot point because of one rotational joint.

Robot Configurations

1. Polar / Spherical Configuration (P2R)



Advantages

- Long reach capabilities in horizontal position
- Good lifting capabilities
- Suitable for small amount of vertical applications

Limitations

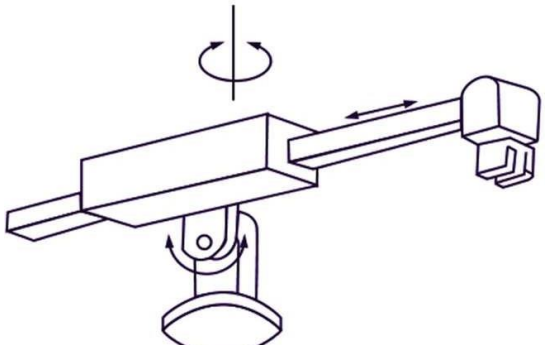
- Low vertical reach
- Reduced mechanical rigidity

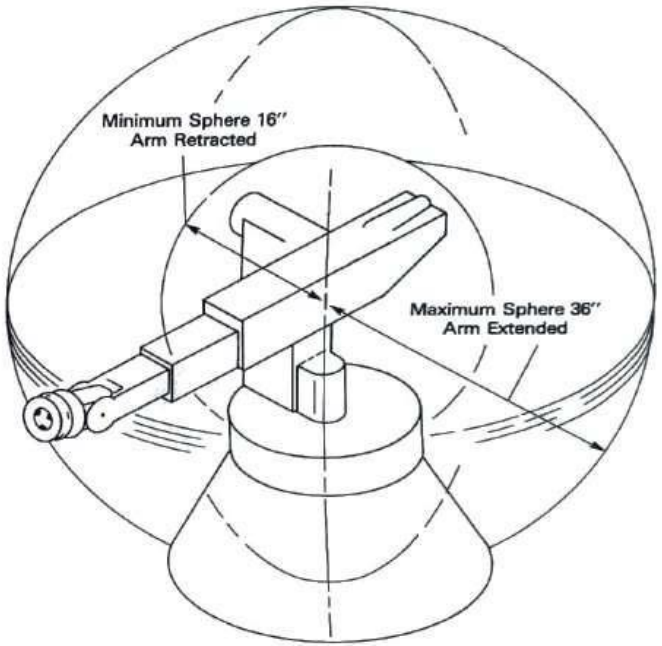
Applications: Machine loading, Material movement, stacking of components, Heat treatment operations

Ref: https://electricalworkbook.com/polar-robot/

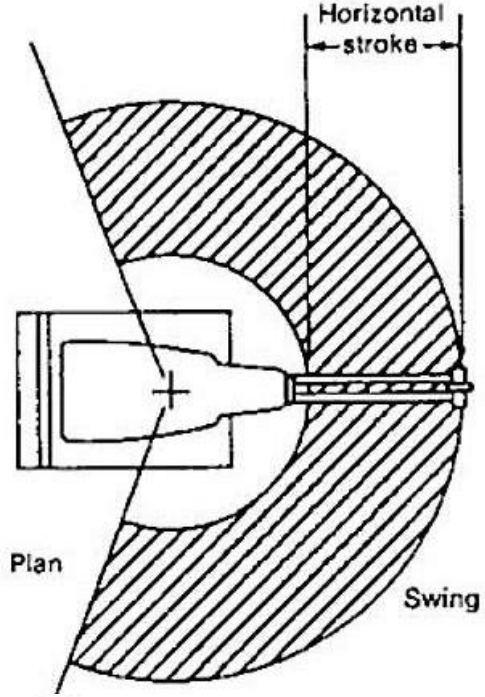
Robot Configurations

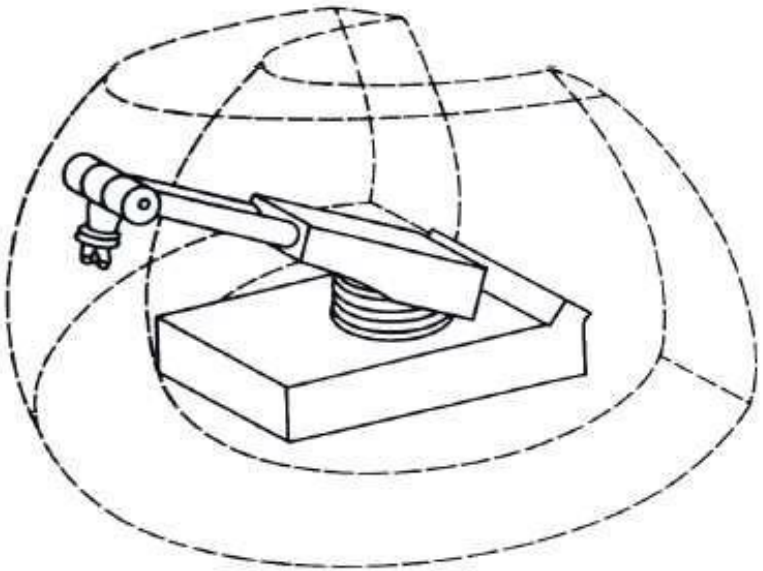
1. Polar / Spherical Configuration (P2R)



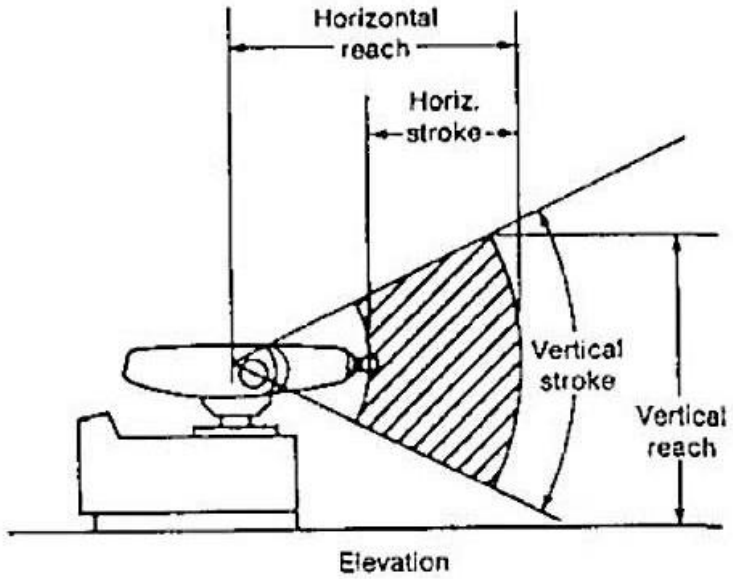


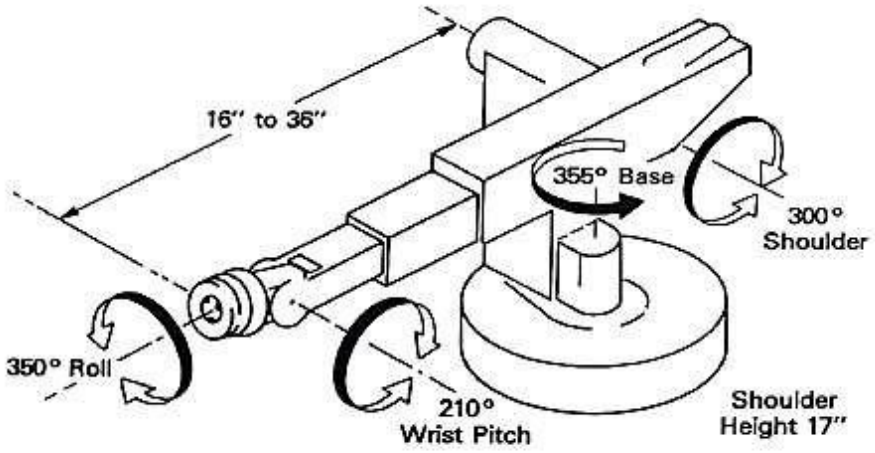
Workspace of robot / Work volume





Geometry of robot major axis

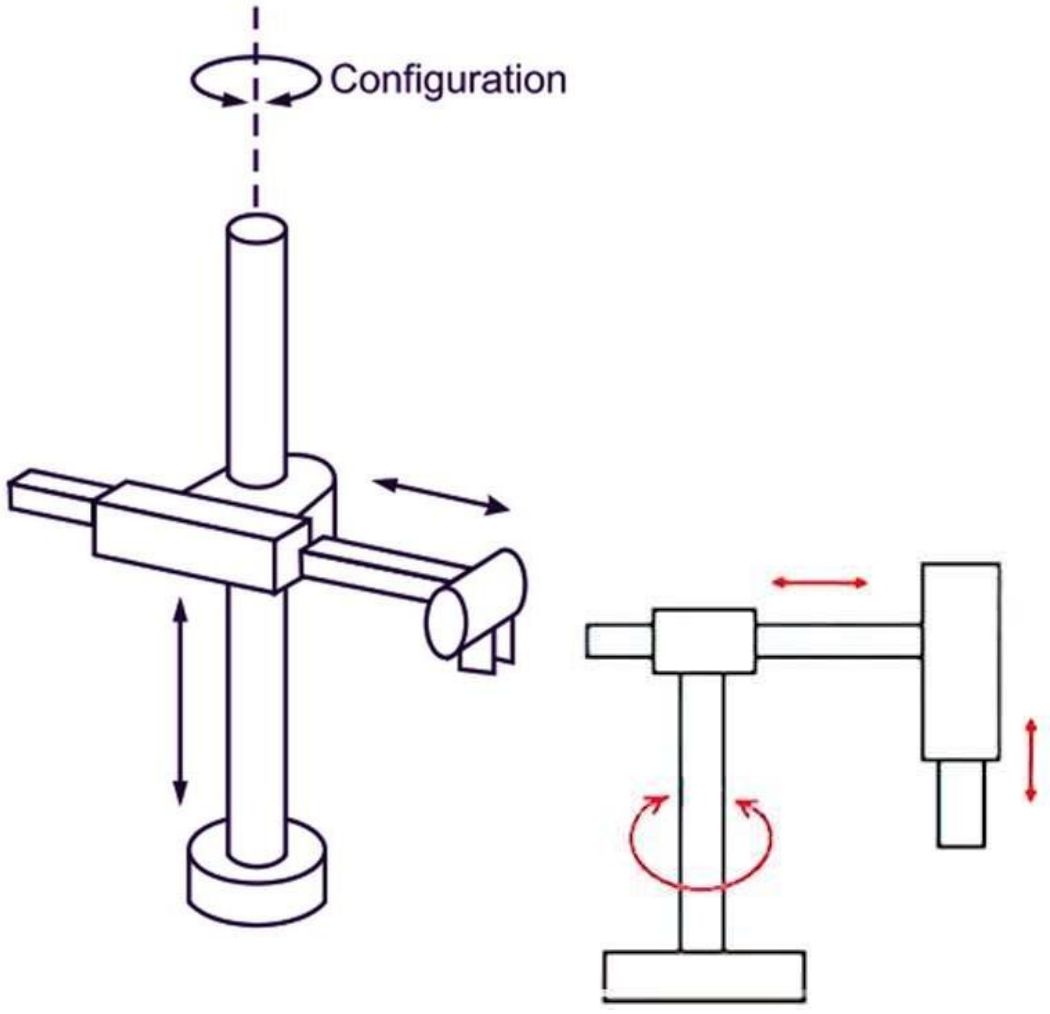




Range of Motion (c)

Robot Configurations

2. Cylindrical Configuration (PRP / 2PR)

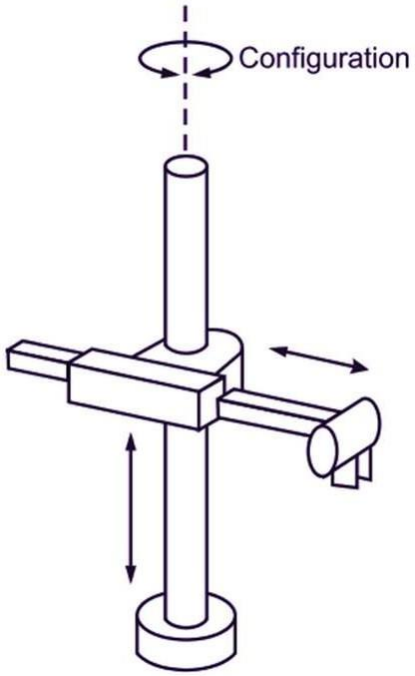


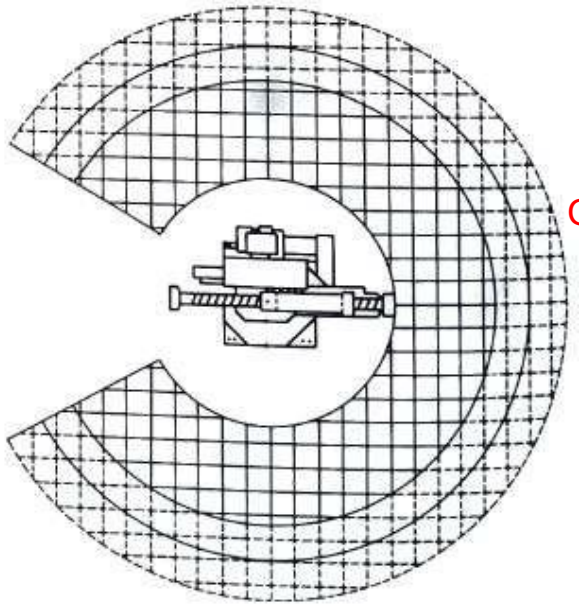
- This combination allows the robot to reach work space in a rotary movement like a cylinder

The robot arm has following movements.

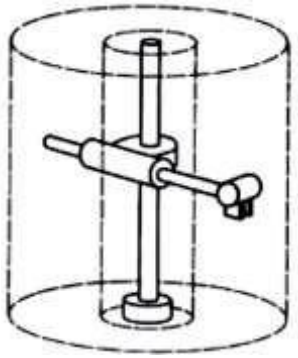
1. **Rotational movement**: of the column about its axis because of one twisting joint
2. Linear movement: of the assembly along the column because of one linear joint
3. Linear movement in and out, relative to the column axis because of one orthogonal jointworkspace

Robot Configurations





Workspace of robot / Work volume



Geometry of robot major axis

Advantages

- Higher load carrying capacity
- Provides high rigidity to the manipulator
- Suitable for pick and place applications

Limitations

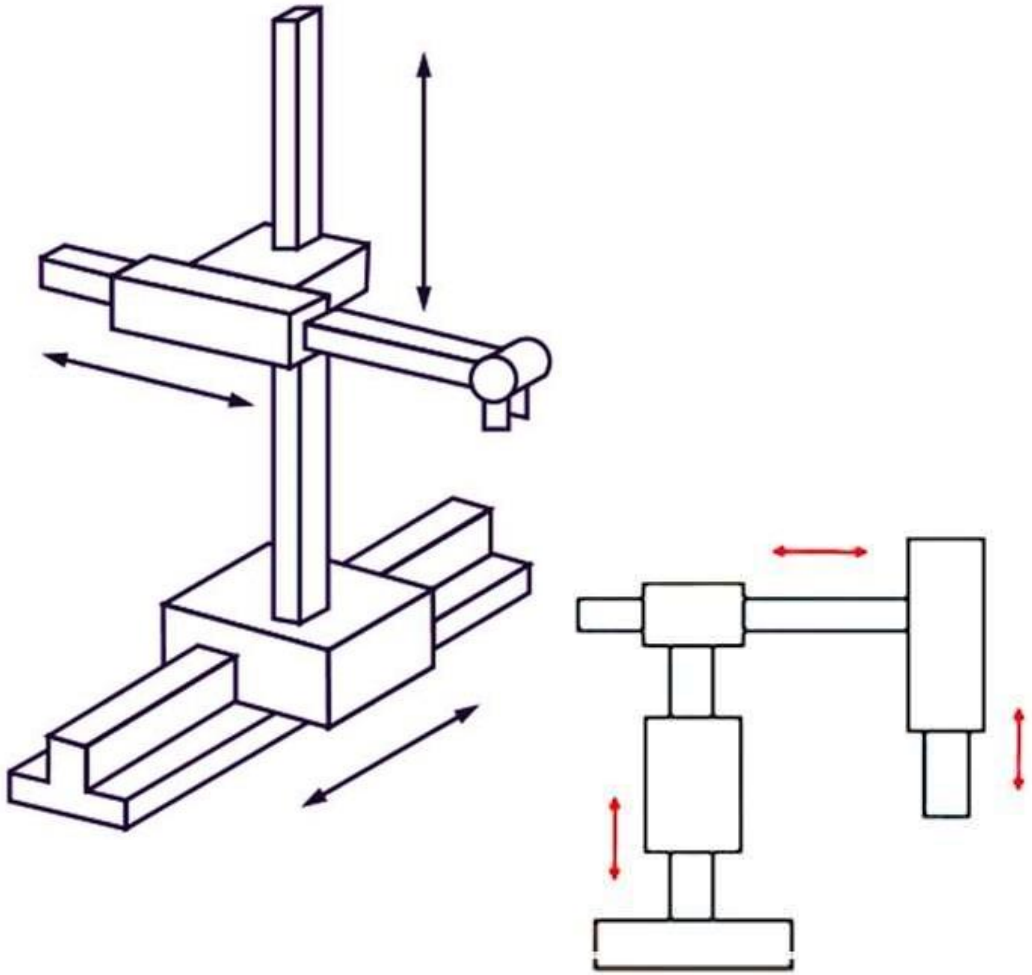
- Require more floor space
- Reduced mechanical rigidity because rotary axis must overcome inertia of the object when rotating

Applications: Conveyor pallet transfer, machine tool loading, forging , packing, precision small assembly etc.

Ref: https://electricalworkbook.com/cylindrical-robot/

Robot Configurations

3. Cartesian Coordinate Configuration



- Also referred as Rectilinear robot or X-Y-Z robot of the spherical configuration, as it is equipped wit three sliding joints.

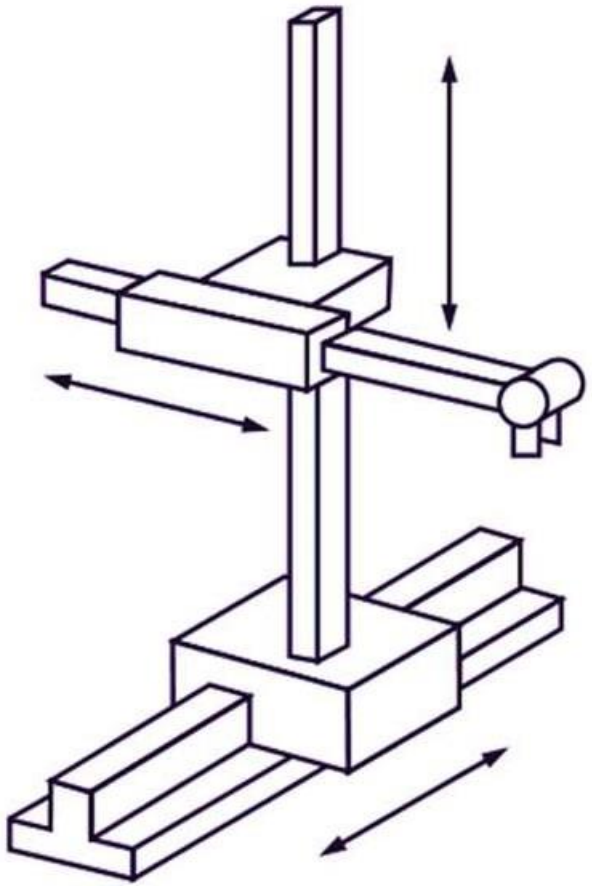
The robot arm has following movements.

1. **Linear movement**: allows vertical lift to the arm because of one linear joint.
2. Two sliding movement: perpendicular to each other because of two orthogonal joint.

This configuration robot process in a rectangular workspace by three joints movement.

Robot Configurations

3. Cartesian Coordinate Configuration



Advantages

- Higher load carrying capacity
- Rigid structure, high degree of mechanical rigidity and accuracy
- High repeatability with least error at good speed.

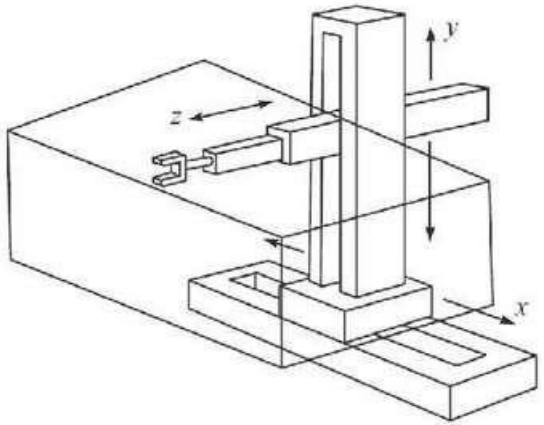
Limitations

- Has small and rectangular work envelope
- Has reduced flexibility

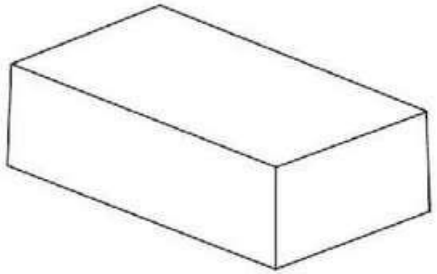
Applications: Inspection, assembly, machining operations, welding, finishing operations etc.

Ref: https://electricalworkbook.com/cartesian-robot/

3. Cartesian Coordinate Configuration



(a) Arm configuration

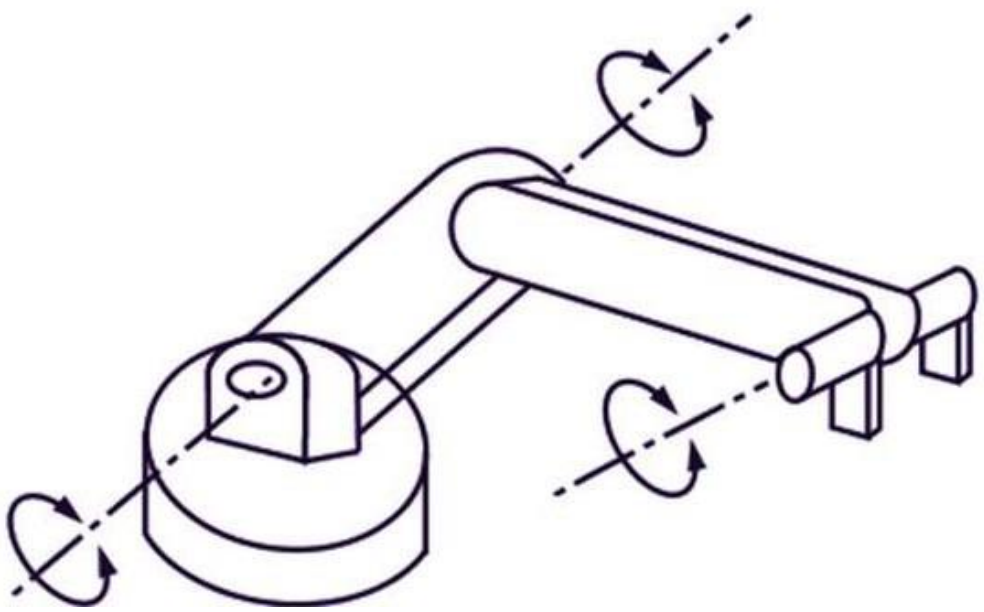


(b) Rectangular box



Robot Configurations

4. Jointed arm Configuration



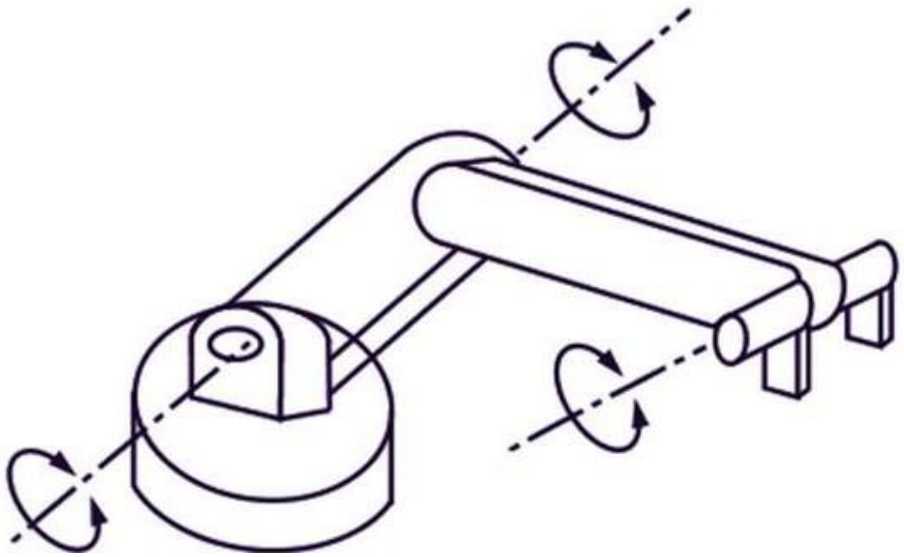
- Resembles to a human arm

1. **Rotary movement**: (vertical column that swivels about base) occurs around an axis (horizontal) parallel to the base because of twisting joint.
2. Rotary movement: at the top of the column about the shoulder joint (along the horizontal axis) because of one rotational joint.
3. Rotary movement at the output arm about the elbow joint (along horizontal axis) because of one rotational joint.

- It has 3 rotary joints and 3 wrist axes which form 6 DOF.

Robot Configurations

4. Jointed arm Configuration



Advantages

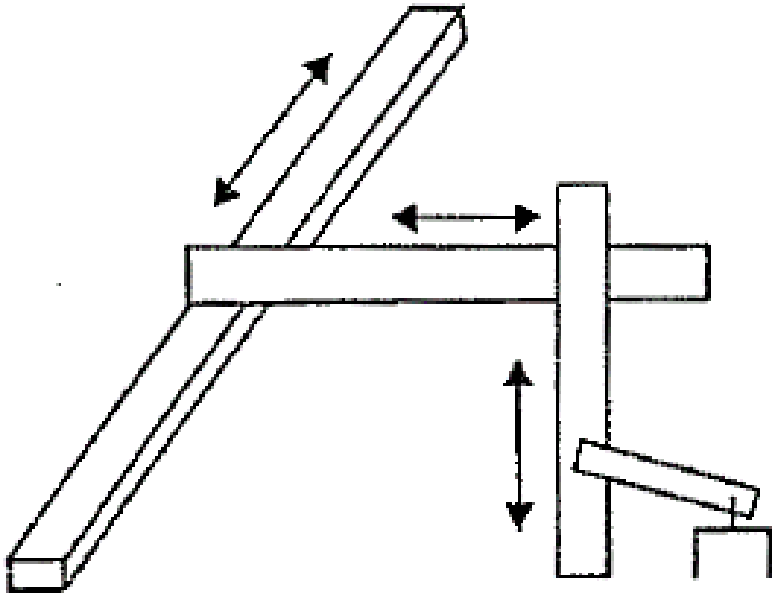
- Huge work volume
- Higher flexibility and quick in operation
- 2 rotational joints allows for higher reach from the base
- Provides reaching congested small opening without restrictions

Limitations

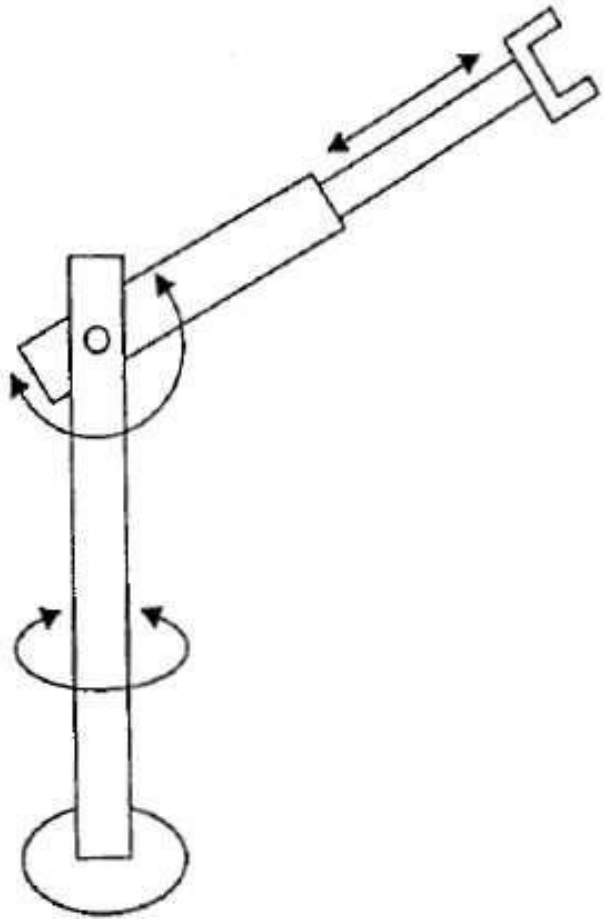
- Difficult operation procedure
- Plenty of components

Applications: spray painting, spot welding, arc welding etc.

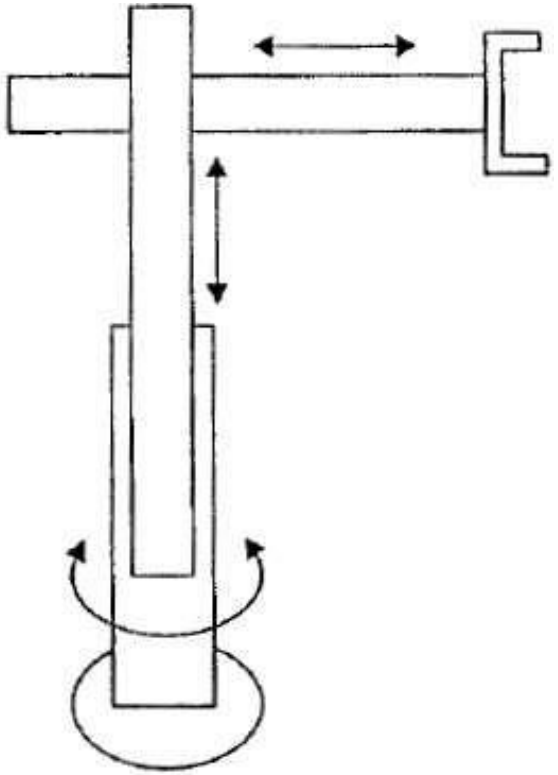
Ref: https://electricalworkbook.com/jointed-arm-robot/



Cartesian



Polar / spherical

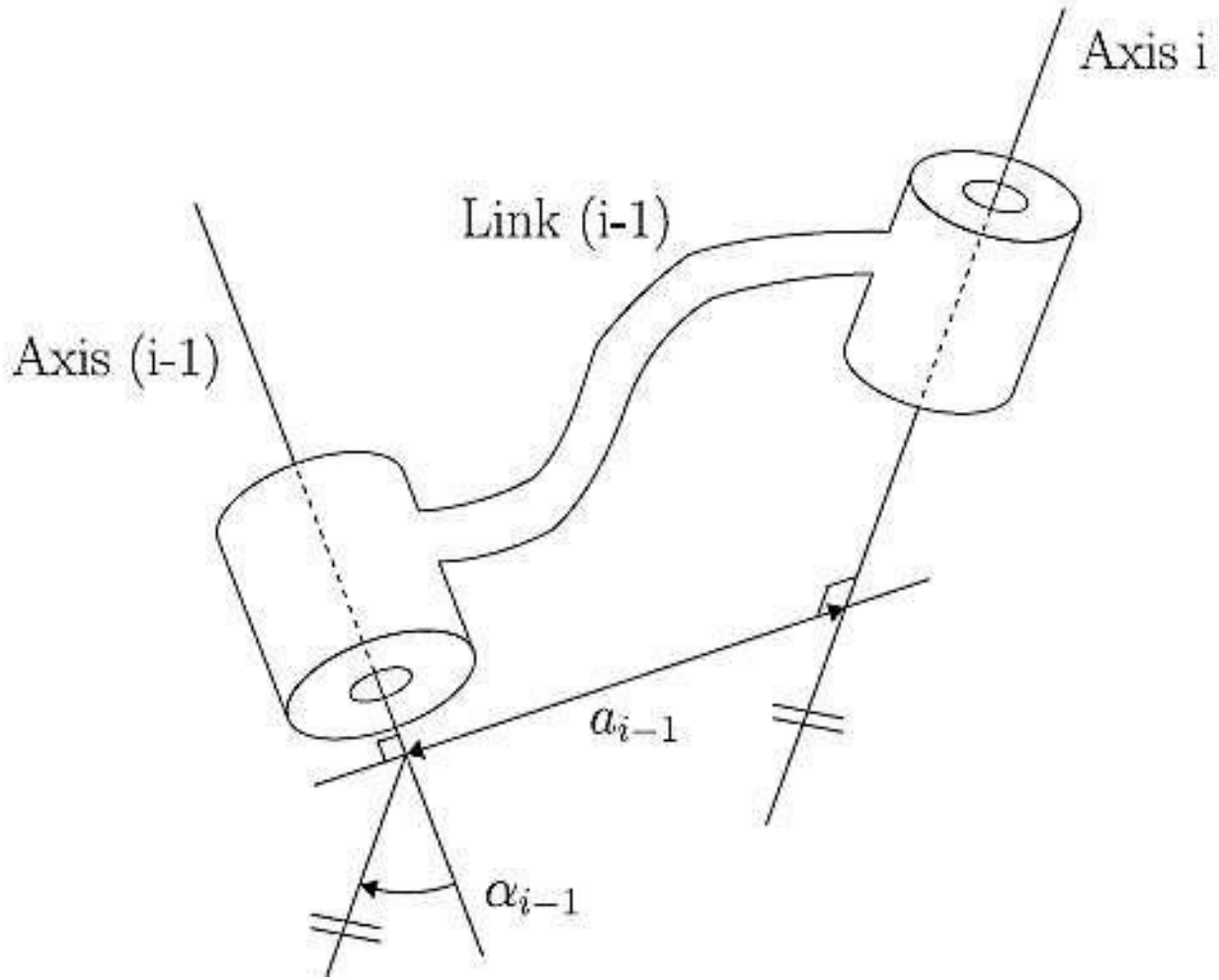


Cylindrical

Robot links and Joints

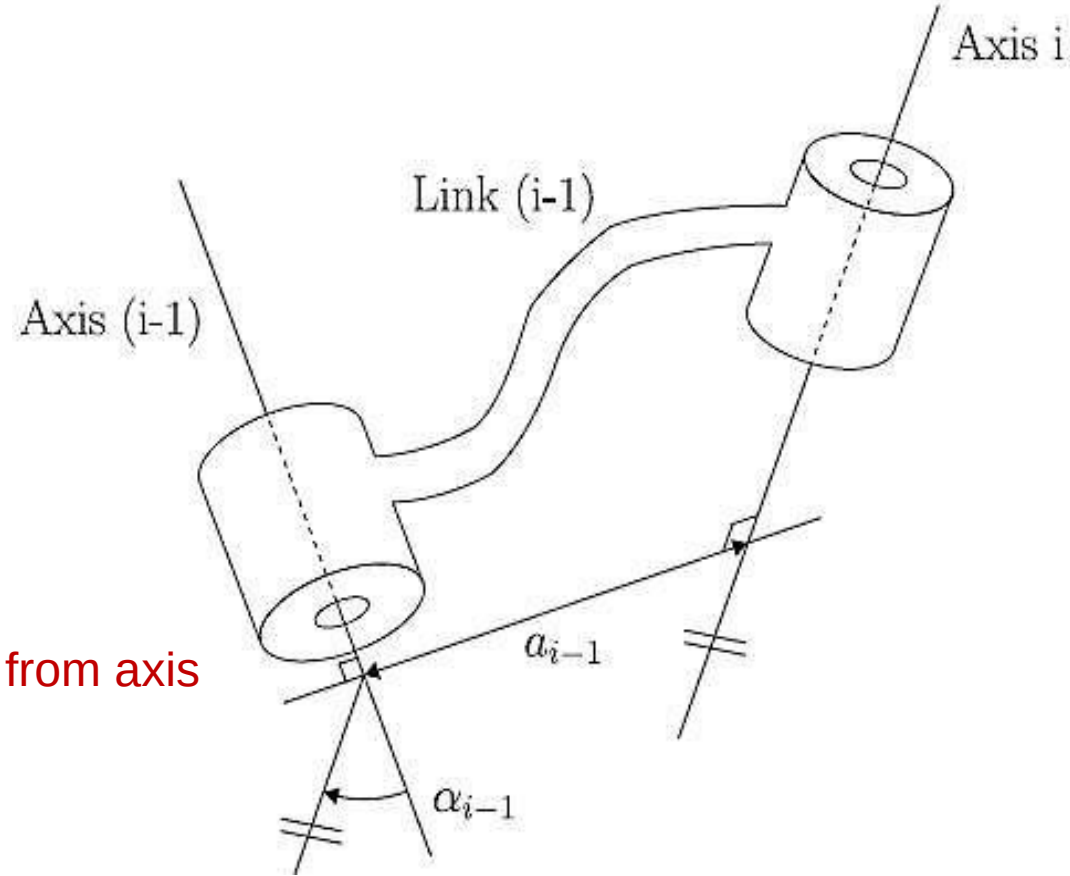
ROBOT LINKS

- A robotic manipulator's two adjacent joint axes are connected, defined by a rigid body called a link.
- The link maintains a fixed relationship between the two joint axes through a kinematic function.



ROBOT LINKS

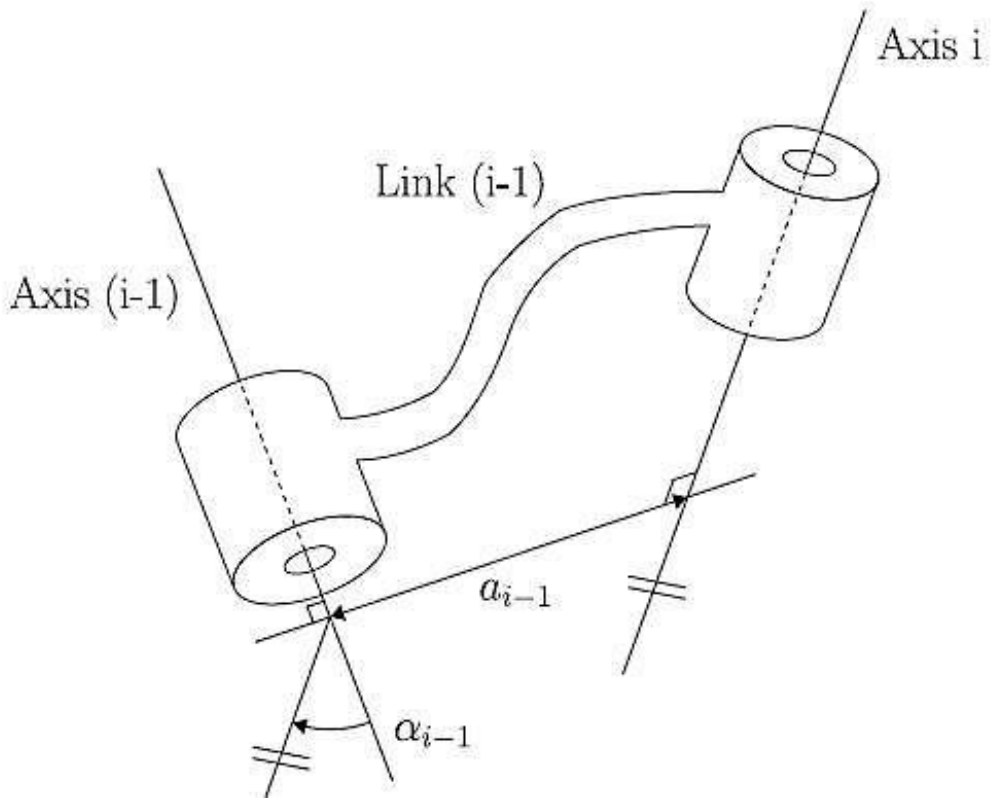
- Consider the i-th link in the kinematic chain.
- This link connects two joints.
- At the end of link i, there is an axis with respect to which the following link, i+1, is going to move.
- There is also an axis at the beginning of link i.
- Those two axes are lines in a three dimensional space.
- They are characterized by a common normal.
- This common normal has a length that is called link length.



a_i-1 (the link length) denotes the length along the common normal from axis i−1 to axis i.

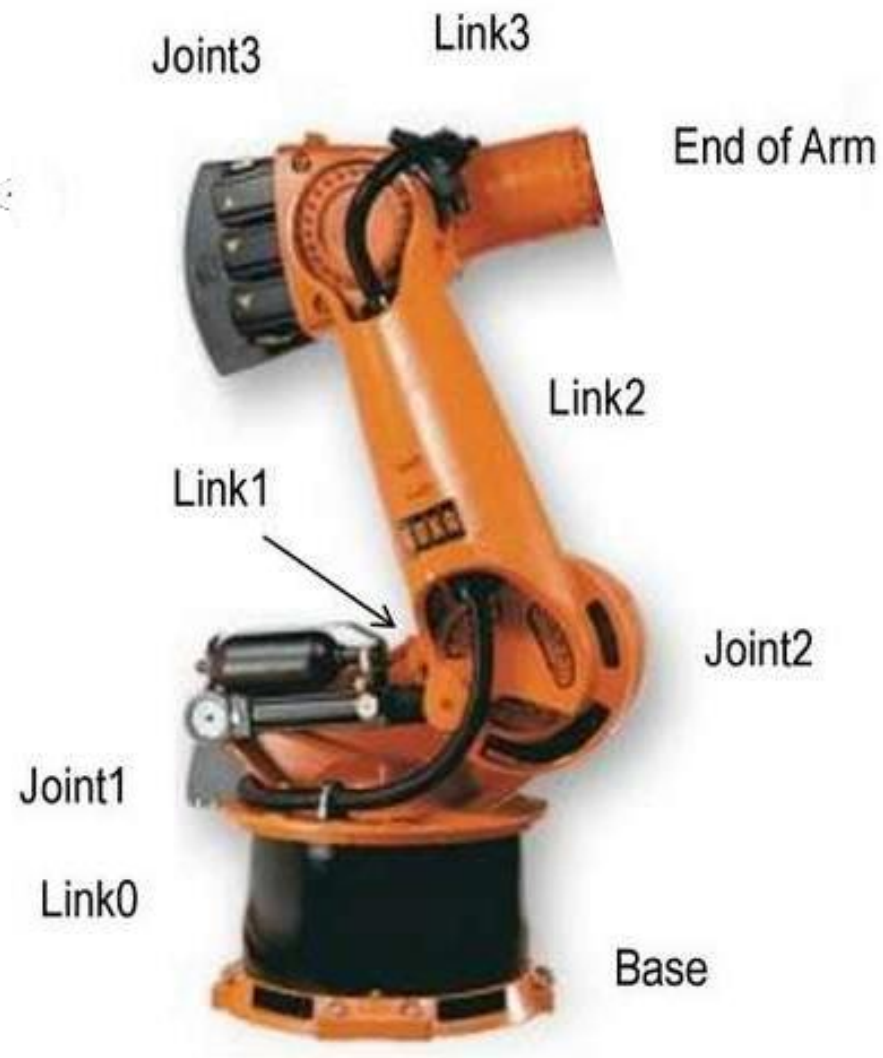
ROBOT LINKS

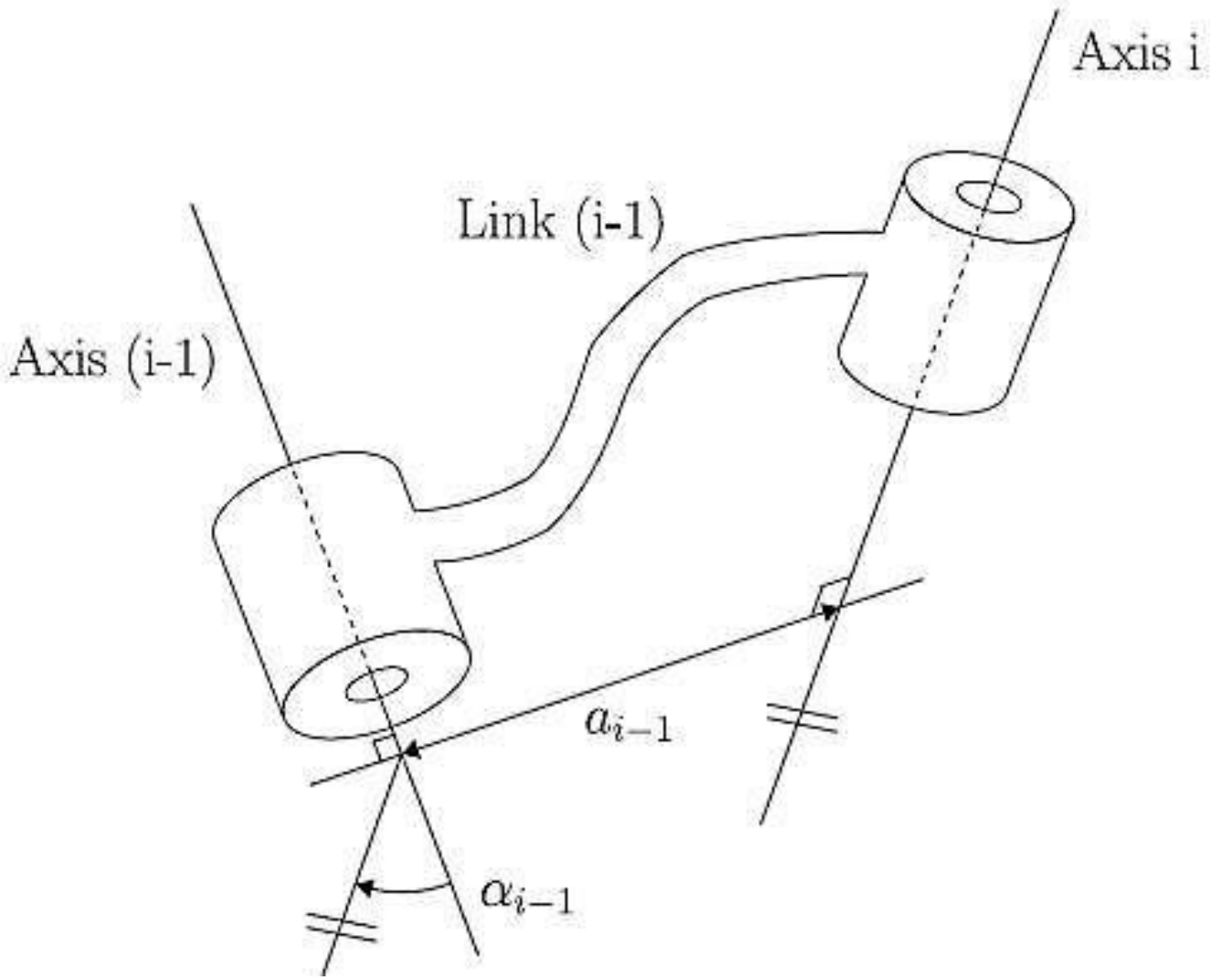
- To define the relative position between two axes in space, in addition to the common normal, the angle between the axes needs to be computed.
- Draw a parallel line to axis i at the point where the common normal intersects the axis i−1.
- The angle between this parallel line and axis i−1, denoted by α_i-1, will be called a link twist.
- This angle is measured in the right-hand sense about the vector defined by a_i-1 directed from axis i−1 to axis i along the common normal.



Robot links and Joints

ROBOT LINKS





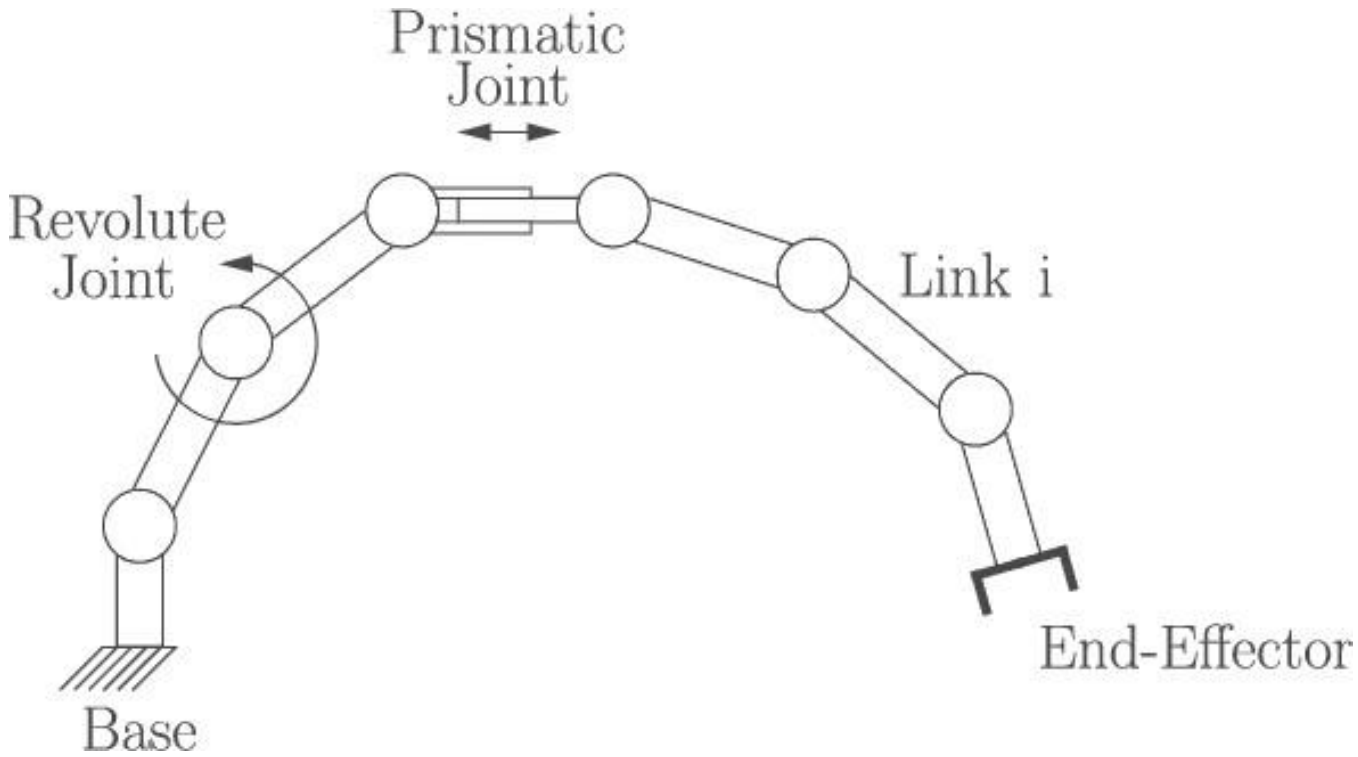
Robot links and Joints

ROBOT JOINTS

- The Robot Joints are an essential element in a robot that helps the links travel in different movements.
- In a robot, the connection of different manipulator joints is called Robot Links.
- The integration of two or more links is called a Robot Joint.

The five major types of joints such as:

1. Rotational joint
2. Linear joint
3. Twisting joint
4. Orthogonal joint
5. Revolving joint

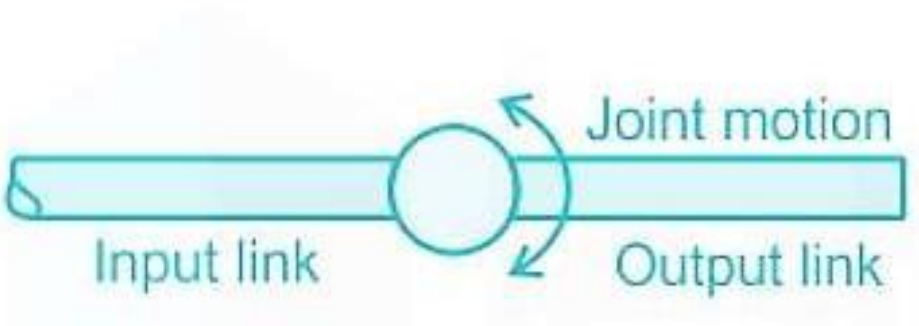


Robot links and Joints

ROBOT JOINTS

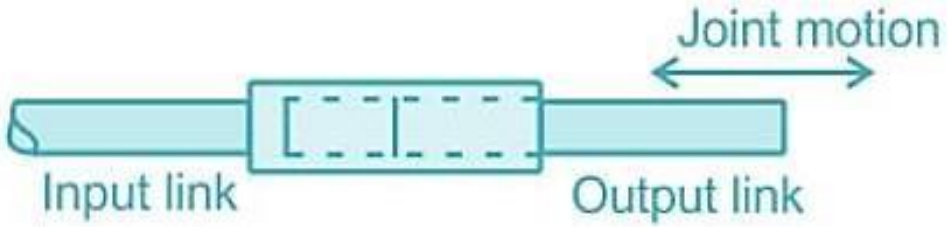
1. Rotational Joint (R)

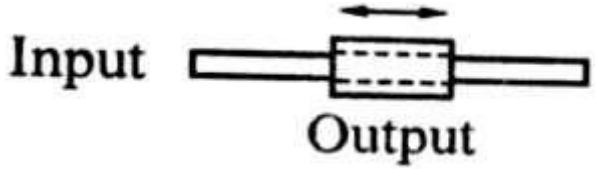
- A rotational joint can also be represented as R – Joint.
- This type will allow the joints to move in a rotary motion along the axis, which is vertical to the arm axes.

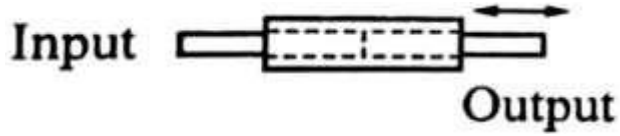


2. Linear Joint (L)

- Linear joint can be indicated by the letter L – Joint.
- This type of joint can perform both translational and sliding movements.
- These motions will be attained in several ways such as telescoping mechanism and piston.
- The two links should be in parallel axes to achieve linear movement.



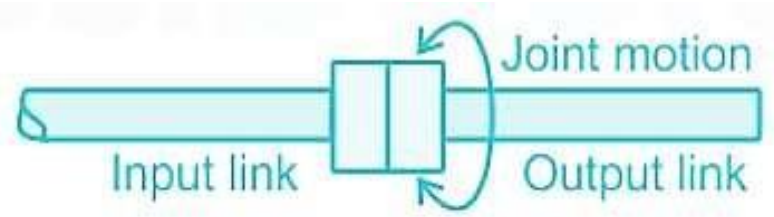




Robot links and Joints

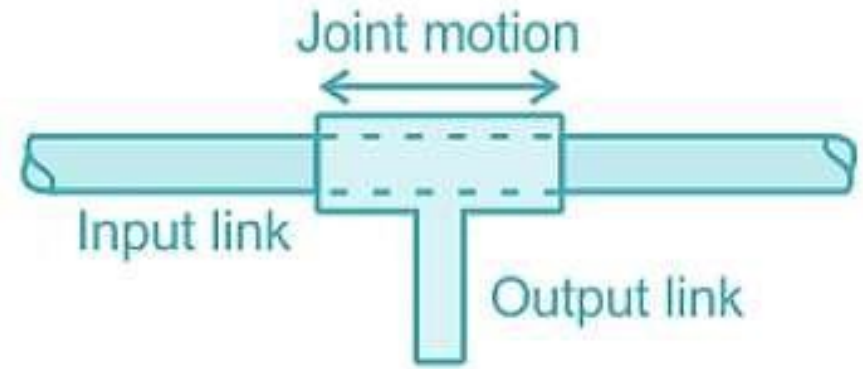
ROBOT JOINTS

3. Twisting Joint (T)

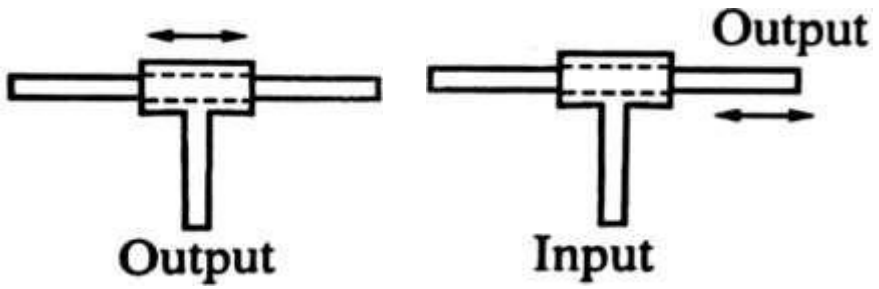


- Twisting joint will be referred to as V – Joint.
- This joint makes a twisting motion between the output and input link.
- During this process, the output link axis will be vertical to the rotational axis.
- The output link rotates about the input link.

4. Orthogonal Joint (O)



- Orthogonal joint is denoted by O
- Similar to the linear joint.
- The only difference is that the output and input links will move at the right angles.

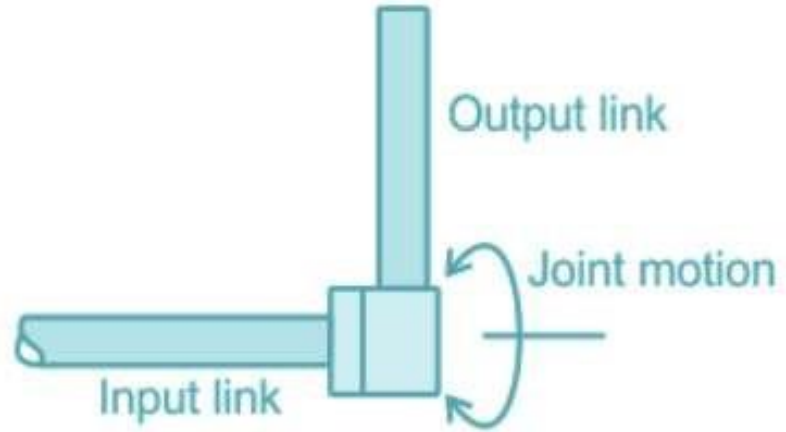


Robot links and Joints

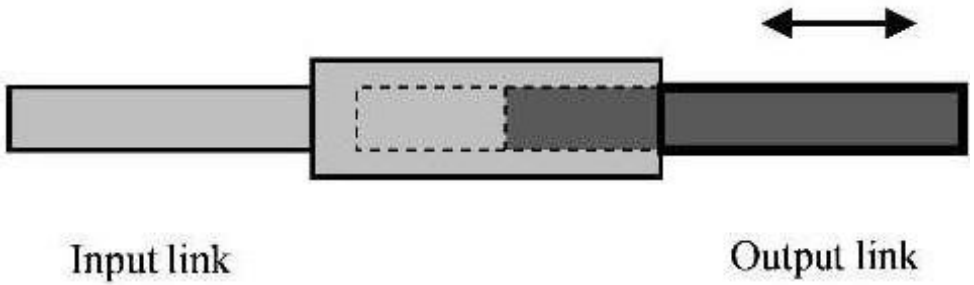
ROBOT JOINTS

5. Revolving Joint (V)

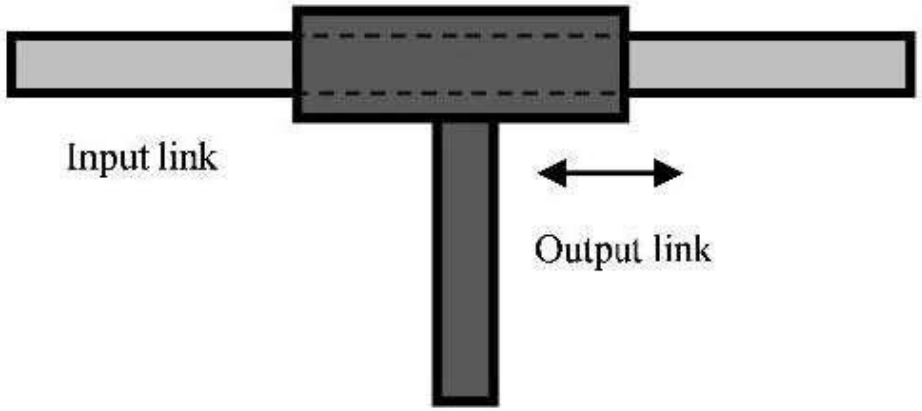
- Revolving joint is generally known as V Joint.
- The output link axis is perpendicular to the rotational axis,
- The input link is parallel to the rotational axes.
- Similar to a twisting joint, the output link spins about the input link.



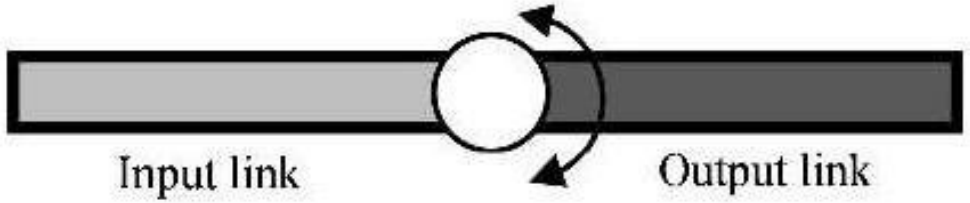
ROBOT JOINTS



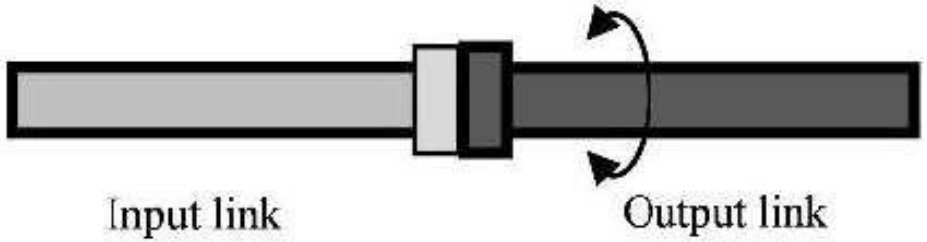
a) Linear Joint



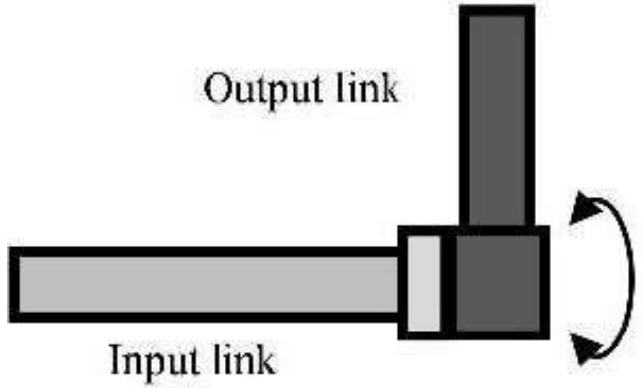
b) Orthogonal Joint



c) Rotational Joint

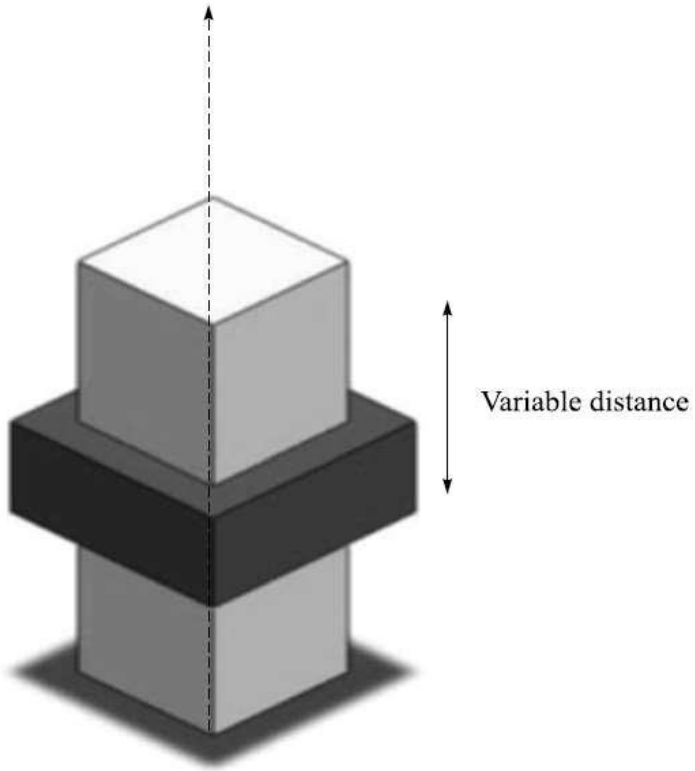


d) Twisting Joint

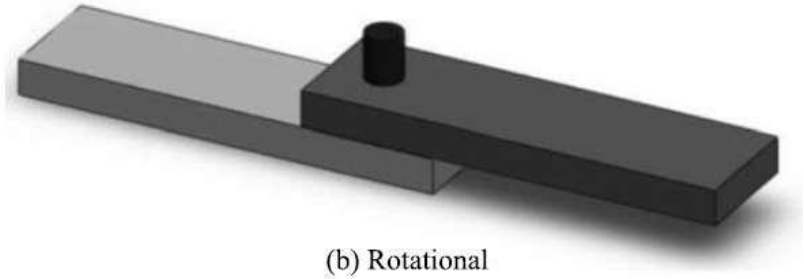


e) Revolving Joint

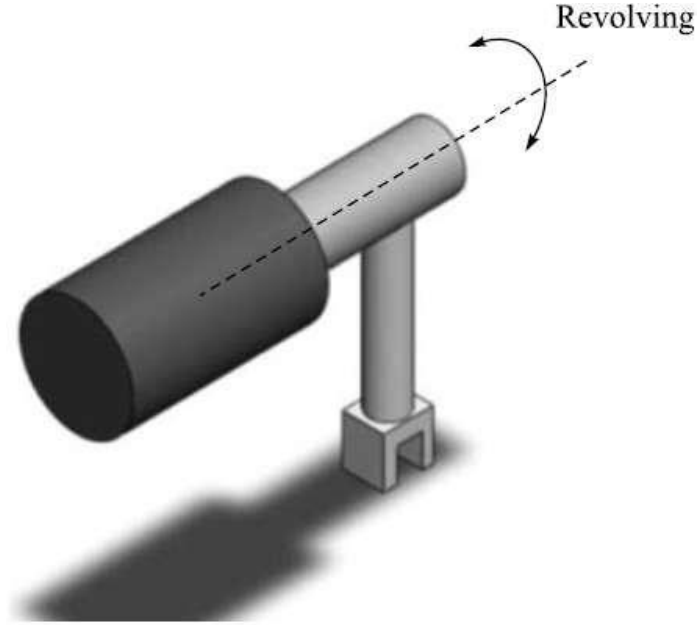
ROBOT JOINTS



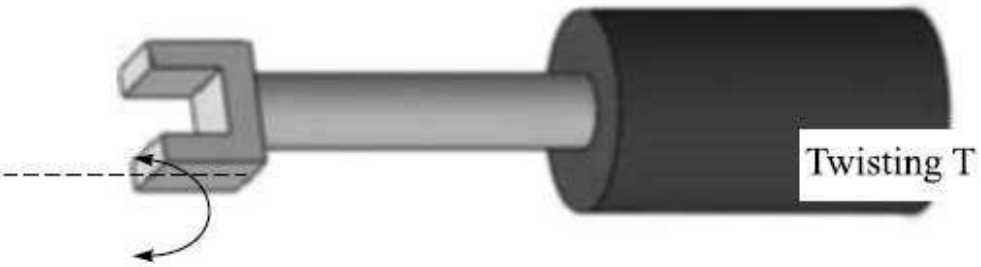
(a) Linear



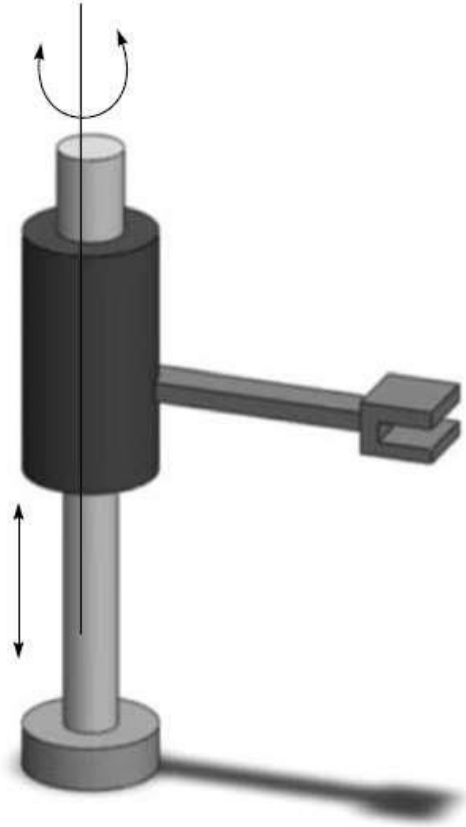
(b) Rotational



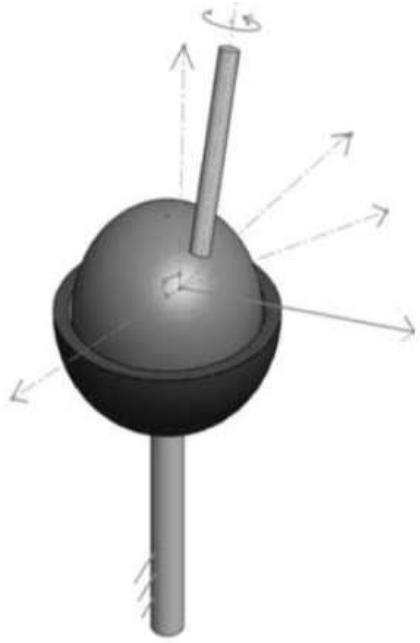
(c) Revolving



(d) Twisting

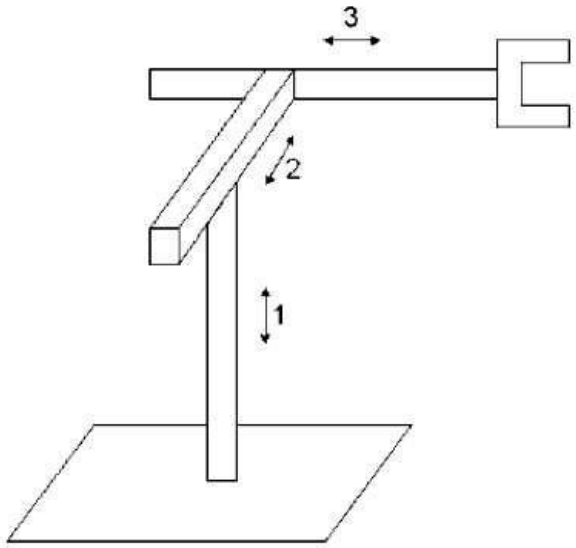


(e) Cylindrical (both linear and Revolute)

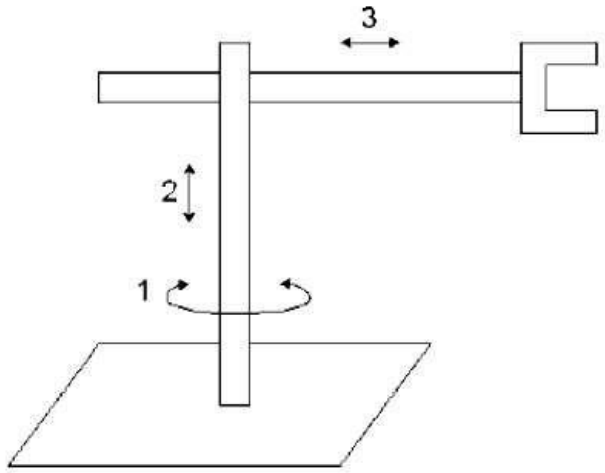


(f) Spherical

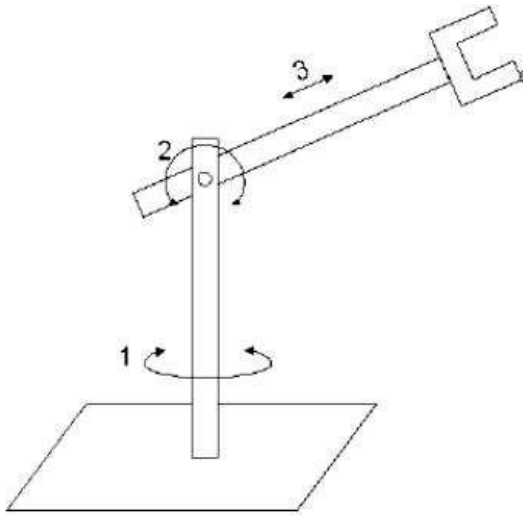
ROBOT JOINTS



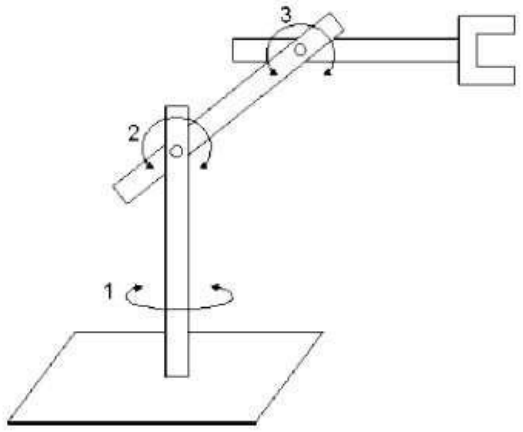
Cartesian: LOO



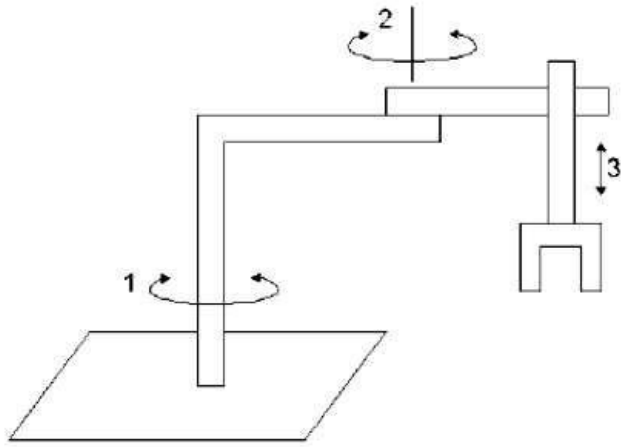
Cylindrical: TLO



Spherical (Polar): TRL



Revolute: TRR



SCARA: VRO

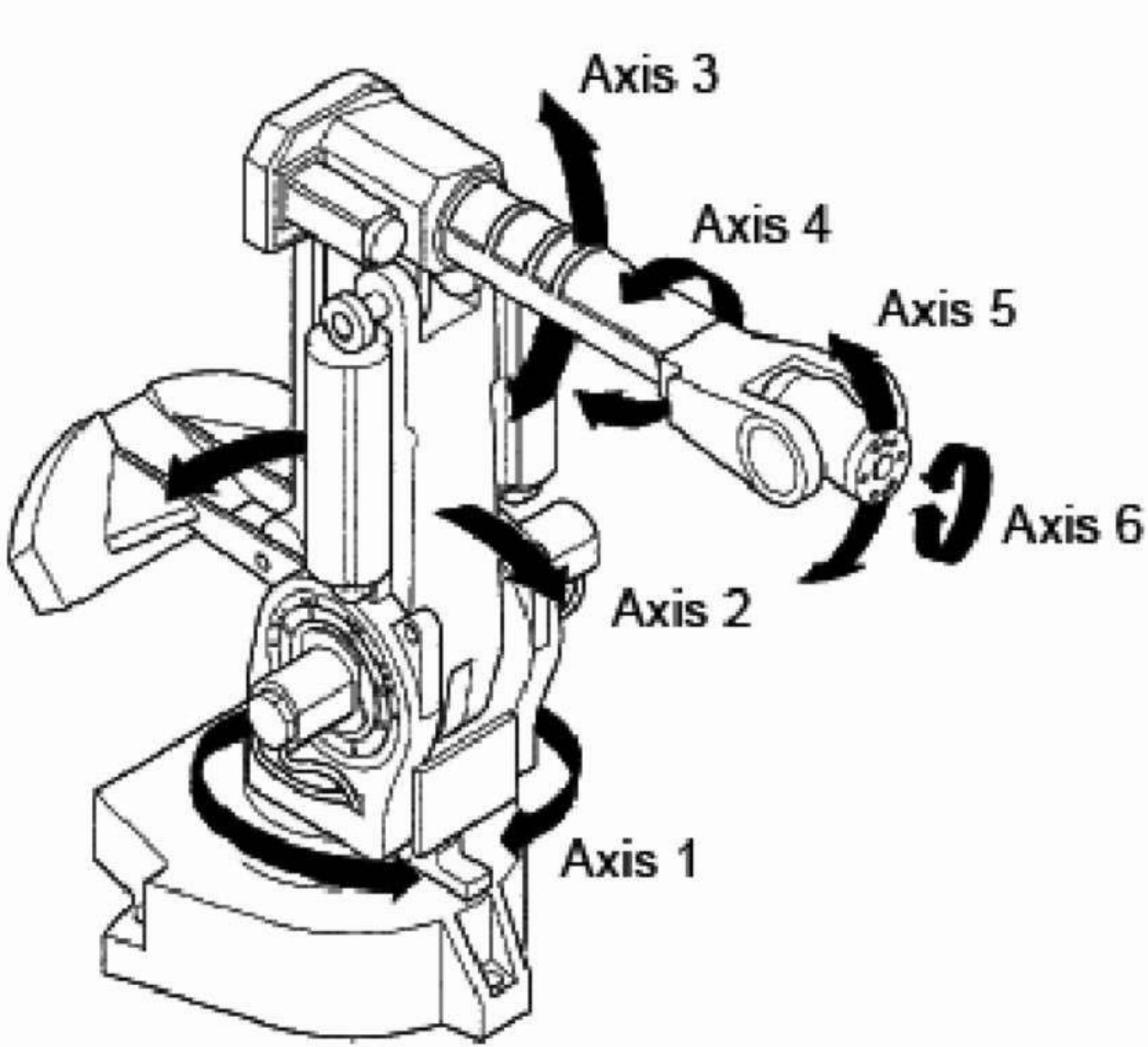
ROBOT JOINTS

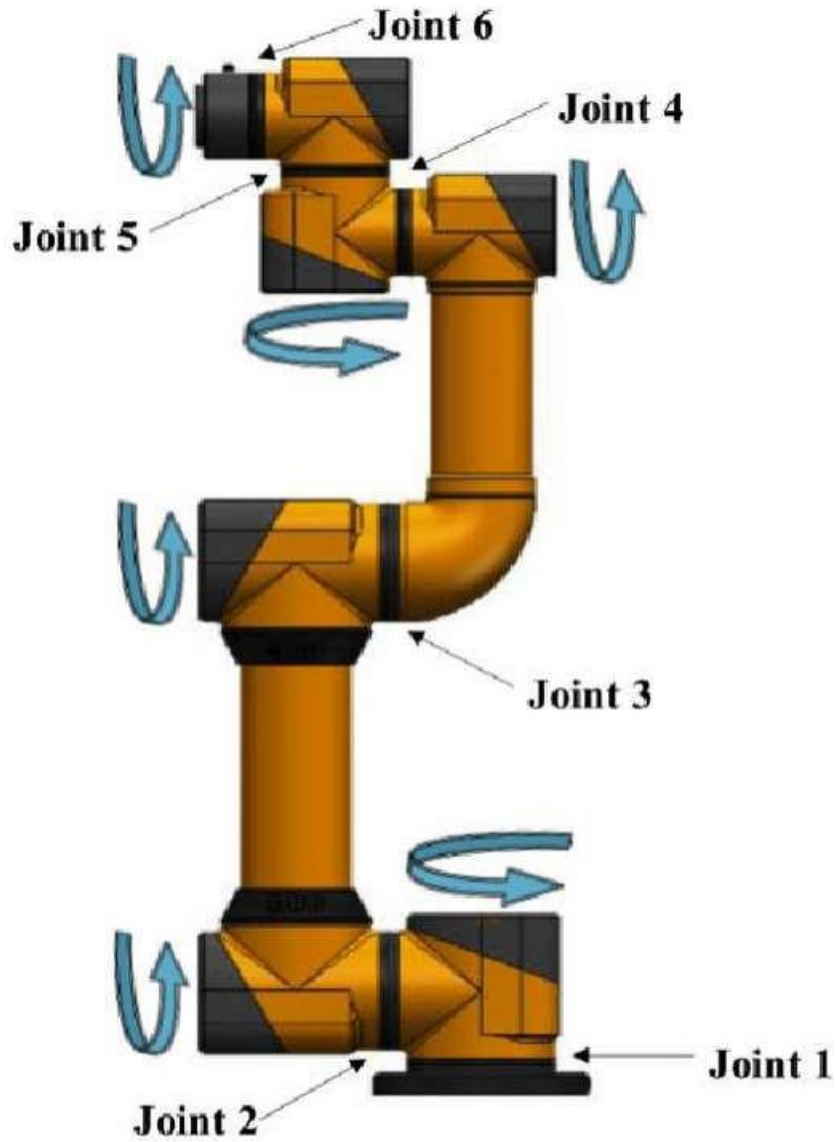
Joint Notation Scheme

- Considering the arm and body joints, the letters can be used to designate the particular robot configuration.
- Start with the joint closest to the base and proceed to the joint that connects to the wrist.
- Typical notations for the four basic configurations are summarized in the table

Notation scheme for Designating the robots

Robot configuration (arm and body)	*Symbol*
Polar configuration	TRL
Cylindrical configuration	TLL,LTL,LVL
Cartesian coordinate robot	LLL
Jointed arm configuration	TRR, VVR
Robot configuration (wrist)	Symbol
Two-axis wrist (typical)	:RT
Three-axis wrist (typical)	:TRT


Axis 3
Axis 4
Axis 5
Axis 6
Axis 2
Axis 1


Joint 6
Joint 4
Joint 5
Joint 3
Joint 1
Joint 2

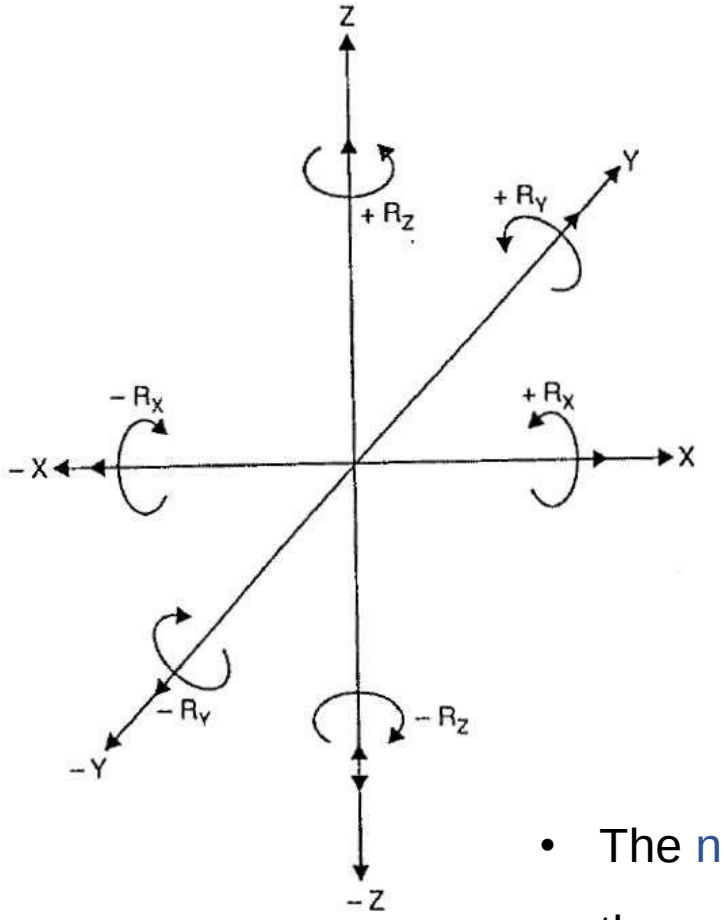
ROBOT MOTIONS

- Industrial robots are designed to perform productive work such as pick and place, welding, assembly, etc.
- To accomplish the work, the robot has to move its body, arm and wrist through a series of motions and positions.
- The individual joint motions associated with the performance of a task are referred to by the term DOF
- Industrial robot will have 4 – 6 DOF
- Opening and closing of the gripper is not considered DOF
- Three joints are normally associated with the action of the arm and body.
- Two or three joints are used to actuate the wrist

DOF (Degrees of Freedom)

ROBOT MOTIONS

- A body in 3D space can have 6 DOF (3 are Rotary & 3 are translatory).



- 6 DOF are positive & 6 DOF are negative.
- 3 DOF are translatory along +ve axis & 3 DOF are along –ve axis.

- The number of independent motions in which the end effector can move is defined by the number of axes of motion of the manipulator.

DOF (Degrees of Freedom)

- The more DOF, the greater the complexity of motions encountered.
- For applications that require more flexibility, additional degrees of freedom are used in the wrist of the robot.
- Three degrees of freedom located in the wrist give the end effector all the flexibility.

DOF (Degrees of Freedom)

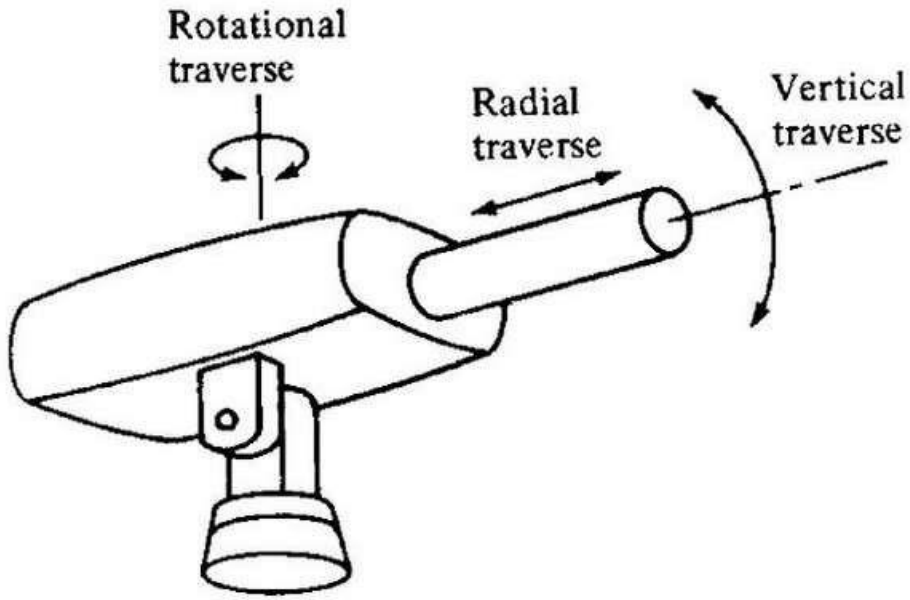
For polar, cylindrical or jointed arm configuration, the 3 DOF associated with arm and body motions are

1. **The rotational traverse:** rotation of the arm about the vertical axis,

   such as the left-and-right swivel of the robot's arm on a base.

2. **The radial traverse** involves extension or retraction (In or Out) of

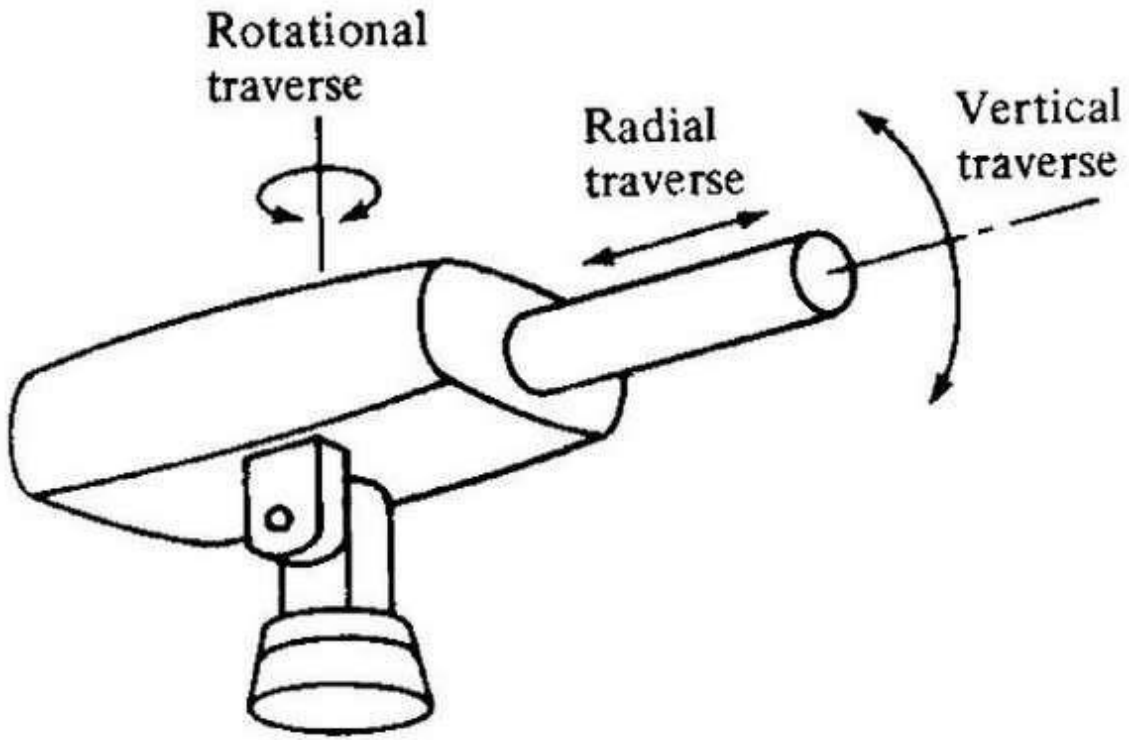
   the arm from the vertical centre of the robot (Base)



3 DOF associated with the arm and body of a polar coordinate robot.

DOF (Degrees of Freedom)

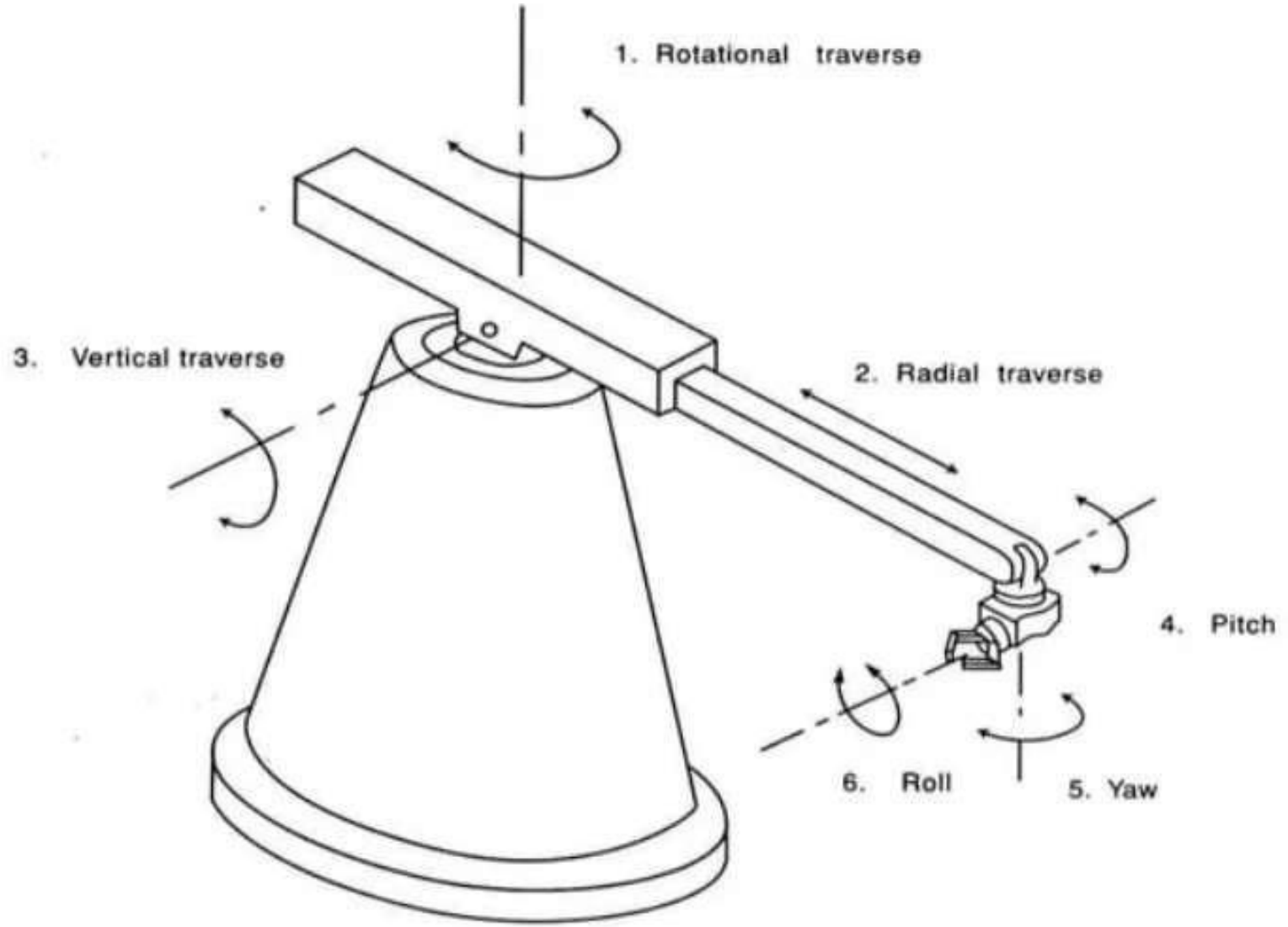
The vertical traverse: Capability to move the wrist up or down to provide the desired vertical attitude



3 DOF associated with the arm and body of a polar coordinate robot.

DOF (Degrees of Freedom)

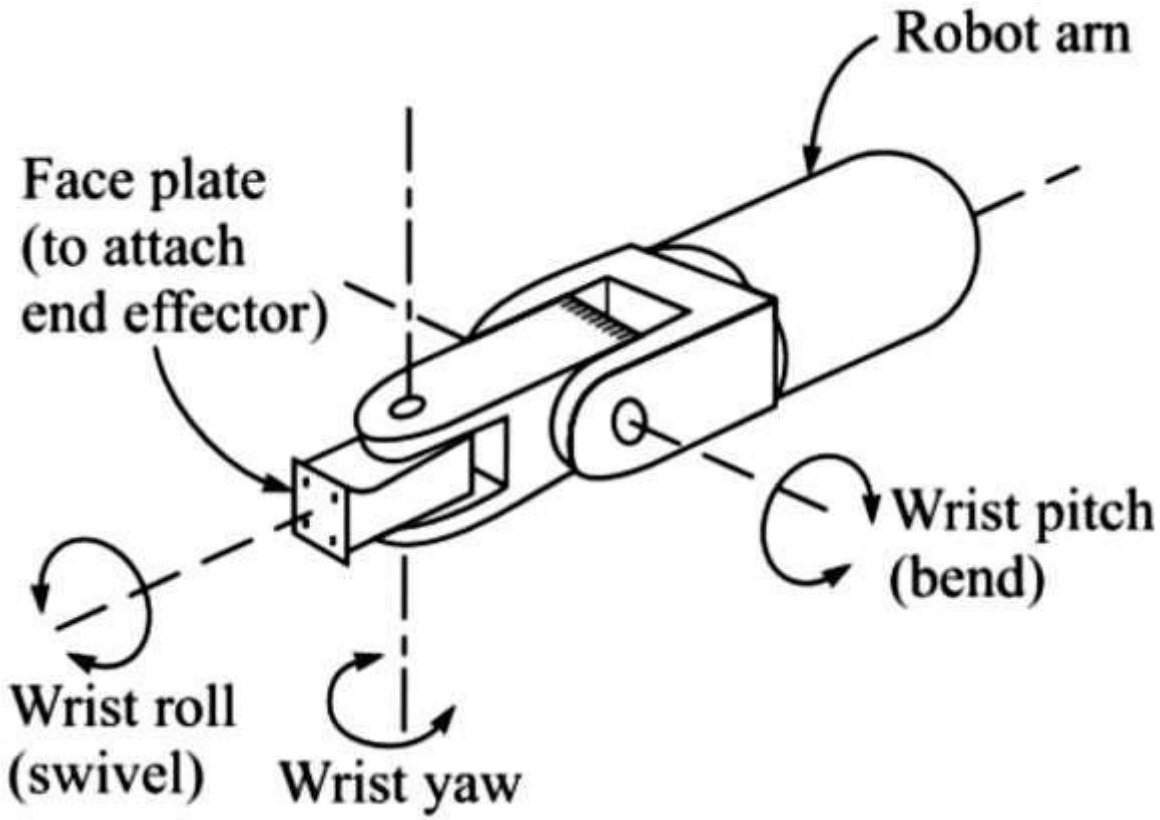
1. The rotational traverse
2. The radial traverse
3. The vertical traverse



ROBOT MOTIONS

- The wrist movement is designed to enable the robot to orient the end effector properly with respect to the task being performed, such as welding, painting, grasping, etc.
- To overcome/solve this problem, normally the wrist is provided with up to 3 DOF (configuration)

1. Wrist Roll / Wrist swivel
2. Wrist Pitch / Wrist bend
3. Wrist Yaw

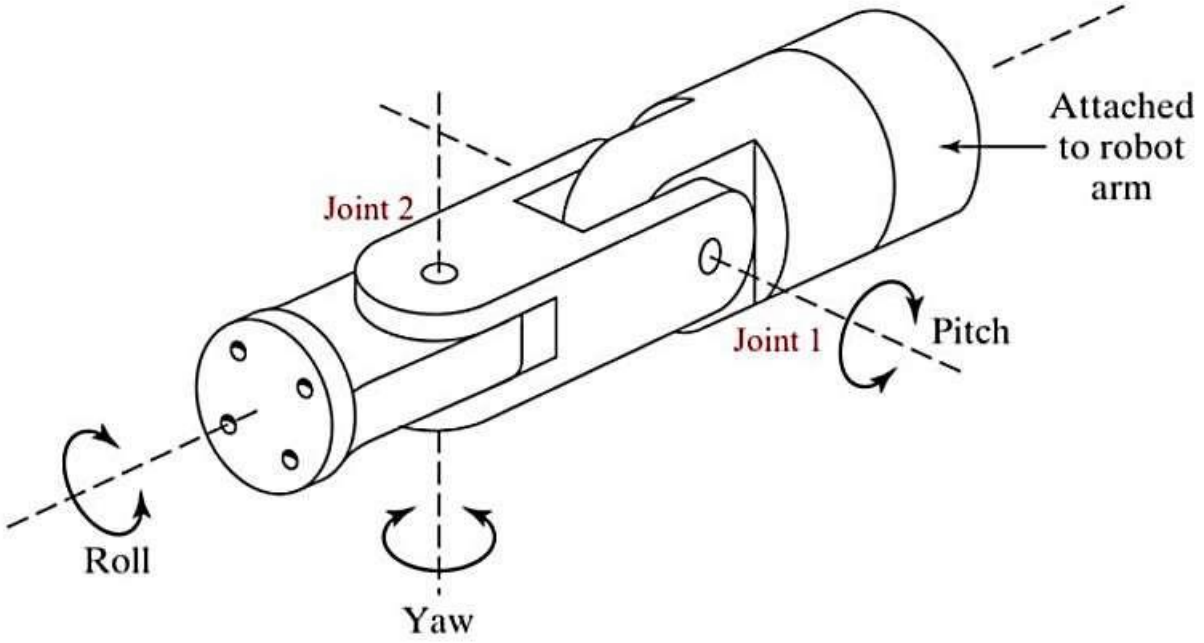


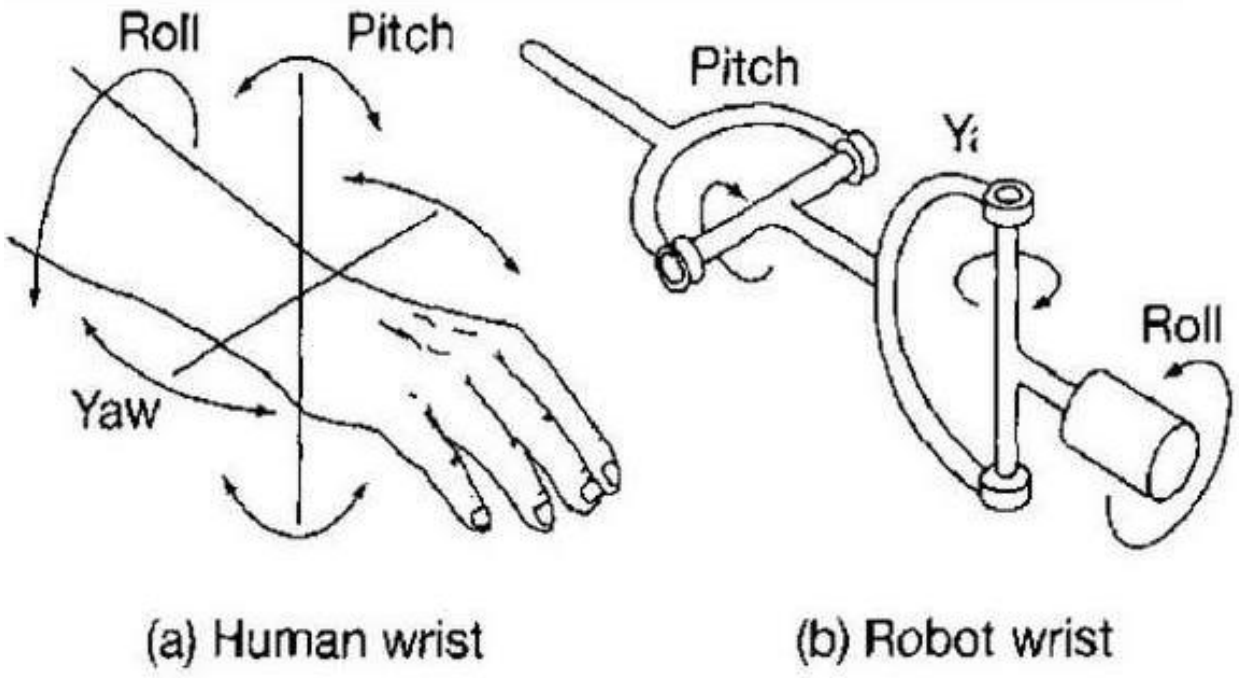
Three degrees of freedom associated with the robot wrist

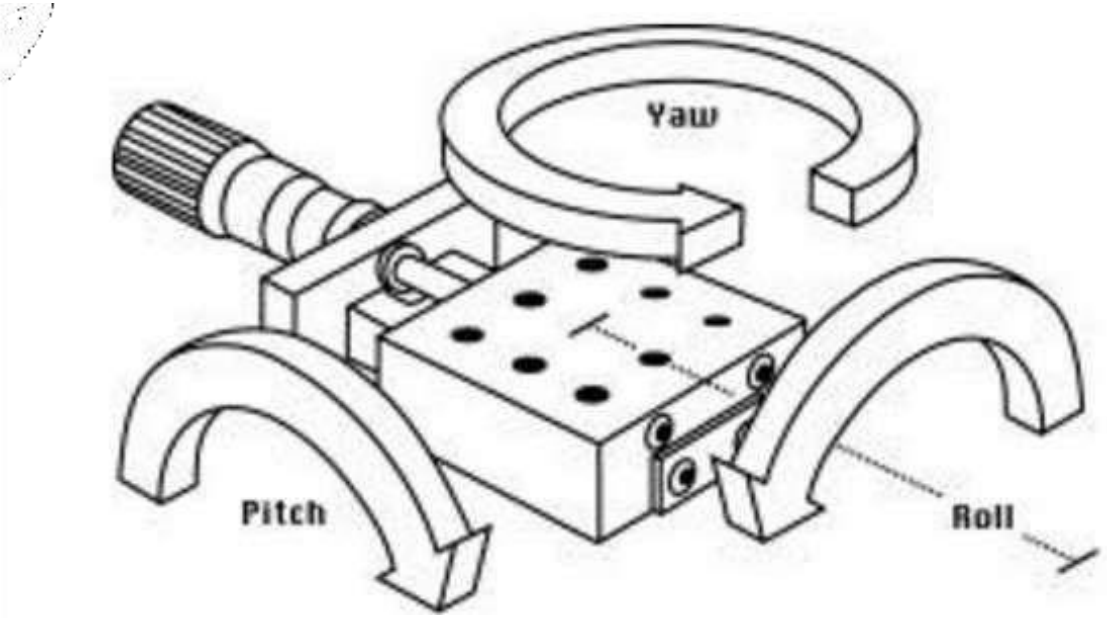
ROBOT MOTIONS

The 3 DOF located in the wrist of a robotic system:

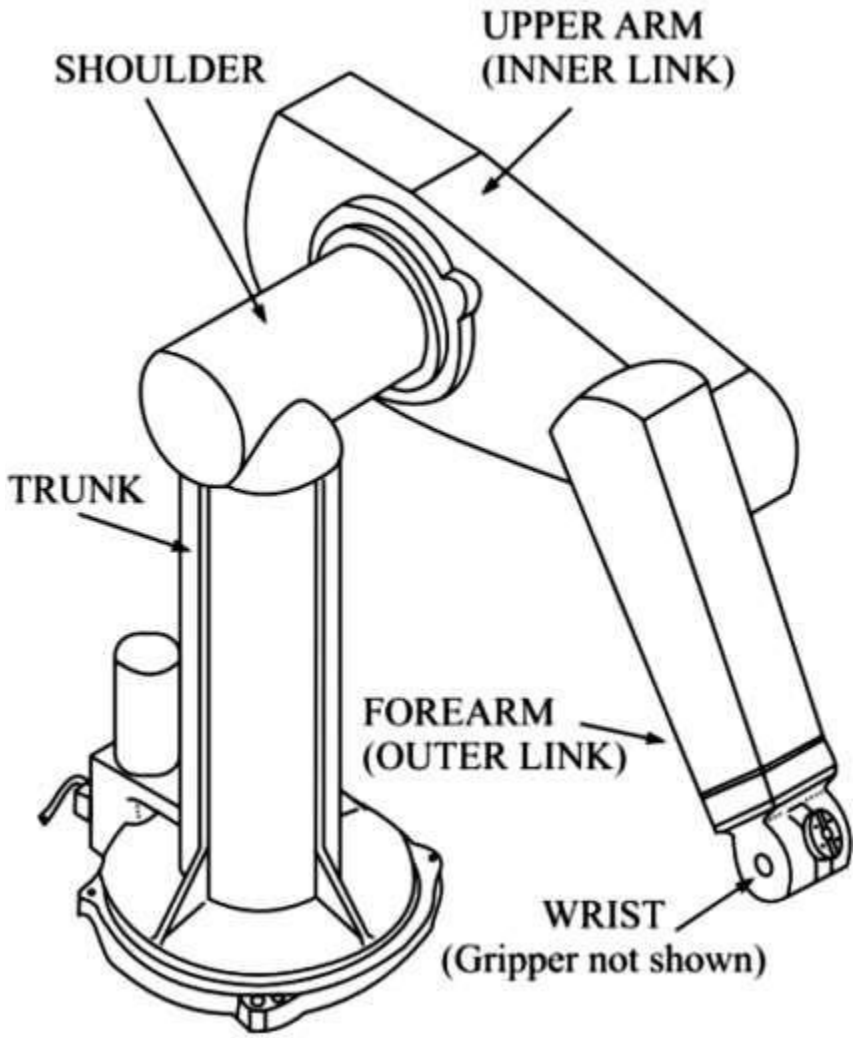
1. Pitch: Bend or up and down movement.
2. Yaw: Right and left movement.
3. Roll: Swivel or rotation of the wrist/hand.

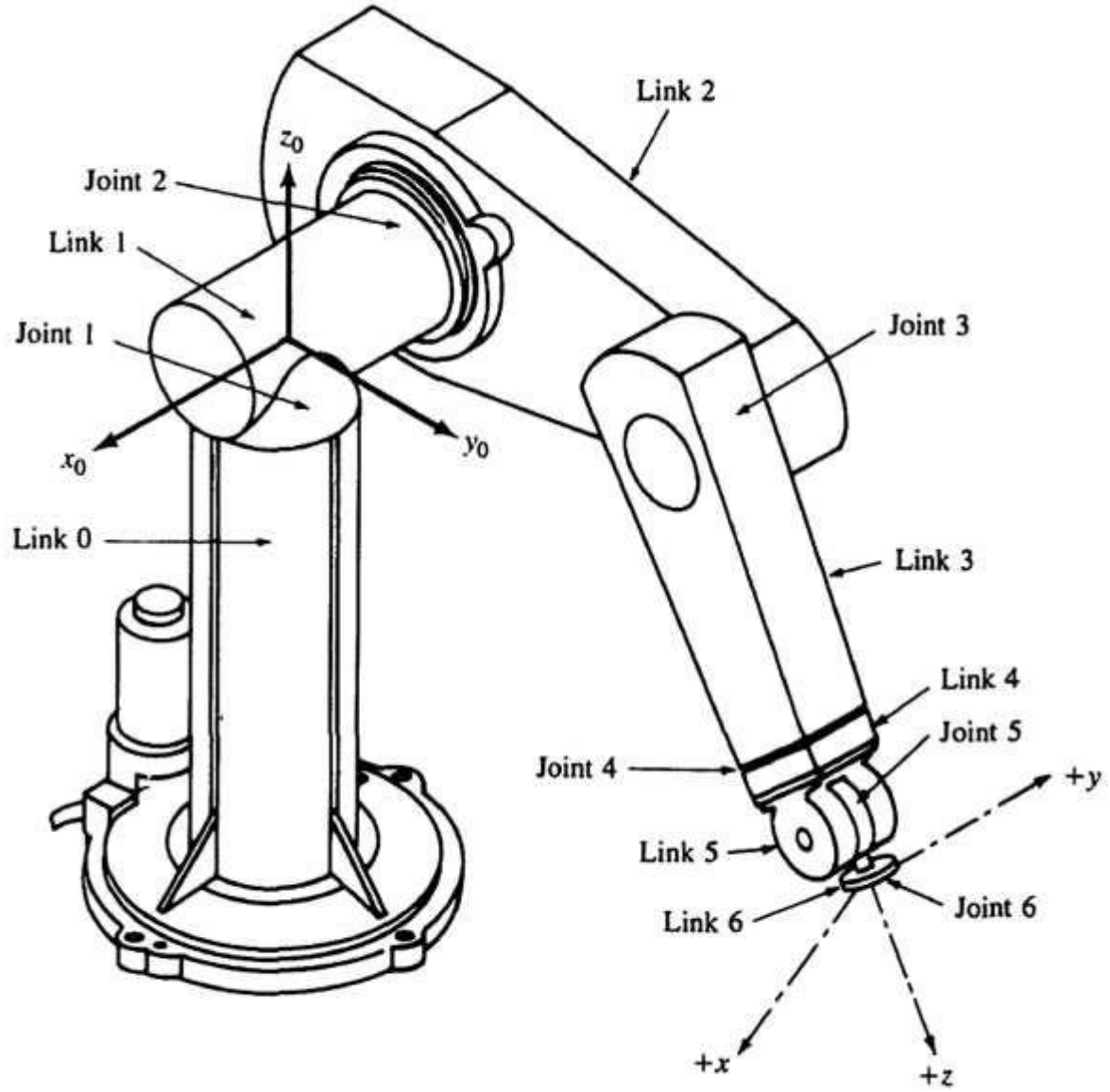






ROBOT MOTIONS





PUMA robot having six degrees of freedom

PUMA (Programmable Universal Machine for Assembly, or Programmable Universal Manipulation Arm)

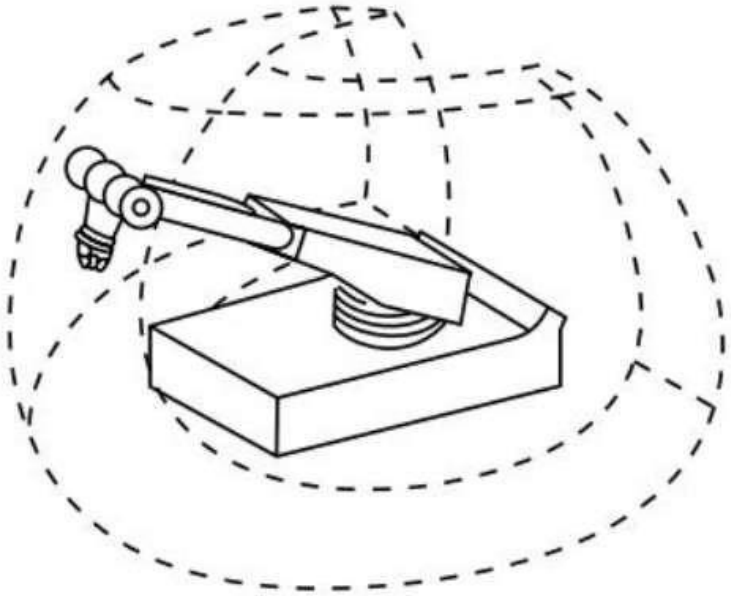
Work Volume

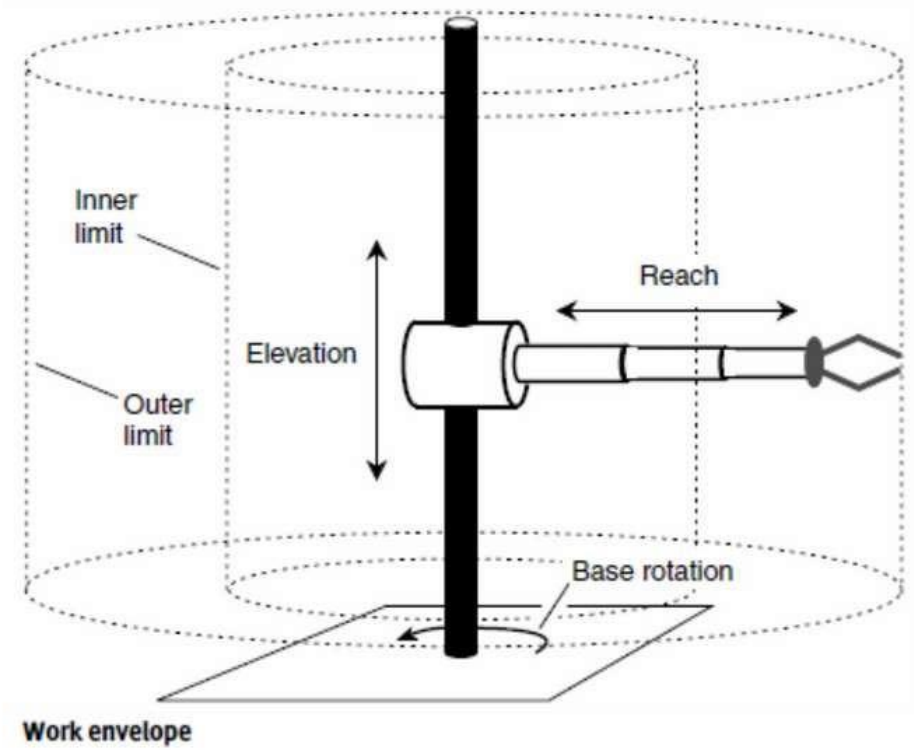
- Work volume refers to the space within which the robot can manipulate its wrist end.
- The extreme position of the robot axes describes a boundary for the region in which the robot operated.
- The end effector is an addition to the basic and should not be counted as part of the robot's working space.

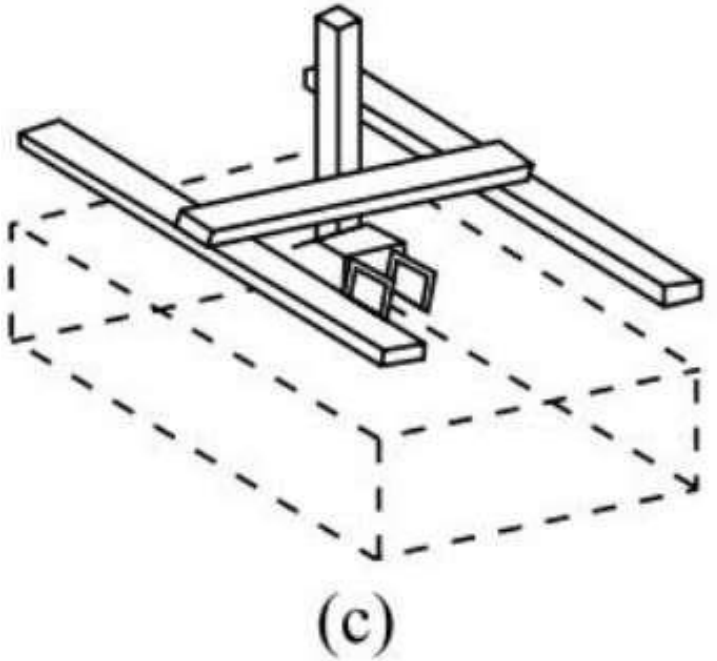
The following physical characteristics determine the work volume.

1. The robot's physical configuration (type of Joint, structure of links)
2. The size of the body, arm and wrist components
3. The limits of the robot's joint movements.

Work Volume

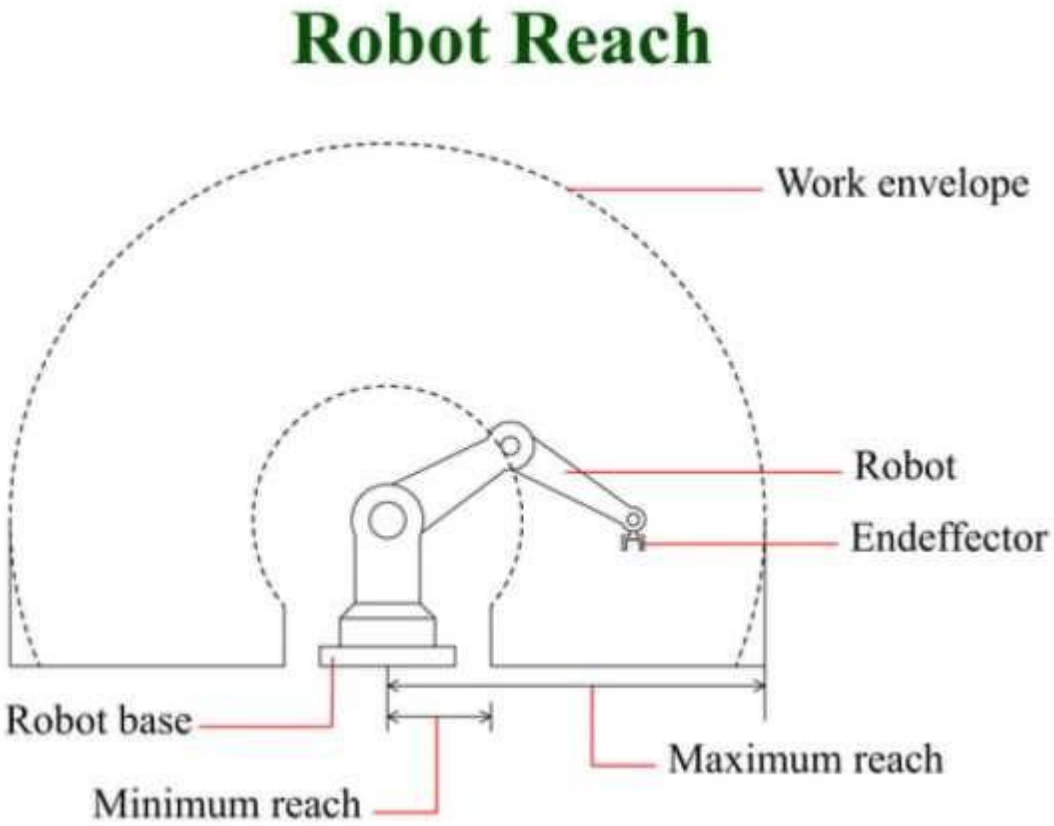


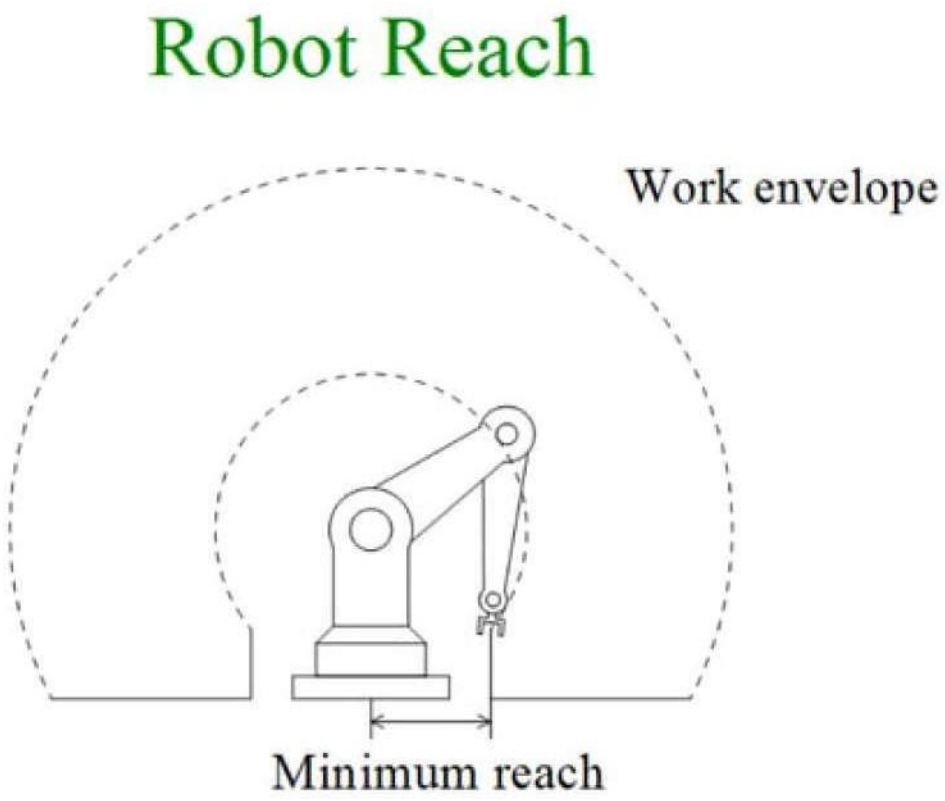




Work volumes for different types of robots: (a) Polar (b) Cylindrical (c) Cartesian

Work Volume


Robot Reach
Work envelope
Robot
Endeffector
Robot base
Maximum reach
Minimum reach


Robot Reach
Work envelope
Minimum reach