ROBOTIC TECHNOLOGY

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UNIT I

FUNDAMENTALS OF ROBOT

Robot – Definition – Robot Anatomy – Co-ordinate systems, Work Envelope, types and classification – specifications – Pitch, yaw, Roll, Joint Notations, Speed of Motion, Pay Load – Robot Parts and their functions – Need for Robots – Different Applications.

ROBOT

A robot is a type of automated machine that can **execute specific tasks with little or no human intervention and with speed and precision.**

In general, robots are designed, and meant, to be controlled by a computer or similar device.

The motions of the robot are controlled through a controller that is under the supervision of the computer, which itself, is running some type of program.

Thus, if the program is changed, the actions of the robot will be changed accordingly.

The intension is to have a device that can perform many different tasks and thus is very flexible in what it can do, without having to redesign the device.

Thus, the robot is designed to be able to perform any task that can be programmed simply by changing the program

CLASSIFICATION OF ROBOT

According to JIRA- Japanese Industrial Robot Association robots can be classified,

1. Material Handling Device
2. Fixed Sequence Robot
3. Variable Sequence Robot
4. Playback Robot
5. Numerical Control Robot
6. Intelligent Robot

Material Handling Device:

A device with multiple degrees of freedom that is actuated by an operator.

Fixed Sequence Robot

A device that performs the successive stages of a task according to a predetermined, unchanging method and is hard to modify.

CLASSIFICATION OF ROBOT

Variable Sequence Robot:

It is more over same as fixed sequence, but easy to modify

Playback Robot:

A human operator performs the task manually by leading the robot, which records the motions for later playback. The robot repeats the same motions according to the recorded information.

Numerical Control Robot:

The operator supplies the robot with a movement program rather than teaching it the task manually

Intelligent Robot:

A robot with the means to understand its environment and the ability to successfully complete a task despite changes in the surrounding conditions under which it is to be performed.

CLASSIFICATION OF ROBOT

The Robotics Institute of America (RIA) only considers classes 3-6 as robots. The Association Francaise de Robotique (AFR) has the following classification

Type A: Handling devices with manual control to telerobotics.

Type B: Automatic Handling devices with predetermined cycles.

Type C: Programmable, servo controlled robots with continuous or point to point trajectories.

Type D: Same as type C, but with capability to acquire information from its environment

"Robotics is an interdisciplinary subject that benefits from Mechanical Engineering, Electrical and Electronics Engineering, Computer Science, Biology, and many other disciplines"

ROBOT ANATOMY:

LINK:

Each part of a machine, which moves relative to some other part, is known as a kinematic link or element. A link may consist of several parts, which are rigidly fastened together, so that they do not move relative to one another.

JOINTS:

The joints (also called axes) are the movable components of the robot that cause relative motion between adjacent links.

In Kinematics, There are 3 joints

Binary Joint

(Two links are joined at same connection)

Ternary Joint

(Three links are joined at same connection) {1TJ=2BJ}

Quaternary Joint

(Four links are joined at same connection) {1QJ=3BJ}

ROBOT ANATOMY:

Manipulator:

In robotics, a manipulator is a device used to manipulate materials without direct physical contact by the operator.

A robot manipulator is an electronically controlled mechanism, consisting of multiple segments, that performs tasks by interacting with its environment. They are also commonly referred to as robotic arms.

Design of Robot manipulators:

The design of robot manipulators Depends upon

Application	Configuration
Work Volume	Payload
Inertia Force	Centre of Gravity
Speed	Kinematics

WORK VOLUME OR WORK ENVELOPE:

The space within which the robot can manipulate its wrist end is known as work volume.

This avoids the complication of different sizes of end effectors that might be attached to robots wrist.

This is determined by the following physical characteristics of the robot.

Robot's Physical configuration, Size of the body, Arm and wrist components, The limits of robots joint movement

According to physical configuration , a robot is classified as

CONFIGURATION	WORK VOLUME
Jointed arm	Spherical
Cylindrical	Cylindrical
Cartesian	Cartesian or Rectangular
Polar	Partial sphere
SCARA	Cylinder

PAYLOAD:

Plays a vital role in the design of manipulators

It is the load carried by the robot at the wrist end of the robot when its arm is fully stretched or fully extended

It includes the end effector weight also

The Payload to Weight ratio should be in the ratio of 1:200

INERTIA FORCE:

Another important parameter influencing the design & performance of robot

Depends upon the payload, speed and acceleration of the robot while in motion

It always acts in the direction opposite to that of the motion of the manipulator

CENTRE OF GRAVITY :

It is the point where the entire weight of the robot is said to be concentrated

Plays a important role in the design of manipulators especially in Bipedal robots, humanoid robots and articulated robots

Depends upon the weight of the links, actuators, joints, transmission elements and payload

SPEED:

It is defined as how quickly the robot will move from one position to the next

Higher speed affects the stability of the robot

Pneumatic actuators give maximum speed compared to hydraulic and electrical actuators

DYNAMICS :

It is the branch of physical science which deals with bodies which are in motion

It can divided into Kinetics and Kinematics

Kinetics deals with the inertia force of the body

Both play vital role in the area of robotics

KINEMATICS:

It is the branch of dynamics which deals with the bodies having an relative motion

Study of relative motion which existing between members

Without kinematics there is no robotics

Motion of one body with respect to another body

Relative Position ;   Relative Motion

Relative Velocity;   Relative Acceleration

DEGREES OF FREEDOM:

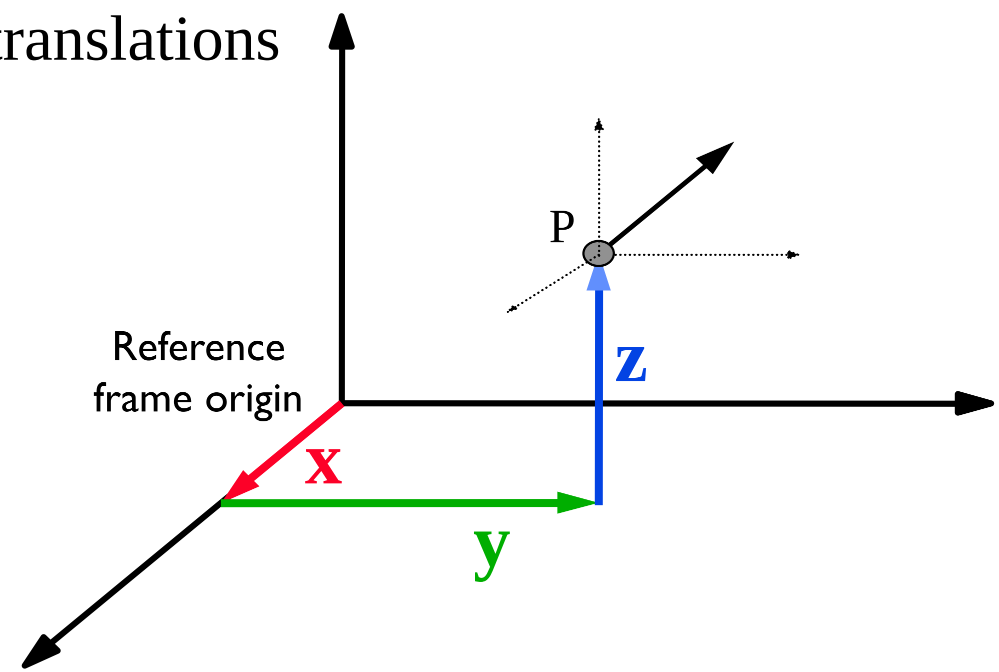
Degree of Freedom is the number of independent relative motion in the form of translation and rotation

The body in space has got the maximum of 6 degrees of motion (3 translatory & 3 rotary motions)

Each joint has 1 DOF, Each Translatory has 1 DOF and each Rotary has 1 DOF

Positioning:

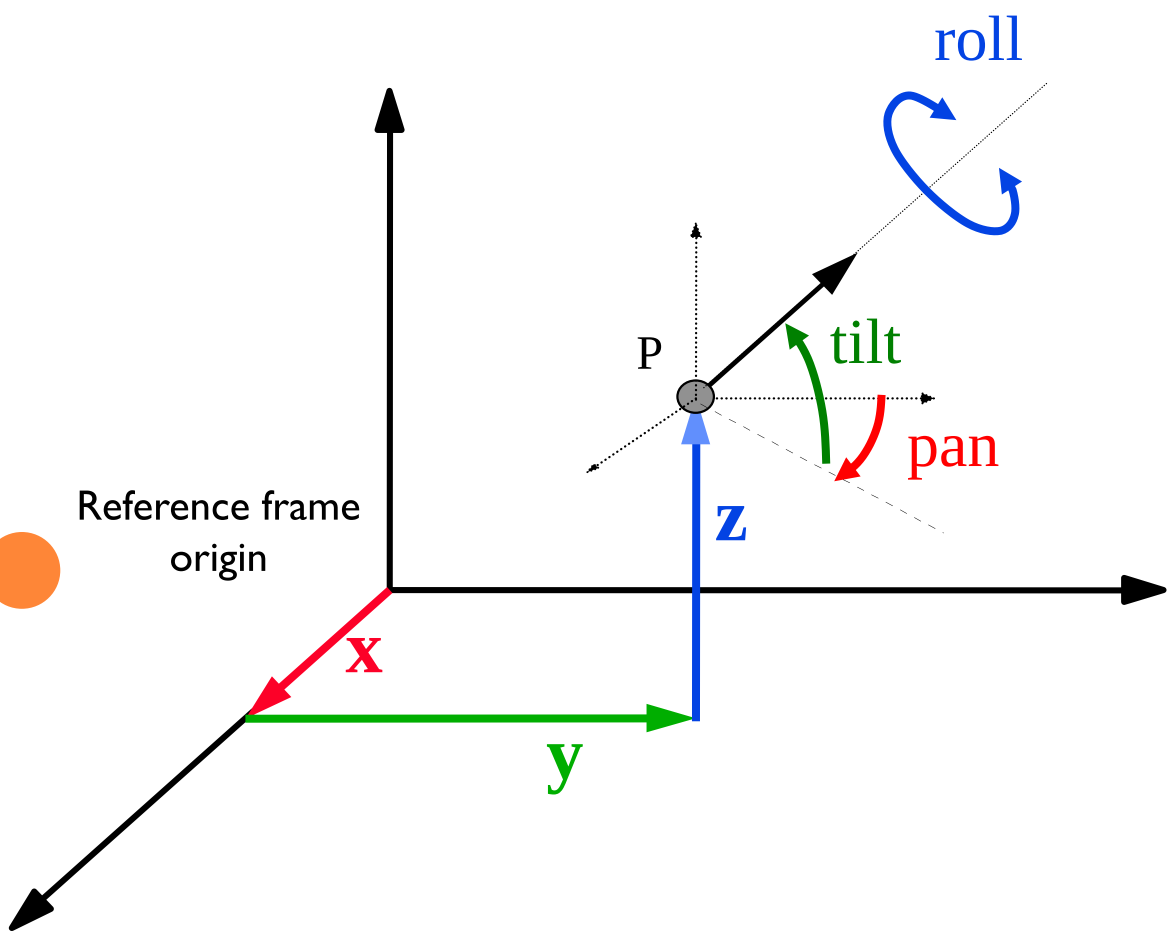
Positioning the end effector in the 3D space, requires three DOF, either obtained from rotations or translations



DEGREES OF FREEDOM:

Orientation :

Orienting the end effector in the 3D space, requires three additional DOF to produce the three rotations.



DEGREES OF FREEDOM:

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

1. **Pitch**

   Bend or up and down movement.

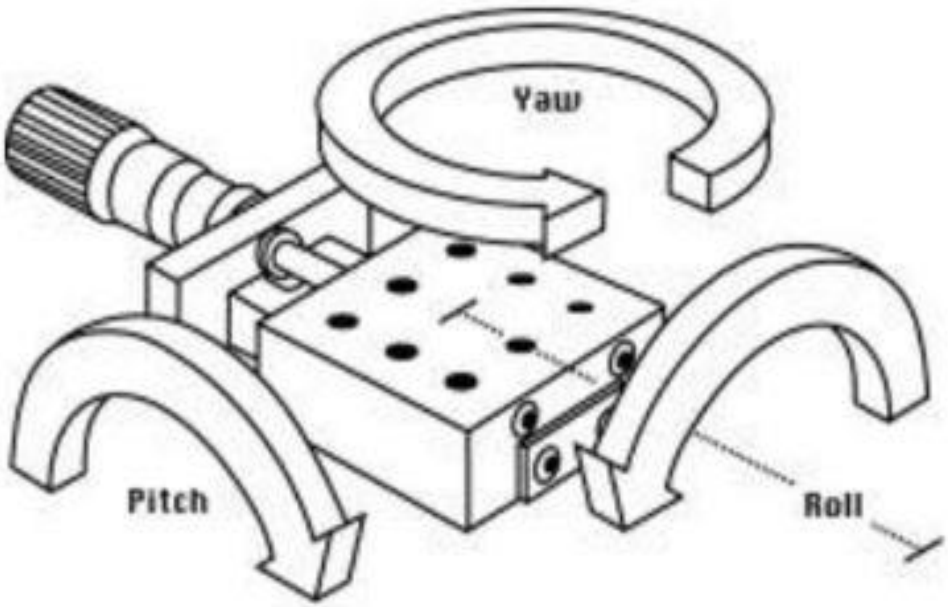
2. **Yaw**

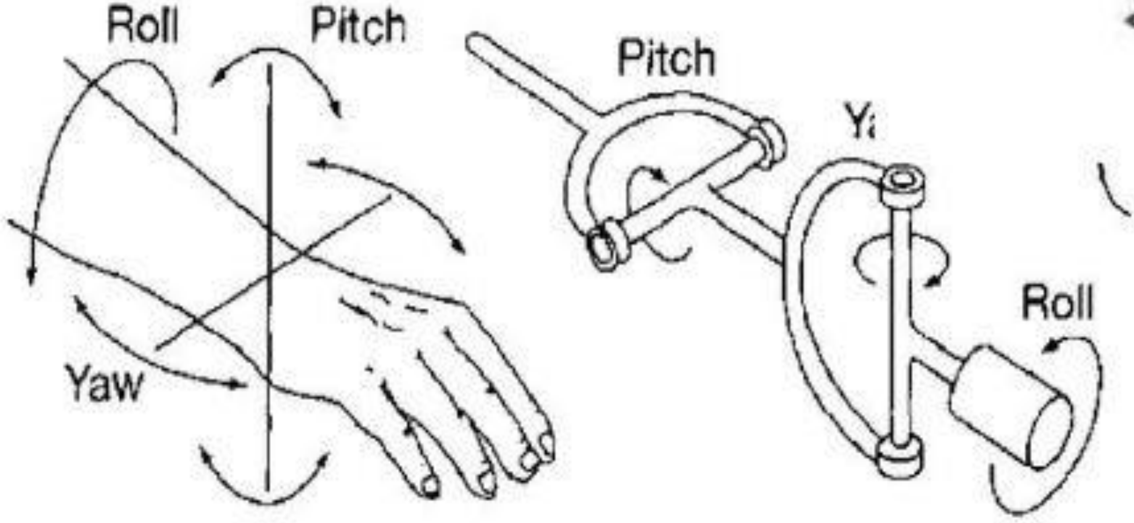
   Right and left movement.

3. **Roll**

   Swivel or rotation of the wrist/hand.

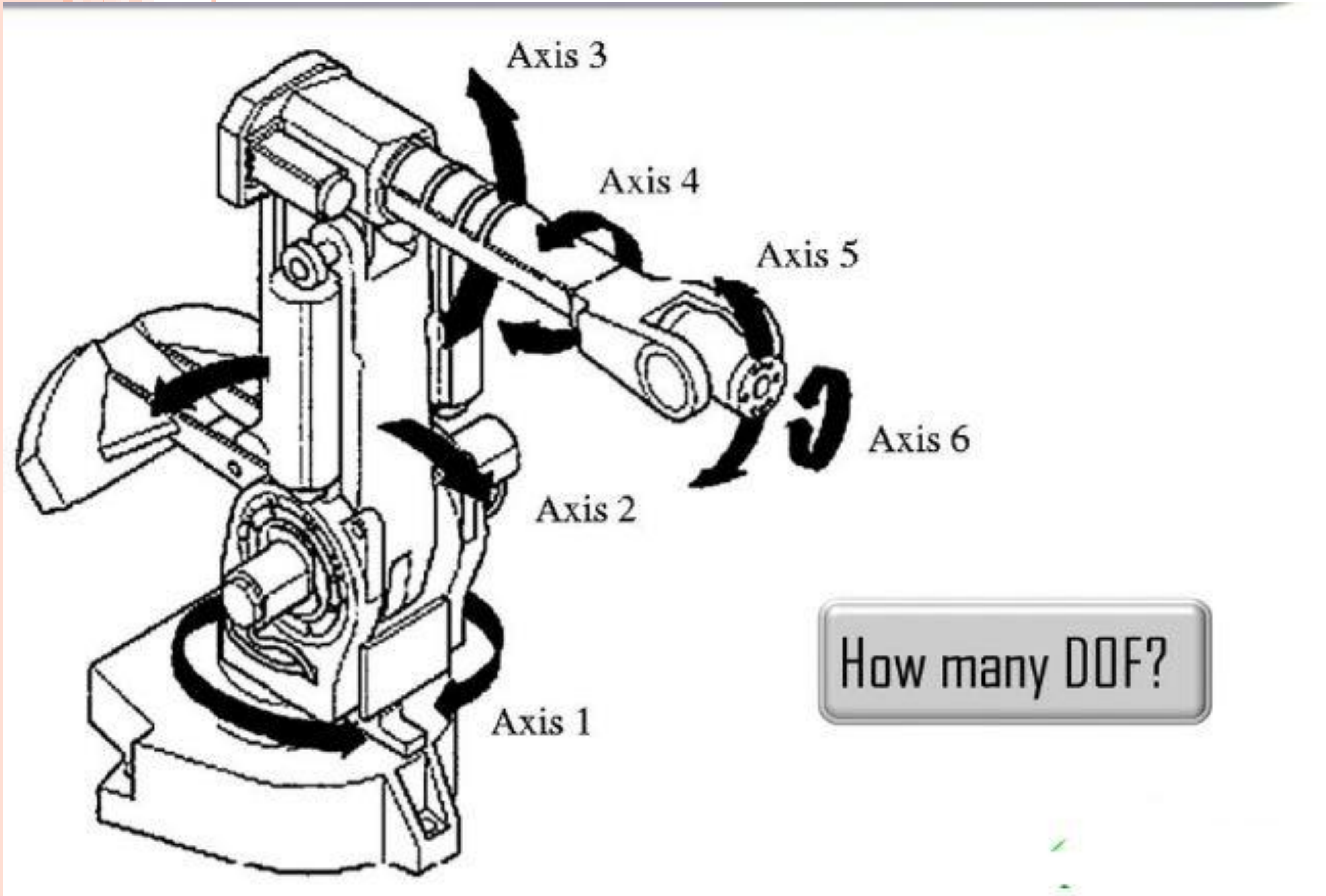
DEGREES OF FREEDOM:





(a) Human wrist (b) Robot wrist

DEGREES OF FREEDOM:



DEGREES OF FREEDOM:

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

1. **The rotational traverse**

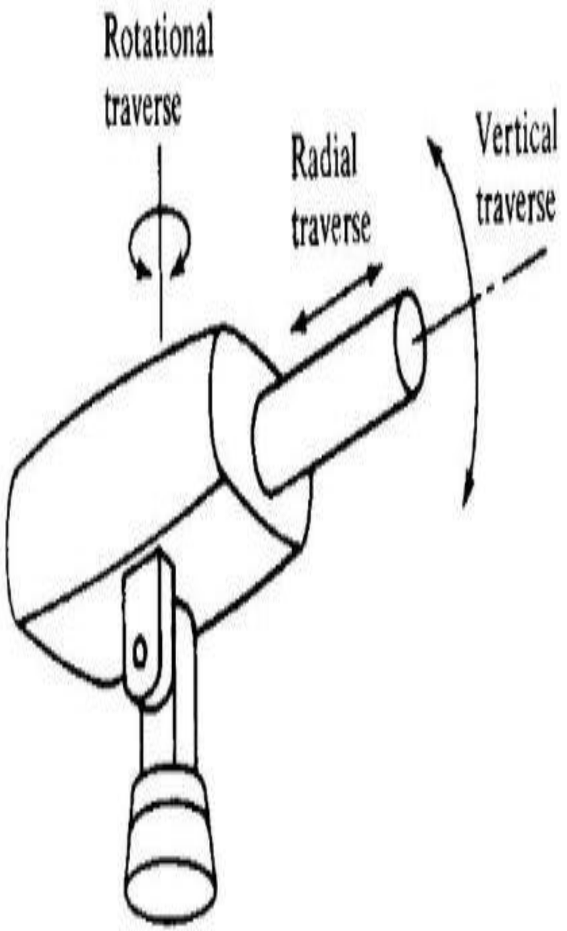
   The rotational traverse is the movement of the arm assembly about a rotary axis, such as the left-and-right swivel of the robot's arm on a base.

2. **The radial traverse**

   The radial traverse is the extension and retraction of the arm or the in-and-out motion relative to the base.

3. **The vertical traverse**

   The vertical traverse provides the up-and-down motion of the arm of the robotic system.

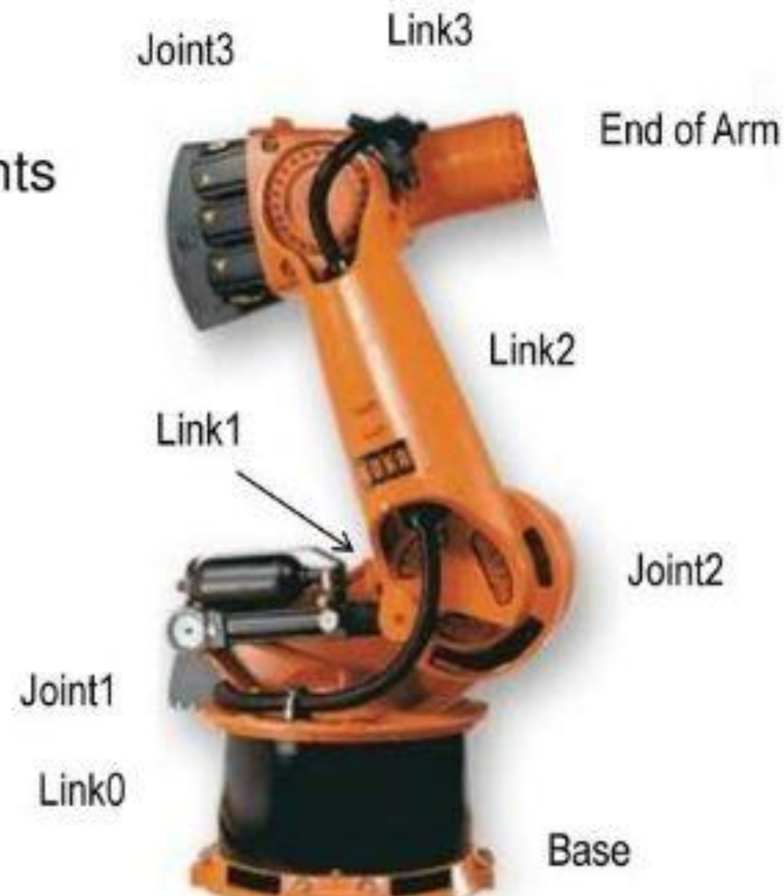


DEGREES OF FREEDOM OF ROBOTS:

- Gruebler's Equation
  - $F = 3(n-1) - 2j$
    - Where, j – no. of joints
    - n - no. of links
- For Spatial Manipulators
  - $F = 6(n-1) - 5P_1 - 4P_2 - 3P_3 - 2P_4 - P_5$
    - n – no. of links
    - P_1 – no. of joints and pairs with 1 DoF
    - P_2 – no. of joints and pairs with 2 DoF
    - P_3 – no. of joints and pairs with 3 DoF
    - P_4 – no. of joints and pairs with 4 DoF
    - P_5 – no. of joints and pairs with 5 DoF
- Kutzback Equation (for Parallel Manipulator)
  - $F = 6(n - j - 1) + \sum_{i=1}^{j} f_i$
    - j – no. of joints
    - n - no. of links
    - f_i – no. of individual joints having i^{th} degree of freedom.

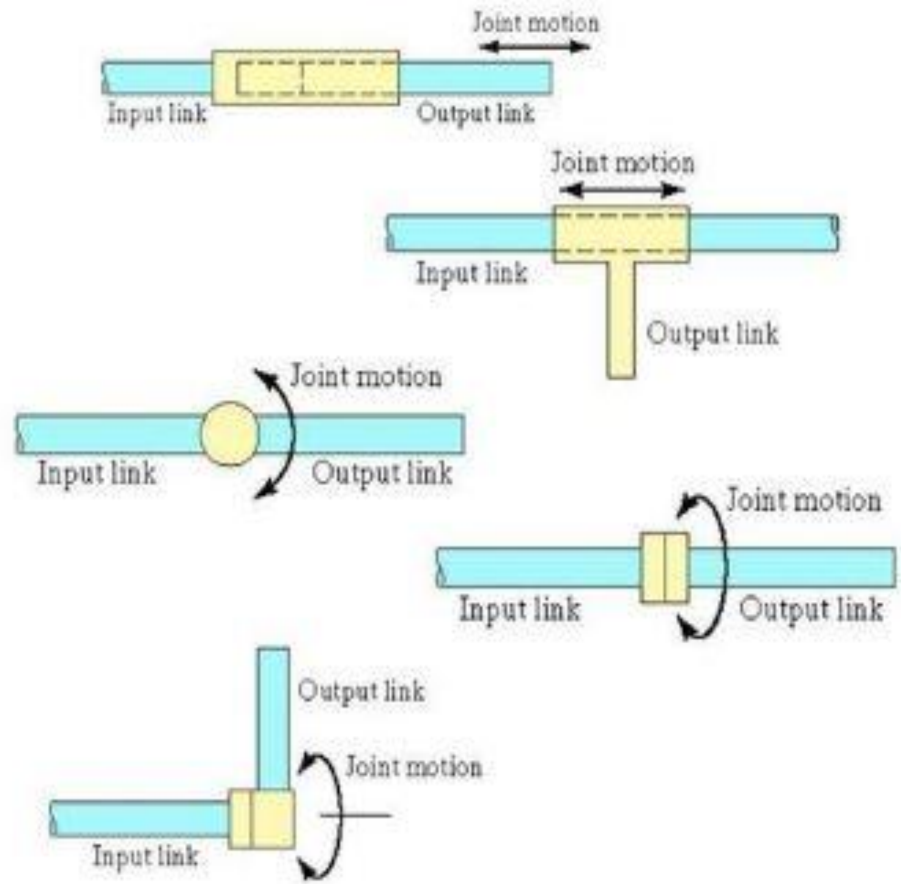
Robot Anatomy

- Manipulator consists of joints and links
  - Joints provide relative motion
  - Links are rigid members between joints
  - Various joint types: linear and rotary
  - Each joint provides a "degree-of-freedom"
  - Most robots possess five or six degrees-of-freedom
- Robot manipulator consists of two sections:
  - Body-and-arm – for positioning of objects in the robot's work volume
  - Wrist assembly – for orientation of objects



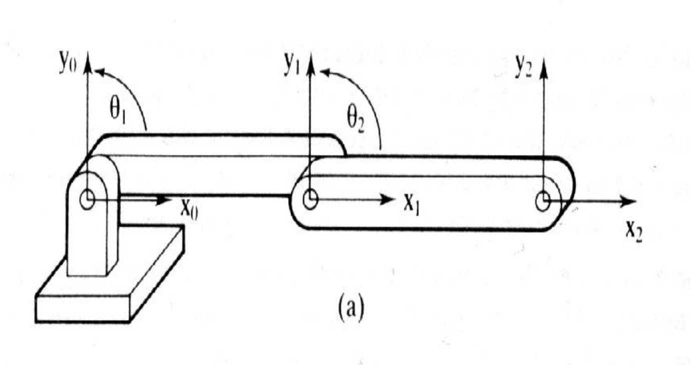
Manipulator Joints

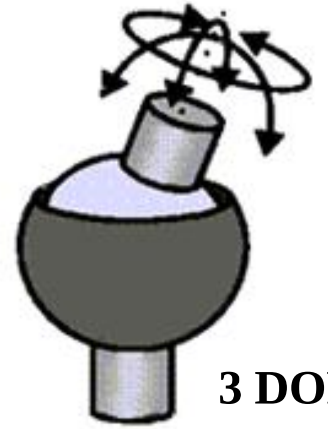
- Translational motion
  - Linear joint (type L)
  - Orthogonal joint (type O)
- Rotary motion
  - Rotational joint (type R)
  - Twisting joint (type T)
  - Revolving joint (type V)



BASIC OF JOINTS

Rotational Joint(R) 1 DOF



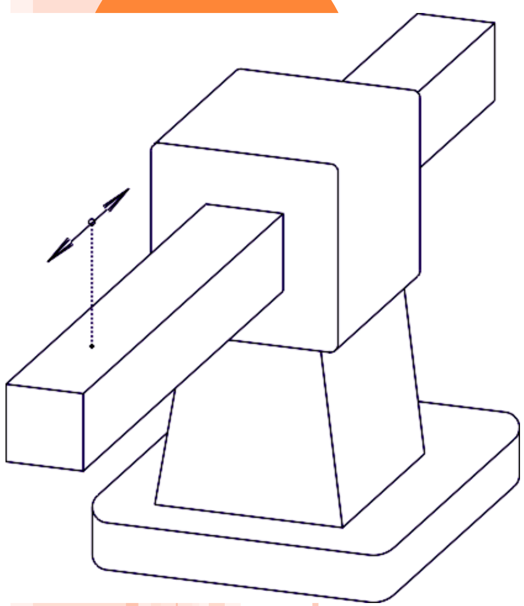


3 DOF

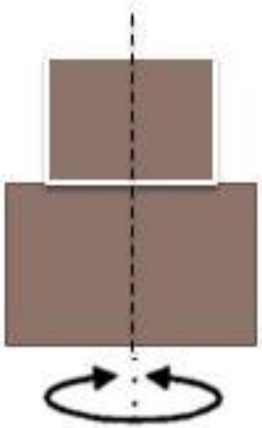
Spherical

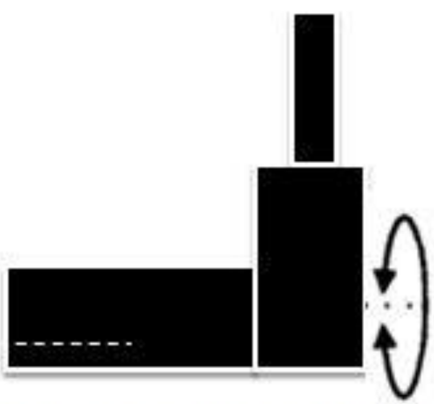
ball-and-socket

Prismatic Joint(L) 1 DOF (linear)



Twist Joint(T) 1 DOF





Revolving Joint(V) 1 DOF

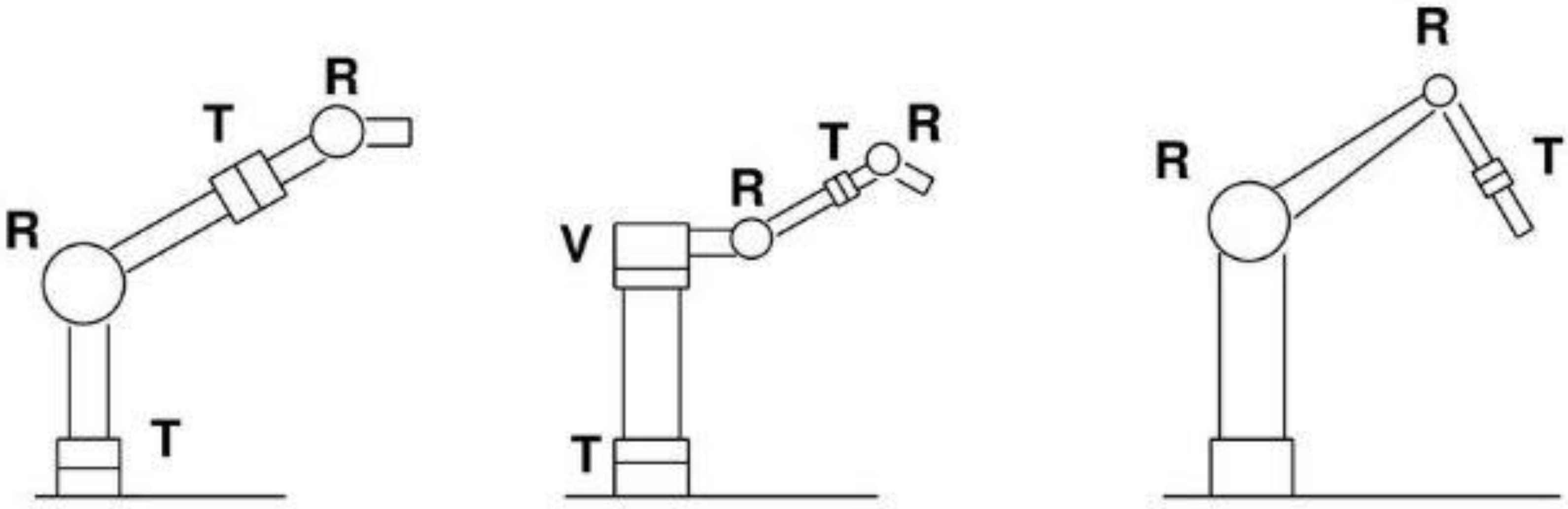
Joint Notation Scheme

- Uses the joint symbols (L, O, R, T, V) to designate joint types used to construct robot manipulator
- Separates body-and-arm assembly from wrist assembly using a colon (:)
- Example: TLR : TR
- Common body-and-arm configurations …

Example

- Sketch following manipulator configurations
- (a) TRT:R, (b) TVR:TR, (c) RR:T.

Solution:



(a) TRT:R (b) TVR:TR (c) RR:T

COORDINATE SYSTEMS:

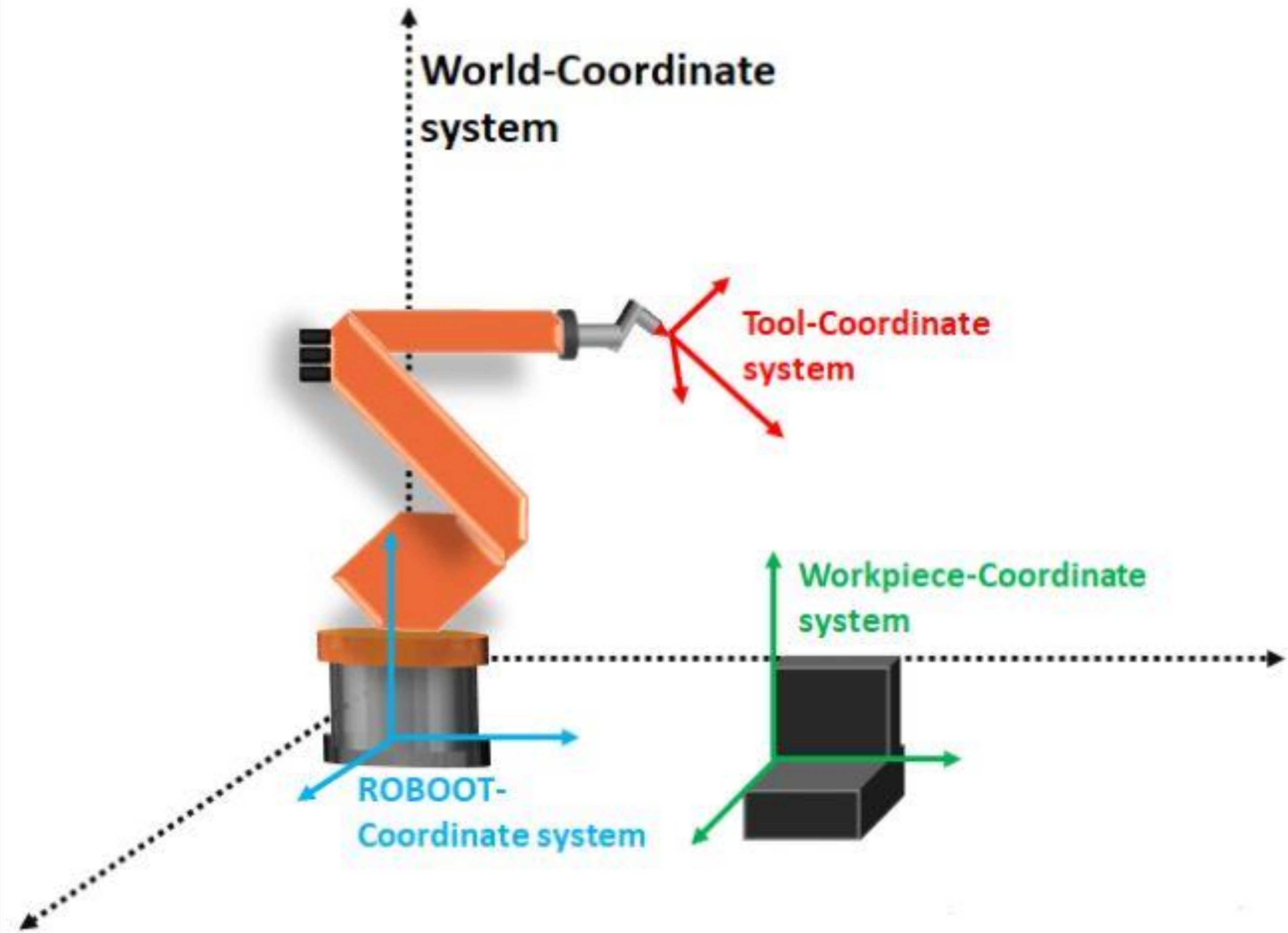
A coordinate system defines a **plane or space by axes** from a **fixed point** called the **origin**. Robot **targets and positions** are located by **measurements** along the **axes of coordinate systems**. A robot uses several coordinate systems, each suitable for specific types of **jogging or programming.**

There are three commonly used coordinate systems:

Cartesian

Cylindrical

Spherical


World-Coordinate system
Tool-Coordinate system
Workpiece-Coordinate system
ROBOOT-Coordinate system

Robot - WORLD-coordinate system

The WORLD-coordinate system is a **cartesian** coordinate system for describing the location of the points within the workspace. Here, a work point is specified in the form of coordinates: **P(x, y, z)**

Robot world coordinate system

Advantage: Detailing the points in WORLD-coordinates is simple. Linear movements can be programmed easily.

Disadvantage: Ambiguity - that means that a certain position can be achieved with a plurality of axial positions. This is concerns especially jointed-arm robots.

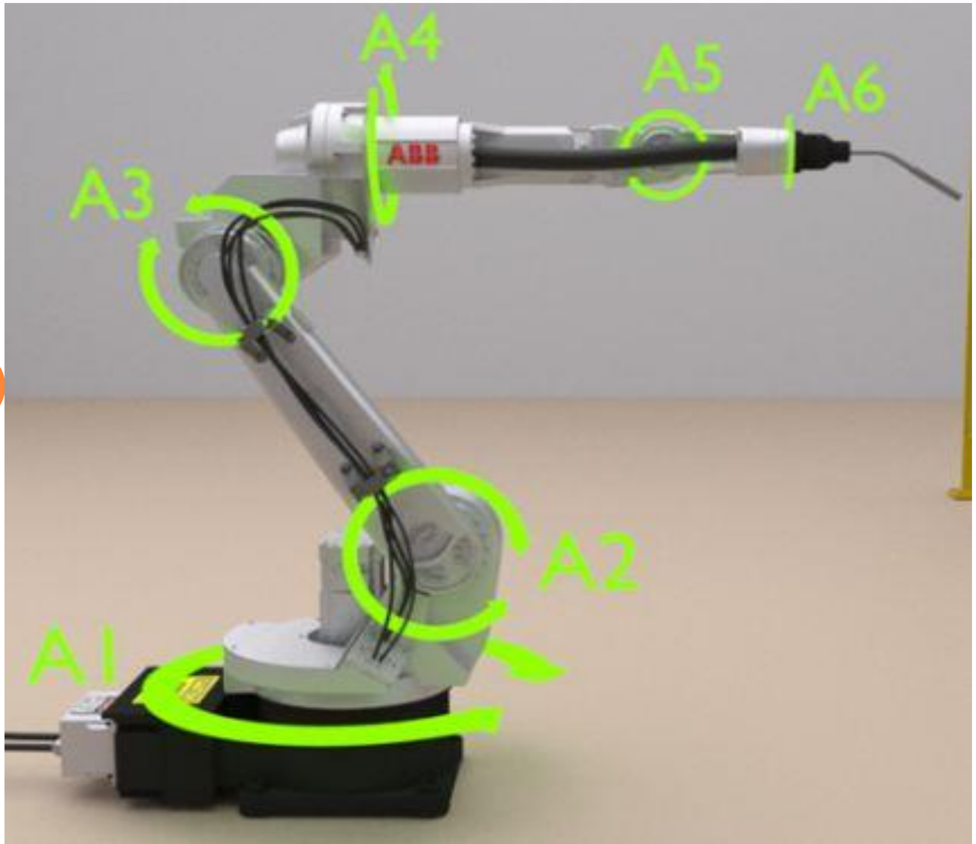
Robot JOINT-coordinates

The angle-position and length of each axis of an articulate robot axes describe the orientation of the TCP exactly. With the joint coordinate-system each robot axis can be moved particularly in positive or negative sense rotation.

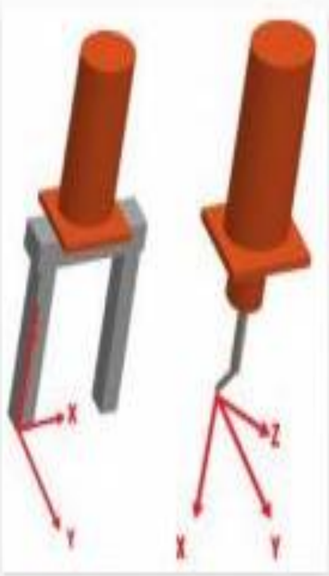
Coordinates: **P (angle A1, angle A2, ... , angle A6)**

Advantage:

- ambiguity can be avoided
- no transformation of coordinates necessary



TOOL COORDINATE SYSTEM



robot-tool-coordinates

Tool-coordinates include data of the tool, such as:

- where is the TCP(tool center point)
- the geometry of the tool (the orientation of the tool)

Gripper coordinates describe the orientation and position of the effector in space. The zero point of the coordinate systems is located at the Tool-Center-Point (TCP) of the effector. Usually the coordinates are stated Cartesian, whereas one of the axes have to point into the extended direction of the gripper.

Which **advantages** you have by using **tool-coordinate-system**? By using the tool coordinate system, many applications are easier to program for the user. **Examples** from the practice in which the tool measurement is used:

The following tasks are easier to program using the tool coordinate system:

- Turning the tool around the TCP (tool center point)
- To maintain the speed at the TCP even with ccomplex paths
- Topush the tool in a certain direction

WORKPIECE COORDINATE SYSTEM

The **workpiece-coordinate-system** is a Cartesian coordinate-system whose origin is within the work piece or at a corner of the workpiece.

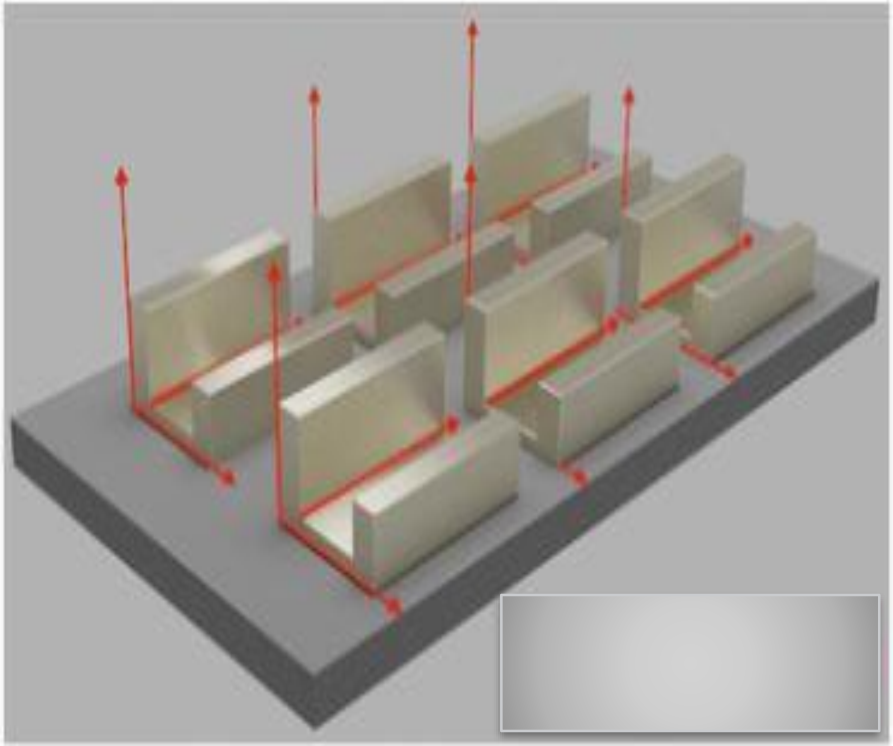


fig.: Robotics - Workpiece Coordinate System

Advantages of measuring the base :

1. Thereby you can determine a specific point on the pallet, the clamping table or the workpiece. To these points all future teach-points can refer to. In the program mode, you now have the option to move the base or to rotate it. Automatically all operation points will be adapted.
2. If there are several workpieces on the pallet, it is sufficient to know the workpiece geometry of one workpiece. Only the zero point of a new pallet has to determined.

ROBOT CONFIGURATION:

- In general, the fundamental mechanical configurations of robot manipulators are categorized as Cartesian, Cylindrical, Spherical and Articulated / Jointed-arm.
- Cartesian is divided into traverse & gantry types.
- Articulated is divided into horizontal & vertical types.

Work envelope / workspace

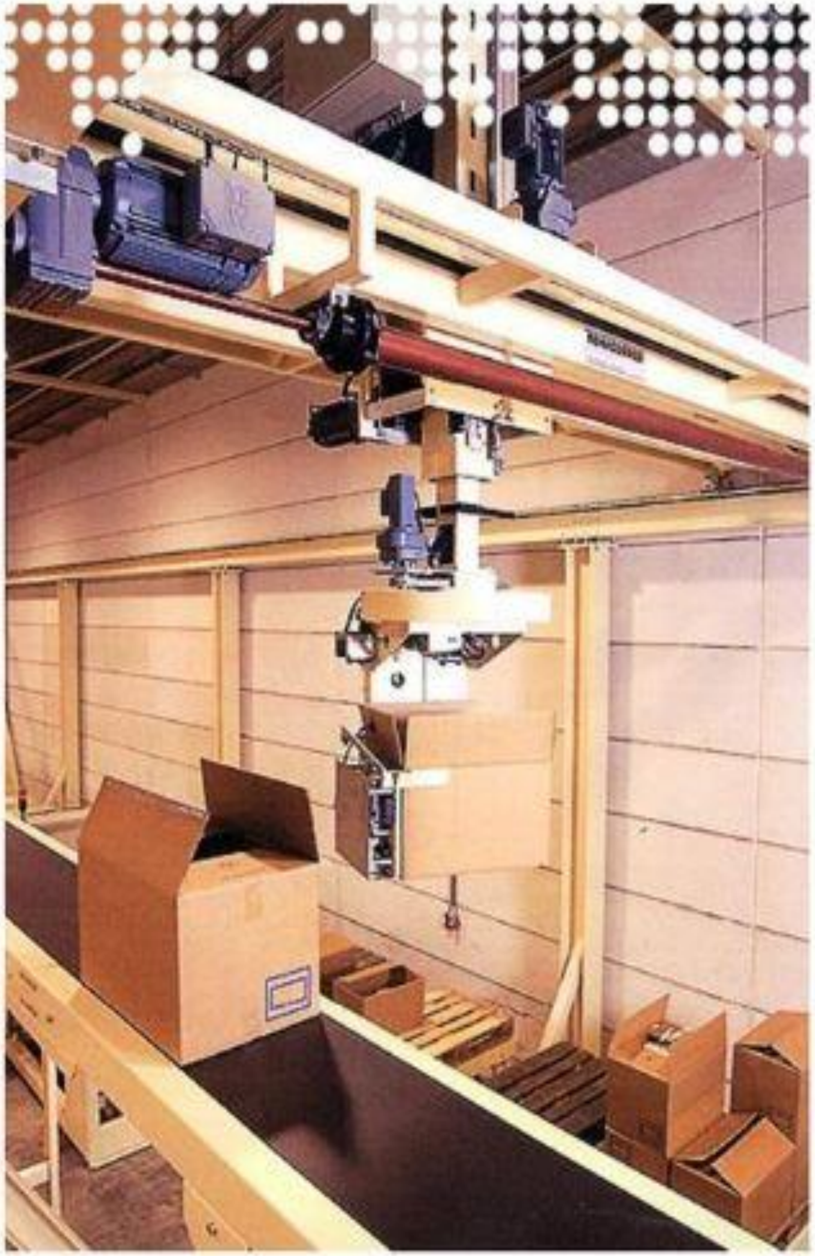
- The extreme position of the robot axes describe a boundary for the region in which the robot operates. This boundary encloses the work envelope.
- The size of a work envelope determines the limits of reach.

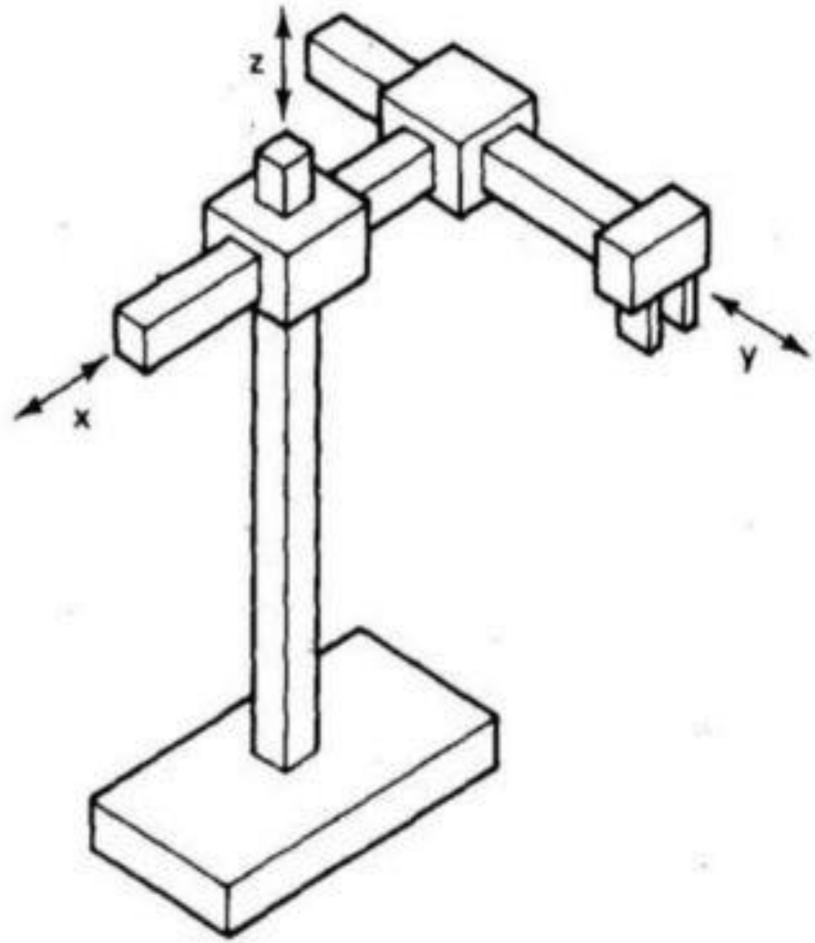
ROBOT CONFIGURATION:

1. Cartesian / Rectangular robot

- It has 3 prismatic joints, whose axes are coincident with a cartesian coordinate system.
- Most cartesian robots come as Gantries, distinguished by a frame structure supporting the linear axes.
- Gantry robots are widely used for:
  - Special machining tasks such as water jet or laser cutting where robot motion cover large surfaces.
  - Palletizing
  - Warehousing

ROBOT CONFIGURATION:



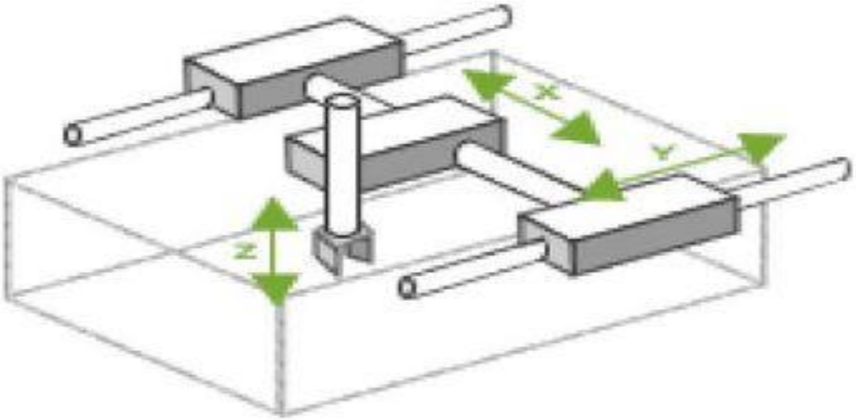


Gantry

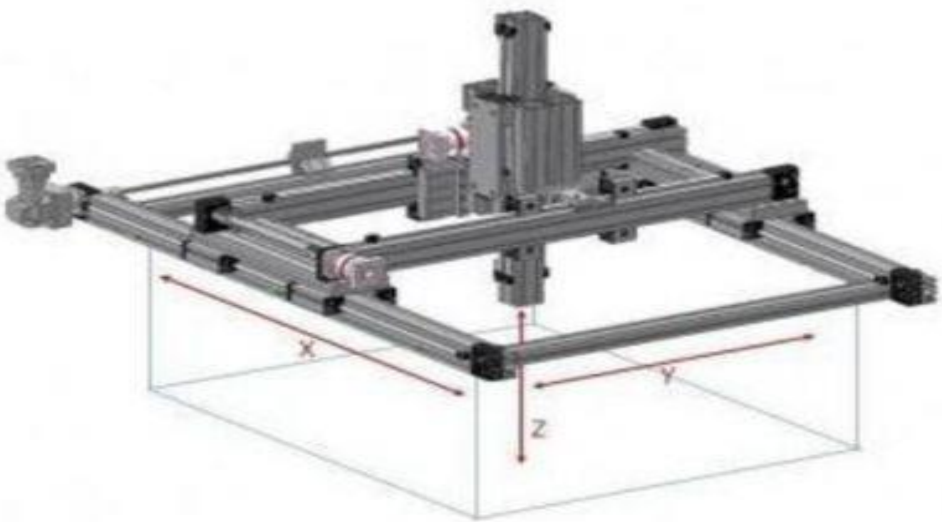
Traverse

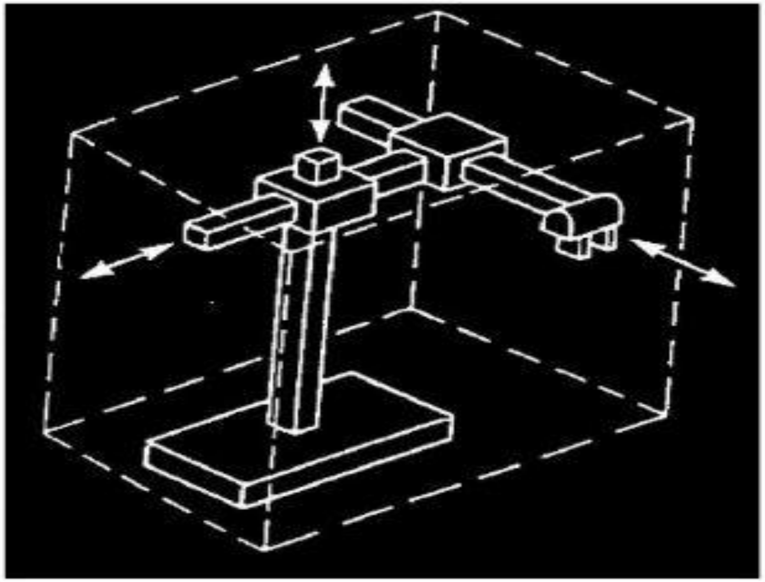
Work envelope: Cartesian /rectangular robot

- Shaped as a cube or a rectangle.



WORKSPACE

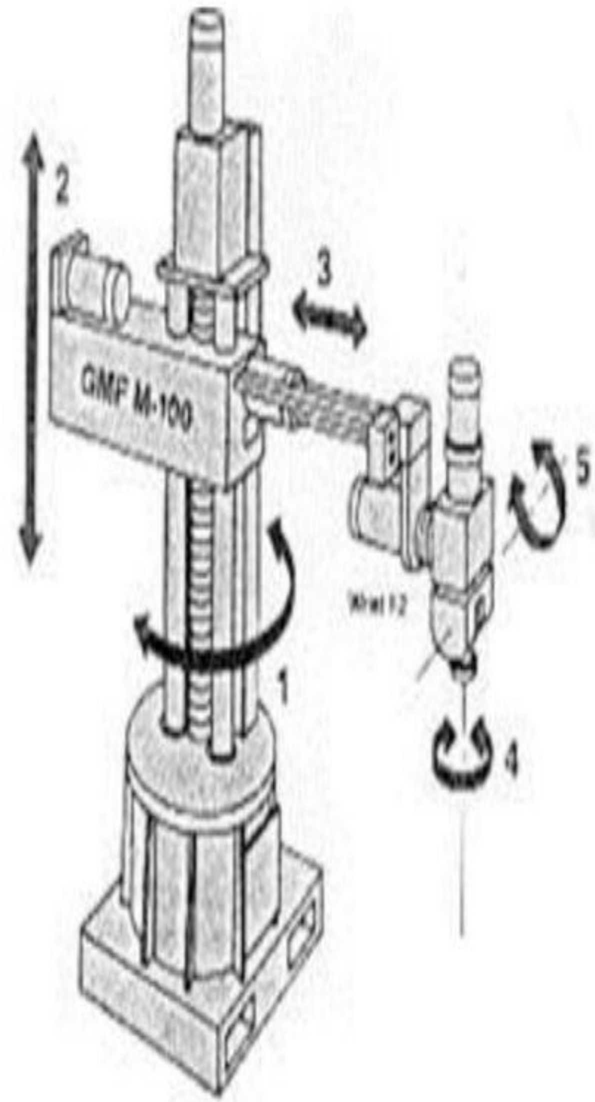




ROBOT CONFIGURATION:

2. Cylindrical robot

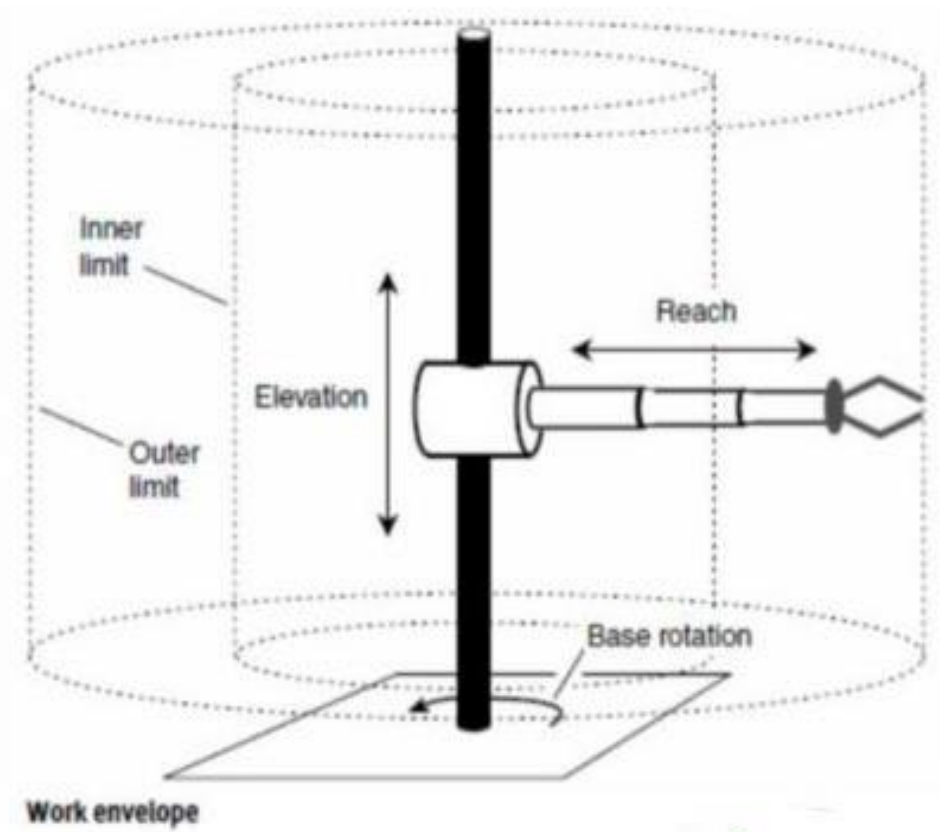
- The manipulator has 2 linear motions and 1 rotary motion.
- Robot's manipulator has 1 rotational degree of freedom and 2 translational (linear) degrees of freedom.
- A cylindrical-coordinated robot generally results in a larger work envelope than cartesian-coordinated robot.
- This robot is ideally suitable for pick and place operation.
- Typical applications are assembly, conveyor pallet transfer, palletizing etc.

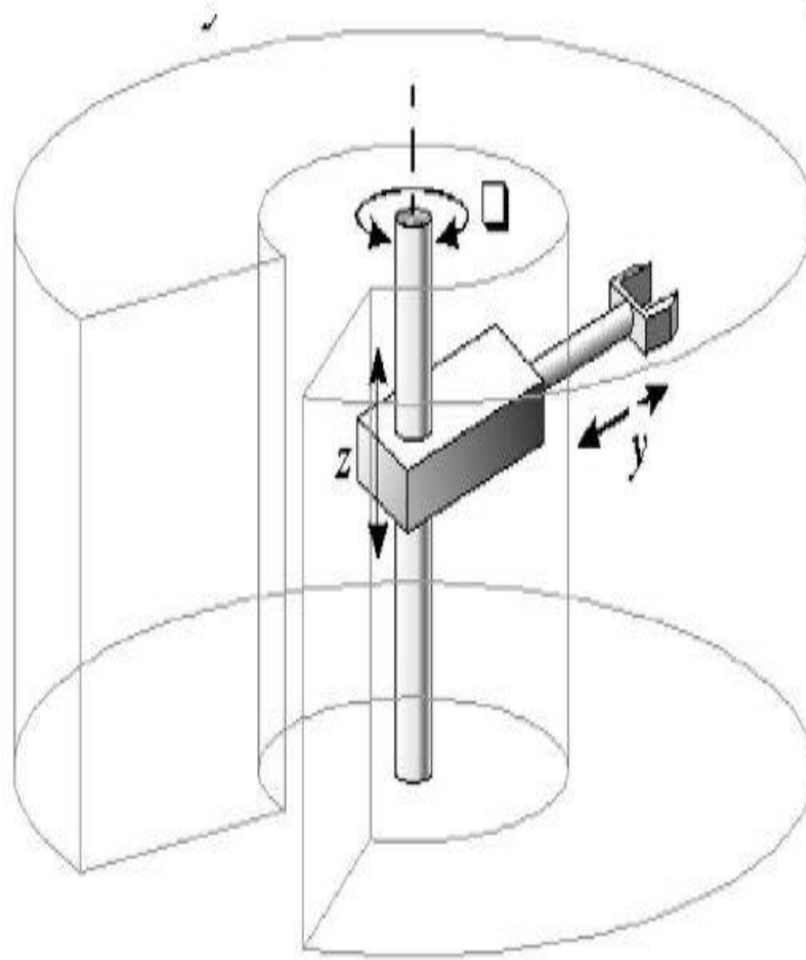


ROBOT CONFIGURATION:

Work envelope: Cylindrical robot

It can move it's gripper within a volume described by a cylinder.



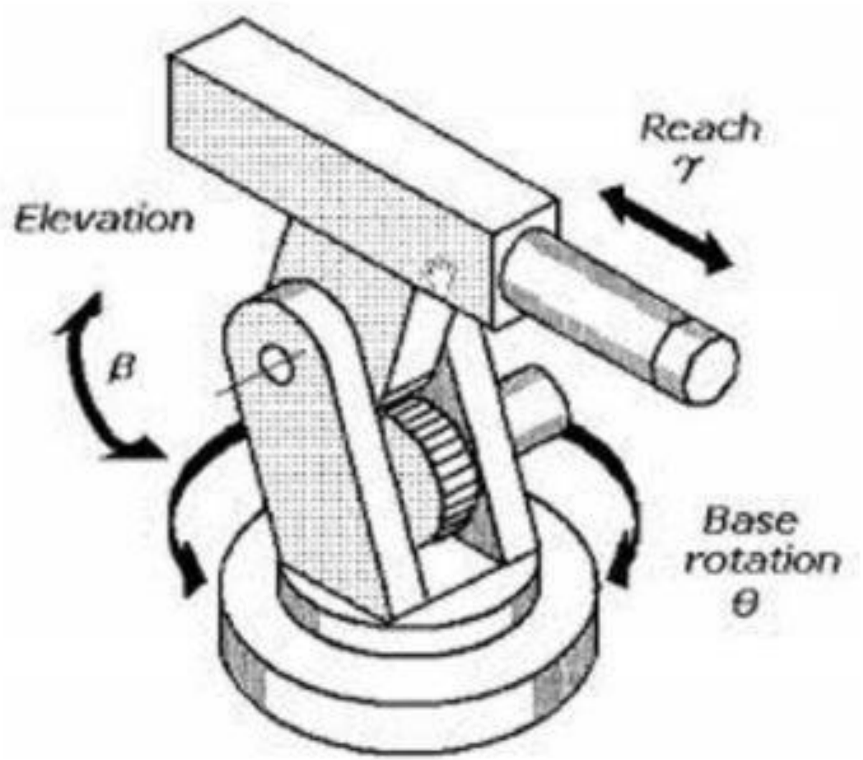


ROBOT CONFIGURATION:

3. Spherical / Polar robot

- The manipulator has 1 linear motion and 2 rotary motions.
- The first motion corresponds to base rotation. The second motion corresponds to an elbow rotation. The third motion corresponds to a radial/in-out/ translation.
- A spherical robot generally results in a larger work envelope than cylindrical and cartesian robot.
- This robot is ideally suitable for applications where a small amount of vertical movement is adequate such as loading & unloading a punch press.

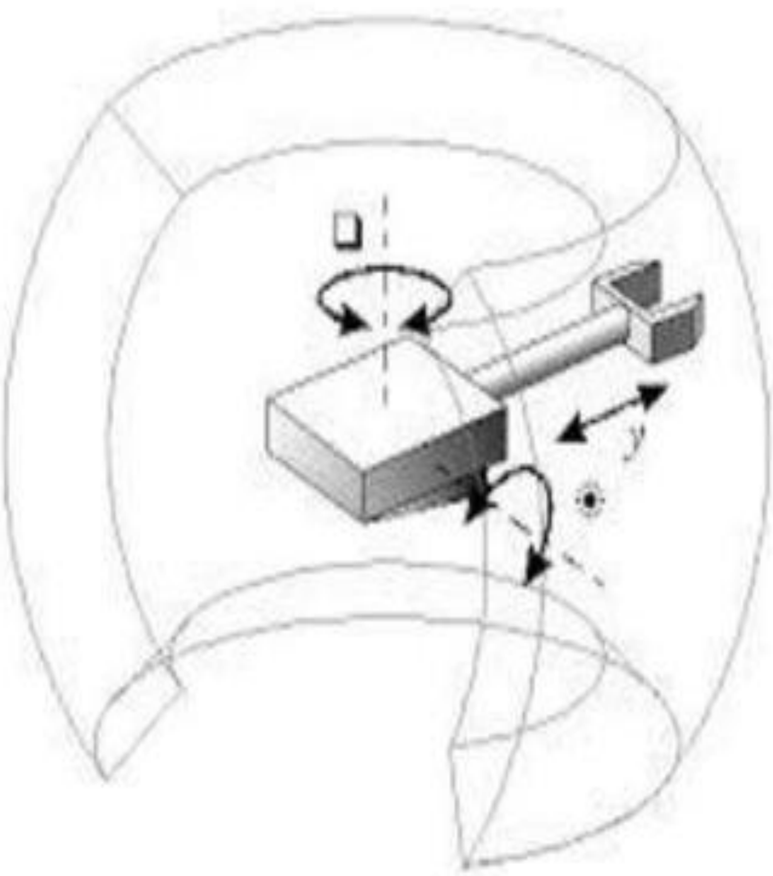
ROBOT CONFIGURATION:

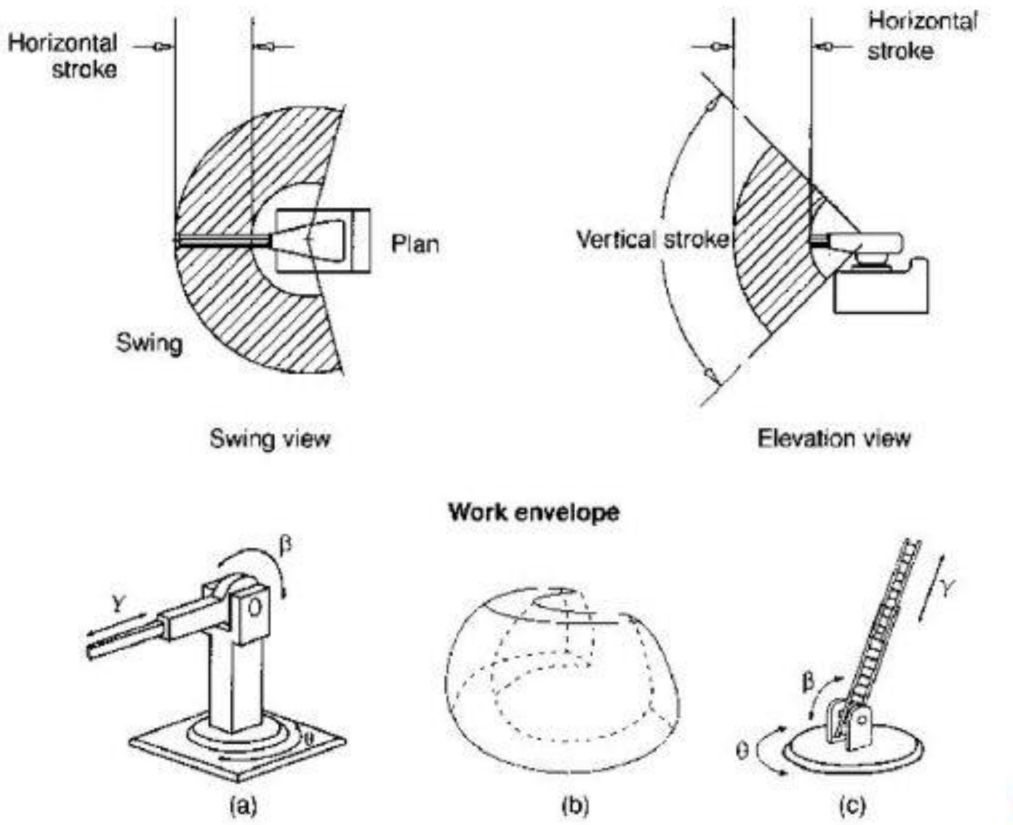


ROBOT CONFIGURATION:

Work envelope: Spherical / Polar robot

The envelope is shaped like a section of a sphere with upper and lower limits imposed by the angular rotations of the arm.



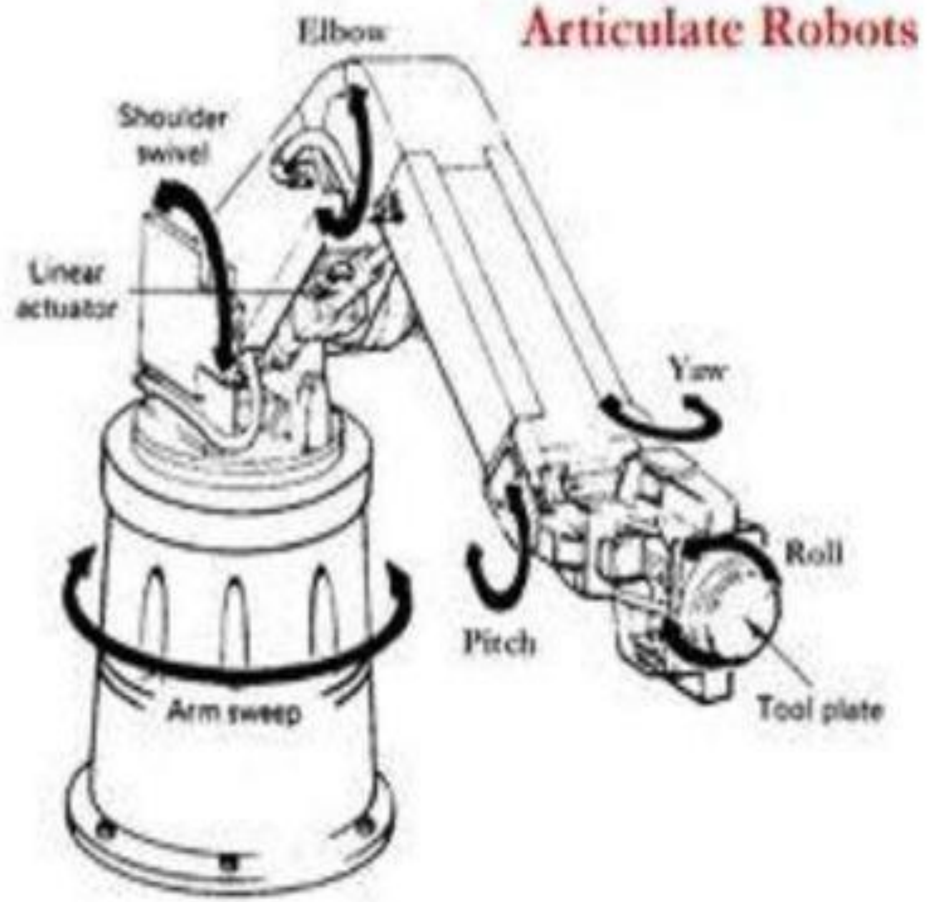


ROBOT CONFIGURATION:

4. Articulated / Jointed-arm robot - Vertical

- The manipulator has 3 rotary motions to reach any point in space.
- The design is similar to human arm.
- The first rotation is about the base, the second rotation is about the shoulder in a horizontal axis and the final motion is rotation about the elbow.
- It can move at high speeds and has a greater variety of angles to approach a given point and thus very useful for painting and welding applications.

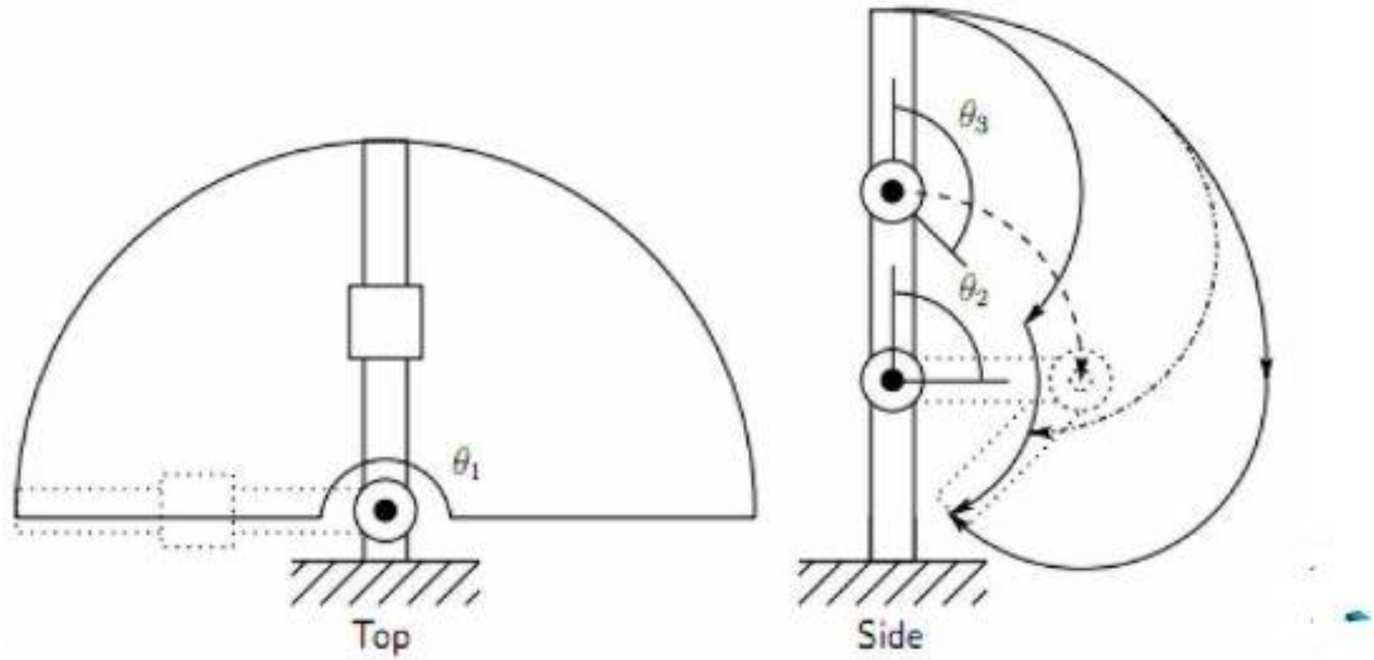
ROBOT CONFIGURATION:



ROBOT CONFIGURATION:

Work envelope: Vertical articulated/jointed-arm robot

The envelope is circular when viewed from the top of the robot. When looked from the side, the envelope has a circular outer surface with an inner scalloped surface.



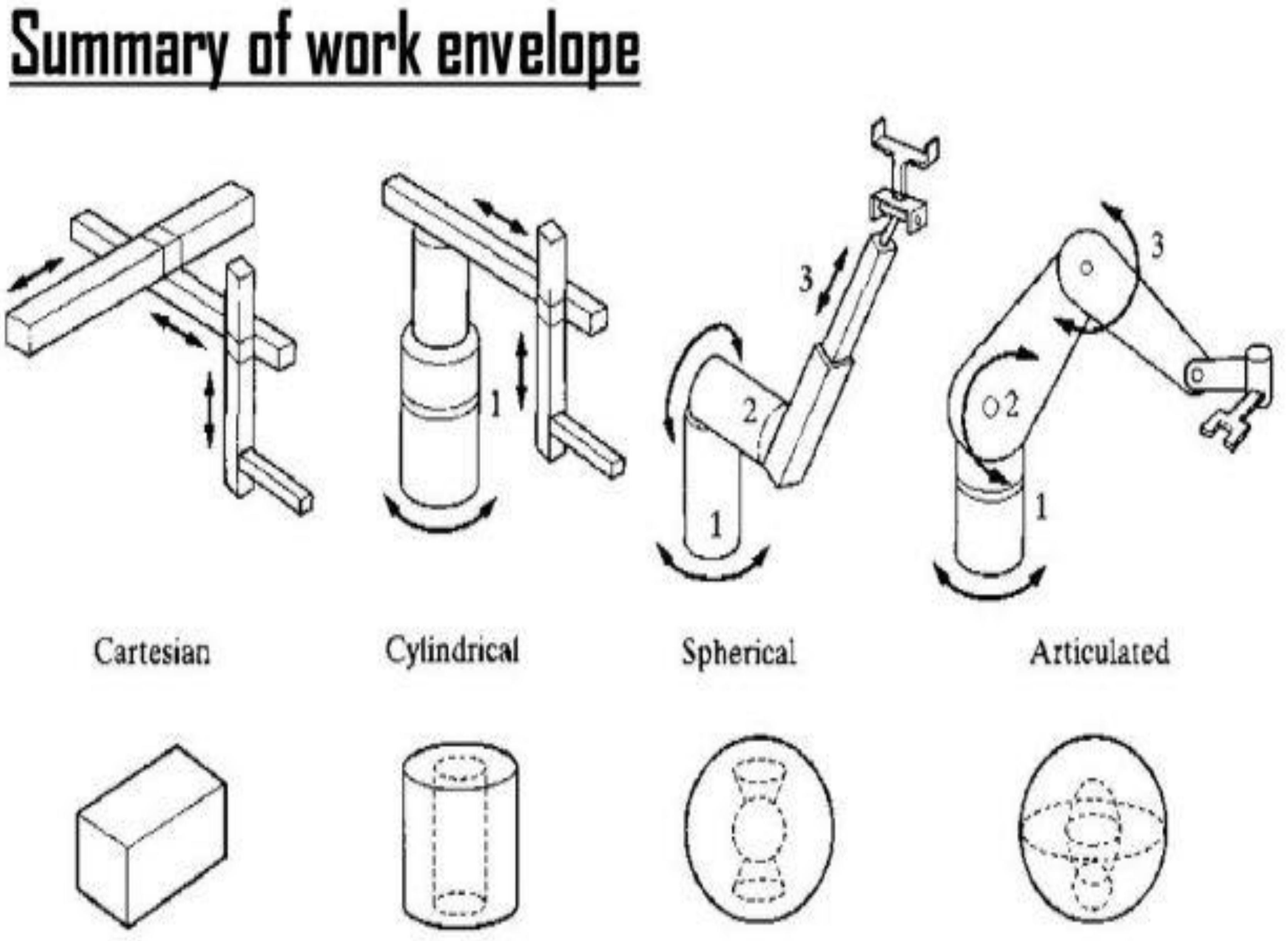
ROBOT CONFIGURATION:

4. Articulated / Jointed-arm robot - Horizontal

- The manipulator has 2 rotary motions and 1 linear (vertical) motion to reach any point in space.
- Also called SCARA (Selective Compliance Assembly Robot Arm).
- This robot has 2 horizontally jointed-arm segments fixed to a rigid vertical member (base) and one vertical linear motion axis.
- It is extremely useful in assembly operations where insertions of objects into holes are required.

ROBOT CONFIGURATION:

ROBOT CONFIGURATION:



Configuration	Advantages	Disadvantages
Cartesian coordinates x, y, z (base travel, reach, and height)	• Three linear axes • Easy to visualize • Rigid structure • Easy to program off-line • Linear axes make for easy mechanical stops	• Can only reach in front of itself • Requires large floor space for size of work envelope • Axes hard to seal
Cylindrical coordinates θ, y, z – (base rotation, reach, and height)	• Two linear axes, one rotating axis • Can reach all around itself • Reach and height axes rigid axis • Rotation axis easy to seal	• Cannot reach above itself • Base rotation axis is less rigid than a linear • Linear axis is hard to seal • Won't reach around obstacles • Horizontal motion is circular
Spherical coordinates (vertical) θ, y, β (base rotation, elevation angle, reach angle)	• One linear axis, two rotating axes • Long horizontal reach	• Can't reach around obstacles Generally has short vertical reach
Articulated (or jointed-arm) coordinates (vertical) θ, β, α (base rotation, elevation angle, reach angle)	• Three rotating axes • Can reach above or below obstacles • Largest work area for least floor space	• Two or four ways to reach a point • Most complex manipulator
SCARA coordinates (horizontal) θ, Φ, z (base rotation, reach angle, height)	• One linear axis, two rotating axes • Height axis is rigid • Large work area for floor space • Can reach around obstacles	• Two ways to reach a point • Difficult to program off-line • Highly complex arm

PARTS OF A ROBOT :

- Manipulator
- Pedestal
- Controller
- End Effectors
- Power Source

PARTS OF A ROBOT :

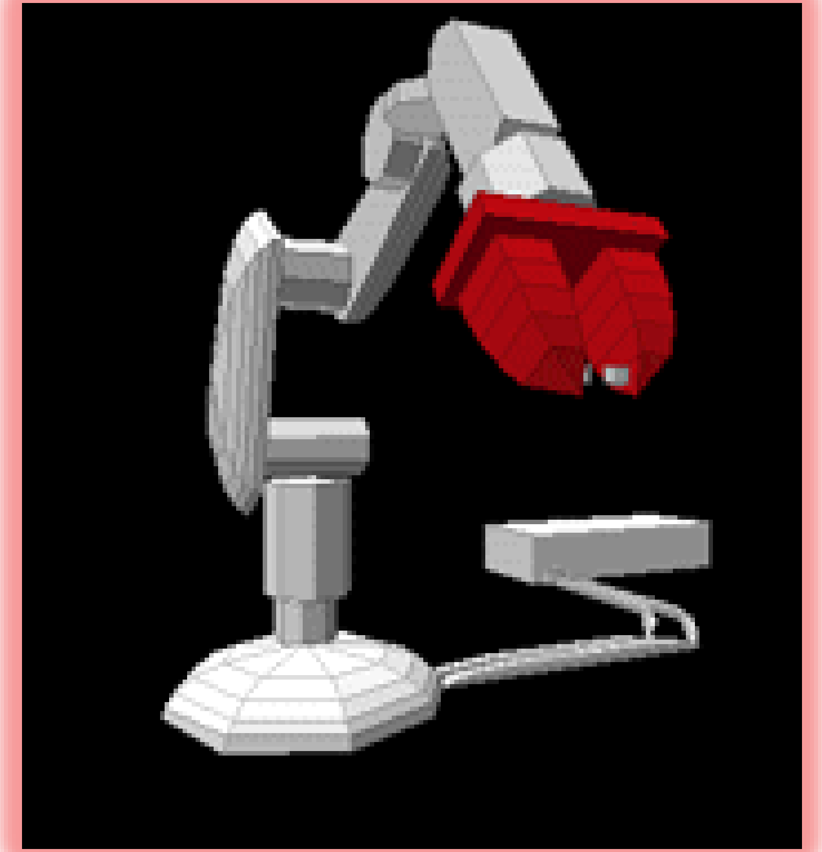
Manipulator:

In robotics, a manipulator is a device used to manipulate materials without direct physical contact by the operator.

Manipulators are composed of an assembly of links and joints.

(Mimics the human arm)

Shoulder, Arm and Gripper



PARTS OF A ROBOT :

Pedestal:

(Human waist)

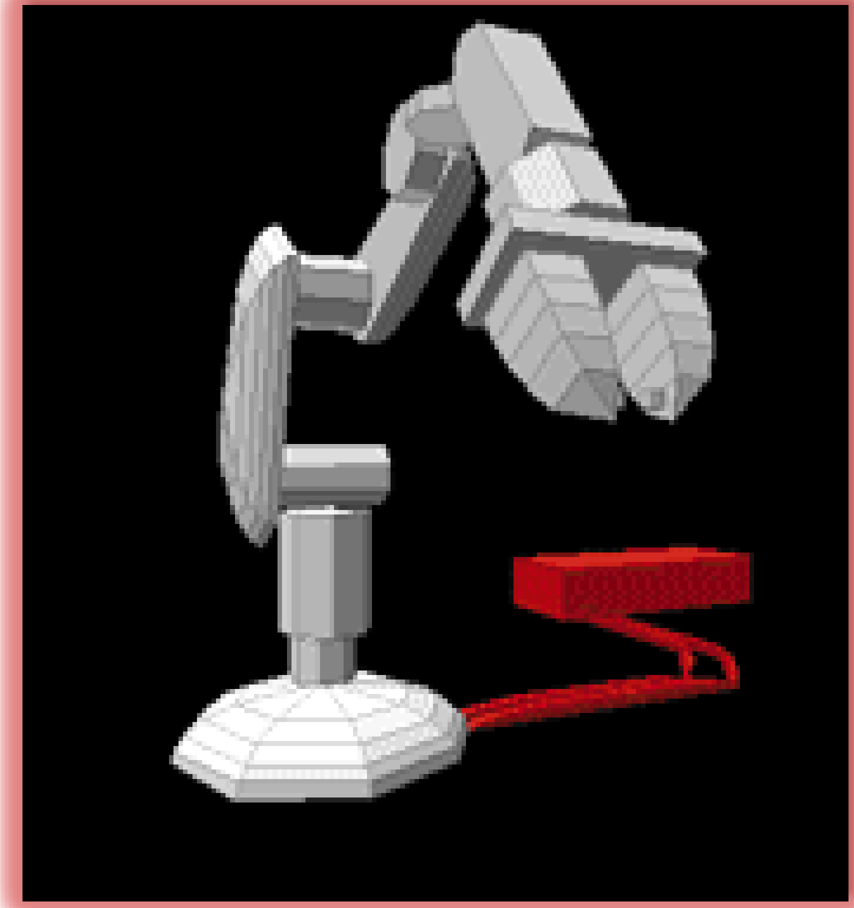
- **Supports the manipulator.**
- **Acts as a counterbalance**

PARTS OF A ROBOT :

Controller:

(The brain)

- Issues instructions to the robot.
- Controls peripheral devices.
- Interfaces with robot.
- Interfaces with humans.



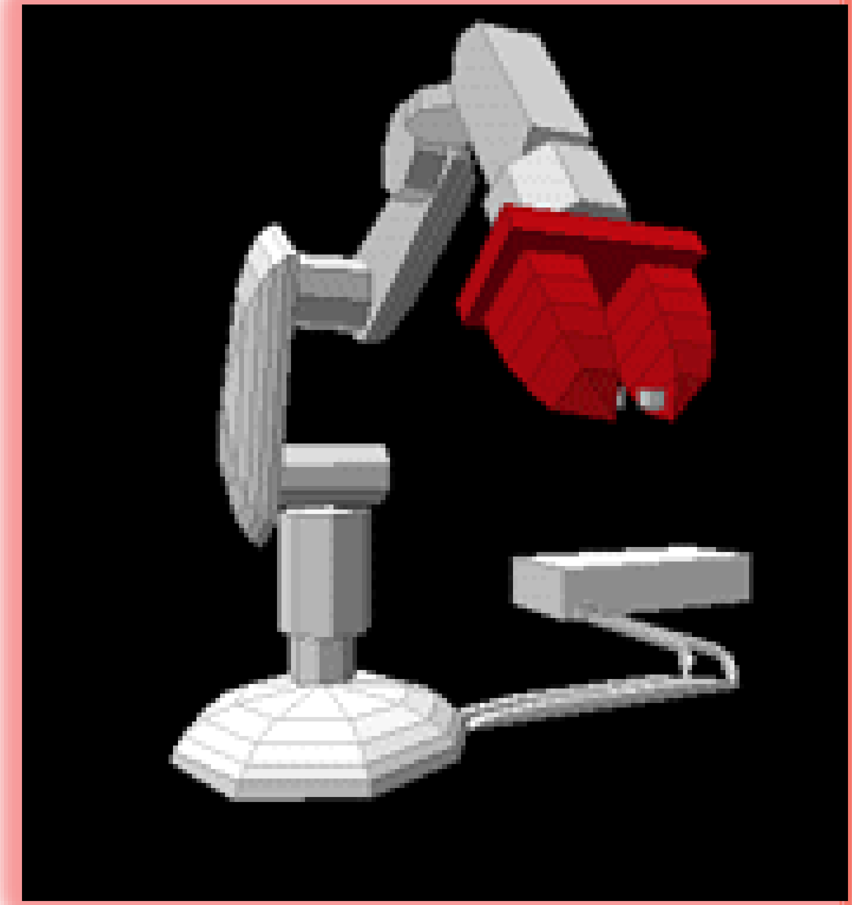
PARTS OF A ROBOT :

End Effector:

The device attached to the manipulator which interacts with its environment to perform tasks is called the end-effector.

(The hand)

- Spray paint attachments
- Welding attachments
- Vacuum heads
- Hands
- Grippers

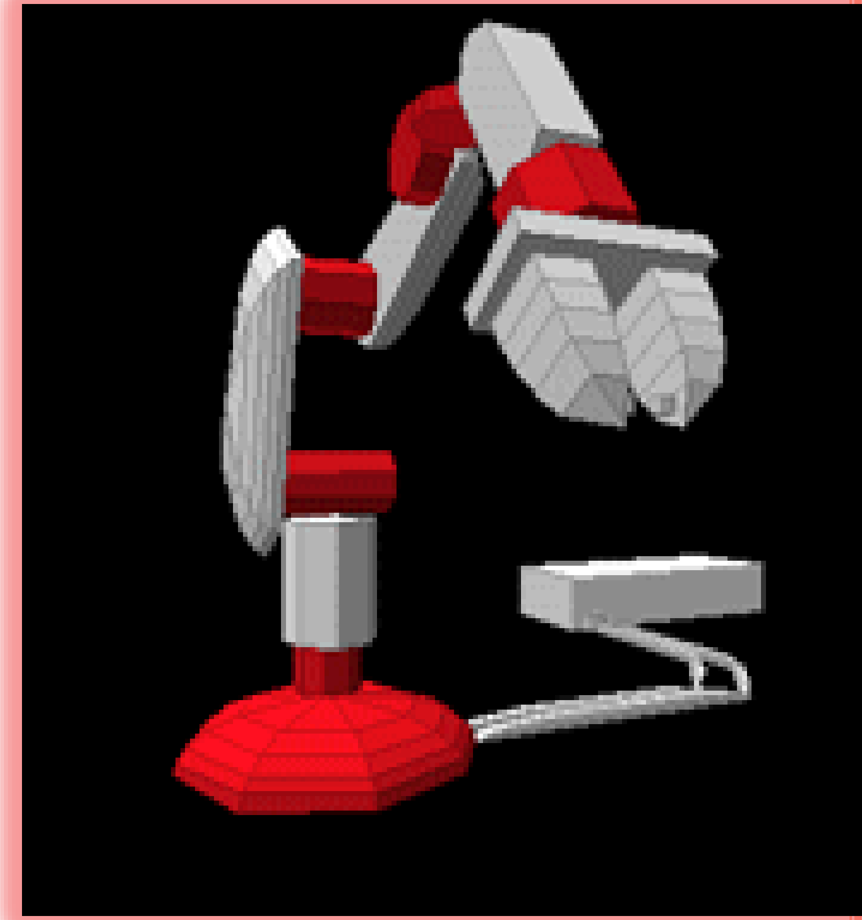


PARTS OF A ROBOT :

Power Source:

(food)

- **Electric**
- **Pneumatic**
- **Hydraulic**



NEED FOR ROBOTS:

Robots save workers from performing **dangerous tasks**.

They can work in **hazardous conditions, such as poor lighting, toxic chemicals, or tight spaces**.

They are capable of lifting heavy loads without **injury or tiring**.

Robots increase worker safety by preventing accidents since humans are not performing risky jobs

APPLICATION OF ROBOTS:

Robots are best suited to work in environments where humans cannot perform the tasks.

Robots have already been used in many industries and for many purposes

They can often perform better than humans and lower costs.

Machine Loading, Pick place Operation, Welding, Painting, Inspection, Sampling, Assembly Operations, Manufacturing, Surveillance, Medical Applications, Assisting Disabled Individuals, Hazardous Environments, Underwater, Space and Remote locations

ROBOTIC TECHNOLOGY

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UNIT 4
SENSORS IN ROBOTICS

MACHINE VISION SYSTEMS OF ROBOT

- Machine vision system consists of: Lighting, camera, A/D convertor, frame grabber, computer processor, robot controller and robot manipulator.
- The hardware and software for performing the function of sensing and processing the image and utilizing the results obtained to command the robot.
- The sensing and digitizing functions involve the input of vision data by means of a camera focused on the scene of interest. Special lighting techniques are frequently used to obtain an image of sufficient contrast for later processing.
- The image viewed by the camera is typically digitized and stored in computer memory. The digital image is called a frame of vision data, and is frequently captured by a hardware device called a frame grabber.
- These devices are capable of digitizing images at the rate of 30 frames per second. The frames consist of a matrix of data representing projections of the scene sensed by the camera.
- The elements of the matrix are called picture elements, or pixels. The number of pixels are determined by a sampling process per formed on each image frame.

MACHINE VISION SYSTEMS OF ROBOT

- A single pixel is the projection of a small portion of the scene which reduces that portion to a single value. The value is a measure of the light intensity for that element of the scene.
- Each pixel intensity is converted into a digital value. (We are ignoring the additional complexities involved in the operation of a color video camera.)
- The digitized image matrix for each frame is stored and then subjected to image processing and analysis functions for data reduction and interpretation of the image.
- These steps are required in order to permit the real-time application of vision analysis required in robotic applications.
- Typically an image frame will be threshold to produce a binary image, and then various feature measurements will further reduce the data representation of the image.
- This data reduction can change the representation of a frame from several.

LIGHTING TECHNIQUES

An essential ingredient in the application of machine vision is proper lighting.

The basic types of lighting devices used in machine vision may be grouped into the following categories:

i) **Diffuse surface devices. Examples of diffuse surface illuminators are the typical fluorescent lamps and light tables.**

ii) **Condenser projectors. A condenser projector transforms an expanding light source into a condensing light source. This is useful in imaging optics.**

iii) **Flood or spot projectors. Flood lights and spot lights are used to illuminate surface areas.**

iv) **Collimators. Collimators are used to provide a parallel beam of light on the subject**

v) **Imagers. Imagers such as slide projectors and optical enlargers form an image of the target at the object plane.**

ANALOG to DIGITAL SIGNAL CONVERSION:

For a Camera utilizing the vidicon tube technology it is necessary to convert the analog signal for each pixel into digital form.

The analogy to digital (A/D) conversion process involves taking an analog input voltage signal and producing an output that represents the voltage signal in the digital memory of a computer.

A/D conversion consists of three phases:

- **Sampling**
- **Quantization**
- **Encoding**

ANALOG to DIGITAL SIGNAL CONVERSION:

SAMPLING:

A given analog signal is sampled periodically to obtain a series of discrete time along signal for each pixel

The sampling rate should be at least twice the highest frequency in the video signal if we wish to reconstruct that signal exactly.

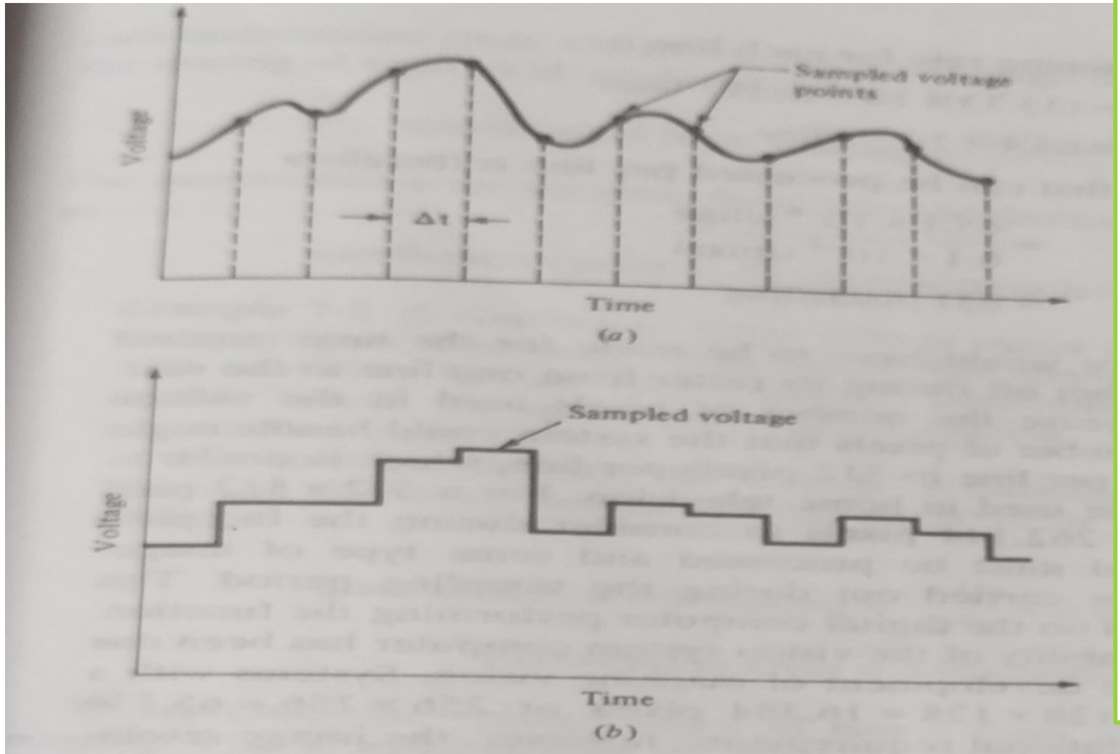


Figure 7-5 Sampling and digitizing an analog waveform. (a) analog waveform indicating sampling interval, t, and sampled voltage points. (b) digital approximation to analog signal.

ANALOG to DIGITAL SIGNAL CONVERSION: Sampling

Example 7-1 Consider a vision system using a vidicon tube. An analog video signal is generated for each line of the 512 lines comprising the faceplate. The sampling capability of the A/D converter is 100 nanoseconds (100×10^{-9} s). This is the cycle time required to complete the A/D conversion process for one pixel. Using the American standard of 33.33 milliseconds ($\frac{1}{30}$ s) to scan the entire faceplate consisting of 512 lines, determine the sampling rate and the number of pixels that can be processed per line.

The cycle time per pixel is limited by the A/D conversion process to 100×10^{-9} s

$$= 0.1 \times 10^{-6} \text{ s/pixel}$$

The scanning rate for the 512 lines in the faceplate is $\frac{1}{30}$ s

$$= 33.33 \times 10^{-3} \text{ s}$$

Accordingly, the scanning rate for each line is

$$= (33.33 \times 10^{-3} \text{ s})/512 \text{ lines}$$

$$= 65.1 \times 10^{-6} \text{ s/line}$$

The number of pixels that can be processed per line is therefore

$$= \frac{65.1 \times 10^{-6} \text{ s/line}}{0.1 \times 10^{-6} \text{ s/pixel}}$$

$$= 651 \text{ pixels/line}$$

ANALOG to DIGITAL SIGNAL CONVERSION:

QUANTIZATION:

number of lines determines the vertical

Quantization Each sampled discrete-time voltage level is assigned to a finite number of defined amplitude levels. These amplitude levels correspond to the gray scale used in the system. The predefined amplitude levels are characteristic to a particular A/D converter and consist of a set of discrete values of voltage levels. The number of quantization levels is defined by

$$\text{number of quantization levels} = 2^n$$

where n is the number of bits of the A/D converter. A large number of bits enables a signal to be represented more precisely. For example, an 8-bit converter would allow us to quantize at $2^8 = 256$ different values whereas 4 bits would allow only $2^4 = 16$ different quantization levels.

ANALOG to DIGITAL SIGNAL CONVERSION:

ENCODING :

Encoding The amplitude levels that are quantized must be changed into digital code. This process, termed encoding, involves representing an amplitude level by a binary digit sequence. The ability of the encoding process to distinguish between various amplitude levels is a function of the spacing of each quantization level. Given the full-scale range of an analog video signal, the spacing of each level would be defined by

$$\text{quantization level spacing} = \frac{\text{full-scale range}}{2^n}$$

The quantization error resulting from the quantization process can be defined as

$$\text{quantization error} = \pm\tfrac{1}{2}\,(\text{quantization level spacing})$$

Example 7-2 A continuous video voltage signal is to be converted into a discrete signal. The range of the signal after amplification is 0 to 5 V. The A/D converter has an 8-bit capacity. Determine the number of quantization levels, the quantization level spacing, the resolution, and the quantization error.

For an 8-bit capacity, the number of quantization levels is $2^8 = 256$. The A/D converter resolution $= \frac{1}{256} = 0.0039$ or 0.39 percent. For the 5-V range,

$$\text{quantization level spacing} = \frac{(5\text{ V})}{(2^8)} = 0.0195\text{ V}$$

$$\text{quantization error} = \pm\tfrac{1}{2}(0.0195\text{ V}) = 0.00975\text{ V}$$

ANALOG to DIGITAL SIGNAL CONVERSION:

IMAGE STORAGE:

Following A/D conversion, the image is stored in computer memory, typically called a frame buffer. This buffer may be part of the frame grabber or in the computer itself.

Frame grabber is one example of a video data acquisition device that will store a digitized picture it in 1/30 S.

VARIOUS TECHNIQUES IN IMAGE PROCESSING AND ANALYSIS

- **In the industrial applications the algorithms and programs are developed to process the images captured, digitized and stored in the computer memory.**
- **The size of data to be processed is huge, of the order of 106 which is to be substantially executed in seconds.**
- **The difficult and time consuming task of processing is handled effectively by the following techniques.**

  (1) Image data reduction

  (2) Segmentation

  (3) Feature extraction

  (4) Object recognition.

VARIOUS TECHNIQUES IN IMAGE PROCESSING AND ANALYSIS

IMAGE DATA REDUCTION:

- **The purpose of image data reduction is to reduce the volume of data either by elimination of some or part processing, leading to the following sub-techniques.**

  (a) Digital conversion

  (b) Windowing

- **Digital conversion is characterized by reduction in number of gray levels. For a 8-bit register each pixel would have 2^8=256 gray levels. When fewer bits are used to represent pixel intensity the digital conversion is reduced, to suit the requirements.**

The data reduction is effected in the following manner generalized as

Total number of bits on the face plate,

$$T_1 = N_r . N_c (2)^n$$

where N_r = number of lines or rows

N_c = number of points per line

2^n = total gray levels.

Binary bit conversion for totally black and white intensities,

$$T_2 = N_c . N_r . (2)$$

Reduction in data volume $= (T_1 - T_2)$

$= 2 N_c N_r (2^{n-1} - 1)$

* *Windowing* is processing a portion of the stored digital image. The portion of focus extracted for image processing is the window. A rectangular window is selected as to highlight the component of interest on the screen. The pixels of the faceplate within the window are processed and analized by the computer.

Example:

Example 7-4 For an image digitized at 128 points per line and 128 lines, determine (a) the total number of bits to represent the gray level values required if an 8 bit A/D converter is used to indicate various shades of gray, and (b) the reduction in data volume if only black and white values are digitized.

(*a*) For gray scale imaging with $2^8 = 256$ levels of gray

$$\text{number of bits} = 128 \times 128 \times 256 = 4{,}194{,}304 \text{ bits}$$

(*b*) For black and white (binary bit conversion)

$$\text{number of bits} = 128 \times 128 \times 2 = 16{,}384 \text{ bits}$$

$$\text{reduction in data volume} = 4{,}194{,}304 - 16{,}384$$
$$= 4{,}177{,}920 \text{ bits}$$

SEGMENTATION:

An image can be broken into regions that can then be used for later calculations. In effect this method looks for different self contained regions, and uses region numbers instead of pixel intensities.

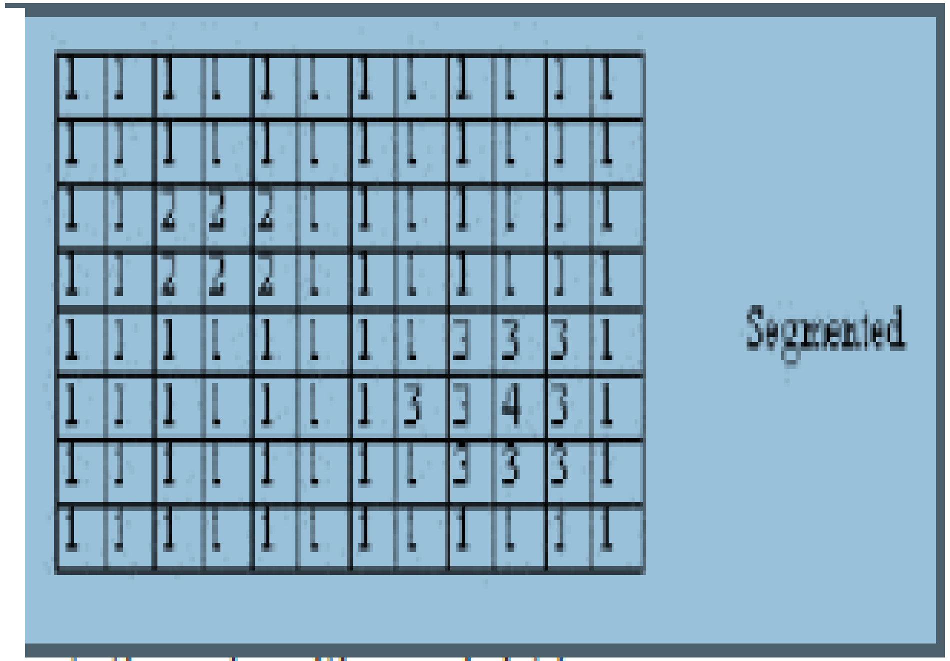
Three important techniques that will discuss are;

- **Thresholding**
- **Region growing**
- **Edge Detection**

SEGMENTATION:

A simple segmentation algorithm might be,

1. Threshold image to have values of 1 and 0.
2. Create a segmented image and fill it with zeros (set segment number variable to one).
3. Scanning the old image left to right, top to bottom.
4. If a pixel value of 1 is found, and the pixel is 0 in the segmented image, do a flood fill for the pixel onto the new image using segment number variable.
5. Increment segment # and go back to step 3.
6. Scan the segmented image left to right, top to bottom.
7. If a pixel is found to be fully contained in any segment, flood fill it with a new segment as in steps 4 and 5.



1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	2	2	2	1	1	1	1	1	1	1
1	1	2	2	2	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	3	3	3	1
1	1	1	1	1	1	1	3	3	4	3	1
1	1	1	1	1	1	1	1	3	3	3	1
1	1	1	1	1	1	1	1	1	1	1	1

FEATURE EXTRACTION

The images formed on the screen can have multiple objects which are to be distinguished from one another for processing and anylysis. The features that characterize uniquely, the objects provide means to extract the identification and comparison. This is accomplished by the features like area, diameter and perimeter, also minimum enclosing rectangle, and gray levels are considered in the feature extraction.

The area of the object is described by the region growing procedure as explained before. The area is given by

$$\text{Area} = \frac{(\text{perimeter})^2}{\text{thickness}},$$

where thickness = compactness of the object.

Diameter = (Thickness × Area).

The enclosing boundary that covers the specific area can be established by the pixel intensity difference, at the boundary.

The diameter of an object image is the maximum distance obtainable on two different points on the perimeter of an object.

An important observation is that the selected feature does not depend upon position and orientation of the boundary.

Example 7-5 Consider the schematic of the image in Fig. 7-9. Determine the area, the minimum aspect ratio, the diameter, the centroid, and the thinness measures of the image.

For the image, the minimum boundary rectangle is as shown. For ease of calculation, the origin is translated to O' with x', y' coordinates. The area may be determined from the moment, $M_{o'o'}$ as

$$M_{o'o'} = \sum_{x', y'} x'y' = 24 \text{ pixels}$$

The minimum aspect ratio would use the minimum boundary rectangle and would simply be

$$\text{minimum aspect ratio} = \frac{\text{length}}{\text{width}} = \frac{9}{4}$$

with the diameter = 9 pixels. The centroid position for the $n = 24$ pixels in the region would be calculated from

$$C.G._{x'} = \frac{1}{n}\sum_{x'} x'$$

$$C.G._{y'} = \frac{1}{n}\sum_{y'} y'$$

or

$$C.G._{x'} = \tfrac{1}{24}[4(\tfrac{1}{2}) + 4(\tfrac{3}{2}) + 4(\tfrac{5}{2}) + 2(\tfrac{7}{2}) + \cdots + 2(\tfrac{17}{2})]$$
$$= \tfrac{1}{24}(90) = \tfrac{15}{4} \text{ units}$$
$$C.G._{y'} = \tfrac{1}{24}[3(\tfrac{1}{2}) + 9(\tfrac{3}{2}) + 9(\tfrac{5}{2}) + 3(\tfrac{7}{2})]$$
$$= \tfrac{96}{48} = 2 \text{ units}$$

where pixel location is taken at the midpoint of each pixel cell. (C.G. =

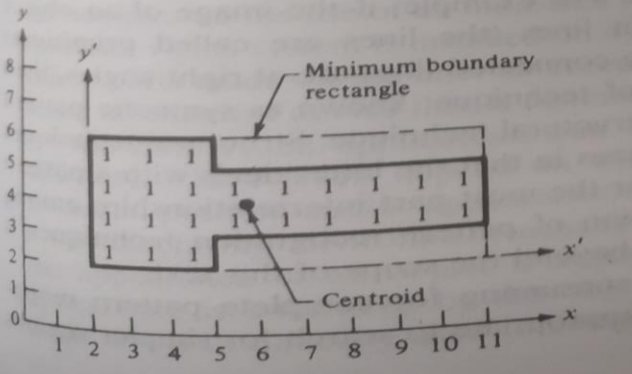


Figure 7-9 Schematic of pixel pattern for Example 7-5.

center of gravity.) The centroid is indicated in Fig. 7-9. Of the two thinness measures defined, the calculations would result in

$$\text{Compactness} = \frac{(\text{perimeter})^2}{\text{area}} = \frac{26^2}{24} = 28.17$$

$$\text{Thinness} = \frac{\text{diameter}}{\text{area}} = \frac{9}{24} = \frac{3}{8}$$

OBJECT RECOGNITION:

Form Fitting

- It can sometimes help to relate a shape to some other geometric primitive using compactness, perimeter, area, etc.
- ellipse
- square
- circle
- rectangle

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UNIT 4
SENSORS IN ROBOTICS

TRANSDUCERS AND SENSORS:

Transducer is a device that converts one type of physical variable to (Example: force, pressure, temperature, velocity and flow rate, etc) into another form.

A sensor is a transducer that is used to make a measurement of a physical variable of interest.

Some of a common sensors and transducers include strain gauges, thermocouples, speedometers and Pitot tubes.

A sensor or transducer requires calibration in order to be useful as a measuring device. Calibration is the procedure by which the relationship between the measured variable and the converted output signal is established.

Transducers and Sensors can be classified into two basic types. They are,

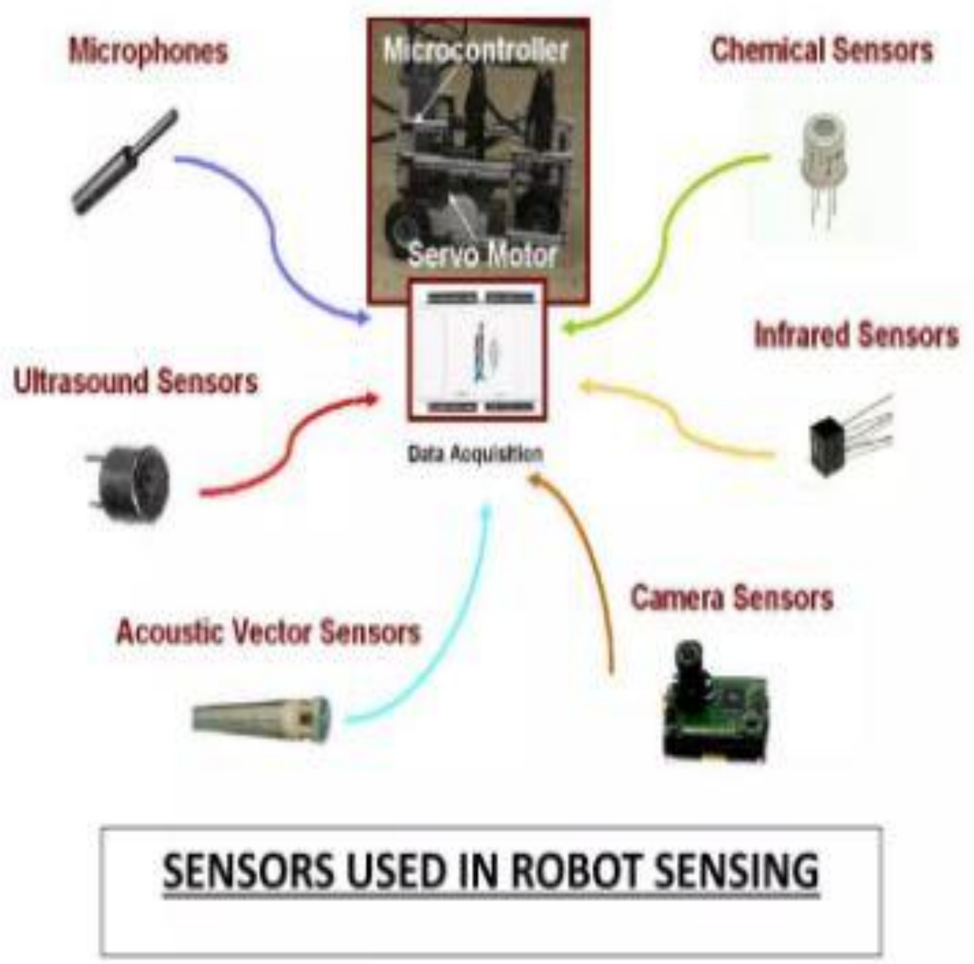
Analog Transducer (this will produce voltage or current)

Digital Transducer (this will produce digital output signal)

SENSORS IN ROBOTICS

Sensors used in robotics include a wide range of devices which can be divided into the following categories.

1. **Tactile Sensors**
2. **Proximity and Range Sensors**
3. **Miscellaneous sensors and sensor based systems**
4. **Machine vision system**



TACTILE SENSORS:

Tactile Sensors are devices which indicate contact between themselves and some other solid object. Tactile sensing devices can be divided into two classes:

Touch sensors

Force Sensors

TOUCH SENSOR:

It will provide a binary output signal which indicates whether or not contact has been made with the object.

FORCE SENSOR:

It indicate not only the contact has been made with the object but also the magnitude of the contact force between the two objects.

TOUCH SENSORS:

Touch Sensors are used to indicate that contact has been made between two objects without regard to the magnitude of the contacting force.

Included within this category are simple devices such as limit switches, micro switches, and the like.

The simpler devices are frequently used in the design of interlock systems in robotics.

For example, they can be used to indicate the presence or absence of parts in a fixture or at the pickup point along a conveyor.

Another use for a touch sensing device would be as part of an inspection probe which is manipulated by the robot to measure dimensions on a work part

FORCE SENSORS:

The capacity to measure forces permits the robot to perform a number of tasks.

These include the capability to grasp parts of different sizes in material handling, machine loading and assembly work, applying the appropriate level of force for the given part.

In assembly applications, force sensing could be used to determine if screws have become cross threaded or if parts are jammed.

Force sensing in robotics can be accomplished in several ways. A commonly used technique is a "Force sensing wrist". This consists of a special load cell mounted between the gripper and wrist.

Another technique is to measure the torque being exerted by each joint. This is usually accomplished by sensing motor current for each of the joint motors.

Finally, a third technique is to form an array of force sensing elements so that the shape and other information about the contact surface can be determined.

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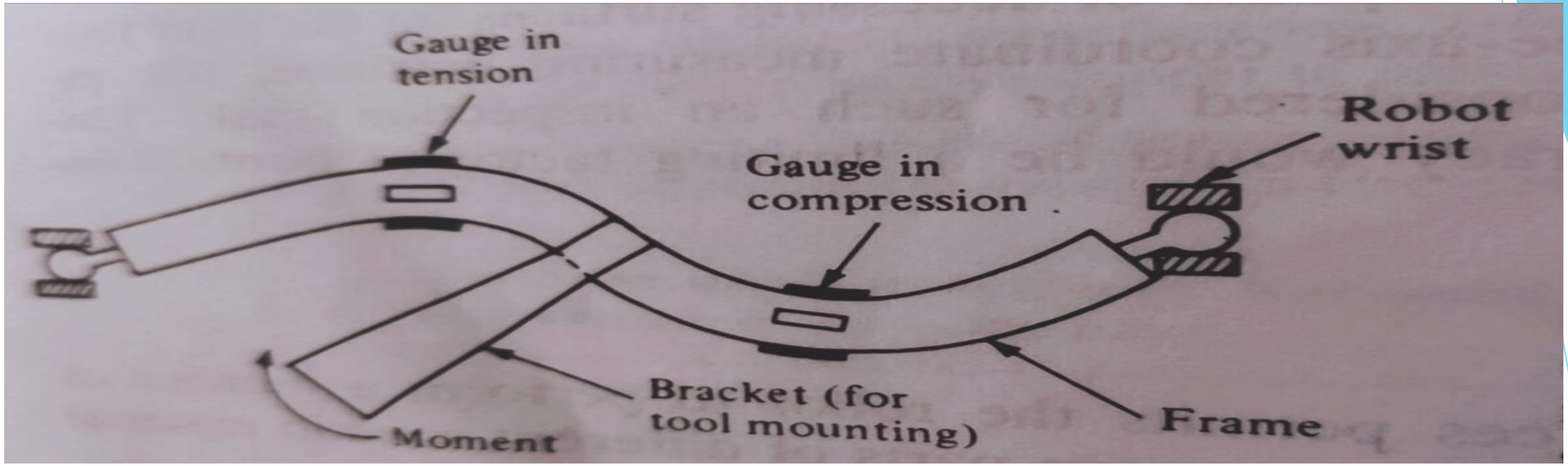
FORCE SENSING WRIST:



The purpose of a force sensing wrist is to provide information about the three components of force Fx, Fy, Fz and the three moments (Mx, My, Mz) being applied at the end of the arm. One possible construction of a force sensing wrist.

The device consists of a metal bracket fastened to a rigid frame. The frame is mounted to the wrist of the robot and the tool is mounted to the center of the bracket.

The figure shows how the sensors might react to a moment applied to the bracket due to forces and moments on the tool

FORCE SENSING WRIST:

Since the forces are usually applied to the wrist in combinations it is necessary to first resolve the forces and moments into their six components. This kind of computation can be carried out by the robot controller or by a specialized amplifier designed for this purpose.

Based on these calculations the robot controller can obtain the required information of the forces and moments being applied at the wrist

This information could be used for a number of applications.

As an example, an insertion operation requires that there are no side forces being applied to the peg.

Another example is where the robots end effector is required to follow along an edge or contour of an irregular surface. This is called force accommodation.

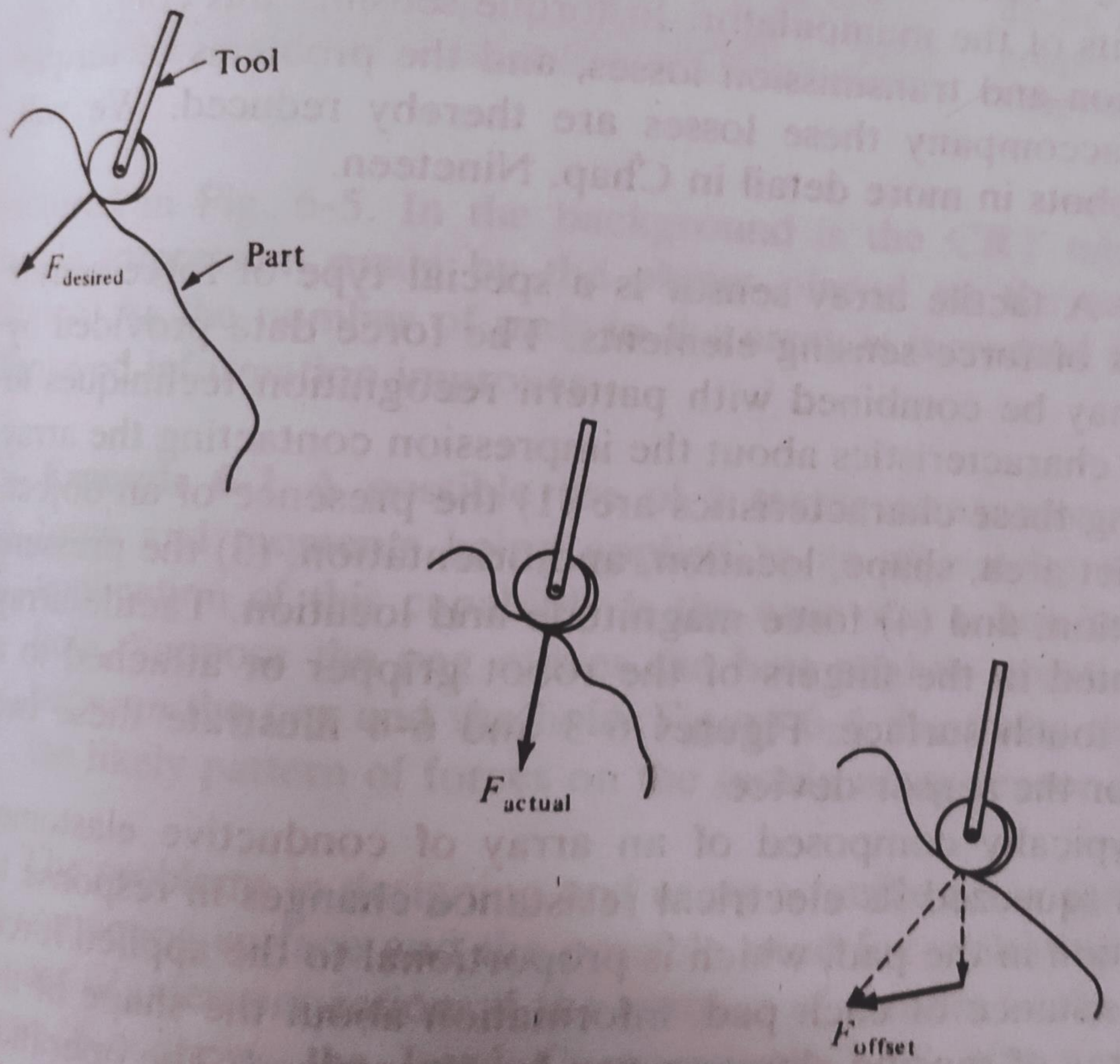
With this technique, certain forces are set equal to zero while others are set equal to specific values. Using force accommodation, one could command the robot to follow the edge or contour by maintaining a fixed velocity in one direction and fixed forces in other directions.

FORCE SENSING WRIST:

The robot Equipped with a force sensing wrist plus the proper computing capacity could be programmed to accomplish these kinds of applications.

The procedure would begin by deciding on the desired force to be applied in each axis direction. The controller would perform the following sequence of operations, with the resulting offset force calculated.

1. Measure the forces at the wrist in each axis direction
2. Calculate the force offsets required. The force offset in each direction is determined by subtracting the desired force from the measured force.
3. Calculate the torques to be applied by each axis to generate the desired force offsets at the wrist. These are moment calculations which take into account the combined effects of the various joints and links of the robot
4. Then the robot must provide the torques calculated in step 3 so that the desired forces are applied in each direction.



Tool
Part
$F_{desired}$
F_{actual}
F_{offset}

FORCE SENSING WRIST:

Force sensing wrists are usually very rigid devices so that they will not deflect undesirably while under load. When designing a force sensing wrist there are several problems that may be encountered.

The end of the arm is often in a relatively hostile environment. This means that the device must be sufficiently rugged to withstand the environment.

For example, it must be capable of tolerating an occasional crash of the robot arm. At the same time the device must be sensitive enough to detect small forces. This design problem is usually solved by using over travel limits. An over travel limit is a physical stop designed to prevent the force sensor from deflecting so far that it would be damaged.

The calculations required to utilize a force sensing wrist are complex and require considerable computation time. Also, for an arm travelling at moderate to high speeds, the level of control over the arm just as it makes contact with an object is limited by the dynamic performance of the arm. The moment of the arm makes it difficult to stop its forward motion quickly enough to prevent a crash

JOINT SENSING:

If the robot uses dc servomotors then the torque being exerted by the motors is proportional to the current flowing through the armature.

A simple way to measure this current is to measure the voltage drop across a small precision resistor in series with the motor and power amplifier.

TACTILE ARRAY SENSING:

A tactile array sensor is a special type of force sensor composed of a matrix of force sensing elements.

This force data provided by this type of device may be combined with pattern recognition techniques to describes a number of characteristics about the impression contacting the array sensor surface.

These characteristics are,

i) The presence of an object

ii) The object's contact area, shape, location and orientation

iii) The pressure and pressure distribution

iv) Force magnitude and location

FORCE SENSING WRIST:

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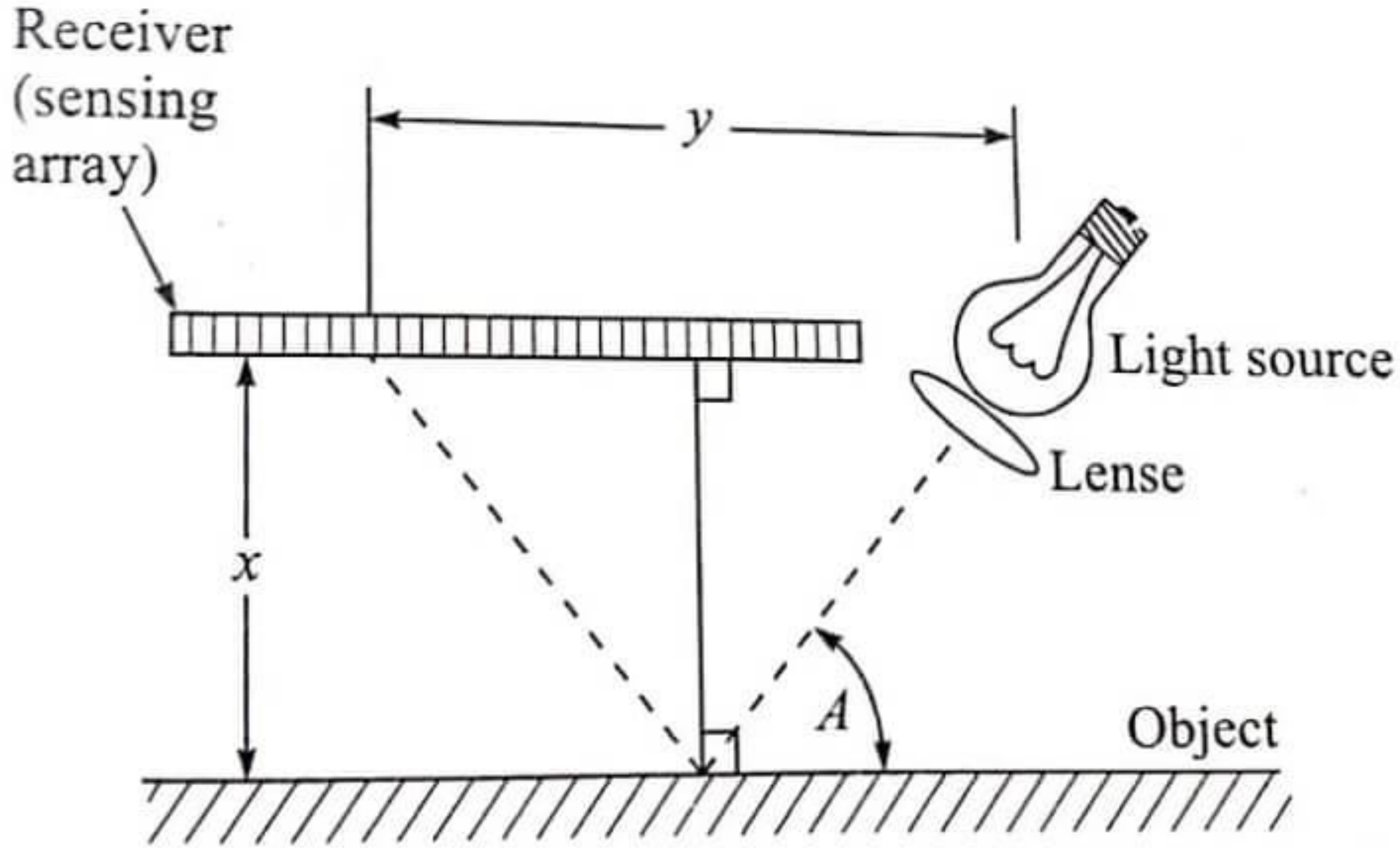
RANGE SENSOR:

- Range Sensor is implemented in the end effector of a robot to calculate the distance between the sensor and a work part. The values for the distance can be given by the workers on visual data. It can evaluate the size of images and analysis of common objects. The range is measured using the Sonar receivers & transmitters or two TV cameras.

SENSORS USED IN ROBOTICS

- **a) Proximity Sensor:** This type of sensor is capable of pointing out the availability of a component. Generally, the proximity sensor will be placed in the robot moving part such as end effector. This sensor will be turned ON at a specified distance, which will be measured by means of feet or millimeters. It is also used to find the presence of a human being in the work volume so that the accidents can be reduced.
- **Infrared (IR) Transceivers**: An IR LED transmits a beam of IR light and if it finds an obstacle, the light is simply reflected back which is captured by an IR receiver. Few IR transceivers can also be used for distance measurement.
- **Ultrasonic Sensor**: These sensors generate high frequency sound waves; the received echo suggests an object interruption. Ultrasonic Sensors can also be used for distance measurement.
- **Photoresistor**: Photoresistor is a light sensor; but, it can still be used as a proximity sensor. When an object comes in close proximity to the sensor, the amount of light changes which in turn changes the resistance of the Photoresistor. This change can be detected and processed.



Scheme for proximity sensor using reflected light against a sensor array

The formula for the distance between the object and the sensor is given as follows:

$$x = 0.5\, y \tan(A)$$

where x the distance of the object from the sensor

y = the lateral distance between the light source and the reflected light beam against the linear array. This distance corresponds to the number of elements contained within the reflected beam in the sensor array

A = the angle between the object and the sensor array as illustrated in fig.

Use of this device in the configuration shown relies on the fact that the surface of the object must be parallel to the sensing array.

MISCELLANEOUS SENSORS AND SENSOR BASED SYSTEMS

The Miscellaneous category covers the remaining types of sensors and transducers that might be used for interlocks and other purposes in robotic work cells.

This category includes devices with the capability to sense variables such as temperature, pressure, fluid flow and electric properties.

USES OF SENSORS IN ROBOTICS

The major uses of sensors in industrial robotics and other automated manufacturing systems can be divided into four basic categories.

1. **Safety Monitoring**
2. **Interlocks in work cell control**
3. **Part inspection for quality control**
4. **Determining positions and related information about objects in the robot cell**

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MADRAS INSTITUTE OF TECHNOLOGY

ANNA UNIVERSITY

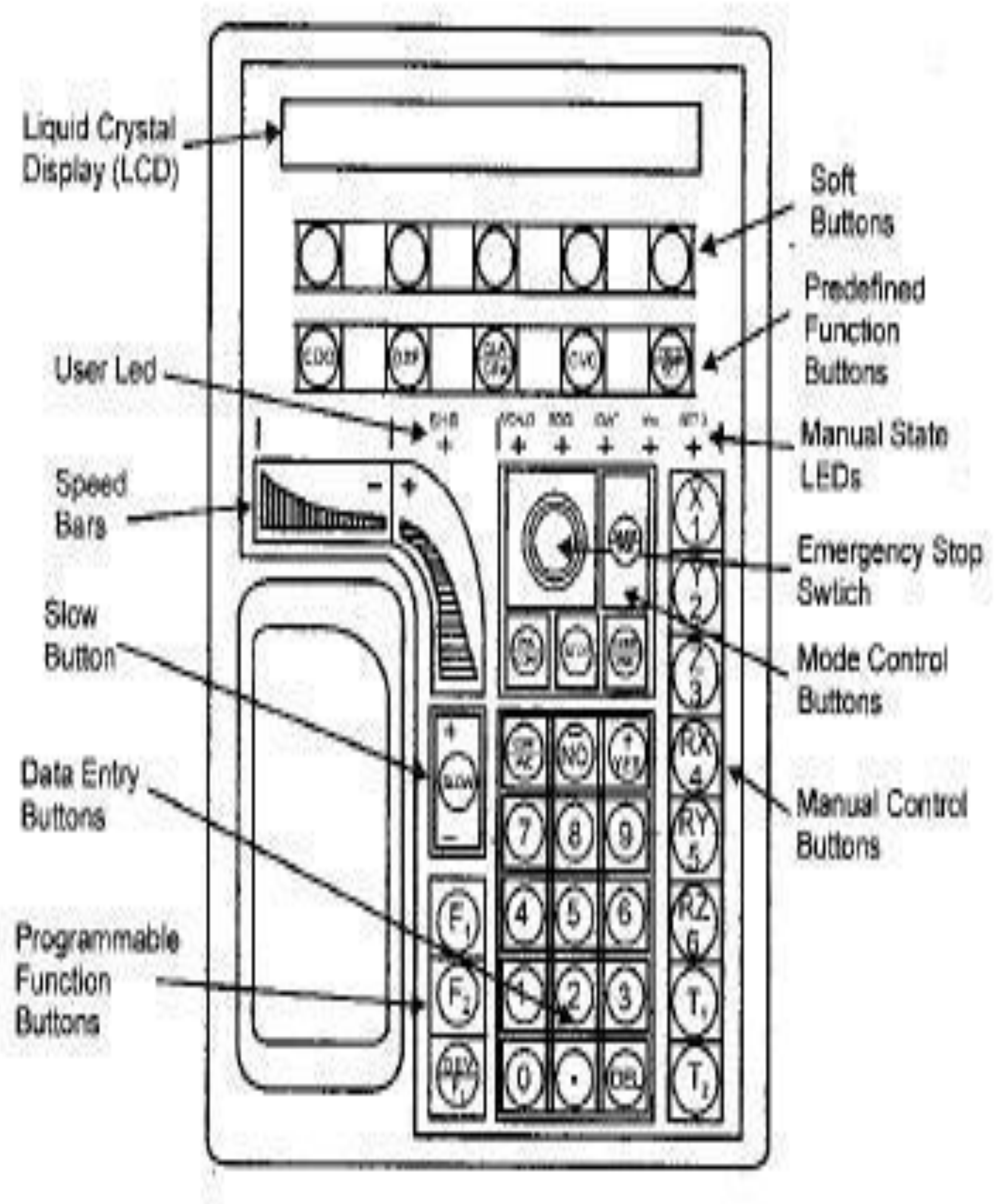
UNIT 4
ROBOT PROGRAMMING

TEACH PENDANT PROGRAMMING:

- The teach pendant has the following primary functions:
- Serve as the primary point of control for initiating and monitoring operations. Guide the robot or motion device, while teaching locations.
- Support application programs.
- The Teach Pendant is used with a robot or motion device primarily to teach.
- Robot locations for use: in application programs. The Teach Pendant is also used with custom. Applications that employ —teach routine's that pause execution at specified points and allow an Operator to teach * re-teach the robot locations used by the program. There are two styles of Teach Pendants: the programmer‘s pendant, which is designed for use while an application is being written and debugged, and the operator‘s pendant, which is designed for use during normal system operation.

TEACH PENDANT PROGRAMMING:

- The operator‘s pendant has a palm-activated switch, which is connected to the remote emergency stop circuitry of the controller. Whenever this switch is released, arm power is removed from the motion device.
- To operate the Teach Pendant left hand is put through the opening on the left-hand side of the pendant and the left thumb is used to operate the pendant speed bars. The right hand is used for all the other function buttons.



TEACH PENDANT PROGRAMMING:

The major areas of the Teach Pendant are:

1. Data Entry Buttons:

The data entry buttons are used to input data, normally in response to prompts that appear on the pendant display The data entry buttons include YES/NO, DEL, the numeric buttons, the decimal point and the REC/DONE button, which behaves like the Return or Enter key on a normal keyboard. In many cases, application programs have users press the REC/DONE button to signal that they have completed a task.

2. Emergency Stop Switch:

The emergency stop switch on the Teach Pendant immediately halts program execution and turns off arm power.

3. User LED:

The pendant is in background mode when the user LED is in not lit and none of the predefined functions are being used. The user LED is lit whenever an application program is making use of the Teach Pendant.

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TEACH PENDANT PROGRAMMING:

4. Mode Control Buttons:

The mode control buttons change the state being used to move the robot, switch control between the Teach Pendant and the application programs and enable arm power when necessary.

5. Manual Control Buttons:

When the Teach Pendant is in manual mode, these buttons select which robot joint will move, or the coordinate axis along which the robot will move.

6. Manual State LEDs:

The manual state LEDs indicates the type of manual motion that has been selected.

7. Speed Bars:

The speed bars are used to control the robot‘s speed and direction. Pressing the speed bar near the outer ends will move the robot faster, while pressing the speed bar near the center will move the robot slower.

TEACH PENDANT PROGRAMMING:

8. Slow Button:

The slow button selects between the two different speed ranges of the speed bars.

9. Predefined Function Buttons:

The predefined function buttons have specific, system- wide functions assigned to them, like display of coordinates, clear error, etc.

10. Programmable Function Buttons:

The programmable function buttons are used in custom application programs, and their functions will vary depending upon the program being run.

11. Soft Buttons:

The ―soft‖ buttons have different functions depending on the application program being run, or the selection made from the predefined function buttons.

LEAD THROUGH PROGRAMMING:

- During this programming method, the traveling of robots is based on the desired movements, and it is stored in the external controller memory. There are two modes of a control system in this method such as a run mode and teach mode. The program is taught in the teach mode, and it is executed in the run mode. The lead through programming method can be done by two methods namely:

  Powered Lead through Method

  Manual Lead through Method

Powered Lead through Method:

- The powered lead through is the common programming method in the industries. A teach pendant is incorporated in this method for controlling the motors available in the joints. It is also used to operate the robot wrist and arm through a sequence of points. The playback of an operation is done by recording these points. The control of complex geometric moves is difficult to perform in the teach pendant. As a result, this method is good for point to point movements. Some of the key applications are spot welding, machine loading & unloading, and part transfer process.

LEAD THROUGH PROGRAMMING:

Manual Lead through Method:

- In this method, the robot‘s end effectors is moved physically by the programmer at the desired movements. Sometimes, it may be difficult to move large robot arm manually. To get rid of it a teach button is implemented in the wrist for special programming. The manual lead through method is also known as Walk Through method. It is mainly used to perform continuous path movements. This method is best for spray painting and arc welding operations.

Limitation:

- Lead through programming is not readily compatible with modern computer based technology.
- Robot cannot be used in production, while it is being programmed.

VARIOUS TYPES OF ROBOT PROGRAMMING LANGUAGES:

Robot Programming Languages :

- Robot languages have been developed for ease of control of motions of robots having different structures and geometrical capabilities.
- Some of the robot languages have been developed by modifying the existing general- purpose computer languages and some of them are written in a completely new style.
- Programming languages have been developed by the pioneer efforts of various researchers at Stanford Artificial Intelligence Laboratory; research laboratories of IBM Corporation, under U.S. Air Force sponsorship, General Electric Co., Unimation and many other robot manufacturers.

WAVE and AL:

- WAVE, developed at Stanford, demonstrated a robot hand—eye coordination while it was implemented in a machine vision system.
- Later a powerful language AL was developed to control robot arms. WAVE incorporated many important features.
- Trajectory calculations through coordination of joint movements, end-effector positions and touch sensing were some of the new features of WAVE. But the algorithm was too complex and not user friendly.

VARIOUS TYPES OF ROBOT PROGRAMMING LANGUAGES:

WAVE and AL:

- They could not be run in real-time and on-line. On the other hand, trajectory calculations are possible at compile time and they can be modified during run time.

AML:

- A manufacturing language, AML was developed by IBM. AML is very useful for assembly operations as different user—robot programming interfaces are possible.
- The programming language AML is also used in other automated manufacturing systems.
- The advantage of using AML is that integers, real numbers and strings can be specified in the same aggregate which is said to be an ordered set of constants or variables.

MCL:

- US Air force ICAM project led to the development of another manufacturing control language known as MCL by Mc Donnel—Douglas.
- This is a modification of the popular APT (Automatically Programmed Tooling) language used in CNC machine tools as many similar commands are used to control machine tools in CAM applications.

VARIOUS TYPES OF ROBOT PROGRAMMING LANGUAGES:

RAIL:

- RAIL was developed by Automatic for robotic assembly, inspection, arc welding and machine vision. A variety of data types as used in PASCAL can be used.
- An interpreter is used to convert the language into machine language commands. It uses Motorola 68000 type microcomputer system; It supports many commands and control of the vision system.

HELP:

- HELP was developed by General Electric Company. It acts more or less like RAIL.
- It has the capability to control two robot arms at the same time. The structure of the language is like PASCAL.

JARS:

JARS was developed by NASA JPL. The base of the language is PASCAL. JARS can be interfaced with PUMA 6000 robot for running robotic programs.

VARIOUS TYPES OF ROBOT PROGRAMMING LANGUAGES:

RPL:

- RPL was developed at SRI International. A compiler is used to convert a program into the codes that can be interpreted by an interpreter. Unimation PUMA 500 can be controlled with the help of RPL. The basic ideas of LISP (an Al language) have been organized into a FORTRAN-like syntax in RPL. It is modular and flexible.
- Besides these, there are some other languages like PAL, ADA etc. PAL has been written by Richard Paul by modifying WAVE and incorporating features of PASCAL. But the representations of syntaxes used in the program are difficult to handle. ADA developed by the Department of Defense (DOD) in USA is a real-time system that can be run on several microcomputers like Zilog, VAX, Motorola 68000, etc. ADA is convenient for controlling the robots used in a manufacturing cell.
- Different textual robot languages have different attributes. Far example, VAL, HELP and MC though powerful for many simple tasks, do not have the same structured modular programming capability like AL, AML, JARS and ADA or VAL II. In a manufacturing cell, multiple robots or robotic equipment work in unison. Control of two or more operations done by the robots in a coordinated manner is complex.

VARIOUS TYPES OF ROBOT PROGRAMMING LANGUAGES:

RPL:

- Synchronizing the motions of the robots requires necessary software commands. AL, ADA, AML, MCL have the capability of controlling multiple arms. The programming language must be capable of expressing various geometric features like joint angles, coordinate transformations such as rotation, translation, and vector quantities. Homogeneous matrices are used to specify the rotation. Rotation can also be specified by Euler angles. AML, RAIL and VAL use Euler angles while AL manipulates homogeneous matrix for control. AL is very suitable for assembly tasks wherein many sensors are employed, though other languages like AML and HELP are flexible enough to run various subroutines. Slewing and straight- line motions control are available with most of the languages.

VARIOUS COMMANDS:

Definition	*Command Statement*	*Explanation*
1. Motion control	APPRO P1, Z1	Command to approach the point P1 in the z-direction by Z1 distance above the object.
	MOVE P1	Command to move the arm from the present position to point P1.
	MOVE P1 VIA P2	Asks the robot to move to point P1 through point P2.
	DMOVE (J1, ΔX)	Moves the joint J1 by an increment of ΔX (linear)
	DMOVE (J1, J2, J3) ($d\alpha$, $d\beta$, $d\theta$)	Command to move joints J1, J2 and J3 by incremental angles of $d\alpha$, $d\beta$, $d\theta$ respectively.
2. Speed control	SPEED V IPS	The speed of the end effector is to be V inch per second at the time of program execution.
	SPEED R	Command to operate the arm end effector at R percent of the normal speed at the time of program execution.
3. Position control	HERE P1	Defining the name of a point as P1.
	DEFINE P1 = POINT (x, y, z, w_α, w_β, w_θ)	The command defines the point P1 with x, y, z co-ordinates and w_α, w_β, w_θ the wrist rotation angles.
	Path control : DEFINE PATH 1 = PATH (P1, P2, P3)	The path of the end effector is defined by the connection between points P1, P2 and P3 in series.
	MOVE PATH 1	Movement of the end effector along path 1.
	Frame definition: DEFINE FRAME 1 = FRAME (P1, P2, P3)	— Assings variable name to FRAME 1 defined by points P1, P2 and P3. P1-origin, P2-point along x-axis and P3-point along xy plane.
	MOVE ROUTE: FRAME 1.	— Defines the movement in the path for frame 1.
4. End effector operation	OPEN	— Opens the gripper fingers.
	CLOSE 50 MM	— In forms gripper to close keeping 50 mm width between the fingers.