



UNIT V

INDUSTRIAL ROBOTICS

ROBOT ANATOMY AND RELATED ATTRIBUTES

- The anatomy of industrial robots deals with the assembling of outer components of a robot such as wrist, arm and body.
- Before jumping into robot configurations, here are some of the key facts about robot anatomy.

(a) Joints and Links

(b) Common Robot Configurations

JOINTS AND LINKS

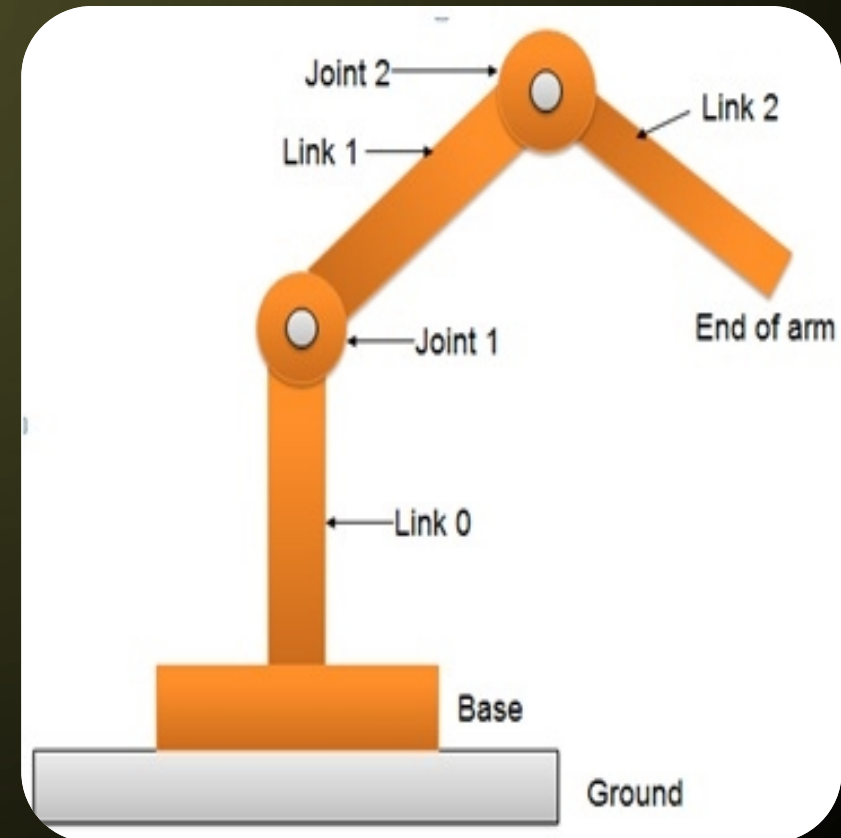
- The manipulator of an industrial robot consists of a series of joints and links.
- Robot anatomy deals with the study of different joints and links and other aspects of the manipulator's physical construction.
- A robotic joint provides relative motion between two links of the robot.
- Each joint, or axis, provides a certain degree-of-freedom (dof) of motion.
- In most of the cases, only one degree-of-freedom is associated with each joint.
- Robot's complexity can be classified according to the total number of degrees -of-freedom they possess.
- Each joint is connected to two links, an input link and an output link.

JOINTS AND LINKS

- A Joint provides controlled relative movement between the input link and output link. A robotic link is the rigid component of the robot manipulator.
- Most of the robots are mounted upon a stationary base, such as the floor. From this base, a joint-link numbering scheme may be recognized as shown in Figure.

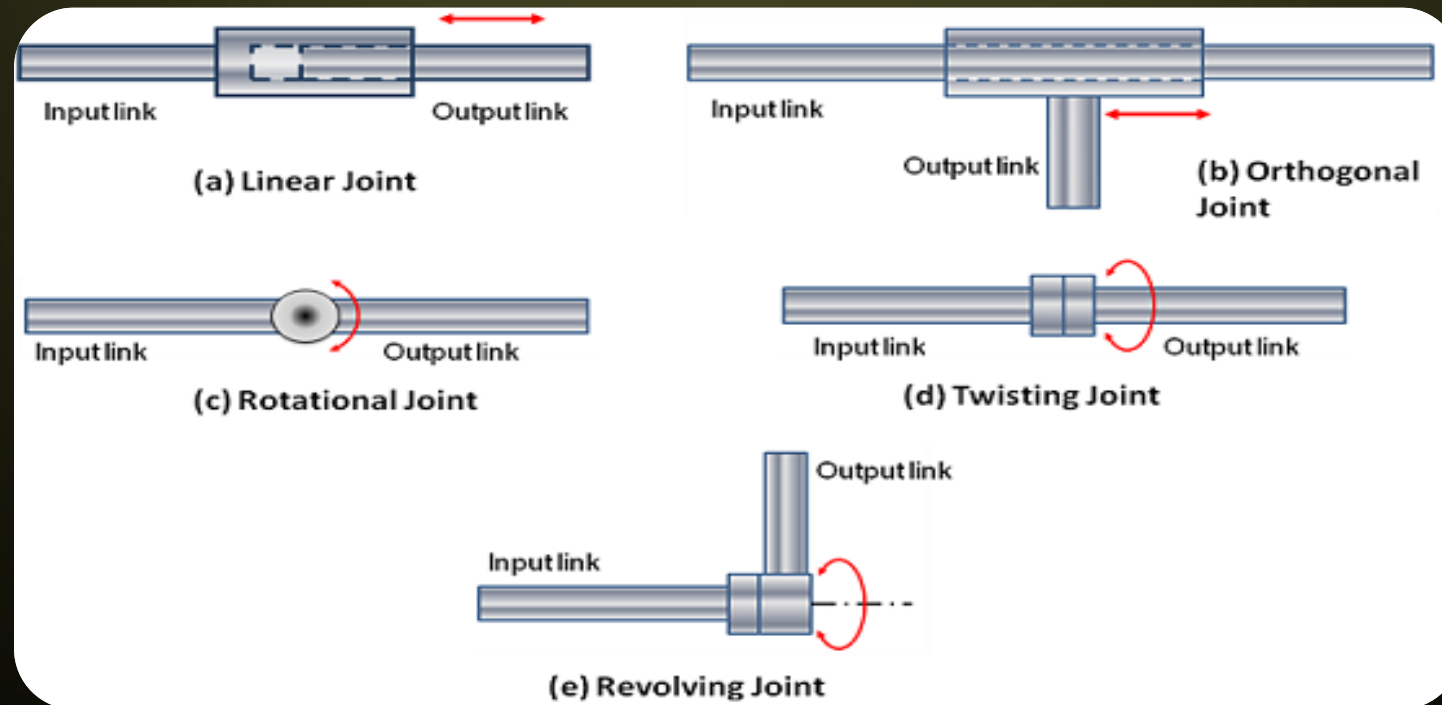
JOINTS AND LINKS

- The robotic base and its connection to the first joint are termed as link-0.
- The first joint in the sequence is joint-1.
- Link-0 is the input link for joint-1, while the output link from joint-1 is link-1 which leads to joint-2.
- Link 1 is the output link for joint-1 and the input link for joint-2.
- This joint-link-numbering scheme is further followed for all joints and links in the robotic systems.



JOINTS AND LINKS

- Nearly all industrial robots have mechanical joints that can be classified into following five types as shown in Figure below.



JOINTS AND LINKS

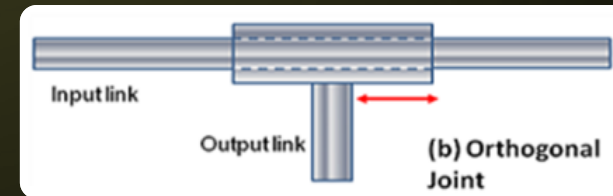
a) Linear joint (type L joint)

- The relative movement between the input link and the output link is a translational sliding motion, with the axes of the two links being parallel.



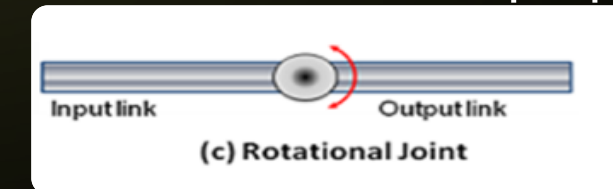
b) Orthogonal joint (type U joint)

- This also has a translational sliding motion, but the input and output links are perpendicular to each other during the move.



c) Rotational joint (type R joint)

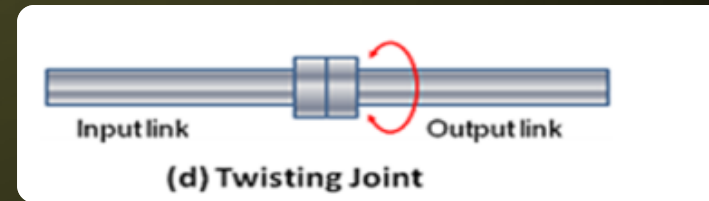
- This type provides rotational relative motion, with the axis of rotation perpendicular to the axes of the input and output links.



JOINTS AND LINKS

d) Twisting joint (type T joint)

- This joint also involves rotary motion, but the axis of rotation is parallel to the axes of the two links.



e) Revolving joint (type V-joint, V from the “v” in revolving)

- In this type, axis of input link is parallel to the axis of rotation of the joint. Axis of the output link is perpendicular to the axis of rotation.

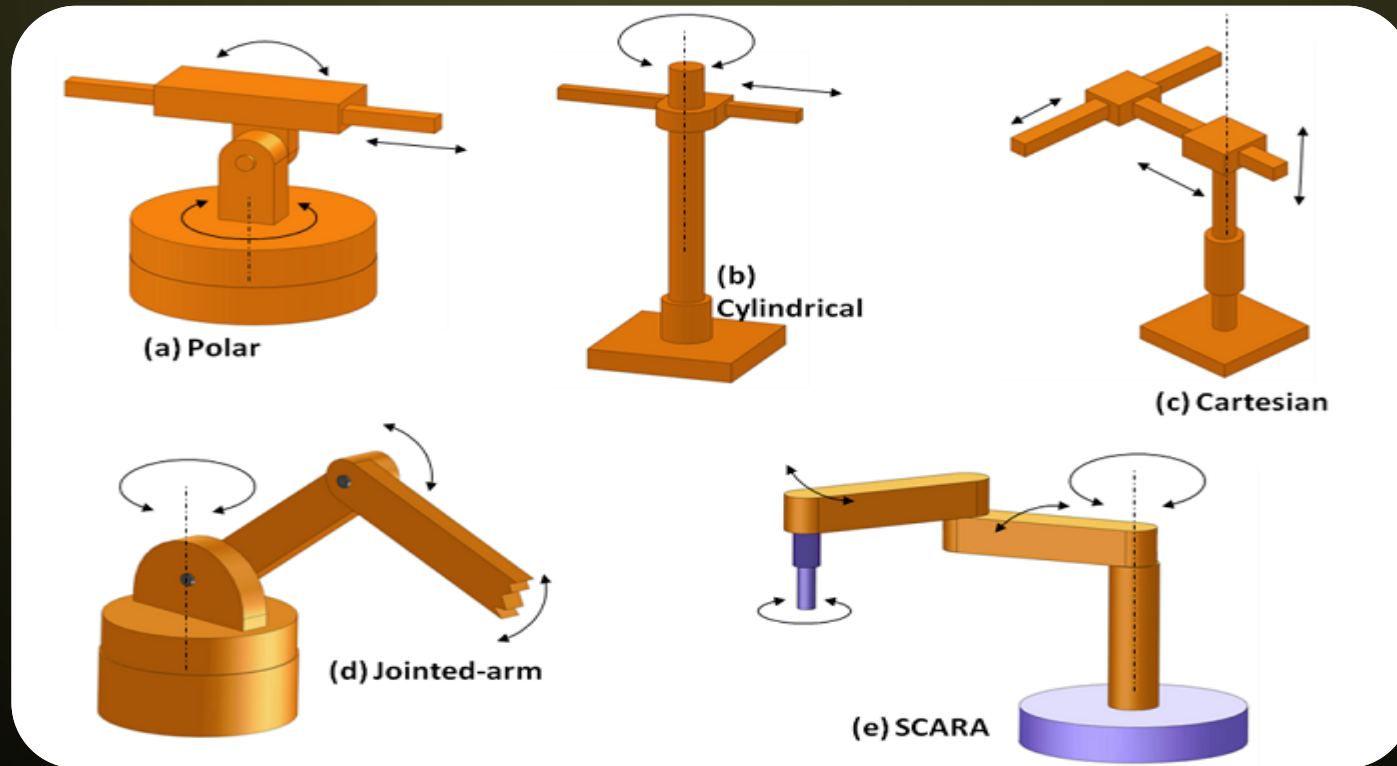


COMMON ROBOT CONFIGURATIONS

- Basically the robot manipulator has two parts viz.
- A body-and-arm assembly with three degrees-of-freedom and A wrist assembly with two or three degrees-of-freedom.
- For body-and-arm configurations, different combinations of joint types are possible for a three-degree-of-freedom robot manipulator.

COMMON ROBOT CONFIGURATIONS

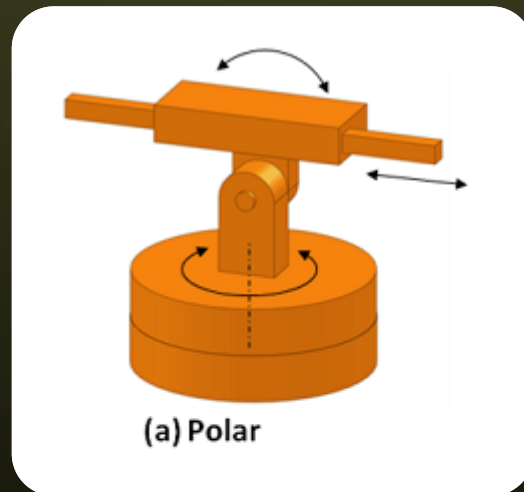
- Five common body-and-arm configurations are outlined below.



COMMON ROBOT CONFIGURATIONS

(i) Polar configuration

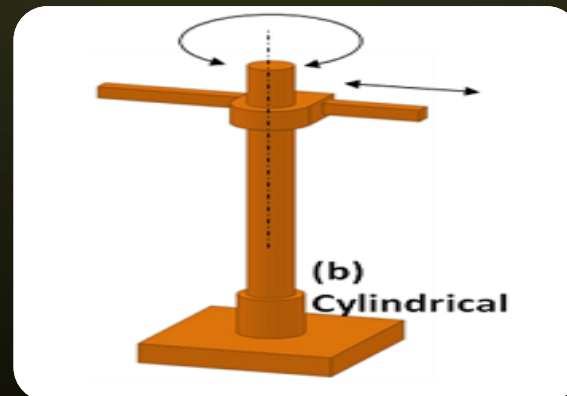
- It consists of a sliding arm L-joint, actuated relative to the body, which rotates around both a vertical axis (T-joint) and horizontal axis (R-joint).



COMMON ROBOT CONFIGURATIONS

(ii) Cylindrical configuration

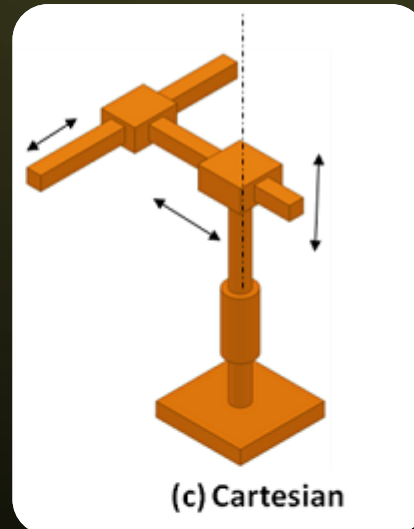
- It consists of a vertical column. An arm assembly is moved up or down relative to the vertical column.
- Arm can be moved in and out relative to the axis of the column. Common configuration is to use a T-joint to rotate the column about its axis.
- An L-joint is used to move the arm assembly vertically along the column, while an O-joint is used to achieve radial movement of the arm.



COMMON ROBOT CONFIGURATIONS

(iii) Cartesian co-ordinate robot

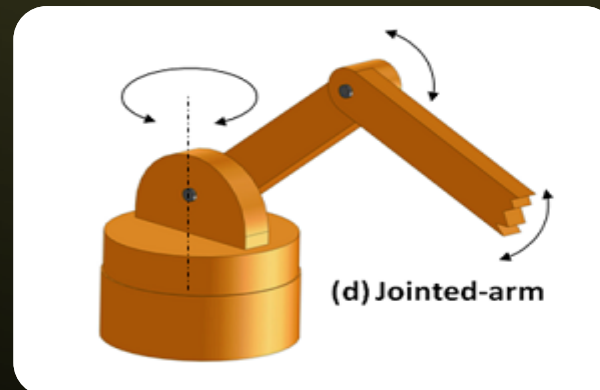
- It is also known as rectilinear robot and x-y-z robot. It consists of three sliding joints, two of which are orthogonal O-joints.



COMMON ROBOT CONFIGURATIONS

(iv) Jointed-arm robot

- It is similar to the configuration of a human arm.
- It consists of a vertical column that swivels about the base using a T-joint. Shoulder joint (R-joint) is located at the top of the column.
- The output link is an elbow joint (another R joint).



COMMON ROBOT CONFIGURATIONS

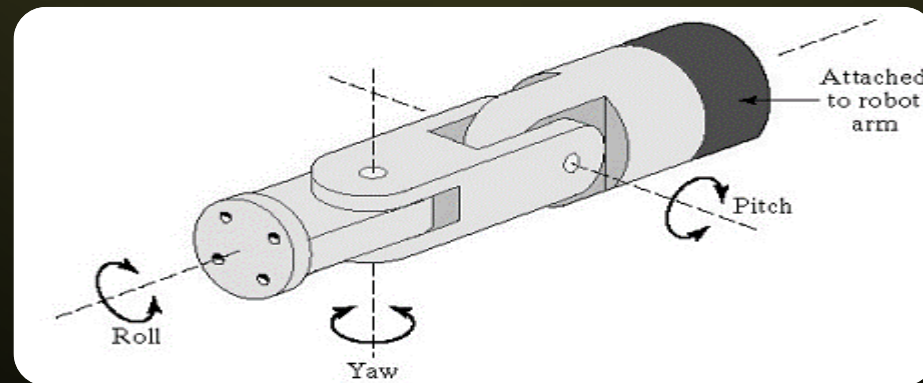
(v) SCARA

- Its full form is 'Selective Compliance Assembly Robot Arm'.
- It is similar in construction to the jointer-arm robot, except the shoulder and elbow rotational axes are vertical.
- The arm is very rigid in the vertical direction, but compliant in the horizontal direction. Robot wrist assemblies consist of either two or three degrees-of-freedom.

COMMON ROBOT CONFIGURATIONS

(v) SCARA

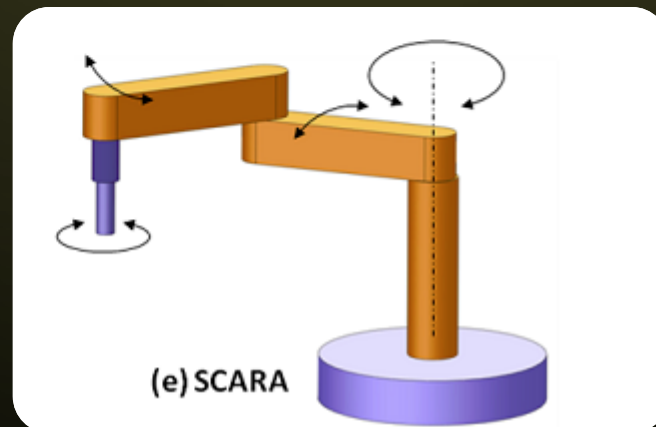
- A typical three-degree-of-freedom wrist joint is depicted in Figure.
- Roll joint is accomplished by use of a T-joint.
- Pitch joint is achieved by recourse to an R-joint. Yaw joint, a right-and-left motion, is gained by deploying a second R-joint.



COMMON ROBOT CONFIGURATIONS

(v) SCARA

- SCARA body and arm configuration does not use a separate wrist assembly.
- Its usual operative environment is for insertion-type assembly operations where wrist joints are unnecessary.
- The other four body and arm configurations more or less follow the wrist-joint configuration by deploying various combinations of rotary joints.



CLASSIFICATION OF ROBOTS

- The three types of drive systems that are generally used for industrial robots are:

(i) Hydraulic drive

(ii) Electric drive

(iii) Pneumatic drive

CLASSIFICATION OF ROBOTS

i) Hydraulic drive

- It gives a robot great speed and strength. They provide high speed and strength, hence they are adopted for large industrial robots.
- This type of drives are preferred in environments in which the use of electric drive robots may cause fire hazards
- Example: In spray painting.

Disadvantages of a hydraulic robot:

- Occupy more floor space for ancillary equipment in addition to that required by the robot.
- There are housekeeping problems such as leaks.

CLASSIFICATION OF ROBOTS

ii) Electric drive

- This provides a robot with less speed and strength. Electric drive systems are adopted for smaller robots.
- Robots supported by electric drive systems are more accurate, exhibit better repeatability and are cleaner to use.
- Electrically driven robots are the most commonly available .

CLASSIFICATION OF ROBOTS

ii) Electric drive

- Electrically driven robots can be classified into two broad categories.

(i) Stepper motor driven.

(ii) Direct Current (DC) servo-motor driven.

- Most stepper motor-driven robots are of the open loop type.
- Feedback loops can be incorporated in stepper-driven robots.
- Servo-driven robots have feedback loops from the driven components back to the driver.

CLASSIFICATION OF ROBOTS

iii) Pneumatic drive

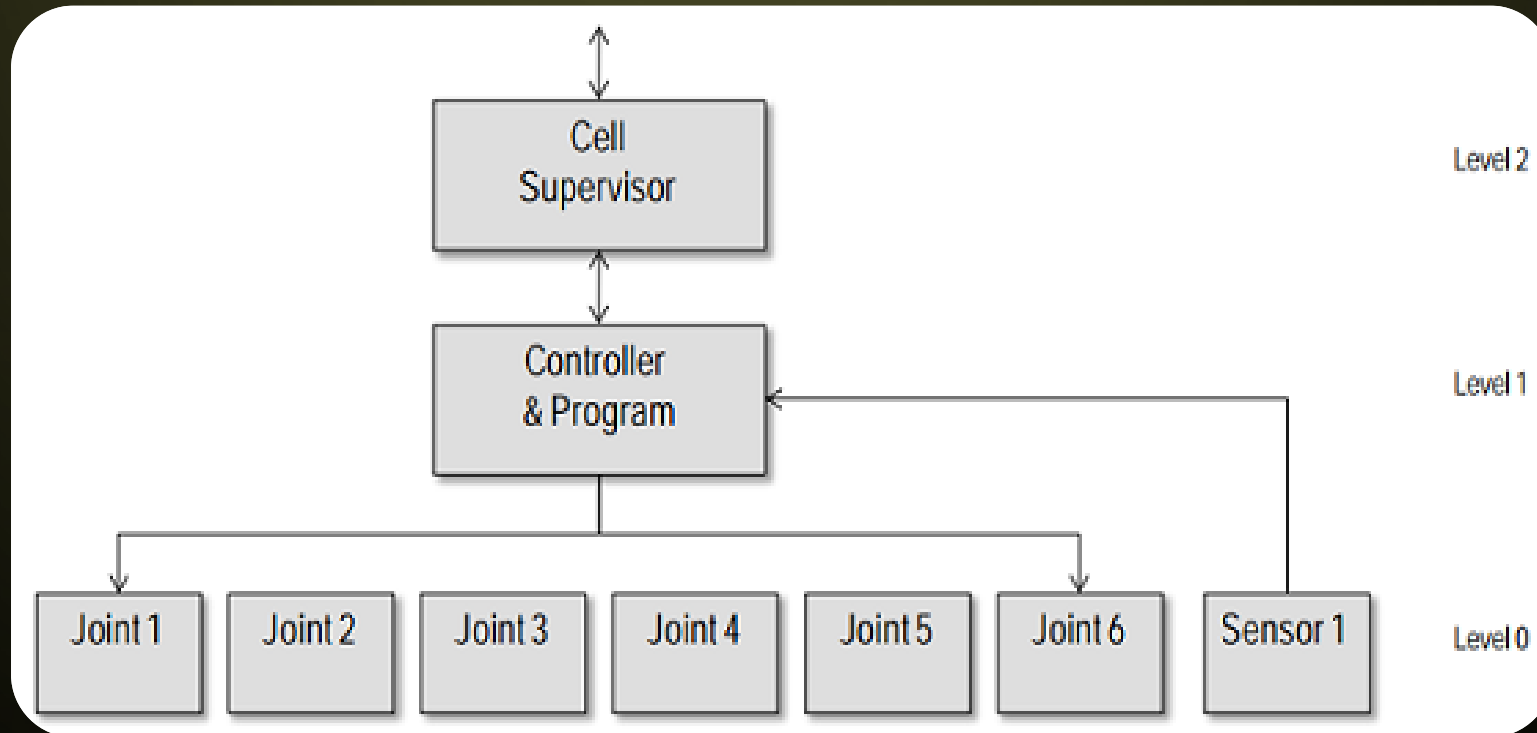
- Generally used for smaller robots.
- Have fewer axes of movement.
- Carry out simple pick-and-place material-handling operations, such as picking up an object at one location and placing it at another location.
- These operations are generally simple and have short cycle times.
- Here pneumatic power can be used for sliding or rotational joints.
- Pneumatic robots are less expensive than electric or hydraulic robots.

ROBOT CONTROL SYSTEMS

- The Joint movements must be controlled if the robot is to perform as desired.
- Micro-processor-based controllers are regularly used to perform this control action.
- Controller is organised in a hierarchical fashion, as illustrated in Figure.
- Each joint can feed back control data individually, with an overarching supervisory controller co-ordinating the combined actuations of the joints according to the sequence of the robot programme.

ROBOT CONTROL SYSTEMS

- Controller is organised in a hierarchical fashion, as illustrated in Figure.



ROBOT CONTROL SYSTEMS

Hierarchical control structure

(a) Limited Sequence Control

- Elementary control type, it is used for simple motion cycles, such as pick and place operations.
- It is implemented by fixing limits or mechanical stops for each joint and sequencing the movement of joints to accomplish operation.
- Feedback loops may be used to inform the controller that the action has been performed, so that the programme can move to the next step.
- No servo-control exists for precise positioning of joint. Many pneumatically driven robots are this type.

ROBOT CONTROL SYSTEMS

Hierarchical control structure

(b) Playback with Point to Point Control

- Playback control uses a controller with memory to record motion sequences in a work cycle, as well as associated locations and other parameters and then plays back the work cycle during programme execution.
- Point to point control means individual robot positions are recorded in the memory.
- These positions include both mechanical stops for each joint and the set of values that represent locations in the range of each joint.
- Feedback control is used to confirm that the individual joints achieve the specified locations in the programme.

ROBOT CONTROL SYSTEMS

Hierarchical control structure

(c) Playback with Continuous Path Control

- Playback is as described above.
- Continuous path control refers to a control system capable of continuous simultaneous control of two or more axes.
- Greater storage capacity—the number of locations that can be stored is greater than in point to point and interpolation calculations may be used, especially linear and circular interpolations.

ROBOT CONTROL SYSTEMS

Hierarchical control structure

(d) Intelligent Control

- An intelligent robot is one that exhibits behaviour that makes it seem intelligent.
- For example, capacities to interact with its ambient surroundings, decision-making capabilities, communication with humans; computational analysis during the work cycle and responsiveness to advanced sensor inputs.
- They may also possess the playback facilities of the above two instances.
- Requires a high level of computer control and an advanced programming language to input the decision-making logic and other 'intelligence' into the memory.

END EFFECTORS

- It is commonly known as robot hand.
- It is mounted on the wrist, enables the robot to perform specified tasks.
- Various types of end-effectors are designed for the same robot to make it more flexible and versatile.
- End-effectors are categorised into two major types:

1. Grippers

2. Tools

END EFFECTORS - GRIPPERS

- Grippers grasp and manipulate objects during the work cycle.
- Typically the objects grasped are work parts that need to be loaded or unloaded from one station to another.
- It may be custom-designed to suit the physical specifications of the work parts they have to grasp.

END EFFECTORS - GRIPPERS

- End effectors, grippers are described in detail in table below.

Type	comment
Mechanical gripper	Two or more fingers that can be actuated by robot controller to open and close on a work part.
Vacuum gripper	Suction cups are used to hold flat objects.
Magnetised devices	Making use of the principles of magnetism, these are used for holding ferrous work parts.
Adhesive devices	Deploying adhesive substances these hold flexible materials, such as fabric.
Simple mechanical devices	For example, hooks and scoops.

END EFFECTORS - GRIPPERS

- End effectors, grippers are described in detail in table below.

Type	comment
Dual grippers	Mechanical gripper with two gripping devices in one end effector for machine loading and unloading. Reduces cycle time per part by gripping two work parts at the same time.
Interchangeable fingers	Mechanical gripper whereby, to accommodate different work part sizes, different fingers may be attached.
Sensory feedback fingers	Mechanical gripper with sensory feedback capabilities in the fingers to aid locating the work part and to determine correct grip force to apply (for fragile work parts).

END EFFECTORS - GRIPPERS

- End effectors, grippers are described in detail in table below.

Type	comment
Multiple fingered grippers	Mechanical gripper with the general anatomy of the human hand.
Standard grippers	Mechanical grippers that are commercially available, thus reducing the need to custom-design a gripper for each separate robot application.

END EFFECTORS - TOOLS

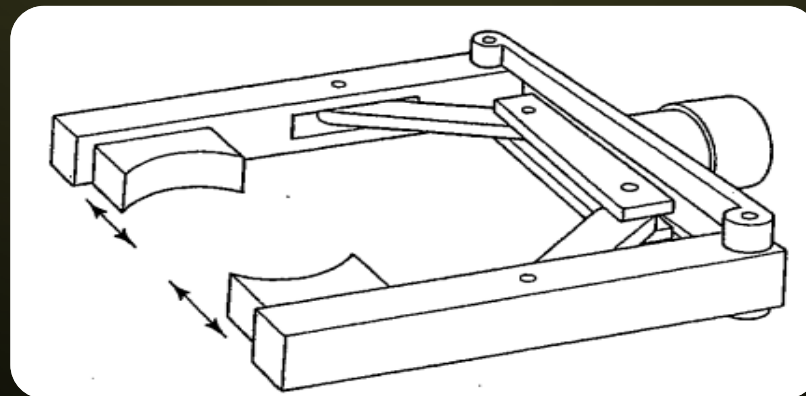
- The robot end effector may also use tools.
- Tools are used to perform processing operations on the work part.
- Typically the robot uses the tool relative to a stationary or slowly moving object.
- In this way the process is carried out.

END EFFECTORS - TOOLS

- Examples of the tools used as end effectors by robots to perform processing applications include:
 - Spot welding gun
 - Arc welding tool
 - Spray painting gun
 - Rotating spindle for drilling, routing, grinding, etc.
 - Assembly tool (e.g. automatic screwdriver)
 - Heating torch
 - Water-jet cutting tool

END EFFECTORS

- For each instance, the robot controls both the position of the work part and the position of the tool relative to the work part.
- For this purpose, the robot must be able to transmit control signals to the tool for starting, stopping and otherwise regulating the tools actions.
- Figure illustrates a sample gripper and tool.



SENSORS IN ROBOTICS

- Two basic categories of sensors used in industrial robots:

(i) Internal sensors

(ii) External sensors

SENSORS IN ROBOTICS

(i) Internal sensors

- Internal sensors are used to monitor and control the various joints of the robot.
- They form a feedback control loop with the robot controller.
- Examples of internal sensors include potentiometers and optical encoders, while tachometers of various types can be deployed to control the speed of the robot arm.

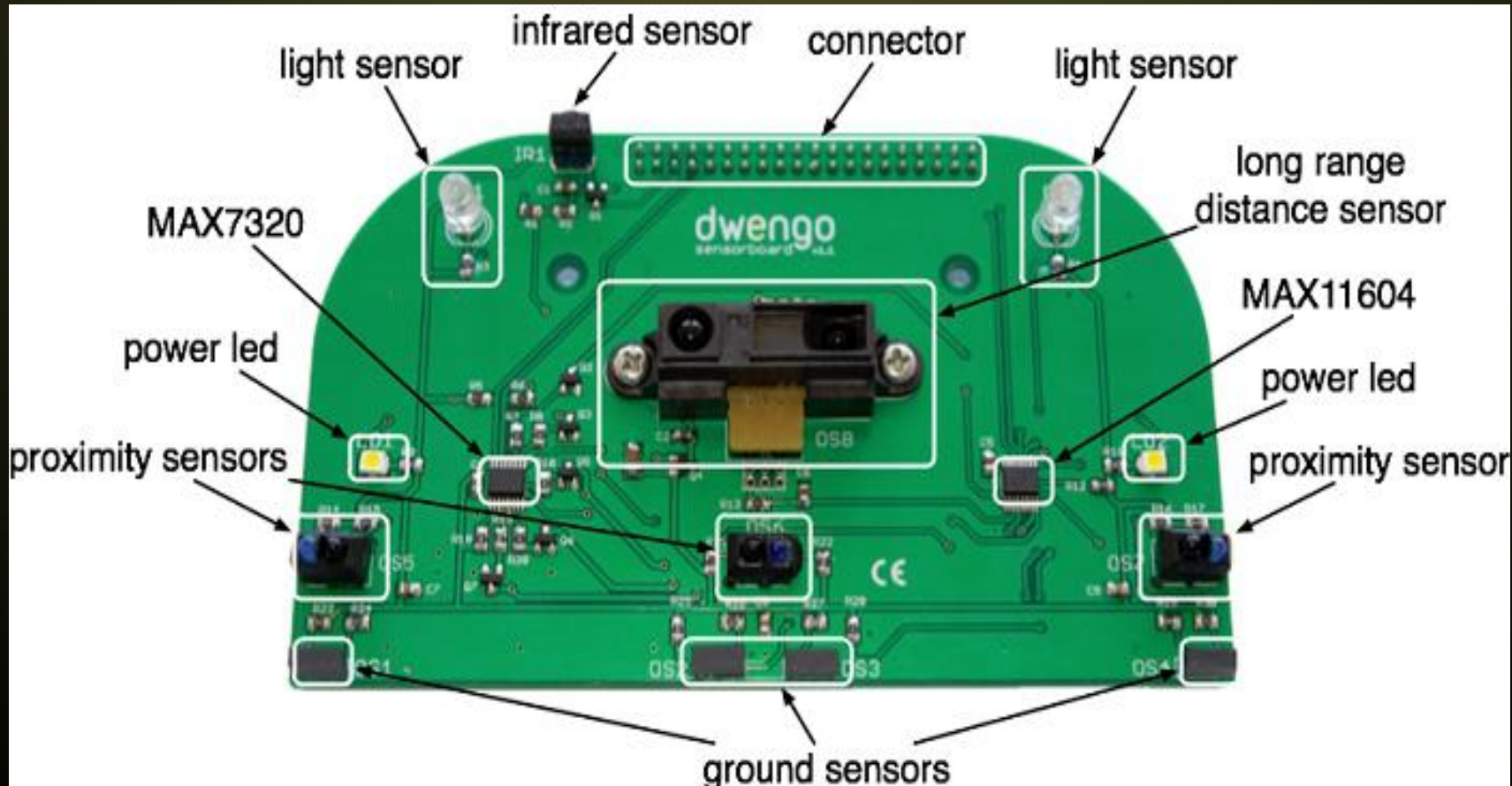
SENSORS IN ROBOTICS

(ii) External sensors

- These are external to the robot itself.
- They are used when we wish to control the operations of the robot with other pieces of equipment in the robotic work cell.
- External sensors can be relatively simple devices, such as limit switches that determine whether a part has been positioned properly or whether a part is ready to be picked up from an unloading bay.

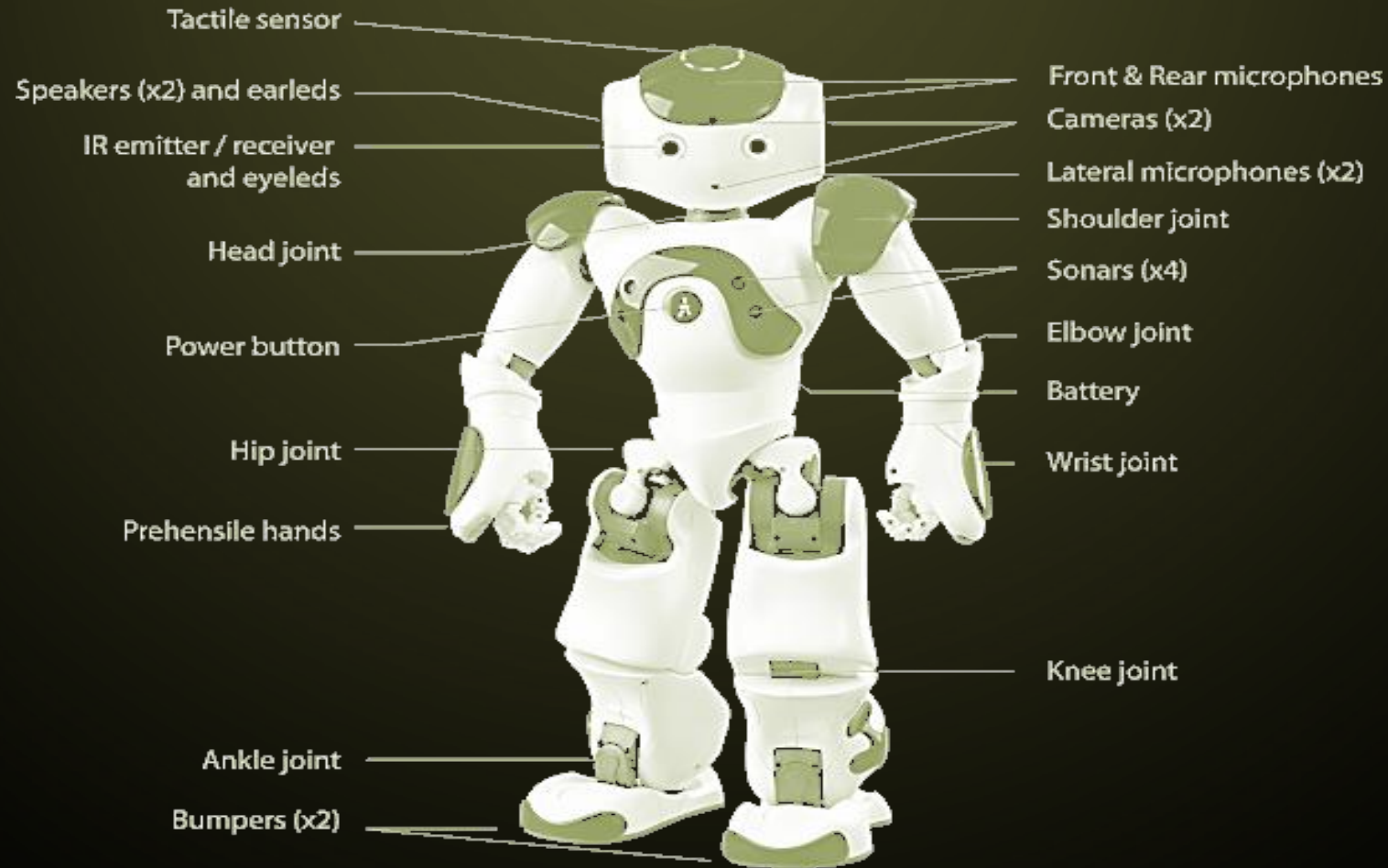
SENSORS IN ROBOTICS

- Micro Sensor board



SENSORS IN ROBOTICS

- Advanced sensor model technologies for robotics



END EFFECTORS - GRIPPERS

- A number of advanced sensor technologies may also be used; these are outlined in Table.

Sensor Type	Description
Tactile sensors	Used to determine whether contact is made between sensor and another object. Two types: touch sensors which indicate when contact is made and force sensors which indicate the magnitude of the force with the object.
Proximity sensors	Used to determine how close an object is to the sensor. Also called a range sensor.
Optical sensors	Photocells and other photometric devices that are used to detect the presence or absence of objects. Often used in conjunction to proximity sensors.

END EFFECTORS - GRIPPERS

- A number of advanced sensor technologies may also be used; these are outlined in Table.

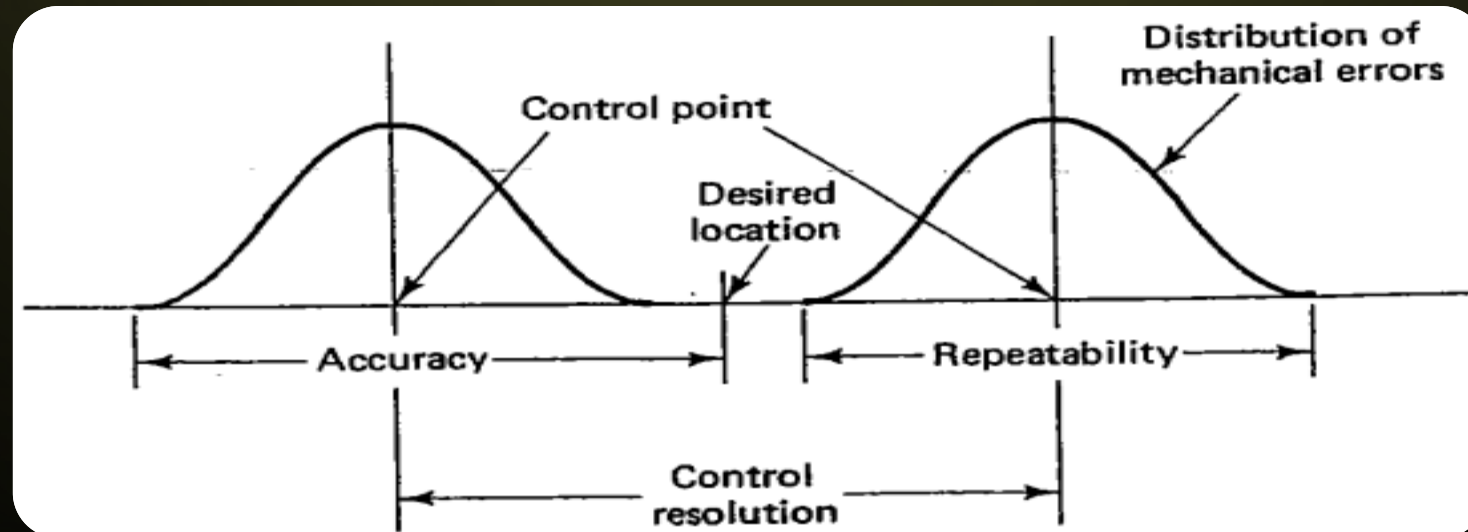
Sensor Type	Description
Machine vision	Used in robotics for inspection, parts identification, guidance and other uses.
Miscellaneous category	temperature, fluid pressure, fluid flow, electrical voltage, current and other physical properties.

ROBOT ACCURACY AND REPEATABILITY

- The capacity of the robot to position and orient the end of its wrist with accuracy and repeatability is an important control attribute in nearly all industrial applications.
- Some assembly applications require that objects be located with a precision of only 0.002 to 0.005 inches.
- Other applications, such as spot welding, usually require accuracies of 0.020 to 0.040 inches.

ROBOT ACCURACY AND REPEATABILITY

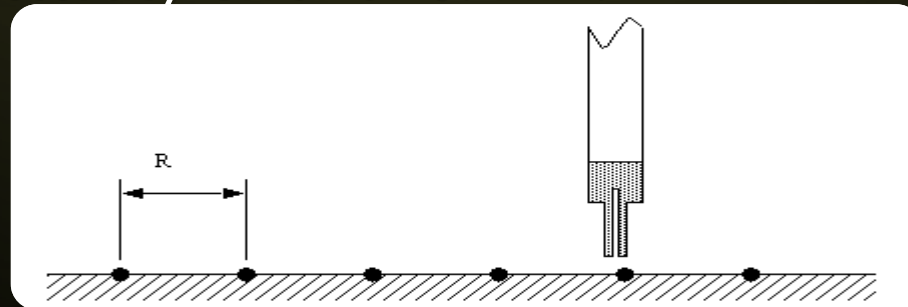
- There are several terms that must be defined in the context of this discussion:
 - Control resolution
 - Accuracy
 - Repeatability



ROBOT ACCURACY AND REPEATABILITY

Resolution

- Resolution is based on a limited number of points that the robot can be commanded to reach for, these are shown here as black dots.
- These points are typically separated by a millimetre or less, depending on the type of robot.
- This is further complicated by the fact that the user might ask for a position such as 456.4mm, and the system can only move to the nearest millimetre, 456mm, this is the accuracy error of 0.4mm.



ROBOT ACCURACY AND REPEATABILITY

Accuracy

- “How close does the robot get to the desired point”.
- This measures the distance between the specified position, and the actual position of the robot end effector.
- Accuracy is more important when performing off-line programming, because absolute coordinates are used.

ROBOT ACCURACY AND REPEATABILITY

Repeatability

- How close will the robot be to the same position as the same move made before”.
- A measure of the error or variability when repeatedly reaching for a single position.
- This is the result of random errors only.
- Repeatability is often smaller than accuracy.

INDUSTRIAL ROBOT APPLICATIONS

- Industrial Robot Applications can be divided into:
 - (i) Material-handling applications
 - (ii) Processing Operations
 - (iii) Assembly Applications

MATERIAL-HANDLING APPLICATIONS

- The robot must have following features to facilitate material handling:

1. The manipulator must be able to lift the parts safely.
2. The robot must have the reach needed.
3. The robot must have cylindrical coordinate type.
4. The robot's controller must have a large enough memory to store all the programmed points so that the robot can move from one location to another.
5. The robot must have the speed necessary for meeting the transfer cycle of the operation.

MATERIAL-HANDLING APPLICATIONS

- This category includes the following:

(1) Part Placement

(2) Palletizing or depalletizing

(3) Machine loading or unloading

(4) Stacking and insertion operations

MATERIAL-HANDLING APPLICATIONS

(1) Part Placement:

- The basic operation in this category is the relatively simple pick-and-place operation.
- This application needs a low-technology robot of the cylindrical coordinate type.
- Only two, three or four joints are required for most of the applications.
- Pneumatically powered robots are often utilized.

MATERIAL-HANDLING APPLICATIONS

(2) Palletizing and/or Depalletizing:

- The applications require robot to stack parts one on top of the other, that is to palletize them or to unstack parts by removing from the top one by one, that is depalletize them.
- Example: Process of taking parts from the assembly line and stacking them on a pallet or vice versa.

MATERIAL-HANDLING APPLICATIONS

(3) Machine loading and/or unloading:

- Robot transfers parts into and/or from a production machine.

There are three possible cases:

- Machine loading in which the robot loads parts into a production machine, but the parts are unloaded by some other means.

Example: A press working operation, where the robot feeds sheet blanks into the press, but the finished parts drop out of the press by gravity.

MATERIAL-HANDLING APPLICATIONS

- Machine loading in which the raw materials are fed into the machine without robot assistance. The robot unloads the part from the machine assisted by vision or no vision.

Example: Bin picking, die casting and plastic moulding.

- Machine loading and unloading that involves both loading and unloading of the work parts by the robot. The robot loads a raw work part into the process and unloads a finished part.

Example: Machine operation

PROCESSING OPERATIONS

- In processing operations, the robot performs some processing actions such as grinding, milling, etc. on the work part.
- The end effector is equipped with the specialised tool required for the process.
- The tool is moved relative to the surface of the work part.
- Robot performs a processing procedure on the part.
- The robot is equipped with some type of process tooling as its end effector.
- Manipulates the tooling relative to the working part during the cycle.

PROCESSING OPERATIONS

- Industrial robot applications in the processing operations include:
 - (1) Spot welding
 - (2) Continuous arc welding
 - (3) Spray painting
 - (4) Metal cutting and deburring operations
 - (5) Various machining operations like drilling, grinding, laser and waterjet cutting and riveting.
 - (6) Rotating and spindle operations
 - (7) Adhesives and sealant dispensing

ASSEMBLY OPERATIONS

- The applications involve both material handling and the manipulation of a tool.
- They typically include components to build the product and to perform material handling operations.

These are classified as:

- **Batch assembly:** As many as one million products might be assembled. The assembly operation has long production runs.
- **Low-volume:** In this a sample run of ten thousand or less products might be made. The assembly robot cell should be a modular cell.
- One of the well suited area for robotics assembly is the insertion of odd electronic components.

FUTURE APPLICATIONS

The medical applications of the robot

- Routine examinations
- Surgical procedures

Underwater applications

- Involves prospecting for minerals on the floor of the ocean.
- Salvaging of sunken vessels, repair the ship either at sea or in dry dock.
- Mobile firefighters to be used by air force and navy.

FUTURE APPLICATIONS

Surveillance and Guard duty

- Used in military
- Used in power generating plants, oil refineries and other civilian facilities that are potential targets of terrorist groups.

ROBOT PART PROGRAMMING

- It is a path in space to be followed by the manipulator, combined with peripheral actions that support the work cycle.
- To programme a robot , specific commands are entered into the robot's controller memory and this action may be performed in a number of ways.
- For limited sequence robots ,programming occurs when limit switches and mechanical stops are set to control the endpoints of its motions.

ROBOT PART PROGRAMMING

- A sequencing device controls the occurrence of the motions, which in turn controls the movement of the joints that completes the motion cycle.
- For industrial robots with digital computers as controllers three programming methods can be distinguished.
 - (a) Lead-through programming
 - (b) Computer-like robot programming languages
 - (c) Off-line programming.
- Lead-through methodologies and associated programming methods, are outlined in detail in table

ROBOT PART PROGRAMMING - LEAD-THROUGH PROGRAMMING

- Task is 'taught' to the robot by manually moving the manipulator through the required motion cycle and simultaneously entering the programme into the controller memory for playback.
- Two methods are used for teaching: powered lead-through and manual lead-through.

ROBOT PART PROGRAMMING - MOTION PROGRAMMING

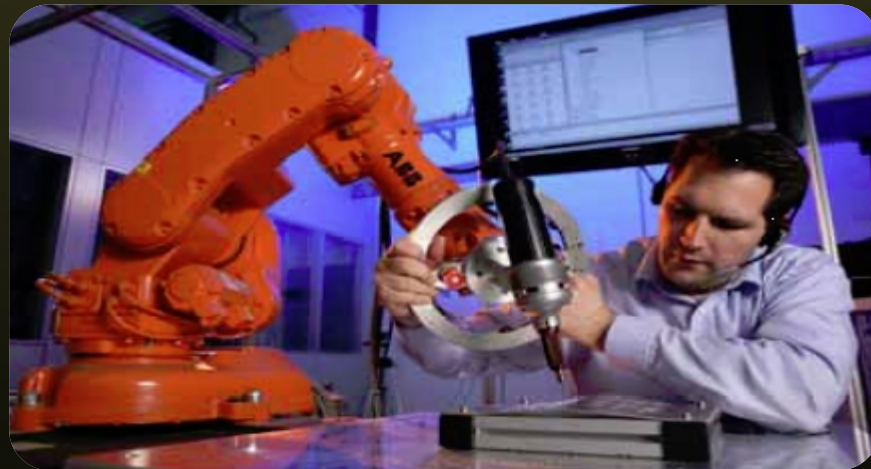
- To overcome difficulties of co-ordinating individual joints associated with lead-through programming, two mechanical methods can be used:
- The world co-ordinate system whereby the origin and axes are defined relative to the robot base and the tool co-ordinate system whereby the alignment of the axis system is defined relative to the orientation of the wrist face plate.
- These methods are typically used with Cartesian co-ordinate robots and not for robots with rotational joints.

ROBOT PART PROGRAMMING - MOTION PROGRAMMING

- The latter robotic types must rely on interpolation processes to gain straight line motion.
- Straight line interpolation where the control computer calculates the necessary points in space that the manipulator must move through to connect two points and Joint interpolation where joints are moved simultaneously at their own constant speed such that all joints start/stop at the same time.

MANUAL LEAD-THROUGH PROGRAMMING

- Manual lead through programming is convenient for programming playback robots with continuous path control where the continuous path is an irregular motion pattern such as in spray painting.
- This programming method requires the operator to physically grasp the end of arm or the tool that is attached to the arm and move it through the motion sequence, recording the path into memory.



MANUAL LEAD-THROUGH PROGRAMMING

- Because the robot arm itself may have significant mass and would therefore be difficult to move, a special programming device often replaces the actual robot for the teaching procedure.
- The programming device has the same joint configuration as the robot and is equipped with a trigger handle (or other control switch) which the operator activates when recording motions into memory.
- The motions are recorded as a series of closely spaced points. During playback the path is recreated by controlling the actual robot arm through the same sequence of points.

ADVANTAGES AND DISADVANTAGES

Advantages

- It can readily be learned by shop personnel.
- It is a logical way to teach a robot.
- It does not require knowledge of computer programming.

Disadvantages

- Downtime regular production must be interrupted to program the robot.
- Limited programming logic capability.
- Not readily compatible with modern computer based technologies.