INDUSTRIAL AUTOMATION AND ROBOTICS(BTME-3505)

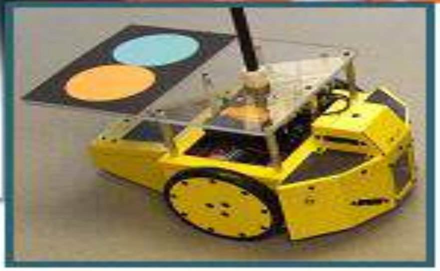
Course Name: IAR

Semester: 5th

Prepared by: Dr. Sachin Saini

Industrial Automation and Robotics

This semester we will study many aspects of robotics.



- General Robot Structures
- General Definitions
- Robot modelling
- Robot Actuators and Drive Systems
- Sensors
- Forward Kinematics
- Inverse Kinematics
- Robot Control
- Robot Programming
- Robots with external sensors
- Robot Application in Manufacturing

Robotics

Robotics is a multi-disciplinary field. Best robotics researchers and engineers will touch upon all disciplines:

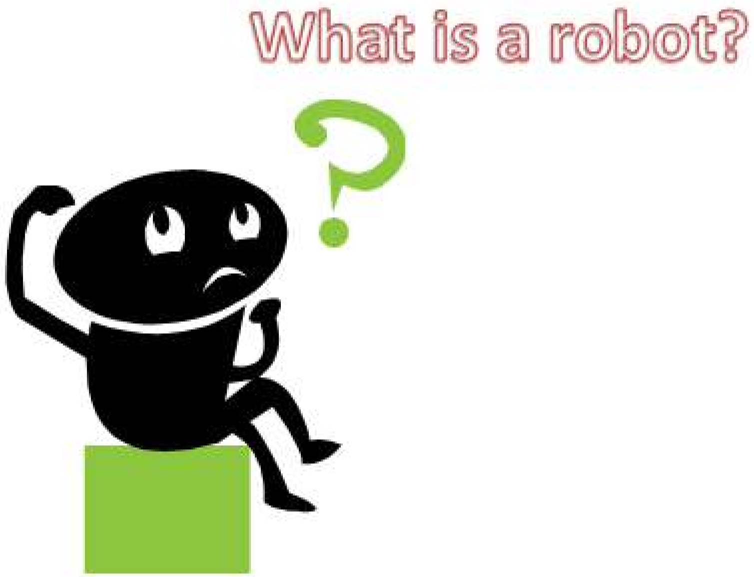
Mechanical Engineering – concerned primarily with manipulator/mobile robot design, kinematics, dynamics, compliance and actuation.

Electrical Engineering – concerned primarily with robot actuation, electronic interfacing to computers and sensors, and control algorithms.

Computer Science – concerned primarily with robot programming, planning, and intelligent behavior.

Robotics

Robotics



A Robot is:

An electromechanical device that is:

- Reprogrammable
- Multifunctional
- Sensible for environment

Robotics

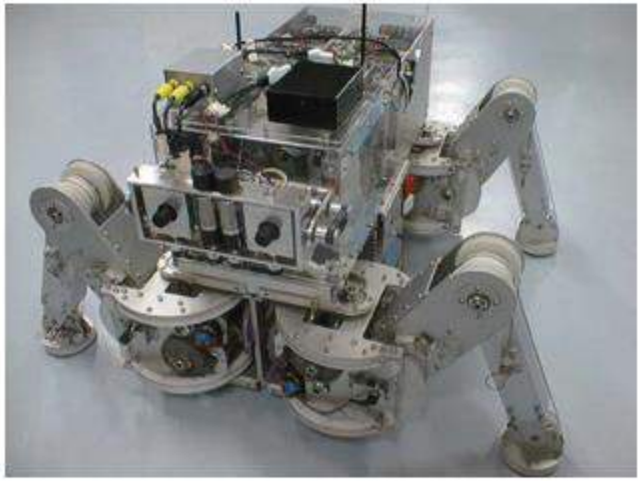
What is a Robot: I

Manipulator

Robotics

What is a Robot: II

Legged Robot



Wheeled Robot

Robotics

What is a Robot: III

Autonomous Underwater Vehicle

Unmanned Aerial Vehicle

Robotics

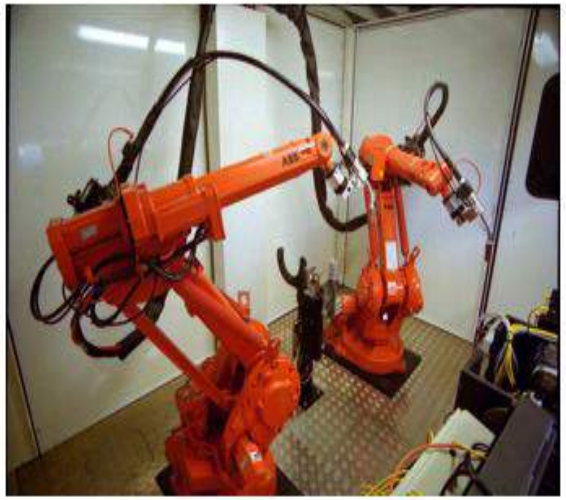
What Can Robots Do: I

Jobs that are dangerous for humans

Decontaminating Robot

Cleaning the main circulating pump housing in the nuclear power plant

What Can Robots Do: II

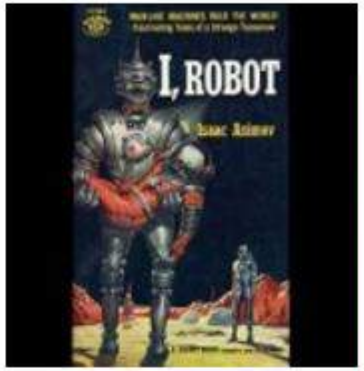


Repetitive jobs that are boring, stressful, or labor-intensive for humans

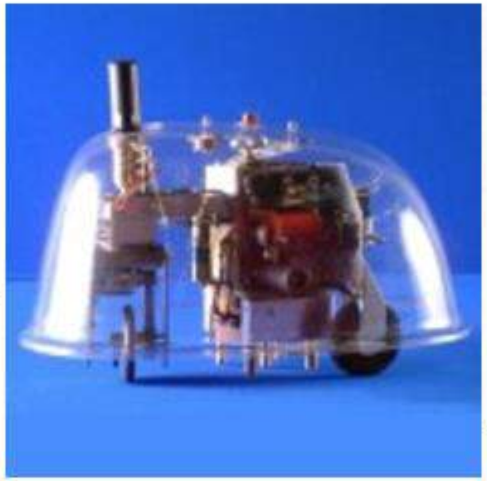
Welding Robot

Robotics

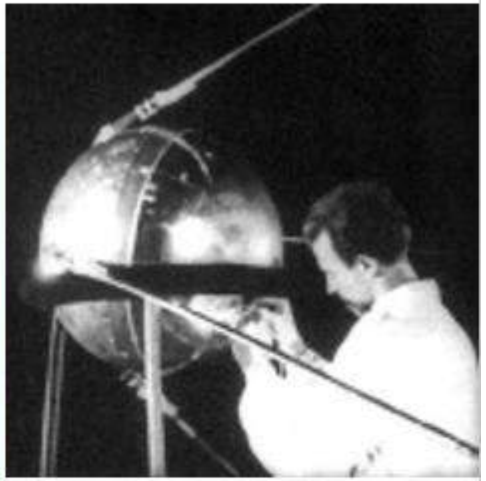
History of Robotics



I, Robot



Turtle robot

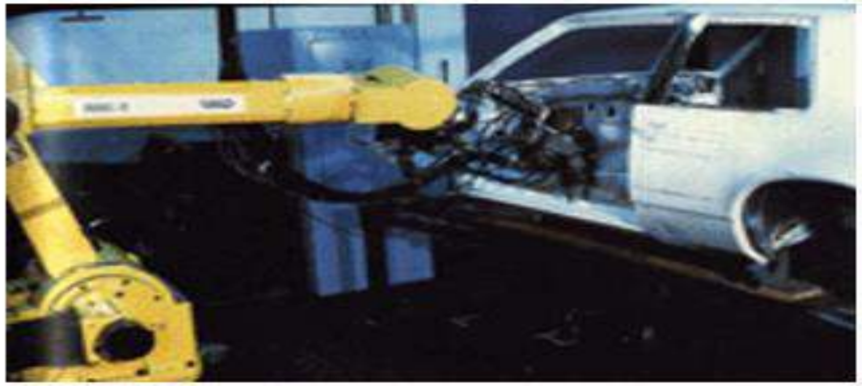


Sputnik I

Robotics

History of Robotics

- **1960`s** - Industrial Robots created. Robotic Industries Association states that an "*industrial robot is a re-programmable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions to perform a variety of tasks*".



Robot Institute of America, 1979

Robotics

History of Robotics

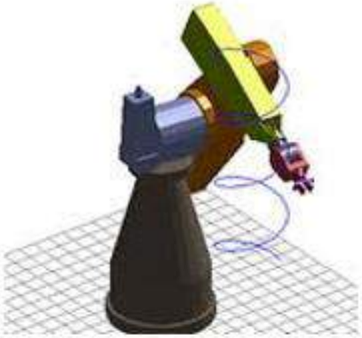
- **1977** – Development of mobile robot Hilaire at Laboratoise d'Automatique et d'Analyse des Systemes (LAAS) in Toulouse, France. This mobile robot had three wheels and it is still in use.

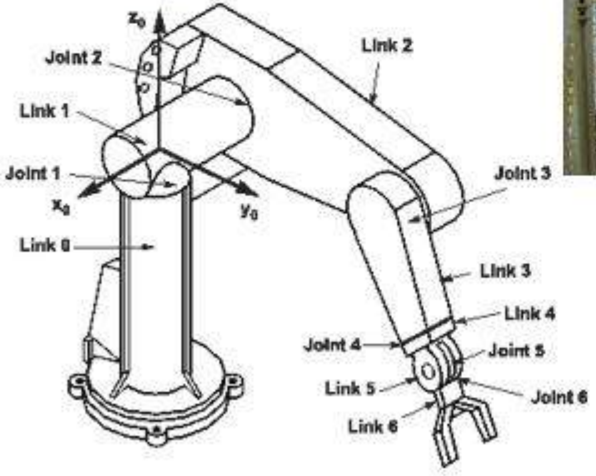
Two famous robots:

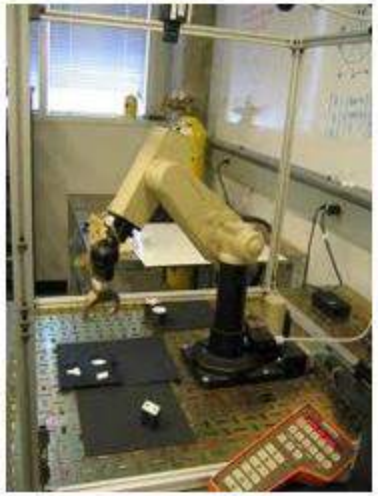
- **1978- Puma** (Programmable Universal Machine for Assembly), by Unimation.
- **1979 - SCARA** (Selective Compliant Articulated Robot for Assembly) introduced in Japan and the US (by Adept Technologies).

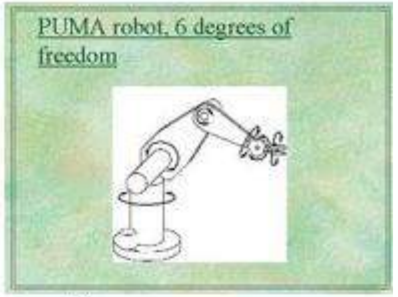
Robotics

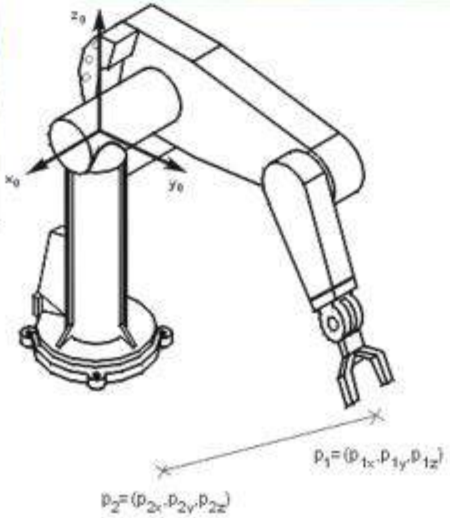
History of Robotics - PUMA











Robotics

History of Robotics - SCARA

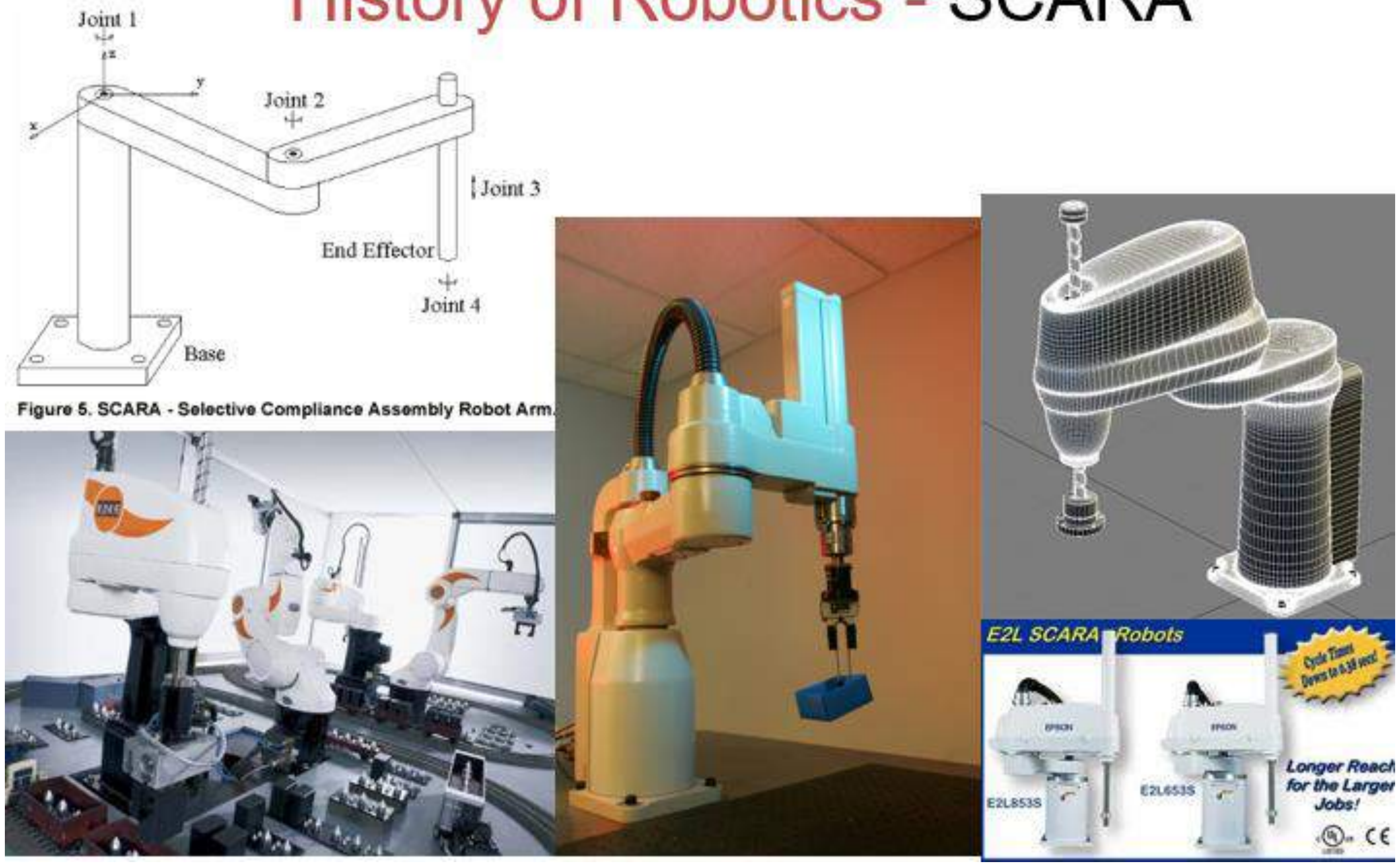


Figure 5. SCARA - Selective Compliance Assembly Robot Arm.

Robotics

1980’s – Innovation in improving the performance of robot arms – feedback control to improve accuracy, program compliance, the introduction of personal computers as controllers, and commercialization of robots by a large number of companies: KUKA (Germany), IBM 7535, Adept Robot (USA), Hitachi, Seiko (Japan).

Early 1980’s – Multi-fingered hands developed, Utah-MIT arm (16 DOF) developed by Steve Jacobsen, Salisbury’s hand (9 dof).

1977-1983 – Stanford cart/CMU rover developed by Hans Moravec, later on became the Nomad mobile robot.
1980’s – Legged and hopping robots (BIPER – Shimoyama) and Raibert 1986.

1984 -1991 – V. Braitenberg revived the tortoise mobile robots of W. Grey Walter creating autonomous robots exhibiting behaviors. Hogg, Martin and Resnick at MIT create mobile robots using LEGO blocks (precursor to LEGO Mindstorms). Rodney Brooks at MIT creates first insect robots at MIT AI Lab – birth of behavioral robotics.

Robotics

So What is a Robot?

Robotics

Robot Anatomy and Related Attributes

The arm or manipulator of an industrial robot consists of a series of joints and links. Robot anatomy is concerned with the types and sizes of these joints and links and other aspects of the manipulator's physical construction. The robot's anatomy affects its capabilities and the tasks for which it is best suited.

Joints and Links

A robot's joint, or axis as it is also called in robotics, is similar to a joint in the human body: It provides relative motion between two parts of the body. Robots are often classified according to the total number of axes they possess. Connected to each joint are two links, an input link and an output link. Links are the rigid components of the robot manipulator. The purpose of the joint is to provide controlled relative movement between the input link and the output link. Most robots are mounted on a stationary base on the floor. Let this base and its connection to the first joint be referred to as link 0. It is the input link to joint 1, the first in the series of joints used in the construction of the robot. The output link of joint 1 is link 1. Link 1 is the input link to joint 2, whose output link is link 2, and so forth. This joint-link numbering scheme is illustrated in Figure .

Robotics

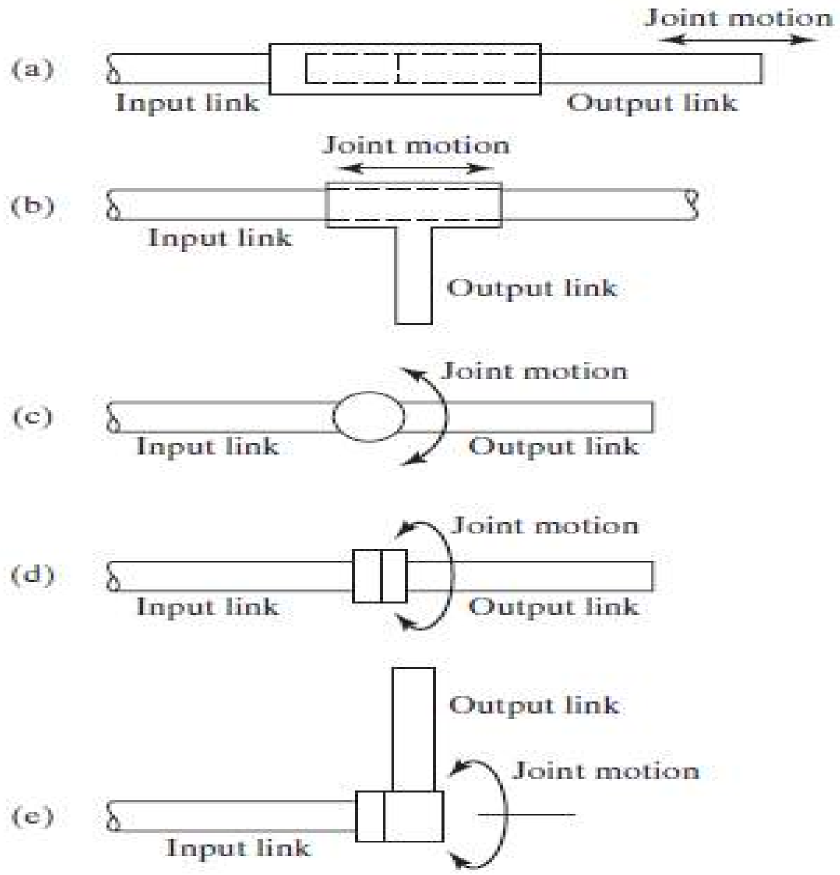
Nearly all industrial robots have mechanical joints that can be classified into one of five types: two types that provide translational motion and three types that provide rotary motion. These joint types are illustrated in Figure 8.2 and are based on a scheme described in [5].

The five joint types are 1. Linear joint (type L joint). The relative movement between the input link and the output link is a translational telescoping motion, with the axes of the two links being parallel. 2. Orthogonal joint (type O joint). This is also a translational sliding motion, but the input and output links are perpendicular to each other.3. 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. 4. 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. 5. Revolving joint (type V joint, V from the "v" in revolving). In this joint type, the axis of the input link is parallel to the axis of rotation of the joint, and the axis of the output link is perpendicular to the axis of rotation. Each of these joint types has a range over which it can be moved. The range for a translational joint is usually less than a meter, but for large gantry robots, the range may be several meters. The three types of rotary joints may have a range as small as a few degrees or as large as several complete revolutions.

Robotics

Common Robot Configurations

A robot manipulator can be divided into two sections: a body-and-arm assembly and a wrist assembly. There are usually three axes associated with the body-and-arm, and either two or three axes associated with the wrist. At the end of the manipulator's wrist is a device related to the task that must be accomplished by the robot. The device, called an end effector (Section 8.3), is usually either (1) a gripper for holding a work part or (2) a tool for performing some process. The body-and-arm of the robot is used to position the end effector, and the robot's wrist is used to orient the end effector.



Robotics

Body-and-Arm Configurations. Given the five types of joints defined earlier, there are 5 * 5 * 5 = 125 possible combinations of joints that could be used to design the body-and-arm assembly for a three-axis manipulator. In addition, there are design variations within the individual joint types (e.g., physical size of the joint and range of motion).

It is somewhat remarkable, therefore, that only a few configurations are commonly available in commercial industrial robots. These configurations are:

1. Articulated robot. Also known as a jointed-arm robot (Figure 8.3), it has the general configuration of a human shoulder and arm. It consists of an upright body that swivels about the base using a T joint. At the top of the body is a shoulder joint (shown as an R joint in the figure), whose output link connects to an elbow joint (another R joint).

2. Polar configuration. This configuration (Figure 8.4) consists of a sliding arm (L joint) actuated relative to the body, which can rotate about both a vertical axis (T joint) and a horizontal axis (R joint).

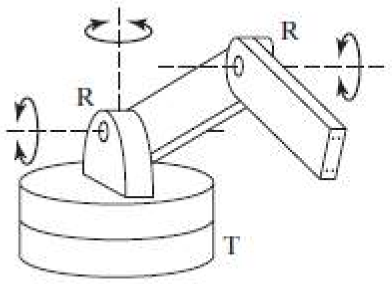


Figure 8.3 Articulated robot (jointed-arm robot).

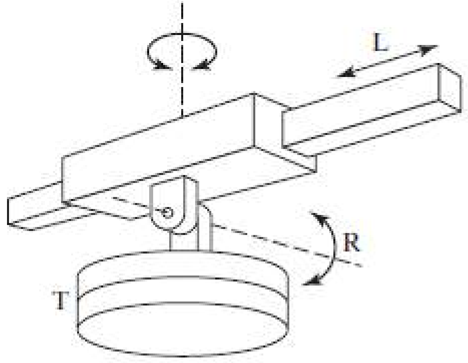


Figure 8.4 Polar configuration.

Robotics

3. SCARA. SCARA is an acronym for Selectively Compliant Arm for Robotic Assembly. This configuration (Figure 8.5) is similar to the jointed-arm robot except that the shoulder and elbow rotational axes are vertical, which means that the arm is very rigid in the vertical direction, but compliant in the horizontal direction. This permits the robot to perform insertion tasks (for assembly) in a vertical direction, where some side-to-side alignment may be needed to mate the two parts properly.

4. Cartesian coordinate robot. Other names for this configuration include gantry robot, rectilinear robot, and x–y–z robot. As shown in Figure 8.6, it consists of three orthogonal joints (type O) to achieve linear motions in a three-dimensional rectangular work space. It is commonly used for overhead access to load and unload production machines.

5. Delta robot. This unusual design, depicted in Figure 8.7, consists of three arms attached to an overhead base. Each arm is articulated and consists of two rotational joints (type R), the first of which is powered and the second is unpowered. All three arms are connected to a small platform below, to which the end effector is attached. The platform and end effector can be manipulated in three dimensions. The delta robot is used for high-speed movement of small objects, as in product packaging.

Robotics

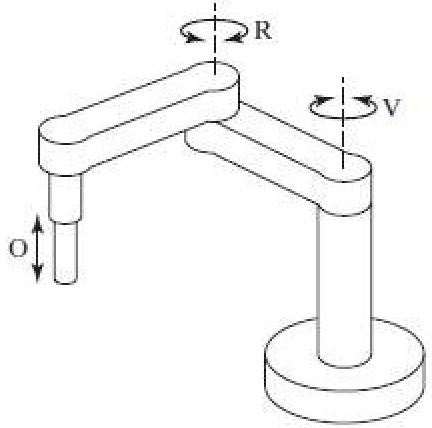


Figure 8.5 SCARA configuration.

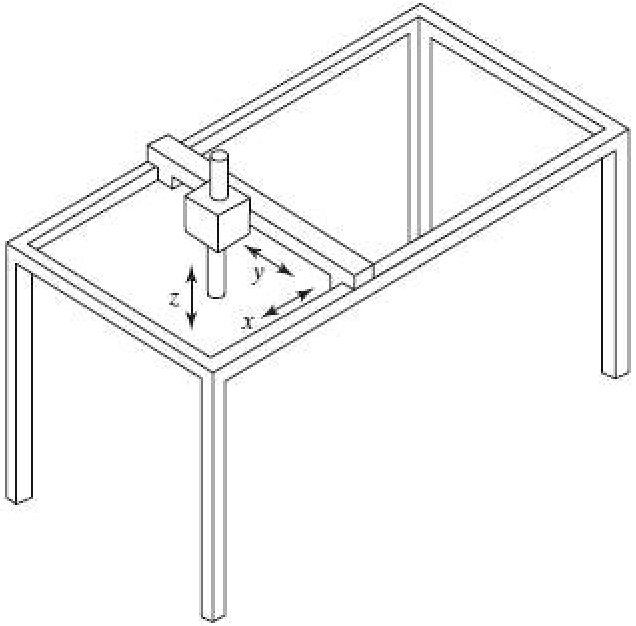


Figure 8.6 Cartesian coordinate robot.

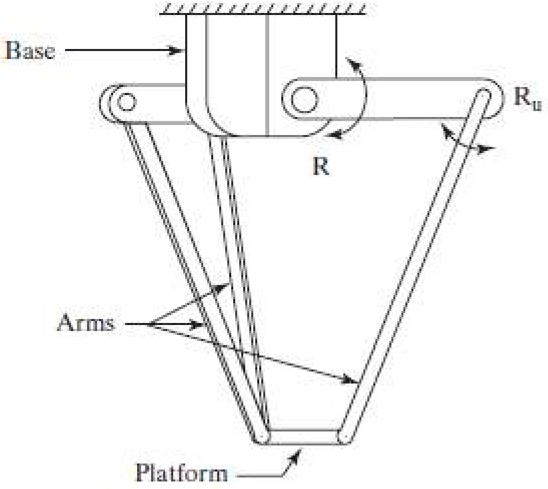


Figure 8.7 Delta robot.

Robotics

There are more manipulator configurations than those described, and they come in many different sizes. The interested reader can peruse the websites of some of the robot manufacturers in [14], [15], and [17]. Wrist Configurations. The robot's wrist is used to establish the orientation of the end effector. Robot wrists usually consist of two or three joints that almost always consist of R and T type rotary joints. Figure 8.8 illustrates one possible configuration for a three-axis wrist assembly. The three joints are defined as follows: (1) roll, using a T joint to accomplish rotation about the robot's arm axis; (2) pitch, which involves up-and-down rotation, typically using an R joint; and (3) yaw, which involves right-and-left rotation, also accomplished by means of an R-joint. A two-axis wrist typically includes only roll and pitch joints (T and R joints). To avoid confusion in the pitch and yaw definitions, the wrist roll should be assumed in its center position, as shown in the figure. To demonstrate the possible confusion, consider a two-jointed wrist assembly. With the roll joint in its center position, the second joint (R joint) provides up-and-down rotation (pitch).

Robotics

However, if the roll position were 90 degrees from center (either clockwise or counterclockwise), the second joint would provide a right-left rotation (yaw). Joint Notation System. The letter symbols for the five joint types (L, O, R, T, and V) can be used in a joint notation system for the robot manipulator and wrist. In this notation system, the manipulator is described by the joint types that make up the body-and-arm assembly, followed by the joint symbols that make up the wrist. For example, the notation TLR:RT represents a five-axis manipulator whose body-and-arm is made up of a twisting joint 1joint 1 = T2, a linear joint 1joint 2 = L2, and a rotational joint 1joint 3 = R2. The wrist consists of two joints, a rotational joint (joint 4 = R) and a twisting joint (joint 5 = T). A colon separates the body-and-arm notation from the wrist notation. Common wrist joint notations are TRR, TR, and RT. Typical joint notations for the five body-and-arm configurations are presented in Table 8.1. The notation for the delta robot indicates that there are three arms, and each arm has two rotational joints, the second of which is unpowered (Ru).

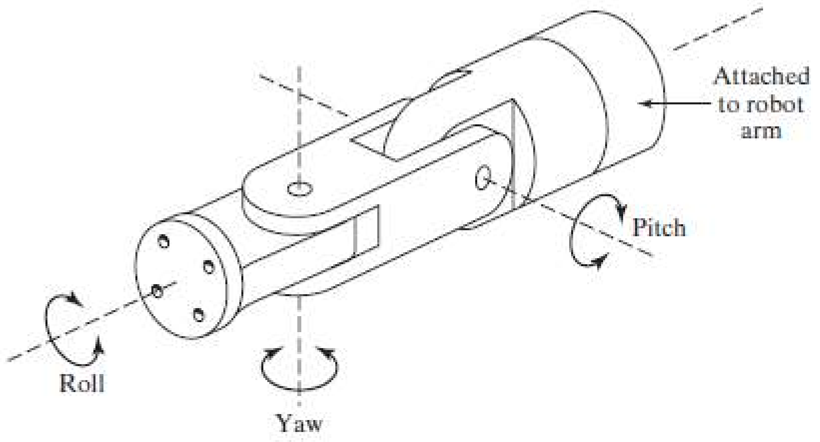


Figure 8.8 Typical configuration of a three-axis wrist assembly showing roll, pitch, and yaw.

Robotics

Joint Drive Systems: Robot joints are actuated using any of three types of drive systems: (1) electric,(2) hydraulic, or (3) pneumatic. Electric drive systems use electric motors as joint actuators (e.g., servomotors or stepper motors, Sections 6.2.1 and 7.4). The motors are connected to the joints either using no gear reduction (called direct drive) or with a gear reduction to increase torque or force. Hydraulic and pneumatic drive systems use devices such as linear pistons and rotary vane actuators (Section 6.2.2) to move the joint. Pneumatic drive is typically limited to smaller robots used in simple part transfer applications. Electric drive and hydraulic drive are used on more sophisticated industrial robots. Electric drive has become the preferred drive system in commercially available robots, as electric motor technology has advanced in recent years. It is more readily adaptable to computer control, which is the dominant technology used today for robot controllers. Electric drive robots are relatively accurate compared with hydraulically powered robots. By contrast, hydraulic drive robots can be designed with greater lift capacity. The drive system, position sensors (and speed sensors if used), and feedback control systems for the joints determine the dynamic response characteristics of the manipulator.

The speed with which the robot can move to a programmed position and the stability of its motion are important characteristics of dynamic response in robotics. Motion speed refers to the absolute velocity of the manipulator at its end-of-arm. The maximum speed of a large robot is around 2 m/sec (6 ft/sec). Speed can be programmed into the work cycle so that different portions of the cycle are carried out at different velocities. What is sometimes more important than speed is the robot's capability to accelerate and decelerate in a controlled manner. In many work cycles, much of the robot's movement is performed in a confined region of the work volume, so the robot never achieves its top-rated velocity. In these cases, nearly all of the motion cycle is engaged in acceleration and deceleration rather than in constant speed.

Robotics

Other factors that influence speed of motion are the weight (mass) of the object that is being manipulate manipulator to move from one point in space to the next. Speed of response is important because it influences the robot's cycle time, which in turn affects the production rate in the application. Motion stability refers to the amount of overshoot and oscillation that occurs in the robot motion at the end-of-arm as it attempts to move to the next programmed location. More oscillation in the motion is an indication of less stability. The problem is that robots with greater stability are inherently slower in their response, whereas faster robots are generally less stable. Load carrying capacity depends on the robot's physical size and construction as well as the force and power that can be transmitted to the end of the wrist. The weight carrying capacity of commercial robots ranges from less than 1 kg up to approximately 1,200 kg (2,600 lb) [15]. Medium sized robots designed for typical industrial applications have capacities in the range of 10–60 kg (22–130 lb). One factor that should be kept in mind when considering load carrying capacity is that a robot usually works with a tool or gripper attached to its wrist. Grippers are designed to grasp and move objects about the work cell. The net load-carrying capacity of the robot is obviously reduced by the weight of the gripper. If the robot is rated at 10 kg (22 lb) and the weight of the gripper is 4 kg (9 lbs), then the net weight carrying capacity is reduced to 6 kg (13 lb).

Robotics

Sensors in Robotics

The general topic of sensors as components in control systems is discussed in Section 6.1. The discussion here is on how sensors are applied in robotics. Sensors used in industrial robotics can be classified into two categories: (1) internal and (2) external. Internal sensors are components of the robot and are used to control the positions and velocities of the robot joints. These sensors form a feedback control loop with the robot controller. Typical sensors used to control the position of the robot arm include potentiometers and optical encoders. Tachometers of various types are used to control the speed of the robot arm. External sensors are external to the robot and are used to coordinate the operation of the robot with other equipment in the cell. In many cases, these external sensors are relatively simple devices, such as limit switches that determine whether a part has been positioned properly in a fixture or that a part is ready to be picked up at a conveyor. Other situations require more advanced sensor technologies, including the following:

• Tactile sensors. These are used to determine whether contact is made between the sensor and another object. Tactile sensors can be divided into two types in robot applications: (1) touch sensors and (2) force sensors. Touch sensors indicate simply that contact has been made with the object. Force sensors indicate the magnitude of the force with the object. This might be useful in a gripper to measure and control the force being applied to grasp a delicate object.

• Proximity sensors. These indicate when an object is close to the sensor. When this type of sensor is used to indicate the actual distance of the object, it is called a range sensor.

Robotics

Optical sensors. Photocells and other photometric devices can be utilized to detect the presence or absence of objects and are often used for proximity detection.

• Machine vision. Machine vision is used in robotics for inspection, parts identification, guidance, and other uses. Section 22.5 provides a more complete discussion of machine vision in automated inspection. Improvements in programming of vision-guided robot (VGR) systems have made implementations of this technology easier and faster [20], and machine vision is being implemented as an integral feature in more and more robot installations, especially in the automotive industry [13].

• Other sensors. A miscellaneous category includes other types of sensors that might be used in robotics, such as devices for measuring temperature, fluid pressure, fluid flow, electrical voltage, current, and various other physical properties (Table 6.2).

Robotics

Robot Control Systems

The actuations of the individual joints must be controlled in a coordinated fashion for the manipulator to perform a desired motion cycle. Microprocessor-based controllers are commonly used today in robotics as the control system hardware. The controller is organized in a hierarchical structure as indicated in Figure 8.9 so that each joint has its own feedback control system, and a supervisory controller coordinates the combined actuations of the joints according to the sequence of the robot program. Different types of control are required for different applications. Robot controllers can be classified into four categories [5]: (1) limited-sequence control, (2) playback with point-to-point control, (3) playback with continuous path control, and (4) intelligent control. Limited-Sequence Control. This is the most elementary control type. It can be utilized only for simple motion cycles, such as pick-and-place operations (i.e., picking an object up at one location and placing it at another location). It is usually implemented by setting limits or mechanical stops for each joint and sequencing the actuation of the joints to accomplish the cycle. Interlocks (Section 5.3.2) are sometimes used to indicate that the particular joint actuation has been accomplished so that the next step in the sequence can be initiated. However, there is no servo-control to accomplish precise positioning of the joint. Many pneumatically driven robots are limited-sequence robots. Playback with Point-to-Point Control. Playback robots represent a more sophisticated
form of control than limited-sequence robots. Playback control means that the controller has a memory to record the sequence of motions in a given work cycle, as well as the locations and other parameters (such as speed) associated with each motion, and then to subsequently play back the work cycle during execution of the program.

Robotics

Playback with Continuous Path Control. Continuous path robots have the same playback capability as the previous type. The difference between continuous path and point-to-point is the same in robotics as it is in NC (Section 7.1.3). A playback robot with continuous path control is capable of one or both of the following:

1. Greater storage capacity. The controller has a far greater storage capacity than its point-to-point counterpart, so the number of locations that can be recorded into memory is far greater than for point-to-point. Thus, the points constituting the motion cycle can be spaced very closely together to permit the robot to accomplish a smooth continuous motion. In PTP, only the final location of the individual motion elements are controlled, so the path taken by the arm to reach the final location is not controlled. In a continuous path motion, the movement of the arm and wrist is controlled during the motion.
2. Interpolation calculations. The controller computes the path between the starting point and the ending point of each move using interpolation routines similar to those used in NC. These routines generally include linear and circular interpolation.

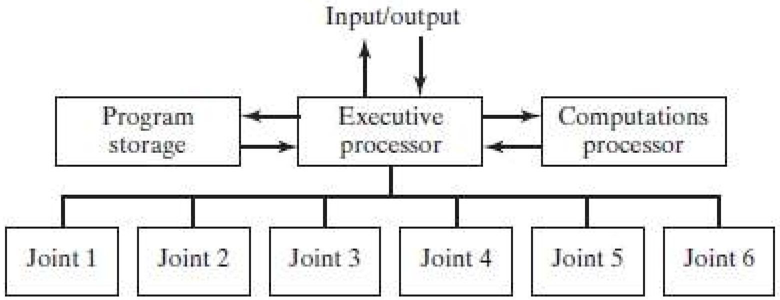


Figure 8.9 Hierarchical control structure of a robot microcomputer controller.

Robotics

8.3 **End Effectors**

As mentioned in Section 8.1.2 on robot configurations, an end effector is usually attached to the robot's wrist. The end effector enables the robot to accomplish a specific task. Because there is a wide variety of tasks performed by industrial robots, the end effector is usually custom-engineered and fabricated for each different application. The two categories of end effectors are grippers and tools.

8.3.1 **Grippers**

Grippers are end effectors used to grasp and manipulate objects during the work cycle. The objects are usually work parts that are moved from one location to another in the cell. Machine loading and unloading applications fall into this category. Owing to the variety of part shapes, sizes, and weights, most grippers must be custom designed. Types of grippers used in industrial robot applications include the following:

- Mechanical grippers, consisting of two or more fingers that can be actuated by the robot controller to open and close on the work part (Figure 8.10 shows a two-finger gripper)
- Vacuum grippers, in which suction cups are used to hold flat objects
- Magnetized devices, for holding ferrous parts
- Adhesive devices, which use an adhesive substance to hold a flexible material such as a fabric
- Simple mechanical devices, such as hooks and scoops. Mechanical grippers are the most common gripper type. Some of the innovations and advances in mechanical gripper technology include:
- Dual grippers, consisting of two gripper devices in one end effector for machine loading and unloading.

Robotics

With a single gripper, the robot must reach into the production machine twice, once to unload the finished part and position it in a location external to the machine, and the second time to pick up the next part and load it into the machine. With a dual gripper, the robot picks up the next work part while the machine is still processing the previous part. When the machine cycle is finished, the robot reaches into the machine only once: to remove the finished part and load the next part. This reduces the cycle time per part.

- Interchangeable fingers that can be used on one gripper mechanism. To accommodate different parts, different fingers are attached to the gripper.
- Sensory feedback in the fingers that provide the gripper with capabilities such as (1) sensing the presence of the work part or (2) applying a specified limited force to the work part during gripping (for fragile work parts).
- Multiple-fingered grippers that possess the general anatomy of a human hand.
- Standard gripper products that are commercially available, thus reducing the need to custom-design a gripper for each separate robot application.

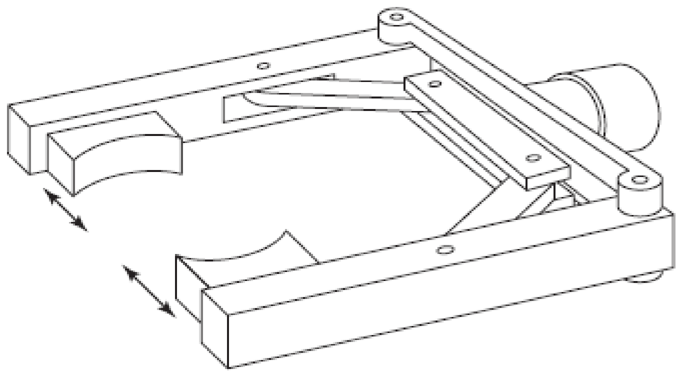


Figure 8.10 Robot mechanical gripper.

Robotics

Tools

The robot uses tools to perform processing operations on the work part. The robot Manipulates the tool relative to a stationary or slowly moving object (e.g., work part or subassembly). Examples of 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, and similar operations; assembly tool (e.g., automatic screwdriver); heating torch; ladle (for metal die casting); and water jet cutting tool. In each case, the robot must not only control the relative position of the tool with respect to the work as a function of time, it must also control the operation of the tool. For this purpose, the robot must be able to transmit control signals to the tool for starting, stopping, and otherwise regulating its actions. In some applications, the robot may use multiple tools during the work cycle. For example, several sizes of routing or drilling bits must be applied to the work part. Thus, the robot must have a means of rapidly changing the tools. The end effector in this case takes the form of a fast-change tool holder for quickly fastening and unfastening the various tools used during the work cycle.

Robotics

Applications:

Industrial robot applications of machine loading and/or unloading include the following processes:

• Die casting. The robot unloads parts from the die casting machine. Peripheral operations sometimes performed by the robot include dipping the parts into a water bath for cooling.

• Plastic molding. Plastic molding is similar to die casting. The robot unloads molded parts from the injection molding machine.

• Metal machining operations. The robot loads raw blanks into the machine tool and unloads finished parts from the machine. The change in shape and size of the part before and after machining often presents a problem in end effector design, and dual grippers (Section 8.3.1) are often used to deal with this issue.

• Forging. The robot typically loads the raw hot billet into the die, holds it during the forging strikes, and removes it from the forge hammer. The hammering action and the risk of damage to the die or end effector are significant technical problems.

• Press working. Human operators work at considerable risk in Sheetmetal pressworking operations because of the action of the press. Robots are used to substitute for the workers to reduce the danger. In these applications, the robot loads the blank into the press, then the stamping operation is performed, and the part falls out of
the machine into a container.

• Heat-treating. These are often relatively simple operations in which the robot loads and/or unloads parts from a furnace.

Summary

In this chapter, an introduction to the field of the robotics and its practical applications in numerous field indicates the ample use of advance technology in saving costs and cutting time for product developments was given and some significant information to be noticed are given below;

- Robotics and its applications