ROBOTICS

- ✓ Definition and Classification of Robots
- ✓ Geometric classification and Control classification
- ✓ Laws of Robotics
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- ✓ Robot anatomy
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DEFINITION OF A ROBOT

- A robot is a computer-controlled machine that is programmed to move, manipulate objects, and accomplish work while interacting with its environment.
- According to the Robot Institute of America (1979) a robot is defined as "a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks."

Or

- Industrial robot is defined as "a number of rigid links connected by joints of different types that are controlled and monitored by computer". One feature that a device must possess if it is to rank as a robot is the ability to operate automatically, on its own.
- This means that there must be in-built intelligence, or a programmable memory, or simply an arrangement of adjustable mechanisms that command manipulation.

INDUSTRIAL ROBOT

- Industrial robots are advanced automation systems, mainly controlled by a computer. Today computers form an important part of industrial automation. They supervise production lines and control manufacturing systems (e.g. machine tools, welders, laser cutting devices etc.).
- The new generation of robots executes various tasks in industrial systems and they participate in the full automation of factories. Japanese defined industrial robot in four levels:
    i. Manual manipulators: perform fixed or preset task sequences.
    ii. Playbacks: repeat pre-programmed fixed instructions.
    iii. NC robot: carry out tasks through numerically loaded information.
    iv. Intelligent robots: perform through their own recognition capabilities.

MOTIVATING FACTORS

- For robotics systems to be introduced to the industrial world they must have positive factors that would make a difference in using them. The motivating factors can be categorized as:
    1. Technical factors
    2. Economic factors
    3. Social factors

Technical Factors

- Robots can do different incomparable tasks that humans can't do. It is generally considered that humans can't match the speed, quality, reliability and the endurance of robotic system. In that they offer:
    (a) High flexibility of product type and variation.
    (b) Lower preparation time than hard automation.

(c) Better quality of products.
(d) Fewer rejects and less waste than labour intensive production.

Economic Factors

(a) The needs to increase production rates to remain competitive.
(b) Pressure from the market place to improve quality.
(c) Increasing costs.
(d) Shortage of skilled labour.

Social factors

- Some people think that the use of robotized systems increases the unemployment of workers and prevent many people from a main income. But the usage of robots causes a reduction of workload on workers and prevent dangerous physically harms as robots can be used in hazardous environments.

ADVANTAGES AND DISADVANTAGES OF ROBOTS

- Robots offer specific benefits to workers, industries and countries. If introduced correctly, industrial robots can improve the quality of life by freeing workers from dirty, boring, dangerous and heavy labor.
- It can be said therefore, that robots give the possibility to humans to occupy with jobs, that they can execute better.
- It is true that robots can cause unemployment by replacing human workers but robots also create jobs such as robot technicians, salesmen, engineers, programmers and supervisors.

The advantages of robots are:

i. Increase in productivity, safety, efficiency, quality and consistency of products with the use of robots.
ii. Robots can work in hazardous environments without the need for life support, comfort, or concern about safety.
iii. Robots need no environmental comfort such as lighting, air conditioning, ventilation and noise protection.
iv. Robots can work continuously without experiencing fatigue or boredom, do not have hangovers and need no medical insurance or vacation.
v. Robots have repeatable precision at all times, unless something happens to them or unless they wear out.
vi. Robots can be much more accurate than humans.

The disadvantages of robots are:

i. Robots replace human workers creating economic problems, such as lost salaries, and social problems such as dissatisfaction and resentment among workers.
ii. Robots lack capability to respond in emergencies, unless the situation is predicted and the response is included in the system. Safety measures are needed to ensure that they do not injure operators and machines working with them.

iii. Robots are costly due to initial cost of equipment, installation costs, need for training and need for programming.

CHARACTERISTICS OF AN INDUSTRIAL ROBOT

- An industrial robot has a hand, wrist, arm, base, lifting power, repeatability, manual control, automatic control, memory, programs, safety interlock, speed of operation, computer interface, reliability, and easy maintenance.
- **The hand** of a robot is known as a gripper or end effector or end-of-arm tooling. It is the driven mechanical device(s) attached to the end of the manipulator.
- **The wrist of the robot** is used to aim the hand at any part of the work piece. The wrist may have three motions: pitch (up-and-down motion), yaw (side-to-side motion) and roll (rotating motion).
- **The arm** is used to move the hand within reach of a part or work piece. It can pivot at its elbow and at its shoulder joint.
- **The waist, or base**, of the robot supports the arm and is called the shoulder. The arm can rotate about the shoulder.
- **Repeatability** is the replication of motion within some specified precision or tolerance.
- **A RCC or remote center compliance device** helps pull the hand or tool into the required position by acting as a multiaxis float.
- **A manual control** device is used to teach the robot how to do a new task.
- **An automatic control** system is used to carry out the instructions stored in the robot's memory.
- The robot's **memory** holds a library of programs to use in executing different tasks.
- **Safety interlocks** prevent the robot from inserting a hand into a machine and causing damage to the robot and machine. The robot's speed of operation in performing a task should be at least equal to that of the human worker it is replacing. The robot's computer interface enables the robot to use the computer's larger memory to hold more task programs and to synchronize its actions with a complete production line of robots and other machines.

COMPONENTS OF AN INDUSTRIAL ROBOT

Industrial robot systems consist of four major subsystems

- Mechanical unit
- Drive
- Control system
- Tooling

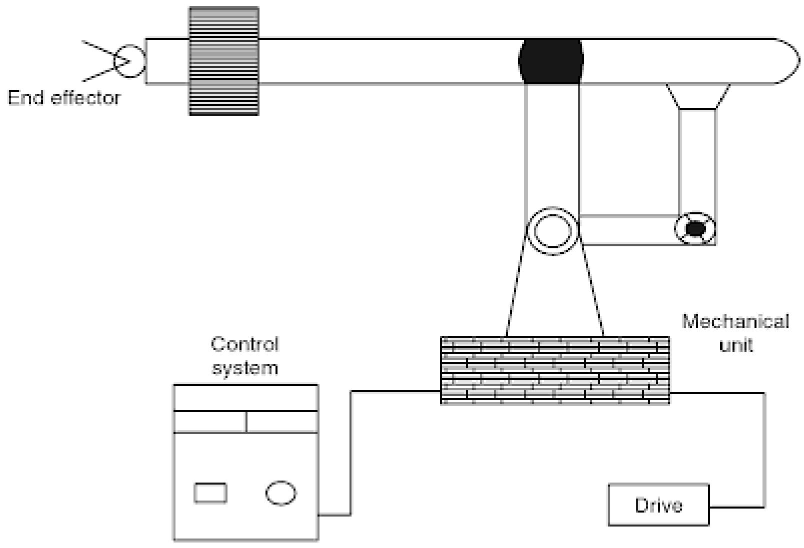


Fig. 13.1. Components of an Industrial Robot

Mechanical Unit.

- The mechanical unit refers to the robot's manipulative arm and its base. Tooling such as end effectors, tool changers, and grippers are attached to the wrist-tooling interface. The mechanical unit consists of a fabricated structural frame with provisions for supporting mechanical linkage and joints, guides, actuators, control valves, limiting devices, and sensors. The physical dimensions, design, and loading capability of the robot depends upon the application requirements.

Drive:

- An important component of the robot is the drive system. The drive system supplies the power, which enables the robot to move.
- Drive for a robot may be hydraulic, pneumatic or electric.
- Hydraulic drives have been used for heavier lift systems. Pneumatic drives have been used for high speed, non-servo robots and are often used for powering tooling such as grippers.
- Electric drive systems can provide both lift and/or precision, depending on the motor and servo system selection and design. An AC or DC powered motor may be used depending on the system design and applications.

Control System:

- Controller is the brain of the robot. Controller is a communication and information-processing device that initiates, terminates and coordinates the motions and sequences of a robot.
- Most industrial robots incorporate computer or microprocessor based controllers. These perform computational functions and interface with sensors, grippers, tooling, and other peripheral equipment.

- Controller programming may be done on-line or from off-line control stations. Programs may be on cassettes, floppy disks, internal drives, or in memory; and may be loaded or downloaded by cassettes, disks, or telephone modem. Some robot controllers have sufficient computational ability, memory capacity, and input/output capability to serve as system controllers for other equipment and processes.

Tooling:

- Tooling is manipulated by the robot to perform the functions required for the application. Depending on the application, the robot may have one functional capability, such as making spot welds or spray-painting. These capabilities may be integrated with the robot's mechanical system or may be attached at the robot's wrist-end effector interface. Alternatively, the robot may use multiple tools that may be changed manually (as part of set-up for a new program) or automatically during a work cycle.
- Tooling and objects that may be carried by a robot's gripper can significantly increase the envelope in which objects or humans may be struck. Tooling manipulated by the industrial robot and carried objects can cause more significant hazards than motion of the bare robotic system. The hazards added by the tooling should be addressed as part of the risk assessment.

Sensors:

- Sensors are used to collect information about the internal state of the robot or to communicate with the outside environment.
- As in humans, the robot controller needs to know where each link of the robot is, in order to know the robot's configuration. The state of the human body is determined because feedback sensors in human's central nervous system embedded in their muscle tendons send information to the brain. The brain uses this information to determine the length of their muscles, and thus, the state of their arms, legs etc. The same is true for robots; sensors integrated into the robot send information about each joint or link to the controller, which determines the configuration of the robot.
- Robots are often equipped with external sensory devices such as a vision system, touch and tactile sensors, speech synthesizers, etc., which enable the robot to communicate with the outside world.

Robot Coordinate System

There are some major coordinate systems based on which robots are generally specified. The common designs of robot coordinates are

- Cartesian coordinate system
- Cylindrical coordinate system
- Polar or spherical coordinate system
- Revolute coordinate system

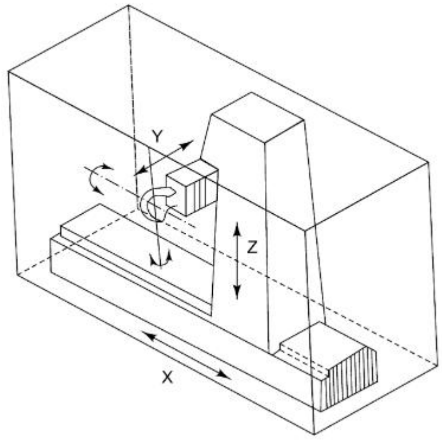


FIG. 1.12 *Cartesian coordinates*

In cylindrical coordinate

- The three degrees of freedom—two linear motions and one rotational—correspond to a radial in or out translation r, an angular motion, 0 about the vertical axis, and a, a translation in the z-direction that corresponds to the up or down motion.
- The manipulator can ideally reach any point in a cylindrical volume of space. In reality, the robot cannot rotate through a complete circle in the space bounded between two cylinders.

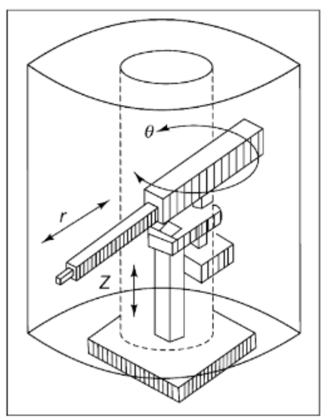


FIG. 1.13 *Cylindrical coordinates*

In the spherical coordinate configuration

- The robot has one linear and two angular motions. The linear motion, r corresponds to a radial in or out translation, the first angular motion. Cylindrical coordinates corresponds to a base rotation, 0 about a vertical axis, and the second angular motion, 0 Is the one that rotates about an axis perpendicular to the vertical through the base and issometimes termed as elbow rotation.
- The two rotations along with the in 9 or out motion enable the robot to reach any specified point in the space bounded by an outer and inner hemisphere. Sometimes, the spherical coordinate system' referred to as the polar coordinate system.

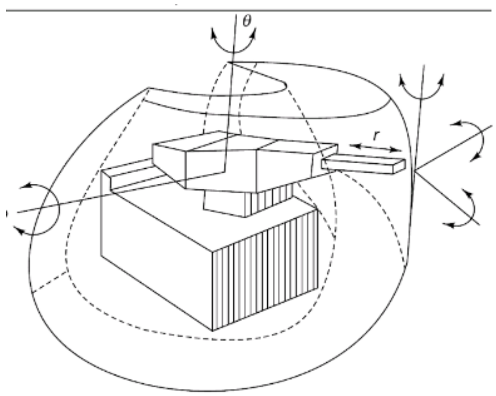


FIG. 1.14 *Spherical coordinates*

In the revolute coordinate,

- That is, anthropomorphic or jointed arm configuration as illustrated in Fig. 1.15, a robot uses three rotations. The anthropomorphic design corresponds to the design of a human arm having waist, shoulder and elbow joints. The link of the arm mounted on the base joint can rotate around the base about the Z-axis and the two links, namely the shoulder and the elbow.
- The shoulder can rotate about a horizontal axis and the elbow motion may either be a rotation about a horizontal axis or may be at any locationin space depending on the rotational motions of the base and the shoulder. The anthropomorphic robot can move in a space bounded between HG. 1.15 Osculate coorciinates a sphencal outer surface and the inner surface having scallops due to the constraints of the joints.
- A simple way to define the manipulator body or arm in terms of lower pair connectors b to represent the robots in a rectangular coordinate system as P-P-P robot, in a cylindrical coordinate system as P-R-P robot, Ina spherical coordinate system as R-R-P robot and in a revolute coordinate system as R-R-R robot.

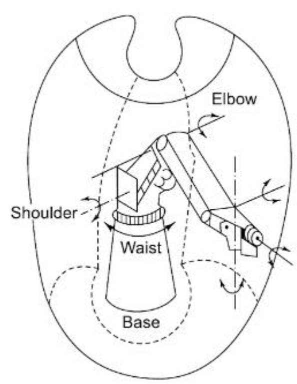


FIG. 1.15 *Revolute coordinates*

ROBOTICS SYSTEMS AND ROBOT ANATOMY

- A system is an integrated whole of parts or subsystems. A system has a specified goal or output for a given set of inputs; a system may have many goals as well. A robot is a system as it combines many subsystems that interact among themselves as well as with the environment in which the robot works.
- A robot has many components which include,
  - (1) A base—fixed or mobile.
  - (2) A manipulator arm with several degrees of freedom (D0F).
  - (3) An end-effector or gripper holding a part or a tool.
  - (4) Drives or actuators causing the manipulator arm or end-effector to move in a space.
  - (5) Controller with hardware and software support for giving commands to the drives.
  - (6) Sensors to feed back the information for subsequent actions of the arm or gripper as well as to interact with the environment in which the robot is working.
  - (7) Interfaces connecting the robotic subsystems to the external world.

ROBOTIC JOINTS

- A robot joint is a mechanism that permits relative movement between parts of a robot arm. The joints of a robot are designed to enable the robot to move its end-effector along a path from one position to another as desired. The basic movements required for a desired motion of most industrial robots are:

• **Rotational movement**: This enables the robot to place its arm in any direction on a horizontal plane.

• **Radial movement**. This enables the robot to move its end-effector radially to reach distant points.

• **Vertical movement:** This enables the robot to take its end-effector to different heights.

Degrees of freedom,

Independently or in combination with others, define the complete motion of the end-effector. These motions are accomplished by movements of individual joints of the robot arm. The joint movements are basically the same as relative motion of adjoining links.

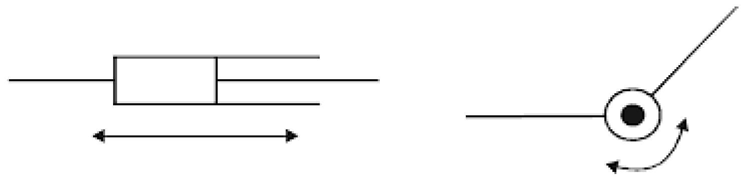
Depending on the nature of this relative motion, the joints are classified as

1. Prismatic joints
2. Revolute joints

1. Prismatic joints are also known as sliding as well as linear joints. They are called prismatic because the cross section of the joint is considered as a generalized prism. They permit links to make a linear displacement along a fixed axis. In other words, one link slides on the other

along a straight line. These joints are used in gantry, cylindrical, or similar joint configurations

2. Revolute joints, the second type of joint is a revolute joint where a pair of links rotates about a fixed axis.



(a) Prismatic joint (b) Revolute joint

The variations of revolute joints are:

- Rotational joint (R)
- Twisting joint (T)
- Revolving joint (V)

A rotational joint (R) is identified by its motion, rotation about an axis perpendicular to the adjoining links. Here, the lengths of adjoining links do not change but the relative position of the links with respect to one another changes as the rotation takes place.

A twisting joint (T) is also a rotational joint, where the rotation takes place about an axis that is parallel to both adjoining links.

A revolving joint (V) is another rotational joint, where the rotation takes place about an axis that is parallel to one of the adjoining links. Usually, the links are aligned perpendicular to one another at this kind of joint. The rotation involves revolution of one link about another.

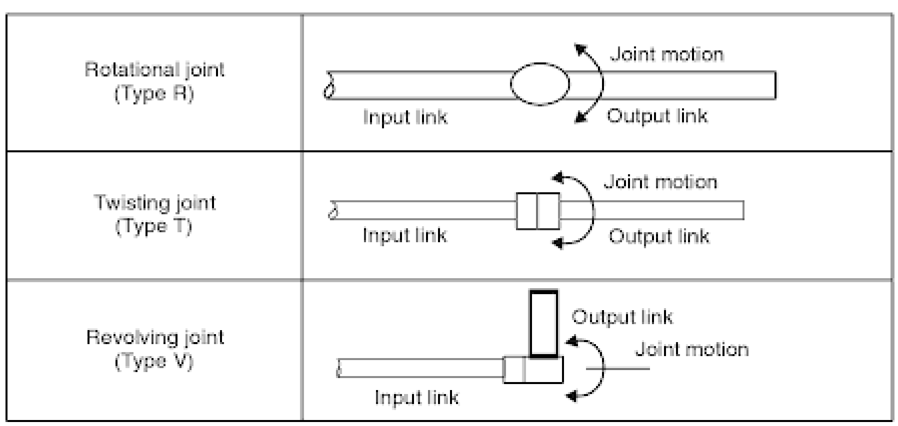


Fig. 13.14. Revolute Joints

LAWS OF ROBOTICS

Sir Isaac Asimov dealing on the subject of robotics framed three basic laws which the robotocists still obey with respect. The laws are philosophical in nature.

They are as follows:

First Law : A robot must not harm a human being or, through inaction, allow one to come to harm.

Second Law : A robot must always obey human beings unless it is in conflict with the first law.
Third Law : A robot must protect itself from harm unless that is in conflict with the first and/or the second laws.

CLASSIFICATION OF ROBOTS

Robots can be classified by four fundamental elements of operation:

- Coordinate systems
- Power source
- Method of Control
- Programming method

ROBOT CLASSIFICATION ON THE BASIS OF CO-ORDINATE SYSTEMS

Structurally, robots are classified according to wrist's co-ordinate system as follows:

1. Cartesian/Rectilinear Robot: The axis or dimensions of these robots are 3 intersecting straight lines (x-y-z) as shown in Figure. The Cartesian co-ordinate robot is one that consists of a column and an arm. It is sometimes called an x-y-z robot, indicating the axis of motion. The x-axis is lateral motion, the y-axis is longitudinal motion, and the z-axis is vertical motion. Thus, the arm can move up and down on the z-axis; the arm can slide along its base on the x-axis; and then it can telescope to move to and from the work area on the y-axis. The features of a cartesian robot (electronic equipment, control program) are same with those of CNC machine tools. Cartesian robots are not preferred in industry because they do not have mechanical flexibility (i.e., they cannot reach objects that lie on the floor or that are not visible from their base). Also speed of operation on horizontal plane is usually less than the corresponding speed of robots with revolute base.

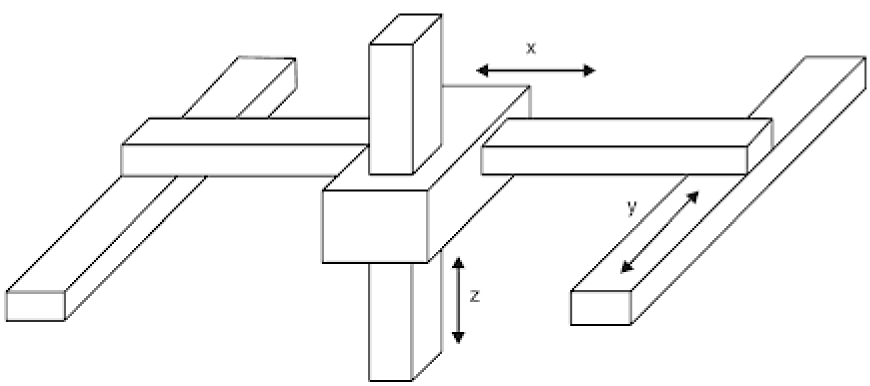


Fig. 13.15. Cartesian Robot

Applications

These types of robots are used for:

- Pick and place work

- Application of sealant
- Assembly operations
- Handling machine tools
- Arc welding

Advantages

- Ability to do straight line insertions into furnaces.
- Easy computation and programming.
- Most rigid structure for given length.

Disadvantages

- Requires large operating volume.
- Exposed guiding surfaces require covering in corrosive or dusty environments.
- Can only reach front of itself.
- Axis hard to seal.

2. Cylindrical Robot:

Cylindrical robots have one angular dimension and 2 linear dimensions as shown in figure. The rigid structure of this system offers them the capability to lift heavy loads through a large working envelope. The main body of such a robot consists of a horizontal arm mounted on a vertical column. The column is mounted on a rotating base. The horizontal arm moves forward and backward on the direction of the longitudinal axis and it also moves up and down on the column. Column and arm are rotating on the base around the vertical axis. Resolution of a cylindrical robot is not constant, but depends on the distance between the column and the tool along the horizontal arm

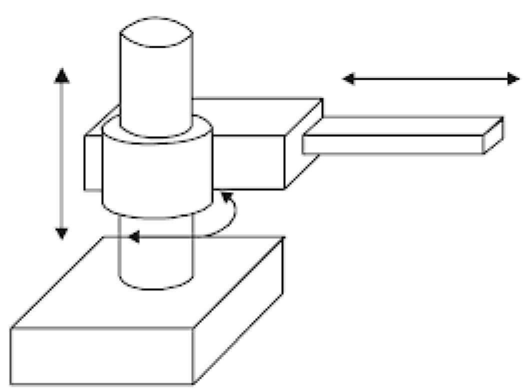


Fig. 13.16. Cylindrical Robot

Applications These types of robots are used for:

- Assembly operations
- Handling machine tools
- Spot-welding
- Handling die-casting machines.

Advantages

- Can reach all around itself.

• Rotational axis easy to seal.
• Relatively easy programming.
• Rigid enough to handle heavy loads through large working space.
• Good access into cavities and machine openings.

Disadvantages

• Can't reach above itself.
• Won't reach around obstacles.
• Exposed drives are difficult to cover from dust and liquids.
• Linear axes is hard to seal.

3. Spherical (Polar) Robot:

Robots of this type consist of a rotating base, a lifting part and a telescopic arm, which moves inwards and outwards .The 2 dimensions of spherical robots are angles and the third is a linear distance from point of origin. These robots operate according to spherical co-ordinates and offer greater flexibility. This design is used where a small number of vertical actions are adequate.

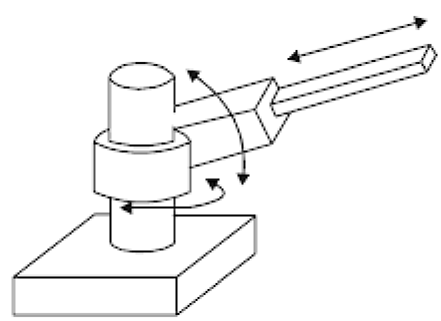


Fig. 13.17. Spherical Robot

Applications These types of robots are used for:

• Handlings at die casting or fettling machines.
• Handling machine tools
• Arc/spot welding.

Advantages

• Large working envelope.
• Two rotary drives are easily sealed against liquids/dust.

Disadvantages

• Complex co-ordinates more difficult to visualize, control, and program.
• Exposed linear drive.
• Low accuracy.

4. Articulated Robot:

Articulated robots consist of three constant parts (links) that are joined with revolute joints and are placed on a rotating base as shown in Figure 13.18. The kinematics layout is similar to human arm. The tool (gripper) is similar to a palm and is adjusted to the lower part of the arm through the wrist. The elbow connects lower and upper part of the arm and the shoulder connects upper part of arm with base. Many times the shoulder joint has a rotational motion in the horizontal plane. The articulated robot has all three axes revolute, so position resolution is completely dependent on the arm's position. The total accuracy of an articulated robot is small, because joint errors are accumulated at the end of the arm, which is at wrist position.

Applications

These types of robots are used for:

- Assembly operations
- Die casting
- Fettling machines
- Gas welding
- Spray-painting
- Arc welding

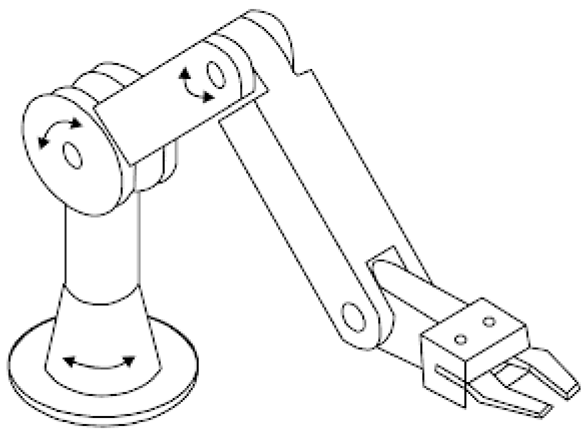


Fig. 13.18. Articulated Robot

Advantages

- High mechanical flexibility.
- They can move with high speed at three degrees of freedom.
- All joints can be sealed from the environment.

Disadvantages

- Extremely difficult to visualize, control, and program.
- Restricted volume coverage.
- Low accuracy.

5. SCARA Robot:

One style of robot that has recently become quite popular is a combination of the articulated arm and the cylindrical robot. This robot has more than three axes and is called a SCARA robot (Refer Figure 13.19). It is used widely in electronic assembly. The rotary axes are mounted vertically rather than horizontally. This configuration minimizes the robot's deflection when it carries an object while moving at a programmed speed. The acronym SCARA stands for Selective Compliance Assembly Robot Arm, a particular design developed in the late 1970's.

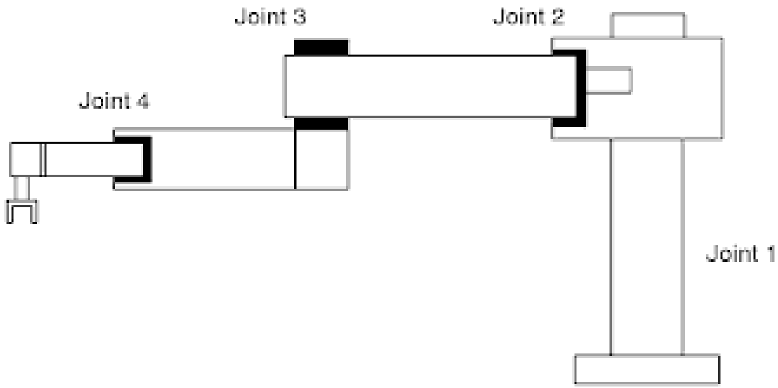


Fig. 13.19. SCARA Robot

Applications

SCARA robots are commonly used for:

- Pick and place work
- Assembly operations
- Application of sealant
- Handling machine tools.

Advantages

- High speed.
- Excellent repeatability.
- Good payload capacity.
- Large work area for floor space.
- Moderately easy to program.

Disadvantages

- Limited applications.
- 2 ways to reach point.
- Difficult to program off-line.
- Highly complex arm.

ROBOT CLASSIFICATION ON THE BASIS OF POWER SOURCE

Actuators drive the mechanical linkages and joints of a manipulator, which can be various types of motors and valves. The energy for these actuators is provided by some power source such as hydraulic, pneumatic or electric. There are three major types of drive systems for industrial robots:

- Hydraulic drive system
- Pneumatic drive system
- Electric drive system

1. Hydraulic Drive System The most popular form of the drive system is the hydraulic drive system because hydraulic cylinders and motors are compact and allow high levels of force and power, together with accurate control. These systems are driven by a fluid that is pumped through motors, cylinders, or other hydraulic actuator mechanisms. A hydraulic actuator converts forces from high pressure hydraulic fluid into mechanical shaft rotation or linear motion. Hydraulic robots are preferred in environments in which the use of electric drive robots may cause fire hazards, for example, in spray painting.

Advantages

- A hydraulic device can produce an enormous range of forces without the need for gears, simply by controlling the flow of fluid.
- Preferred for moving heavy parts.
- Preferred to be used in explosive environments.
- Self-lubrication and self-cooling.
- Smooth operation at low speeds.
- There is need for return line.

Disadvantages

- Occupy large space area.
- There is a danger of oil leak to the shop floor.

2. Pneumatic Drive System

Pneumatic drive systems are found in approximately 30 percent of today's robots. These systems use compressed air to power the robots. Since machine shops typically have compressed air lines in their working areas, the pneumatically driven robots are very popular. These robots generally have fewer axis of movement and can 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. The pneumatic power can be used for sliding or rotational joints.

Advantages

- Less expensive than electric or hydraulic robots.
- Suitable for relatively less degrees of freedom design.
- Do not pollute work area with oils.
- No return line required.
- Pneumatic devices are faster to respond as compared to a hydraulic system as air is lighter than fluid.

Disadvantages

- Compressibility of air limits control and accuracy aspects.
- Noise pollution from exhausts.
- Leakage of air can be of concern.

3. Electric Drive System

Electrical drive systems are used in about 20 percent of today's robots. These systems are servomotors, stepping motors, and pulse motors. These motors convert electrical energy into mechanical energy to power the robot. Compared with a hydraulic system; an electric system provides a robot with less speed and strength. Electric drive systems are adopted for smaller robots. Electrically driven robots are the most commonly available and used industrial robots.

There are three major types of electric drive that have been used for robots:

(a) **Stepper Motors:** These are used mainly for simple pick and place mechanisms where cost is more important than power or controllability.

(b) **DC Servos:** For the early electric robots the DC servo drive was used extensively. It gave good power output with a high degree of control of both speed and position.

(c) **AC Servos:** In recent years the AC servo has taken over from the DC servo as the standard drive. These modern motors give higher power output and are almost silent in operation. As they have no brushes they are very reliable and require almost no maintenance in operation.

Advantages

- Good for small and medium size robots.
- Better positioning accuracy and repeatability.
- Less maintenance and reliability problems.

Disadvantages

- Provides less speed and strength than hydraulic robots.
- Not all electric motors are suited for use as actuators in robots.
- Require more sophisticated electronic controls and can fail in high temperature, wet, or dusty environments.

ROBOT CLASSIFICATION ON THE BASIS OF METHOD OF CONTROL

The motions of a robot are controlled by a combination of software and hardware that is programmed by the user. Robots are classified by control method into servo and non-servo robots.

1. Non-Servo Controlled Robots

Non-servo control is a purely mechanical system of stops and limit switches, which are pre-programmed for specific repetitive movements. This can provide accurate control for simple motions at low cost. The motions of non-servo controlled robots are controlled only at their endpoints, not throughout their paths. Non-servo robots are often referred as "endpoint," "pick and place." or "limited seauence" mbots. These robots are used primarily for materials transfer.

Characteristics:

Characteristics of non-servo robots include:

- Relatively high speed possible due to smaller size of the manipulator
- These robots are low cost and simple to operate, program and maintain.
- These robots have limited flexibility in terms of program capacity and positioning capability.

2. Servo Controlled Robots

Servo control system is capable of controlling the velocity, acceleration, and path of motion, from the beginning to the end of the path. It uses complex control programs. These systems use Programmable Logic Controller (PLCs) and sensors to control the motions of robots. They are more flexible than non-servo systems, and they can control complicated motions smoothly.

Sensors are used in servo-control systems to track the position of each of the axis of motion of the manipulator.
Servo controlled robots are classified according to the method that the controller uses to guide the end-effector.
These are:

- Point-to-point (PTP) control robot
- Continuous-path (CP) control robot
- Controlled-path robot

(a) Point-to-Point Control Robot (PTP) Point-to-point robot is capable of moving from one discrete point to another within its working envelope. During point-to-point operation the robot moves to a position, which is numerically defined, and it stops there. The end effector performs the desired task, while the robot is halted. When task is completed, the robot moves to the next point and cycle is repeated. Such robots are usually taught a series of points with a teach pendant. The points are then stored and played back.

Applications: Point-to-point robots are severely limited in their range of applications. Common applications include:

- Component insertion
- Spot-welding
- Hole drilling
- Machine loading and unloading
- Assembly operations

Example of a typical point-to-point system is found in a spot welding robot. In this case robot moves until the point to be welded is positioned between the two electrodes of the welding pistol, and welding is performed. Then the robot moves to another point, which is again welded. This procedure is repeated until all necessary points are welded.

(b) Continuous-path (CP) Control Robot

In continuous path robot the tool performs its task, while the robot its axes) is in motion, like in the case of arc welding, where the welding pistol is driven along the programmed path. All axes of continuous path robots move simultaneously, each with a different speed. The computer co-ordinates the speeds so that the required path is followed. The robot's path is controlled by storing a large number of spatial points in the robot's memory during the teach sequence. During teaching, and while the robot is being moved, the co-ordinate points in space of each axis are continually monitored and placed into the control system's computer memory. These are the most advanced robots and require the most sophisticated computer controllers and software development.

Applications: Typical applications include:

- Spray painting.
- Finishing
- Gluing
- Arc welding operations.

- Cleaning of metal articles.
- Complex assembly processes.

(c) Controlled-path Robot

In controlled-path robots, the robot is moved along a computer-generated, predictable path as the robot travels from point to point. The computer-generated path may be a straight line with end-effector orientation or it may involve curved paths through successive points and/or gradual orientation changes. Good accuracy can be obtained at any point along the specified path. Only the start and finish points and the path definition function must be stored in the robot's control memory. The robot movements are more precise than with point-to-point programming and are less likely to present a hazard to personnel and equipment.

ROBOT CLASSIFICATION ON THE BASIS OF PROGRAMMING METHOD

Robots can be classified according to the programming method such as:

- Manual Programming
- Lead-through Programming
- Walk-through Programming

These methods are discussed in detail in chapter of Robot Programming.