CHAPTER 3
INDUSTRIAL ROBOT

3.1 INTORDUCTON

An industrial robot is general - purpose, programmable machine possessing certain anthropomorphic characterics. The most typical anthoropomorphic, or humanlike, characteric of a robot is its arm. This arm, together with the robot's capactity to the programmed, makes it ideally suited to a variety of production tasks, including machine loading, spot welding, spray painting and assembly. The robot can be programmed to perform a sequence of mechanical motions, and it can repeat that motion sequence over and over until reprogrammed to perform some other job.

The Robot Institute of America has developed the following definition:

A robot is a programmable, multi - function manipulator designed to move material parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks.

3.2 ELEMENT OF A ROBOT SYSTEM

Robots are available in a wide of cabilities and configurations. The robot system consists of the following major subsystems.

1. Manipulator system: The mechanical arm mechanism, consisting of a series of links and joints that perform the motion by moving the end effector tooling through space. The end of the wirst can reach a point in space (location) with a specific orientation. It closely resembles a human arm and consists of a base, shoulder, elbow and wirst.

2. End - effector tooling. The end of the wirst in a robot is equipped with an end effector. Depending on the type of operation, conventional end effectors are equipped with

(a) Grippers, hooks, scoops, electromagnets, vacuum cups, and adhesive fingers for material handling.

(b) Spray gun for painting

(c) Attachments for spot and arc welding and arc cutting.

(d) Power tools such as drill, net drivers.

(e) Measuring instruments such as dial indicators

3. Power supply: Each motion of the manipulator in linear and rotational axes is controlled and regulated by independent acuators, using electric, pneumatic or hydraulic power supplies.

4. Control system: Also known as controller. The contol system is the communications and information processing system that gives commands for the movements of the robot.

It is the brain of the robot and stores data to indicate and terminates movements of the manipulators.

3.3 ROBOT PHYSICAL CONFIGURATIONS

Industrial robots come in a variety of shapes and sizes. They are capable of various arm manipulations and they posses different motion systems. This section discusses the various physical configurations of robots.

Almost all present - day commercially available industrial robots have one of the following four configurations.

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

The four types are schematically illustrated in Figure and described below.

Polar coordiante configuration

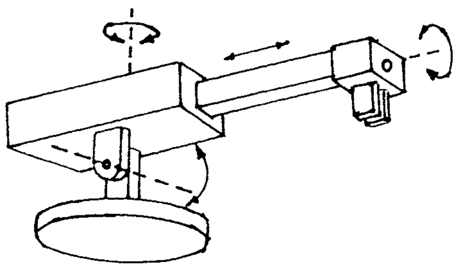

Fig. 3.1 Polar coordinate configuration

This configuration also goes by the name "spherical coordinate," because the workspace within which it can move its arm is a partial sphere. The robot has a rotary base and a pivot that can be used to raise and lower a telescoping arm.

Cylindrical coordinate configuration

In this configuration , the robot body is a vertical column that swivels about a vertical axis. The arms consists of several orthogonal slides which allow the arm to be moved up or down and in and out with respect to the body.

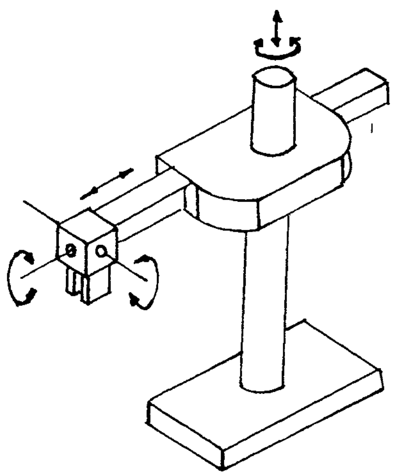

Fig. 3.2 Cylindrical coordinate configuration

Jointed arm conifguration

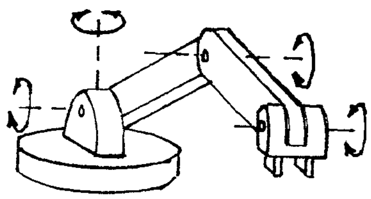

Fig 3.3 Jointed arm configuration

The jointed arm configuration is similar in appearance to the human arm. The arm consists of several straight members connected by joints which are analogous to the human shoulder, elbow, and wirst. The robot arm is mounted to a base which can be rotated to provide the robot with the capacity to work within a quasi - spherical space.

. **Cartesian coordinate configuration**

A robot which is constructed around this configuration consists of three orthogonal slides. The three slides are parallel to the x, y and z axes of the cartesian coordinate system. By appropriate movements of these slides, the robot is capable of moving its arm to any point within its three dimensional rectangularly shaped workspace.

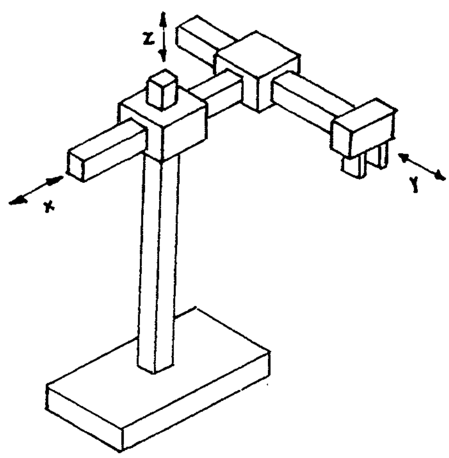

Fig. 3.4 Cartesian coordinate configuration

3.4 BASIC ROBOT MOTIONS

Whatever the configuration, the purpose of the robot of the robot is to perform a useful task. To accomplish the task, an end effector, or hard, is attached to the end of the robot's arm. It is this end effector which adapts the general - purpose robot to a particular task. To do the task, the robot arm must be capable of moving the end of effector through a sequence of motions and / or positiions.

Six degrees of freedom

There are six basic motions, or degrees of freedom, which provide the robot with the capability to move the end effector through the required sequence of motions. These six degrees of freedom are intended to emulate the versatility of movement possessed by the human arm. Not all robots are equipped with the ability to move in all six degrees. The six basic motions consist of three arm and body motions and three wrist motions, as illustrated in figure. These motions are described below.

Arm and body motions:

1. *Vertical traverse*: up - and - down motions of the arm, caused by pivoting the entire arm about a horizontal axis or moving the arm along a vertical slide
2. *Radial traverse*: extension and retraction of the arm (in - and - out movement)
3. *Rotational traverse*: rotation about the vertical axis (right or left swivel of the robot arm)
4. *Wrist swivel*: rotation of the wrist
5. *Wrist bend*: up - or - down movement of the wirst, which also involves a rotational movement

6. *Wrist yaw*: right - or - left swivel of the wirst

Additional axes of motion are possible, for example, by putting the robot on a track or slide. The slide would be mounted in the floor or in an overhead track system, thus providing a conventional six - axis robot with a seventh degree of freedom. The gripper device is not normally considered to be an additional axis of motion.

MOTION SYSTEMS

Similar to NC machine tool systems, the motion systems of industrial robots can be classified as either point - to - point (PTP) or contouring (also called continuous path).

In PTP, the robot's movement is controlled from one point location in space to another. Each point is programmed into the robot's control memory and then played back during the work cycle. No particular attention is given to the path followed by the robot in its move form one point to the next. Point - to - point robots would be quite capable of performing certain kinds of productive operation, such as machine loading and unloading, pick- and -place activities, and spot welding.

Contouring robots have the capability to follow a closely spaced locus of points which describe a smooth compound curve. The memory and control requirements are greater for contouring robots than for PTP because the complete path taken by the robot must be remembered rather than merely the end points of the motion sequence. However, in certain industrial operations, continuous control the work cycle path is essential to the use of the robot in the operation. Example, of these operations are paint spraying, continuous welding processes, and grasping objects moving along a conveyor.

3.5 OTHER TECHNICAL FEATURES

In additon to the robot's physical configuration and basic motion capabilities there are numerous other technical features of an industrial robot which determine its efficiency and effectiveness at performing a given task. The following are some of the most important among technical features:

1. Work volume
2. Precision of movement
3. Speed of movement
4. Weight - carrying capacity
5. Type of drive system

Work volume

The term " work volume" refers to the space within which the robot can operate.

The work volume of an industrial robot is determined by its physical configuration, size and the limits of its arm and joint manipulations. The work volume of a cartesian coordinate robot will be rectangular. The work volume of a cylindrical coordinate robot will be cylindrical. A polar coordinate configuration will generate a work volume which is a partial sphere. The work volume of a jointed arm robot will be somewhat irregular, the outer reaches generally resembling a partial sphere.

Precision of movement

The precision with which the robot can move the end of tis wrist is a critical consideration in most applications. In robotics, precision of movement is a complex issue, and we will describe it as consisting of three attributes:

1. Control Resolution
2. Accuracy
3. Repeatability

. **Control resolution:** refers to the capability of the robot's controller and positioning system to divide the range of the joint into closely spaced points that can be idnetified by the controller. Bit storage capacity is the determining factor in the control resolution.

If n represent the number of bits for an axis, the number of control point is given by mamber of control points = 2^n.

The control resoluation is therefore defined as

$$\text{Control resolution (CR)} = \frac{\text{range of axis movement}}{2^n}$$

Spatial resolution: The term "spatial resolution" refers to the smallest increment of motion at the wrist end that can be controlled by the robot. This is determined largely by the robot's control resolution, which depends on its position control system and/or its feedback measurement system. In addition, mechanical inaccuracis in the robot's joints would tend to degrade its ability to position its inaccuracies in the robot's joints would tend to degrade its ability to position its arm. The spatial resolution is the sum of the control resolutin plus these mechanical inaccuracies. The factors determining control resolution are the range of movement of the arm and the bit storage capacity in the control memory for that movement. Spatical resolution = CR + mechanical error.

EXAMPLE 4.1

Assume that we want to find the spatial resolution for a cartesian coordinate robot that two degrees of freedom. The two degrees of freedom are manifested by two orthogonal slides. Each slide has a range of 0.4 m (about 15.75 in), hence giving the robot a work volume which is a plane square, with 0.4m on a side. Suppose that the robot's control memory has a 10-bit storage capacity for each axis.

To determine the control resolution, we must first determine the number of control increments of which the control memory is capable. For the 10-bit storage, there $2^{10} = 1024$ control increments (the number of distinct zones into which the slide range 0.4m can be divided)

Then the control resolution would be found by dividing the slide range by the number of control increments.

$$\text{control resolution} = \frac{0.4\text{m}}{1024} = 0.3906 \text{ mm}$$

Since there are two orthogonal slides, the control resolution of this robot, would be square iwth 0.39 mm per side. Any mechanical inaccuracies would be added to this figure to get the spatial resolution.

ACCURACY

The accuracy of the robot refers to its capability to position its wrist end (or a tool attached to the wrist) at a given target point within its work volume. Accuracy is closely related to spatial resolution, since the robot's ability to reach a particular point in space depends on its ability to divide its joint movements into small increments. According to this relaton, the accuracy of the robot would be one-half the distance between two adjacent resolution points.

REPEATABILITY

This refers to the robot's ability to positin its wrist end (or tool) back to a point in space that was previously taught. Repeatability is different from accuracy. The difference is illustrated in Figure. The robot was initially programmed to move the wrist end to the target point T. Because it is limited by its accuracy the robot was only capable of achieving point A. The distance between points A and T is the accuracy. Later, the robot is instructed to return to this previously programmed point A. However, because it is limited by it repeatability, it is only capable of moving to point R. The distance between points R and A is a measure of the robot's repeatability. As the robot is instructed to return to the same position in subsequent work cycles, it will not always return to point R , but instead will form a cluster of positions about point A. Repeatability errors form a random variable. In general, repeatability will be better (less) than accuracy. Mecahnical inaccuracies in the robot's arm and wrist components are principal sources of repeatability errors.

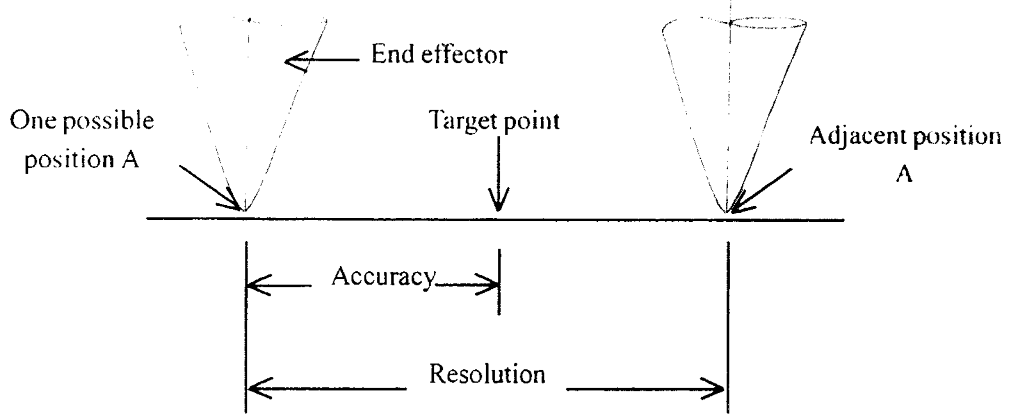

Fig.4.5 Illustration of accuracy versus resolution

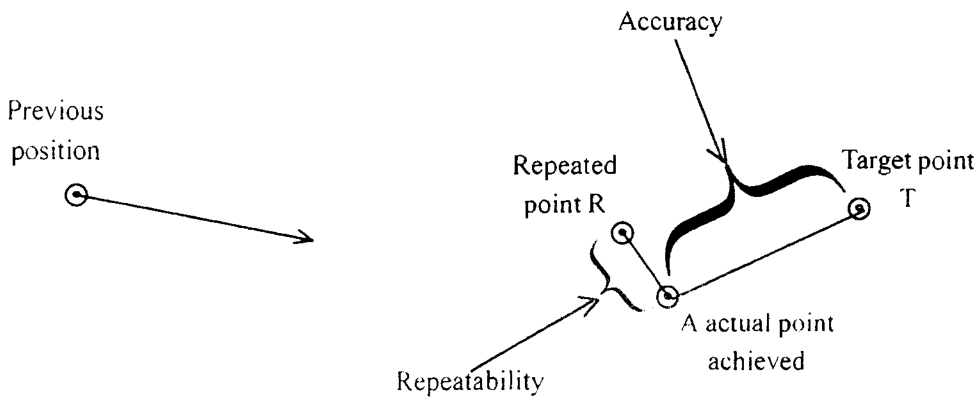

Fig.4.6 Illustration of repeatability versus accuracy

Speed of movement

The speed with which the robot can manipulate the end effector ranges up to a maximum of about 1.5m/s. Almost all robots have an adjustment to set the speed to the desirable level for the task performed. This speed should be determined by such factors as the weights of the object beng moved, the distance moved, and the precision with which the object must be positioned during the work cycle. Heavy objects cannot be moved as fast as light objects of inertia problems. Also objects must be moved more slowly when high positional accuracy is required.

Weight - carrying capacity

The weight - carrying capacity of commercially available robots covers a wide range. At the upper end of the range, there are robots capable of lifting over 1000 lb. The Versatran FC model has a maximum load - carrying capacity rated at 2000 lb. At the lower end of the range, the Unimate PUMA Model 250 has a load capacity of only 2.5lb. What complicates the issue for the low - weight-capacity robots is that the rated capacity includes the weight of the end effector. For example, the gripper for the PUMA 250 weights 1 lb, the net capacity of the robot is only 1.5 lb.

Type of dirve system

There are the three basic drive systems used in commercially available robots:

1. Hydraulic
2. Electric motor
3. Pneumatic

Hydraulically driven robots are typified by the Unimate 2000 series robots and the Cinicinnati Milacron T^3. These drive systems are usually associated with large robots, and the hydraulic drive system adds to the floor space required by the robot. Advantages which this type of system give to the robot are mechanical simplicity (hydraulic systems are familiar to maintenance personnel), high strength, and high speed.

Robots driven by electric motors (dc stepping motors or stepping motors or servomotors) do not possess the physical strength or speed of hydraulic units, but their accuracy and repeatability is generally better. Less floor space is required due to the absence of the hydraulic power unit.

Pneumatically driven robots are typically smaller and technologically less sophisticated than the other two types. Pick - and - place tasks and other simple, high - cycle - rate operations are examples of the kinds of applications usually reserved for these robots.

3.6 WORK CELL CONTROL AND INTERLOCKS

Work cell control

Industril robots usually work with other things processing equipment, workparts conveyors, tools, and perhaps, human opertors. A means must be provided for coordinating all of the activities which are going on within the robot workstation. Some of the activities occur sequantitially, while others take place simultaneously. To make certain that the various activities are coordinated and occur in the proper sequence, a device called the work cell controller is used (another name for this is workstation controller). The work cell controller usually resides within the robot and has overall responsibility for regulating the activties of hte work cell components.

EXAMPLE 3.2

The workstation consists of the robot; the machine tool, which operates on semiautomatic cycle; and two conveyors, one for incoming raw workparts and the other for outgoing finished pieces. The setup is shown in Figure. The work cycle consists of the following activities.

1. Incoming conveyor delivers raw workpart to fixed position.
2. Robot picks up part from conveyor and loads it into machine.
3. Machine processes workpart.
4. Robot unloads finished part from machine and places it on outgoing conveyor.
5. Outgoing conveyor delivers part out of work cell, and robot returns to ready position near incoming conveyor.

As this work cycle is described, most of the activities occur sequenctially. The work cell controller would have to make sure that certain steps are completed before subsequent steps are initiated. For example, the machine tool must finish processing the workpart before the robot attempts to reach in and grasp the part for unloading. Similarly, the machine cycle must not begin until the robot has loaded the raw workpiece removed its arm. The robot cannot pick up the raw part from the incoming conveyor unless and until the part has been positioned for gripping. The purpose of the work cell controller in this example is to ensure that the work elements are sequenced correctly and that each step is finished before the next one begins.

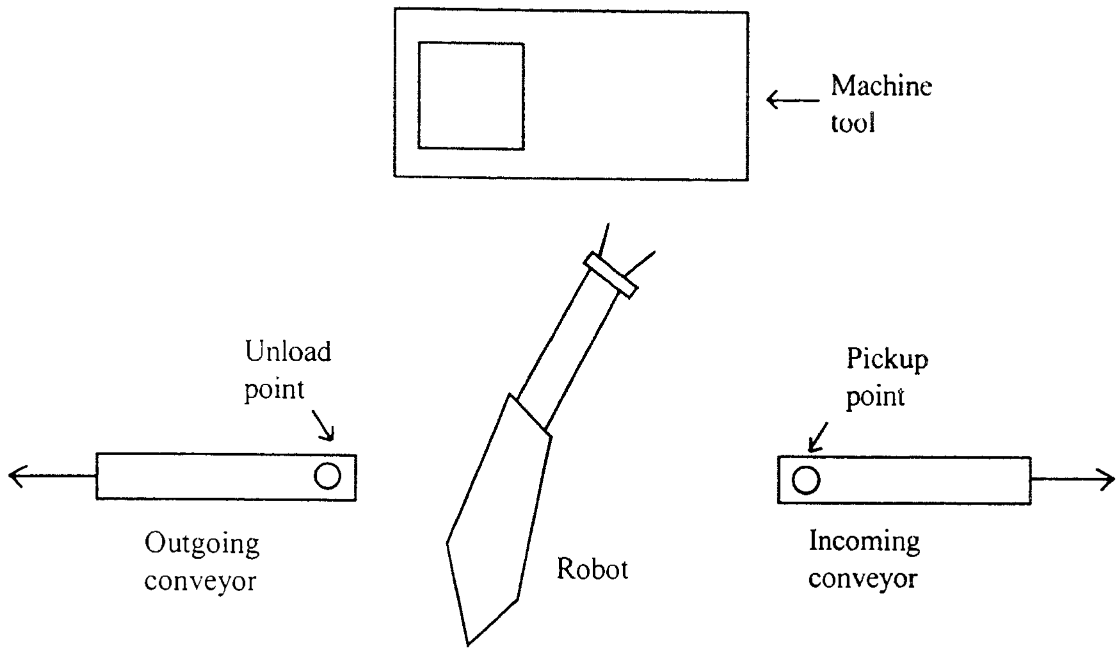

Fig.3.7 Workplace layout for robot cell

Interlocks

An interlock is the feature of work cell control which prevents the work cycle sequence from continuing until a certain condition or set of conditions has been satisfied. In a robotic work cell, there are two types: outgoing and incoming. The outgoing interlock is a signal sent from the workstation controller to some external machine or device that will cause it to operate or not operate. For example, this would be used to prevent a machine from initiating is process until was commanded to proceed by the work cell controller. An incoming interlock is a signal from some external machine or device to the work controller is a signal from some external machine or device to the work controller which determine whether or not the programmed work cycle sequence will proceed. For example, this would be used to prevent the work cycle program from continuing until the machine signaled that it had completed its processing of the workpiece.

The use of interlocks provides an important benefit in the control of the work cycle because it prevents actions from happening when they shouldn't, and it causes actions to occur when they should. Interlocks are needed to help coordinate the activities of the various independent components in the work cell and to help avert damage of one component by another.

3.7 ROBOTIC SENSORS

For certain robot applications, the type of workstation control using interlocks is not adequate.The robot must take on more humanlike senses and capabilitites in order to perform the task in a satisfactory way. These senses and capabilities include vision and hand - eye coordination, touch, and hearing. Accordingly, we will divide the types of sensors used in robotics into the following three categories:

1. Vision sensors
2. Tactile and proximity sensors
3. Voice sensors

Vision sensors

Robot vision is made possible by means of a video camera, a sufficient light source, and a computer programmed to process image data. The camera is mounted either on the robot or in a fixed position above the robot so that its field of vision includes the robot's work volume. The computer software enables the vision system to sense the presence of an object and its position and orientation. Vision capability would enable the robot to carry out the following kinds of operations:

Retrieve parts which are randomly oriented on a conveyor.

Recognize particular parts which are intermixed with other objects.

Perform visual inspection tasks.

Perform assembly operations which require alignment.

Tactile and proximity sensors

Tactile sensors provide the robot with the capability to respond to contact forces, between itself and other objects within its work volume. Tactile sensors can be divided two types:

1. Touch sensors
2. Stress sensors (also called force sensors)

Touch sensors are used simply to indicate whether contact has been made with an object. Stress sensors are used to measure the magnitude of the contact force. Strain gage devices are typically employed in force - measuring sensors.

Potential uses of robots with tactile sensing capabilities would be in assembly and inspection operations. In assembly, the robot the robot could perform delicate part alignment and joining operations. In inspection, touch sensing would be useful in gauging operations and dimensional - measuring activities. Proximity sensors are used to sense when one object is close to another object. On a robot, the proximity sensor would be located on or near the end effector. This sensing capability can be engineered by means of optical - proximity devices.

In robotics, proximity sensors might be used to indcate the presence or absence of a workpart or other object. They could also be helpful in preventing injury to the robot's human coworkers in the factorty.

Voice sensors

Another area of robotics research is voice sensing or voice programming. Voice programming can be defined as the oral communication of commands to the robot or other machine.

The robot controller is equipped with a speech recognition system which analyzes the voice input and compares it with a set of stored world patterns. When a match is found between the input and the stored vocabulary word, the robot performs some action which corresponds to that word.

Voice sensors would be useful in robot programming to speed up the programming procedure, hazardous working enviroments for performing unique operations such maintenance and repair work. The robot could be placed in the hazardous enviornment and remotely commanded to perform the repair chores by means of step - instructions.

3.8 ROBOT APPLICATIONS

Major application of industrial robots include:

1. Material handling, loading, unloading and transfering workpieces in manufacturing operation.

   eg. arc casting & molding, in which molten metal, raw materials and lubricants and parts in various stages of completion are handle with operator interfaces.

   - In heat treating parts are loaded and unloaded from furnances and quench baths.
   - Forming operation.

2. Spot welding automobiles and truck bodies producing welds of good quality.

3. Machining operations such as deburring, grinding and polishing with appropriate tools attached to their end effectors.
4. Applying adhesives and sealants, as in automobile frame.
5. Spray painting, particularly of complex shapes and cleaning operations.
6. Automated assembly.
7. Inspection and gauging in various stage of manufacture.

3.9 ECONOMIC CONSIDERATIONS OF ROBOTIC SYSTEMS

Factors that influence the selction of robot in manufacturing plants are :

1. Load carrying capacity
2. Speed of movement
3. Reliability
4. Repeatability
5. Arm configuration
6. Degree of freedom
7. Control system
8. Program memory
9. Work envelop (volume)
10. Cost (economics)

Economics: In addition to technical factors, cost and benefit considerations are significant aspects of robot selection and their use. The increasing availability and reliability, and reduced costs of sophisticated intelligent robots are having a major economic impact on manufacturing operations and gradually replacing human labor. Whereas hourly wages are steadily rising, particularly in industrial nations, the cost of robot operation per hour has increased more slowly.

3.10 ROBOT SAFETY

Depending on the size of robot's work envelope, its speed, and its proximity to humans, safety in a robot enviroment is an important consideration. Particularly important are programmers and maintenance personnel who are in direct interaction with robots. In addition, the movements of the robot with respect to other machinery requires a high of reliability in order to avoid collisions and serious damage, and its material - handling activities require proper securing of raw materials and parts in the robot gripper at various stages in the production.