Contents

1 Introduction to Robotics

1.1 INTRODUCTION

The word 'robot' has the origination in the Czech dictionary word 'robota', meaning work. The perception of a robot as given in science fiction literature in the mid-twentieth century is different from the present form of industrial robot which cannot move on its own but their physical pattern resembles the human arm. Hence the industrial robots are known as anthropomorphic 'robotic manipulators' or 'robot arms'. The industrial applications and atmospheres are diverse in nature, frequent, complex, non-reachable or harmful to human being. In all these cases the robot can be an alternative to human hands. In this advanced technological world the skill, the perfection, the productivity and the speed with which the work has to be done influence the people making decision regarding introducing a robot for manufacture and manipulate efficiently. The break even between the present practices and robotic adoption controls the investment philosophy in the Indian scenario. The entry of robotics calls for updating the education system witn the basic understanding of the robot-definition, anatomy, design, control and application.

The articulated industrial robots are patterned to look like human hands with upper arm, fore arm and fingers at the end. The chest and the arms are corresponded by the links in the manipulator. The robot joints represent the shoulder, elbow and the wrist. The robot fingers are called end-effector which may be a tool or a gripper which is a holding device. The opening and closing or a movement can be by a mechanical mechanism. The movements are programmed by a computer.

1.2 DEFINITION

"A robot is a mechanical device with links and joints, guided by sensors, driven by actuators and controlled through a programmed software, to handle and manipulate parts, materials, tools and devices for performing various tasks in variety of work environments".

The definition stated above answers the question like—what type of device is the robot ?—What's are its elements ?—How is it moved ?—How is it made to function ?—what does it do ? and where can it work ? The study of the above questions appear as separate chapters dealing in detailed explanation and analysis.

The study and understanding 'Robotics' is interdisciplinary with mechanical in the domain and other streams like electrical, electronics and computer, being the supplementary and essential for the industrial robot to be flexible, efficient and accurate in operation. The links and joints are to be designed for strength and rigidity through static and dynamic force analysis. While the electric motors and hydraulic/pneumatic actuators produce robot motion.

The required positions are computed through transformations. The electronics contributes in the form of control system to closely match the desired output with the achieved output. The computer programs add flexibility for performing variety of jobs executed by the robotic manipulators. The software programs with the developed algorithms, controllers and sensing systems make the robot to posses intelligence to carry out jobs with in the work envelope, defined by the movements (degree of freedom) given to links. The motion of the links are translatory and/or rotary explaining the configuration and category of a robotic manipulator.

1.3 AUTOMATION AND ROBOTICS

When the units of production and the rate of manufacture are high the specialized machines are more useful. These machines were developed to operate faster and better, to produce mechanical and electrical automobile parts in auto-industries. Introduction of such machines lead to industrial automation which can be defined as.

"For the operation and control of production or manufacture the mechanical, electrical, electronics and computer based systems are integrated to form a technology known as Industrial Automation".

Few examples for industrial automation are

- —Special purpose machine (SPM) tools.
- —Computer Numerical controlled (CNC) machines.
- —Transfer lines.
- —Flexible Manufacturing systems (FMS).
- —Robotics.

Hence it is clear that all automatic machines are not robots. But robotics is a type of industrial automation. Based on the flexibility and adoptability to volume and speed of different type of production processes the industrial production is classified into (*a*) Hard Automation (*b*) Soft Automation.

- **Comparison between Hard Automation and soft Automation**

Features	*Hard Automation*	*Soft Automation*
1. Cost effectiveness	• Good at very high production volume.	• Good for moderate production volume.
2. Flexibility	• limited	• High.
3. Life cycle	• To be for a longer period.	• For short and medium period of cycle.
4. Batch Production	• Not suitable.	• Highly suitable.
5. Control through software	• Not possible.	• Easily possible.
6. Obsolescence of the machine	• Happens with change in model for which the part is manufactured.	• Does not happen because the software can be changed.
7. Efficiency of the operation.	• Comparably high.	• Equally high.
8. Examples	• Automatic machines, special purpose machines, machines not controlled through software, Transfer lines etc.	• CNC machines, Robots and reprogrammable machines, etc.

The Fig. 1.1 summarises the qualitative comparison of cost effectiveness of manual operation, hard automation and soft automation, [4] with respect to the volume of production. The unit cost of production is minimum for volumes less than q_1. This is generally possible in cases of small batch processing. For a volume of production beyond q_2, a very high quantity, the unit cost is least, for which hard automation is most convenient.

The break-even between manual labour and soft automation, the point A, and the break-even between soft automation and hard automation, the point B, gives the range of production volume over which 'robots' are cost effective. Over the production band between q_1 and q_2 the industrial robots are more sophisticated and less expensive.

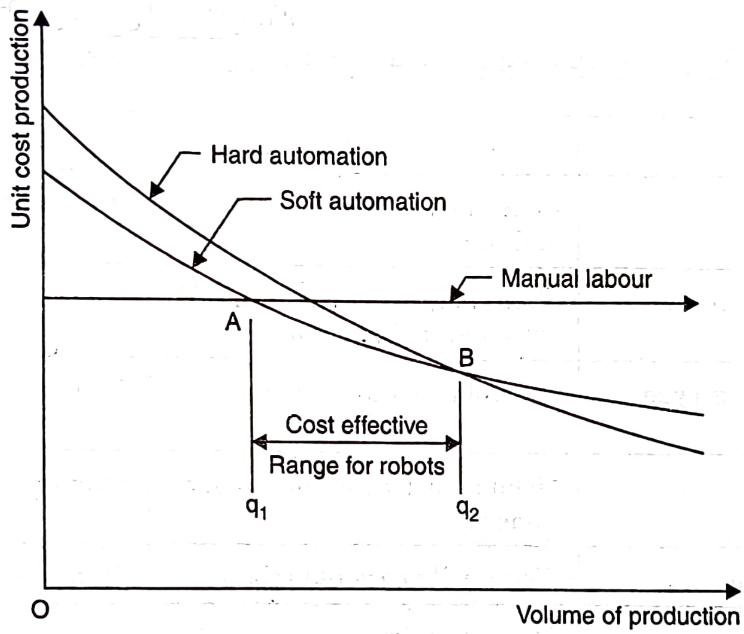

Fig. 1.1. Cost Effectiveness Comparison.

Risks of Hard Automation

- As the initial investment cost on the machine is too high, if the volume of production expected becomes to be lower, the cost per unit turns out to be higher and the profit margin declines relatively.
- The machinery specialized to produce a particular product, becomes obsolete when the design of the model is changed to cope with competition in the market.

The soft automation can be further divided into

— programmable automation, and

— Flexible automation.

The features of programmable automation are :

— The products of small batches are produced one after the other.

— The machine is reprogrammed after one product to process the further product batch.

— All product configuration are to be kept programmed and stored, and loaded in sequence for faster production.

— An industrial robot is the correct example for this type of soft automation.

The features of flexible automation are :

— Using the same manufacturing facility, different product configuration can be produced at the same instance.

— Variety of product patterns can be mixed and processed parallelly through preloaded programs.

— This possibility depends on the computational power of the computer integrated with the system.

— The ideal examples are flexible manufacturing systems, computer integrated manufacturing systems (CIMS), etc.

2nd History of Robots.

1.4 OCCURANCE OF EVENTS IN THE HISTORY OF ROBOTS

Year	*Type, name*	*Application Feature*	*Firm Developed.*
1959	Commercial	Controlled by limit switches and cams.	Planet corporation.
1960	'Unimate' Hydraulic drive robot.	'Programmed article Transfer' with manipulator control.	Devol's U.S. firm.
1966	Spray painting Type of Robot.	Controlled spray of paint.	Trallfa, a Norwegian firm.
1968	'Shakey'	Mobile robot with sensors and camera.	Stanford research Institute.
1971	Stanford Arm.	Electrically powered robot.	Stanford University.
1974	IRB6 robot	All electric drive.	ASEA
1974	T^3 Robot (The Tomorrow Tool)	Computer controlled robot.	Cincinnati Malicron.
1975	Sigma	Assembly operation	Olivetti "Sigma"
1978	PUMA (Programmable Universal Machine for Assembly)	Assembly operation.	Unimation by GM.
1979	SCARA (Selective compliance arm for Robotic Assembly)	Assembly operation.	Yamanashi University of Japan.
1982	RS-1 robot with robot language AML	Assembly operation.	IBM
1983	APAS-adoptable programmable assembly system	Flexible automated Assembly line.	Westinghouse Corporation.

1.5 ADVANTAGES AND DISADVANTAGES

Imp

No.	Comparative Characteristics	An Advantage	A Disadvantage
1.	Environmental Safety	✓	
2.	Cost constraint in investment		✓
3.	Productivity parameter	✓	
4.	Unit cost in the long run and batch	✓	
5.	Decision intelligence		✓
6.	Replacement of labour in a populated place		✓
7.	Accuracy, repeatability and work quality of new robot	✓	
8.	Stimulation multiplicity–it can work with multiple stimulli	✓	
9.	Advanced technological accessories like sensors and vision camera	✓	
10.	Degeneration of human skill and capability		✓

Health affecting environments are not hazardous to robots, where as human beings need a comfortable and safe surroundings never-the-less life supporting accessories partly take care of human activities. Air polution, noise polution and light variations do not disturb the robot activities.

Purchase cost, education and training, installation cost and maintenance make the investment decisions to be taken carefully.

The input variables and the output income units decide the productivity parameters. For a given operational time the unit output is more in case of robots compared to human labour.

Robots are more advantageous in the long run and batch-production. By changing the program robot can process the parts in batches and can produce the same for a longer period.

Handling the intelligence of a situation is art of human brain. Programming can not take care of all the possible patterns naturally embedded in the human capabilities.

In a densely populated country like India robotic adoption poses social problems leading to unemployment and labour resentment, hence replacement by robots is a management problem.

Accurate manipulability of operation and the repeatability of work are the better characteristics of robots, that make it advantageous over other machines. Quality of the jobs produced on robotic manipulators is uniform and consistence.

Human hands can process one or two ideas at a time, where as manipulators are capable of performing tasks of many stimuli at a given instance.

Advanced engineering and technological parts like sensors and vision cameras can be attached to the robot arms to resemble the human arms in carrying out the work procedure.

Skill is developed over a period of time by experience obtained by continuous work and application and determination. However robots with built in skill requires human help, which is limited to simple operations.

Although robots have superiority and certainity in some senses they lack in exactness of the responses and cannot sense the presence of undefined obstructions. Real time responses have been the limitation on the programming capabilities. The complex degree of freedom can not be tackled by the robots. Robots depend upon external source of power like electricity transformed into movements.

1.6 INVESTMENT ON ROBOT

A cost analysis and Revenue analysis.

Expenses		*Revenue*	
Direct	*Indirect*	*Direct*	*Indirect*
• Material cost	• Operational time-reduced.	• Finished goods revenue.	• Faster production revenue.
• Robot purchase cost.	• Cost of consumable peripherals-reduced.	• Labour : less requirement.	• On time supply of the product.
• Cost of programming.	• Storage cost increases due to small lot size.	• Well finished product quality.	• Increase in productivity.
• Maintenance cost.	• Installation cost is more.	• Variety of product for varies applications.	• Can work all 24 hours.
• Material storage cost increases	• Batch change over cost.	• Increase in export potential and reserve.	• Compete ahead in marketing.
• Cost of scrap.	• Materials handling cost.	• Expansion of the market leading to more sale.	• Miscellaneous.
• Tooling cost	• Building a separate work cell.	• Diversification of product range.	
	• Rework cost.		
	• Paper cost and ordering cost.		
• Remuneration	• Educating and training the operators.	• Estimated flexibility.	
	• House keeping.		
	• Estimated safety cost.		
	• Miscellaneous.		

Cost Analysis

Cost of Investment	*Operational Costs*
1. **Engineering Costs :** The cost of project planning by the company's professional staff to install a robot.	1. **Training :** This is the first operational cost which prevents displacement old workers and induction of new.
2. **Purchase Cost of Robot :** The basic price of the robot conforming to needed specification.	2. **Resources and Utilities :** The cost of energy sources like electricity, gases and hydraulic/pneumatic fluids.
3. **Cost of Installation :** Preparation of the floors and utilities—respective labour and materials.	3. **Direct Labour :** The operation of the robot work cell is included in this.
4. **Tools and Fixture Cost :** This includes the cost of end effectors, tools and fixtures to be kept in the work cell.	4. **Indirect Labour :** The labour cost not included in the direct labour. The costs like programming, supervision, set up costs are generally included in this.
5. **Miscellaneous Expenses :** The cost other than the above costs, incurred due to peripherals and display monitors.	5. **Cost of Maintenance :** The robot's part wear-out over a period of time of operation, leading to maintenance and repair of the robots. It is customary to enter into maintenance contract while purchase itself or an appointment of a separate personell to do the job.

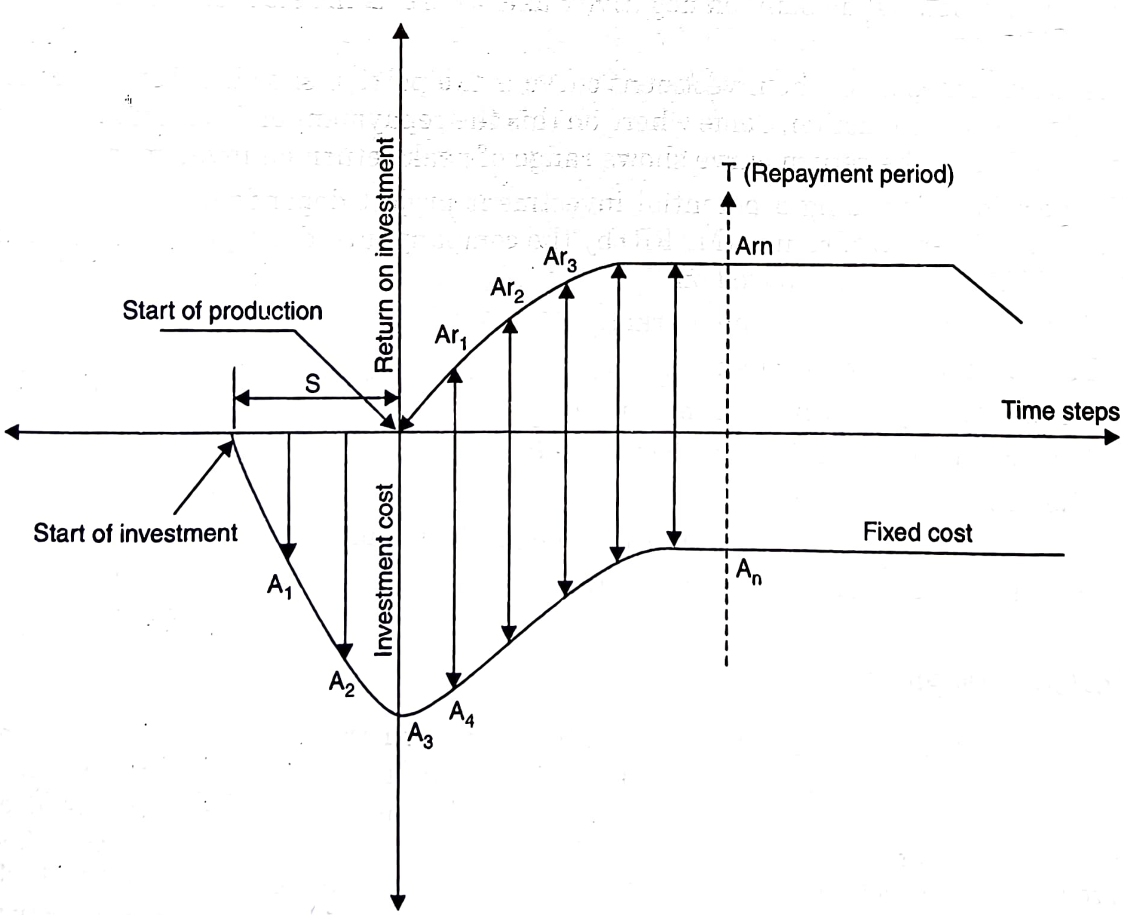

Fig. 1.2. Repayment Period Plot.

Calculation of the Repayment Period (T)

$$\frac{\begin{Bmatrix}\text{Average of the investment}\\ \text{till the break even}\end{Bmatrix}}{\begin{Bmatrix}\text{Time taken for break even from}\\ \text{the start of production}\end{Bmatrix}} = \frac{\begin{Bmatrix}\text{Average of the return}\\ \text{till the break even}\end{Bmatrix}}{\begin{Bmatrix}\text{Time taken to break even}\\ \text{from start of investment}\end{Bmatrix}}$$

$$\frac{A_i}{T} = \frac{A_r}{(T+s)}$$

and

$$T = \frac{s \, . \, A_r}{A_i - A_r} = \text{Repayment Period.}$$

where

$$A_1 = \frac{A_1 + A_2 + A_3 + \ldots\ldots A_n}{n}$$

and

n = number of steps of calculation of cost.

$$A_r = \frac{A_{r1} + A_{r2} + A_{r3} + \ldots\ldots A_{rn}}{rn}$$

rn = number of steps of calculation of return from the start of production.

s = time taken for the start of production from the date of investment.

The plot of time step against cost-investment and return value is depicted in the Fig. (1.2). The x-axis is the representative of time steps and the y-axis above the x-axis is the portion giving return on investment where as the portion below x-axis is indicator of investment-cost. The start of investment is the point on negative x-axis where as the start of production is at the origin.

The horizontal part of the investment curve is the portion showing fixed cost incurred after stabilization of production. Some where on this the repayment on investment starts. The horizontal portion on the return curve shows range of peak return on investment.

The decision of funding a potential investment project depends on the selection of a minimum-attractive-rate of return (MARR) by the company introducing robotics in its industrial setups. MARR is selected based on

- The growth potential of the market.
- The competitor's market share.
- Market survey of own company share.
- The product price and the projected profit.
- The capacity utilization.
- The introduction of a new product in the product range.

Generally MARR ranges from 20%–50%.

1.7 SOCIAL IMPACT

Replacement of the conventional machinery by industrial robots has a transforming impact on the industrial society, especially direct labour, in the form of displacement, convertion and change in the employment pattern, and also training and education system is also to be modified. The management is inclined to opt for introducing robots in the industry, biased by the derived benefits like higher productivity and flexibility. Robotics has stretched its hands in various industrial fields like assembly of parts, material handling, welding and spray painting, irrespective of environs of operation hazardous or non-hazardous in nature. The impact of robotics can be studied and analysed under the following sub headings.

- **Impact of Robotics on Direct Labour**

A robot performing multiple tasks, can be a substitution for more than one human workers leading to the displacement, shift of direct labour to indirect labour activities and change in strategy in the appointment of new workers. The set up of the work-space and operating the robots need the education and training the direct labour in convertion to indirect labour, which involves diversion from direct manual participation in the production work performed. The change from direct to indirect jobs is subjected removal of high degree of skill, monotony and organization of activities in the conventional work area occupied by non-robotic machines. The new workers appointed in a robot installed industries need to be knowledged in installing, programming, inspecting, trouble shooting and maintenance of the industrial robots. The knowledge content, the technological skill and the education standard of the operator has to be improvised as the expertise needed in a robotic cell has to match consistently. The job opportunities open up in the robot manufacturing industries for the upgraded technical human skills.

To counter the unrest among the workers the labour unions have to be taken into confidence through sufficient prior notice, minimum-careful-displacement, new technology adaption training and guidance, also convincing the security of job is a serious task as well.

- **Professional Adjustment Impact**

The professional and the semi-professional forces in a conventional industry are adjusted to age old techniques like process plans, try outs, personell management, quality control, rigorous testing procedures and material movements. With the advent in automation they have to be familiar with and expertised in computer programming, altering the software, robot maintenance, optimization of processes, system analysis, product planning etc. The engineers from specialization in machine design, machine tool technology, control system engineering, electronics and computer science can fulfill the need of professionals in the robotic industries.

- **Need for Education and Training**

The present standard of education has to be revised to care of the (1) need of highly educated force (2) shortage of robot technicians (3) deficiency in robot language programmers (4) good well equipped laboratory facilities and instructors (5) short fall in training institutions (6) consultants to retrain the existing task force.

1.8 LABOUR, ROBOTS AND PRODUCTIVITY

According to the management perspective the productivity enhancement is a social issue of major concern to enable the company to withstand the competition locally and globally. The productivity of a robot over the human labour, especially in the batch production industry is remarkably high and effective in the unit cost of the product. The definition and the factor contributing to productivity make the understanding better.

$$\text{Productivity} = \frac{\text{units generated}}{\text{units fed into}}$$

The units generated can easily accountable by the output of the products, the unit cost of which depends again on the productivity.

The factors contributing to decide on the units fed in are

— Capital investment on machinery.

— Technical knowledge inductment.

— The direct and indirect labour hours.

The difference in input and the output is attributed by the following factors,

- The machine idle time.
- The man idle time.
- The generation of scraps.
- The possibility of rework.
- The equipment breakdown.
- Insufficient tooling aids.

Substantial improvement over these factors can be observed by the use of robotics as the means of industrial automation providing higher productivity factor. Another aspect is that the robots can work all 24 hours in a day and throughout the week leading to the better utilization of the equipment. But also the robotic automation improves the quality and appearance of the product produced by induction of technical knowledge in the form of software control.

The change over, certainly is a important social issue as it denies job opportunity to human beings with definitely serious financial and emotional impact on the workers themselves and their families as well.

1.9 MANAGEMENT AND ROBOTICS

The decision for induction robot in an industry has to be based on certain workouts by the low level management on the directions of the high level management. The following steps can be identified to be the workout approaches.

- Technology familiarization in the beginning.
- Identification of the application potentials through plant survey.
- Suitable selection of the operation.
- Study of the robot specification to the application.
- Thorough economic analysis and capital flow pattern estimation.
- Planning and control.
- Engineering and installation.

1.10 OVERVIEW OF ROBOTS

The general understanding about the robotics applicable in industries in particular are discussed in detail in the following sub-headings.

- **Degree of Freedom :** The translatory and rotary motions of the arms of the robots.
- **The Reference Frames :** The cartesian frames attributed to the base, joints and the tip of the robot arms.
- **Robot Joints :** The type of arm connections between which different types of motions are, like linear and rotational, possible.
- **Configurations :** The total set of movements of the robot manipulators of different types generally available in the industry.
- **Robot Components :** All possible types of components used in the industrial robots, which constitute them in complete.

- **Robot Specification :** The characteristics that has to be incorporated while desining and selection of the components, also to be considered while purchasing it.
- **Modes of Programming and Control :** The modes of programs and languages to produce a controlled action in a robot for the robot to function effectively.

The selection of the above features while making and purchase decision of the industrial robots depends upon the application of the robot in the various types of jobs, which is discussed in the forth coming section sub-headings.

Degree of Freedom

A body suspended in space can have six positive degrees of freedom and six negative degrees of freedom. The three degrees of freedom are the translatory or linear degrees of freedoms along the positive cartesian axes and three along the negative cartesian axes which are opposite. Six rotary movements about the cartesian axes of which three are clockwise and remaining three are anticlockwise. The illustration of the degree of freedom is shown in Fig. 1.3.

6 - rotatory
6 - linear

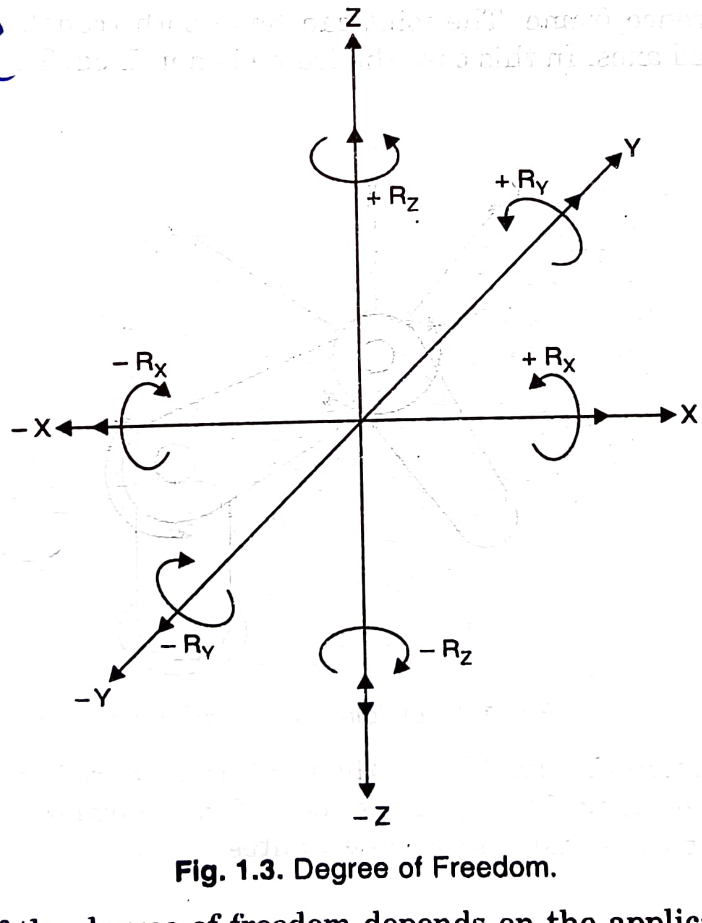

Fig. 1.3. Degree of Freedom.

The selection of the degree of freedom depends on the application to reach a specific point in the work, envelope in which the job is located.

• The Reference Frames

There are three types of reference frames attributed to the robot structure.

1. Base Reference Frame. The basic x, y and z axes are the three axes of the base. The base may be fixed or rotate about the z-axis according to the need of the application. The base reference frame is the universal frame of reference for a robot which is dipicted as in Fig. 1.4 (*a*).

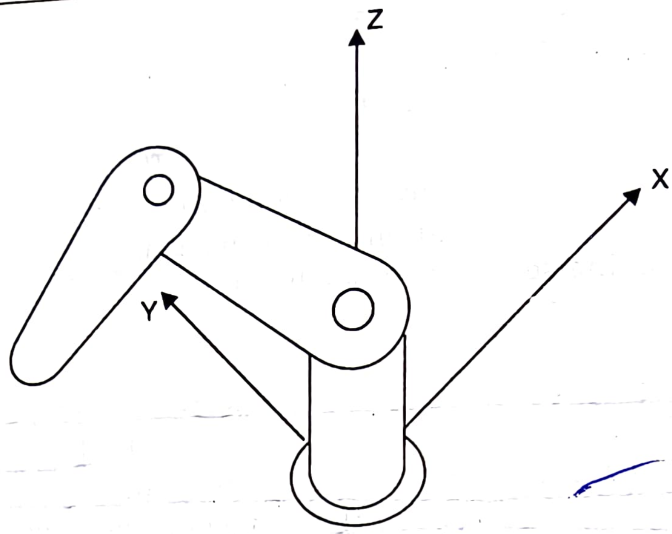

Fig. 1.4. (*a*) Base Reference Frame.

2. Joint Reference Frame. The reference axes defined at the joints of the robot, are called the joint reference frame. The joint can have both translatory and rotational movements about it defined axes. In this case the frame is not fixed. The joint frame is a shown in the Fig. 1.4 (*b*).

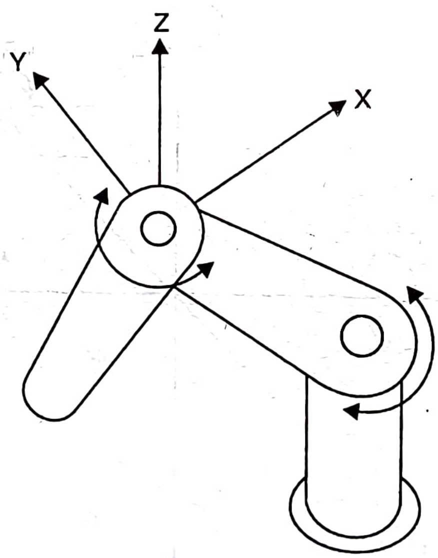

Fig. 1.4. (*b*) Joint Reference Frame.

3. Tool Reference Frame. This is the local frame of reference defined by the axes at the arm tip or the robot hand. The tip or the tool reference frame is related to the base reference frame by the transformation of the co-ordinates.

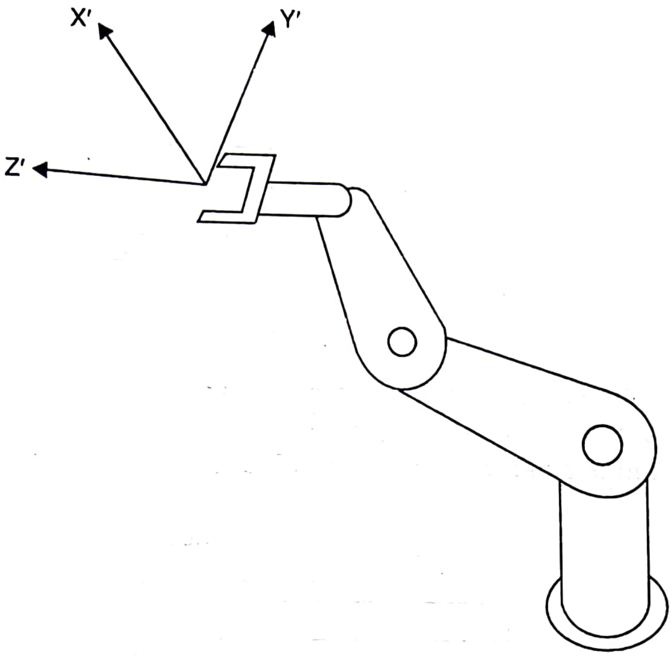

Fig. 1.4. (*c*) Tool Reference Frame.

• Robot Joints

The robot joints are made to produce motions which can be linear, rotary or spherical in nature. The joints that give linear motion are known as 'prismatic joints', and the joints producing rotary movements are named as 'revolute joints'. The joints that produce multiple rotations are 'spherical joints' which are uncommon in industrial applications.

The motion to the joints can be given by hydraulic, pneumatic or electric drives. The hydraulic or pneumatic drives can take higher payloads and for light payloads the electric drives are sufficient. The most of the industrial application robots have either prismatic joints or the revolute joints as the incorporation of the drives in these kinds of joint is easy and the control of the drives is simple.

• Robot Configurations

The possible types of movements that a robot can provide defines the configuration of a particular robot. The different configurations of different robots help in positioning of the robot hand in the defined co-ordinate of the work-envelope. If 'P' represents the prismatic joint and 'R' represents the revolute joint then a robot with three prismatic and 2 revolute joint is configured as 3P2R robot.

1. Cartesian (3P) Robot. These type of robots have three degrees of rigid body freedom. They have three prismatic joint which produces three linear motions in x, y and z directions. The illustration is given in Fig. 1.5 (*a*).

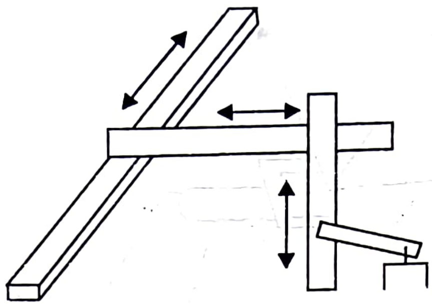

Fig. 1.5. (*a*) Cartesian.

2. Cylindrical (2 PR) Robot. This type of robots have two prismatic joints and one revolute joint. The two prismatic joints give linear movements about any two axes and the thrid movement, rotation is produced by the revolute joint. The sketch of such a robot is given in Fig. 1.5 (*b*).

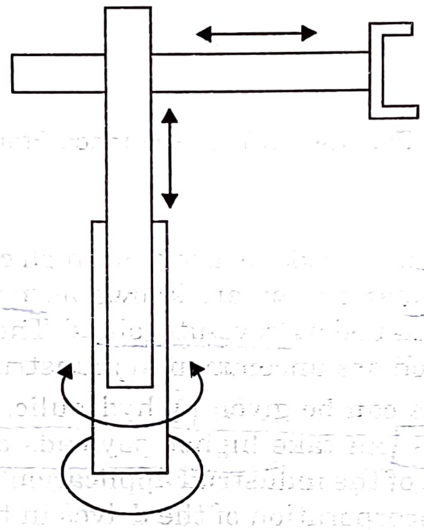

Fig. 1.5. (*b*) Cylindrical.

3. Articulated/Anthropomorphic Robot (3 R). The robots of this type have three revolute joints giving three rotary movements resembling the human hand.

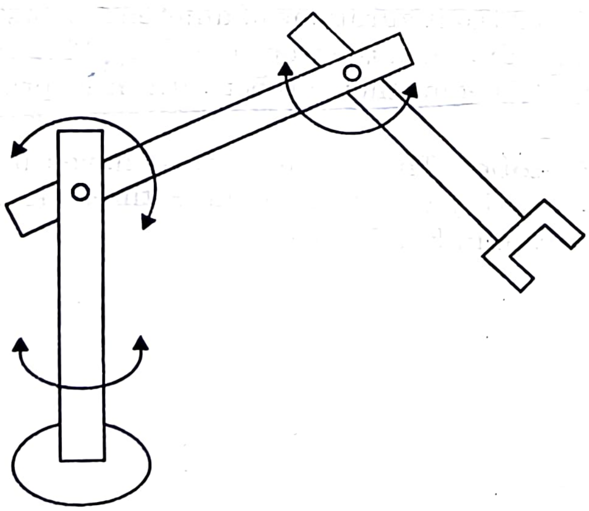

Fig. 1.5. (*c*) Articulated.

• **Spherical (2 RP) Robot.** Two revolute joints and one prismatic joint characterize this type of robot in which there are one linear and two rotary movements produced at the joints. Refer Fig. 1.5 (*d*) for the illustration.

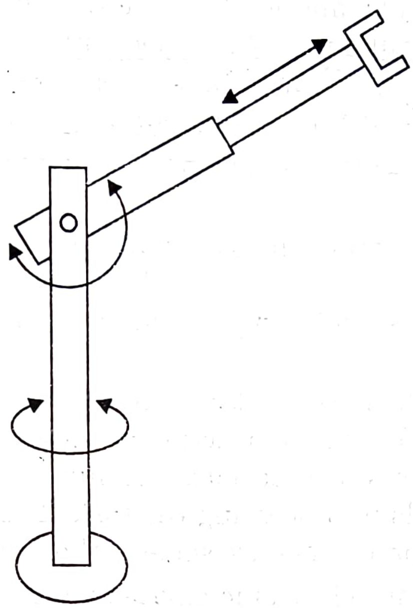

Fig. 1.5. (*d*) Spherical.

• **SCARA (Selective Compliance Assembly Robot Arm).** This is a specially configured robot which has two horizontal and parallel revolute joints with the axis vertical and one prismatic joint which can move the arm vertically up and down. This finds use in assembly operations. The Fig. 1.5 (*e*) shows schematic of the SCARA robots.

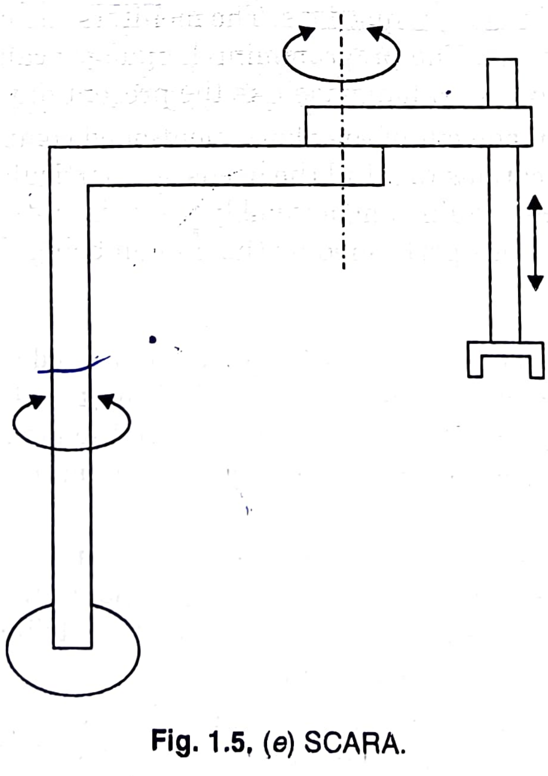

Fig. 1.5. (*e*) SCARA.

• Robot Components

Structural characteristics

For an industrial robot to carry out the assigned task of its capability, it has to have certain parts and accessories as listed and explained below.

1. Arms. The various links and joints make the anatomy of the robot which are also known as manipulators. Manipulators are the mechanical parts of a robot.

2. End-effectors. The part that is connected to the end of the arm constituting the robot hand is the end-effector which in itself is different for different applications, like spray coat gun, a welding electrode hodler, part gripper, glue applying device or a special purpose tool.

3. Actuators. The joints of the robots are powered by what are known as actuators, that produce, rotary or translatory movement in the links. The power delivering systems can be hydraulic or pneumative drives, and servo-motors or stepper motors which are direct drive types.

4. Sensors. These are the parts that recognise the robots position while in movements or when static. The further movements or action depend on the feedback of the information collected by the sensors. Sensors also perform the function of gathering data about it surrounding (work cell) which aids in processing the task. The touch and tactile sensors, vision system, force sensors, speech processors are some of the examples to the sensors.

5. Controllers. These are electronic devices which manipulate the signals from the sensors, to be provided to the drives in a understandable pattern to produce actions. The action produced may be matching or may not be tallying with the desired output. The deviation is fed back in the form of an error which adjusts the reference input to a actuating signal. The control elements and the feed back elements constitute the control system.

6. Software and Hardware. A computer software and hardware process through computation of the symbolic codes to derive the needed purpose of position, speed and accuracy of motion obtained by the kinematic equations. The monitors the peripherals and computer systems are the hardware parts. The programming languages can be a low level language like machine language or a high level language like the present day high-level languages.

The robots can be made out of the above mentioned components designed and selected to suit the derived specifications to fulfill the needs of a particular industrial tasks of material handling, welding, painting, gluing and assembly tasks, in spite of that the present day robots copy the functions and actions performed by the human beings.

• Robot Specifications

Any standard product has to be designed and marketed under certain requisite specifications or characteristics which aids in making decision to select and categorize it. Definite specifications that an industrial robot should bear are the maximum load carrying capacity, the repeatability or accuracy, the precision and the maximum and minimum reach defining the work space.

+ Payload : The rated load carrying capacity of an industrial robot is defined by its weight of the object or the tool held by the gripper, without affecting other functional characteristics like allowed tip deflection, control of motion along defined path etc. The overload may lead to the malfunctioning of the robot systems.

+ Repeatability : The accuracy with which the particular defined position can be repeatedly achieved by a robot is the repeatability. To arrive at the repeatability of a robot the statistical procedure of distribution of the positions have to be recorded and analysed and the estimated error has to be adjusted through programming the repeatability is affected by the condition of the robot components also. The error in robot positions can give a random picture also, which has to be defined by the experimentations.

+ Precision : The reach of a position of a robot is defined by the resolution of the actuators and the control feed back systems. The robots precision is given in length units.

+ Reach : The lengths of the lengths of the links the configurations define the reach of an industrial robot. The maximum and the minimum extents of the robot positions give an idea about the reach of the robot, which is also useful in the specification of the work-envelope of the robot.

• Modes of Programming and Control

The instructions for path and position controls are provided through different programming languages for different robots manufactured by different companies. The instructions are the codes which vary from low level machine languages to high level languages understandable easily. The optimal paths to be followed to achieve the desired positions through the control system actions are coded and recorded in the form of software. In the process of development the following robot languages are generated for the purpose of programming.

APT	—	Automatically Programmed Tooling.
AL	—	Assembly Language
VAL	—	Victor's Assembly Language
AML	—	A Manufacturing Language
MCL	—	Manufacturing Control Language.
AUTO PASS	—	An IBM Language.

1.11 THE CHARACTERISTICS AND APPLICATION OF THE PRESENT ROBOTS (INDUSTRIAL)

Features → / *← Application*	*Degree of Freedom*	*Structure*	*Drive System*	*Program*	*Control System*
Material Handling	3–5	Jointed arm	Pneumatic or Hydraulic	Manual or Powered lead through	Limited sequence or point-to-point playback
Machine Loading and Unloading	4–5	Polar, Cylindrical, Jointed arm	Electric or Hydraulic for (Heavy pay loads)	Powered lead through	Limited sequence or point-to-point playback
Spot Welding	5–6	Polar, Jointed arm	Hydraulic or Electric (light)	Powered lead through	Point-to-point playback
Arc Welding	5–6	Polar, Cartesian, Jointed arm	Electric or Hydraulic	Manual or Powered lead through	Continuous path playback
Spray Painting	6 or more	Jointed arm	Hydraulic	Manual lead through	Continuous path playback
Assembly line	3–6	Jointed arm, Cartesian, SCARA.	Electric	Powered lead through or textual language	Point-to-point or continuous.

1.12 ADVANCED TECHNOLOGICAL FEATURES OF A MODERN ROBOTS

- Multiple adaptable robotic arms with modular construction.
- Multiple nodes with one controller assisted by temperature gauge, pressure gauge and position sensors.
- **Motion Control :** By mechanical couplings (coupled motion control) and co-ordinated kinematics and dynamics.
- Large work envelopes and higher payloads managed and controlled with servo tuning to avoid resonance and vibration.
- Usage of micro-controllers and embedded systems for less power requirement, compact in size, changeable functions, less movable parts for longer life, chip forming the brain.
- Controller Area Network (CAN) connections.
  — controls efficiently the distributed intelligence.
  — good price-performance ratio.
  — give reliability through error detection and error handling system.
  — with immunity against electromagnetic interference.
  — giving dynamic connection and disconnection of nodes for flexibility.
  — providing real time capability for better repeatability, accuracy and precision.
  — **Communication :** Radio frequency and infra red links for digital communications.
- Programmable Automation Control (PAC) for rapid advancement in capability for which re-engineering is needed, good portability of control engine.
- **Robot Vision :** Machine vision replaces human vision through video cameras, special computer hardware and software.

1.13 NEED FOR ROBOTS

• Accuracy aspect	:	The robots can perform tasks with highest accuracy, repeatability and the finish is of high quality.
• Environmental aspect	:	They can operate under the environments hazardous to human being.
• Human aspect	:	The human error is eliminated by use of robot. Human beings cannot work round the clock without fatigue.
• Skill aspect	:	The robots controlled by computer program can execute the tasks with better skill than human being.
• Performance aspect	:	Productivity is enhanced by induction of robots. They can produce better performance and efficiency than human being.
• Automation aspect	:	The highest technology component of automation in robots can give a competitive edge in the international level.

1.14 THE CHARACTERISTICS AND APPLICATIONS OF FUTURE INDUSTRIAL ROBOT

Features → / ↓ Application	Degree of Freedom	Structure	Drive System	Program	Nature of Task	Control System
• Material handling	3–5	Jointed adaptable robot arm	Servo motors	Programmable automation control (PAC)	Safe/hazardous complicated	Motion controllers with sensor technology.
• Part loading and unloading	4–5 Multiple arms	Polar, cylindrical, Jointed arm (Adaptable)	Electronic, Servo motors (For heavy payloads)	Programmable automation control (PAC)	Complicated and safe environs.	Micro controllers and Motion controllers with vision.
• Spot (Tack) Welding	5–6	Polar, Jointed adaptable robotic arm	Electronic stepper Motors.	Programmable Logic controllers (PLC)	Simple and safe.	Micro controllers with changeable functions.
• Arc Welding	5–6	Polar, modular cartesian with adaptable jointed arm.	Direct drive servo motors	Programmable automation control (PAC)	Complicated and unsafe.	Continuous path motion controllers with sensor technology.
• Spray Coating	6 or more	Jointed arm with adaptable gun	Hydraulic actuators	Programmable Logic Controllers (PLC)	Simple and unsafe.	Continuous path motion controllers.
• Electronic Assembly	3–6 Multiple arms coupled motion.	Jointed adaptable, cartesian modular robotic arm.	Stepper motors and direct drives	Programmable Automation Control with Controller area Network (CAN)	Complicated and safe.	Micro controllers, nodes with sensors and end effectors with vision.

- **Application of Robots :**

1. **Material handling.** The jointed arm robots with 3–5 degrees of freedom can serve the material handling application. Hydraulic or pneumatic drive with manual or powered lead through teaching would give motion in the present robot designs. The next generation robots are expected to use servo motors with Programmable Automation Control (PAC). In the future robot motion controllers with sensor technology would replace the point-to-point and sequence control action. They are expected to be used in both safe and hazardous environments.
2. **Machine loading and unloading robots.** Polar (P2R) robots, cylindrical (2PR) robots jointed arm (3P) robots with 4–5 degrees of freedom are used for such application. Electronic and servo drives are the future trends in the drives as compared to present electrical and hydraulic drives. PAC can replace the powered

lead programs. Micromotion controllers with vision can be control system of next generation rather than the present point-to-point or limited response systems. They find application in both safe and diverse atmospheres.

3. **Welding.** Welding classified into spot welding and continuous welding. Polar, cartesian and jointed arm robot with 5–6 degrees of freedom are presently used. Similar robots with adaptable arms can replace in future. The Programmable Logic Controllers (PLC) are replacing the earlier manual and powered lead through robots. The hydraulic and electric drives are replaced by stepper and servo motors for higher accuracy. Point to point and continuous path are being controlled by micro motion controllers with sensor technology. Simple, safe, complicated and unsafe environments are to be considered.
4. **Spray painting.** The jointed arm robots with 6 degrees of freedom having hydraulic drive are operated in continuous path controlled by manual lead through, as seen in present robots. Adaptable arm and PLC controls operating in complicated and unsafe atmosphere are future trend.
5. **Assembly robots.** Jointed arm, cartesian, SCARA robots with 3–6 degrees of freedom having electric drive and powered lead through control are the seen features in robots. Use of adaptable modular arm with coupled motion using PAC and CAN programs operating in unsafe atmospheres controlled by micro controllers, sensors and vision system having arms driven by stepper and direct drive are advanced features being incorporated.

EXERCISE

1.1. Define a Robot. *(VTU–Jan./Feb. 2003)*

1.2. Discuss the advantages and disadvantages of using robots in industry. *(VTU–Jan./Feb. 2003)*

1.3. Explain the relationship of robotics with industrial automation and illustrate the same with a suitable example. *(VTU–Jan./Feb. 2004)*

1.4. Enlist the choronology of developments related to robotics technology until 1990. *(VTU–Jan./Feb. 2004)*

1.5. What are the costs involved in the calculation of pay back period for investment made on robot? *(VTU–May/June 2004)*

1.6. What are the advantages of using robots in industry ? *(VTU–May/June 2004)*

1.7. What is industrial automation ? What are its types ?

1.8. Compare hard automation with soft automation.

1.9. Explain the cost-effectiveness of using robots in industries with an illustration.

1.10. Explain the features of programmable and flexible automation in industry.

1.11. Explain the cost and revenue analysis of investment on robotic implementation in an industry.

1.12. Explain the calculation of repayment period on the implementation of robotics, with a cost-return plot.

1.13. What is MARR ? What are the basis on which MARR is selected ?

1.14. Discuss the impact of robotic induction on direct labour.

1.15. How are the professional staff adjusted to the impact of robotics ?

1.16. What are the needs of revised education system to take care of induction of robots in industry ?

1.17. What is productivity ? What are the factors that assigns variation to productivity in an ordinary industry as compared to robotics ?

1.18. What are the look-outs of management implementing robotics in an industry ?

1.19. Give a brief overview of robots.

1.20. What are various types of reference frames attached to a robotic structure ? Explain with example.

1.21. Briefly discuss the various robot components.

1.22. Enlist the characteristics and applications of presently used industrial robots.

1.23. What are the advanced technological features of modern robots ?

1.24. Enlist the applications and characteristics of future industrial robots.

1.25. Explain the application of robots with the features available at present and the features of future trend.

1.26. State and explain various aspects that justify the needs of robots in industry.