SICX1020 THEORY OF ROBOTICS AND AUTOMATION
(Common to EIE, E&C, ECE, ETCE, EEE & BIOMED)

UNIT I BASIC CONCEPTS:

History of Robot (Origin):

1968 Shakev, first mobile robot with vision capacity made at SRI.

1970 The Stanford Arm designed eith electrical actuators and controlled by a computer

1973 Cincinnati Milacron’s (T3) electrically actuated mini computer controlled by industrial robot.

1976 Viking II lands on Mars and an arm scoops Martian soil for analysis.

1978 Unimation Inc. develops the PUMA robot- even now seen in university labs

1981 Robot Manipulators by R. Paul, one of the first textbooks on robotics.

1982 First educational robots by Microbot and Rhino.

1983 Adept Technology, maker of SCARA robot, started.

1995 Intuitive Surgical formed to design and market surgical robots.

1997 Sojourner robot sends back pictures of Mars; the Honda P3 humanoid robot, started in unveiled

2000 Honda demonstrates Asimo humanoid robot capable of walking.

2001 Sony releases second generation Aibo robot dog.

2004 Spirit and Opportunity explore Mars surface and detect evidence of past existence of water.

2007 Humanoid robot Aiko capable of “feeling” pain.

2009 Micro-robots and emerging field of nano-robots marrying biology with engineering.

An advance in robotics has closely followed the explosive development of computers and electronics. Initial robot usage was primarily in industrial application such as part/material handling, welding and painting and few in handling of hazardous material. Most initial robots operated in teach-playback mode, and replaced ‘repetitive’ and ‘back-breaking’ tasks. Growth and usage of robots slowed significantly in late 1980’s and early 1990’s due to “lack of intelligence” and “ability to adapt” to changing environment – Robots were essentially blind, deaf and dumb!.Last 15 years or so, sophisticated sensors and programming allow robots to act much more intelligently, autonomously and react to changes in environments faster.

Present-day robots:

1. Used in cluttered workspaces in homes and factories,
2. Interact safely with humans in close proximity,
3. Operate autonomously in hazardous environments,
4. Used in entertainment and in improving quality of life.

GENERATIONS OF ROBOT

The various generations of robots are as follows.

First generation: The first generation robots are repeating, non-servo controlled type used for pick and place and point to point operations.

Second generation: The addition of sensing devices and enabling the robot to alter its movements in response to sensory feedback marked in the second generation. These robots exhibit path control capabilities.

Third generation: This generation is introduced in late 1970’s have human like intelligence. The growth in computers led to high speed processing of information, robot acquired artificial intelligence, self – learning and decision making capability by past experiences. Online computations & control, artificial vision and active force/torque interaction with the environment are the significant characteristics of these robots.

Fourth generation: These are artificial biological robots or a super humanoid capable of producing its own clones

Definition for Robot:

The Robot Institute of America (1969) defines robot as ".... a re-programmable, multi-functional manipulator designed to move materials, parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks".

Asimov's laws of robotics:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

Robotics system components:

- **Mechanical platforms or hardware base** is a mechanical device, such as a wheeled platform, arm, fixed frame or other construction, capable of interacting with its environment and any other mechanism involve with his capabilities and uses.
- **Sensors** systems is a special feature that rest on or around the robot. This device would be able to provide judgment to the controller with relevant information about the environment and give useful feedback to the robot.
- **Joints** provide more versatility to the robot itself and are not just a point that connects two links or parts that can flex, rotate, revolve and translate. Joints play a very crucial role in the ability of the robot to move in different directions providing more degree of freedom.
- **Controller** functions as the "brain" of the robot. Robots today have controllers that are run by programs - sets of instructions written in code. In other words, it is a computer used to command the robot memory and logic. So it, be able to work independently and automatically.
- **Power Source** is the main source of energy to fulfill all the robots needs. It could be a source of direct current as a battery, or alternate current from a power plant, solar energy, hydraulics or gas.
- **Artificial intelligence** represents the ability of computers to "think" in ways similar to human beings. Present day "AI" does allow machines to mimic certain simple human thought processes, but cannot begin to match the quickness and complexity of the brain. On the other hand, not all robots possess this type of capability. It requires a lot of programming and sophisticates controllers and sensorial ability of the robot to reach this level.

- **Actuators** are the muscles of robot. An actuator is a mechanism for activating process control equipment by the use of pneumatic, hydraulic or electronic signals. There are several types of actuators in robotic arms namely synchronous actuator – brush and brushless DC servo, stepper motor and asynchronous actuator – AC servo motor, traction motor, pneumatic, hydraulic.

CLASSIFICATION OF ROBOT

The ways of classifying a robot as follows

1) According to the structural capability of robot – i) mobile or ii) fixed robot.

i) **Mobile robot**: A mobile robot is an automatic machine that is capable of locomotion. . Example: spying robot. Mobile robots have the capability to move around in their environment and are not fixed to one physical location. Mobile robots can be "autonomous" (AMR - autonomous mobile robot) which means they are capable of navigating an uncontrolled environment without the need for physical or electro-mechanical guidance devices. Alternatively, mobile robots can rely on guidance devices that allow them to travel a pre-defined navigation route in relatively controlled space (AGV - autonomous guided vehicle). By contrast, industrial robots are usually more-or-less stationary, consisting of a jointed arm (multi-linked manipulator) and gripper assembly (or end effector), attached to a fixed surface

ii) **Fixed Robot**: Most industrial robots are fixed with the base but the arms are moving.

2) According to the control

To perform as per the program instructions, the joint movements an industrial robot must accurately be controlled. Micro-processor-based controllers are used to control the robots. Different types of control that are being used in robotics are given as follows.

a. Limited Sequence Control:

It is an elementary control type. It is used for simple motion cycles, such as pick-and-place operations. It is implemented by fixing limits or mechanical stops for each joint and sequencing the movement of joints to accomplish operation. Feedback loops may be used to inform the controller that the action has been performed, so that the program can move to the next step. Precision of such control system is less. It is generally used in pneumatically driven robots.

b. Playback with Point-to-Point Control

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

c. Playback with Continuous Path Control

Continuous path control refers to a control system capable of continuous simultaneous control of two or more axes. The following advantages are noted with this type of playback control: greater storage capacity—the number of locations that can be stored is greater than in point-to-point; and interpolation calculations may be used, especially linear and circular interpolations.

d. Intelligent Control

An intelligent robot exhibits behavior that makes it seems to be intelligent. For example, it may have capacity to interact with its ambient surroundings; decision-making capability; ability to communicate with humans; ability to carry out computational analysis during the work cycle; and responsiveness to advanced sensor inputs. They may also possess the playback facilities. However, it requires a high level of computer control, an advanced programming language for decision-making logic and other ‘intelligence' into the memory.

ROBOT ANATOMY

Joints and Links:

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

Each joint is connected to two links, an input link and an output link. Joint provides controlled relative movement between the input link and output link. A robotic link is the rigid component of the robot manipulator. Most of the robots are mounted upon a stationary base, such as the floor. From this base, a joint-link numbering scheme may be recognized as shown in Figure 1. The robotic base and its connection to the first joint are termed as link-0. The first joint in the sequence is joint-1. Link-0 is the input link for joint-1, while the output link from joint-1 is link-1—which leads to joint-2. Thus link 1 is, simultaneously, the output link for joint-1 and the input link for joint-2. This joint-link-numbering scheme is further followed for all joints and links in the robotic systems.

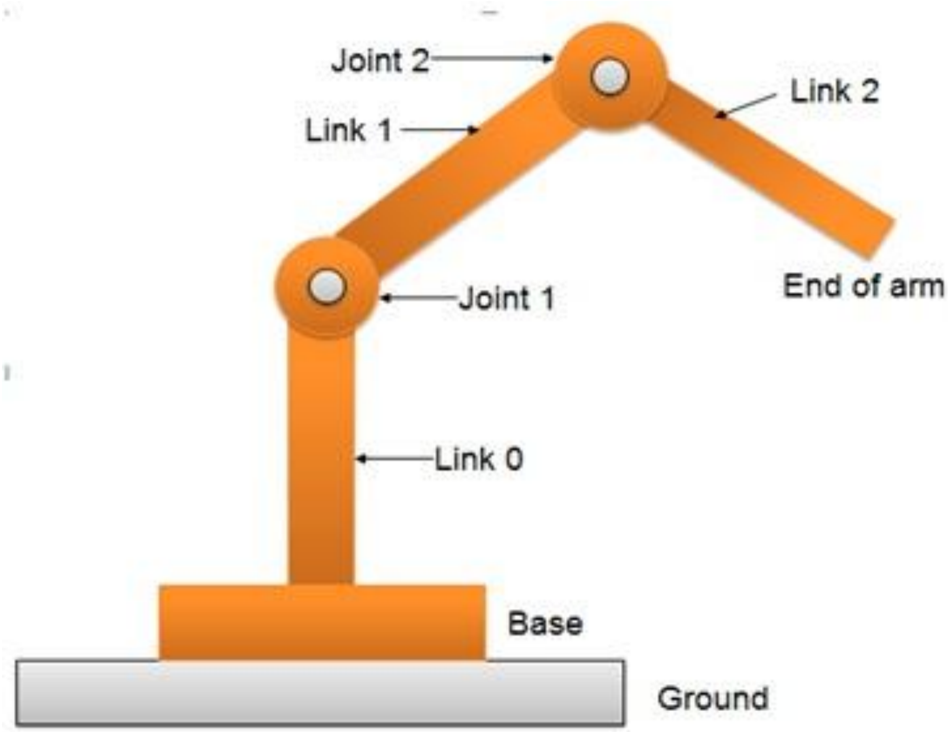

Fig. 1 Joint-link scheme for robot manipulator

Nearly all industrial robots have mechanical joints that can be classified into following five types as shown in Figure 2.

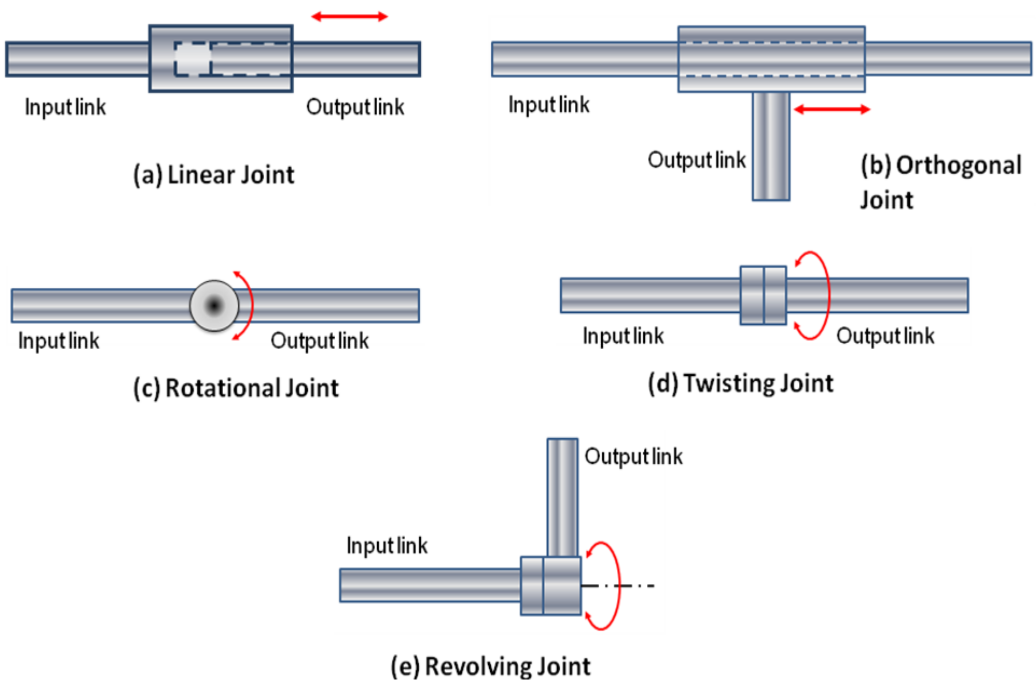

Fig. 2 Types of Joints

a) Linear joint (type L joint)

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

b) Orthogonal joint (type U joint)

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

c) Rotational joint (type R joint)

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

d) Twisting joint (type T joint)

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

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

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

Robotic arm configurations:

For body-and-arm configurations, there are many different combinations possible for a three-degree-of-freedom robot manipulator, comprising any of the five joint types.

Common body-and-arm configurations are as follows.

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

1) Polar coordinate arm configuration(RRP):

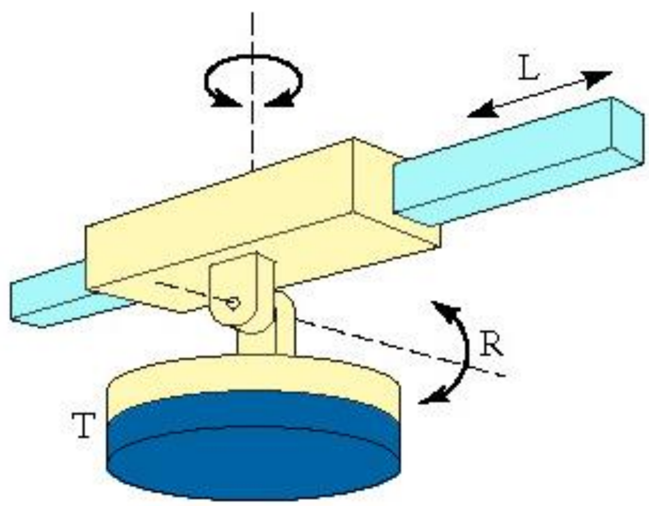

Fig 3: 3-dof polar arm configuration

The polar arm configuration is shown in the fig 3.It consists of a prismatic joint that can be raised or lowered about a horizontal revolute joint. The two links are mounted on a rotating base. These various joints provide the capability of moving the arm endpoint within a partial spherical space. Therefore it is called as “Spherical co-ordinate” configuration. This configuration allows manipulation of objects on the floor.

Drawbacks:

i. Low mechanical stiffness
ii. Complex construction
iii. Position accuracy decreases with the increasing radial stroke.

Applications: Machining, spray painting

Example: Unimate 2000 series, MAKER 110

2) Cylindrical coordinate arm configuration (RPP):

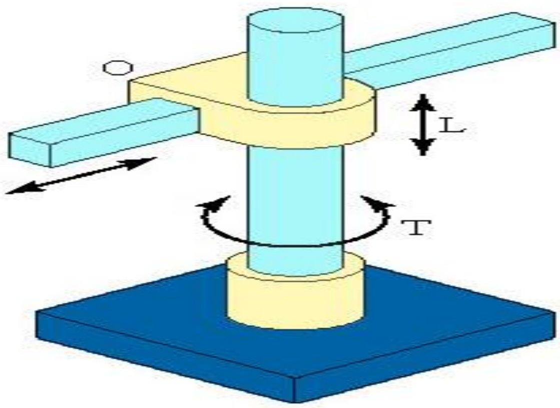

Fig 4: 3-dof cylindrical arm configuration

The cylindrical configuration uses two perpendicular prismatic joints and a revolute joint as shown in fig 4.This configuration uses a vertical column and a slide that can be moved up or down along the column. The robot arm is attached to the slide, so that it can be moved radially with respect to column. By rotating the column, the robot is capable of achieving a workspace that approximates a cylinder. The cylindrical configuration offers good mechanical stiffness.

Drawback: Accuracy decreases as the horizontal stroke increases.

Applications: suitable to access narrow horizontal capabilities, hence used for machine loading operations. **Example**: GMF model M-1A.

3) Cartesian coordinate arm configuration (PPP):

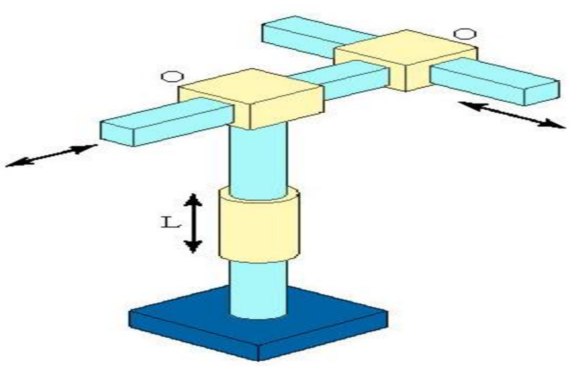

Fig 5: 3-dof Cartesian arm configuration

From fig 5.Cartesian coordinate or rectangular coordinate configuration is constructed by three perpendicular slides, giving only linear motions along the three principal axes. It consists of three prismatic joints. The endpoints of the arm are capable of operating in a cuboidal space. Cartesian arm gives high precision and is easy to program.

Drawbacks:

- limited manipulatability
- low dexterity (not able to move quickly and easily)

Applications: use to lift and move heavy loads.

Exa

4) Joint

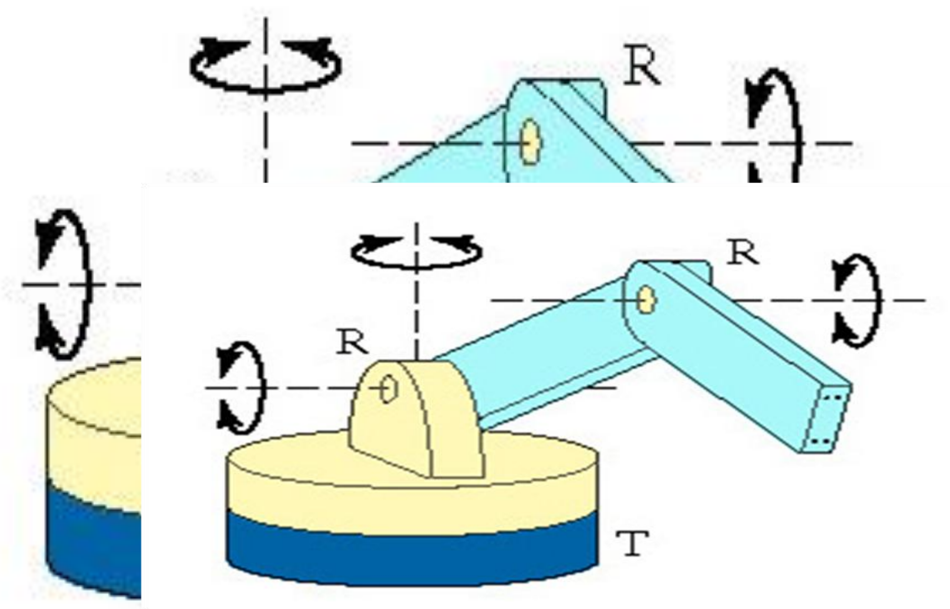

Fig 6. 3-dof jointed arm configuration

From fig 6. jointed arm configurations are similar to that of human arm. It consists of two straight links, corresponding to human ‘fore arm’ and ‘upper arm’ with two rotary joint corresponding to the elbow and shoulder joints. These two are mounted on a vertical rotary table corresponding to human waist joint. The work volume is spherical. This structure is the most dexterous one. This configuration is very widely used.

Applications: Arc welding, Spray coating.

Example: **SCARA** robot (Selective compliance Assembly Robot Arm)

Its full form is ‘Selective Compliance Assembly Robot Arm'. It is similar in construction to the jointed-arm robot, except the shoulder and elbow rotational axes are vertical. It means that the arm is very rigid in the vertical direction, but compliant in the horizontal direction.

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

Robot Wrist:

Wrist assembly is attached to end-of-arm. End effectors are attached to wrist assembly Function of wrist assembly is to orient end effectors .Body-and-arm determines global position of end effector It has three degrees of freedom:

- **Roll (R)** axis – involves rotation of the wrist mechanism about the arm axis.
- **Pitch (P)** axis – involves up or down rotation of the wrist.
- **Yaw (Y)**axis - involves right or left rotation of the wrist.

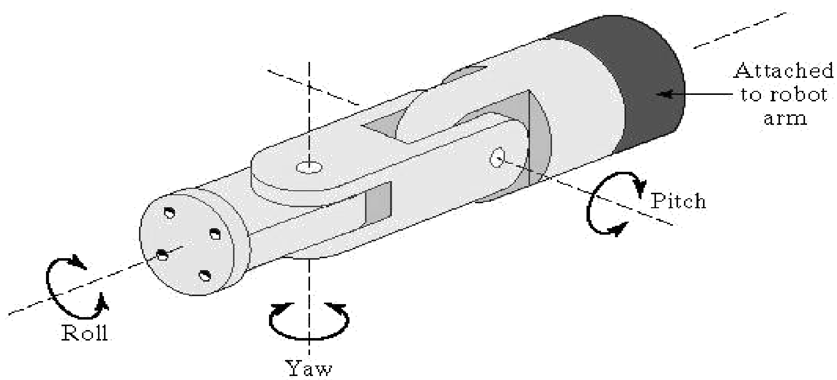

Fig 7: Robotic wrist

Robot wrist assembly consists of either two or three degrees-of -freedom. A typical three-degree-of-freedom wrist joint is depicted in Figure 7,: the roll joint is accomplished by use of a T joint; the pitch joint is achieved by recourse to an R joint; and the yaw joint, a right-and-left motion, is gained by deploying a second R joint. Care should be taken to avoid confusing pitch and yaw motions, as both utilize R joints.

Degree of freedom:

In mechanics, the degree of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration. It is the number of parameters that determine the state of a physical system and is important to the analysis of systems of bodies in mechanical engineering, aeronautical engineering, robotics, and structural engineering.

The position and orientation of a rigid body in space is defined by three components of translation and three components of rotation, which means that it has six degrees of freedom.

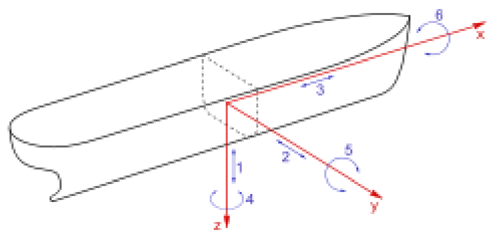

Fig 8.The six degrees of freedom of movement of a ship

The motion of a ship at sea has the six degrees of freedom of a rigid body, and is described as shown in fig 8 .

Translation:

1. Moving up and down (heaving);
2. Moving left and right (swaying);
3. Moving forward and backward (surging);

Rotation:

4. Tilts forward and backward (pitching);
5. Swivels left and right (yawing);
6. Pivots side to side (rolling).

From fig 9.The trajectory of an airplane in flight has three degrees of freedom and its attitude along the trajectory has three degrees of freedom, for a total of six degrees of freedom.

Fig 9 .Attitude degrees of freedom for an airplane.

Robot work volume:

A space on which a robot can move and operate its wrist end is called as a work volume. It is also referred as the work envelope and work space. For developing a better work volume, some of the physical characteristics of a robot should be considered such as:

- The anatomy of various robots
- The maximum value for moving a robot joint
- The size of the robot components like wrist, arm, and body

An industrial robot is a general-purpose, programmable machine possessing certain anthropomorphic characteristics—that is, human-like characteristics that resemble the human physical structure, or allow the robot to respond to sensory signals in a manner that is similar to humans. Such anthropomorphic characteristics include mechanical arms, used for various industry tasks, or sensory perceptive devices, such as sensors, which allow robots to communicate and interact with other machines and make simple decisions.

Both robots and numerical control are similar in that they seek to have co-ordinated control of multiple moving axes (called joints in robotics). Both use dedicated digital computers as controllers. Robots, however, are designed for a wider variety of tasks than numerical control. Typical applications include spot welding, material transfer (pick and place), machine loading, spray painting, and assembly. The general commercial and technological advantages of robot use are listed.

Table 2.General Commercial and Technological Advantages of Robot Use

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Factor	Description
Work environment	Robots are ideal candidates for many harsh and dangerous working environments that are unsuitable for human personnel.
Work cycle	Robots have a level of consistency and repeatability in performing the work cycle, which cannot be attained by humans.
Reprogramming	Robots can be reprogrammed and equipped as necessary to perform different work tasks one after another.
Computing systems	Robots use computers which allow them to be networked with other computers and machines, thus enabling computer integrated manufacturing.

Need for Automation:

Automation refers to the use of computers and other automated machinery for the execution of business-related tasks. Automated machinery may range from simple sensing devices to robots and other sophisticated equipment. Automation of operations may encompass the automation of a single operation or the automation of an entire factory.

There are many different reasons to automate. Increased productivity is normally the major reason for many companies desiring a competitive advantage. Automation also offers low operational variability. Variability is directly related to quality and productivity. Other reasons to automate include the presence of a hazardous working environment and the high cost of human labor. Some businesses automate processes in order to reduce production time, increase manufacturing flexibility, reduce costs, eliminate human error, or make up for a labor shortage. Decisions associated with automation are usually concerned with some or all of these economic and social considerations.

Types of Automation:

Automation of production systems can be classified into three basic types:

1. Fixed automation (Hard Automation)
2. Programmable automation (Soft Automation)
3. Flexible automation.

1. **Fixed automation** (Hard automation): Fixed automation refers to the use of special purpose equipment to automate a fixed sequence of processing or assembly operations. Each of the operation in the sequence is usually simple, involving perhaps a plain linear or rotational motion or an uncomplicated combination of two. It is relatively difficult to accommodate changes in the product design. This is called hard automation.

Advantages:

i. Low unit cost

ii. Automated material handling

iii. High production rate.

Disadvantages:

i. High initial Investment

ii. Relatively inflexible in accommodating product changes.

2**. Programmable automation**: In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a program, which is a set of instructions coded. So, that they can be read and interpreted by the system. New programs can be prepared and entered into the equipment to produce new products.

Advantages:

i. Flexible to deal with design variations.

ii. Suitable for batch production.

Disadvantages:

i. High investment in general purpose equipment

ii. Lower production rate than fixed automation.

Example: Numerical controlled machine tools, industrial robots and programmable logic controller.

3. **Flexible Automation** (Soft automation): Flexible automation is an extension of programmable automation. A flexible automation system is capable of producing a variety of parts with virtually no time lost for changeovers from one part style to the next. There is no lost production time while reprogramming the system and altering the physical set up.

***Advantages*:**

i. Continuous production of variable mixtures of product.

ii. Flexible to deal with product design variation.

***Disadvantages*:**

i. Medium production rate

ii. High investment.

iii. High ‘unit cost relative to fixed automation.

Model Questions

Part A

1. Define the terms (i) Robots, (ii) Robotics
2. List out the power transmission devices.
3. State Asimov’s laws of robotics.
4. Define the terms (i) Repeatability (ii) Compliance.
5. Explain the terms: Roll, Yaw and pitch of the wrist.
6. Define DOF.
7. Define work volume, What is the physical characteristics that determine the work volume.
8. Distinguish between hard automation and flexible automation.
9. What is an end – effector?

Part B

1. With neat diagram, explain the anatomy of a robot and also define degrees of freedom.
2. Explain the robot classification based on the type of control employed.
3. With neat diagram, explain four common configurations.
4. (i) What is meant by Degrees Of Freedom (DOF) with respect to a robot.

   (ii) How do you determine that in a robot?

   (iii) How many DOFs are required in a robot?

   (iv) How can you increase the versatility of a robot in terms of DOF?

5. Describe spatial resolution, accuracy and repeatability of robot.
6. Briefly enumerate a chronology of historical events in the development of robotics.
7. State the Asimov's laws of robotics. What are the basic components of a robotic system? State the main function of each of the component.
8.