Introduction to Robotics

By

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- **The term: robot has come from the Czech word: robota, which means forced or slave laborer**

- **In 1921, Karel Capek, a Czech playwright, used the term: robot first in his drama named Rossum's Universal Robots (R.U.R)**

- **According to Karel Capek, a robot is a machine look-wise similar to a human being**

Robot has been defined in various ways:

1) **According to Oxford English Dictionary: A machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer**

2) **According to International Organization for Standardization (ISO): An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications**

3) **According to Robot Institute of America (RIA): It is a reprogrammable multi-functional manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks**

Note: A CNC machine is not a robot

Robotics

- It is a science, which deals with the issues related to design, manufacturing, usages of robots

- In 1942, the term: robotics was introduced by Isaac Asimov in his story named Runaround

- In robotics, we use the fundamentals of Physics, Mathematics, Mechanical Engg., Electronics Engg., Electrical Engg., Computer Sciences, and others

Motivation

To cope with increasing demands of a dynamic and competitive market, modern manufacturing methods should satisfy the following requirements:

- Reduced production cost
- Increased productivity
- Improved product quality

Interdisciplinary Areas in Robotics

Mechanical Engineering

- **Kinematics:** Motion of robot arm without considering the forces and /or moments
- **Dynamics:** Study of the forces and/or moments
- **Sensing:** Collecting information of the environment

Computer Science

- **Motion Planning:** Planning the course of action
- **Artificial Intelligence:** To design and develop suitable brain for the robots

Electrical and Electronics Engg.

- **Control schemes** and **hardware** implementations

General Sciences

- Physics
- Mathematics

Definition of a Robot:

A robot is a reprogrammable multifunctional manipulator designed to move material through various programmed motions for the performance of a variety of tasks.

Three 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 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 Law.

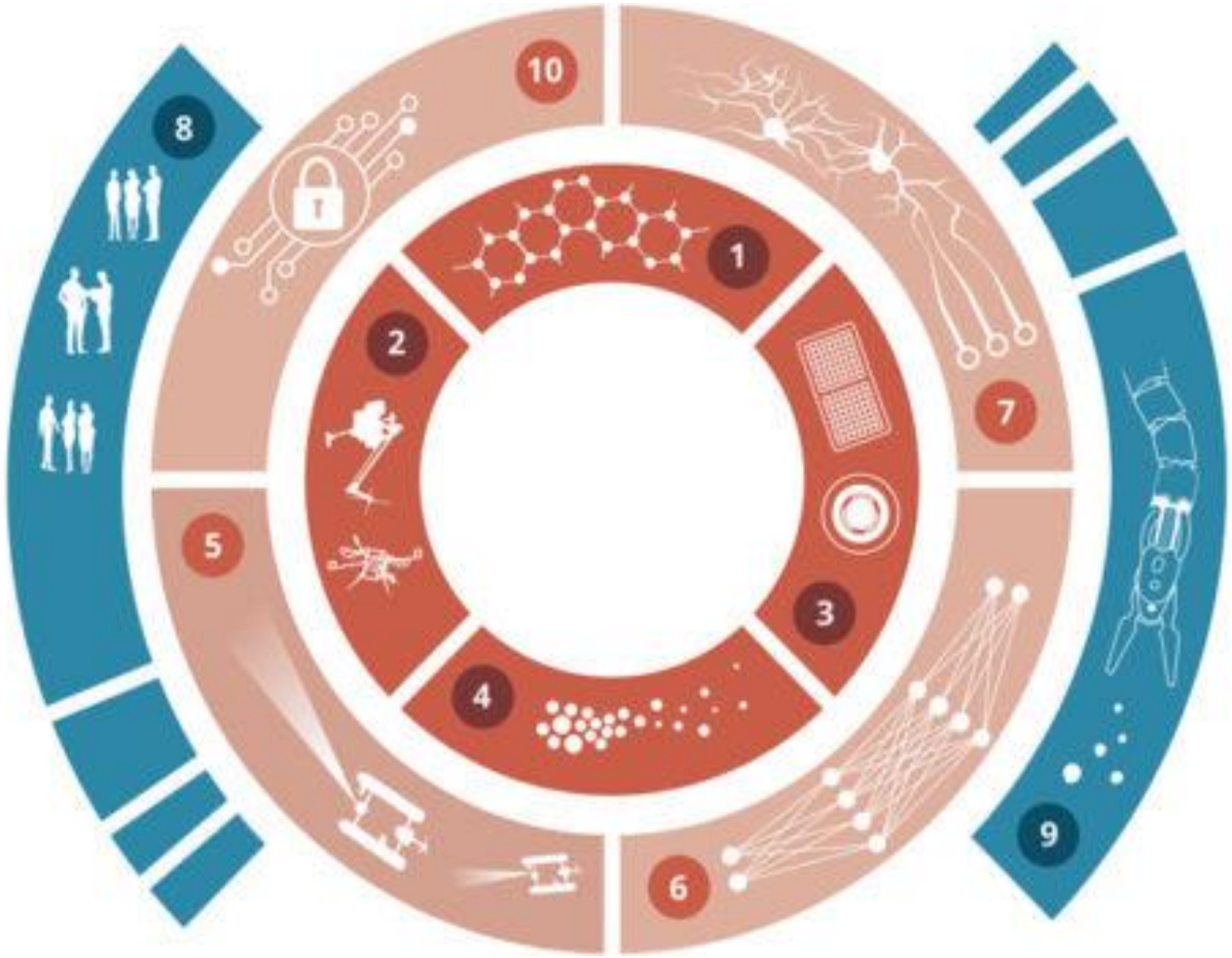
Need for using robotics in industries:

Industrial robot plays a significant role in automated manufacturing to perform different kinds of applications.

1. Robots can be built a performance capability superior to those of human beings. In terms of strength, size, speed, accuracy…etc.
2. Robots are better than humans to perform simple and repetitive tasks with better quality and consistence's.
3. Robots do not have the limitations and negative attributes of human works. such as fatigue, need for rest, diversion of attention…..etc.
4. Robots are used in industries to save the time compared to human beings.
5. Robots are in value poor working conditions
6. Improved working conditions and reduced risks.

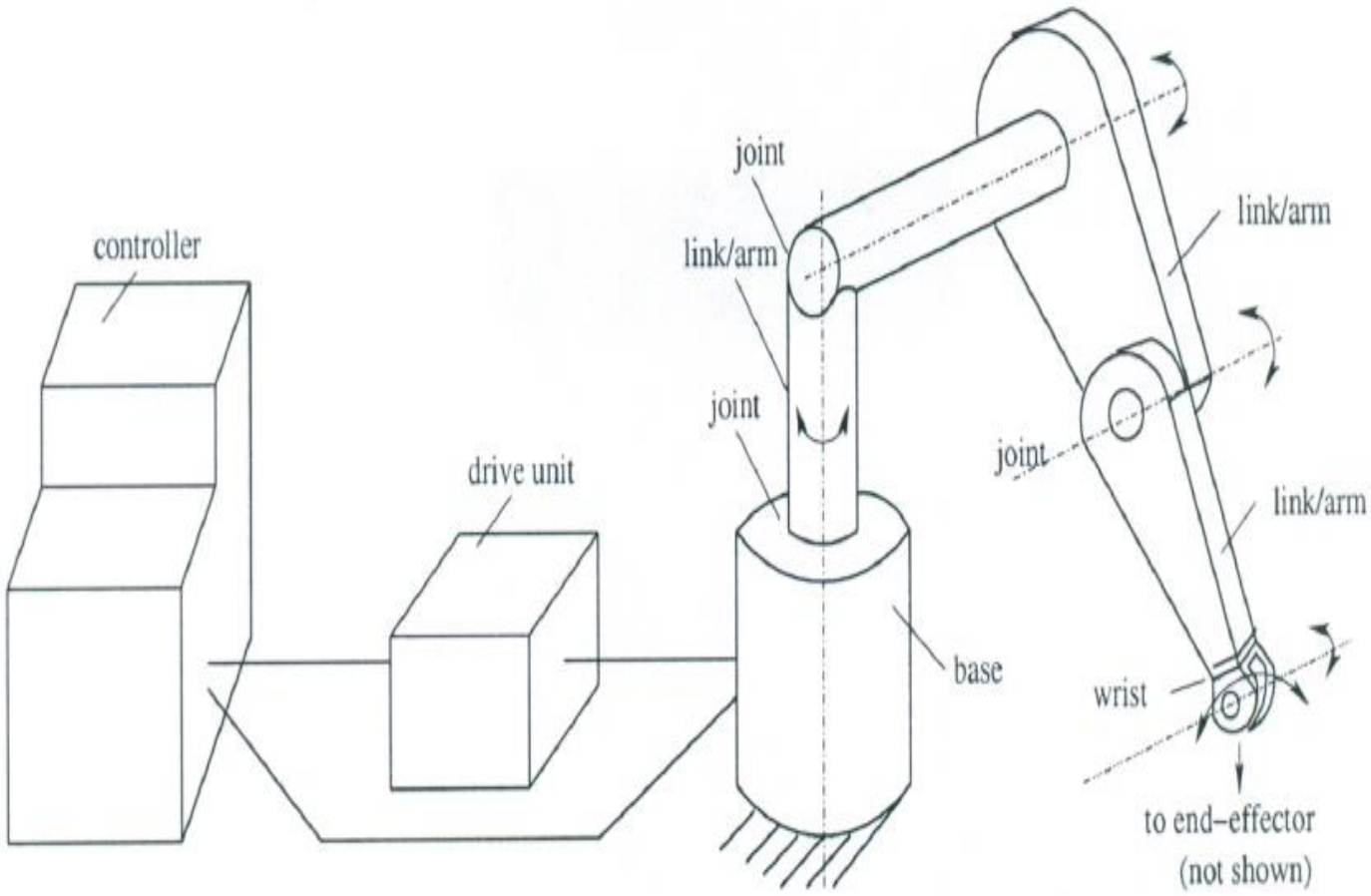
Challenges

1. New Materials and Fabrication Schemes
2. Biohybrid and Bioinspired Robots
3. Power and Energy
4. Robot Swarms
5. Navigation and Exploration



6. AI for Robotics
7. Brain-Computer Interfaces
8. Social Interaction
9. Medical Robotics
10. Robot Ethics and Security

A Robotic System



Various Components

1.Base

2.Manipulator arm

3.End-effector / gripper

4.Actuator and transmissions

5.Controller

6. Sensors

Classification by co-ordinate system

Co-ordinate systems:- Industrial robots are available in a wide variety of sizes, shapes, and physical configurations.

The vast majority of today's commercially available robots possess one of the basic configurations:

1. Cartesian (rectangular) configuration- all three are P-joints.

2. Cylindrical configuration- One R and two P-joints.

3. Polar (Spherical) configuration- Two Rand one P-joint.

4. Articulated (revolute or Jointed-arm) Configuration- All three R joints.

1. Cartesian (rectangular) configuration

- It is constructed by three perpendicular slides, giving only linear motions along the three principal axis.
- The workspace of Cartesian configuration is cuboidal.
- Cartesian gives high precision and is easy to program.
- It is not preferred for many applications due to limited manipulability.
- Gantry configuration is used when heavy loads must be precisely moved.
- The Cartesian configuration gives large work volume but has a low dexterity.

Dexterity: Dexterity implies that the manipulator can reach a subspace, which is obstructed by objects, by the capability of going around these.

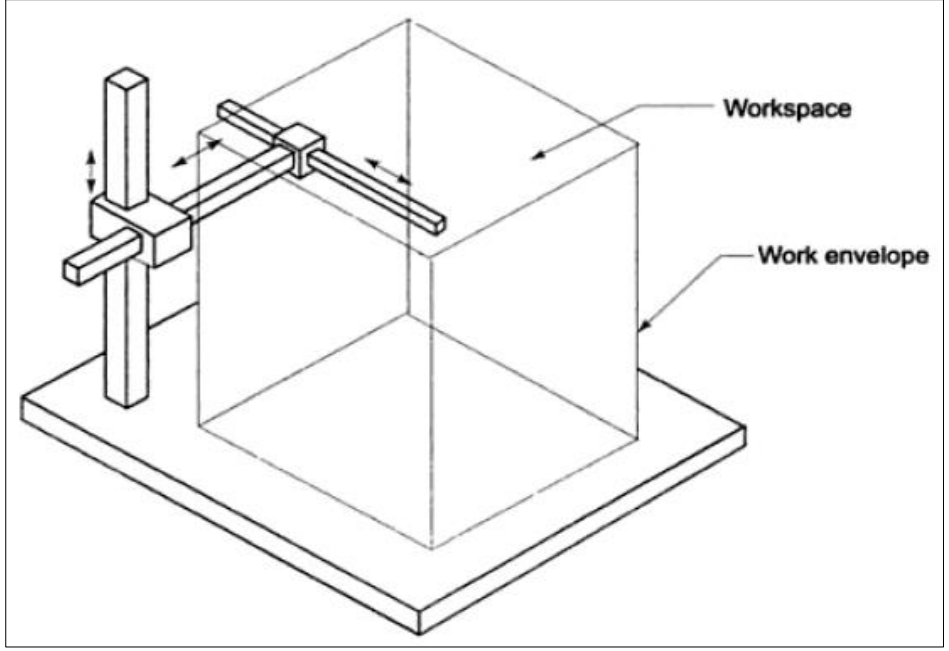


Fig: 3-DOF Cartesian arm (Cantilevered Cartesian) configuration and its workspace.

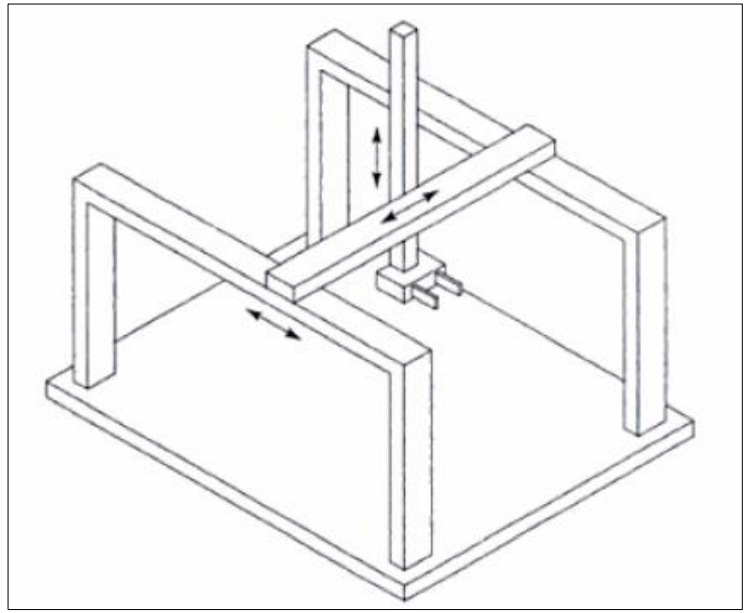


Fig: Gantry or box configuration Cartesian manipulator

Advantages:

- Work envelope can be increased by travelling along the X-axis.
- Linear movement and hence simpler control.
- High degree of accuracy and repeatability due to their structure.
- Can carry heavier loads since load carrying capacity does not differ at different position of the workshop envelope.

Disadvantages:

- Movement is limited only one direction at a time.

Applications:

- Pic and place operation.
- Adhesive applications.
- Assembly and sub-assembly.
- Nuclear Material Handling.
- Welding.

2. Cylindrical configuration

- It consists of a vertical column.
- An arm assembly is moved up or down relative to the vertical column. The arm can be moved in and out relative to the axis of the column.
- Common configuration is to use a T-joint to rotate the column about its axis.
- An L-joint is used to move the arm assembly vertically along the column, while an O-joint is used to achieve radial movement of the arm.
- The cylindrical configuration offers good mechanical stiffness and the wrist positioning accuracy decreases as the horizontal stroke increases.
- It is suitable to access narrow horizontal cavities and hence, it is useful for machine loading operation.

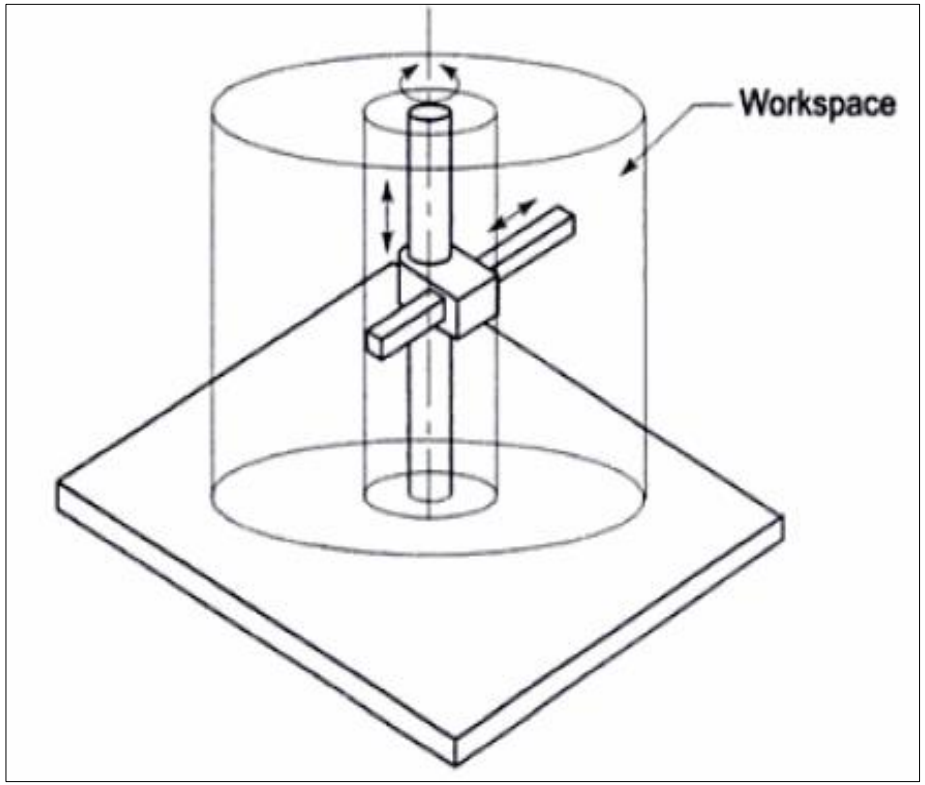


Fig: A 3-DOF cylindrical arm configuration and its workspace.

Advantages:

- Results in larger work volume than a rectangular manipulator.
- Vertical structure conserves floor space.
- Capable of carrying large payloads.

Disadvantages

- Repeatability and accuracy are lower in the direction of rotary motion.
- Requires more sophisticated control system.

Applications

- Assembly.
- Coating application
- Die casting.
- Foundry and forging application
- Machine loading and unloading

3. Polar (Spherical) configuration:

- The work volume of a polar configuration robot is in the form of a sphere.
- It uses a arm that can be raised or lowered about a horizontal pivot.
- The pivot is mounted on a rotating base.
- The various joints provide the robot with capability to move its arm within a spherical space, and hence it is also called as "Spherical Coordinate Robot."
- It has one linear and two rotary motions.

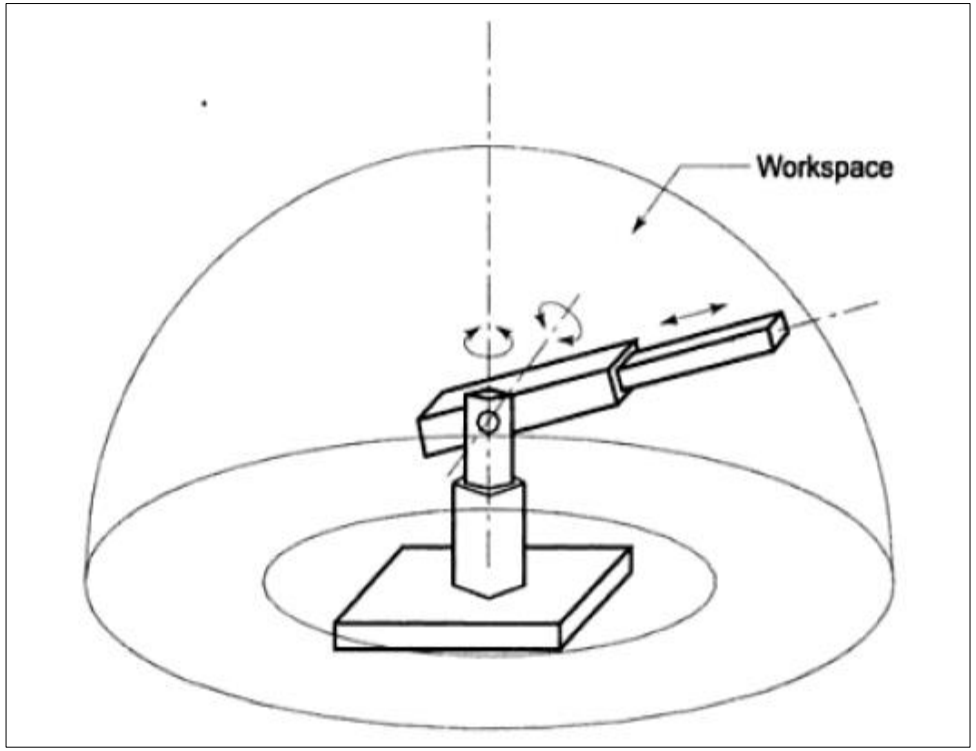


Fig: A 3-DOF polar arm configuration and its workspace.

Advantages:

- Larger work envelope than the rectilinear or cylindrical configuration.
- Vertical structure conserves less space.

Disadvantages:

- Repeatability and accuracy are also lower in the direction of rotary motion.
- Requires more sophisticated control system.

Applications:

- Die casting.
- Forging.
- Glass handling.
- Injection molding.
- Stacking and unstacking.

4. Articulated (revolute or Jointed-arm) Configuration:

- Its configuration is similar to that of a human arm.
- These components are connected by two rotary joints corresponding to shoulder and elbow.
- A wrist is attached to the end of forearm, thus providing several additional joints.

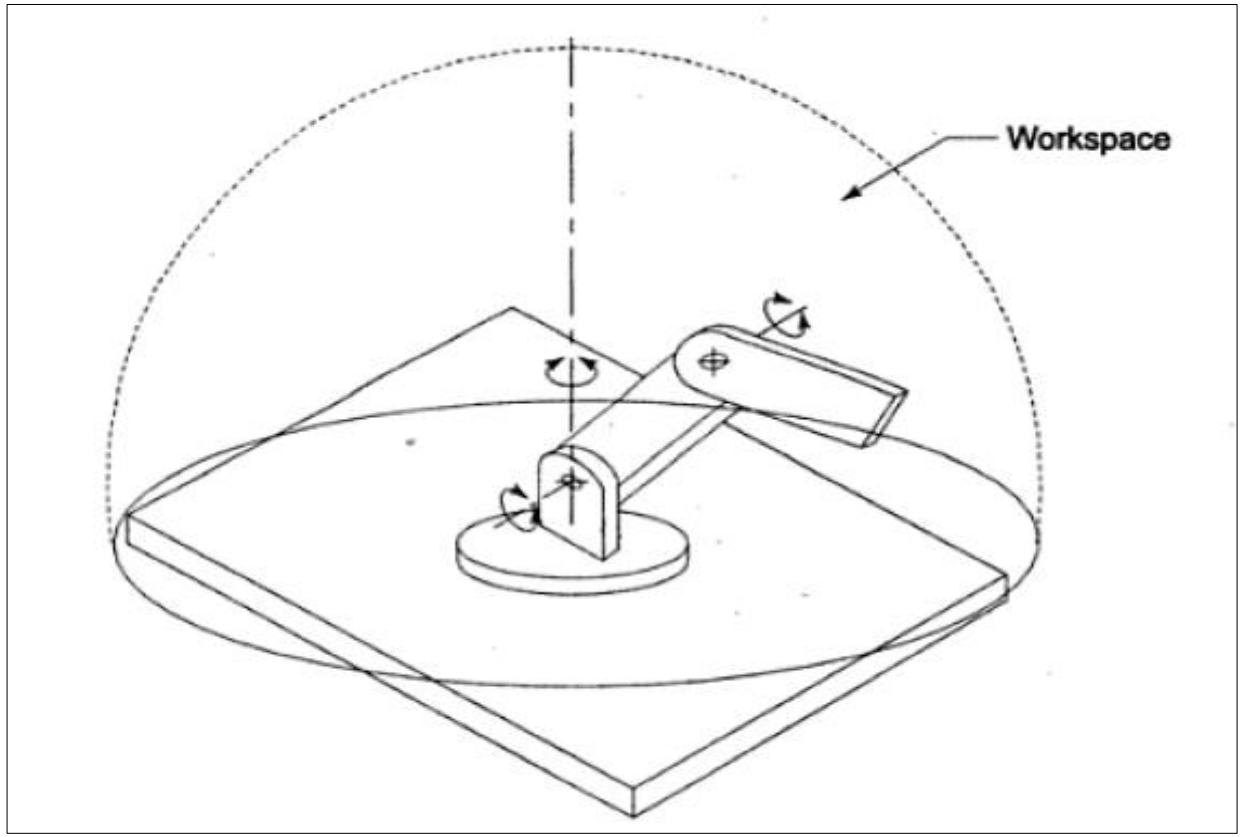


Fig: A 3-DOF articulated arm configuration and its workspace.

Work Envelope of Jointed-Arm Configuration

- It is similar to the configuration of a human arm.
- It consists of a vertical column that swivels (rotate) about the base using a T-joint.
- Shoulder joint (R-joint) is located at the top of the column.
- The output link is an elbow joint (another R joint).

Advantages:

- It can reach above or below objects
- Largest work area for least floor space.

Disadvantages:

- Difficult program off-line.
- Two or more ways to reach a point.
- Most complex robot.

SCARA- Selective Compliance Assembly Robot Arm

The SCARA configuration has vertical major axis rotations such that gravitational load, coriolis, and Centrifugal forces do not stress the structure as much as they would if the axis were horizontal.

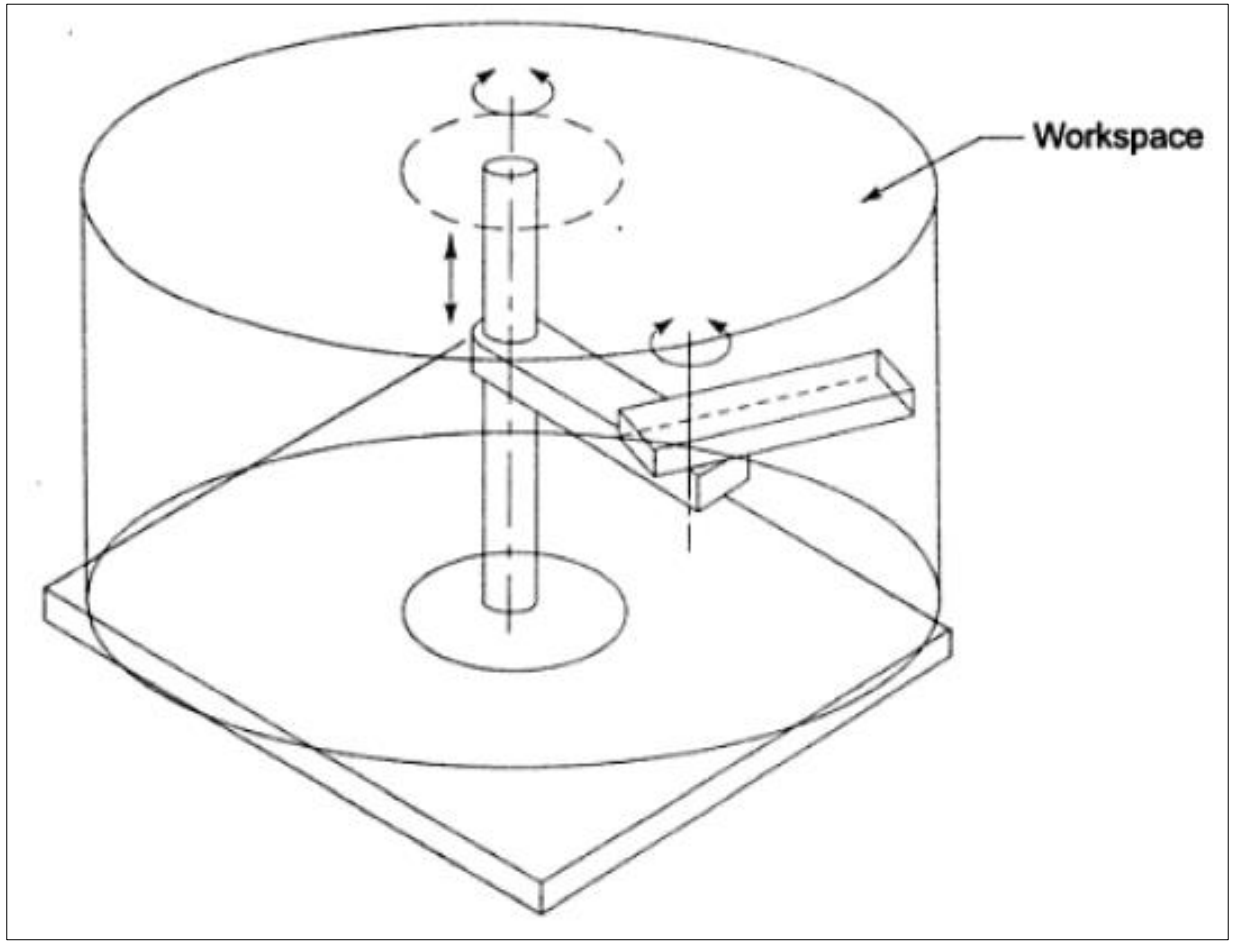


Fig: The SCARA configuration and its workspace.

- Advantage is very important at high speeds and high precision.
- This configuration provides high stiffness to the arm in the vertical direction and high compliance in the horizontal plane, thus making SCARA congenital for many assembly tasks.
- Disadvantages of Scara robots is that they are limited in movement, priced a little higher than most, larger work envelopes with a larger portion they cannot reach.

Degrees of freedom: The number of independent moments that an object can perform in a 3-D space is called the number of degrees of freedom.

Workspace: The endpoint of the arm is capable of operating in a cuboidal space is called workspace.

Work volume: The volume of space that can swept by the end effector of the manipulator.

Classification by *Workspace Geometry:* The workspace of a manipulator can be defined as the volume of space the end of effecter can reach.

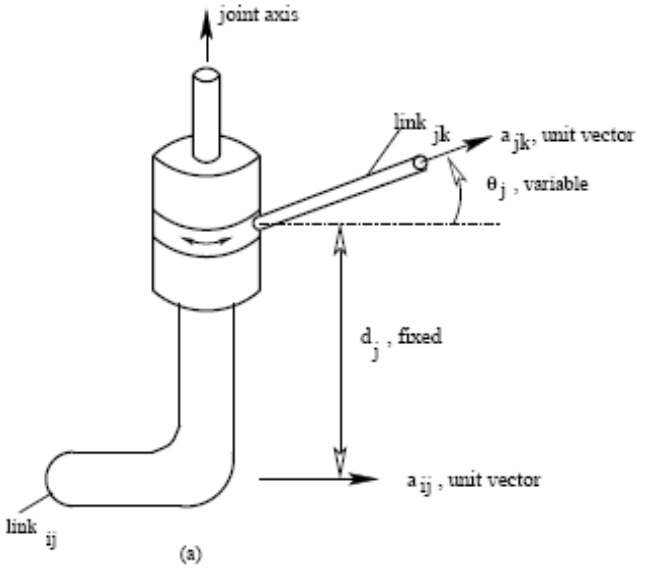
The workspace can be of two types:

A *reachable workspace* is the volume of space within which every point can be reached by the end effecter in at least one orientation.

A *dextrous workspace* is the volume of space within which every point can be reached by the end effecter in all possible orientation.

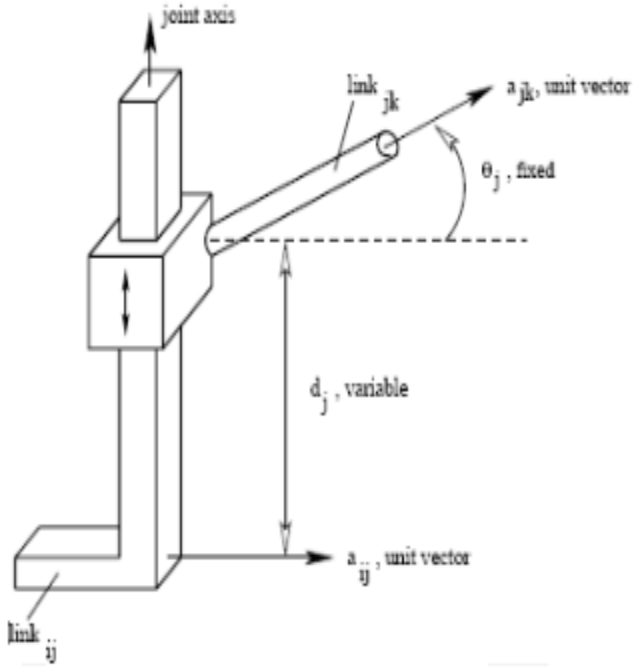
Connectivity / Degrees of Freedom of a Joint

It indicates the number of rigid (bodies) that can be connected to a fixed rigid body through the said joint



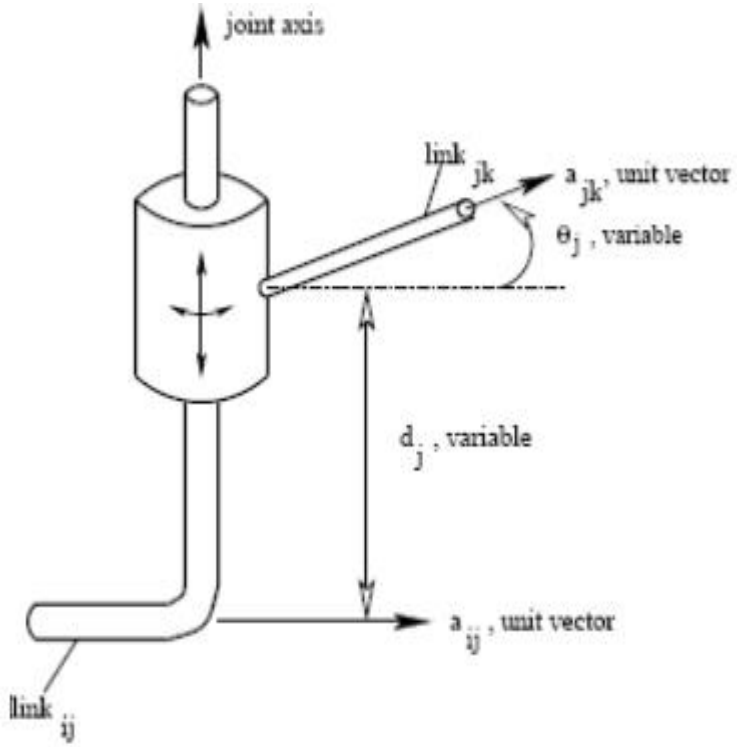
Joints with One dof

Revolute Joint (R)



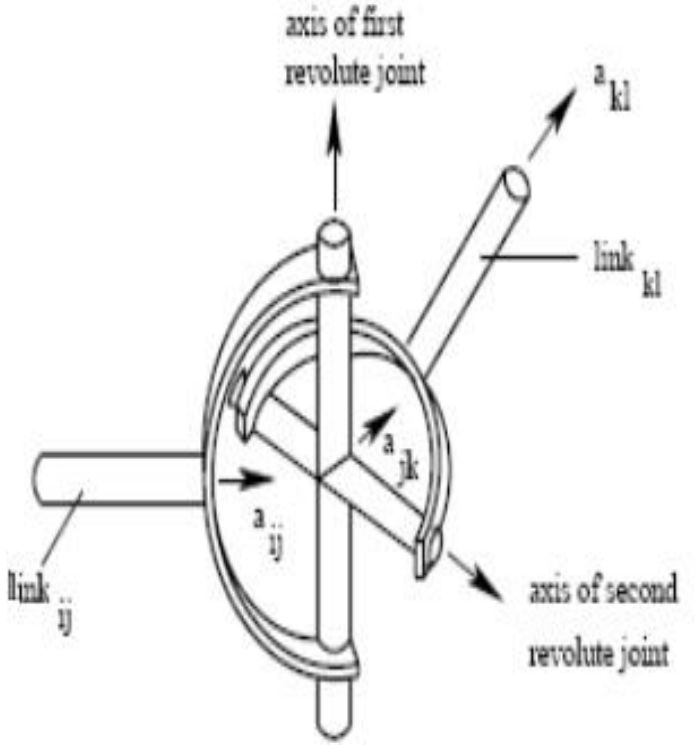
Joints with One dof

Prismatic Joint (P)



Joints with two dof

Cylindrical Joint (C)

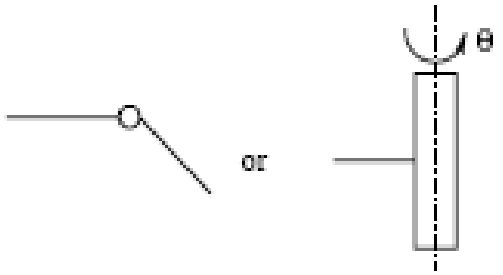


Joints with two dof

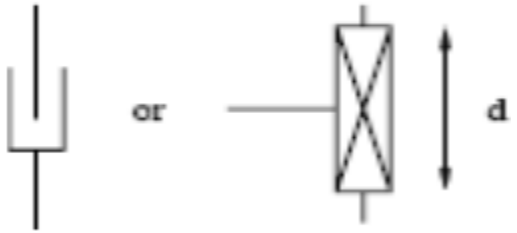
Hooke Joint or Universal Joint (U)

Representation of the Joints

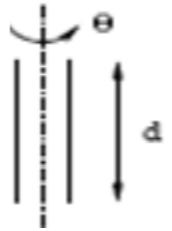
Revolute joint (R)



Prismatic joint (P)

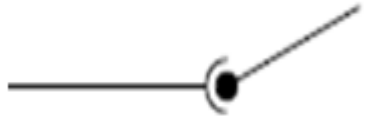


Cylindrical joint (C)

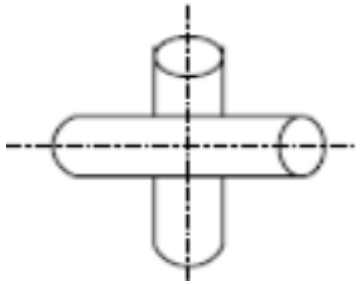


Representation of the Joints

Spherical joint (S')



Hooke joint (U)



Twisting joint (T)

Kinematic Diagram

Redundant Manipulator

Either a Spatial Manipulator with more than 6 dof
or a Planar Manipulator with more than 3 dof

Under-actuated Manipulator

Either a Spatial Manipulator with less than 6 dof
or a Planar Manipulator with less than 3 dof

Precision of movement (or) parameters of robot:

- To measure the precision of the robot's movement.

The precision as a function of three following features.

1. Spatial resolution

2. Accuracy

3. Repeatability

These terms will be defined with the following assumptions.

(i) The definitions will apply at the robot’s wrist end with no hand attached to the wrist.

(ii) The terms apply to the worst case conditions, the conditions under which the robot's precision will be at its wont. It means that the robot’s arm is fully extended in the case of a jointed arm or polar configurable.

(iii) Third, the definitions will he developed in the context of a point-to-point robot.

Spatial resolution:

The spatial resolution of a robot is the smallest increment of movement into which the robot can divide its work volume.

Spatial resolution depends on two factors:

- The system's control resolution
- The robot's mechanical inaccuracies.

It is easiest to conceptualize these factors in terms of a robot with 1 degree of freedom.

$$\text{The no of increments} = 2^n$$

Where n = the number of bits in the control memory.

The control resolution = $Total\ moments\ range / The\ number\ of\ increament$

Accuracy:

- Accuracy refers to a robot's ability to position its wrist end at a desired target point within the work volume.
- The accuracy of a robot can be defined in terms of spatial resolution because the ability to achieve a given target point depends on how closely the robot can define the control increments for each of its joint motions.

Repeatability:

- Repeatability is concerned with the robot's ability to position its wrist or an end effector attached to its wrist at a point in space is known as repeatability.
- Repeatability and accuracy refer to two different aspects of the robot’s precision. Accuracy relates to the robot's capacity to be programmed to achieve a given target point.
- The actual programmed point will probably be different from the target point due to limitations of control resolution Repeatability refers to the robot’s ability to return to the programmed point when commanded to do so.

Load Carrying Capacity:

The load carrying capacity of a robot depends on:

(i) Its physical size and construction.

(ii) Its capability to transmit force and torque to the end effector in the wrist.

While this capacity for very light models can be as low as 1.5 Kg (Including the weight of end effectors), the heavier class of robots can have their capacities as high as 1000 kg.

Applications:

Currently, robots perform a number of different jobs in numerous fields and the amount of tasks delegated to robots is rising progressively. The best way to split robots into types is a partition by their application.

1. Industrial robots – These robots bring into play in an industrialized manufacturing atmosphere. Typically these are articulated arms particularly created for applications like- material handling, painting, welding and others. If we evaluate merely by application then this sort of robots can also consist of some automatically guided automobiles and other robots.

2. Domestic or household robots – Robots which are used at home. This sort of robots consists of numerous different gears for example- robotic pool cleaners, robotic sweepers, robotic vacuum cleaners, robotic sewer cleaners and other robots that can perform different household tasks. Also, a number of scrutiny and tele-presence robots can also be considered as domestic robots if brought into play in that sort of environment.

3. Medical robots – Robots employed in medicine and medicinal institutes. First & foremost surgical treatment robots. Also, a number of robotic directed automobiles and perhaps lifting supporters.

4. Service robots – Robots that cannot be classed into any other types by practice. These could be various data collecting robots, robots prepared to exhibit technologies, robots employed for research, etc.

5. Military robots – Robots brought into play in military & armed forces. This sort of robots consist of bomb discarding robots, various shipping robots, exploration drones. Often robots at the start produced for military and armed forces purposes can be employed in law enforcement, exploration and salvage and other associated fields.

6. Entertainment robots – These types of robots are employed for entertainment. This is an extremely wide-ranging category. It begins with model robots such as robosapien or the running photo frames and concludes with real heavy weights like articulated robot arms employed as movement simulators.

7. Space robots – I would like to distinct out robots employed in space as a split apart type. This type of robots would consist of the robots employed on Canadarm that was brought into play in space Shuttles, the International Space Station, together with Mars explorers and other robots employed in space exploration & other activities.

8. Hobby and competition robots – Robots that is created by students. Sumo-bots, Line followers, robots prepared merely for learning, fun and robots prepared for contests.

Characteristics of robots

A robot has these essential characteristics:

- **Sensing:** First of all your robot would have to be able to sense its surroundings. It would do this in ways that are not unsimilar to the way that you sense your surroundings. Giving your robot sensors: light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), and taste sensors (tongue) will give your robot awareness of its environment.
- **Movement:** A robot needs to be able to move around its environment. Whether rolling on wheels, walking on legs or propelling by thrusters a robot needs to be able to move. To count as a robot either the whole robot moves, like the Sojourner or just parts of the robot moves, like the Canada Arm.

- **Energy** A robot needs to be able to power itself. A robot might be solar powered, electrically powered, battery powered. The way your robot gets its energy will depend on what your robot needs to do.
- **Intelligence** A robot needs some kind of "smarts." This is where programming enters the pictures. A programmer is the person who gives the robot its 'smarts.' The robot will have to have some way to receive the program so that it knows what it is to do.

Actuators:

- Actuation is the process of conversion of energy to mechanical form. A device that accomplishes this conversion is called actuator.
- Actuator plays a very important role while implementing control. The controller provides command signal to the actuator for actuation.
- The control codes aims at “deriving the actuator when an event has occurred”

Actuators for Robots:

1. Actuators are used in order to produce mechanical movement in robots.

2. Actuators are the muscles of robots. There are many types of actuators available depending on the load involved. The term load is associated with many factors including force, torque, speed of operation, accuracy, precision and power consumption.

Types of Actuators:

1. Electric Actuators.

- Servomotor
- Stepper Motor
- DC Motor

2. Hydraulic Actuators.

3. Pneumatic Actuators.

4. Magnetostrictive Actuators.

5. Shape Memory Metal Actuators.

CHARACTERISTICS OF ACTUATING SYSTEMS:

Weight, Power-to-weight Ratio, Operating pressure:

1) Stepper motors are generally heavier than servomotors for the same power.

2) The high the voltage of electric motors, the better power-to- weight ratio.

3) Pneumatic systems delivers the lowest power-to-weight ratio.

4) Hydraulic systems have the highest power-to-weight ratio. In these systems, the weight is actually composed of two portions. One is the hydraulic actuators, and the other is the hydraulic power unit (pump, cylinders, rams, reservoirs, filter, and electric motor). If the power unit must also move with the robot, the total power-to-weight ratio will be much less.

Stiffness versus compliance

1) Stiffness is the resistance of a material against deformation. The stiffer the system, the larger the load that is needed to deform it. Conversely, the more compliant the system the easier it deforms under the load.

2) Stiffness is directly related to the modulus of elasticity of the material. Hydraulic systems are very stiff and non-compliant while pneumatic systems are easily compressed and thus are compliant.

3) Stiff systems have a more rapid response to changing loads and pressures and are more accurate.

4) Although stiffness causes a more responsive and more accurate systems, it also creates a danger if all things are not always perfect.

Thanking You

Automation

- It is a system that is used to reduce the need for human work in the production of goods and services.
- They help to increase productivity and the quality of the goods produced.
- In ideal, no human workers are needed except to perform auxiliary functions such as tool changing, loading and unloading parts, and repair and maintenance activities.
- Modern automated systems are integrated systems, operating under computer control.

Automation Advantages

- **Reduction in production time** – having a machine that is automated definitely speeds up the production time since no thinking is needed by the machine, there is better repeatability, and less human error.
- **Increase in accuracy and repeatability** – when an automated machine is programmed to perform a task over and over again, the accuracy and repeatability compared to an employee is far greater.
- **Less human error** – no one is perfect, and we are all prone to making mistakes. Which is why a machine that performs repeated tasks is less likely to make mistakes than an employee.
- **Less employee costs** – by adding automated machines to an operation, means less employees are needed to get the job done. It also indicates less safety issues, which leads to financial savings. With having less employees, there are numerous costs that are diminished or reduced such as payroll, benefits, sick days, etcetera.
- **Increased safety** – having automated machines means having less employees who perform tasks that can be dangerous and prone to injury, which can make the work environment safer.
- **Higher volume production** – investing in automated equipment creates a valuable resource for large production volumes, which in turn, will increase profitability.

Automation Disadvantages

•**Less versatility** – by having a machine that can perform a certain task limits to the flexibility and variety of tasks that an employee could do.

•**More pollution** – different types of machines operate using motor which may require gases or chemicals in order to operate. This can cause an increase in pollution in the workplace.

•**Large initial investment** – automated machines can be one of the most costly operating costs for a company. With automated machines running anywhere between thousands and millions of dollars depending on the type and degree of automation.

•**Increase in unemployment** – by increasing the amount of automation, there are less employees required causing high unemployment rates.

•**Unpredictable costs** – there can be several unpredictable costs that may exceed the actual cost saved by the automation itself. Some of these costs could include research and development costs of automating a process, preventative maintenance costs, and the cost of training employees to operate automated machines.

Types of automated manufacturing systems

Automated manufacturing systems can be classified into three basic types:

a. Fixed automation.

b. Programmable automation, and

c. Flexible automation.

Fixed Automation:

- Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration.
- Each of the operations in the sequence is usually simple, involving perhaps a plain linear or rotational motion or an uncomplicated combination of the two; for example, the feeding of a rotating spindle.
- It is the integration and coordination of many such operations into one piece of equipment that makes the system complex.

Typical features of fixed automation are:

- High initial investment for custom-engineered equipment
- High production rates
- Relatively inflexible in accommodating product variety.

Programmable Automation:

- In programmable automation the production equipment is designed with the capability to change the sequence of operations to accommodate different product configuration.
- 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.

Some of the features that characterize programmable automation include:

- High investment in general purpose equipment
- Lower production rates than fixed automation
- Flexibility to deal with variations and changes in product configuration
- Most suitable for batch production.

Flexible Automation:

- Flexible automation is an extension of programmable automation.
- A flexible automated system is capable of producing a variety of parts (or products) 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 setup (tooting, fixtures, machine settings).
- Consequently, the system can produce various combinations and schedules of parts or products instead of requiring that they be made in batches.
- What makes flexible automation possible is that the differences between parts processed by the system arc not significant.
- It is a case of soft variety. So that the amount of changeover required between styles is minimal.

The features of flexible automation can be summarized as follows:

- High investment for a custom-engineered system
- Continuous production of variable mixtures of products
- Medium production rate
- Flexibility to deal with product design variations