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NPTEL ONLINE CERTIFICATION COURSES

AUTOMATION IN PRODUCTION SYSTEMS AND MANAGEMENT

Fundamentals of Robotic Systems

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Fundamentals of Robotic Systems

- **Lecture-1:** Fundamentals of Robotics and its Applications
- **Lecture-2:** Robot Movement and Precision
- **Lecture-3:** Robot Motion Analysis, Robotic Joints and Links
- **Lecture-4:** Robot Classification System, Industrial Robot Applications
- **Lecture-5:** Numerical Examples

Fundamentals of Robotic Systems

✓ **Fundamentals of Robotics and its Applications**

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Fundamentals of Robotic Systems

- Since the development of the first articulated arm in the 1950s and subsequent developments in the area of microprocessor technology, robots have become available in a variety of types, styles, and sizes. They are capable of performing a wide variety of tasks.

- In fact, the driving force for the purchase of robots is their applicability in hostile, strenuous, and repetitive environments as well as in highly competitive situations with strong economic pressure to perform.

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Fundamentals of Robotic Systems

- Such applications include welding, painting, and pick-and-place material handling, among others.

- Robotics is now becoming an integral part of automated discrete-parts manufacturing systems such as flexible manufacturing systems.

What Is An Industrial Robot?

- The word “robot” is derived from a satirical fantasy play, “Rossum’s Universal Robots, “ written by Karel Capek in 1921.
- In his play, Capek used the word to mean “forced labour”.
- Robotics Industries Association (RIA), formerly known as the Robotics Institute of America.
- An industrial robot is a programmable, multi-functional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks.

What Is An Industrial Robot?

- The first articulated arm was developed in the 1950s.
- There have been many advances in the area of robotics since then, motivated primarily by the developments in the area of industrial automation in particular and computer-integrated manufacturing systems in general.
- An industrial robot consists of a number of rigid links connected by joints of different types, controlled and monitored by a computer.
- To a large extent, the physical construction of a robot resembles a human arm.

What Is An Industrial Robot?

- The link assembly is connected to the body, which is usually mounted on a base.
- This link assembly is generally referred to a robot arm.
- A wrist is attached to the arm. To facilitate gripping or handling, a hand is attached at the end of the wrist.
- In robotics terminology, this hand is called an end-effector.
- The complete motion of the end-effector is accomplished through a series of motions and positions of the links, joints and wrist.
- A typical industrial robot with six-degrees of freedom is shown in Figure 8.1.

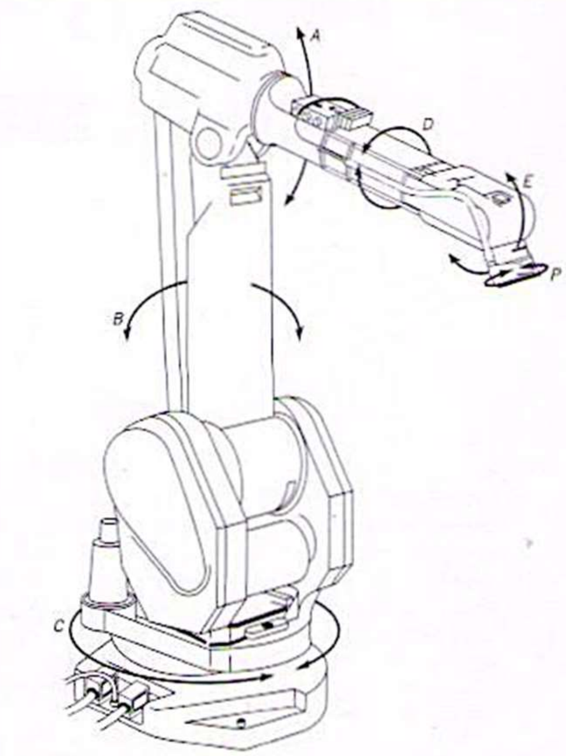

FIGURE 8.1 A typical industrial robot with six-degrees of freedom. The robot's movement pattern is briefly described as follows: Axis 1 (*C*), turning of the complete mechanical robot; Axis 2 (*B*), forward and reverse movement of the lower arm; Axis 3 (*A*), up and down movement of the upper arm; Axis 4 (*D*), turning of the complete wrist center; Axis 5 (*E*), bending of wrist around the wrist center; Axis 6 (*P*), turning of mounting flange (turn disk). (Courtesy of ABB Robotics, Inc.).

Fundamentals of Robotics and Robotics Technology

- The basic components of a robot include the manipulator, the controller, and the power supply sources.

❑ **Power Sources for Robots**

- An important element of a robot is the drive system. The drive system supplies the power, which enables the robot to move. The dynamic performance of the robot is determined by the drive system adopted, which depends mainly on the type of application and the power requirements.

Fundamentals of Robotics and Robotics Technology

- The three types of drive systems are generally used for industrial robots:

  1. Hydraulic drive

  2. Electric drive

  3. Pneumatic drive

Fundamentals of Robotics and Robotics Technology

- Hydraulic Drive

- A hydraulic drive system gives a robot great speed and strength. These systems can be designed to actuate linear or rotational joints.

- The main disadvantage of a hydraulic system is that it occupies floor space in addition to that required by the robot.

Fundamentals of Robotics and Robotics Technology

- There are problems of leaks, making the floor messy.

- Because they provide high speed and strength, hydraulic systems are adopted for large industrial robots. Hydraulic robots are preferred in environments in which the use of electric-drive robots may cause fire hazards, for example, in spray painting.

Fundamentals of Robotics and Robotics Technology

- Electric drive

- Compared with a hydraulic system, an electric system provides a robot with less speed and strength.
- Electric drive systems are adopted for smaller robots.
- Robots supported by electric drive systems are more accurate, exhibit better repeatability, and are cleaner to use.
- Electrically driven robots are the most commonly available and used industrial robots.

Fundamentals of Robotics and Robotics Technology

- Like numerically controlled (NC) machines, electrically driven robots can be classified into two broad categories: stepper motor-driven and direct current (DC) servo motor-driven.
- Most stepper motor-driven robots are of the open-loop type, but feedback loops can be incorporated in stepper-driven robots.
- Servo-driven robots invariably have feedback loops from the driven components back to the driver.

Fundamentals of Robotics and Robotics Technology

- Pneumatic drive

- Pneumatic drive systems are generally used for smaller robots.
- These robots, with fewer degrees of freedom, carry out simple pick-and-place material-handling operations, such as picking up an object at one location and placing it at another location.
- These operations are generally simple and have short cycle times.
- The pneumatic power can be used for sliding or rotational joints.
- Pneumatic robots are less expensive than electric or hydraulic robots.

Fundamentals of Robotics and Robotics Technology

- Normally, shop air compressed at approximately 90 pounds per square inch (psi), which is used on machine tools and presses, is available for use in robots without extra cost.
- But mostly pneumatic robots operate at mechanically fixed end points for each axis. That means these are limited sequence robots.
- A big advantage of such robots is their simple modular construction, using standard commercially available components.
- This makes it possible for a firm to build its own robots at substantial cost savings for simple tasks such as pick and place, machine loading and unloading, and so forth.

Robotic Sensors

- The motion of a robot is obtained by precise movements at its joints and wrist. While the movements are obtained, it is important to ensure that the motion is precise and smooth.

- The drive systems should be controlled by proper means to regulate the motion of the robot.

- Along with controls, robots are required to sense some characteristics of their environment. These characteristics provide the feedback to enable the control system to regulate the manipulator movements efficiently.

Robotic Sensors

- Sensors provide feedback to the control systems and give the robots more flexibility.
- Sensors such as visual sensors are useful in the building of more accurate and intelligent robots. The sensors can be classified in many different ways based on their utility.
- A few typical sensors that are normally used in robots:
  a) Position Sensors
  b) Range Sensors
  c) Velocity Sensors
  d) Proximity Sensors

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Robotic Sensors

- Position Sensors

- Position sensors are used to monitor the position of joints.

- information about the position fed back to the control systems that are used to determine the accuracy of joints movements. Accurate joint movements are reflected in correct positioning of the end-effector, which eventually carries out the prescribed task.

Robotic Sensors

- Range Sensors

- Range sensors measure distances from a reference point to other points of importance. Range sensing is accomplished by means of television cameras or sonar transmitters and receivers.

- The major drawback of range sensing is that it may miss certain points that cannot be seen from the positions of the transmitters. This problem may be reduced by using a greater number of sensors.

Robotic Sensors

❑ Velocity Sensors

- Velocity sensors are used to estimate the speed with which a manipulator is moved.
- The velocity is an important part of the dynamic performance of the manipulator. Variations in acceleration during the movements between points give rise to the dynamic nature of the manipulator.
- Inertial forces due to changes in acceleration, damping forces due to changes in velocity, and spring forces due to elongations in the links caused by gravity and the weights carried should be monitored and controlled to fine-tune the dynamic performance of the manipulator.

Robotic Sensors

- The DC techometer is one of the most commonly used devices for feedback of velocity information.

- The techometer, which is essentially a DC generator, provides an output voltage proportional to the angular velocity of the armature. This information is fed back to the controls for proper regulation of the motion.

Robotic Sensors

- Proximity Sensors

- Proximity sensors are used to sense and indicate the presence of an object within a specified distance or space without any physical contact
- This helps prevent accidents and damage to the robot. These sensors act on reflected signals that they receive from the object. The signals are generated using a light-emitting diode transmitter and are received by a photodiode receiver. Range sensors can, in fact, replace proximity sensors.
- These are many other types of sensors with different sensing abilities.

Robotic Sensors

- Acoustic sensors sense and interpret acoustic waves in a gas, liquid, or solid.
- Touch sensors sense and indicate physical contact between the sensor-carrying object and another object.
- Force sensors measure all the components of force and torque between two objects.

Robotic Sensors

- Tactile sensors are being developed to provide more accurate data on the position of parts that are in contact than is provided by vision.
- The sophistication of a sensor is reflected in the flexibility, accuracy, and repeatability of robots. Machine vision, an important sensor technology, has been developed significantly during the past decade and is being applied in various robot applications.
- This technology is also applied in inspection systems and quality design, control, and automated inspection systems.
- Sensors are important for both the safety of robotic systems and the safety of workers.

The Hand of a Robot: End-Effector

- The end-effector (commonly known as robot hand) mounted on the wrist enables the robot to perform specified tasks.

- Various types of end-effector are designed for the same robot to make it more flexible and versatile.

- End-effector are categorized into two major types: grippers and tools.

The Hand of a Robot: End-Effector

- Grippers are generally used to grasp and hold an object and place it at a desired location. Grippers can be further classified as mechanical grippers, vacuum or suction cups, magnetic grippers, adhesive grippers, hooks, scoops, and so forth.
- Mechanical grippers are further classified as single grippers and double grippers. A double gripper can handle two objects at the same time, and the two gripping devices can be actuated separately.
- More than two grippers can also be used when needed; however, such occasions are not common.

The Hand of a Robot: End-Effector

- Grippers may also be classified as external or internal, depending on whether the part is grasped on its external or internal surface.

- At times, a robot is required to manipulate a tool to perform an operation on a workpart. In such applications the end-effector is used as a gripper that can grasp and handle a variety of tools and the robot has multitool handling function.

The Hand of a Robot: End-Effector

- However, in most robot applications in which only one tool is to be manipulated, the tool is directly mounted on the wrist. Here the tool itself acts as end-effector.

- Spot-welding tools, arc-welding tools, spray-painting nozzles, and rotating spindles for drilling and grinding are typical examples of tools used as end-effectors.

Industrial Robot

- An industrial robot is defined as “an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which may be either fixed in-place or mobile for use in industrial automation applications.
- It is a general-purpose machine possessing certain anthropomorphic characteristics, the most obvious of which is its mechanical arm.
- Other human-like characteristics are the robot’s capabilities to respond to sensory inputs, communicate with other machines, and make decisions.

Industrial Robot

Some of the qualities that make industrial robots commercially and technologically. important are the following:

- Robots can be substituted for humans in hazardous or uncomfortable work environments.
- A robot performs its work cycle with a consistency and repeatability that cannot be attained by humans.
- Robots can be reprogrammed. When the production run of the current task is completed, a robot can be reprogrammed and equipped with the necessary tooling to perform an altogether different task.
- Robots are controlled by computers and can therefore be connected to other computer systems to achieve computer integrated manufacturing.

Fundamentals of Robotic Systems

✓ **Robot Movement and Precision**

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Robot Movement and Precision

- Speed of response and stability are two important characteristics of robot movement.
- Speed defines how quickly the robot arm moves from one point to another.
- Stability refers to robot motion with the least amount of oscillation.
- A good robot is one that is fast enough but at the same time has good stability.

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Robot Movement and Precision

- Speed and stability are often conflicting goals. However, a good controlling system can be designed for the robot to facilitate a good trade-off between the two parameters.

- The precision of robot movement is defined by three basic features:

  a) Spatial resolution
  b) Accuracy
  c) Repeatability

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Spatial Resolution

- The spatial resolution of a robot is the smallest increment of movement into which the robot can divide its work volume.
- It depends on the system’s control resolution and the robot’s mechanical inaccuracies.
- The control resolution is determined by the robot’s position control system and its feedback measurement system.

Spatial Resolution

- The controller divides the total range of movements for any particular joint into individual increments that can be addressed in the controller.
- The bit storage capacity of the control memory defines this ability to divide the total range into increments.
- For a particular axis, the number of separate increments is given by, number of increments = 2^n
- where n is the number of bits in the control memory.

Accuracy

- Accuracy can be defined as the ability of a robot to position its wrist end at a desired target point within its reach. In terms of control resolution, the accuracy can be defined as one-half of the control resolution. This definition of accuracy applies in the worst case when the target point is between two control points.
- The reason is that displacements smaller than one basic control resolution unit (BCRU) can be neither programmed nor measured and, on average, they account for one-half BCRU.

- The accuracy of a robot is affected by many factors:

Accuracy

- When the arm is fully stretched out, the mechanical inaccuracies tend to be larger because the loads tend to cause larger torques at the joints, resulting in greater deformations.
- When the arm is closer to its base, the inaccuracies tend to be minimal and better accuracy is observed.
- In robots with only linearly varying links, ideally the accuracy may be considered uniform. However, for robots with other configurations that employ rotational and/or linear joints, it is difficult to combine the effect of all joints and define accuracy.

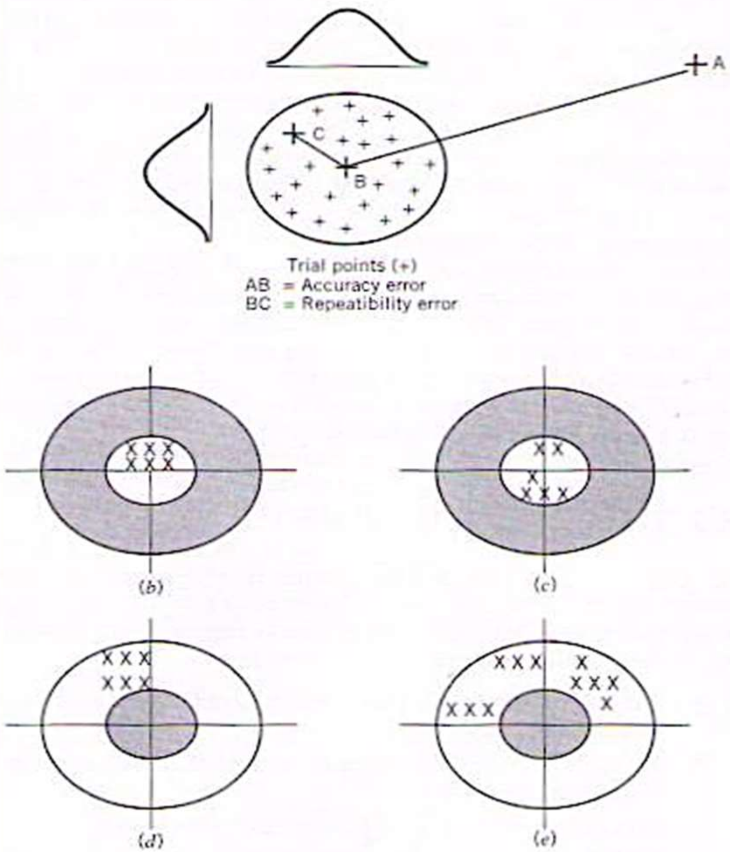

FIGURE 8.2 (*a*) Accuracy and repeatability; (*b*), high accuracy and high repeatability; (*c*) high accuracy and low repeatability; (*d*) low accuracy and high repeatability; (*e*) low accuracy and low repeatability.

Repeatability

- Repeatability refers to the robot's ability to position its end-effector at a point that had previously been taught to the robot.

- Let point A be the target point as shown in Figure 8.2a.

- Because of the limitations of spatial resolution and therefore accuracy, the programmed point becomes point B. The distance between points A and B is a result of the robot's limited accuracy due to the spatial resolution. When the robot is instructed to return to the programmed point B, it returns to point C instead.

Repeatability

- The distance between points B and C is the result of limitations on the robot’s repeatability.

- However, the robot does not always go to the point C every time it is asked to return to the programmed point B. Instead, it forms a cluster of points. This gives rise to a random phenomenon of repeatability errors. The repeatability errors are generally assumed to be normally distributed. If the mean error is large, we say that the accuracy is poor. However, if the standard deviation of the error is low, we say that the repeatability is high.

Repeatability

- We pictorially represent the concept of low and high repeatability as well as accuracy in Figure 8.2b, c, d, and e.

- Consider the center of the two concentric circles as the desired target point. The diameter of the inner circle represents the limits up to which the robot end-effector can be positioned and considered to be of high accuracy. Any point outside the inner circle is considered to be of poor or low accuracy. A group of closely clustered points implies high repeatability, whereas a sparsely distributed cluster of points indicates low repeatability.

Fundamentals of Robotic Systems

- ✓ **Robot Motion Analysis,**
- ✓ **Robotic Joints and Links**

The Robotic Joints

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

1. Rotational movement
2. Radial movement
3. Vertical movement

The Robotic Joints

- These degrees of freedom, independently or in combination with others, define the complete motion of the end-effector.

- These motions are accomplished by movements of individual joints of the robot arm. The joint movements are basically the same as relative motion of adjoining links. Depending on the nature of this relative motion, the joints are classified as prismatic or revolute.

The Robotic Joints

- Prismatic joints are also known as sliding as well as linear joints. They are called prismatic because the cross section of the joint is considered as a generalized prism.
- Revolute joints permit only angular motion between links. Their variations include:
  1. Rotational joint (R)
  2. Twisting joint (T)
  3. Revolving joint (V)
- Revolute joints are also referred to as rotational joints.

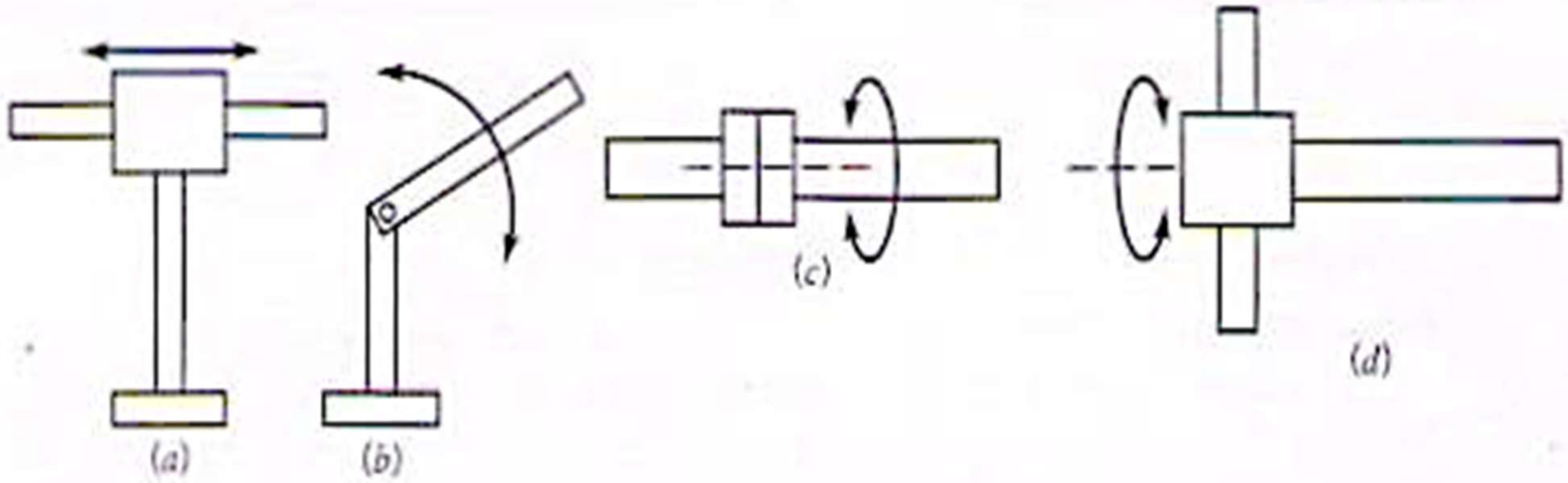

FIGURE 8.3 Types of joints: (*a*) linear joint; (*b*) rotational joint; (*c*) twisting joint; (*d*) revolving joint.

The Robotic Joints

- In a prismatic joint, also known as a sliding or linear joint (L), the links are generally parallel to one another. In some cases, adjoining links are perpendicular but one link slides at the end of the other link. The joint motion is defined by sliding or translational movements of the links. The orientation of the links remains the same after the joint movement, but the lengths of the links are altered.

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

The Robotic Joints

- A twisting joint (T) is also rotational joint, where the rotation takes place about an axis that is parallel to both adjoining links. Here the rotation involves the twisting of one link with respect to another, hence the name twisting joint.
- A revolving joint (V) is another rotational joint, where the rotation takes place about an axis that is parallel to one of the adjoining links. Usually, the links are aligned perpendicular to one another at this kind of joint. The rotation involves revolution of one link about another, hence the name.
- In addition to the movements of the robot's arm and body, the movements of its wrist are also important.

The Joint Notation

- This notation basically identifies the types of joints used in the configuration of the robot.

- The joints can be denoted by the letters L, R, T, and V for linear, rotational, twisting, and revolving, respectively.

Robot Anatomy and Related Attributes

- The arm or manipulator of an industrial robot consists of a series of joints and links.
- Robot anatomy is concerned with the types and sizes of these joints and links and other aspects of the manipulator's physical construction.
- The robot's anatomy affects its capabilities and the tasks for which it is best suited.

Joints and Links

- A robot's joint, or axis as it is also called in robotics, is similar to a joint in the human body: It provides relative motion between two parts of the body. Robots are often classified according to the total number of axes they possess. Connected to each joint are two links, an input link and an output link.

- Links are the rigid components of the robot manipulator.

- The purpose of the joint is to provide controlled relative movement between the input link and the output link.

Joints and Links

- Most robots are mounted on a stationary base on the floor. Let this base and its connection to the first joint be referred to as link 0.
- It is the input link to joint 1, the first in the series of joints used in the construction of the robot.
- The output link of joint 1 is link 1.
- Link 1 is the input link to joint 2, whose output link is link 2, and so forth.
- This joint-link numbering scheme is illustrated in Figure 8.1.

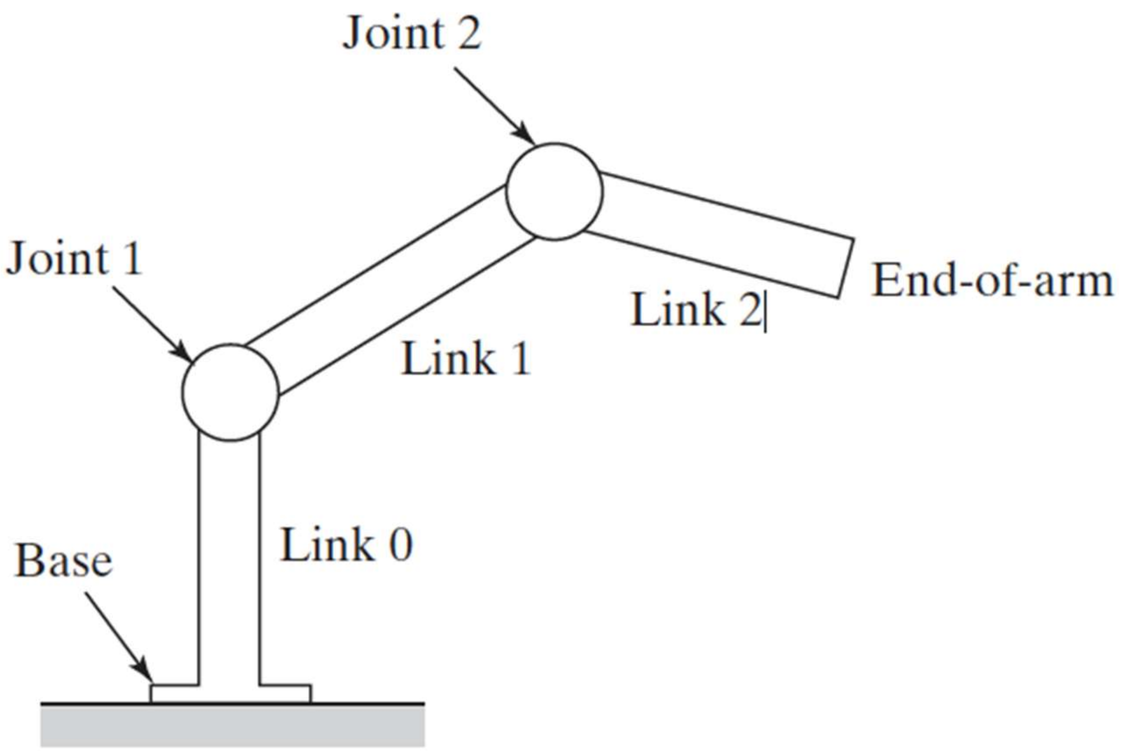

Figure 8.1 Diagram of robot construction showing how a robot is made up of a series of joint-link combinations.

Joints and Links

- Nearly all industrial robots have mechanical joints that can be classified into one of five types: two types that provide translational motion and three types that provide rotary motion.
- These joint types are illustrated in Figure 8.2.
- The five joint types are

Joints and Links

- **Linear joint (type L joint)**: The relative movement between the input link and the output link is a translational telescoping motion, with the axes of the two links being parallel.

- **Orthogonal joint (type O joint):** This is also a translational sliding motion, but the input and output links are perpendicular to each other.

- **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.

Joints and Links

- Twisting joint (type T joint). This joint also involves rotary motion, but the axis of rotation is parallel to the axes of the two links.

- Revolving joint (type V joint, V from the "v" in revolving). In this joint type, the axis of the input link is parallel to the axis of rotation of the joint, and the axis of the output link is perpendicular to the axis of rotation.

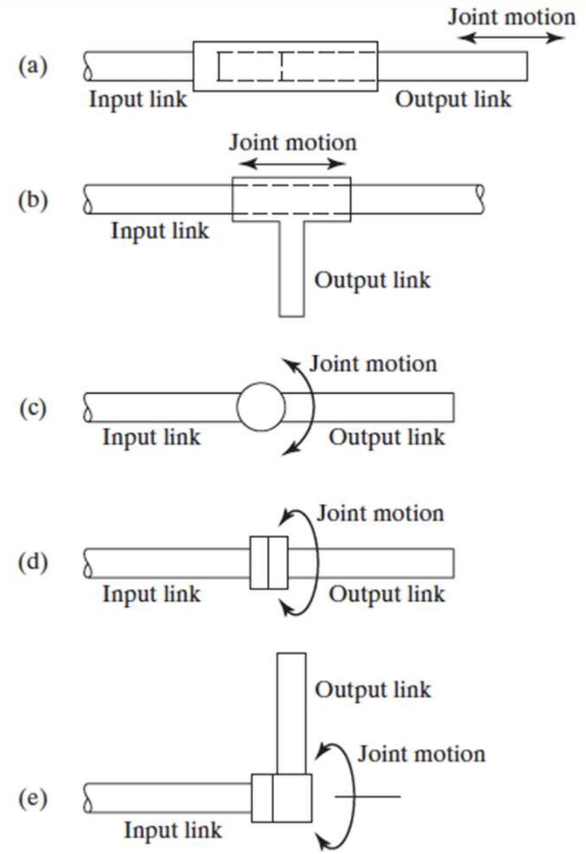

Figure 8.2 Five types of joints commonly used in industrial robot construction: (a) linear joint (type L joint), (b) orthogonal joint (type O joint), (c) rotational joint (type R joint), (d) twisting joint (type T joint), and (e) revolving joint (type V joint).

Joints and Links

- Each of these joint types has a range over which it can be moved. The range for a translational joint is usually less than a meter, but for large gantry robots, the range may be several meters.

- The three types of rotary joints may have a range as small as a few degrees or as large as several complete revolutions.

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Fundamentals of Robotic Systems

- ✓ **Robot Classification System,**
- ✓ **Industrial Robot Applications**

Robot Classification And Robot Reach

- Normally robots are classified on the basis of their physical configuration.
- Robots are also classified on the basis of the control systems adopted.

Classification Based on Physical Configuration

- Four basic configuration are identified with most of the commercially available industrial robots. They are:
  a. Cartesian configuration
  b. Cylindrical configuration
  c. Polar configuration
  d. Jointed-arm configuration

Robot Classification And Robot Reach

❑ Cartesian Configuration

- Robots with Cartesian configurations consist of links connected by linear joints (L). The configuration of the robot's arm can be designated as LLL.
- Because the configuration has three perpendicular slides, they are also called rectilinear robots.
- Another robot that is similar to this configuration is a *gantry robot.* The structure of a gantry robot resembles a gantry-type crane. Gantry robots are Cartesian robots that are mounted on a gantry structure and operate from the top to perform the specified task.

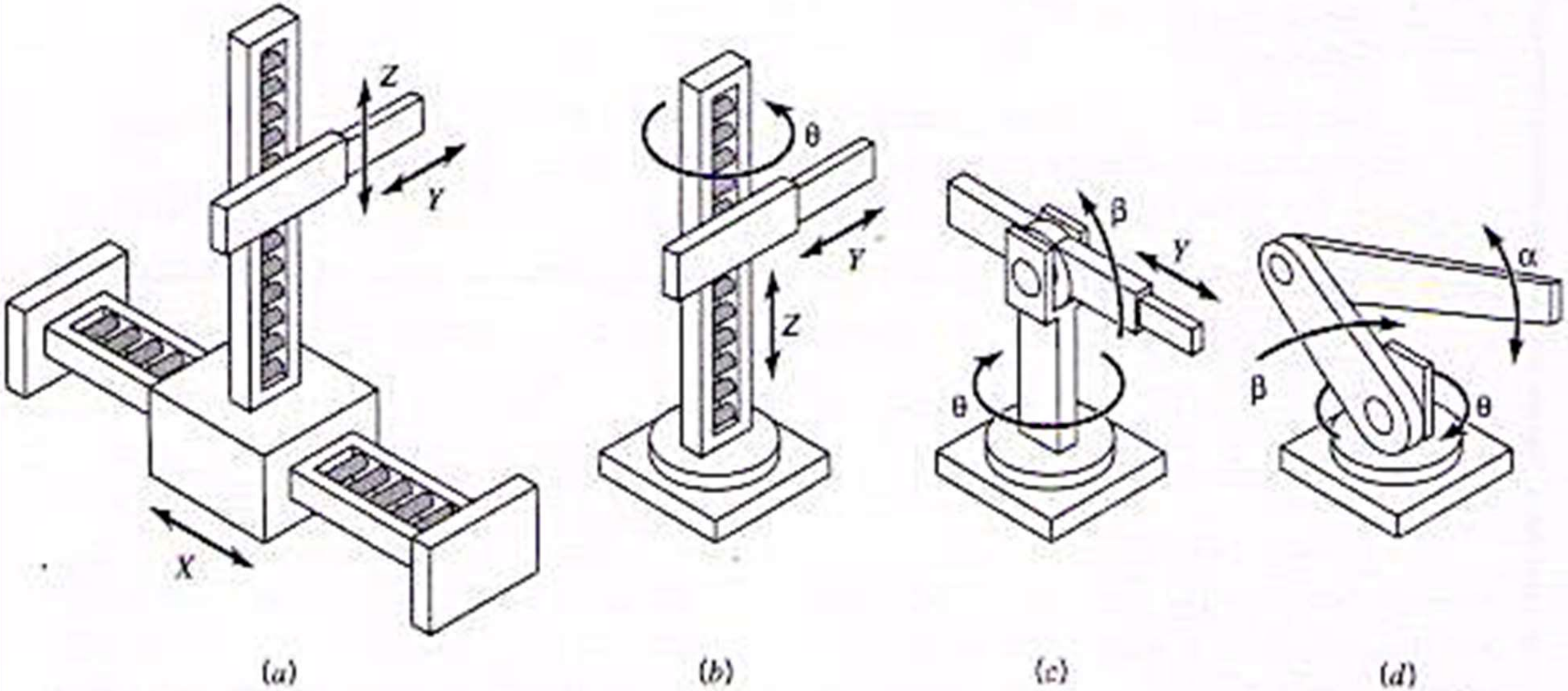

FIGURE 8.6 Robot classification: (*a*) Cartesian robot; (*b*) cylindrical robot; (*c*) polar robot; (*d*) jointed-arm (revolute) robot. (Reprinted with the permission of the publisher from *Robotics in Practice* by J. F. Engelberger, page 31 © 1980 by J. L. Engelberger, published in the U.S.A. by AMACOM, a division of American Management Association, New York, all rights reserved.)

Applications of Industrial Robots

Robots are used in a wide field of applications in industry. The general characteristics of the industrial work situations that tend to promote the substitution of robot for human labour are the following:

1. Hazardous work for humans
2. Repetitive work cycle
3. Difficult handling for humans
4. Multishift operations
5. Infrequent changeovers
6. Part position and orientation are established in the work cell.

Applications of Industrial Robots

- **Material Handling Applications**

- In material handling applications, the robot moves materials or parts from one place to another.

- To accomplish the transfer, the robot is equipped with a gripper that must be designed to handle the specific part or parts to be moved. Included within this application category are (1) material transfer and (2) machine loading and/or unloading.

Applications of Industrial Robots

- In many material handling applications, the parts must be presented to the robot in a known position and orientation.

- This requires some form of material handling device to deliver the parts into the work cell in this position and orientation.

Material Transfer

- These applications are ones in which the primary purpose of the robot is to move parts from one location to another. In many cases, reorientation of the part is accomplished during the move.

Applications of Industrial Robots

- The basic application in this category is called a pick-and-place operation, in which the robot picks up a part and deposits it at a new location.

- A more complex example of material transfer is **palletizing**, in which the robot retrieves parts, cartons, or other objects from one location and deposits them onto a pallet or other container at multiple positions on the pallet.

- The problem is illustrated in Figure 8.11.

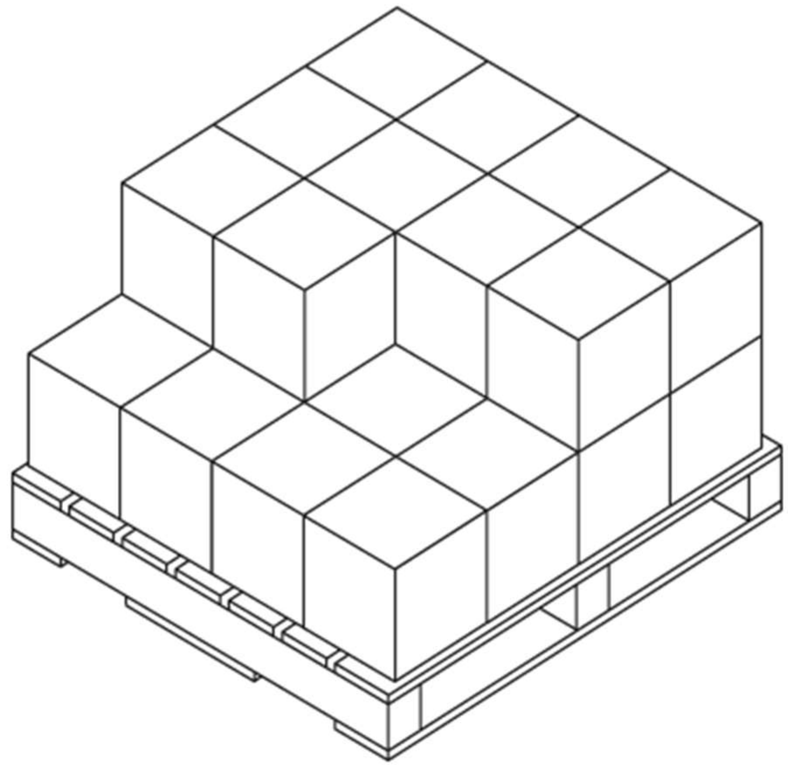

Figure 8.11 Typical part arrangement for a robot palletizing operation.

Applications of Industrial Robots

- Other applications similar to palletizing include **depalletizing**, which consists of removing parts from an ordered arrangement in a pallet and placing them at another location (e.g., onto a moving conveyor);

- **Stacking** operations, which involve placing flat parts on top of each other, such that the vertical location of the drop-off position is continuously changing with each cycle;

- And **insertion** operations, in which the robot inserts parts into the compartments of a divided carton.

Applications of Industrial Robots

- **Machine Loading and/or Unloading**

- In machine loading and/or unloading applications, the robot transfers parts into and/or from a production machine.
- The three possible cases are (1) machine loading, in which the robot loads parts into the production machine, but the parts are unloaded from the machine by some other means; (2) machine unloading, in which the raw materials are fed into the machine without using the robot, and the robot unloads the finished parts; and (3) machine loading and unloading, which involves both loading of the raw work part and unloading of the finished part by the robot.

Applications of Industrial Robots

- Industrial robot applications of machine loading and/or unloading include the following processes:

1. Die casting
2. Plastic moulding
3. Metal machining operations
4. Forging
5. Pressworking
6. Heat-treating

Applications of Industrial Robots

- **Processing Operations**

- In processing applications, the robot performs some operation on a work part, such as grinding or spray painting.
- A distinguishing feature of this category is that the robot is equipped with some type of tool as its end effector.
- To perform the process, the robot must manipulate the tool relative to the part.
- Examples of industrial robot applications in the processing category include spot welding, arc welding, spray painting, and various machining and other rotating spindle processes.

Applications of Industrial Robots

❑ Spot Welding

- Spot welding is a metal joining process in which two sheet metal parts are fused together at localized points of contact.
- Two electrodes squeeze the metal parts together and then a large electrical current is applied across the contact point to cause fusion to occur.
- The electrodes, together with the mechanism that actuates them, constitute the welding gun in spot welding.
- Because of its widespread use in the automobile industry for car body fabrication, spot welding represents one of the most common applications of industrial robots today.

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Applications of Industrial Robots

❑ Arc Welding

- Arc welding is used to provide continuous welds rather than individual spot welds at specific contact points.

- The resulting arc-welded joint is substantially stronger than in spot welding. Because the weld is continuous, it can be used in airtight pressure vessels and other weldments in which strength and continuity are required.

- The robot used in arc welding must be capable of continuous path control.

Applications of Industrial Robots

❑ Spray Coating

- Spray coating directs a spray gun at the object to be coated. Fluid (e.g., paint) flows through the nozzle of the spray gun to be dispersed and applied over the surface of the object.
- Spray painting is the most common application in the category, but spray coating refers to a broader range of applications that includes painting.
- Robot applications include spray coating of automobile car bodies, appliances, engines, and other parts; spray staining of wood products; and spraying of porcelain coatings on bathroom fixtures.

Applications of Industrial Robots

- **Other Processing Applications**

- Drilling, routing, and other machining processes
- Grinding, wire brushing, and similar operations
- Waterjet cutting
- Laser cutting

Applications of Industrial Robots

- **Assembly and Inspection**

- Assembly and inspection can involve either the handling of materials or the manipulation of a tool.
- Traditionally, assembly and inspection are labour-intensive activities. They are also highly repetitive and usually boring.
- For these reasons, they are logical candidates for robotic applications.
- However, assembly work typically involves diverse and sometimes difficult tasks, often requiring adjustments to be made in parts that don’t quite fit together.

Applications of Industrial Robots

- **Assembly**

- Assembly involves the combining of two or more parts to form a new entity, called a subassembly or assembly.
- The new entity is made secure by fastening the parts together using mechanical fastening techniques (e.g., screws, bolts and nuts, rivets) or joining processes (e.g., welding, brazing, soldering, or adhesive bonding).
- Because of the economic importance of assembly, automated methods are often applied.
- Fixed automation is appropriate in mass production of relatively simple products.

Applications of Industrial Robots

❑ Assembly

- Industrial robots used for the types of assembly operations described here are typically small, with light load capacities.
- The most common configurations are jointed arm, SCARA, and Cartesian coordinate.
- Accuracy and repeatability requirements in assembly work are often more demanding than in other robot applications, and the more precise robots in this category have repeatabilities of $\pm 0.05\ mm$ ($\pm 0.002\ mm$)

Applications of Industrial Robots

❑ **Inspection**

- There is often a need in automated production to inspect the work that is done.
- Inspections accomplish the following functions: (1) making sure that a given process has been completed, (2) ensuring that parts have been assembled as specified, and (3) identifying flaws in raw materials and finished parts.
- Inspection tasks performed by robots can be divided into the following two cases:

Applications of Industrial Robots

- Case 1

- The robot performs loading and unloading to support an inspection or testing machine.
- This case is really machine loading and unloading, where the machine is an inspection machine.
- The robot picks parts (or assemblies) that enter the cell, loads and unloads them to carry out the inspection process, and places them at the cell output.
- In some cases, the inspection may result in sorting of parts that must be accomplished by the robot. Depending on the quality level of the parts, the robot places them in different containers or on different exit conveyors.

Applications of Industrial Robots

- Case 2

- The robot manipulates an inspection device, such as a mechanical probe or vision sensor, to inspect the product.
- This case is similar to a processing operation in which the end effector attached to the robot's wrist is the inspection probe.
- To perform the process, the part is delivered to the workstation in the correct position and orientation, and the robot must manipulate the inspection device as required.

Fundamentals of Robotic Systems

✓ **Numerical Examples**

Numerical Example-1

- The following example shows how control resolutions are computed for different joints. To obtain the control resolution for the entire robot, component resolutions would have to be summed up vectorially. However, the robot's control resolution is a complex quantity to determine because joints of different types (rotatory and linear) are present.

Numerical Example-1

- A robot's control memory has 8 bit storage capacity. It has two rotational joints and one linear joint. Determine the control resolution for each joint, if the linear link can vary its length from as short as 0.2 m to as long as 1.2 m.

Solution

Control memory = 8 bit

For a particular axis, the number of separate increments is given by, number of increments = 2^n

So, the number of increments = $2^8 = 256$

(a) Total range for rotational joints = 360^o

Control resolution for each rotational joint $= {}^{360}/_{256} = 1.40625^o$

Solution

(b) Total range for linear joint = $1.2 \ - 0.2 = 1.0 \ m$

Control resolution for linear joint = 1/256 = 0.003906 m = 3.906 mm

Numerical Example-2

- Designate the robot configuration shown in Figure 8.4. using the joint notation scheme.

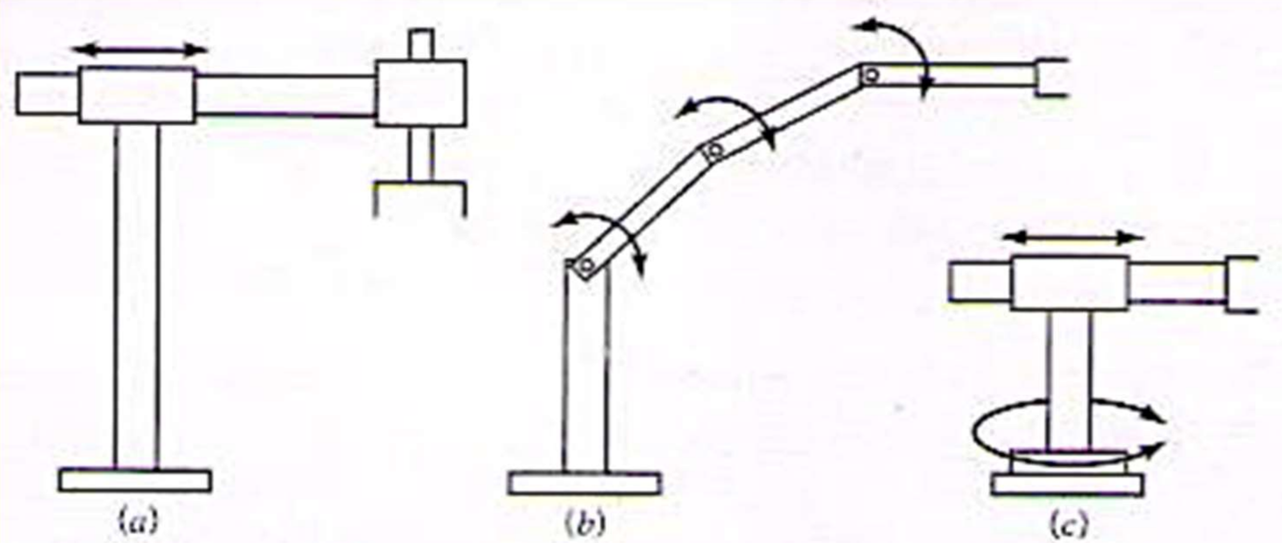

FIGURE 8.4 Robot configurations for Example 8.2: (*a*) LL robot; (*b*) RRR robot; (*c*) TL robot.

Solution

(a) This configuration has two linear joints. Hence, it is designated LL.

(b) The configuration has three rotational joints. Hence, it is designated RRR.

(c) This configuration has one twisting joint and one linear joint. This is indicated by TL

Numerical Example-3

- For the following joint notation, give sketches to illustrate the robot are configuration. (a) LRL, (b) RRL, (c) TRL and, (d) LVL.

Numerical Example-3

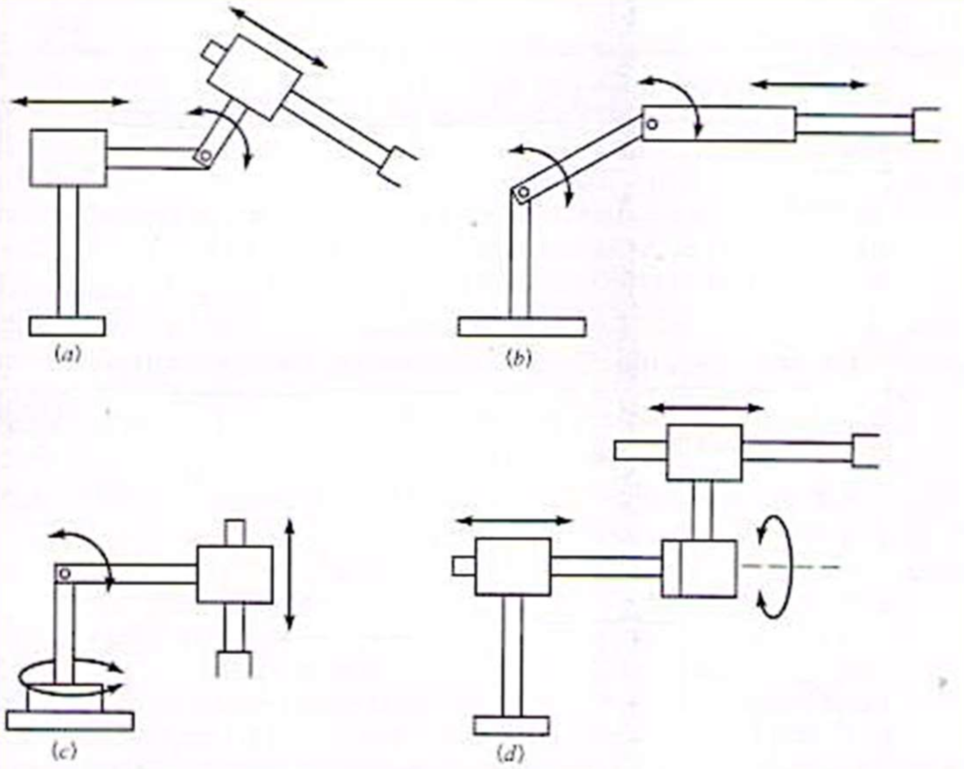

FIGURE 8.5 Robot configurations for Example 8.3: (*a*) LRL robot; (*b*) RRL robot; (c) TRL robot; (*d*) LVL robot.

Numerical Example-3

- The robots described in Numerical Example 2 and 3 are equipped with a wrist that has twisting, rotatory, and twisting joints in sequence from the arm to the end-effector. Give the designation for the completion configuration for each robot.

Solution

- The wrist has three joints denoted by T, R, and T (T for twisting and R for rotation). Using the joint rotation scheme for the wrist, the wrist can be designated as TRT.

- Hence, for the robots in Numerical Example-2, the complete designation is as follows:

  (a) LL : TRT
  (b) RRR : TRT
  (c) TL : TRT

Solution

- For the robots shown in this example, the complete designation is as follows:

  (a) LRL: TRT
  (b) RRL: TRT
  (c) TRL: TRT
  (d) LVL: TRT

List of Reference Textbooks

- Groover, M P, Automation, Production Systems, and Computer Integrated Manufacturing, Third Edition, Pearson Prentice Hall, Upper Saddle River.

- Groover, M P and Zimmers, E W Jr, CAD/CAM: Computer-aided Design and Manufacturing, Prentice-Hall of India Private Ltd.

- Singh, N. Systems Approach to Computer-integrated Design and Manufacturing, Wiley

Thank You!!