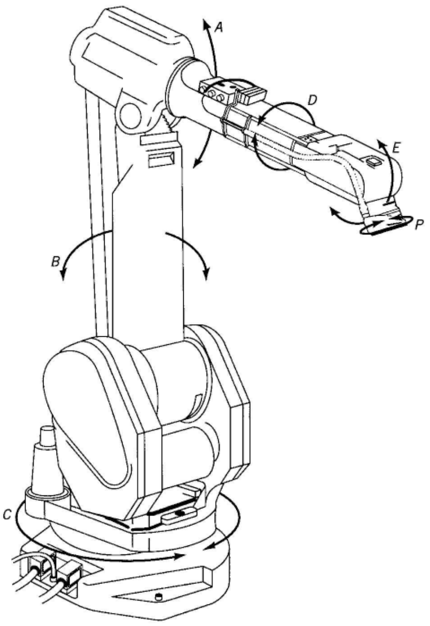
Robotic Systems

What is an Industrial Robot?

- 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.
- An industrial robot consists of a number of rigid links connected by joints of different types, controlled and monitored by a computer.



<u>Fundamentals of Robotics and Robotics Technology</u>

- Power sources for robots
    1. *Hydraulic drive:* 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.
    2. *Electric drive:* compared with a hydraulic system, an electric system provides a robot with less speed and strength. Accordingly, electric drive systems are adopted for smaller robots. However, robots supported by electric drive systems are more accurate, exhibit better repeatability, and are cleaner to use.
    3. *Pneumatic drive:* are generally used for smaller robots. These robots, with fewer degrees of freedom, carry out simple pick-and-place material handling operations.

- Robotic sensors
    1. *Position sensors:* are used to monitor the position of joints. Information about the position is fed back to the control systems that are used to determine the accuracy of joint movements.
    2. *Range sensors:* measure distances from the reference point to other points of importance. Range sensing is accomplished by means of television cameras or sonar transmitters and receivers.
    3. *Velocity sensors:* are used to estimate the speed with which a manipulator is moved. The velocity is an important part of 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 elongation in the links caused by gravity and the weights carried should be monitored and controlled to fine-tune the dynamic performance of the manipulator.
    4. *Proximity sensor:* are used to sense and indicate the presence of an object within a specified distance or space without any physical contact.
- The hand of a robot: End-effector mounted on the wrist enables the robot to perform specified tasks. Various types of end-effectors are designed for the same robot to make it more flexible and versatile.
    1. *Grippers:* are generally used to grasp and hold an object and place it at a desired location. Grippers can be classified as mechanical grippers, vacuum or suction cups, magnetic grippers, adhesive grippers, hooks, scoops, and so forth.
    2. *Tools:* a robot is required to manipulate a tool to perform an operation on a workpart. Here the tool 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.
- 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. Speed and stability are often conflicting. The precision of robot movement is define by three basic feature:
    1. 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. For a particular axis, the number of separate increments is given by

$$\text{Number of increments} = 2^n$$

where n is the number of bits in the control memory

2. Accuracy
3. Repeatability

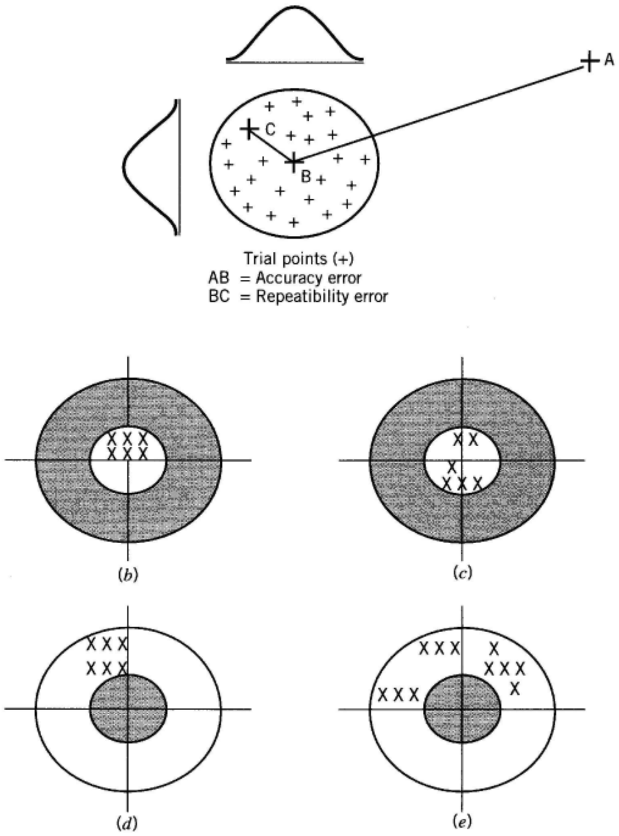


FIGURE 2 (*a*) Accuracy and repeatability; (*b*), high accuracy and high repeatability; (*c*) high accuracy and low repeatability; (*d*) low accuracy and high repeatability; (*e*) low accuracy and low repeatability.

<u>The Robotic Joints</u>

- A robot joint is a mechanism that permits relative movement between parts of a robot arm. The basic movements required for the desired motion of most industrial robots are:
  - Rotational movement: this enables the robot to place its arm in any direction on a horizontal plane.
  - Radial movement: this enables the robot to move its end-effector radically to reach distant points.
  - Vertical movement: this enables the robot to take its end-effector to different heights.

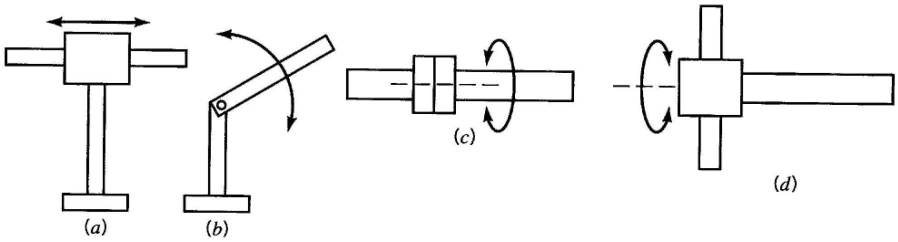


FIGURE 3 Types of joints: (*a*) linear joint; (*b*) rotational joint; (*c*) twisting joint; (*d*) revolving joint.

The Joint Notation

EXAMPLE 2

Designate the robot configurations shown in Figure 4, using the joint notation scheme.

Solution

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

(b) This 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.

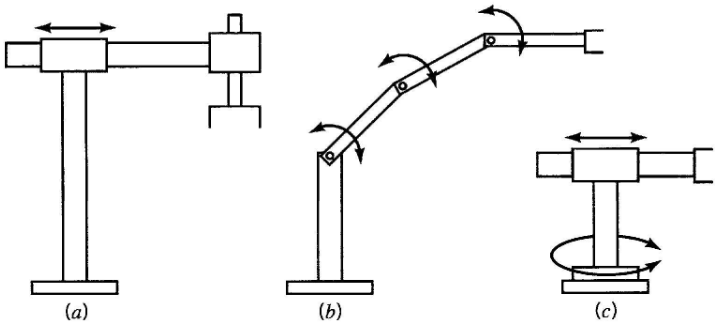


FIGURE 4 Robot configurations for Example .2: (*a*) LL robot; (*b*) RRR robot; (*c*) TL robot.

EXAMPLE 3

For the following joint notation, give sketches to illustrate the robot arm configuration.

(a) LRL, (b) RRL, (c) TRL and, (d) LVL.

Solution

Figure 5 shows schematic diagrams of the given robot configurations.

This notation scheme can be expanded to include wrist motions. In that case, the notation begins with the joint closest to the arm and proceeds up to the joint with the end-effector. For example, a two-axis wrist can be denoted as RT, which means that the wrist joints are rotational and twisting, respectively. The complete designation for a robot with arm and wrist configurations similar to those discussed here is TRR:RT.

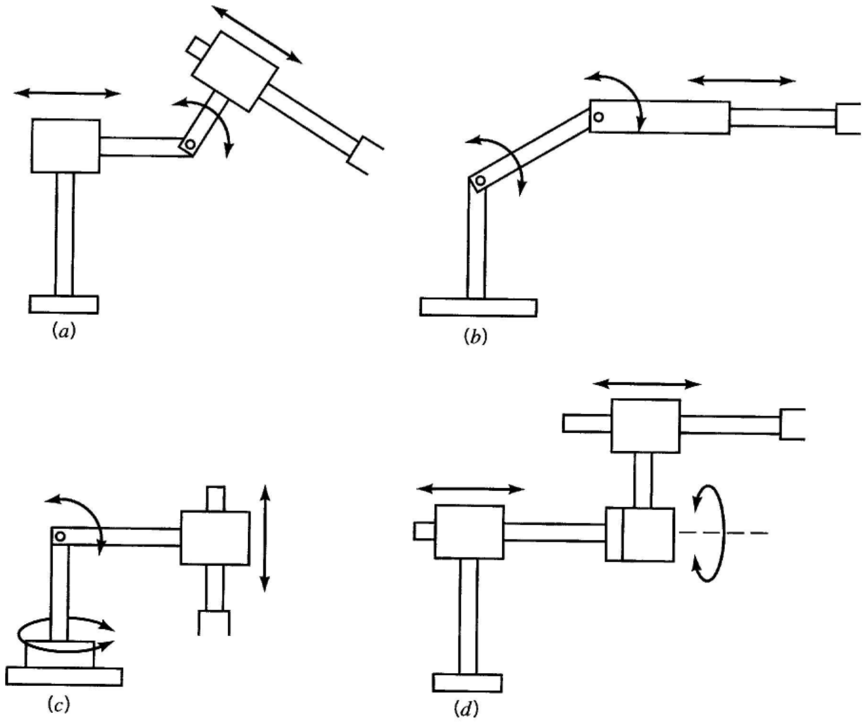
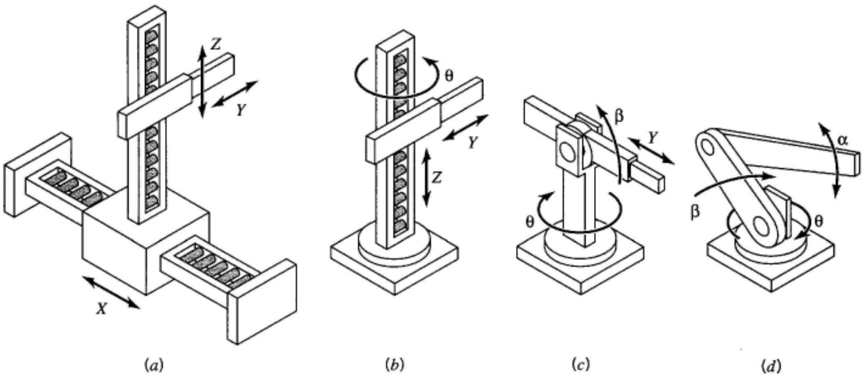


FIGURE 5 Robot configurations for Example 3: (*a*) LRL robot; (*b*) RRL robot; (*c*) TRL robot; (*d*) LVL robot.

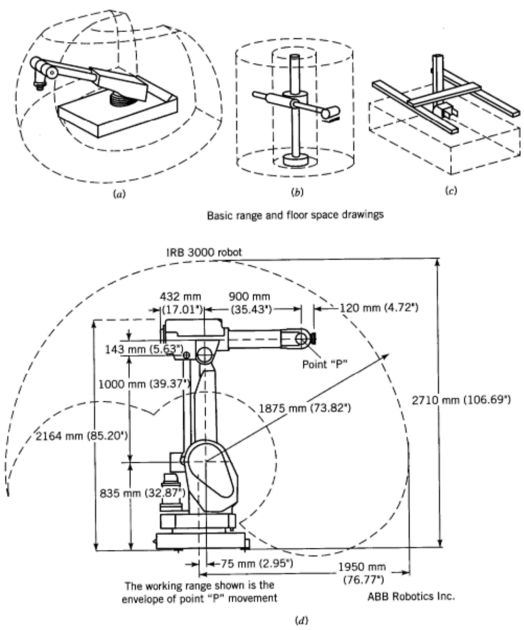
Robot Classification and Robot Reach

- Classification based on Physical configurations, four basic configurations are identified with most of the commercially available industrial robots.
  1. *Cartesian configuration:* consist of links connected by linear joints (L). (a) is designated as LLL, they are also called rectilinear robots. Another robot that is similar to this configuration is a gantry robot.
  2. *Cylindrical configuration:* robots have one rotate (R) joint at the base and linear (L) joints succeed to connect to the links. (b) in this configuration can be designed as TLL.
  3. *Polar configuration:* have a work space of spherical shape. Generally, the arm is connected to the base with a twisting (T) joint and rotate (R) and/or linear (L) joints follow. (c)for this configuration can be TRL or TRR. TRR (also called articulated robot) robot more closely resembles the human arm.
  4. *Jointed-arm configuration:* is combination of cylindrical and articulated configurations. The arm of robot is connected to the base with a twisting joint. (d) Rotate joints connect the links in the arm. The most popular robot, which is very close to this configuration, is SCARA (selective compliance assembly robot arm). In the SCARA robot rotations take place in horizontal planes, thus reducing the possibility of large deformations in the links.



- Classification Based on Control Systems
    1. *Point-to-point (PTP) control robot*: is capable of moving from one point to another point. The locations are recorded in the control memory. PTP robots do not control the path to get from one point to the next point. Common applications include component insertion, spot welding, hole drilling, machine loading and unloading, and crude assembly operations.
    2. *Continuous-path (CP) control robot:* with CP control, the robot can stop at any specified point along the controlled path. All the points along the path must be stored explicitly in the robot's control memory. Typical applications include spray painting, finishing, gluing, and arc welding operations.
    3. Controlled-path robot: the control equipment can generate paths of different geometry such as straight lines, circles, and interpolated curves with a high degree of accuracy. All controlled-path robots have a servo capability to correct their path.
- Robot Reach

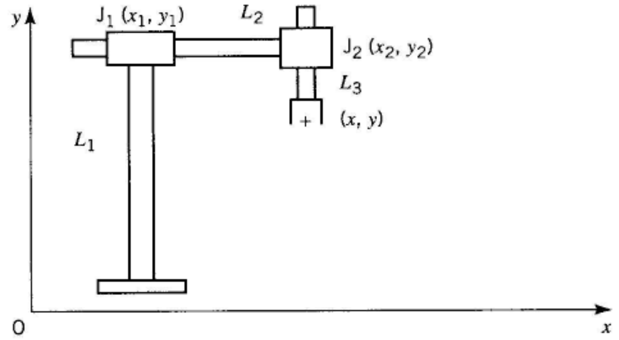
(a) Polar; (b)Cylindrical robot; (c)Cartesian; (d)Joint arm (revolute) robot.



Robot Motion Analysis: Forward and Backward Kinematics Transformation

- The kinematics analysis involves two different kinds of problems:
  1. Determining the coordinates of the end-effector or end of arm for a given set of joints coordinates and
  2. Determining the joints coordinates for a given location of the end-effector or end of arm

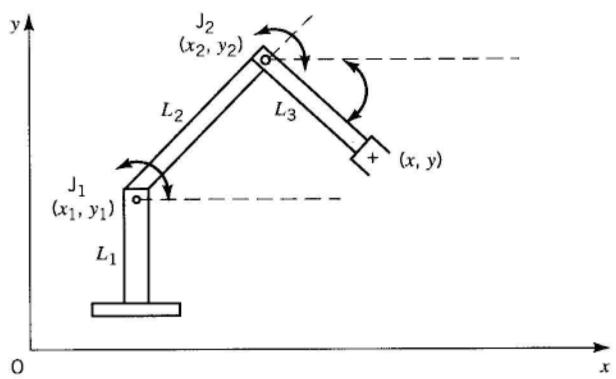
LL Robot:



$$X_2 = T_1 X_1$$
$$X = T_2 X_2$$
$$T_{LL} = T_2 T_1$$

$$T = \begin{bmatrix} 1 & 0 & L \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

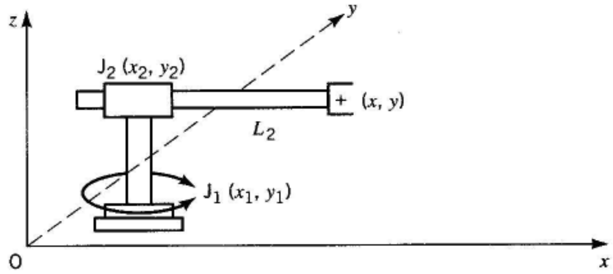
RR Robot:



$$X_2 = T_1 X_1$$
$$X = T_2 X_2$$
$$T_{RR} = T_2 T_1$$

$$T = \begin{bmatrix} 1 & 0 & L\cos\theta \\ 0 & 1 & L\sin\theta \\ 0 & 0 & 1 \end{bmatrix}$$

TL Robot:



$$X = T_{TL} X_2$$

$$T_{TL} = \begin{bmatrix} 1 & 0 & L_2\cos\alpha \\ 0 & 1 & L_2\sin\alpha \\ 0 & 0 & 1 \end{bmatrix}$$

- In joint space, the joint parameters such as rotating or twisting joint angles and variable link lengths are use to represent the position of the end-effector.

  $V_j = (\theta, \alpha)$ for RR robot

$= (L_1, L_2)$ for LL robot

$= (\alpha, L_2)$ for TL robot

where V_j refers to the position of the end-effector in joint space.

- In world space, rectilinear coordinates with reference to the basic Cartesian system are used to define the position of the end-effector. Usually the origin of the Cartesian axes is located in the robot's base.

$$V_w = (x, y)$$

where V_w refers to the position of the end-effector in world space.

Robot Programming and Languages

- The primary objective of robot programming is to make the robot understand its work cycle. The program teaches the robot
  1. The path it should take
  2. The points it should reach precisely
  3. How to interpret the sensor data
  4. How and when to actuate the end-effector
  5. How to move parts from one location to another, and so forth
- A computer-like program that is user friendly is most suitable for these purposes. Programming of conventional robots normally takes one of two forms:
  1. Teach-by-showing, which can be divided into
     - Powered lead-through or discrete point programming: it is also called pendant teaching. Points are recorded in memory for subsequent playback. For playback robots, this is the most common programming method used. In cases such as machine loading and unloading, transfer tasks, and spot welding, the movements of the manipulator are basically of a point-to-point nature.
     - Manual lead-through or walk-through or continuous path programming: in walk-through programming, the programming simply moves the robot physically through the required motion cycle.
  2. Textual language programming: use an English-like language to establish the logical sequence of a work cycle.
     - Most robot language implemented today are a combination of textual and teach-pendant programming. Programming in these languages is much like computer programming.
     - Some of the languages that have been developed are WAVE, VAL, AML, RAIL, MCL, TL-10, IRL, PLAW, SINGLA, and VAL II.

Develop a program in VAL II to command a PUMA robot to unload a cylindrical part of 10 mm diameter from machine 1 positioned at point P1 and load the part on machine 2 positioned at P2. The speed of robot motion is 40 in./s. However, because of safety precautions, the speed is reduced to 10 in./s while moving to a machine for an unloading or loading operation.

Solution

A robot program in VAL II:

```
        SIGNAL 5
        SPEED 40 IPS
        OPEN 100
        APPRO P1, 50
        SPEED 10 IPS
        MOVE P1
        GRASP 10, 100
50      TYPE "THE OPENING IS NOT 10mm."
        PROMPT "ENTER : 1 TO PROCEED OR 0 TO STOP.", INDEX
        CASE INDEX OF
        VALUE 1
        TYPE "I AM PROCEEDING."
        GO TO 100
        VALUE 0
        TYPE "I STOPPED ON YOUR INSTRUCTIONS."
        STOP
        ANY
        TYPE "ERROR IN INPUT."
        GO TO 50
        END
100     DEPART P1, 50
        SPEED 40 IPS
        APPRO P2, 50
        SPEED 10 IPS
        MOVE P2
        BELOW
        OPENI 100
        ABOVE
        DEPART P2, 50
        STOP
```

The program is self-explanatory.

Robot Selection

- The technical features are the prime considerations in the selection of a robot.
    1. Degrees of freedom
    2. Control system to be adopted
    3. Work volume
    4. Load-carrying capacity
    5. Accuracy and repeatability
- The characteristics of robots generally considered in a selection process include

1. Size of class
   - Micro ($x \le 1$ m)
   - Small ($1 < x \le 2$ m)
   - Medium ($2 < x \le 5$ m)
   - Large ($x > 5$ m)
2. Degrees of freedom: the cost of increases with increasing number of DOF.
3. Velocity
4. Actuator type
5. Control mode
6. Repeatability
7. Lift capacity
8. Right-Left traverse
9. Up-down-traverse
10. In-out-traverse
11. Yaw
12. Pitch
13. Roll
14. Weight of the robot

Robot Applications

- The common industrial applications of robots in manufacturing involve loading and unloading of parts.
  1. The robot unloading parts from die-casing machines
  2. The robot loading a raw hot billet into a die, holding it during forging, and unloading it form the forging die
  3. The robot loading sheet blanks into automatic pressed, with the parts falling out of the back of the machine automatically after the press operation is performed
  4. The robot unloading molded parts formed in injection molding machines
  5. The robot loading raw balks into NC machine tools and unloading the finished parts from the machines
- a single-machine robotic cell application
- a single-machine cell with a double-gripper robot
- multi-machine robotic cell applications
- welding
- spray painting
- assembly
- other applications