CBCS SCHEME

18ME732

USN 1CR18ME007

Seventh Semester B.E. Degree Examination, Feb./Mar. 2022
Automation and Robotics

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Module-1

1 a. Explain the basic elements of an automated system with the help of a block diagram. (10 Marks)

b. What are the reasons for automation? List them and explain. (10 Marks)

OR

2 a. What are different types of sensors used in industrial automation? List them. (05 Marks)

b. Describe input/output devices for discrete data. (10 Marks)

c. What are hardware components for automation and process control? (05 Marks)

Module-2

3 a. Explain Transfer lines. Sketch and explain rotary transfer machine. (08 Marks)

b. A ten station in-line assembly machine has an ideal cycle time of 6 sec. The base part is automatically loaded prior to the first station and components are added to each of the stations. The fraction defect rate at each of the ten stations is q = 0.01 and the probability that a defect will Jam is m = 0.5. When a jam occurs, the average down time is 2 minutes. Cost to operate the assembly machine is Rs.2940/hour. Other costs are ignored.
Determine:
i) Average production rate of all assemblies.
ii) Yield of good assemblies.
iii) Average production rate of good product.
iv) Efficiency of the assembly machines.
v) Cost per unit produced. (12 Marks)

OR

4 a. What is AIDC? Explain. (10 Marks)

b. Write a brief note on bar-code technology. (10 Marks)

Module-3

5 a. Define a Robot Enumerate the robot physical configurations. Explain any two configurations with neat sketch. (10 Marks)

b. With a neat sketch, explain roll, pitch and yaw motions. (05 Marks)

c. List applications of industrial robots. (05 Marks)

OR

6 a. Define the terms accuracy and repeatability. (08 Marks)

b. What do you mean by dynamic stabilization of robots? Give an example. (06 Marks)

c. State the laws of Asimov's. (06 Marks)

Module-4

7 a. What is a servomotor? Explain its characteristics and advantages. **(06 Marks)**

b. Differentiate between tactile and proximate sensors. **(04 Marks)**

c. Explain potentiometer with neat sketch. **(10 Marks)**

OR

8 a. Obtain the relation between the body attached frame with base frame of reference by transformation matrix (4 × 4). **(06 Marks)**

b. For a 6 joint robotic manipulator, equipped with a digital TV camera and it is capable of monitoring the position and orientation of an object. The position and orientation of the object with respect to the camera is expressed by a matrix $[T_1]$, the origin of the robot base coordinate with respect to the camera is given by $[T_2]$ and the position and orientation of the gripper with respect to the base coordinate frame is given by $[T_3]$.

$$[T_1]=\begin{bmatrix}0 & 1 & 0 & 5\\ 1 & 0 & 0 & 6\\ 0 & 0 & -1 & 10\\ 0 & 0 & 0 & 1\end{bmatrix} \quad [T_2]=\begin{bmatrix}1 & 0 & 0 & -25\\ 0 & -1 & 0 & 10\\ 0 & 0 & -1 & 12\\ 0 & 0 & 0 & 1\end{bmatrix} \quad [T_3]=\begin{bmatrix}1 & 0 & 0 & 8\\ 0 & 1 & 0 & 6\\ 0 & 0 & 1 & 6\\ 0 & 0 & 0 & 1\end{bmatrix}$$

Determine:

i) The position and orientation of the object with respect to the base coordinate.

ii) The position and orientation of the object with respect to gripper. **(14 Marks)**

Module-5

9 a. Explain the following:

i) Object level programming

ii) Lead through programming. **(10 Marks)**

b. Explain the requirements of a robot programming language. **(10 Marks)**

OR

10 a. Write the robot programming using AL for the following palletizing operation. Working; Pick a part from a pallet with r_1 – rows and c_1 columns and put into a pallet of r_2 rows and c_2 columns; signal or wait for representation and removal of full or empty pallets. **(15 Marks)**

b. Discuss the central issues in OLP system. **(05 Marks)**

* * * * *

1. a Basic elements of an automated system

An automated system consists of three basic elements:

(1) *power* to accomplish the process and operate the system.

(2) a *program of instructions* to direct the process, and

(3) a control system to actuate the instructions.

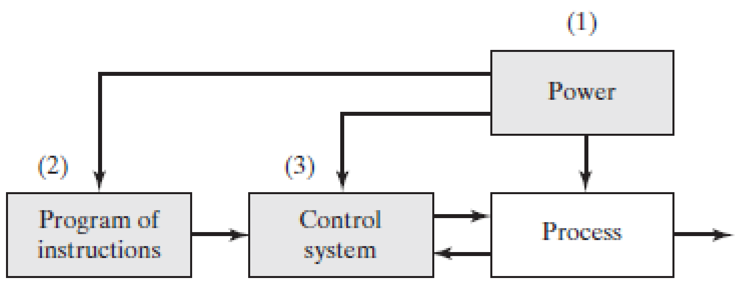


Figure 4.2 Elements of an automated system: (1) power, (2) program of instructions, and (3) control systems.

Fig.1 Basic elements of an automated system

1. Power to accomplish the automated process

An automated system is used to operate some process, and power is required to drive the process as well as the controls. The principal source of power in automated systems is electricity. Electric power has many advantages in automated as well as non-automated processes.

In addition to driving the manufacturing process itself, power is also required for the following material handling functions:

• *Loading and unloading the work unit.* All of the processes listed in Table 4.1 are accomplished on discrete parts. These parts must be moved into the proper position and orientation for the process to be performed, and power is required for this transport and placement function. At the conclusion of the process, the work unit must be removed. If the process is completely automated, then some form of mechanized power is used. If the process is manually operated or semi automated, then human power may be used to position and locate the work unit.

• *Material transport between operations.* In addition to loading and unloading at a given operation, the work units must be moved between operations.

Power for Automation.

Above and beyond the basic power requirements for the manufacturing operation, additional power is required for automation. The additional power is used for the following functions:

• *Controller unit.* Modern industrial controllers are based on digital computers, which require electrical power to read the program of instructions, perform the control calculations, and execute the instructions by transmitting the proper commands to actuating devices.

• *Power to actuate the control signals.* The commands sent by the controller unit are carried out by means of electromechanical devices, such as switches and motors, called *actuators* The commands are generally transmitted by means of low-voltage control signals. To accomplish the commands, the actuators require more power, and so the control signals must be amplified to provide the proper power level for the actuating device.

• *Data acquisition and information processing.* In most control systems, data must be collected from the process and used as input to the control algorithms. In addition, for some processes, it is a legal requirement that records be kept of process performance and/or product quality. These data acquisition and record-keeping functions require power, although in modest amounts.

2. Program of instructions

The actions performed by an automated process are defined by a program of instructions. Whether the manufacturing operation involves low, medium, or high production, each part or product requires one or more processing steps that are unique to that part or product. These processing steps are performed during a work cycle. A new part is completed at the end of each work cycle (in some manufacturing operations, more than one part is produced during the work cycle: for example, a plastic injection molding operation may produce multiple parts each cycle using a multiple cavity mold). The particular processing steps for the work cycle are specified in a work cycle program, called *part programs* in numerical control.

3. Control System

The control element of the automated system executes the program of instructions. The control system causes the process to accomplish its defined function, which is to perform some manufacturing operation.

The controls in an automated system can be either closed loop or open loop. A ***closed loop control system***, also known as a *feedback control system*, is one in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output into agreement with the input.

1. b Reasons for Automation

1. ***Increased productivity:*** Automation of manufacturing operations holds the promise of increasing the productivity of labor. This means greater output per hour of labor input. Higher production rates (output per hour) are achieved with automation than with the corresponding manual operations.
2. ***High cost of labor:*** The trend in the industrialized societies of the world has been toward ever-increasing labor costs. As a result, higher investment in automated equipment has become economically justifiable to replace manual operations. The high cost of labor is forcing business leaders to substitute machines for human labor. Because machines can produce at higher rates of output, the use of automation results in a lower cost per unit of product.
3. ***Labor shortages:*** In many advanced nations there has been a general shortage of labor. Labor shortages stimulate the development of automation as a substitute for labor.
4. ***Trend of labor toward the service sector:*** This trend has been especially prevalent in India. There are also social and institutional forces that are responsible for the trend. There has been a tendency for people to view factory work as tedious, demeaning, and dirty. This view has caused them to seek employment in the service sector of the economy government, insurance, personal services, legal, sales, etc. Hence, the proportion of the work force employed in manufacturing is reducing.
5. ***Safety:*** By automating the operation and transferring the operator from an active participation to a supervisory role, work is made safer.
6. ***High cost of raw materials:*** The high cost of raw materials in manufacturing results in the need for greater efficiency in using these materials. The reduction of scrap is one of the benefits of automation.
7. ***Improved product quality:*** Automated operations not only produce parts at faster rates but they produce parts with greater consistency and conformity to quality specifications.
8. ***Reduced manufacturing lead time:*** With reduced manufacturing lead time automation allows the manufacturer a competitive advantage in promoting good customer service.
9. ***Reduction of in-process inventory:*** Holding large inventories of work-in-process represents a significant cost to the manufacturer because it ties up capital. In-process inventory is of no value. It serves none of the purposes of raw materials stock or finished product inventory. Automation tends to accomplish this goal by reducing the time a workpart spends in the factory.
10. ***High cost of not automating:*** A significant competitive advantage is gained by automating a manufacturing plant. The benefits of automation show up in intangible and unexpected ways, such as, improved quality, higher sales, better labor relations, and better company image. All of these factors act together to make production automation a feasible and attractive alternative to manual methods of manufacture.

2. a. Types of sensors used in Automation

There are many different types of sensors, the main categories are;

- Position Sensors.
- Pressure Sensors.
- Temperature Sensors.

- Force Sensors.
- Vibration Sensors.
- Piezo Sensors.
- Fluid Property Sensors.
- Humidity Sensors.

2.b

Input/Output Devices for Discrete Data

Discrete data can be processed by a digital computer without the kinds of conversion procedures required for continuous analog signals. Discrete data divide into three categories: (a) binary data, (b) discrete data other than binary, and (c) pulse data.

Contact Input/Output Interfaces

Contact interfaces are of two types, input and output. These interfaces read binary data from the process into the computer and send binary signals from the computer to the process, respectively. The terms *input* and *output* are relative to the computer.

A ***contact input interface*** is a device by which binary data are read into the computer from some external source (e.g., a process). It consists of a series of simple contacts that can be either closed or open (on or off) to indicate the status of binary devices connected to the process such as limit switches (contact or no contact), valves (open or closed), or motor pushbuttons (on or off). The computer periodically scans the actual status of the contacts to update the values stored in memory.

The ***contact output interface*** is a device that communicates on/off signals from the computer to the process. The contact positions are set either on or off. These positions are maintained until changed by the computer, perhaps in response to events in the process. In computer process-control applications, hardware controlled by the contact output interface include alarms, indicator lights (on control panels), solenoids, and constant-speed motors. The computer controls the sequence of on/off activities in a work cycle through this contact output interface.

Pulse Counters and Generators

A ***pulse counter*** is a device that converts a series of pulses into a digital value. The value is then entered into the computer through its input channel. The most common type of pulse counter is one that counts electrical pulses. It is constructed using sequential logic gates, called *flip-flops*, which are electronic devices that possess memory capability and that can be used to store the results of the counting procedure.

Pulse counters can be used for both counting and measurement applications. A typical counting application might add up the number of packages moving past a photoelectric sensor along a conveyor in a distribution center. A typical measurement application might indicate the rotational speed of a shaft. One possible method to accomplish the measurement is to connect the shaft to a rotary encoder which generates a certain number of electrical pulses for each rotation. To determine rotational speed, the pulse counter measures the number of pulses received during a certain time period and divides this by the duration of the time period and by the number of pulses in each revolution of the encoder.

A ***pulse generator*** is a device that produces a series of electrical pulses whose total number and frequency are determined and sent by the control computer. The total number of pulses might be used to drive a stepper motor in a positioning system. The frequency of the pulse train, or pulse rate, could be used to control the rotational speed of a stepper motor. A pulse generator operates by repeatedly closing and opening an electrical contact, thus producing a sequence of discrete electrical pulses. The amplitude (voltage level) and frequency are designed to be compatible with the device being controlled.

2.c **Hardware components for automation & process control**

To implement automation and process control, the control computer must collect data from and transmit signals to the process.

The digital computer operates on digital (binary) data, whereas at least some of the data from the physical process are continuous and analog. Accommodations for this difference must be made in the computer–process interface.

The components required to implement this interface are the following:

1. Sensors to measure continuous and discrete process variables.
2. Actuators to drive continuous and discrete process parameters.
3. Devices to convert continuous analog signals into digital data and digital data into analog signals.
4. Input/output devices for discrete data.

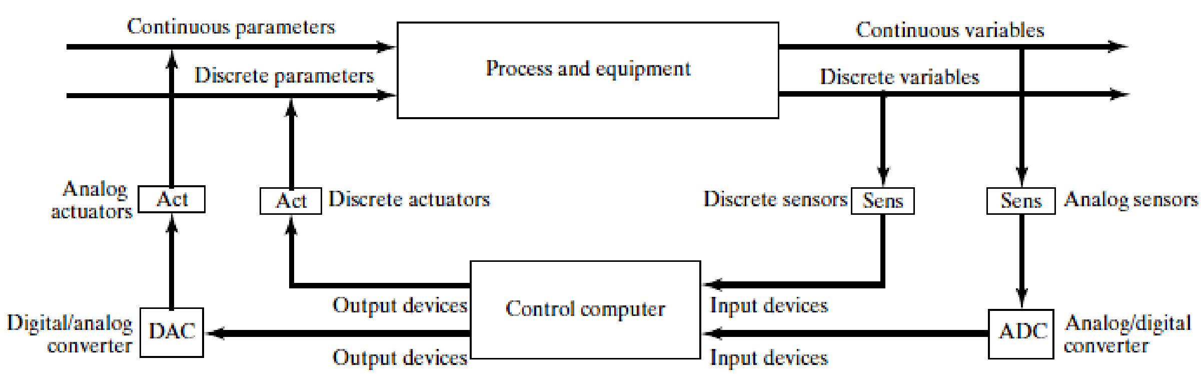


Figure 6.1 The computer process control system, showing the various types of components required to interface the process with the computer.

3.a Transfer Lines. In a transfer line, the workstations containing machining work heads are arranged in an in-line or segmented in-line configuration and the parts are moved between stations by transfer mechanisms such as the walking-beam system. The transfer line is the most highly automated and productive system in terms of the number of operations that can be performed to accommodate complex work geometries. It is also the most expensive of the systems discussed in this section. Machining type transfer lines are pictured in Figure 16.3. The transfer line can include a large number of workstations, but reliability of the system decreases as the number of stations is increased.

Rotary Transfer Machines: A rotary transfer machine consists of a horizontal circular worktable, upon which are fixtured the parts to be processed, and around whose periphery are located stationary work heads. The worktable is indexed to present each part to each work head to accomplish the sequence of machining operations. By comparison with a transfer line, the rotary indexing machine is limited to smaller, lighter work parts and fewer workstations.

In the rotary configuration, the work parts are attached to fixtures around the periphery of a circular worktable, and the table is indexed (rotated in fixed angular amounts) to present the parts to workstations for processing. A typical arrangement is illustrated in Figure 16.4. The worktable is often referred to as a dial, and the equipment is called a *dial-indexing machine*.

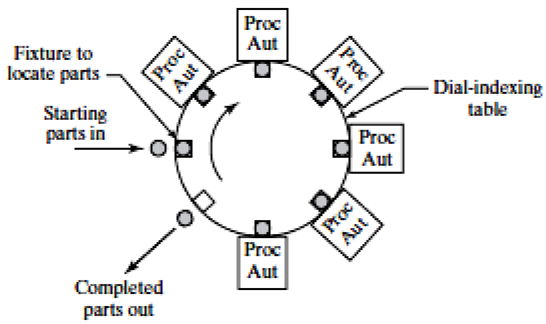


Figure 16.4 Rotary indexing machine (dial-indexing machine). Key: Proc = processing operation, Aut = automated workstation.

3.b The average production cycle time is

$$T_p = 0.1 + (10)(0.5)(0.01)(2.0) = 0.2 \text{ min}$$

The production rate is therefore

$$R_p = \frac{60}{0.2} = 300 \text{ assemblies/h}$$

The yield is given by Eq. (7.8) :

$$P_{ap} = (1 - 0.01 + 0.5 \times 0.01)^{10} = 0.9511$$

This is the proportion of assemblies coming off the machine that contain no defective parts.

Therefore, the proportion of assemblies that contain one or more defects is

$$P_{qp} = 1 - 0.9511 = 0.0489$$

The efficiency of the assembly machine is

$$E = \frac{0.1}{0.2} = 0.50 = 50\%$$

Cost per unit produced

$$C_{pc} = 0.30 + 1.00(0.3) = \$0.60/\text{assembly}$$

4.a ***Automatic identification and data capture*** (AIDC) refers to technologies that provide direct entry of data into a computer or other microprocessor-controlled system without using a keyboard. Many of these technologies require no human involvement in the data capture and entry process. Automatic identification systems are being used increasingly to collect data in material handling and manufacturing applications. In material handling, the applications include shipping and receiving, storage, sortation, order picking, and kitting of parts for assembly. In manufacturing, the applications include monitoring the status of order processing, work-in-process, machine utilization, worker attendance, and other measures of factory operations and performance.

Nearly all of the automatic identification technologies consist of three principal components, which also comprise the sequential steps in AIDC.

1**.** ***Data encoder***. A ***code*** is a set of symbols or signals that usually represent alphanumeric characters. When data are encoded, the characters are translated into a machine-readable code. (For most AIDC techniques, the encoded data are not readable by humans.) A label or tag containing the encoded data is attached to the item that is to be identified.

2. ***Machine reader* or *scanner***. This device reads the encoded data, converting them to alternative form, usually an electrical analog signal.

3. ***Data decoder***. This component transforms the electrical signal into digital data and finally back into the original alphanumeric characters.

AIDC technologies can be divided into the following six categories:

1. ***Optical*.** Most of these technologies use high-contrast graphical symbols that can be interpreted by an optical scanner. They include linear (one-dimensional) and two dimensional bar codes, optical character recognition, and machine vision.

2. ***Electromagnetic***. The important AIDC technology in this group is radio frequency identification (RFID), which uses a small electronic tag capable of holding more data than a bar code. Its applications are gaining on bar codes due to several mandates from companies like Walmart and from the U.S. Department of Defense.

3. ***Magnetic*.** These technologies encode data magnetically, similar to recording tape. The two important techniques in this category are (a) magnetic stripe, widely used in plastic credit cards and bank access cards, and (b) magnetic ink character recognition, widely used in the banking industry for check processing.

4**.** ***Smart card***. This term refers to small plastic cards (the size of a credit card) imbedded with microchips capable of containing large amounts of information. Other terms used for this technology include *chip card* and *integrated circuit card*.

5. ***Touch techniques***. These include touch screens and button memory.

6. ***Biometric***. These technologies are utilized to identify humans or to interpret vocal commands of humans. They include voice recognition, fingerprint analysis, and retinal eye scans.

4.b BAR CODE TECHNOLOGY

Bar codes divide into two basic types: (1) linear, in which the encoded data are read using a linear sweep of the scanner, and (2) two-dimensional, in which the encoded data must be read in both directions.

(a) (b)

Figure 12.1 Two forms of linear bar codes are (a) width-modulated, exemplified here by the Universal Product Code, and (b) height-modulated, exemplified here by Postnet, used by the U.S. Postal Service.

Linear (One-Dimensional) Bar Codes

Linear bar codes are the most widely used automatic identification and data capture technique. There are actually two forms of linear bar code symbologies, illustrated in Figure 12.1: (a) width-modulated, in which the symbol consists of bars and spaces of varying width; and (b) height-modulated, in which the symbol consists of evenly spaced bars of varying height. The only significant application of the height-modulated bar code symbologies is in the U.S. Postal Service for ZIP code identification, so the discussion here focuses on the width-modulated bar codes, which are used widely in retailing and manufacturing.

In linear width-modulated bar code technology, the symbol consists of a sequence of wide and narrow colored bars separated by wide and narrow spaces (the colored bars are usually black and the spaces are white for high contrast). The pattern of bars and spaces is coded to represent numeric or alphanumeric character.

Bar code readers interpret the code by scanning and decoding the sequence of bars. The reader consists of the scanner and decoder. The scanner emits a beam of light that is swept past the bar code (either manually or automatically) and senses light reflections to distinguish between the bars and spaces. The light reflections are sensed by a photo detector, which converts the spaces into an electrical signal and the bars into absence of an electrical signal. The width of the bars and spaces is indicated by the duration of the corresponding signals.

The Bar Code Symbol. The bar code standard adopted by the automotive industry, the Department of Defense, the General Services Administration, and many other manufacturing industries is Code 39, also known as AIM USD–2 (Automatic Identification Manufacturers Uniform Symbol Description-2). Code 39 uses a series of wide and narrow elements (bars and spaces) to represent alphanumeric and other characters. The wide elements are equivalent to a binary value of one and the narrow elements are equal to zero. The width of the wide bars and spaces is between two and three times the width of the narrow bars and spaces. Whatever the wide-to-narrow ratio, the width must be uniform throughout the code for the reader to be able to consistently interpret the resulting pulse train. Figure 12.4 presents the character structure for USD–2.

The reason for the name Code 39 is that nine elements (bars and spaces) are used in each character and three of the elements are wide. The placement of the wide spaces and bars in the code uniquely designates the character. Each code begins and ends with either a wide or narrow bar. The code is sometimes referred to as code three-of-nine. In addition to the character set in the bar code, there must also be a so-called "quiet-zone" both preceding and following the bar code, in which there is no printing that might confuse the decoder.

Bar Code Readers. Bar code readers come in a variety of configurations; some require a human to operate them and others are stand-alone automatic units. They are usually classified as contact or noncontact readers.

Contact bar code readers are handheld wands or light pens operated by moving the tip of the wand quickly past the bar code on the object or document. The wand tip must be in contact with the bar code surface or in very close proximity during the reading procedure. In a factory data collection application, they are usually part of a keyboard entry terminal. The terminal is sometimes referred to as a stationary terminal in the sense that it is placed in a fixed location in the shop. When a transaction is entered in the factory, the data are usually communicated to the computer system immediately. In addition to their use in factory data collection systems, stationary contact bar code readers are widely used in retail stores to enter the item in a sales transaction.

Noncontact bar code readers focus a light beam on the bar code, and a photo-detector reads the reflected signal to interpret the code. The reader probe is located a certain distance from the bar code (several inches to several feet) during the read procedure. Noncontact readers are classified as fixed beam and moving beam scanners. Fixed beam readers are stationary units that use a fixed beam of light. They are usually mounted beside a conveyor and depend on the movement of the bar code past the light beam for their operation. Applications of fixed beam bar code readers are typically in warehousing and material handling operations where large quantities of materials must be identified as they flow past the scanner on conveyors.

Char.	Bar pattern	9 bits	Char.	Bar pattern	9 bits
1		100100001	K		100000011
2		001100001	L		001000011
3		101100000	M		101000010
4		000110001	N		000010011
5		100110000	O		100010010
6		001110000	P		001010010
7		000100101	Q		000000111
8		100100100	R		100000110
9		001100100	S		001000110
0		000110100	T		000010110
A		100001001	U		110000001
B		001001001	V		011000001
C		101001000	W		111000000
D		000011001	X		010010001
E		100011000	Y		110010000
F		001011000	Z		011010000
G		000001101	-		010000101
H		100001100	.		110000100
I		001001100	space		011000100
J		000011100	*		010010100

*Denotes a start/stop code that must be placed at the beginning and end of every bar code message.

Moving beam scanners use a highly focused beam of light, often a laser, actuated by a rotating mirror to traverse an angular sweep in search of the bar code on the object. A scan is defined as a single sweep of the light beam through the angular path. The high rotational speed of the mirror allows for very high scan rates—up to 1,440 scans/sec. This means that many scans of a single bar code can be made during a typical reading procedure, thus permitting verification of the reading. Moving beam scanners can be either stationary or portable units. Stationary scanners are located in a fixed position to read bar codes on objects as they move past on a conveyor or other material handling equipment. They are used in warehouses and distribution centers to automate the product identification and sortation operations. A typical setup using a stationary scanner is illustrated in Figure 12.5. Portable scanners are handheld devices that the user points at the bar code like a pistol. The vast majority of bar code scanners used in factories and warehouses are of this type.

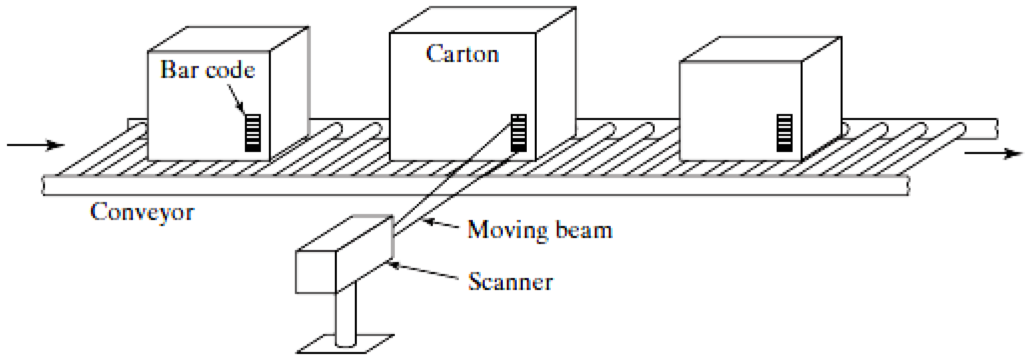


Figure 12.5 Stationary moving beam bar code scanner located along a moving conveyor.

Bar Code Printers. In many bar code applications, the labels are printed in medium-to-large quantities for product packages and the cartons used to ship the packaged products. These preprinted bar codes are usually produced off-site by companies specializing in these operations. The labels are printed in either identical or sequenced symbols. Printing technologies include traditional techniques such as letterpress, offset lithography, and flexographic printing. Bar codes can also be printed on-site by methods in which the process is controlled by microprocessor to achieve individualized printing of the bar coded document or item label. These applications tend to require multiple printers distributed at locations where they are needed. The printing technologies used in these applications include ink-jet, laser printing, and laser etching.

Two-Dimensional Bar Codes

Two-dimensional symbologies divide into two basic types: (1) stacked bar codes and (2) matrix symbologies.

Stacked Bar Codes. The first 2-D bar code to be introduced was a stacked symbology. It was developed in an effort to reduce the area required for a conventional bar code. But its real advantage is that it can contain significantly greater amounts of data. A stacked bar code consists of multiple rows of conventional linear bar codes stacked on top of each other. Several stacking schemes have been devised over the years, nearly all of which allow for multiple rows and variations in the numbers of encoded characters possible.

Matrix Symbologies. A matrix symbology consists of 2-D patterns of data cells that are usually square and are colored dark (usually black) or white. The 2-D matrix symbologies were introduced around 1990. Their advantage over stacked bar codes is their capability to contain more data. They also have the potential for higher data densities—up to 30 times more dense than Code 39. Their disadvantage compared to stacked bar codes is that they are more complicated, which requires more sophisticated printing and reading equipment.

Figure 12.6 A 2-D stacked bar code. Shown is an example of a PDF417 symbol.

Figure 12.7 A 2-D matrix bar code. Shown is an example of the Data Matrix symbol.

5.a A robot is a reprogrammable multi functional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of variety of tasks.

Four common robot configurations

1. Polar configuration
2. Cylindrical Configuration
3. Cartesian Configuration
4. Jointed Arm configuration

5. SCARA

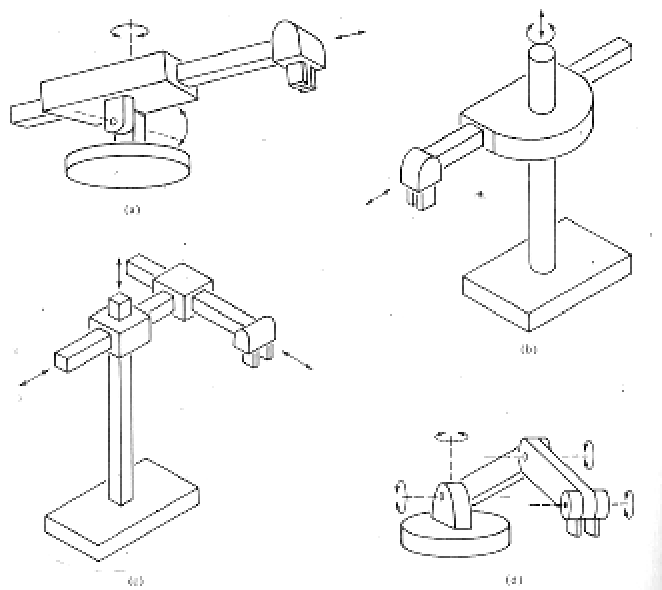


Figure 2-1 The four basic robot anatomies: (a) polar, (b) cylindrical, (c) cartesian, and (d) jointed-arm. (Reprinted from Reference [7].)

1. Polar configuration/Spherical configuration

Notation: [**LTR**]: Linear, Twisting and Rotational joint

This configuration also called as Polar coordinate configuration. It goes by the name “spherical coordinate” also because the workspace within which it can move its arm is a partial sphere as shown in figure. The robot has a rotary base and a pivot that can be used to raise and lower a telescoping arm.

i) Operate within a **spherical** work volume
ii) Has 1 prismatic and 2 revolute axes.
iii) First motion is a base rotation, Second motion correspond to an elbow rotation and Third motion is radial or in-out motion
iv) Elbow rotation and arm reach limit the design of full spherical motion.
v) Rarely used in industries but common in automated cranes.

2. Cylindrical Configuration

Notation: [**TLL**]: Twisting, Linear and Linear.

This also has 3 degrees of freedom, 2 prismatic and 1 revolute joints. It moves linearly along X and Y axes and rotaion about at its base i.e. Z- axis. The robot body is a vertical column that swivels about a vertical axis. The arm consists of several orthogonal slides which allow the arm to be moved up or down and in and out with respect to the body. This is illustrated schematically in figure.

Features:

- i) Operate within a **cylindrical** work volume
- ii) 2 prismatic and 1 revolute joints.
- iii) Position is specified by Y value (height) extension of arm X axis and angle of rotation of Z axis (θ)
- iv) Recommended for pick and place operation such as machine loading and unloading.
- v) Lower repeatability and accuracy
- vi) Require more sophisticated control
- vii) Rigid structure & high lift-carrying capacity

3. Cartesian / Rectangular configuration

Notation: [**LOO**]: Linear, Orthogonal, Orthogonal

Cartesian configuration is also called as **Rectilinear or Rectangular** configuration as the joints allow only translational or linear relative motion between the adjacent links of the joint. A robot using such a configuration is called as X-Y-Z robot. Other names are xyz robot or Rectilinear robot or **Gantry robot**. Any point in X, Y and Z coordinate system can be reached using this configuration. By appropriate movements of these slides, the robot is capable of moving its arm at any point within its three dimensional rectangular spaced work space.

Features:

- i) Operate within a **rectangular** work volume
- ii) Three prismatic joints are used.
- iii) The position is specified by X, Y and Z locations.
- iv) Easy to visualize motion
- v) Easy to program the motions
- vi) Adapted in gantry crane and CNC milling machines.
- vii) Gantry type can handle heavy loads.
- viii) Addition axes can be incorporated to the wrist action.
- ix) Difficult to protect the sliding axes from contaminants such as dust and moisture as it is open.

4. Revolute / Articulate / Jointed-arm configuration:

Notation: [**TRR**]: Twisting, Rotational and Rotational joint

It is combination of cylindrical and articulated configurations. This is similar in appearance to the human arm, as shown in fig. the arm consists of several straight members connected by joints which are analogous to the human shoulder, elbow, and wrist. The robot arm is mounted to a base which can be rotated to provide the robot with the capacity to work within a quasi-spherical space.

Features:

i) Operate within a **quasi-spherical** work volume.
ii) All 3 are revolute joints.
iii) Can reach above, below and around obstacles.
iv) Joints can be sealed easily.
v) Difficult to calculate angular motion of the axis for a given top or end motion.

5. SCARA (Selective Compliance Assembly Robot Arm)

Notation: [**VRL**]: Revolving, Rotational and Linear joint

This configuration consists of 1 prismatic and 2 revolute joint. The important features being the relative motion of all the links at the joints are about vertical axes.

SCARA stands for Selective Compliance Assembly Robot Arm. This joint is similar to jointed-arm robot except that vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction for vertical insertion tasks.

Features:

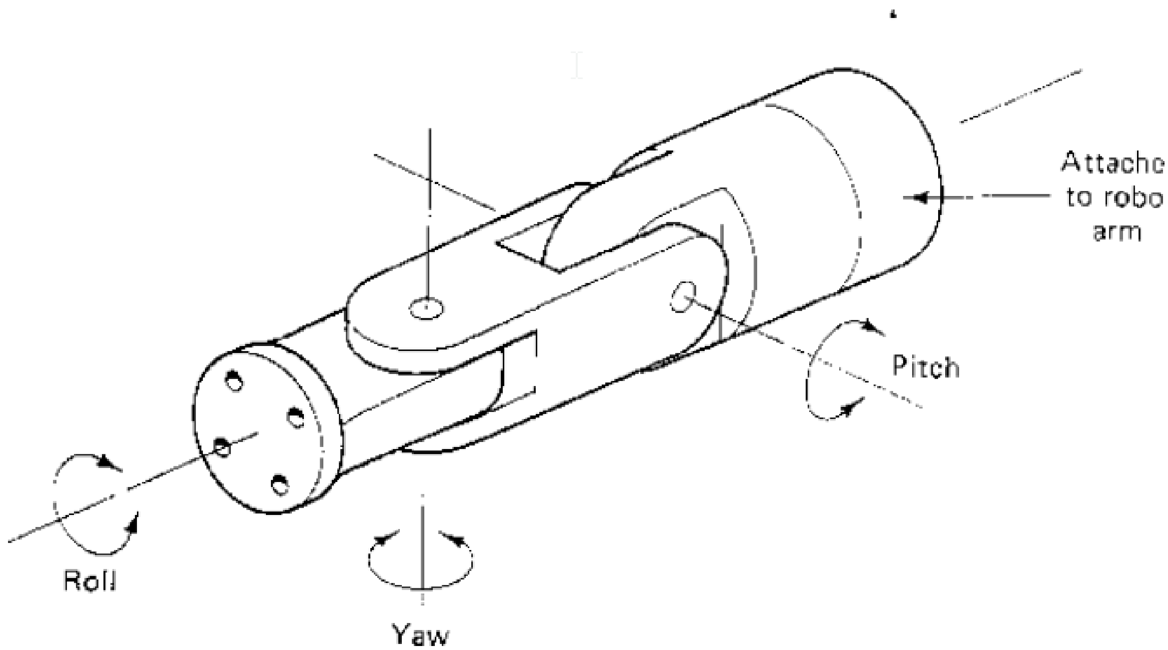
i) Work volume is **cylindrical** in nature
ii) Most common in assembly robot
iii) Arm consists of two horizontal revolute joints at the wrist and elbow and a one prismatic joint
iv) Can reach at any point within horizontal planar defined by two concentric circles
v) Most assembly operations involve building up assembly by placing parts on top of a partially complete assembly
vi) Floor area is small compare to work area
vii) Rectilinear motion requires complex control of the revolute joints

5.b Typically has 3 degrees of freedom

Roll involves rotating the wrist about the arm axis

Pitch up-down rotation of the wrist

Yaw left-right rotation of the wrist



5.c

Robots are used in a wide field of applications in industry. Most of the current applications are in manufacturing. The applications can usually be classified into one of the following categories: (1) material handling, (2) processing operations, and (3) assembly and inspection.

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. 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 **Material Transfer.** 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. 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.

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 for a robot palletizing operation into the work cell in this position and orientation. 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. Industrial robot applications of machine loading and/or unloading include the following processes:

• *Die casting.* The robot unloads parts from the die casting machine. Peripheral operations sometimes performed by the robot include dipping the parts into a water bath for cooling.

• *Plastic molding.* Plastic molding is similar to die casting. The robot unloads molded parts from the injection molding machine.

• *Metal machining operations.* The robot loads raw blanks into the machine tool and unloads finished parts from the machine. The change in shape and size of the part before and after machining often presents a problem in end effector design, and dual grippers (Section 8.3.1) are often used to deal with this issue.

• *Forging.* The robot typically loads the raw hot billet into the die, holds it during the forging strikes, and removes it from the forge hammer. The hammering action and the risk of damage to the die or end effector are significant technical problems.

• *Pressworking.* Human operators work at considerable risk in sheetmetal pressworking operations because of the action of the press. Robots are used to substitute for the workers to reduce the danger. In these applications, the robot loads the blank into the press, then the stamping operation is performed, and the part falls out of the machine into a container.

• *Heat-treating.* These are often relatively simple operations in which the robot loads and/or unloads parts from a furnace.

Processing Operations

In processing applications, the robot performs some operation on a work part, such as grinding or spray painting.

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 use of industrial robots in this application has dramatically improved the consistency of the welds.

Robots used for spot welding are usually large, with sufficient payload capacity to wield the heavy welding gun. Five or six axes are generally required to achieve the required position and orientation of the welding gun. Playback robots with point-to-point control are used. Jointed-arm robots are the most common type in automobile spot-welding lines, which may consist of several dozen 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. The robot used in arc welding must be capable of continuous path control. Jointed arm robots consisting of six joints are frequently used. Some robot vendors provide manipulators that have hollow upper arms, so that the cables connected to the welding torch can be contained in the arm for protection, rather than attached to the exterior. Also, programming improvements for arc welding based on CAD/CAM have made it much easier and faster to implement a robot welding cell.

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.

Assembly and Inspection

In some respects, assembly and inspection are hybrids of the previous two categories: material handling and processing. Assembly and inspection can involve either the handling of materials or the manipulation of a tool.

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). 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.

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.

6.a. **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. In the worst case, the desired point would lie in the middle between two adjacent control increments.

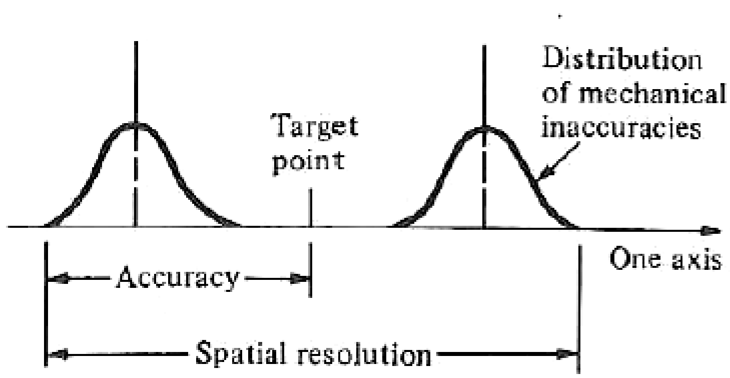


Fig: Illustration of accuracy and spatial resolution in which mechanical inaccuracies are represented by a spatial resolution.

First, the accuracy varies within the work volume, tending to be worse when the arm is in the outer range of its work volume and better when the arm is closer to its base. The reason for this is that the mechanical inaccuracies are magnified with the robot's arm fully extended. The term error map is used to characterize the level of accuracy possessed by the robot as a function of location in the work volume.

Second, the accuracy is improved if the motion cycle is restricted to a limited work range. The mechanical errors will tend to be reduced when the robot is exercised through a restricted range of motions. The robot's ability to reach a particular reference point within the limited work space is sometimes called its local accuracy. When the accuracy is assessed within the robot's full work volume, the term global accuracy is used.

A third factor influencing accuracy is the load being carried by the robot. Heavier workloads cause greater deflection of the mechanical links of the robot, resulting in lower accuracy.

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 that had previously been taught to the robot. Repeatability and accuracy has 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.

6.b
Dynamic stability is a measure of the ability of a robot to maintain its balance while in motion. A robot with two or three legs, or that rolls on two wheels, can have excellent stability while it is moving, but when it comes to rest, it is unstable.
Dynamic Stability
Statically stable walking is very energy inefficient • As an alternative, dynamic stability enables a robot to stay up while moving • This requires active control (i.e., the inverse pendulum problem) • Dynamic stability can allow for greater speed, but requires harder control

6.c
Asimov proposed three "Laws of Robotics"

Law 1: A robot may not injure a human being or through inaction, allow a human being to come to harm.

Law 2: A robot must obey orders given to it by human beings, except where such orders would conflict with the first law.

Law 3: A robot must protect its own existence

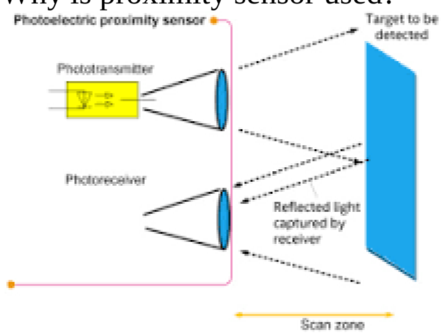
7.a Servo motors are used for robotic applications that require precision positioning. Before diving too deeply into the ways servos are used in robotics, it's helpful to first learn about the basic function and form of these critical components of motion control.

1. The servo receives a signal from a motion controller.
2. Depending on the pulse width modulation (PWM) of the input signal, the servo will rotate a certain amount. At rest, the output spline of a servo is usually at 0°. Based on an expected pulse frequency of 20 milliseconds (ms), a pulse width of 1.5ms will make the output spline rotate 90° in one direction. A pulse width of 2ms will make the output spline continue rotating 90° further to the 180° position. A pulse width of 1ms will make the output spline rotate 180° backward to the 0° starting position.
3. The potentiometer constantly monitors the position of the output spline. When the output spline reaches the desired position, the power to the motor is cut and the servo will hold that position until it receives a signal not to. While stopped in a given position, a servo motor will actively try to hold that position.

4. A key feature of servos is proportional operation. A servo motor will operate only as fast as it needs in order to rotate from its current position to its desired position. If a servo is stopped at the 180° position but needs to be at the 0° position, the motor will rotate very quickly to get there. If stopped at a position that is already closer to 0°, the motor will rotate much more slowly to get there.

Servo motors provide numerous benefits in robotic applications. They are small, powerful, easily programmable, and accurate. Most importantly, though, they allow for near perfect repeatability of motion. They are used in robotic applications such as:
Robotic Welding: Servo motors are mounted in every joint of a robotic welding arm, actuating movement and adding dexterity.
Robotic Vehicles: Servos are used in the steering systems of the autonomous vehicles used to disarm and dispose of bombs.

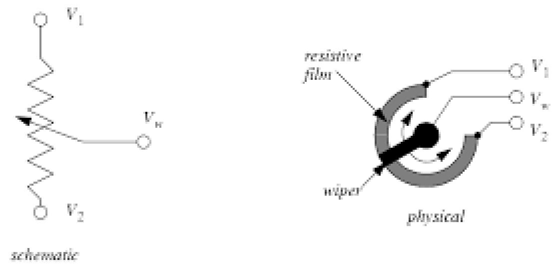
7.b. Tactile sensors have been developed for use with robots. Tactile sensors can complement visual systems by providing added information when the robot begins to grip an object. At this time vision is no longer sufficient, as the mechanical properties of the object cannot be determined by vision alone.
A tactile sensor is a device. It **measures the coming information in response to the physical interaction with the environment**. The sense of touch in humans is generally modeled, i.e. cutaneous sense and the kinesthetic sense.
Proximity sensing is the ability of a robot to tell when it is near an object, or when something is near it. This sense keeps a robot from running into things. It can also be used to measure the distance from a robot to some object.
Why is proximity sensor used?



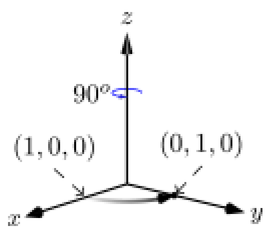
A proximity sensor is a device that can detect or sense the approach or presence of nearby objects and for this it does not need physical contact. There are different kinds of proximity sensors. Some of them are listed. This type of sensor is used to detect nearby metallic objects.

7.c Potentiometers are analog devices whose output voltage is proportional to the position of wiper.
Potentiometers offer a low cost method of contact displacement measurement.
Depending upon their design, they may be used to measure either rotary or linear motion.
In either case, a movable slide or wiper is in contact with a resistive material or wire winding.
The slide is attached to the target object in motion.
 A DC or an AC voltage is applied to the resistive material.

- When the slide moves relative to the material, the output voltage varies linearly with the total resistance included within the span of the slide.
- An advantage of potentiometers is that they can be used is applications with a large travel requirement.
- It is possible to use pots to provide a limited amount of feedback control in robots where high proportional resolution and accuracy are not required.



8.a Equivalently, we may think of points in space as three-dimensional column vectors: $x\ y\ z^T$. This view is convenient because certain spatial transformations may be accomplished through matrix operations. In particular, any rotation can be encoded as a 3 × 3 rotation matrix. Pre-multiplying the matrix by a point will have the effect of performing the desired rotation around the origin. The following three matrices correspond to rotations around the x, y, z axes respectively: Figure 11 shows the example of rotating the point $1\ 0\ 0^T$ by 90^o around the z-axis. It is possible to represent any orienation as a product of three rotation matrices around the x, y and z axes. It is straightforward to convert from an Euler angle representation to the corresponding rotation matrix. For static rotations, the three elementary rotation matrices must be multiplied in the order that the rotations should be applied. This means that the rotation matrix that corresponds to the Euler angle rotations illustrated in Figure 8 would be: $R_{static} = R_x(45^o) \times R_y(30^o) \times R_z(75^o)$ For Euler angles represented using relative rotations, the order is reversed. The rotation matrix corresponding to Figure 9 would be: $R_{relative} = R_z(75^o) \times R_y(30^o) \times R_x(45^o)$ The main advantage of rotation matrices is that they provide a convenient mechasism for composing rotations and for applying rotations to a point. The downside is that this is a highly redundant represenatation. A 3 × 3 rotation matrix contains 9 values.



$$R_z(90^o) \times \begin{bmatrix}1\\0\\0\end{bmatrix} = \begin{bmatrix}\cos 90^o & -\sin 90^o & 0\\ \sin 90^o & \cos 90^o & 0\\ 0 & 0 & 1\end{bmatrix} \times \begin{bmatrix}1\\0\\0\end{bmatrix}$$
$$= \begin{bmatrix}0 & -1 & 0\\ 1 & 0 & 0\\ 0 & 0 & 1\end{bmatrix} \times \begin{bmatrix}1\\0\\0\end{bmatrix}$$
$$= \begin{bmatrix}0\\1\\0\end{bmatrix}$$

Figure 11: Example rotation

$$R_x(\Theta) = \begin{bmatrix}1 & 0 & 0\\ 0 & \cos\Theta & -\sin\Theta\\ 0 & \sin\Theta & \cos\Theta\end{bmatrix} \tag{5}$$

$$R_y(\Theta) = \begin{bmatrix}\cos\Theta & 0 & \sin\Theta\\ 0 & 1 & 0\\ -\sin\Theta & 0 & \cos\Theta\end{bmatrix} \tag{6}$$

$$R_z(\Theta) = \begin{bmatrix}\cos\Theta & -\sin\Theta & 0\\ \sin\Theta & \cos\Theta & 0\\ 0 & 0 & 1\end{bmatrix} \tag{7}$$

8.b.

A camera is attached to the hand frame T_H of a robot as given. The corresponding inverse Jacobian of the robot at this location is also shown. The robot makes a differential motion described as $D = [0.05 \quad 0 \quad -0.1 \quad 0 \quad 0.1 \quad 0.03]^T$.

(a) Find which joints must make a differential motion, and by how much, in order to create the indicated differential motions.
(b) Find the change in the Hand frame.
(c) Find the new location of the camera after the differential motion.
(d) Find how much the differential motions should have been instead, if measured relative to Frame T_H, to move the robot to the same new location as in part (c).

$$T_H = \begin{bmatrix} 0 & 1 & 0 & 3 \\ 1 & 0 & 0 & 2 \\ 0 & 0 & -1 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad J^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & -1 & 0 & 0 & 0 \\ 0 & -0.2 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Solution: Substituting the values into the corresponding equations, we get:

(a) $$D_\theta = J^{-1} \cdot D = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & -1 & 0 & 0 & 0 \\ 0 & -0.2 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0.05 \\ 0 \\ -0.1 \\ 0 \\ 0.1 \\ 0.03 \end{bmatrix} = \begin{bmatrix} 0.05 \\ 0.2 \\ 0 \\ 0.1 \\ 0 \\ 0.08 \end{bmatrix}$$

From this, we can tell that joints 1, 2, 4, and 6 need to move as shown.

(b) The change in the hand frame is:

$$dT = \Delta \cdot T = \begin{bmatrix} 0 & -0.03 & 0.1 & 0.05 \\ 0.03 & 0 & 0 & 0 \\ -0.1 & 0 & 0 & -0.1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} 0 & 1 & 0 & 3 \\ 1 & 0 & 0 & 2 \\ 0 & 0 & -1 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} -0.03 & 0 & -0.1 & 0.79 \\ 0 & 0.03 & 0 & 0.09 \\ 0 & -0.1 & 0 & -0.4 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

(c) The new location of the camera is:

$$T_{new} = T_{old} + dT = \begin{bmatrix} 0 & 1 & 0 & 3 \\ 1 & 0 & 0 & 2 \\ 0 & 0 & -1 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix} + \begin{bmatrix} -0.03 & 0 & -0.1 & 0.79 \\ 0 & 0.03 & 0 & 0.09 \\ 0 & -0.1 & 0 & -0.4 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} -0.03 & 1 & -0.1 & 3.79 \\ 1 & 0.03 & 0 & 2.09 \\ 0 & -0.1 & -1 & 7.6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(d) ${}^{T}\Delta = T^{-1} \cdot \Delta \cdot T = T^{-1} \cdot dT$

$${}^{T}\Delta = \begin{bmatrix} 0 & 1 & 0 & -2 \\ 1 & 0 & 0 & -3 \\ 0 & 0 & -1 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} -0.03 & 0 & -0.1 & 0.79 \\ 0 & 0.03 & 0 & 0.09 \\ 0 & -0.1 & 0 & -0.4 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 0.03 & 0 & 0.09 \\ -0.03 & 0 & -0.1 & 0.79 \\ 0 & 0.1 & 0 & 0.4 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

and therefore, the differential motions relative to the frame will be:

TD ¼ ½ 0:09 0:79 0:4 0:1 0 0:03 T

9.a i)Object-oriented programming (OOP) is a computer programming model that organizes software design around data, or objects, rather than functions and logic. An object can be defined as a data field that has unique attributes and behavior.

OOP focuses on the objects that developers want to manipulate rather than the logic required to manipulate them. This approach to programming is well-suited for programs that are large, complex and actively updated or maintained. This includes programs for manufacturing and design, as well as mobile applications; for example, OOP can be used for manufacturing system simulation software.

The organization of an object-oriented program also makes the method beneficial to collaborative development, where projects are divided into groups. Additional benefits of OOP include code reusability, scalability and efficiency.

The first step in OOP is to collect all of the objects a programmer wants to manipulate and identify how they relate to each other -- an exercise known as data modeling.

Examples of an object can range from physical entities, such as a human being who is described by properties like name and address, to small computer programs, such as widgets.

Once an object is known, it is labeled with a class of objects that defines the kind of data it contains and any logic sequences that can manipulate it. Each distinct logic sequence is known as a method. Objects can communicate with well-defined interfaces called messages.

What is the structure of object-oriented programming?

The structure, or building blocks, of object-oriented programming include the following:

- **Classes** are user-defined data types that act as the blueprint for individual objects, attributes and methods.
- **Objects** are instances of a class created with specifically defined data. Objects can correspond to real-world objects or an abstract entity. When class is defined initially, the description is the only object that is defined.
- **Methods** are functions that are defined inside a class that describe the behaviors of an object. Each method contained in class definitions starts with a reference to an instance object. Additionally, the subroutines contained in an object are called instance methods. Programmers use methods for reusability or keeping functionality encapsulated inside one object at a time.
- **Attributes** are defined in the class template and represent the state of an object. Objects will have data stored in the attributes field. Class attributes belong to the class itself.

ii) The lead through method involves programming industrial robots through demonstration. This method is also referred to as hand guidance programming or the walk-through method. During programming a robot operator will physically move the robotic manipulator through the waypoints of a desired task. Some industrial robots have a joystick attached to their wrist above the EOAT which can also be used to move the robotic manipulator for lead through programming.

This programming method is best for robotic applications involving a continuous path such as welding automation or painting. Lead through programming has declined in use when it comes to traditional industrial robots. The size and weight of the robotic manipulators makes it difficult for robot operators to physically move them through an application path. However, lead through programming has started to make a comeback as many collaborative robots have incorporated the method as their main programming source. The lighter weight and smaller size of cobots makes it easier for operators to physically manipulate the robot arm. FANUC's Cr-15ia is a cobot featuring hand guidance programming. Universal’s cobots also feature this programming method, including their Universal UR10.

9.b REQUIREMENTS OF A ROBOT PROGRAMMING LANGUAGE

World modeling

Manipulation programs must, by definition, involve moving objects in three-dimensional space, so it is clear that any robot programming language needs a means of describing such actions. The most common element of robot programming languages is the existence of special geometric types. For example, types are introduced to represent joint-angle sets, Cartesian positions, orientations, and frames. Predefined operators that can manipulate these types often are available. The "standard frames" introduced in Chapter 3 might serve as a possible model of the world: All motions are described as tool frame relative to station frame, with goal frames being constructed from arbitrary expressions involving geometric types.

Given a robot programming environment that supports geometric types, the robot and other machines, parts, and fixtures can be modeled by defining named variables associated with each object of interest. Figure 12.3 shows part of our example workcell with frames attached in task-relevant locations. Each of these frames would be represented with a variable of type "frame" in the robot program.

In many robot progranmiing languages, this ability to define named variables of various geometric types and refer to them in the program forms the basis of the world model. Note that the physical shapes of the objects are not part of such a world model, and neither are surfaces, volumes, masses, or other properties. The extent to which objects in the world are modeled is one of the basic design decisions made when designing a robot programming system. Most present-day systems support only the style just described.

Some world-modeling systems allow the notion of a flixments between named objects [3] —that is, the system can be notified that two or more named objects have become "affixed"; from then on, if one object is explicitly moved with a language statement, any objects affixed to it are moved with it. Thus, in our application, once the pin has been inserted into the hole in the bracket, the system would be notified (via a language statement) that these two objects have become affixed. Subsequent motions of the bracket (that is, changes to the value of the frame variable "bracket") would cause the value stored for variable "pin" to be updated along with it. Ideally, a world-modeling system would include much more information about the objects with which the manipulator has to deal and about the manipulator itself. For example, consider a system in which objects are described by CAD-style models that represent the spatial shape of an object by giving definitions of its edges, surfaces, or volume.

10. a.

```
<?xml version="1.0" encoding="gb2312" ?>
<start>
      <pallet>// pallet information
            <length>1.3</length><width>1.1</width><high>10</high><tag>0</tag>
      </pallet>
      <cargoinfo>//cargo infomation
            <length>0.5</length><width>0.3</width><high>0.25</high><tag>001</tag>
                <weight>5</weight>
      </cargoinfo>
      <type>//pattern information
            <totallayer>3</totallayer>//layer number
            <parity>1</parity>// parity
      </type>
      <floor id="0">//even layer
            <num>9</num>//the total number of production of one layer
            <cargo id="0">//No. 0 production
                  <node id="0"><x>0</x><y>0</y><z>0</z></node><angle>0</angle>
            </cargo>
        <cargo id="1">//No. 1 produciton
                <neigh><index>0</index><bian>32</bian><dian id="0">0</dian></neigh>
                <angle>0</angle>
        </cargo>
......
      </floor>
     </start>
```

10.b. CENTRAL ISSUES IN OLP SYSTEMS

1 User interface

• A major motivation for developing an OLP system is to create an environment that makes programming manipulators easier.

• However, another major motivation is to remove reliance on use of the physical equipment during programming.

• Manufacturers of industrial robots have learned that the RPLs they provide with their robots cannot be utilized successfully by a large percentage of manufacturing personnel. • For this reasons, many industrial robots are provided with a two-level interface, one for programmers and one for nonprogrammers.

• Nonprogrammers utilize a teach pendant and interact directly with the robot to develop robot programs.

• Programmers write code in the RPL and interact with the robot in order to teach robot work points and to debug program flow.

• For use as an RPL, interactive languages are much more productive than compiled languages.

• A well-designed user interface should enable nonprogrammers to accomplish many applications from start to finish.

2. 3-D modeling

• A central element in OLP systems is the use of graphic depictions of the simulated robot and its work cell.

• This requires the robot and all fixtures, parts, and tools in the work cell to be modeled as three-dimensional objects

• To speed up program development, it is desirable to use any CAD models of parts or tooling that are directly available from the CAD system on which the original design was done.

• If an OLP system is to be a stand-alone system, it must have appropriate interfaces to transfer models to and from external CAD systems.

• An important use of the three-dimensional geometry of the object models is in automatic collision detection, example in assembly

3. Kinematic emulation

• A central component in maintaining the validity of the simulated world is the faithful emulation of the geometrical aspects of each simulated manipulator.

• With regard to inverse kinematics, the OLP system can interface to the robot controller in two distinct ways.

• First, the OLP system could replace the inverse kinematics of the robot controller and always communicate robot positions in mechanism joint space.

• The second choice is to communicate Cartesian locations to the robot controller and let the controller use the inverse kinematics supplied by the manufacturer to solve for robot configurations.

• The simulator must use the same algorithm as the controller in order to avoid potentially catastrophic errors in simulating the actual manipulator

4 Path-planning emulation

• In addition to kinematic emulation for static positioning of the manipulator, an OLP system should accurately emulate the path taken by the manipulator in moving through space.

• Again, the central problem is that the OLP system needs to simulate the algorithms in the employed robot controller, and such path planning and -execution algorithms vary considerably from one robot manufacturer to another.

• When a robot is operating in a moving environment (e.g., near another robot), accurate simulation of the temporal attributes of motion is necessary to predict collisions accurately

5. Dynamic emulation

• Simulated motion of manipulators can neglect dynamic attributes if the OLP system does a good job of emulating the trajectory-planning algorithm of the controller and if the actual robot follows desired trajectories with negligible errors.

• However, at high speed or under heavy loading conditions, trajectory tracking errors can become important. • Simulation of these tracking errors necessitates both modeling the dynamics of the manipulator and of the objects that it moves and emulating the control algorithm used in the manipulator controller.

• Currently, practical problems exist in obtaining sufficient information from the robot vendors to make this kind of dynamic simulation of practical value, but, in some cases, dynamic simulation can be pursued fruitfully.

6. Multi process simulation

• Some industrial applications involve two or more robots cooperating in the same environment.

• Even single-robot workcells often contain a conveyor belt, a transfer line, a vision system, or some other active device with which the robot must interact.

• For this reason, it is important that an OLP system be able to simulate multiple moving devices and other activities that involve parallelism.

• Adding signal and wait primitives to the language enables the robots to interact with each other just as they might in the application being simulated.

7. Simulation of sensors

• Studies have shown that a large component of robot programs consists not of motion statements, but rather of initialization, error-checking, I/O, and other kinds of statements.

• Hence, the ability of the OLP system to provide an environment that allows simulation of complete applications, including interaction with sensors, various I/O, and communication with other devices, becomes important.

• An OLP system that supports simulation of sensors and multiprocessing not only can check robot motions for feasibility, but also can verify the communication and synchronization portion of the robot program.

8. Language translation to target system

• If an OLP system aspires to be universal in the equipment it can handle, it must deal with the problem of translating to and from several different languages. • One choice for dealing with this problem is to choose a single language to be used by the OLP system and then postprocess the language in order to convert it into the format required by the target machine.

• An ability to upload programs that already exist on the target machines and bring them into the OLP system is also desirable.

• Two potential benefits of OLP systems relate directly to the language translation topic.

• Having single, universal interface, one that enables users to program a variety of robots, solves the problem of learning and dealing with several automation languages.

• A second benefit stems from economic considerations in future scenarios in which hundreds or perhaps thousands of robots fill factories.

9. Workcell calibration

• In order to make programs developed on an OLP system usable, methods for workcell calibration must be an integral part of the system. • The magnitude of this problem varies greatly with the application; this variability makes off-line programming of some tasks much more feasible that of others.

• If the majority of the robot work points for an application must be retaught with the actual robot to solve inaccuracy problems, OLP systems lose their effectiveness.

• Many applications involve the frequent performance of actions relative to a rigid object.

• for example, PC-board component insertion, routing, spot welding, arc welding, palletizing, painting, and deburring.