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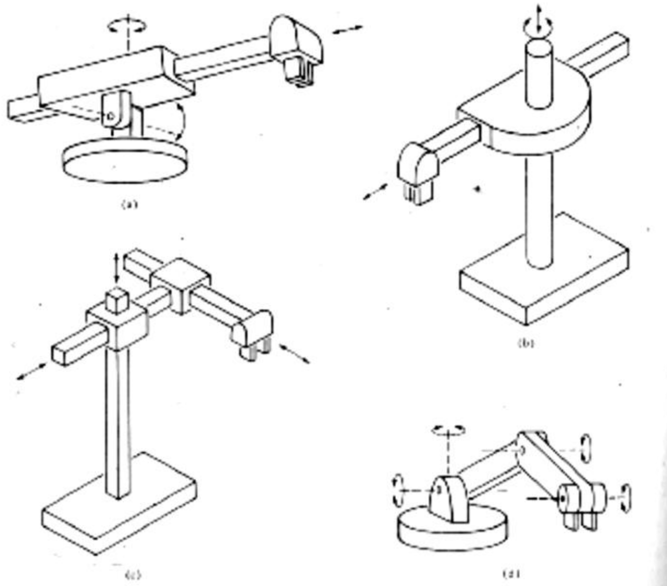
Internal Assessment Test 2 – Oct. 2019

Sub:	Automation & Robotics					Sub Code:	17ME563	Branch: Mech
Date:	15.10.19	Duration:	90 min's	Max Marks:	50	Sem / Sec:	V/A&B	OBE

	Answer **ALL** the Questions	MARKS	CO	RBT
1	Briefly describe the various robot configurations with a neat sketch.	[10]	CO3	L1
	(Or)			
	Write short notes on i) Robot sensors	[5]	CO3	L1
	ii) Industrial applications of Robots	[5]		
2	Using a block diagram, explain the various types of controllers used in robotics.	[10]	CO3	L1
	(Or)			
	Derive an expression for transformation through pure rotation. A point $(7,3,1)^T$ attached to F_{noa} is subjected to the following transformations. Find the coordinates of the point relative to the reference frame at the conclusion of the transformations. i) Rotation of 90° about Z axis ii) Followed by rotation of 90° about y axis iii) Followed by a translation of (4,-3,7).	[10]	CO4	L2
3	Briefly describe the various end effectors used in robots.	[10]	CO3	L1
	(Or)			
	Describe the procedure for link-frame attachment with an example as per Denavit-Hartenberg notations.	[10]	CO4	L1
4.	Describe the following terms with neat sketch i) Link length ii) Link twist	[10]	CO4	L1
	(Or)			
	Briefly describe the various parameters to be considered for specifying link connection description.	[10]	CO4	L1
5.	Explain the various types of joints used in robots with neat sketches	[10]	CO3	L1
	(Or)			
	Write short notes on i) Actuator space, Joint Space and Cartesian Space	[5]	CO4	L1
	ii) Completely specify 3 Link Planar Manipulator as per Denavit Hartenberg conventions.	[5]		

Solutions Key

Q.No	Solution
1.a)	 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
1.b)	i) Robot Sensors **Sensors in Robotics** The sensors used in robotics include a wide range of devices which can be divided into the following general categories: a. Tactile sensors b. Proximity and range sensors

Tactile Sensors

Tactile sensors are devices which indicate contact between themselves and some other solid object. Tactile sensing devices can be classified into two classes: Touch Sensors and Force sensors.

Touch sensors provide a binary output signal which indicates whether or not contact has been made with the object.

Force sensors (Stress Sensors) indicate not only the contact has been made with the object but also the magnitude of the contact force between the two objects.

Proximity and Range sensors

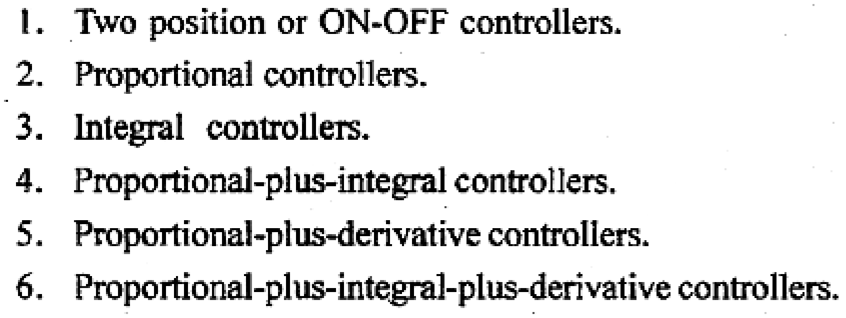
Proximity sensors are devices that indicate when one object is close to another object. Some of these sensors can also be used to measure the distance between the object and the sensor and these sensors are called as range sensors.

A variety of technologies are available for designing proximity and range sensors. These technologies include optical devices, acoustics, electrical field techniques (e.g. - eddy currents and magnetic fields), and others.

ii) Industrial Applications of robotics

Pick and Place in Production floor
Welding
Inspection and Quality control
Material Handling

2.a)



1. Two position or ON-OFF controllers.
2. Proportional controllers.
3. Integral controllers.
4. Proportional-plus-integral controllers.
5. Proportional-plus-derivative controllers.
6. Proportional-plus-integral-plus-derivative controllers.

$$\begin{aligned} u(t) &= u_1 ; \quad \text{for } e(t) < 0 \\ &= u_2 ; \quad \text{for } e(t) > 0 \end{aligned}$$

$$\boxed{E(s) = \mathcal{L}\{e(t)\} \; ; \quad U(s) = \mathcal{L}\{u(t)\}}$$

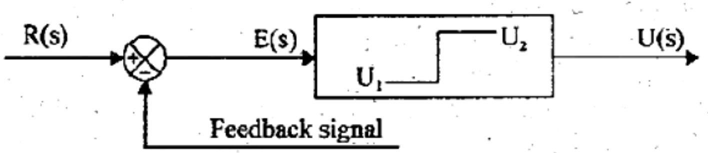
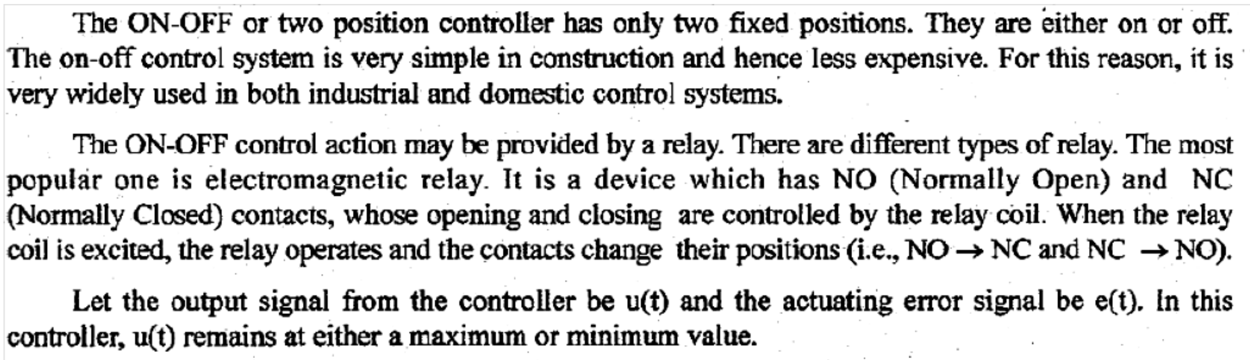


Fig 2.17 : Block diagram of on-off controller.



The ON-OFF or two position controller has only two fixed positions. They are either on or off. The on-off control system is very simple in construction and hence less expensive. For this reason, it is very widely used in both industrial and domestic control systems.

The ON-OFF control action may be provided by a relay. There are different types of relay. The most popular one is electromagnetic relay. It is a device which has NO (Normally Open) and NC (Normally Closed) contacts, whose opening and closing are controlled by the relay coil. When the relay coil is excited, the relay operates and the contacts change their positions (i.e., NO → NC and NC → NO).

Let the output signal from the controller be $u(t)$ and the actuating error signal be $e(t)$. In this controller, $u(t)$ remains at either a maximum or minimum value.

PROPORTIONAL CONTROLLER (P - CONTROLLER)

The proportional controller is a device that produces a control signal, u(t) proportional to the input error signal, e(t).

In P-controller, $u(t) \propto e(t)$

$$\therefore \quad u(t) = K_p \, e(t) \qquad .....(2.81)$$

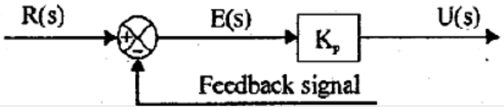
where, K_p = Proportional gain or constant

On taking Laplace transform of equation (2.81) we get,

$$U(s) = K_p E(s) \qquad .....(2.82)$$

$$\boxed{\therefore \ \text{Transfer function of P - controller, } \frac{U(s)}{E(s)} = K_p} \qquad .....(2.83)$$

The equation (2.82) gives the output of the P-controller for the input E(s) and equation (2.83) is the transfer function of the P-controller. The block diagram of the P-controller is shown in fig 2.18.



INTEGRAL CONTROLLER (I-CONTROLLER)

The integral controller is a device that produces a control signal u(t) which is proportional to integral of the input error signal, e(t).

In I-controller, $u(t) \ \alpha \int e(t)\,dt$; $\therefore u(t) = K_i \int e(t)\,dt$ .....(2.98)

where, K_i = Integral gain or constant.

On taking Laplace transform of equation (2.98) with zero initial conditions we get,

$$U(s) = K_i \frac{E(s)}{s} \qquad .....(2.99)$$

$$\boxed{\therefore \ \text{Transfer function of I - controller, } \frac{U(s)}{E(s)} = \frac{K_i}{s}} \qquad ....(2.100)$$

The equation (2.99) gives the output of the I-controller for the input E(s) and equation (2.101) is the transfer function of the I-controller. The block diagram of I-controller is shown in fig 2.24.

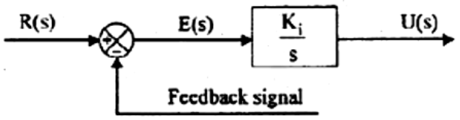


Fig 2.24 : Block diagram of an integral controller.

PROPORTIONAL PLUS INTEGRAL CONTROLLER (PI-CONTROLLER)

The proportional plus integral controller (PI-controller) produces an output signal consisting of two terms : *one proportional to error signal and the other proportional to the integral of error signal.*

In PI - controller, $u(t) \ \alpha \left[e(t) + \int e(t)\,dt\right]$; $\quad \therefore u(t) = K_p \, e(t) + \frac{K_p}{T_i} \int e(t)dt$ ....(2.111)

where, K_p = Proportional gain

T_i = Integral time.

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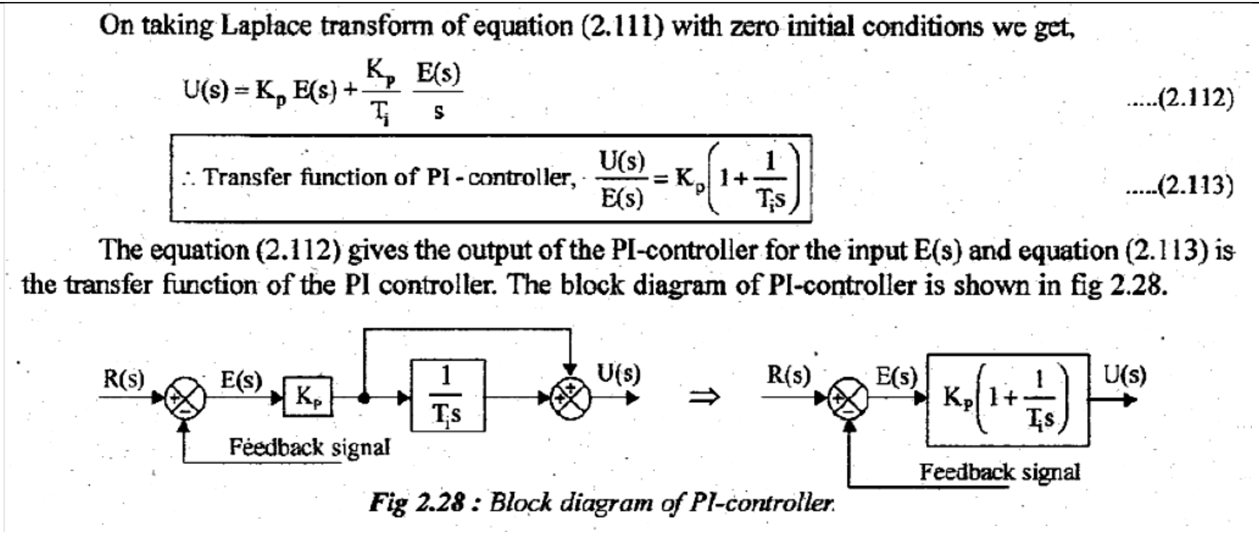

On taking Laplace transform of equation (2.111) with zero initial conditions we get,

$$U(s) = K_p\,E(s) + \frac{K_p}{T_i}\,\frac{E(s)}{s} \qquad .....(2.112)$$

$$\boxed{\therefore \text{ Transfer function of PI - controller, } \frac{U(s)}{E(s)} = K_p\left(1 + \frac{1}{T_i s}\right)} \qquad .....(2.113)$$

The equation (2.112) gives the output of the PI-controller for the input E(s) and equation (2.113) is the transfer function of the PI controller. The block diagram of PI-controller is shown in fig 2.28.

Fig 2.28 : Block diagram of PI-controller.
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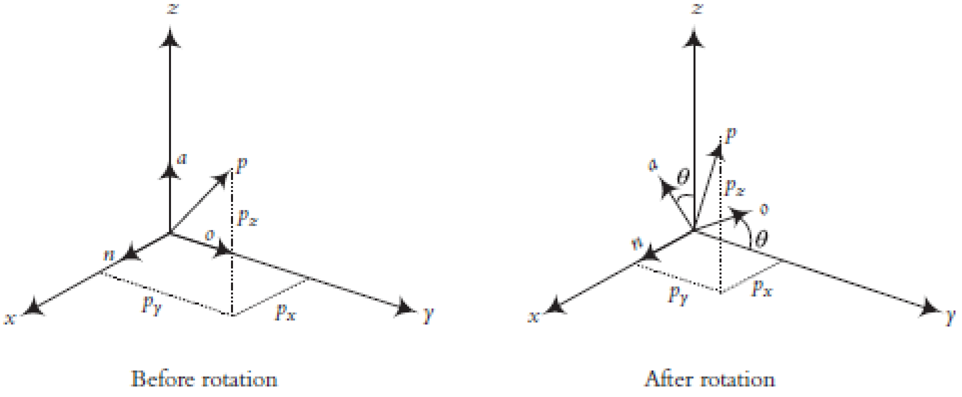

Before rotation

After rotation

Figure 2.12 Coordinates of a point in a rotating frame before and after rotation.

Let’s assume that a frame F_{noa}, located at the origin of the reference frame F_{xyz}, rotates an angle of u about the x-axis of the reference frame. Let’s also assume that attached to the rotating frame F_{noa}, is a point p, with coordinates p_x, p_y, and p_z relative to the reference frame and p_n, p_o, and p_a relative to the moving frame. As the frame rotates about the x-axis, point p attached to the frame will also rotate with it. Before rotation, the coordinates of the point in both frames are the same (remember that the two frames are at the same location and are parallel to each other). After rotation, the p_n, p_o, and p_a coordinates of the point remain the same in the rotating frame F_{noa}, but p_x, p_y, and p_z will be different in the F_{xyz} frame (Figure 2.12). We want to find the new coordinates of the point relative to the fixed reference frame after the moving frame has rotated. Now let’s look at the same coordinates in 2-D as if we were standing on the x-axis. The coordinates of point p are shown before and after rotation in Figure 2.13. The coordintes of point p relative to the reference frame are p_x, p_y, and p_z, while its coordinates relative to the rotating frame (to which the point is attached) remain as p_n, p_o, and p_a.
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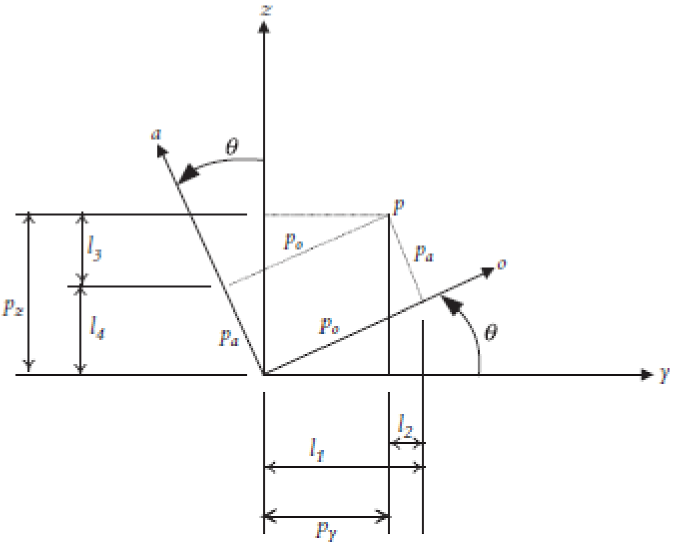


Figure 2.13 Coordinates of a point relative to the reference frame and rotating frame as viewed from the *x*-axis.

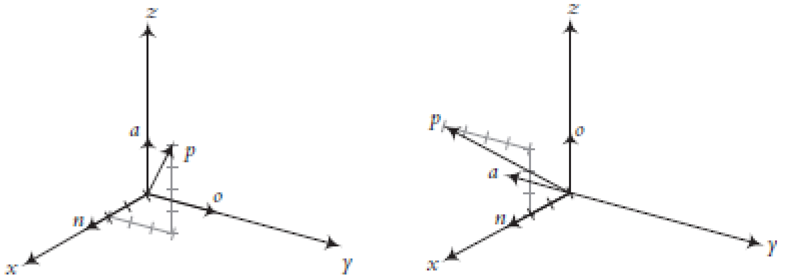
$$\begin{aligned} p_x &= p_n \\ p_y &= l_1 - l_2 = p_o \cos\theta - p_a \sin\theta \\ p_z &= l_3 + l_4 = p_o \sin\theta + p_a \cos\theta \end{aligned} \tag{2.17}$$

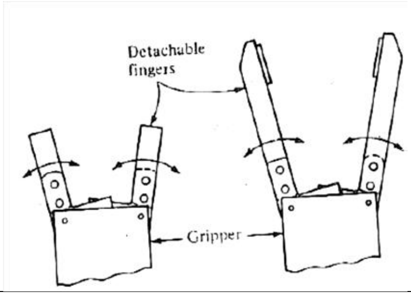
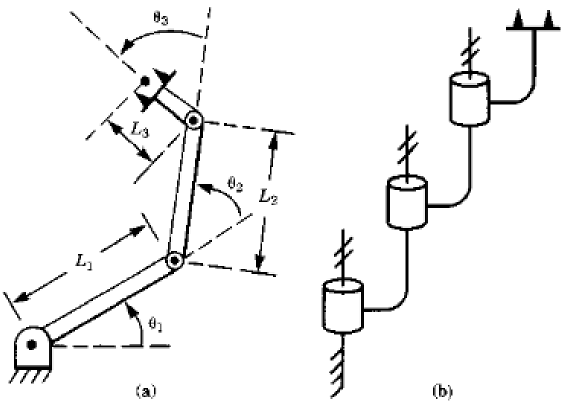
and in matrix form:

$$\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} p_n \\ p_o \\ p_a \end{bmatrix} \tag{2.18}$$

This means that the coordinates of the point *p* (or vector **p**) in the rotated frame must be pre-multiplied by the rotation matrix, as shown, to get the coordinates in the reference frame. This rotation matrix is only for a pure rotation about the *x*-axis of the reference frame and is denoted as:

$$p_{xyz} = Rot(x, \theta) \times p_{noa} \tag{2.19}$$

	Solution: Of course, since the point is attached to the rotating frame, the coordinates of the point relative to the rotating frame remain the same after the rotation. The coordinates of the point relative to the reference frame will be: $\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & C\theta & -S\theta \\ 0 & S\theta & C\theta \end{bmatrix} \times \begin{bmatrix} p_n \\ p_o \\ p_a \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} 2 \\ 3 \\ 4 \end{bmatrix} = \begin{bmatrix} 2 \\ -4 \\ 3 \end{bmatrix}$ As shown in Figure 2.14, the coordinates of point *p* relative to the reference frame after rotation are 2, −4, 3, as obtained by the above transformation.  **Figure 2.14** Rotation of a frame relative to the *x*-axis of the reference frame. ■
3.a)	The End effectors can be divided into two major categories: 1 . Grippers 2. Tools Grippers are and effectors used to grasp and hold objects. The objects are generally work parts that are to be moved by the robot. These part handling applications include machine loading and unloading, picking parts from a conveyor and arranging parts onto a pallet. Grippers can be classified as single, double or multiple. The single gripper is distinguished with only one grasping device mounted to the robot's wrist. A double gripper has two gripping devices attached to the wrist and is used to handle two separate objects. The two gripping devices can be actuated independently. The double gripper is especially useful in machine loading and unloading applications. To illustrate, suppose that a particular job calls for a raw work part to be loaded from a conveyor onto a machine and the finished part to be unloaded onto another conveyor. With a single gripper, the robot would have to unload the finished part before picking up the raw part. This would consume valuable time in the production cycle because the machine would have to remain open during these handling motions. With a double gripper, the robot can pick the part from the incoming conveyor with one of the gripping devices and have it ready to exchange for the finished part. When the machine cycle is completed, the robot can reach in tor the finished part with the available grasping device, and insert the raw part into the machine with the other grasping device. The amount of time that the machine is open is minimized. The term multiple gripper is used in the case where two or more grasping devices attached to the wrist. The occasions when more than two grippers would be required are somewhat rare. There is also a cost and reliability penalty which accompanies an increasing number of gripper devices on one robot arm. Tools are end effectors designed to perform work on the part rather than to merely grasp it. By definition, the tool-type end effector is attached to the robot's wrist. One of the most common applications of industrial robots is spot welding, in which the welding electrodes constitute the end effector of the robot. Other examples of robot applications in which tools are used as end effectors include spray painting and are welding.

	Mechanical Grippers A mechanical gripper is an end effector that uses mechanical fingers actuated by a mechanism to grasp an object. The fingers, sometimes called jaws, are the appendages of the gripper that actually make contact with the object. The fingers are either attached to the mechanism or are an integral part of the mechanism. If the fingers are of the attachable type, then they can be detached and replaced. The use of replaceable fingers allows for wear and 'inter-changeability. Different sets of fingers lor use with the same gripper mechanism .can be designed to accommodate different part ' models. 
3.b)	The following is a summary of the procedure to follow when faced with a new mechanism in order to properly attach the link frames: 1. Identify the joint axes and imagine (or draw) infinite lines along them. For steps 2 through 5 below, consider two of these neighboring lines (at axes i and $i+1$). 2. Identify the common perpendicular between them, or point of intersection. At the point of intersection, or at the point where the common perpendicular meets the ith axis, assign the link frame origin. 3. Assign the $\hat{Z}_i$ axis pointing along the ith joint axis. 4. Assign the $\hat{X}_i$ axis pointing along the common perpendicular, or if the axes intersect, assign $\hat{X}_i$ to be normal to the plane containing the two axes. 5. Assign the $\hat{Y}_i$ axis to complete a right-hand coordinate system. 6. Assign $\{0\}$ to match $\{1\}$ when the first joint variable is zero. For $\{N\}$ choose an origin location and $\hat{X}_N$ direction freely, but generally so as to cause as many linkage parameters as possible to become zero. 

4.a)

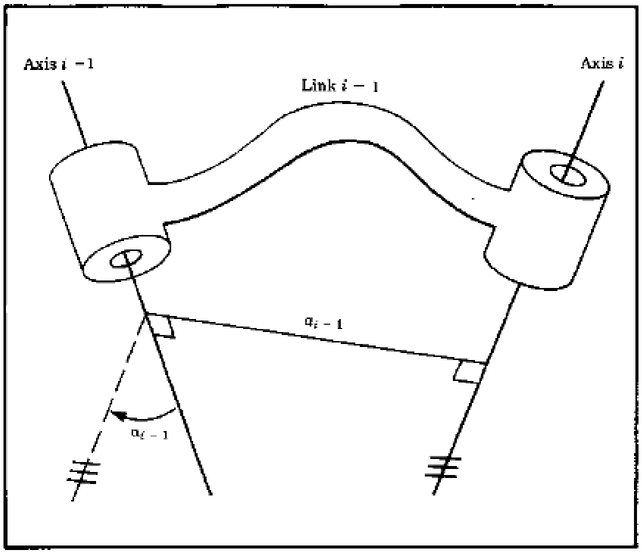
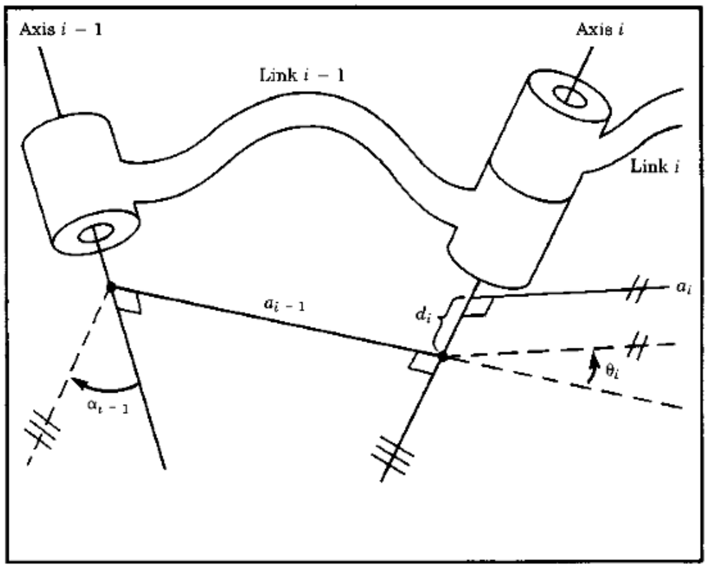


FIGURE 3.2 The kinematic function of a link is to maintain a fixed relationship between the two joint axes it supports. This relationship can be described with two parameters, the link length, a, and the link twist, α.

For any two axes in 3-space there exists a well-defined measure of distance between them. This distance is measured along a line which is mutually perpendicular to both axes. This mutual perpendicular always exists and is unique except when both axes are parallel, in which case there are many mutual perpendiculars of equal length. Figure 3.2 shows link $i-1$ and the mutually perpendicular line along which the **link length**, a_{i-1}, is measured. Another way to visualize the link parameter a_{i-1} is to imagine an expanding cylinder whose axis is the joint $i-1$ axis — when it just touches joint axis i the radius of the cylinder is equal to a_{i-1}.

The second parameter needed to define the relative location of the two axes is called the **link twist**. If we imagine a plane whose normal is the mutually perpendicular line just constructed, we can project both axes $i-1$ and i onto this plane and measure the angle between them. This angle is measured from axis $i-1$ to axis i in the right-hand sense about a_{i-1}.[†] We will use this definition of the twist of link $i-1$, α_{i-1}. In Fig. 3.2, α_{i-1} is indicated as the angle between axis $i-1$ and axis i (the lines with the triple hash marks are parallel). In the case of intersecting axes, twist is measured in the plane containing both axes, but the sense of α_{i-1} is lost. In this special case, one is free to assign the sign of α_{i-1} arbitrarily.

4.b)



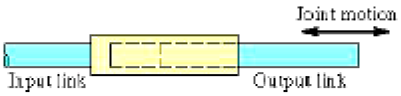
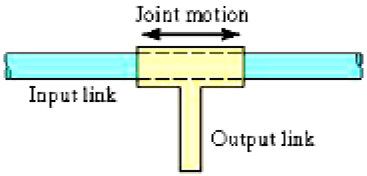
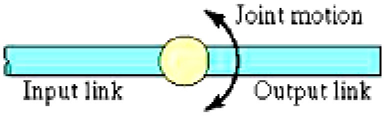
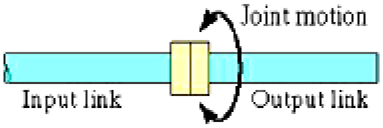
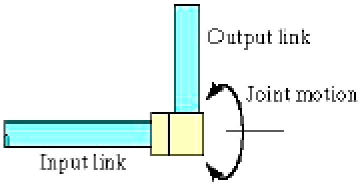
Intermediate links in the chain

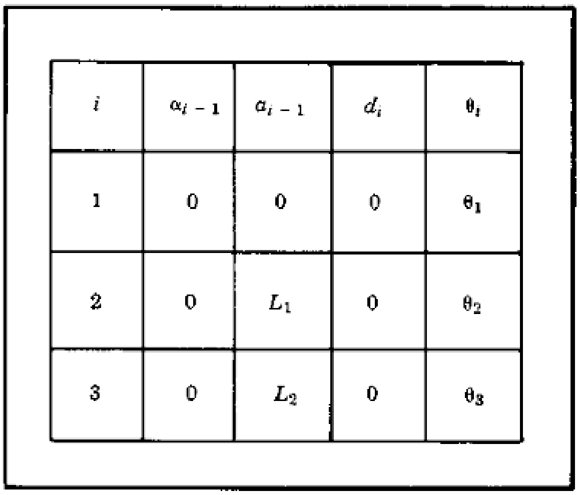
Neighboring links have a common joint axis between them. One parameter of interconnection has to do with the distance along this common axis from one link to the next. This parameter is called the **link offset.** The offset at joint axis i is called d_i. The second parameter describes the amount of rotation about this common axis between one link and its neighbor. This is called the **joint angle**, θ_i.

Figure 3.4 shows the interconnection of link $i-1$ and link i. Recall that a_{i-1} is the mutual perpendicular between the two axes of link $i-1$. Likewise a_i is the mutual perpendicular defined for link i. The first parameter of interconnection is the link offset, d_i, which is the signed distance measured along the axis of joint i from the point where a_{i-1} intersects the axis to the point where a_i intersects the axis. The offset d_i is indicated in Fig. 3.4. The link offset d_i is variable if joint i is prismatic.

First and last links in the chain

Link length, a_i, and link twist, α_i, depend on joint axes i and $i+1$. Hence a_1 through a_{n-1} and α_1 through α_{n-1} are defined as discussed above in this section. At the ends of the chain, it will be our convention to assign zero to these quantities. That is, $a_0 = a_n = 0.0$ and $\alpha_0 = \alpha_n = 0.0$.* Link offset, d_i, and joint angle, θ_i, are well defined for joints 2 through $n-1$ according to the conventions discussed above in this section. If joint 1 is revolute, the zero position for θ_1 may be chosen arbitrarily and $d_1 = 0.0$ will be our convention. Similarly, if joint 1 is prismatic, the zero position of d_1 may be chosen arbitrarily, and $\theta_1 = 0.0$ will be our convention. Exactly the same statements apply to joint n.

5.a)	**Robot Joints** A) **Prismatic joint** - Translational motion 1. **Linear joint (type L)** The relative motions between input and output links are linear and axis of the two links and that of joints are parallel.  2 **Orthogonal joint (type O)** This is also linear motion but input and output links are perpendicular to each other.  B) **Revolute joints** - Rotary motion 1. **Rotational joint (type R)** This gives a rotational motion with axis of rotation perpendicular to both link axes.  2. **Twisting joint (type T)** This also gives rotary motion between links and axis of rotation is parallel to both link axes.  3. **Revolving joint (type V)** This is also rotary motion. One input link axis is parallel to rotation axis and perpendicular to output link 
5.b)	The position of all the links of a manipulator of n degrees of freedom can be specified with a set of n joint variables. This set of variables is often referred to as the $n \times 1$ **joint vector**. The space of all such joint vectors is referred to as **joint space**. Thus far in this chapter we have been concerned with computing the **Cartesian space** description from knowledge of the joint space description. We use the term *Cartesian space* when position is measured along orthogonal axes, and orientation is measured according to any of the conventions outlined in Chapter 2. Sometimes the terms **task-oriented space** or **operational space** are used for what we will call Cartesian space.



i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3