Sensors in Robotics

Manufacturing industry applications

a. Mechanical—for measuring quantities such as position, shape, velocity, force, torque, pressure, vibration, strain, and mass

b. Electrical—for measuring voltage, current, charge, and conductivity

c. Magnetic—for measuring magnetic field, flux, and permeability

d. Thermal—for measuring temperature, flux, conductivity, and specific heat

e. Others—such as acoustic, proximity, chemical, photoelectric, radiation, lasers, optical systems (fiber optics and light-emitting diodes), tactile, voice and visual sensing

Function Performed

According to their function performed, sensors can be categorized under manipulation or acquisition.

Those that allow the robot to interact with its surroundings, like tactile and force sensors attached to the manipulator are grouped under manipulation. Tactile sensors are devices that indicate contact between themselves and another solid object. Tactile sensing devices can be divided into two classes: touch sensors and force sensors. Touch sensors provide a binary output signal that indicates whether or not contact has been made with the object. Force sensors (also sometimes called stress sensors) indicate not only that contact has been made with the object but also the magnitude of the contact force between the two objects.

Those sensors that let the robot know its own present state are grouped under acquisition. These devices measure the distance to the nearest object within a zone of information-collection space. An example of a point-measuring device may be found in the distance-measuring ultrasound devices developed by Polaroid, as shown in Figure 6.2.1.

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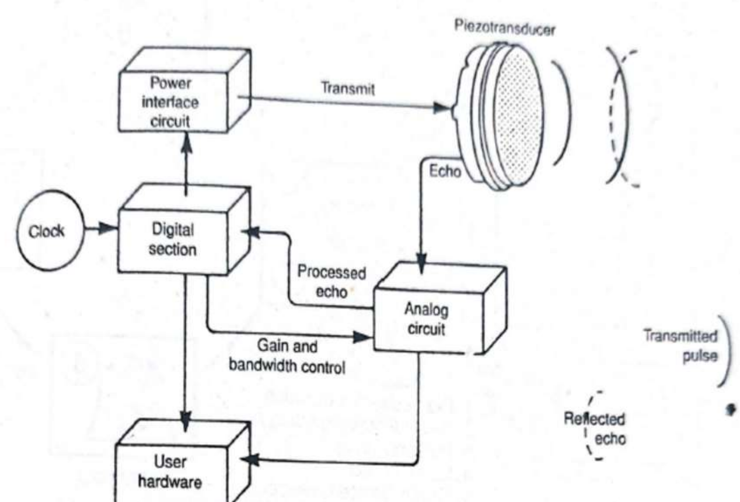
Piezotransducer



The circuit of a piezotransducer

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Location and Type of Detection

According to their location and type of detection, sensors are categorized as internal, external, or interlock.

Internal sensors use feedback information internally to ascertain their present condition. The first complex sensor used by industrial robots is known as **haptic perception.** This is the robotic equivalent of the human sense of kinesthesia,

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Internal Sensors

- Industrial Robot’s internal sensors use mechanical, electrical, electronic & hydraulic devices to obtain feedback information.
- These devices are called closed –loop and servo controlled system.

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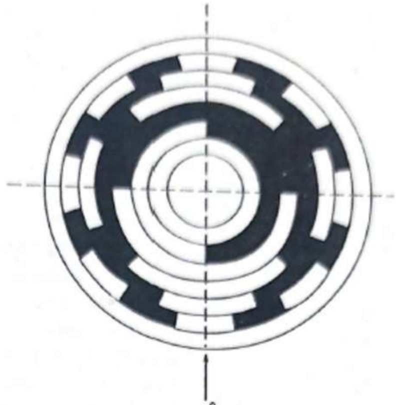
Encoder



Direct-readout shaft encoder

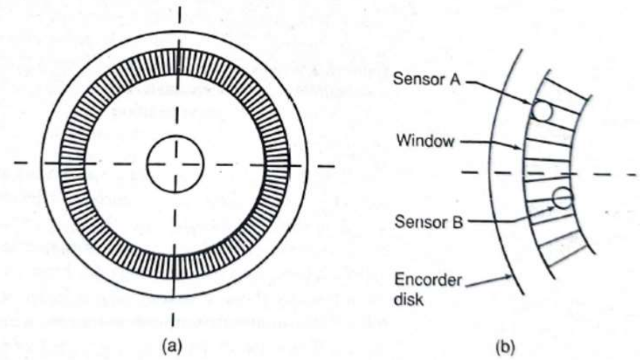


Figure 6.2.4 Pulse-reading shaft encoder: (a) encoder disk; (b) sensors—the direction of rotation can be determined by using two sensors 90° from each other and half a window apart.

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Internal Sensors

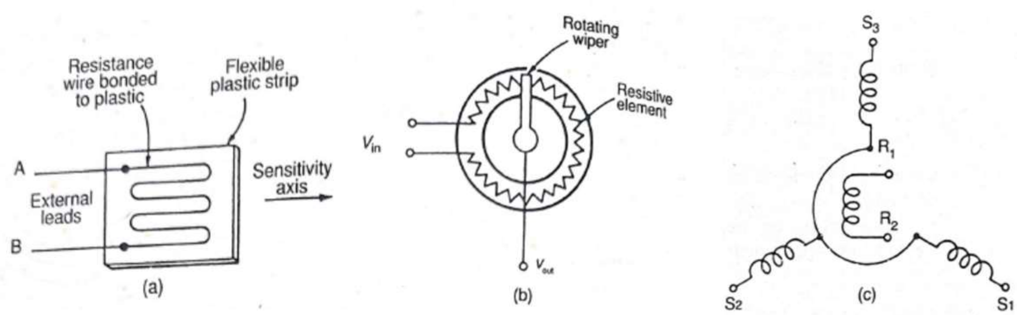

Figure 6.2.5 Inexpensive internal sensors: (a) bonded-wire strain gauge; (b) circular wirewound potentiometer; and (c) two circuits synchro.

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External Sensors

The four most common external sensors are the microswitches, the simple touch or tactile sensors, the photoelectric devices, and the proximity sensors.

The senses of hearing, speech, vision, and touch for robots are still in the experimental stages. Development of the sense of voice recognition (hearing) is mainly intended to make it easier for humans to give commands to the robots when training them to do a specific task. Speech synthesis or voice will enable a robot to communicate warnings to humans when something is wrong. Vision will make self-orientation and proper grasping of parts easier for the robot, because vision can be used to correct small errors of positioning or alignment. The tactile sense will help a robot tell when it is gripping a part and what the orientation of the part is.

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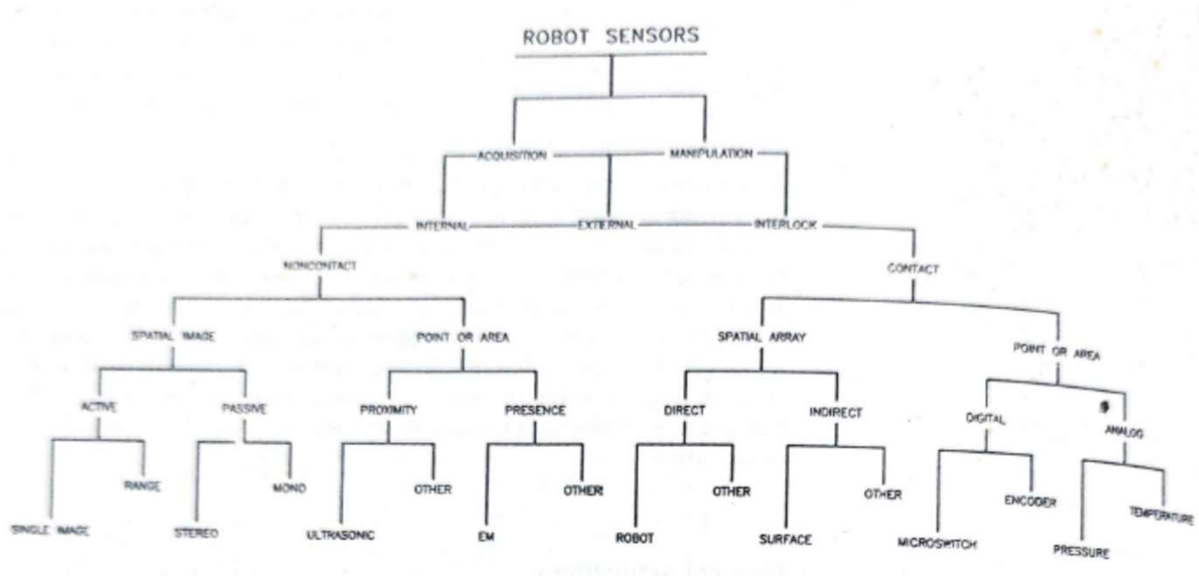

Figure 6.2.6 Classification of sensors available for an intelligent robot

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Interlock sensors are devices that do not allow an operation to be performed until certain conditions exist. They are very old devices that are used to protect the unauthorized person from harmful conditions. Some interlock devices may sound an alarm or stop the motion without switching its power off in an emergency.

An interlock sensor may also be used to protect a robot. Examples include the airflow in the robot's controller that can reach the level before power is applied to the controller's system; hydraulic pressure that can reach some minimum level before hydraulic actuators are allowed to move; the temperature of the hydraulic fluid, which can remain below a certain level if the hydraulic system is to be used. In all these cases, the robot must receive an electrical interlock signal indicating that it has finished its cycle and is open before the robot can be allowed to move to the next operation. Interlock sensors are electromechanical or completely mechanical. They also can be viewed as internal sensors as well as external sensors, because they can be used for measuring the state of the device as well as warning of an intruder.

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Physical Activation

According to their physical activation, sensors are categorized as contact or noncontact.

Contact sensors, as the name implies, must physically touch an object before the sensor is activated. Contact sensors include microswitches and all tactile-sensing devices. In each category, the sensors can be in direct or indirect action with digital or analog output signals.

Noncontact sensors measure the condition of an object without physically touching the part. Most frequently, noncontact sensors are those that measure a point of response and others that give a spatial array of measurements at neighboring points of information. A vision system is the most common example of a device that measures spatial information.

By point of response, these sensors may be further divided into sensors that measure proximity and sensors that measure the presence of an object, like the photoelectric devices.

Further subdivision of the noncontact sensors includes devices that measure spectral range, such as infrared, visible, and X ray. Such sensors may be used for inspection tasks, part identification, and other applications and are based on electrical fields, ultrasonic, and radiation. The classifications of sensors available for use on an intelligent robot are shown diagrammatically in Figure 6.2.6. Microswitches, solid-state switches, proximity, photoelectric, and rotary position sensors are discussed in more detail in the following sections. (Vision systems are discussed in Chapter 7.) In reality there are two main classifications of sensors based on their output: discrete sensors and complex sensors.

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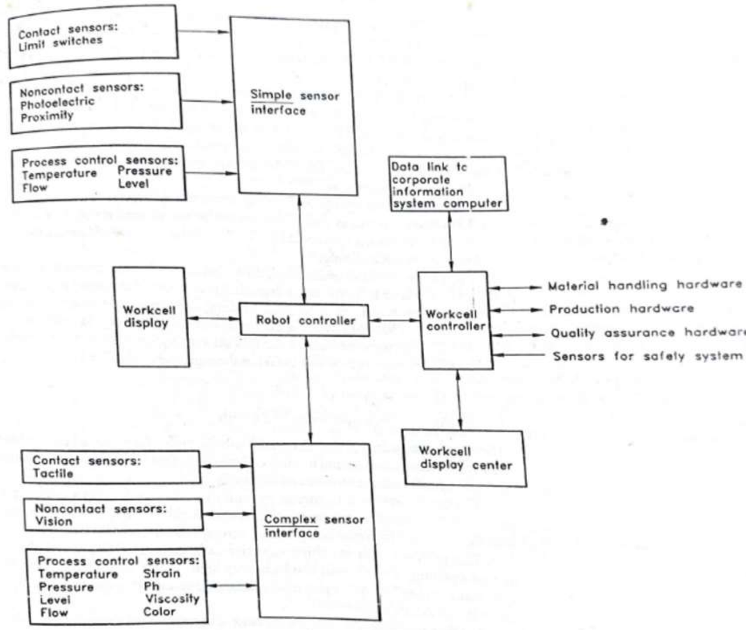

Figure 6.2.7 Sensor system block diagram

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Types of Microswitches

There are five types of microswitches used in workcells:

1. Manual switches
2. Limit switches
3. Impulse limit switches
4. Reed switches
5. Pressure switches

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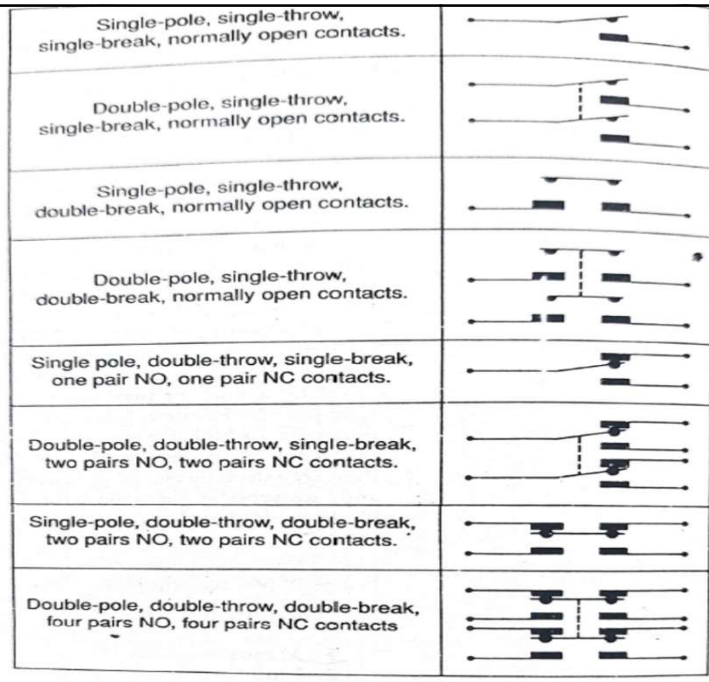

Figure 6.3.1 Electromagnetic contact arrangements

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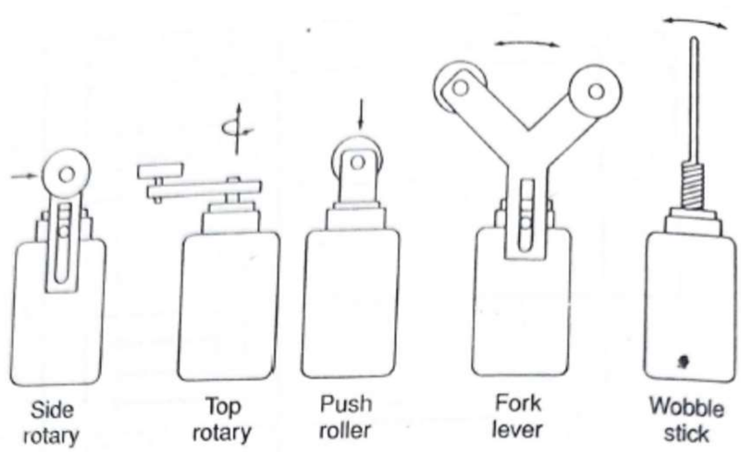

Figure 6.3.3 Limit switch actuators

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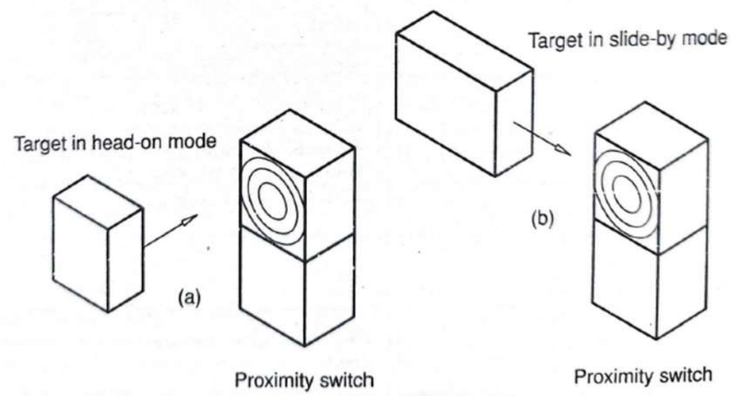

Figure 6.5.1 (a) Proximity switch mounted in head-on mode; (b) proximity switch mounted in slide-by mode

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Other proximity sensors are ava lable commercially and utilize different operating principles.

Capacitive-type proximity senso s obtain their switching signal based on the air gap between the sensor and nonconductive materials.

Magnetic reed switch sensing s hemes are used for proximity sensing by placing a permanent magnet on the tr veling target. When the magnet comes into proximity to the stationary switch, th reeds close.

Hall effect sensors are used whe e the output of a voltage is proportional to the magnetic field. A magnet mount d on the target creates a Hall voltage as it nears the sensor. This signal is amplified, and when it reaches a threshold value, solid-state switch outputs are actuated.

Ultrasonic proximity sensors operate on the principle of reflected ultrasound. The time between signal output and return of the reflected signal is proportional to distance between the sensor and the target. Developed initially as automatic focusing devices for cameras, these sensors operate over the range of 1–20 feet. Accuracy of switching is not as repeatable as that of the previously discussed sensors.

Ring-type proximity sensors are available that actuate (switching signal) when objects pass through the ring. Coin counters or small-parts counters are examples of ring proximity switch applications.

Proximity probes of all types are usually sealed. Cylindrical or square devices have leads protruding from the nonactive end. Heavy-duty proximity sensors are often square assemblies, much like mechanical limit switches but without the actuator.

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Photoelectric sensors are noncontact position-sensing devices that the output responds to:

1. Interruption of a light beam by an object or part
2. Reflection of a light beam back to its source by an object or part passing in front of the projected beam

The four types of photoelectric sensors are defined as follows and are shown in Figure 6.6.1:

1. Light source and receiver
2. Retroreflector
3. Diffuse scanner
4. Reflect scanner

The light source and receiver type consists of a light source and photoreceiver for a direct scan or through a scan photoelectric control system.

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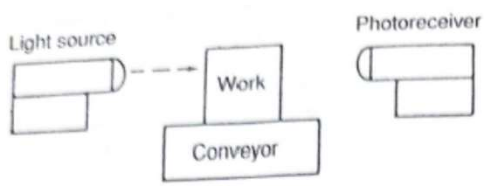
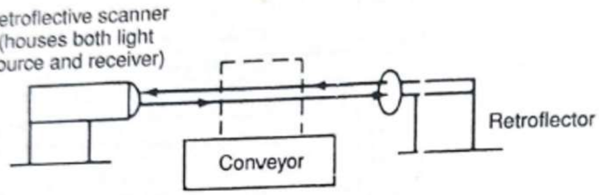


As work moves between light source and receiver, the light beam is interrupted, resulting in a switch closure (or opening).
(a)



Light beam from source to retroflector and back to scanner is interrupted by object, initiating a control signal.
(b)

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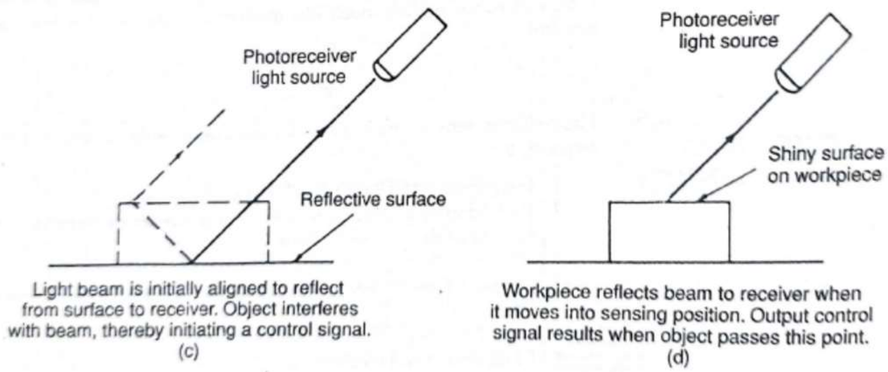

Figure 6.6.1 Photoelectric sensors: (a) light source and receiver type; (b) retroflector type; (c) diffuse scanner type; (d) reflect scanner type

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a. Encoders
b. Synchros
c. Resolvers
d. Potentiometers

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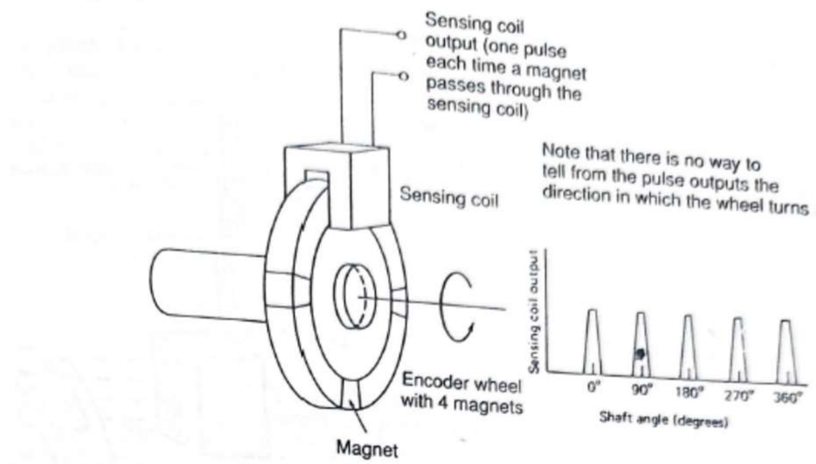

Figure 6.7.1 Magnetic tachometer encoder

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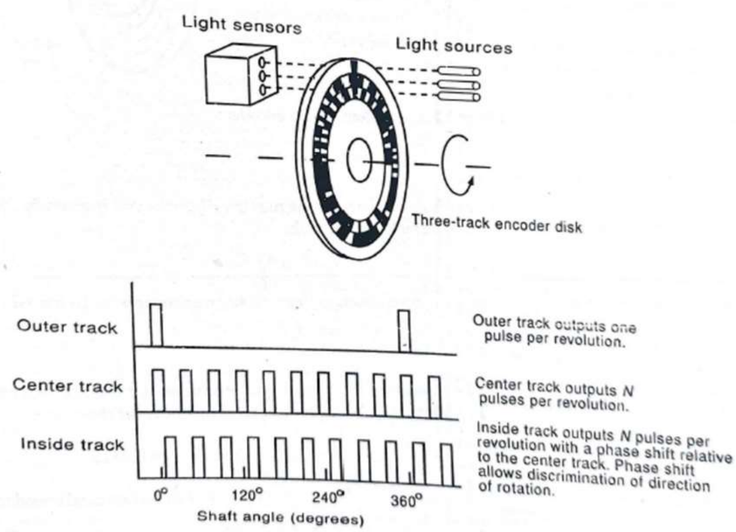

Figure 6.7.2 Incremental optical encoder

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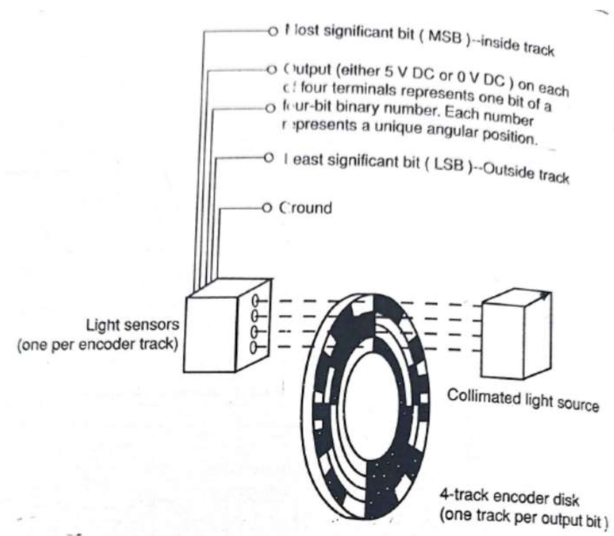

Figure 6.7.3 Absolute optical encoder

25

What is the resolution, in degrees, of an encoder with 10 tracks?

Solution

The number of increments per revolution is $2^{10} = 1{,}024$ increments/rev.
The angular width of each control increment is therefore:

$$360^\circ / 2^{10} = 360^\circ / 1{,}024 = 0.3515^\circ$$

The output of an absolute encoder or of an incremental encoder and counter combination is represented by:

$$\text{out}(t) = K_e \theta\ (t)$$

where *out* is a number,
K_e is the number of pulses per radian, and
θ is the shaft angle, expressed in radians.

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What is the output value of an absolute encoder if the shaft angle is 1 rad and the encoder has 8 tracks?

Solution

The resolution is $2^8 = 256$ parts/rev. There are 2π rad/rev. Therefore, the output is: $256 / 2\pi = 41$.

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Synchros

A synchro is a rotating transformer in which a single-pole rotor winding is excited by AC voltage (60 Hz or 400 Hz). AC rotor current induces voltage in three stator coil windings that are wound 120° apart. The synchro is no different in appearance than a small AC motor.

Figure 6.7.4 shows the basic construction of a synchro and its circuit representation. If a voltage excitation of $A \sin wt$ is applied to the synchro rotor, then the output that will appear at the various stator terminals will be:

$$V_{13} = A \sin wt \sin \theta$$

$$V_{32} = A \sin wt \sin (\theta + 120^\circ)$$

$$V_{21} = A \sin wt \sin (\theta + 240^\circ)$$

where θ is the shaft angle of the synchro.

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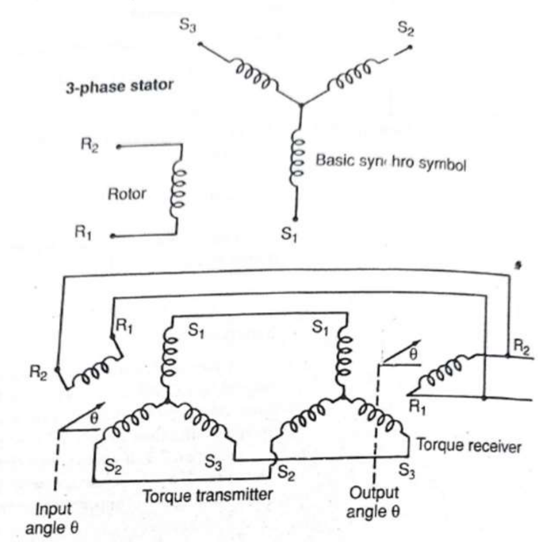

Figure 6.7.4 Synchro circuit diagram

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Resolvers

Resolvers are a form of synchro, in which there are only two stator windings, placed 90° mechanically out of phase with each other. If the rotor is excited with a voltage $A \sin wt$, then the outputs on stator terminals will be:

$$V_1 = A \sin wt \sin \theta$$

$$V_2 = A \sin wt \cos \theta$$

where θ is the angle of the rotor with respect to the stator.

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At time t the excitation voltage to a resolver is 24 V. The shaft angle is 90°. What is the output signal from the resolver?

Solution

$$V_1 = (24\ V)(\sin 90°) = 24\ V$$

$$V_2 = (24\ V)(\cos 90°) = 0\ V$$

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At time t the excitation voltage to a resolver is 24 V and $V_1 = 17$ and $V_2 = -17$ V. What is the angle?

Solution

$$\arcsin(17/24) = 45° \text{ or } 135°$$

$$\arccos(17/24) = 135° \text{ or } 225°$$

The shaft angle must be 135°.

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Potentiometers

Potentiometers are analog devices whose output voltage is proportional to the position of a wiper. Figure 6.7.5 illustrates a typical potentiometer (pot). A voltage is applied across the resistive element. The voltage between the wiper and ground is proportional to the ratio of the resistance on one side of the wiper to the total resistance of the resistive element. Essentially, the pot acts as a voltage divider network. That is, the voltage across the resistive element is divided into two parts by a wiper. Measuring this voltage gives the position of the wiper. The function of the potentiometer can be represented by the following function:

$$V_0(t) = K_p\theta\,(t) \qquad \text{(Equation 7.6.1)}$$

where $V_0(t)$ is the output voltage,

K_p is the voltage constant of the pot in volts per radian (or volts per inch in the case of a linear pot), and

$\theta\,(t)$ is the position of the pot in radians (or inches).

Because a pot requires an excitation voltage in order to calculate V_0, we can use:

$$V_0 = V_{ex}\,(\theta_{act} / \theta_{tot}) \qquad \text{(Equation 7.6.2)}$$

where V_{ex} is the excitation voltage,

θ_{tot} is the total travel available of the wiper, and

θ_{act} is the actual position of the wiper.

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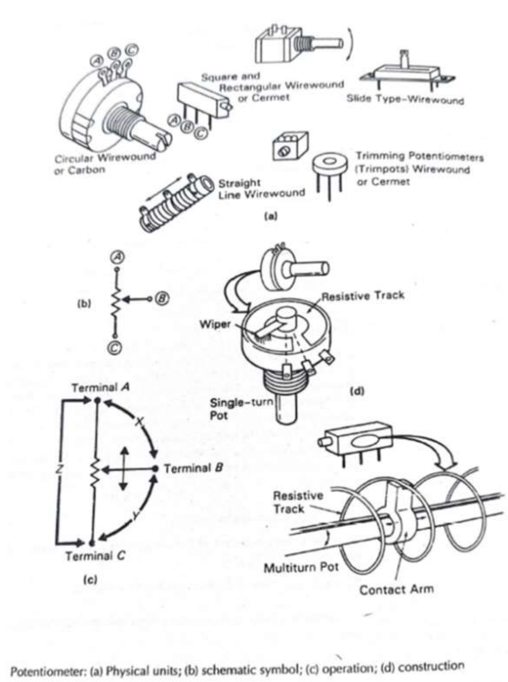

Potentiometer: (a) Physical units; (b) schematic symbol; (c) operation; (d) construction

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Find the output voltage of a potentiometer with the following characteristics. Also determine the K_p. The excitation voltage is 12 V; total wiper travel is 320°; and the wiper position is 64°.

Solution

$K_p = V_{ex} / \theta_{tot}$, which is 12V / 320° = 0.375 V/deg. The output voltage is:

$$(64°)(0.0375 \text{ V / deg}) = 2.4 \text{ V}$$

Table 6.2 summarizes the types of rotary position sensors used in robotics and automation.

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The major uses of sensors in industrial robots and other automated manufacturing systems can be divided further into four basic categories:

1. Safety monitoring
2. Control interlocking
3. Quality control inspection
4. Positions and related information

Safety monitoring is one of the important applications of sensor technology in automated manufacturing operations that concerns the protection of human workers who work in the vicinity of the robot or other equipment.

Control interlocking in robots is used to coordinate and verify the sequence of activities of the different pieces of equipment in the workcell and to verify before proceeding with the next element of the cycle.

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Table 6.2 Rotary position sensors

Device	Output	Accuracy
Multipole resolver	analog (voltage)	7 arc seconds
Absolute optical encoder	digital pulse	23 arc seconds
Standard resolver	analog (voltage)	7 arc minutes
Potentiometer	analog (resistance)	7 arc minutes
Incremental optical encoder	digital pulse	11 arc minutes
Contact encoder	digital pulse	26 arc minutes

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Quality control inspection is used to determine a variety of part quality characteristics. This generally involves the checking of parts, assemblies, or products for conformance to certain criteria specified by the design engineering department.

Position and related information sensors are used to determine the positions and other related information about various objects in the robot cell: such as work parts, fixtures, people, equipment, and so on. This kind of data will determine work-part identification, random position and orientation of parts, and accuracy on requirements by feedback supporting data.

The selection of a sensor for a particular application depends on factors such as the quantity to be measured or sensed, the sensor's interaction with other components in the system, expected service life, level of sophistication, difficulties associated with the sensor's use, power source, and cost. Another importanc consideration is the environment in which the sensors are to be used. Rugged sensors are being developed to withstand extremes of temperature, shock and vibration, humidity, corrosion, dust and various contaminants, fluids, electromagnetic radiation, and other interferences.

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There are three basic elements that constitute the interaction of a modern robot:

1. Controller—A mix of hardware and software that controls the positioning and motion of the robot, as dictated by the teach pendant or computer
2. Sensors—Monitor the robot's surroundings and behavior and provide the information directly, either to the controller or the computer
3. Decision making—Generally, software that provides the robot with decision-making capability (primarily made by the programmer)

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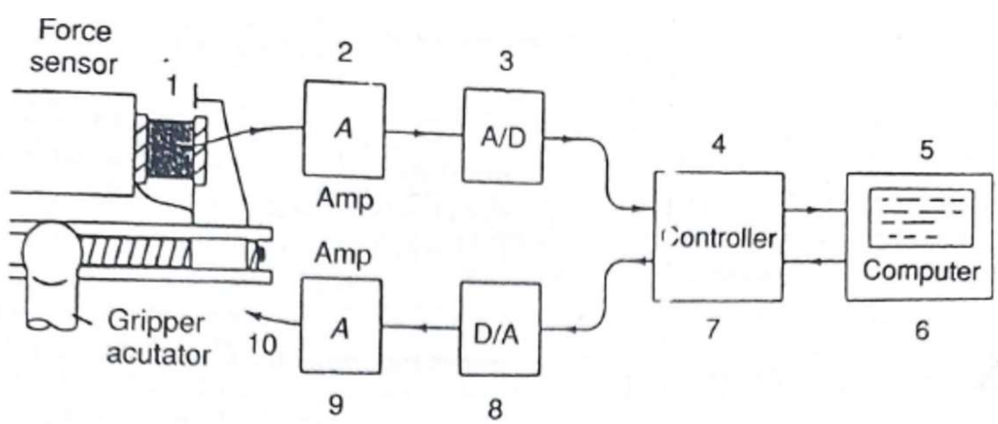

Figure 6.9.1 Sensor-to-actuator signal processing

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A schematic processing loop is shown in Figure 6.9.1. Follow the signal as it proceeds around the loop in terms of its transition from one numbered station to the next:

- $1 \to 2$ The force sensor has been calibrated so that a force F_0 corresponds to an output voltage V_0. Because this signal is generally rather weak, it needs to be amplified.
- $2 \to 3$ The amplified signal voltage is then fed into an analog-to-digital (A/D) converter, replacing the analog (continuous) signal with discrete signal levels. Generally, such analog-to-digital converters may include an encoder, which assigns a binary code corresponding to each signal level.
- $3 \to 4$ This binary signal now moves to a controller, a piece of hardware that basically keeps track of where a signal comes from and where it is going. Here, the controller will note that it received a signal of a certain level, say from force sensor 1 on the gripper.

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- $4 \to 5$ The controller will then pass this binary signal to the computer, with an identifying code indicating that the signal comes from force sensor 1. The computer, in turn, through its software, may now display a statement of the form "force sensor 1 indicates a force F_0." That is, it recognizes where the signaled force level exists and displays this to an operator or operating program.
- $5 \to 6$ The computer now processes this information by comparing F_0 to some required force F_1; for example, with $F_0 < F_1$ implying an order to continue closing the gripper.
- $6 \to 7$ Hence the computer now sends a signal to the controller, indicating a certain coded binary voltage level for the gripper motor and an identifying code for the motor.
- $7 \to 8$ The controller again identifies where the signal is to go and sends out a binary signal to the motor. If the motor runs on an analog signal, then there is a decoder and a digital-to-analog (D/A) converter, which eventually provides the specified analog voltage level.
- $8 \to 9$ Because computer and controller voltages may run between 0 V and 5 V, this may not be enough to drive the motor, so that amplification is again necessary.
- $9 \to 10$ The motor now turns the amount indicated by the voltage level. If it is a stepper motor, the signal voltage may simply be enough to have it step through a specified number of segments, or we might have some other device indicating the amount of rotation of the motor.

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1. Accuracy—means no systematic positive or negative errors in the measurement.
2. Precision—means no random variability in the measurement.
3. Operating range—means that the entire operating range is accurate and precise.
4. Speed of response—means that it should be capable of responding in minimum time.
5. Calibration—means that it should be easy to calibrate.
6. Reliability—means that it should possess a high reliability without failures.
7. Cost and ease of operation—means that the costs to purchase, install, and operate should be as low as possible.

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Sensors are classified according to:

1. Measuring quantity values—such as mechanical, electrical, magnetic, thermal, and other sensors
2. Function performed—such as manipulation and acquisition sensors
3. Location and type of detection—such as internal, external, and interlock sensors
4. Physical activation—such as contact and noncontact sensors

The four major uses of sensors in robots and automated systems are:

1. Safety monitoring, which concerns the protection of human workers
2. Control interlocking, which coordinates and verifies the sequence of activities
3. Quality control inspection, which conforms with the criteria of design
4. Positions and related information, which determines the accuracy and reliability of parts

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