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Sensors & Transducers

By

Nishant Gupta

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SENSORS AND TRANSDUCERS

Pre-requisites of course: Basic Electrical Engineering, Basic signals & systems

Course Outcomes:		**Knowledge Level, KL**
Upon the completion of the course, the student will be able to:		
CO 1	Understand the working of commonly used sensors in industry for measurement of displacement, force and pressure.	**K3**
CO2	Recognize the working of commonly used sensors in industry for measurement of temperature, position, accelerometer, vibration sensor, flow and level.	**K3**
CO3	Identify the application of machine vision.	**K2**
CO4	Conceptualize signal conditioning and data acquisition methods.	**K2**
CO5	Comprehend smart sensors and their applications in automation systems.	**K4**

KL- Bloom's Knowledge Level (K_1, K_2, K_3, K_4, K_5, K_6)
K_1 – Remember K_2 – Understand K_3 – Apply K_4 – Analyze K_5 – Evaluate K_6 – Create

Detailed Syllabus:

Unit- I:

Sensors & Transducer: Definition, Classification of transducers, Advantages and Disadvantages of Electrical Transducers; Measurement of displacement using Potentiometer, LVDT & Optical Encoder; Measurement of force using strain gauges & load cells; Measurement of pressure using LVDT based diaphragm & piezoelectric sensor.

Unit-II:

Measurement of temperature using Thermistors, Thermocouples & RTD, Concept of thermal imaging; Measurement of position using Hall effect sensors; Proximity sensor: Inductive, Capacitive & Photoelectric, Use of proximity sensor as accelerometer and vibration sensor; Flow Sensor: Ultrasonic & Laser; Level Sensor: Ultrasonic & Capacitive.

Unit -III:

Machine Vision: Introduction to machine vision, Difference between machine vision and computer vision; Imaging Sensors: CCD and CMOS; sensing & digitizing function in machine vision, image processing and analysis, training the vision system in a pick and place robot.

Unit-IV:

Signal Conditioning: Introduction, Functions of signal conditioning equipment, need for amplification of signals, Types of amplifiers.

Data Acquisition Systems and Conversion: Introduction, Objectives & configuration of data acquisition system, Analog & Digital IO, Counters, Timers, need of data conversion.

Unit V:

Smart Sensors: General Structure of smart sensors & its components, Characteristic of smart sensors: Self calibration, Self-testing & self-communicating, Application of smart sensors: Smart city, Industrial robots & electric vehicles.

Text Books:

1. D. V. S. Murty, Transducers and Instrumentation –, 2nd Edition, PHI, 2009
2. BC Nakra & K. Chaudhary, "Instrumentation, Measurement and Analysis," McGraw Hill, 2nd Edition.
3. E. O. Doebelin, "Measurements Systems: Applications and Design", 6th Edition, McGraw Hill, 2017.
4. D Patranabis, Sensors and Transducers, 2nd Edition PHI 2013.
5. S. Gupta, J.P. Gupta "PC interfacing for Data Acquisition & Process Control", 2nd Edition, Instrument Society of America, 1994.

Reference Books:

1. Arun K. Ghosh, Introduction to measurements and Instrumentation, PHI, 4th Edition 2012.
2. A.D. Helfrick and W.D.Cooper, Modern Electronic Instrumentation & Measurement Techniques, PHI – 2001
3. Hermann K.P. Neubert, "Instrument Transducers" 2nd Edition, Oxford University Press.

1
UNIT

Sensors and Transducers-I

CONTENTS

PART-1

Definition, Classification of Transducers.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. Define sensor and transducer with a common example.

Answer

A. Sensor :

1. It is defined as an element which produces signal relating to the quantity being measured.
2. It can also be defined as "A device which provides a usable output in response to a specified measurand."

B. Transducer :

1. It is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measurand into a usable output by using a transduction principle.
2. It can also be defined as a device that converts a signal from one form of energy to another form.

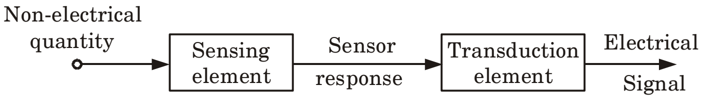


Fig. 1.1.1.

C. Example :

1. A wire of constantan alloy (copper-nickel 55-45 % alloy) can be called as a sensor because variation in mechanical displacement (tension or compression) can be sensed as change in electric resistance.
2. This wire becomes a transducer with appropriate electrodes and input-output mechanism attached to it. Thus we can say that 'sensors are transducers'.

Que 1.2. Explain the characteristics of sensors.

Answer

A. **Static characteristics :**

a. **Accuracy specified by inaccuracy or usually error :** It is given by,

$$\varepsilon_n \% = \frac{x_m - x_t}{x_t} \times 100$$

where,
t stands for true value,
m for measured value, and
x stands for measurand.

b. **Precision :** It describes how far a measured quantity is reproducible as also how close it is to the true value.

c. **Resolution :**

1. It is defined as the smallest incremental change in the input that would produce a detectable change in the output. This is often expressed as percentage of the measured range (MR).
2. The measured range is defined as the difference of the maximum input and the minimum input, that is, $MR = x_{max} - x_{min}$.
3. For a detectable output Δy, if the minimum change in x is $(\Delta x)_{min}$, then the maximum resolution is

$$R_{max}(\%) = \frac{100(\Delta x)_{min}}{MR}$$

d. **Minimum detectable signal (MDS) :**

1. Noise in a sensor occurs because of many reasons—internal sources or fluctuations due to externally generated mechanical and electromagnetic influences.
2. Noise is considered in detail, on individual merits and often an equivalent noise source is considered for test purposes.
3. If the input does not contain any noise, the minimum signal level that produces a detectable output from the sensor is determined by its noise performance or noise characteristics.
4. For this, the equivalent noise source is connected to the input side of the ideal noiseless sensor to yield an output which is the actual output level of the sensor.
5. The MDS is then taken as the RMS equivalent input noise. When signal exceeds this value, it is called a detectable signal.

e. **Threshold :** At the zero value condition of the measurand, the smallest input change that produces a detectable output is called the threshold.

f. **Sensitivity :**

1. It is the ratio of the incremental output to incremental input, *i.e.*,

$$S = \frac{\Delta y}{\Delta x}$$

2. In normalized form, this can be written as

$$S_n = \frac{\Delta y / \Delta x}{y / x}$$

g. Selectivity and specificity :

1. The output of a sensor may change when afflicted by environmental parameters or other variables and this may appear as an unwanted signal. The sensor is then said to be non-selective.
2. It is customary to define selectivity or specificity by considering a system of n sensors each with output $y_k (k = 1, 2, ..., n)$.
3. The partial sensitivity S_{jk} is defined as the measure of sensitivity of the k^{th} sensor to these other interfering quantities or variables x_j as :

$$S_{jk} = \frac{\Delta y_k}{\Delta x_j}$$

4. A selectivity matrix would thus be obtained with S_{jk} as the jk^{th} entry. An ideally selective system will have only diagonal entries S_{jj} in the selectivity matrix.
5. An ideally specific system is characterized by having a matrix with a single entry in the diagonal. Following relationship describes selectivity, λ :

$$\lambda = \min \left[\frac{S_{jj}}{\sum_{k=1}^{n} |S_{jk}| - |S_{jj}|} \right] \quad j = 1, 2, ..., n$$

h. Nonlinearity : Nonlinearity can, be specified in two different ways,

1. Deviation from best fit straight line obtained by regression analysis.
2. Deviation from a straight line joining the end points of the scale.

i. Hysteresis : It is the difference in the output y of the sensor for a given input x, when x reaches this value in upscale and downscale directions. The causes are different for different types of sensors. In magnetic types, for example, it is the lag in alignment of the dipoles, in semiconductor types; it is the injection type slow traps producing the effect, and so on.

j. Output impedance : It is a characteristic to be considered on individual merit. It causes great restriction in interfacing, specifically in the choice of the succeeding stage.

k. Isolation and grounding :

1. Isolation is necessary to eliminate or at least reduce undesirable electrical, magnetic, electromagnetic, and mechanical coupling among various parts of the system and between the system and the environment.
2. Similarly, grounding is necessary to establish a common node among different parts of the system with respect to which potential of any point in the system remains constant.

B. Dynamic characteristics :

1. These involve determination of transfer function, frequency response, impulse response and step response and then evaluation of the time-dependent outputs.

2. The two important parameters in this connection are :
a. Fidelity determined by dynamic error.
b. Speed of response determined by lag.
3. For determining the dynamic characteristics, different specified inputs are given to the sensor and the response characteristics are studied.
4. With step input, the specifications in terms of the time constant of the sensor are made.
5. Generally, the sensor is a single time constant device and if this time constant is t, then one has the specifications as given in Table 1.2.1.

Table 1.2.1. % Response time of the sensors

% Response time	**Value in terms of τ**
$t_{0.1}$ or 10	0.104 τ
$t_{0.5}$ or 50	0.693 τ
$t_{0.9}$ or 90	2.303 τ

6. This gives $t_{0.9}/t_{0.5} = 3.32$ which is taken as a quick check relation. Impulse response as well as its fourier transform are also considered for time domain as well as frequency domain studies.

Que 1.3. **Give the classification of sensors.**

Answer

Sensors can be classified based on the quantity being measured :

1. **Displacement, position and proximity sensors :**
i. Potentiometer
ii. Strain-gauged element
iii. Capacitive element
iv. Differential transformers
v. Eddy current proximity sensors
vi. Inductive proximity switch
vii. Optical encoders
viii. Pneumatic sensors
ix. Proximity switches (magnetic)
x. Hall effect sensors.
2. **Velocity and motion :**
i. Incremental encoder
ii. Tachogenerator
iii. Pyroelectric sensors.

3. Force :

i. Strain gauge load cell.

4. Fluid pressure :

i. Diaphragm pressure gauge

ii. Capsules, bellows, pressure tubes

iii. Piezoelectric sensors

iv. Tactile sensor.

5. Liquid flow :

i. Orifice plate

ii. Turbine meter.

6. Liquid level :

i. Floats

ii. Differential pressure.

7. Temperature :

i. Bimetallic strips

ii. Resistance temperature detectors

iii. Thermistors

iv. Thermo-diodes and transistors

v. Thermocouples

vi. Light sensors

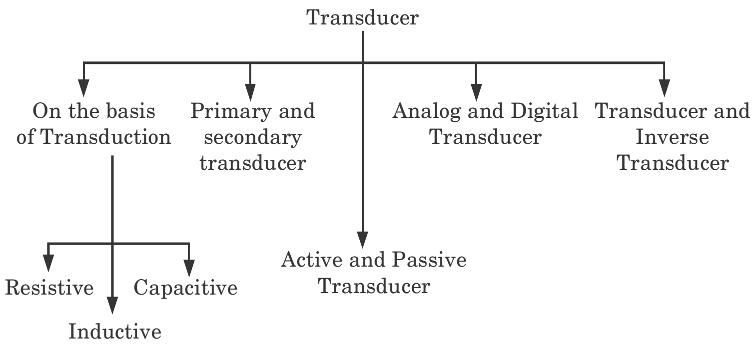
vii. Photo diodes

viii. Photo resistors

ix. Photo transistor.

Que 1.4. **Classify transducers.**

Answer



A. Classification based on the principle of transduction :

i. The transducer is classified by the transduction medium.

ii. The transduction medium may be resistive, inductive or capacitive depends on the conversion process that how input transducer converts the input signal into resistance, inductance and capacitance respectively.

B. Primary and secondary transducer :

a. Primary transducer :

i. The transducer consists of mechanical as well as the electrical devices.

ii. The mechanical devices of the transducer change the physical input quantities into a mechanical signal. This mechanical device is known as the primary transducers.

b. Secondary transducer :

i. The secondary transducer converts the mechanical signal into an electrical signal.

ii. The magnitude of the output signal depends on the input mechanical signal.

C. Passive and active transducer :

a. Passive transducer :

i. The transducer which requires the power from an external supply source is known as the passive transducer.

ii. They are also known as the external power transducer.

iii. The capacitive, resistive and inductive transducers are the example of the passive transducer.

b. Active transducer :

i. The transducer which does not require the external power source is known as the active transducer.

ii. Such type of transducer develops theirs owns voltage or current, hence known as a self-generating transducer.

iii. The output signal is obtained from the physical input quantity.

D. Analog and digital transducer :

a. Analog transducer :

i. The analog transducer changes the input quantity into a continuous function.

ii. The strain gauge, LVDT, thermocouple and thermistor are the examples of the analog transducer.

b. Digital transducer : These transducers convert an input quantity into a digital signal or in the form of the pulse. The digital signals work on high or low power.

E. Transducer and inverse transducer :

a. **Transducer :** The device which converts the non-electrical quantity into an electric quantity is known as the transducer.

b. **Inverse transducer :** The transducer which converts the electric quantity into a physical quantity, such type of transducers is known as the inverse transducer. The transducer has high electrical input and low non-electrical output.

PART-2

Advantages and Disadvantages of Electrical Transducers.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.5. What are the various advantages of transducers ?

Answer

1. Electrical amplification and attenuation can be done easily and that to with a static transducer device.
2. No moving mechanical parts are involved in the electrical systems. Therefore there is no question of mechanical wear and tear and no possibility of mechanical failure.
3. The electric or electronic system can be controlled with a very small electric power.
4. Electrical signal obtained from electrical transducer can be easily processed (mainly amplified) and brought to a level suitable for output device which may be an indicator or recorder.
5. With the advent of IC technology, the electronic systems have become extremely small in size, requiring small space for their operation.

Que 1.6. Give the various disadvantages of transducers.

Answer

1. While designing the circuit the effects of ageing and drifts of parameters of active components must be considered. This makes the design complicated.
2. The electrical transducer is sometimes less reliable than mechanical type because of the ageing and drift of the active components.

3. Using negative feedback technique, the accuracy of measurement and the stability of the system are improved, but all at the expense of increased circuit complexity, more space, and obviously, more cost.

Que 1.7. What are the factors to be considered while selecting transducer ?

Answer

1. It should have high input impedance and low output impedance, to avoid loading effect.
2. It should have good resolution over is entire selected range.
3. It must be highly sensitive to desired signal and insensitive to unwanted signal.
4. It should be preferably small in size.
5. It should be able to work in corrosive environment.
6. It should be able to withstand pressure, shocks, vibrations etc.
7. It must have high degree of accuracy and repeatability.
8. Selected transducer must be free from errors.

Que 1.8. What are the applications of transducers in various fields ?

Answer

1. Electromagnetic :

i. Antennas
ii. Hall-effect sensors
iii. Disk read and write heads
iv. Magnetic cartridges.

2. Electromechanical :

i. Accelerometers
ii. Pressure sensors
iii. Galvanometers
iv. LVDT
v. Load cells
vi. Potentiometers.

3. Electrochemical :

i. Hydrogen sensors
ii. Oxygen sensors
iii. pH meters.

4. Electroacoustic :

i. Speakers (Loudspeakers, earphones)
ii. Microphones
iii. Ultrasonic transceivers
iv. Piezoelectric crystals
v. Sonar
vi. Tactile transducers.

5. Photoelectric :

i. LED
ii. Incandescent and fluorescent lamps
iii. Photovoltaic cells
iv. Laser diodes
v. Photoresistors (LDR)
vi. Phototransistors.

6. Thermoelectric :

i. Thermistors
ii. Thermocouples
iii. RTD (Resistance temperature detectors).

7. Radioacoustic :

i. Radio transmitters and receivers
ii. G-M tube (Geiger-Muller tube).

PART-3

Measurement of Displacement Using Potentiometer, LVDT & Optical Encoder.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.9. What is potentiometer? Discuss about its working.

Answer

1. A potentiometer or variable electrical resistance transducer is composed of a sliding contact and a winding. The winding is made of many turns of wire, wrapped around a non-conducting substrate.

2. Output signals from such a device can be realized by imposing a known voltage across the total resistance of the winding and by measuring the output voltage, which is proportional to the fraction of the distance the contact point has moved along the winding.
3. Potentiometers can also be configured in a rotary form, with numerous total revolutions of the contact possible in a helical arrangement.
4. The output from the sliding contact as it moves along the winding is actually discrete; the resolution is limited by the number of turns per unit distance.
5. The loading errors associated with voltage-dividing circuits should be considered in choosing a measuring device for the output voltage.
6. During the sensing operation, a voltage V_s is applied across the resistive element. A voltage divider circuit is formed when slider comes into contact with the wire.
7. The output voltage (V_A) is measured as shown in Fig. 1.9.1. The output voltage is proportional to the displacement of the slider over the wire.
8. Then the output parameter displacement is calibrated against the output voltage V_A.

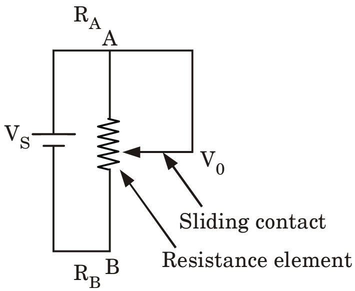


Fig. 1.9.1. Potentiometer : electric circuit.

$$V_A = I R_A \quad ...(1.9.1)$$

But $$I = V_S/(R_A + R_B) \quad ...(1.9.2)$$

Putting the value of I in eq. (1.9.1), we get

Therefore $$V_A = V_S R_A/(R_A + R_B) \quad ...(1.9.3)$$

As we know that, $R = \rho L / A$

where, ρ = Electrical resistivity.

L = Length of resistor.

A = Area of cross section

$$V_A = V_S L_A/(L_A + L_B) \quad ...(1.9.4)$$

Que 1.10. **Describe briefly with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a cell.**

Answer

1. Measurement of internal resistance of a cell using potentiometer.

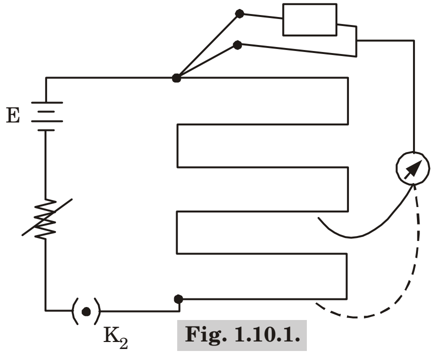


Fig. 1.10.1.

2. The cell of emf, E (internal resistance r) is connected across a resistance box (R) through key K_2.

$$E = \phi l_1 \qquad ...(1.10.1)$$

3. When K_2 is open balance length is obtained at length $AN_1 = l_1$

$\therefore$
$$V = \phi l_2 \qquad ...(1.10.2)$$

4. From eq. (1.10.1) and (1.10.2), we get

$$\frac{E}{V} = \frac{l_1}{l_2} \qquad ...(1.10.3)$$

$$E = l(r + R)$$

$$V = lR$$

$$\frac{E}{V} = \frac{r + R}{R} \qquad ...(1.10.4)$$

5. Comparing eq. (1.10.3) and (1.10.4), we get

$$\frac{R + r}{R} = \frac{l_1}{l_2}$$

$$r = R\left(\frac{l_1}{l_2} - 1\right)$$

$\because$
$$\frac{E}{V} = \frac{l_1}{l_2}$$

So
$$r = R\left[\frac{E}{V} - 1\right]$$

6. We known l_1, l_2 and E so we can calculate r.

Que 1.11. **A potentiometer wire of length 1 m has a resistance of 10 Ω. It is connected to a 6 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 40 cm.**

Answer

Given : $l = 1$ m = 100 cm, $R = 10\ \Omega$, $E_1 = 6$ V, $R_1 = 5\ \Omega$, $x = 40$ cm

To Find : Emf of the primary cell.

1. Current, $$I = \frac{E_1}{R + R_1} = \frac{6}{10+5} = \frac{6}{15}\ A$$
2. $$V_{AB} = IR = \frac{6}{15} \times 10 = \frac{60}{15} = 4\ \text{V}$$
3. Emf of the primary cell $= \dfrac{VAB}{l} \times x$
$$= \frac{4}{100} \times 40 = 1.6\ \text{V}$$

Que 1.12. **A potentiometer wire of length 1 m has a resistance of 5 Ω. It is connected to a 8 V battery in series with a resistance of 15 Ω. Determine the emf of the primary cell which gives a balance point at 60 cm.**

Answer

The procedure is same as Q. 1.11, Page 1–13E, Unit-1.

[**Answer :** Emf of the primary cell = 1.2 V]

Que 1.13. **Give the construction and working of LVDT for displacement measurement.**

Answer

A. Main features of construction :

1. The transformer consists of a primary winding P and two secondary windings S_1 and S_2 wound on a cylindrical former (which is hollow in nature and contains the core).
2. Both the secondary windings have an equal number of turns, and we place them on either side of primary winding.
3. The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
4. A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.

5. The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
6. The LVDT is placed inside stainless steel housing because it will provide electrostatic and electromagnetic shielding.
7. The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings as shown in Fig. 1.13.1.

B. Principle of operation and working :

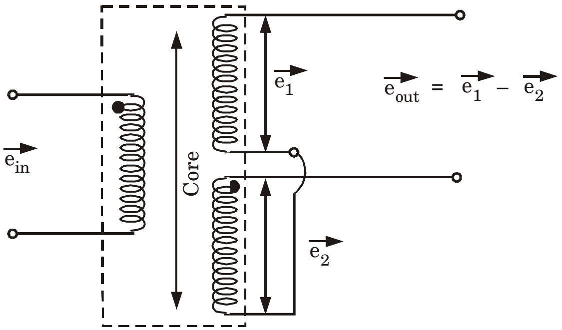


Fig. 1.13.1.

1. As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S_1 is e_1 and in the secondary S_2 is e_2. So the differential output is,

$$e_{out} = e_1 - e_2 \quad \text{...(1.13.1)}$$

2. Eq. (1.13.1) explains the principle of operation of LVDT.
3. Now three cases arise according to the locations of core which explains the working of LVDT :

a. Case I : When the core is at null position (for no displacement) :

i. When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings.

ii. So for no displacement the value of output e_{out} is zero as e_1 and e_2 both are equal. So it shows that no displacement took place.

b. Case II : When the core is moved to upward of null position (For displacement to the upward of reference point) :

In this case the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Due to this e_1 will be more as that of e_2. Due to this output voltage e_{out} is positive.

c. **Case III : When the core is moved to downward of null position (for displacement to the downward of the reference point) :**

In this case magnitude of e_2 will be more as that of e_1. Due to this output e_{out} will be negative and shows the output to downward of the reference point.

Que 1.14. What are the advantages and disadvantages of LVDT transducers ?

Answer

A. **Advantages :**

1. **High output and high sensitivity :** The LVDT gives a high output and a high sensitivity.
2. **Ruggedness :** These transducers can usually tolerate high degree of shock and vibrations especially when the core is spring loaded without any adverse effects.
3. **Low hysteresis :** LVDTs show a low hysteresis and hence repeatability is excellent under all conditions.
4. **Low power consumption :** Most of LVDTs consume power which is less than 1 W.

B. **Disadvantages :**

1. Relatively large displacements are required for appreciable differential output.
2. They are sensitive to stray magnetic fields but shielding is possible. This is done by providing magnetic shields with longitudinal slots.
3. Many a times, the transducer performance is affected by vibrations.
4. The receiving instrument must be selected to operate on AC signals or a demodulator network must be used if a DC output is required.
5. The dynamic response is limited mechanically by the mass of the core and electrically by the frequency of applied voltage.

Que 1.15. The output voltage of a LVDTs 1.5 V at maximum displacement. At a load of 0.5 MΩ, the deviation from linearity is maximum and it is ± 0.003 V from a straight line through origin. Find the linearity at the given load.

Answer

Given : Output voltage = 1.5 V, Deviation = ± 0.003 V.

To Find : Linearity.

$$\text{Percentage linearity} = \pm \frac{0.003}{1.5} \times 100 = \pm 0.2\ \%$$

Que 1.16. **The output of an LVDT is connected to a 5 V voltmeter through an amplifier whose amplification factor is 250. An output of 2 mV appears across the terminals of LVDT when the core moves through a distance of 0.5 mm. Calculate the sensitivity of the LVDT and that of the whole set-up. The milli-voltmeter scale has 100 divisions. The scale can be read to 1/5 of a division. Calculate the resolution of the instrument in mm.**

Answer

Given : Amplification factor = 250, Output voltage = 2 mV, Distance = 0.5 mm.

To Find : Sensitivity, Resolution.

1. Sensitivity of LVDT

$$= \frac{\text{Output voltage}}{\text{Displacement}}$$

$$= \frac{2 \times 10^{-3}}{0.5} = 4 \times 10^{-3} \text{ V/mm}$$

$$= 4 \text{ mV/mm}$$

2. Sensitivity of instrument

$$= \text{Amplification factor} \times \text{sensitivity of LVDT}$$

$$= 250 \times 4 \times 10^{-3}$$

$$= 1 \text{ V/mm} = 1000 \text{ mV/mm}$$

$$1 \text{ scale division} = \frac{5}{100} \text{ V} = 50 \text{ mV}$$

3. Minimum voltage that can be read on the voltmeter

$$= (1/5) \times 50 = 1 \text{ mV}$$

4. Resolution of instrument

$$= 1 \times \frac{1}{1000} = 1 \times 10^{-3} \text{ mm}$$

Que 1.17. **A steel cantilever is 0.25 m long, 20 mm wide and 4 mm thick.**

a. Calculate the value of deflection at the free end for the cantilever when a force of 25 N is applied at this end. The modulus of elasticity for steel is 200 GN/m.

b. An LVDT with a sensitivity of 0.5 V/mm is used. The voltage is read on a 10 V voltmeter having 100 divisions. Two lengths of a division can be read with certainty.

c. Calculate the minimum and maximum value of force that can be measured with this arrangement.

Answer

a.

1. Moment of area of cantilever

$$I = \frac{1}{12}bt^3$$

$$= \frac{1}{12} \times (0.02) \times (0.004)^3$$

$$= 0.107 \times 10^{-9}\ \text{m}^4$$

2. Deflection $x = \dfrac{Fl^3}{3EI}$

$$= \frac{25 \times (0.25)^3}{3 \times 200 \times 10^9 \times 0.107 \times 10^{-9}}$$

$$= 6.08 \times 10^{-3}\ \text{m} = 6.08\ \text{mm}$$

b.

1. Deflection per unit force

$$\frac{x}{F} = \frac{6.08}{25} = 0.2432\ \text{mm/N}$$

2. Overall sensitivity of measurement system :

$$= 0.2432\ \text{mm/N} \times 0.5\ \text{V/mm}$$

$$= 0.1216\ \text{V/N}$$

$$1\ \text{scale division} = (10/100) = 0.1\ \text{V}$$

3. Since two tenths of a scale division can be read with certainty, resolution

$$= (2 / 10) \times 0.1 = 0.02\ \text{V}$$

c.

1. Minimum force that can be measured

$$= 0.02 / 0.1216 = 0.1645\ \text{N}$$

2. Maximum force that can be measured

$$= (10/0.1216) = 82.2\ \text{N}$$

Que 1.18. Explain the construction and working of optical encoder for displacement measurement with suitable diagram.

Answer

1. An optical encoder is an electromechanical device which has an electrical output in digital form proportional to the angular position of the input shaft.
2. Optical encoders enable an angular displacement to be converted directly into a digital form. An optical encoder is an angular position sensor.
3. It has a shaft mechanically coupled to an input driver which rotates a disc rigidly fixed to it.
4. Light from infrared emitting diodes reaches the infrared receivers through the transparent slits of the rotating disc.
5. Then electronically, the signal is amplified and converted into digital form. This signal is then transmitted to the data processor.
6. It comprises of a disc with three concentric tracks of equally spaced holes.
7. Three light sensors are employed to detect the light passing through the holes.
8. These sensors produce electric pulses which give the angular displacement of the mechanical element e.g. shaft on which the optical encoder is mounted.

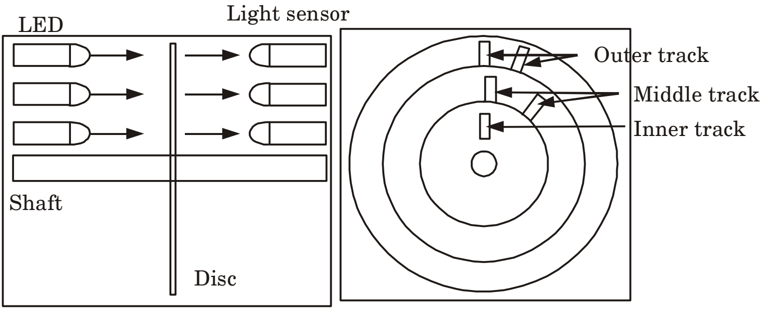


Fig. 1.18.1. Construction and working of optical encoder.

9. The inner track has just one hole which is used locate the 'home' position of the disc. The holes on the middle track offset from the holes of the outer track by one-half of the width of the hole. This arrangement provides the direction of rotation to be determined.
10. When the disc rotates in clockwise direction, the pulses in the outer track lead those in the inner; in counter clockwise direction they lag behind.
11. The resolution can be determined by the number of holes on disc. With 100 holes in one revolution, the resolution would be,

$$360°/100 = 3.6°$$

PART-4

Measurement of Force Using Load Cells and Strain Gauges.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.19. **What are load cells ? What are its types ?**

Answer

A. **Load cell :** A load cell is a force gauge that consists of a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured.

B. **Types :**

a. Pneumatic
b. Hydraulic
c. Strain gauge
d. Piezoresistive
e. Magnetostrictive.

Que 1.20. **What is strain gauge? Give its principle.**

Answer

1. Strain gauge load cells are a type of load cell where a strain gauge assembly is positioned inside the load cell housing to convert the load acting on them into electrical signals.
2. The weight on the load cell is measured by the voltage fluctuation caused in the strain gauge when it undergoes deformation.
3. The resistance of a strain gauge varies with applied force and, it converts parameters such as force, pressure, tension, weight, etc. into a change in resistance that can be measured later on.
4. Whenever an external force is applied to an object, it tends to change its shape and size thereby, altering its resistance.
5. The stress is the internal resisting capacity of an object while a strain is the amount of deformation experienced by it.
6. Any basic strain gauge consists of an insulating flexible backing that supports a metallic foil pattern.

7. The gauge is attached to the object under stress using an adhesive. The deformation in the object causes the foil to get distorted which ultimately changes the electrical resistivity of the foil.
8. This change in resistivity is measured by a Wheatstone bridge which is related to strain by a quantity called, gauge factor.
9. A strain gauge works on the principle of electrical conductance and its dependence on the conductor's geometry.
10. Whenever a conductor is stretched within the limits of its elasticity, it doesn't break but, gets narrower and longer.
11. Similarly, when it is compressed, it gets shorter and broader, ultimately changing its resistance.

Que 1.21. **How do you measure strain with a strain gauge?**

Answer

1. Strain gauges work on the principle of the conductor's resistance which gives you the value of gauge factor by the formula:

   Gauge factor (GF) = $[\Delta R / (RG * \varepsilon)]$
2. Now, the change in the strain of an object is a very small quantity which can only be measured using a Wheatstone bridge.
3. A Wheatstone bridge is a network of four resistors with an excitation voltage, V_{EX} that is applied across the bridge. The Wheatstone bridge is the electrical equivalent of two parallel voltage divider circuits with R_1 and R_2 as one of them and R_3 and R_4 as the other one.

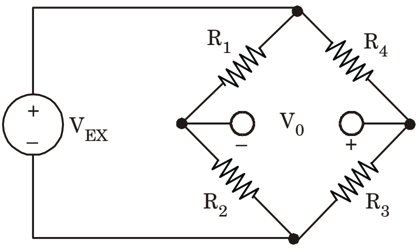


Fig. 1.21.1. Strain gauge circuit.

4. The output of the Wheatstone circuit is given by :

$$V_O = [(R_3/R_3 + R_4) - (R_2/R_1 + R_2)] \times V_{EX} \quad ...(1.21.1)$$

5. Whenever $R_1/ R_2 = R_4/ R_3$, the output voltage V_O is zero and the bridge is said to be balanced. Any change in the values of R_1, R_2, R_3, and R_4 will, therefore, change the output voltage.
6. If you replace the R_4 resistor with a strain gauge, even a minor change in its resistance will change the output voltage V_{EX} which is a function of strain.

7. The equivalent strain output and voltage output always have a relation of 2 : 1.
8. In a load cell, these resistors are replaced by strain gauges in alternating tension and compression measurements. When a force is applied to the load cell, the resistance in each strain gauge changes and V_O is measured.
9. From the resulting data, V_O can be easily determined using the eq. (1.21.1).

Que 1.22. **Explain the characteristics of strain gauges.**

Answer

1. They are highly precise and don't get influenced due to temperature changes. However, if they do get affected by temperature changes, a thermistor is available for temperature corrections.
2. They are ideal for long distance communication as the output is an electrical signal.
3. Strain gauges require easy maintenance and have a long operating life.
4. The production of strain gauges is easy because of the simple operating principle and a small number of components.
5. The strain gauges are suitable for long-term installation. However, they require certain precautions while installing.
6. All the strain gauges are hermetically sealed and made up of stainless steel thus, waterproof.
7. They are fully encapsulated for protection against handling and installation damage.
8. The remote digital readout for strain gauges is also possible.

Que 1.23. **Give the applications of strain gauges.**

Answer

1. Strain gauges are widely used in experimental stress analysis and diagnosis on machines and failure analysis.
2. They are basically used for multi-axial stress fatigue testing, proof testing, residual stress and vibration measurement, torque measurement, bending and deflection measurement, compression and tension measurement and strain measurement.
3. Strain gauges are primarily used as sensors for machine tools and safety in automotive.
4. In particular, they are employed for force measurement in machine tools, hydraulic or pneumatic press and as impact sensors in aerospace vehicles.

PART-5

Measurement of Pressure Using LVDT Based Diaphragm and Piezoelectric Sensor.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.24. **Explain the working of LVDT based diaphragm pressure sensor.**

Answer

1. The diaphragm pressure gauge uses the elastic deformation of diaphragm (*i.e.* membrane) instead of a liquid level to measure the difference between the unknown pressure and a reference pressure.

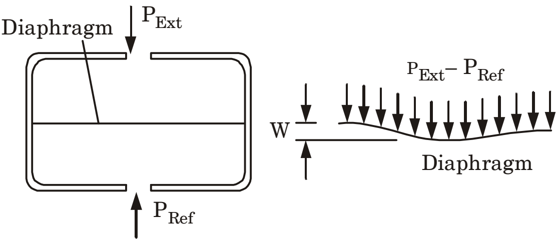


Fig. 1.24.1. Typical diaphragm pressure gauge.

2. A typical diaphragm pressure gauge contains a capsule divided by a diaphragm, as shown in Fig. 1.24.1.
3. One side of diaphragm is open to the external targeted pressure, $P_{Ext.}$, and the other side is connected to a known pressure, P_{Ref}. The pressure difference $P_{Ext} - P_{Ref}$, mechanically deflects the diaphragm.
4. The membrane of the diaphragm is connected to LVDT as shown in Fig. 1.24.2.
5. Due to application of pressure on diaphragm, a displacement is applied on core or primary winding of LVDT. As a result a voltage is induced in the secondary winding of LVDT. This induced voltage is directly proportional to applied pressure.

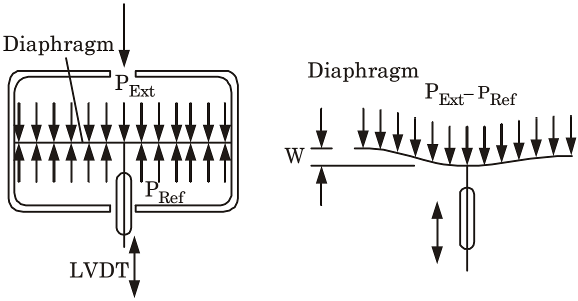


Fig. 1.24.2. LVDT-based diaphragm pressure gauge.

Que 1.25. **Discuss piezoelectric sensor or transducer with suitable diagram.**

Answer

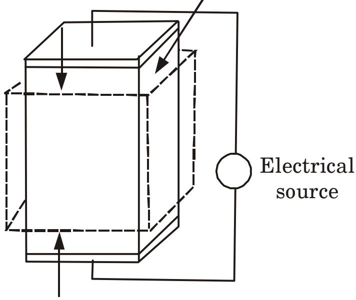


Fig. 1.25.1. Principle of working of piezoelectric sensor.

1. A piezoelectric transducer (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.
2. When pressure is applied to a crystal, it is elastically deformed. This deformation results in a flow of electric charge (which lasts for a period of a few seconds).
3. The resulting electric signal can be measured as an indication of the pressure which was applied to the crystal.

4. These sensors cannot detect static pressures, but are used to measure rapidly changing pressures resulting from blasts, explosions, pressure pulsations (in rocket motors, engines, compressors) or other sources of shock or vibration.
5. Piezoelectric sensor is used for the measurement of pressure, acceleration and dynamic-forces such as oscillation, impact, or high speed compression or tension.
6. It contains piezoelectric ionic crystal materials such as Quartz as shown in Fig. 1.25.1. On application of force or pressure these materials get stretched or compressed.
7. During this process, the charge over the material changes and redistributes. One face of the material becomes positively charged and the other negatively charged.
8. The net charge q on the surface is proportional to the amount x by which the charges have been displaced. The displacement is proportional to force. Therefore we can write,

$$q = kx = SF \qquad ...(1.25.1)$$

where k = Constant

S = Constant termed the charge sensitivity.

Que 1.26. **Give the advantages, disadvantages and applications of piezoelectric sensor or transducer.**

Answer

A. Advantages :

1. No need for an external force.
2. Easy to handle and use as it has small dimensions.
3. High-frequency response it means the parameters change very rapidly.

B. Disadvantages :

1. It is not suitable for measurement in static condition.
2. It is affected by temperatures.
3. The output is low so some external circuit is attached to it.
4. It is very difficult to give the desired shape to this material and also desired strength.

C. Applications :

1. In microphones, the sound pressure is converted into an electric signal and this signal is ultimately amplified to produce a louder sound.
2. Automobile seat belts lock in response to a rapid deceleration is also done using a piezoelectric material.

3. It is also used in medical diagnostics.
4. It is used in electric lighter used in kitchens. The pressure made on piezoelectric sensor creates an electric signal which ultimately causes the flash to fire up.
5. They are used for studying high-speed shock waves and blast waves.
6. It is used infertility treatment.
7. It is used in inkjet printers.

Que 1.27. **Explain the properties of piezoelectric crystal.**

Answer

Properties :

1. The desirable properties of piezo-electric materials are stability, high output, humidity and the ability to be formed into most desirable shape.
2. Quartz is the most stable piezo-electric material. However, its output is quite small. On the other hand, Rochelle salt provides the highest output but it can be worked over a limited humidity range and has to be protected against moisture. The highest temperature is limited to 45°C.

Que 1.28. **A quartz piezo-electric crystal having a thickness of 2 mm and voltage sensitivity of 0.055 V-m/N is subjected to a pressure of 1.5 MN/m^2. Calculate the voltage output. If the permittivity of quartz is 40.6 × 10^{-12} F/m. Calculate its charge sensitivity.**

Answer

Given : Thickness (t) = 2 mm, Voltage sensitivity (g) = 0.055 V-m/N, Pressure (P) = 1.5 MN/m^2, Permittivity of quartz = 40.6 × 10^{-12} F/m

To Find : Voltage output (E_0), Charge sensitivity (d)

1. Voltage output

$$E_0 = g \times t \times \rho = 0.055 \times 2 \times 10^{-3} \times 1.5 \times 10^6 = 165 \text{ V}$$

2. Charge sensitivity

$$\begin{aligned} d &= \varepsilon_0 \varepsilon_r g \\ &= 40.6 \times 10^{-12} \times 0.055 \\ &= 2.23 \times 10^{-12} \text{ C/N} = 2.23 \text{ pC/N} \end{aligned}$$

Que 1.29. **A piezo-electric crystal having dimensions of 5 mm × 5 mm × 1.5 mm and a voltage sensitivity of 0.055 V-m / N is used for force measurement. Calculate the force if the voltage developed is 100 V.**

Answer

Given : Voltage (E_0) = 100 V, Voltage sensitivity (g) = 0.055 V-m/N, Dimensions = 5 mm × 5 mm × 1.5 mm, Thickness (t) = 1.5 mm

To Find : Force (F).

1. Applied pressure,

$$P = \frac{E_0}{g \times t} = \frac{100}{0.055 \times 1.5 \times 10^{-3}} \text{ N/ m}^2$$

$$= 1.2 \text{ MN/m}^2$$

2. Force, $F = PA$

$$= 1.2 \times 10^6 \times 5 \times 5 \times 10^{-6} = 30 \text{ N}$$

Que 1.30. A barium titanate pickup has the dimensions of 5 mm × 5 mm × 1.25 mm. The force acting on it is 5 N. The charge sensitivity of barium titanate is 150 pC/N and its permittivity is 12.5 × 10^{-9} F/m. If the modulus of elasticity of barium titanate is 12 × 10^6 N/m^2, calculate the strain. Also calculate the charge and the capacitance.

Answer

Given : Force (F) = 5 N, Charge sensitivity (d) = 150 pC/N, Dimensions = 5 mm × 5 mm × 1.25 mm, Permittivity = 12.5 × 10^{-9} F/M, Modulus of elasticity = 12 × 10^6 N/m^2

To Find : Strain (ε), Charge (Q), Capacitance (C_p)

1. Area of plates,

$$A = 5 \times 5 \times 10^{-6} = 25 \times 10^{-6} \text{ m}^2$$

2. Pressure,

$$P = \frac{5}{25 \times 10^{-6}}$$

$$= 0.2 \text{ MN/m}^2$$

3. Voltage sensitivity

$$g = \frac{d}{\varepsilon_0 \varepsilon_r} = \frac{150 \times 10^{-12}}{12.5 \times 10^{-9}}$$

$$= 12 \times 10^{-3} \text{ Vm/N}$$

4. Voltage generated $E_0 = g \times t \times \rho$

$$= 12 \times 10^{-3} \times 1.25 \times 10^{-3} \times 0.2 \times 10^6 = 3 \text{ V}$$

5. Strain $\varepsilon = \Delta t$

$$= \frac{\text{Stress}}{\text{Young's modulus}}$$

$$= \frac{0.2 \times 10^6}{12 \times 10^6} = 0.0167$$

6. Charge $Q = d \times F$

$$= 150 \times 10^{-12} \times 5 = 750 \text{ pC}$$

7. Capacitance $C_p = \frac{Q}{E_0} = \frac{750 \times 10^{-12}}{3} = 250 \text{ pF}$

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Define sensor and transducer with a common example.

Ans. Refer Q. 1.1.

Q. 2. Classify transducers.

Ans. Refer Q. 1.4.

Q. 3. What are the various advantages of transducers ?

Ans. Refer Q. 1.5.

Q. 4. Give the various disadvantages of transducers.

Ans. Refer Q. 1.6.

Q. 5. What is potentiometer ? Discuss about its working.

Ans. Refer Q. 1.9.

Q. 6. Describe briefly with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a cell.

Ans. Refer Q. 1.10.

Q. 7. A potentiometer wire of length 1 m has a resistance of 10 Ω. It is connected to a 6 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 40 cm.

Ans. Refer Q. 1.11.

Q. 8. What are the advantages and disadvantages of LVDT transducers ?

Ans. Refer Q. 1.14.

Q. 9. A steel cantilever is 0.25 m long, 20 mm wide and 4 mm thick.

a. Calculate the value of deflection at the free end for the cantilever when a force of 25 N is applied at this end. The modulus of elasticity for steel is 200 GN/m.

b. An LVDT with a sensitivity of 0.5 V/mm is used. The voltage is read on a 10 V voltmeter having 100 divisions. Two lengths of a division can be read with certainty.

c. Calculate the minimum and maximum value of force that can be measured with this arrangement.

Ans. Refer Q. 1.17.

Q. 10. Explain the construction and working of optical encoder for displacement measurement with suitable diagram.

Ans. Refer Q. 1.18.

☺☺☺

2 UNIT

Sensors and Transducers-II

CONTENTS

PART-1

Measurement of Temperature Using Thermistors, Thermocouples and RTD.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. Explain the construction and characteristics of thermistor.

Answer

A. Thermistor :

1. A thermistor (or thermal resistor) is defined as a type of resistor whose electrical resistance varies with changes in temperature.
2. Although all resistors' resistance will fluctuate slightly with temperature, a thermistor is particularly sensitive to temperature changes.
3. Thermistors follow the principle of decrease in resistance with increasing temperature.
4. The material used in thermistor is generally a semiconductor material such as a sintered metal oxide (mixtures of metal oxides, chromium, cobalt, iron, manganese and nickel) or doped polycrystalline ceramic containing barium titanate ($BaTiO_3$) and other compounds.
5. As the temperature of semiconductor material increases the number of electrons able to move about increases which results in more current in the material and reduced resistance.
6. Thermistors are rugged and small in dimensions. They exhibit nonlinear response characteristics.
7. Thermistors are available in the form of a bead (pressed disc), probe or chip. Fig. 2.1.1 shows the construction of a bead type thermistor.

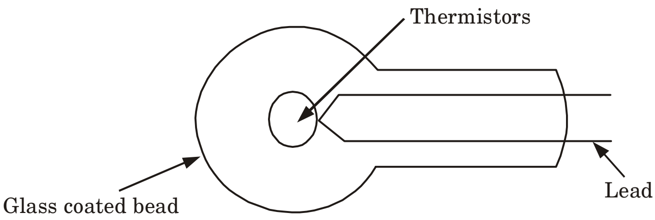


Fig. 2.1.1. Schematic of a thermistor.

8. It has a small bead of dimension from 0.5 mm to 5 mm coated with ceramic or glass material.
9. The bead is connected to an electric circuit through two leads. To protect from the environment, the leads are contained in a stainless steel tube.

B. Thermistor characteristics :

1. The relationship between temperature and resistance is given as :

$$R_1 = R_2 e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)} \quad ...(2.1.1)$$

where, R_1 = Resistance of the thermistor at absolute temperature T_1[K].

R_2 = Resistance of the thermistor at temperature T_2[K].

β = Constant depending upon the material of the transducer.

2. As we can see in the eq. (2.1.1) the relationship between temperature and resistance is highly nonlinear.
3. A standard NTC thermistor usually exhibits a negative thermal resistance temperature coefficient of about 0.05/°C.

Que 2.2. **Discuss the working principle of thermistor.**

Answer

A. Working principle :

1. The working principle of a thermistor is that its resistance is dependent on its temperature. We can measure the resistance of a thermistor using an ohmmeter.
2. As we have relationship between the temperature and the resistance of the thermistor by measuring the thermistor's resistance we can derive its temperature.

$$R_1 = R_2 e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

3. Change in resistance depends on the type of material used in the thermistor.
4. The relationship between a thermistor’s temperature and resistance is non-linear. A typical thermistor graph is shown in Fig. 2.2.1.

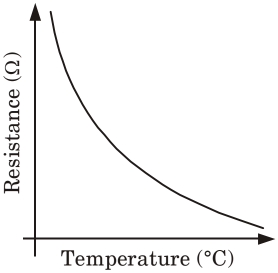


Fig. 2.2.1.

B. Applications of thermistors :

1. To monitor the coolant temperature and/or oil temperature inside the engine.
2. To monitor the temperature of an incubator.
3. Thermistors are used in modern digital thermostats.
4. To monitor the temperature of battery packs while charging.
5. To monitor temperature of hot ends of 3D printers.
6. To maintain correct temperature in the food handling and processing industry equipments.
7. To control the operations of consumer appliances such as toasters, coffeemakers, refrigerators, freezers, hair dryers, etc.

Que 2.3. Describe the construction and working of thermocouple.

Answer

A. Principle :

1. The basic principle of thermocouple is based on a law called Seebeck effect.
2. Seebeck effect states that when two dissimilar metals are in contact, a potential difference or a voltage is generated. That voltage is a function of temperature.

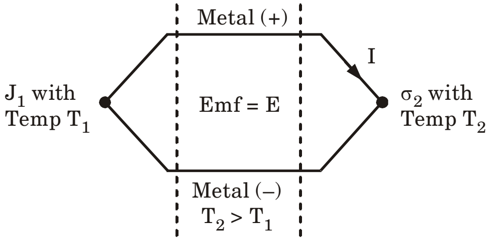


Fig. 2.3.1.

3. The device with two dissimilar metals is called thermocouple and the voltage is known as Seebeck voltage. It is mostly used for measurement of temperature.

B. Construction :

1. For the construction of thermocouple, a pair of two dissimilar metals is welded together at the junction point to form a thermocouple.
2. The junction J_1 and junction J_2 must be at different temperature.

C. Working :

1. In Fig. 2.3.1, when heat is applied to any one junction J_1 or J_2, of two dissimilar metals an emf or voltage is produced which is to be measured at the another junction.
2. These two dissimilar metals make an electric circuit, due to this potential difference, and a voltage is generated in the circuit.
3. Hence, a current (I) flows in the circuit. This current flows in the circuit as long as $T_1 > T_2$. The T_1 and T_2 are the temperatures at the junctions.
4. The voltage produced is a function of difference in temperature of the two junctions J_1 and J_2 and is given by,

$$V = a\Delta\theta$$

where, $\Delta\theta$ = Temperature difference of two functions

a = Constant.

C. Advantages :

i. Active transducer

ii. Cheaper

iii. They are convenient to measure the temperature at one particular point in a piece of apparatus.

D. Disadvantage :

i. Low accuracy.

Que 2.4. Explain the operation of RTD (Resistance Temperature Detector).

Answer

A. Operation :

1. A resistance thermometer or resistance temperature detector is a device which used to determine the temperature by measuring the resistance of pure electrical wire.

2. This wire is referred to as a temperature sensor. If we want to measure temperature with high accuracy, RTD is the only one solution in industries.
3. It has good linear characteristics over a wide range of temperature.
4. They are based on semiconductors which behave as a resistor. Semiconductor has negative temperature co-efficient.
5. When a temperature is applied on it, the resistance of device decreases with increase in temperature.
6. This decrement in resistance is inversely proportional to temperature.
7. Relation between resistance and temperature is given as,

$$R_{T1} = R_{T2} \exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

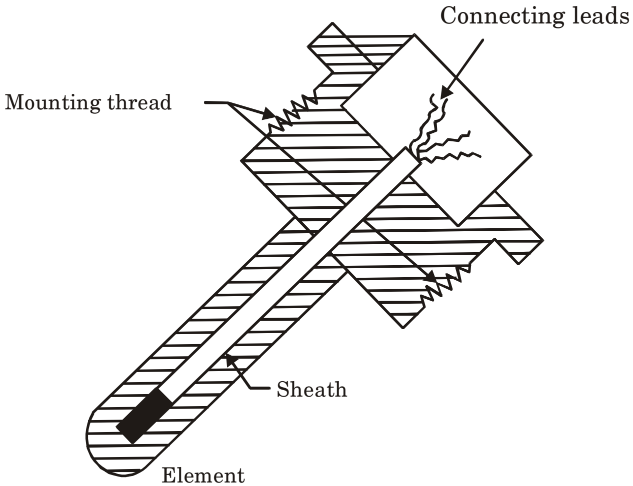


Fig. 2.4.1.

where, R_{T1} = Resistance of device at absolute temperature T_1 (K)

R_{T2} = Resistance of device at absolute temperature T_2 (K)

β = Constant which depends on material.

8. Fig. 2.4.2 shows the relationship between resistance and temperature of different materials.

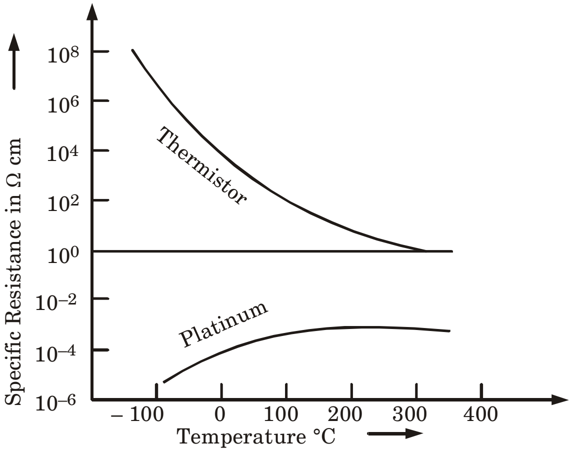


Fig. 2.4.2.

B. Advantages :

i. Highly sensitive

ii. Wide temperature range (– 100°C to 300°C)

iii. Small size.

Que 2.5. **Compare RTD, Thermocouple and Thermistor.**

Answer

Basis	RTD	Thermocouple	Thermistor
Temperature range	–260 to 850°C (–436 to 1562°F)	–270 to 1800°C (–454 to 3272°F)	–80 to 150°C (–112 to 302°F) (typical)
Sensor cost	Moderate	Low	Low
System cost	Moderate	High	Moderate
Stability	Best	Low	Moderate
Sensitivity	Moderate	Low	Best
Linearity	Best	Moderate	Poor
Specific for :	• General purpose sensing • Highest accuracy • Temperature averaging	• Highest temperatures	• Best sensitivity • Narrow ranges (e.g. medical) • Point sensing

Que 2.6. **A thermistor has a resistance of 3980 Ω at the ice point (0°C) and 794 Ω at 50°C. The resistance-temperature relationship is given by $R_T = aR_0 \exp(b/T)$. Calculate the constants a and b. Calculate the range of resistance to be measured in case the temperature varies from 40 °C to 100 °C.**

Answer

Given : Resistance at ice point $(R_0) = 3980\ \Omega$,
Resistance at 50 is $(R_t) = 794\ \Omega$.
To Find : Constant a and b, Range of resistance in case of temperature variation from 40 °C to 100 °C.

1. The resistance at ice point $R_0 = 3980\ \Omega$
2. Absolute temperature at ice point = 273 K

$$\therefore \quad 3980 = a \times 3980 \times \exp(b/273)$$

$$\text{or} \quad 1 = a \exp(b/273) \quad \text{...(2.6.1)}$$

3. Resistance at 50°C is $R_T = 794\ \Omega$.
4. Absolute temperature corresponding to 50 °C

$$T = 273 + 50° = 323 \text{ K}.$$

Hence,

$$794 = a \times 3980 \exp(b/323) \quad \text{...(2.6.2)}$$

$$= 3980\, a \exp(b/323)$$

Solving eq. (2.6.1) and eq. (2.6.2), we have,

$$a = 30 \times 10^{-6} \text{ and } b = 2843$$

5. Absolute temperature at 40 °C

$$= 273 + 40 = 313 \text{ K}.$$

6. Resistance at 40 °C

$$= 30 \times 10^{-6} \times 3980 \times \exp(2843/313) = 244\ \Omega$$

7. Absolute temperature at 100°C

$$= 273 + 100 = 373 \text{ K}$$

8. Resistance at 100 °C

$$= 30 \times 10^{-6} \times 3980 \times \exp(2843/373) = 1051\ \Omega$$

Que 2.7. **A thermocouple circuit uses a chromel-alumel thermocouple which gives an emf of 33.3 mV. When measuring a temperature of 800 °C with reference temperature 0 °C. The resistance of the meter coil, R_m is 50 Ω and a current of 0.1 mA gives full scale deflection. The resistance of junctions and leads, R_e is 12 Ω. Calculate :**

a. Resistance of the series resistance if a temperature of 800 °C is to give full scale deflection.

b. **The approximate error due to rise of 1 Ω in R_e.**
c. **The approximate error due to a rise of 10°C in the copper coil of the meter.**
The resistance temperature co-efficient of coil is 0.00426/°C.

Answer

Given : Emf (E) = 33.3 mV, Resistance of meter coil (R_m) = 50 Ω, Current (I) = 0.1 mA, Resistance of junction and leads (R_e) = 12 Ω.
To Find : Series resistance, Approximate error due to rise of 1 Ω, in (R_e), Approximate error due to a rise of 10 °C.

a. **Series resistance :**

1. $$\text{Emf } (E) = I(R_m + R_s + R_e)$$
or $$33.3 \times 10^{-3} = 0.1 \times 10^{-3} (50 + R_s + 12)$$
2. Series resistance (R_s) = 271 Ω

b. **Approximate error due to rise of 1 Ω in R_e :**

1. Current in the circuit with increased resistance
$$= \frac{33.3 \times 10^{-3}}{(50 + 271 + 1 + 12)} = 0.0997 \text{ mA}$$
2. Approximate error in temperature
$$= \frac{0.0997 - 0.1}{0.1} \times 800 = -2.4\ °\text{C}$$

c. **Approximate error due to a rise of 10 °C in the copper coil of the meter :**

1. Change in resistance of coil with a temperature increase of 10 °C
$$= 50 \times 0.00426 \times 10 = 2.13\ \Omega$$
2. Current in the circuit with increase resistance or coil
$$= \frac{33.33 \times 10^{-3}}{50 + 2.13 + 271 + 12} \text{ A} = 0.09936 \text{ mA}$$
3. Approximate error in temperature $= \dfrac{0.09936 - 0.1}{0.1} \times 800 = -5.12\ °\text{C}$

PART-2

Concept of Thermal Imaging.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.8. **What is thermal imaging ?**

Answer

1. Thermal imaging is a method of improving visibility of objects in a dark environment by detecting the object's infrared radiation and creating an image based on that information.
2. Thermal imaging, near-infrared illumination, low-light imaging and are the three most commonly used night vision technologies.
3. Thermal imaging works in environments without any ambient light. Thermal imaging can penetrate obscurants such as smoke, fog and haze.

Que 2.9. **How thermal imaging works ?**

Answer

1. All objects emit infrared energy (heat) as a function of their temperature. The infrared energy emitted by an object is known as its heat signature.
2. In general, the hotter an object is, the more radiation it emits. A thermal imager (also known as a thermal camera) is essentially a heat sensor that is capable of detecting tiny differences in temperature.
3. The device collects the infrared radiation from objects in the scene and creates an electronic image based on information about the temperature differences.
4. Because objects are rarely precisely the same temperature as other objects around them, a thermal camera can detect them and they will appear as distinct in a thermal image.
5. Thermal cameras more or less record the temperature of various objects in the frame, and then assign each temperature a shade of a colour, which lets you see how much heat its radiating compared to objects around it.
6. Thermal images are normally grayscale in nature: black objects are cold, white objects are hot and the depth of gray indicates variations between the two.
7. Some thermal cameras, however, add color to images to help users identify objects at different temperatures.
8. There are two common types of thermal-imaging devices:

a. Un-cooled :

i. This is the most common type of thermal-imaging device. The infrared-detector elements are contained in a unit that operates at room temperature.

ii. This type of system is completely quiet, activates immediately and has the battery built right in.

b. Cryogenically cooled :

i. More expensive and more susceptible to damage from rugged use, these systems have the elements sealed inside a container that cools them to below 32 F (zero °C).

ii. The advantage of such a system is the incredible resolution and sensitivity that result from cooling the elements.

iii. Cryogenically-cooled systems can "see" a difference as small as 0.2 F (0.1 °C) from more than 1,000 ft (300 m) away.

PART-3

Measurement of Position Using Hall Effect Sensors.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.10. What is Hall Effect sensor ? How it can be used to measure fluid level/position ?

Answer

A. Hall Effect Sensor :

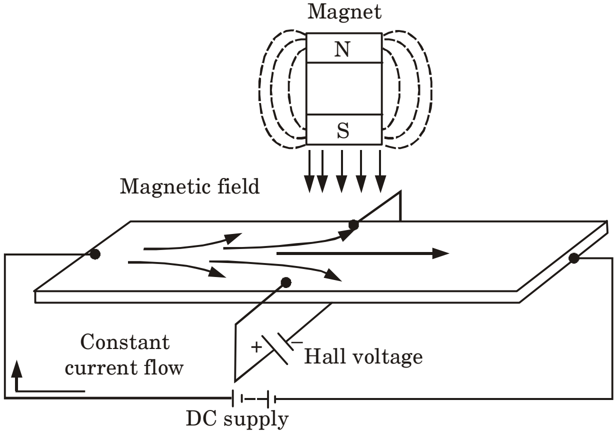


Fig. 2.10.1. Principle of working of hall effect sensor.

1. A Hall Effect sensor is a device that is used to measure the magnitude of a magnetic field. Its output voltage is directly proportional to the magnetic field strength through it.

2. Hall effect sensors consist basically of a thin piece of rectangular p-type semiconductor material such as Gallium Arsenide (GaAs), Indium Antimonide (InSb) or Indium Arsenide (InAs) passing a continuous current through itself.
3. When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab.
4. This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.
5. As these electrons and holes move side-wards a potential difference is produced between the two sides of the semiconductor material by the build-up of these charge carriers.
6. Then the movement of electrons through the semiconductor material is affected by the presence of an external magnetic field which is at right angles to it and this effect is greater in a flat rectangular shaped material.
7. Fig. 2.10.1 shows the principle of working of Hall Effect sensor. Hall Effect sensor work on the principle that when a beam of charge particles passes through a magnetic field, forces act on the particles and the current beam is deflected from its straight line path.
8. Thus one side of the disc will become negatively charged and the other side will be of positive charge.
9. This charge separation generates a potential difference which is the measure of distance of magnetic field from the disc carrying current.

B. Hall effect sensor to measure the fluid level in a container :

1. The typical application of Hall Effect sensor is the measurement of fluid level in a container.
2. The container comprises of a float with a permanent magnet attached at its top. An electric circuit with a current carrying disc is mounted in the casing.
3. When the fluid level increases, the magnet will come close to the disc and a potential difference generates. This voltage triggers a switch to stop the fluid to come inside the container.
4. These sensors are used for the measurement of displacement and the detection of position of an object. Hall Effect sensors need necessary signal conditioning circuitry.
5. They can be operated at 100 kHz. Their non-contact nature of operation, good immunity to environment contaminants and ability to sustain in severe conditions make them quite popular in industrial automation.

Que 2.11. **A Hall Effect transducer is used for the measurement of a magnetic field of 0.5 Wb/m^2. The 2 mm thick slab is made of Bismuth for which the Hall's co-efficient is – 1 × 10^{-6} V *m*/(*A* – *Wb m*$^{-2}$) and the current is 3 A. Calculate the output voltage.**

Answer

Given : Magnetic field (B) = 0.5 Wb/m^2, Thickness (t) = 0.2 mm,

Hall's co-efficient = – 1 × 10^{-6} Vm/A-Wbm^{-2}, Current (I) = 3 Amp.

To Find : Output voltage (E_H).

Output voltage,

$$E_H = \frac{K_H \times I \times B}{t}$$

$$= \frac{-1 \times 10^{-6} \times 3 \times 0.5}{2 \times 10^{-3}}$$

$$= -0.75 \times 10^{-3} \text{ V} = -0.75 \text{ mV}$$

PART-4

Proximity Sensor : Inductive, Capacitive and Photoelectric; Use of Proximity Sensor as Accelerometer and Vibration Sensor.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.12. **Explain inductive proximity sensors.**

Answer

1. These non-contact inductive proximity sensors detect ferrous targets, ideally mild steel thicker than one millimeter.
2. They consist of four major components :
   a. A ferrite core with coils
   b. An oscillator
   c. Schmitt trigger
   d. An output amplifier.

3. The oscillator creates a symmetrical, oscillating magnetic field that radiates from the ferrite core and coil array at the sensing face.
4. When a ferrous target enters this magnetic field, small independent electrical currents called eddy currents are induced on the metal's surface.
5. This changes the reluctance (natural frequency) of the magnetic circuit, which in turn reduces the oscillation amplitude.
6. As more metal enters the sensing field the oscillation amplitude shrinks, and eventually collapses. (This is the "Eddy Current Killed Oscillator" or ECKO principle).
7. The Schmitt trigger responds to these amplitude changes, and adjusts sensor output.
8. When the target finally moves from the sensor's range, the circuit begins to oscillate again, and the Schmitt trigger returns the sensor to its previous output.
9. If the sensor has a normally open configuration, its output is an ON signal when the target enters the sensing zone. With normally closed, its output is an OFF signal with the target present.
10. Output is then read by an external control unit (e.g., PLC, motion controller, smart drive) that converts the sensor ON and OFF states into useable information. Inductive sensors are typically rated by frequency, or ON/OFF cycles per second.
11. Their speeds range from 10 to 20 Hz in AC, or 500 Hz to 5 kHz in DC. Because of magnetic field limitations, inductive sensors have a relatively narrow sensing range from fractions of millimeters to 60 mm on average, though longer-range specialty products are available.
12. To accommodate close ranges in the tight confines of industrial machinery, geometric and mounting styles available include shielded (flush), unshielded (non-flush), tubular, and rectangular "flat-pack".
13. Tubular sensors, by far the most popular, are available with diameters from 3 to 40 mm.

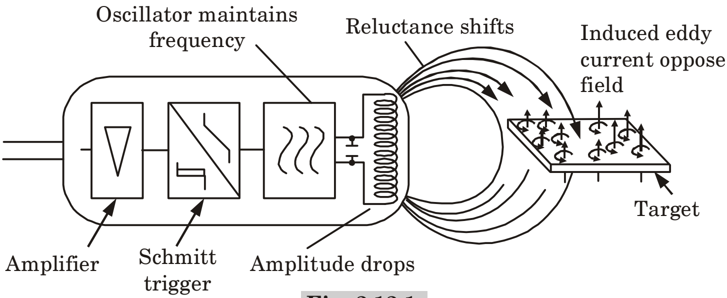


Fig. 2.12.1.

Que 2.13. Discuss capacitive proximity sensors.

Answer

1. Capacitive proximity sensors can detect both metallic and non-metallic targets in powder, granulate, liquid, and solid form.
2. This, along with their ability to sense through nonferrous materials, makes them ideal for sight glass monitoring, tank liquid level detection, and hopper powder level recognition.
3. In capacitive sensors, the two conduction plates (at different potentials) are housed in the sensing head and positioned to operate like an open capacitor.
4. Air acts as an insulator, at rest there is little capacitance between the two plates. Like inductive sensors, these plates are linked to an oscillator, a Schmitt trigger, and an output amplifier.
5. As a target enters the sensing zone the capacitance of the two plates increases, causing oscillator amplitude change, in turn changing the Schmitt trigger state, and creating an output signal.

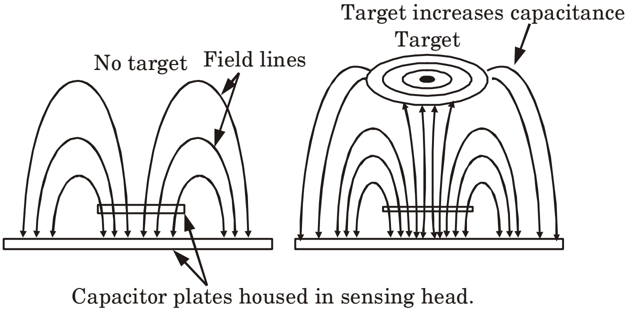


Fig. 2.13.1.

Que 2.14. Explain photoelectric sensors.

Answer

1. These sensors use light sensitive elements to detect objects and are made up of an emitter (light source) and a receiver.
2. Three types of photoelectric sensors are available. These are classified by the method in which light is emitted and delivered to the receiver as shown in Fig. 2.14.1.

a. **Direct reflection :** Emitter and receiver are housed together and use the light reflected directly off the object for detection.

b. **Reflection with reflector :** Emitter and receiver are housed together and requires a reflector. An object is detected when it interrupts the light beam between the sensor and reflector.

c. **Through beam :** Emitter and receiver are housed separately and detects an object when it interrupts the light beam between the emitter and receiver.

3. Photoelectric technology has so rapidly advanced they now commonly detect targets less than 1 mm in diameter, or from 60 m away.
4. All photoelectric sensors consist of a few of basic components: each has an emitter light source (light emitting diode, laser diode), a photodiode or phototransistor receiver to detect emitted light, and supporting electronics designed to amplify the receiver signal.
5. The emitter, sometimes called the sender, transmits a beam of either visible or infrared light to the detecting receiver.

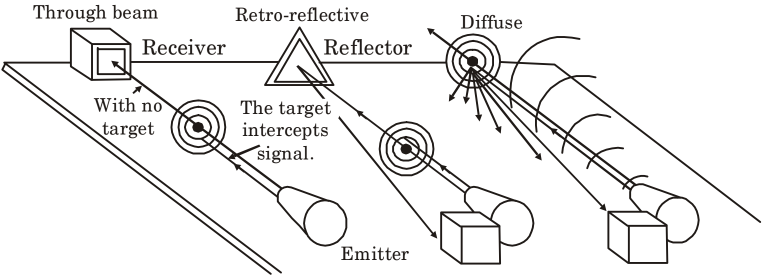


Fig. 2.14.1.

Que 2.15. **What are the types of vibration sensor ?**

Answer

1. **Accelerometer :** Accelerometers are devices that measure the vibration, or acceleration of motion of a structure.
2. **Strain gauge :**

i. A strain gauge is a sensor whose resistance varies with applied force.

ii. It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured.

3. **Eddy-current :**

i. Eddy-current sensors are non-contact devices that measure the position and/or change of position of a conductive component. These sensors operate with magnetic fields.

ii. The sensor has a probe which creates an alternating current at the tip of the probe.

Que 2.16. **How do we measure vibration with the help of proximity sensors ?**

Answer

1. Sensors used to measure vibration come in three basic types: displacement, velocity, and acceleration.
2. These sensors use electromagnetic eddy current technology to sense the distance between the probe tip and the rotating machine shaft.
3. The sensor itself is an encapsulated coil of wire, energized with high-frequency alternating current (AC).
4. The magnetic field produced by the coil induces eddy currents in the metal shaft of the machine, as though the metal piece were a short-circuited secondary coil of a transformer (with the probe's coil as the transformer primary winding).
5. The closer the shaft moves toward the sensor tip, the tighter the magnetic coupling between the shaft and the sensor coil, and the stronger the eddy currents.
6. The high-frequency oscillator circuit providing the sensor coil's excitation signal becomes loaded by the induced eddy currents.
7. Therefore, the oscillator's load becomes a direct indication of how close the probe tip is to the metal shaft.
8. This is not unlike the operation of a metal detector: measuring the proximity of a wire coil to any metal object by the degree of loading caused by eddy current induction.
9. In this design, the oscillator circuit providing sensor coil excitation is called a proximitor.
10. The proximitor module is powered by an external DC power source, and drives the sensor coil through a coaxial cable.
11. Proximity to the metal shaft is represented by a DC voltage output from the proximitor module.
12. Since the proximitor's output voltage is a direct representation of distance between the probe's tip and the shaft's surface, a "quiet" signal (no vibration) will be a pure DC voltage.
13. The probe is adjusted by a technician such that this quiescent voltage will lie between the proximitor's output voltage range limits.
14. Any vibration of the shaft will cause the proximitor's output voltage to vary in precise step.
15. An oscilloscope connected to this output signal will show a direct representation of shaft vibration, as measured in the axis of the probe.

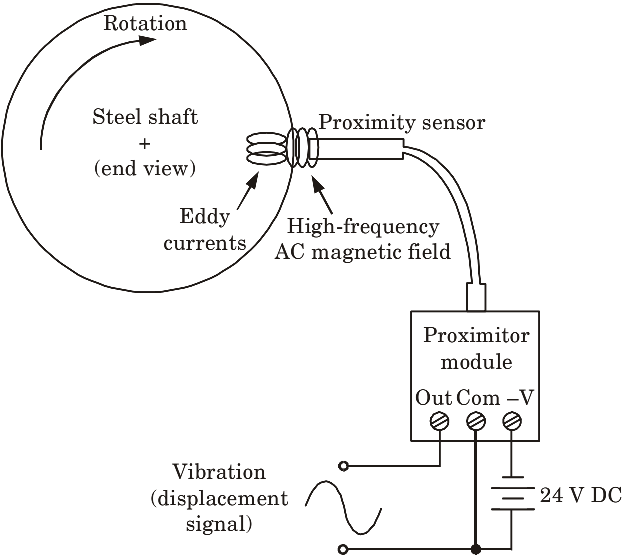


Fig. 2.16.1.

PART-5

Flow Sensor : Ultrasonic and Laser.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.17. **How ultrasonic flow sensor work ?**

Answer

1. Ultrasonic flow sensors use sound waves to determine the velocity of a fluid flowing in a pipe.
2. At no flow conditions, the frequencies of an ultrasonic wave transmitted into a pipe and its reflections from the fluid are the same.
3. Under flowing conditions, the frequency of the reflected wave is different due to the Doppler Effect.

4. When the fluid moves faster, the frequency shift increases linearly. The transmitter processes signals from the transmitted wave and its reflections to determine the flow rate.

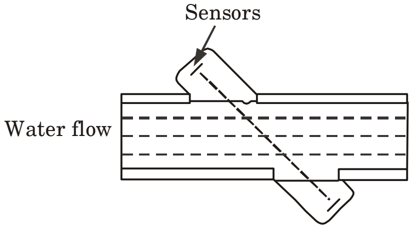


Fig. 2.17.1.

5. Transit time ultrasonic flow sensors send and receive ultrasonic waves between transducers in both the upstream and downstream directions in the pipe.
6. At no flow conditions, it takes the same time to travel upstream and downstream between the transducers.
7. Under flowing conditions, the upstream wave will travel slower and take more time than the (faster) downstream wave.
8. When the fluid moves faster, the difference between the upstream and downstream times increases.
9. The transmitter processes upstream and downstream times to determine the flow rate.

Que 2.18. **What are the advantages, disadvantages and applications of ultrasonic flow sensors ?**

Answer

A. Advantages :

1. It does not block the path of liquid flow.
2. The output of this meter is different for density, viscosity and temperature of the liquid.
3. The flow of liquid is bidirectional.
4. The dynamic response of this meter is good.
5. The output of this meter is in analog form.
6. Versatility is good.
7. There is no contact to liquid.

8. There is no leakage risk.
9. There are no moving parts, pressure loss.
10. High accuracy.

B. Disadvantages :

1. It is expensive as compared with other mechanical flow meters.
2. Design of this meter is complex.
3. Auditory parts of this meter are expensive.
4. These meters are complicated as compared with other meters.
5. It cannot measure cement or concrete pipes one they rusted.
6. It doesn't work once the pipe contains holes or bubbles in it.

C. Applications :

1. These meters are used in wastewater and dirty liquid applications.
2. These meters are used wherever chemical compatibility, less maintenance, and low-pressure drop are required.
3. These meters are used to measure the velocity of a liquid through ultrasound to analyze volume flow.
4. These meters measure the disparity between the transit time of ultrasonic pulses which transmits with the direction of liquid flow.
5. This is one kind of device for volumetric flow measurement for liquids as well as gases.

Que 2.19. **Discuss the working of laser (or optical) flow sensor.**

Answer

1. Laser (or optical) flow sensor work on the principle of optics *i.e.*, they measure the flow rate using light.
2. Usually, they employ a set-up consisting of a laser beam and photo-detectors.
3. Here, the particles of the gas flowing through the pipe scatter the laser beam to produce pulses which are picked-up by the receiver as shown in Fig. 2.19.1.
4. Then, the time between these signals is determined as one would know the distance by which the photo-detectors would be separated, which in turn leads to the measurement of the speed of gas.

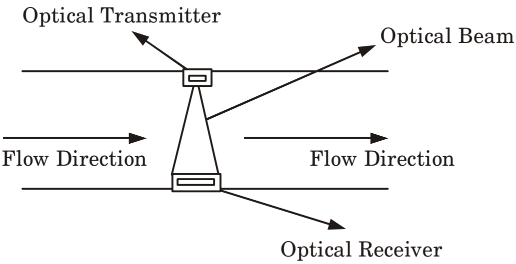


Fig. 2.19.1. Optical flow meter.

5. As these meters measure the actual speed of the particles constituting the gases, they remain unaffected by the thermal conditions and the variations in gas flow.
6. Hence, they are capable of providing highly accurate flow data even when the environment is most unfavourable

PART-6

Level Sensors : Ultrasonic and Capacitive.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.20. **How ultrasonic level sensors work ?**

Answer

1. Ultrasonic level sensors work by the "time of flight" principle using the speed of sound.
2. The sensor emits a high-frequency pulse, generally in the 20 kHz to 200 kHz range, and then listens for the echo. Ultrasonic / level sensors measure distance by using ultrasonic waves.
3. The sensor head emits an ultrasonic wave and receives the wave reflected back from the target.
4. Ultrasonic / level sensors measure the distance to the target by measuring the time between the emission and reception.
5. Basically, the transmitter divides the time between the pulse and its echo by two, and that is the distance to the surface of the material.

6. The transmitter is designed to listen to the highest amplitude return pulse (the echo) and mask out all the other ultrasonic signals in the vessel.
7. The distance can be calculated with the following formula,

$$L = 1/2 \times T \times C$$

where, L = Distance

T = Time between the emission and reception

C = Sonic speed.

8. The value is multiplied by 1/2 because T is the time for go-and-return distance.

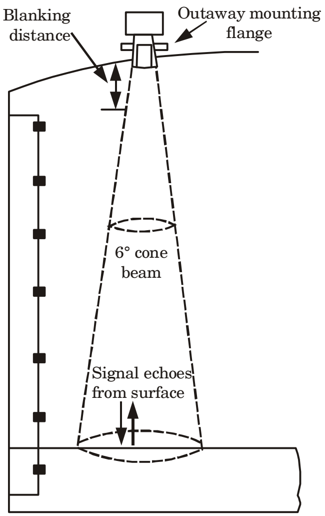


Fig. 2.20.1. The sensor sends pulses toward the surface and receives echoes pulses back.

Que 2.21. **What are the advantages and disadvantages of ultrasonic level sensors ?**

Answer

A. Advantages :

1. Non-contact with product.

2. Suitable for wide range of liquids and bulk products like powders and grains.
3. Reliable performance in difficult service.
4. No moving parts.
5. Measurement without physical contact.
6. Accuracy of 0.25 % with temperature compensation and self-calibration.

B. Disadvantages :

1. Not suitable for higher pressures or in a vacuum.
2. The temperature is limited to 170 °C.

Que 2.22. Discuss the working principle of capacitive level sensors.

Answer

A. Working principle :

1. The principle of capacitive level measurement is based on change of capacitance.
2. An insulated electrode acts as one plate of capacitor and the tank wall (or reference electrode in a non-metallic vessel) acts as the other plate. The capacitance depends on the fluid level.
3. An empty tank has a lower capacitance while a filled tank has a higher capacitance.
4. A simple capacitor consists of two electrode plate separated by a small thickness of an insulator such as solid, liquid, gas, or vacuum. This insulator is also called as dielectric.
5. Value of C depends on dielectric used, area of the plate and also distance between the plates.

$$C = E(K\,A/d)$$

where,
C = Capacitance in picofarads (pF)
E = A constant known as the absolute permittivity of free space
K = Relative dielectric constant of the insulating material
A = Effective area of the conductors
d = Distance between the conductors.

6. This change in capacitance can be measured using AC Bridge.

B. Measurement :

1. Measurement is made by applying a Radio Frequency (RF) signal between the conductive probe and the vessel wall.
2. The RF signal results in a very low current flow through the dielectric process material in the tank from the probe to the vessel wall.
3. When the level in the tank drops, the dielectric constant drops causing a drop in the capacitance reading and a minute drop in current flow.
4. This change is detected by the level switch's internal circuitry and translated into a change in the relay state of the level switch in case of point level detection.
5. In the case of continuous level detectors, the output is not a relay state, but a scaled analog signal.

Que 2.23. Give the advantages, disadvantages and applications of capacitive level sensors.

Answer

A. Advantages :

1. Relatively inexpensive
2. Versatile
3. Require minimal maintenance
4. Reliable
5. Contains no moving parts
6. Easy to clean
7. Rugged
8. Simple to use.

B. Disadvantages :

1. This system cannot work with materials having varying dielectric materials.
2. Even acids and caustics that don't appear to coat the sensing element are so conductive that the thin film they leave can cause serious errors in measurement.

C. Applications :

1. To measures levels of :

i. Liquids

ii. Powered and granular solids

iii. Liquid metals at very high temperature

iv. Liquefied gases at very low temperature

v. Corrosive materials like hydrofluoric acid

2. Very high pressure industrial processes.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Discuss the working principle of thermistor.

Ans. Refer Q. 2.2.

Q. 2. Describe the construction and working of thermocouple.

Ans. Refer Q. 2.3.

Q. 3. Explain the operation of RTD (Resistance Temperature Detector).

Ans. Refer Q. 2.4.

Q. 4. A thermocouple circuit uses a chromel-alumel thermocouple which gives an emf of 33.3 mV. When measuring a temperature of 800 °C with reference temperature 0 °C. The resistance of the meter coil, R_m is 50 Ω and a current of 0.1 mA gives full scale deflection. The resistance of junctions and leads, R_e is 12 Ω. Calculate :

a. Resistance of the series resistance if a temperature of 800 °C is to give full scale deflection.

b. The approximate error due to rise of 1 Ω in R_e.

c. The approximate error due to a rise of 10°C in the copper coil of the meter.
The resistance temperature co-efficient of coil is 0.00426/°C.

Ans. Refer Q. 2.7.

Q. 5. What is thermal imaging ?

Ans. Refer Q. 2.8.

Q. 6. How thermal imaging works ?

Ans. Refer Q. 2.9.

Q. 7. What is Hall Effect Sensor ? How it can be used to measure fluid level/position ?

Ans. Refer Q. 2.10.

Q. 8. Explain photoelectric sensors.

Ans. Refer Q. 2.14.

Q. 9. How do we measure vibration with the help of proximity sensors ?

Ans. Refer Q. 2.16.

Q. 10. How ultrasonic flow sensor work ?

Ans. Refer Q. 2.17.

Q. 11. Discuss the working of laser (or optical) flow sensor.

Ans. Refer Q. 2.19.

☺☺☺

3 UNIT

Machine Vision

CONTENTS

PART-1

Machine Vision : Introduction to Machine Vision.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. What is machine vision ?

Answer

1. Machine vision systems analyze images from cameras to generate image feature data that guides robotic and automation machines in their understanding of the physical world as shown in Fig. 3.1.1.
2. Vision is a sensory input capable of producing detailed data that in many instances could only be obtained by means of vision.
3. The machine vision system is needed to take the vast amount of data contained in images and measure features of the image content that can be used directly.

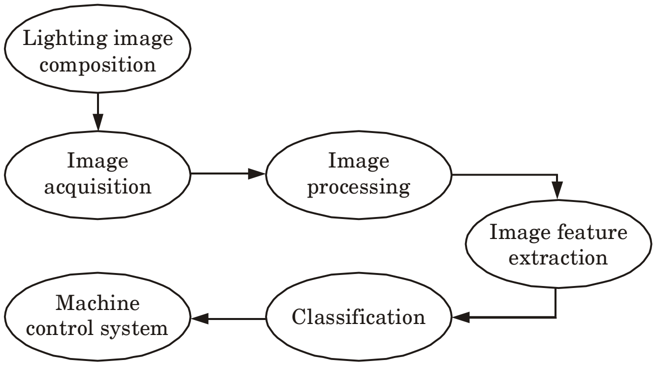


Fig. 3.1.1. Process flow of a machine vision system.

4. Machine vision uses image processing, but the two terms are not the same. Image processing generates new images from existing images.
5. Image processing is used in the early machine vision stages for tasks such as filtering, segmentation, edge detection, and geometric operations.
6. Not all image processing algorithms are typically used in machine vision systems.
7. Examples of image processing algorithms that are of secondary concern to machine vision include de-blurring, image stitching, and image and video compression.

8. Two other related terms in common usage, computer vision and robotic vision, have essentially the same meaning as machine vision and primarily differ in usage only in the intended application.
9. The term computer vision is used in relation to a system does not control external machines.
10. For example, face recognition for security verification would typically be labelled as a computer vision application.

PART-2

Difference Between Machine Vision and Computer Vision.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.2. Give the difference between computer and machine vision.

Answer

S. No.	Computer vision	Machine vision
1.	It doesn't depend on machine vision.	It can't exist without computer vision because it employs computer vision algorithms.
2.	It is a scientific domain.	It is an engineering one.
3.	It often deals with the objects of the "outside world" and their activities which are uncontrolled.	It deals with light and motion that are controlled.
4.	It has a much greater processing capability of acquired visual data when compared to machine vision.	It has a lesser processing capability of acquired visual data as compared to computer vision.
5.	It is more useful for identifying, predicting, and observing trends; gaining advanced feedback about abstract visual data, and analyzing large numbers of variables.	It is less useful as compared to computer vision.

Que 3.3. **What are the applications of computer and machine vision ?**

Answer

A. Computer vision :

1. **Medical :** This process is used to detect abnormalities in medical scans like X-rays, CT scans, MRIs, or cardiograms.
2. **Insurance :** Computer vision differentiates between intentional and accidental damage based on pattern recognition.
3. **Defense and security :** Surveillance may be automated with computer vision to detect potential criminal activity.
4. **Automotive :** Self-driving vehicles rely on computer vision technology to power machine learning processes.

B. Machine vision :

1. **Automatic inspection :** Machine vision can assess products far faster than a human can, leading to increased operational efficiency.
2. **Quality control :**
   i. Automated quality control is invaluable for detecting flaws in intricate designs like barcodes that humans would be unable to easily judge.
   ii. It can also speed up almost any routine quality check, executing automatic pass/fail functions depending on the result of the assessment.
3. **Robot guidance :**
   i. Machine vision is a necessary component of many robotic guidance processes.
   ii. By analyzing visual information about the robot's surroundings, these programs increase speed while allowing for more precise positioning and sorting.

PART-3

Imaging Sensors : CCD and CMOS.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.4. **Explain Charge-Coupled Device (CCD) imaging sensors with suitable example.**

Answer

1. The charge-coupled device (CCD) is a technology for capturing images, from digital astrophotography to machine vision inspection. The CCD sensor is a silicon chip that contains an array of photosensitive sites as shown in Fig. 3.4.1.

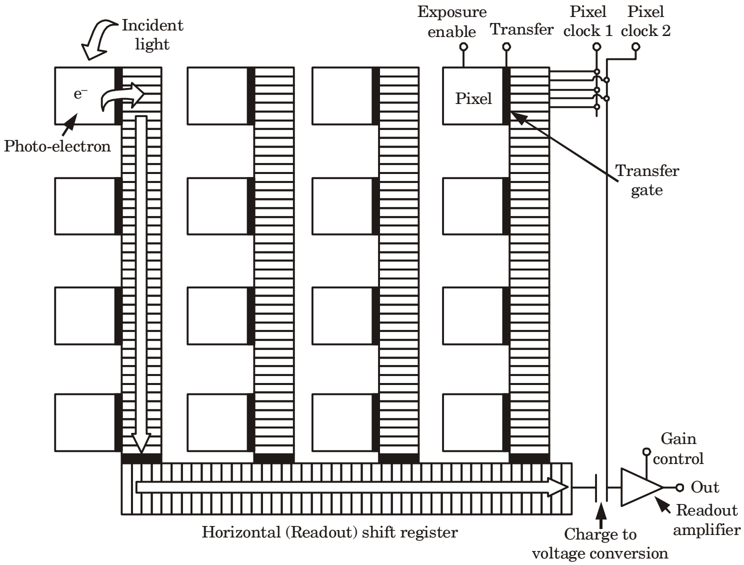


Fig. 3.4.1. Block diagram of a charge-coupled device (CCD).

2. The term charge-coupled device actually refers to the method by which charge packets are moved around on the chip from the photosites to readout, a shift register, akin to the notion of a bucket brigade.
3. Clock pulses create potential wells to move charge packets around on the chip, before being converted to a voltage by a capacitor.
4. The CCD sensor is itself an analog device, but the output is immediately converted to a digital signal by means of an analog-to-digital converter (ADC) in digital cameras, either ON or OFF chip.
5. In analog cameras, the voltage from each site is read out in a particular sequence, with synchronization pulses added at some point in the signal chain for reconstruction of the image.
6. The charge packets are limited to the speed at which they can be transferred, so the charge transfer is responsible for the main CCD

drawback of speed, but also leads to the high sensitivity and pixel-to-pixel consistency of the CCD.

7. Since each charge packet sees the same voltage conversion, the CCD is very uniform across its photosensitive sites.
8. The charge transfer also leads to the phenomenon of blooming, wherein charge from one photosensitive site spills over to neighbouring sites due to a finite well depth or charge capacity.
9. This phenomenon manifests itself as the smearing out of bright spots in images from CCD cameras.
10. To compensate for the low well depth in the CCD, microlenses are used to increase the fill factor, or effective photosensitive area, to compensate for the space on the chip taken up by the charge-coupled shift registers.
11. This improves the efficiency of the pixels, but increases the angular sensitivity for incoming light rays, requiring that they hit the sensor near normal incidence for efficient collection.

Que 3.5. **Discuss Complementary Metal Oxide Semiconductor (CMOS) imaging sensors.**

Answer

1. In a complementary metal oxide semiconductor (CMOS) sensor, the charge from the photosensitive pixel is converted to a voltage at the pixel site and the signal is multiplexed by row and column to multiple on chip digital-to-analog converters (DACs).
2. Inherent to its design, CMOS is a digital device. Each site is essentially a photodiode and three transistors, performing the functions of resetting or activating the pixel, amplification and charge conversion, and selection or multiplexing as shown in Fig. 3.5.1.
3. This leads to the high speed of CMOS sensors, but also low sensitivity as well as high fixed-pattern noise due to fabrication inconsistencies in the multiple charges to voltage conversion circuits.
4. The multiplexing configuration of a CMOS sensor is often coupled with an electronic rolling shutter.
5. Although, with additional transistors at the pixel site, a global shutter can be accomplished wherein all pixels are exposed simultaneously and then readout sequentially.
6. An additional advantage of a CMOS sensor is its low power consumption and dissipation compared to an equivalent CCD sensor, due to less flow of charge, or current.

7. Also, the CMOS sensor's ability to handle high light levels without blooming allows for its use in special high dynamic range cameras, even capable of imaging welding seams or light filaments.
8. CMOS cameras also tend to be smaller than their digital CCD counterparts, as digital CCD cameras require additional off-chip ADC circuitry.
9. The multilayer MOS fabrication process of a CMOS sensor does not allow for the use of microlenses on the chip, thereby decreasing the effective collection efficiency or fill factor of the sensor in comparison with a CCD equivalent.
10. This low efficiency combined with pixel-to-pixel inconsistency contributes to a lower signal-to-noise ratio and lower overall image quality than CCD sensors.

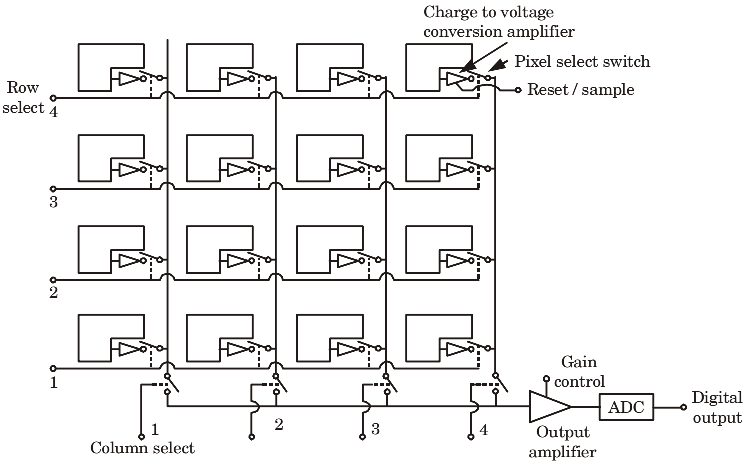


Fig. 3.5.1. Block diagram of a Complementary Metal Oxide Semiconductor (CMOS).

Que 3.6. **Compare CCD and CMOS.**

Answer

S. No.	Sensor	CCD	CMOS
1.	Pixel signal	Electron packet	Voltage
2.	Chip signal	Analog	Digital
3.	Fill factor	High	Moderate

4.	Responsivity	Moderate	Moderate - High
5.	Noise level	Low	Moderate - High
6.	Dynamic range	High	Moderate
7.	Uniformity	High	Low
8.	Resolution	Low - High	Low - High
9.	Speed	Moderate - High	High
10.	Power consumption	Moderate - High	Low
11.	Complexity	Low	Moderate
12.	Cost	Moderate	Moderate

PART-4

Sensing & Digitizing Function in Machine Vision, Image Processing and Analysis.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.7. **Explain the tasks included in machine vision system.**

Answer

a. Machine vision system is a sensor used in the robots for viewing and recognizing an object with the help of a computer.

b. It has several components such as a camera, digital computer, digitizing hardware, and an interface hardware & software.

c. The machine vision process includes three important tasks :

A. Sensing and digitizing image data :

1. A camera is used in the sensing and digitizing tasks for viewing the images. It will make use of special lighting methods for gaining better picture contrast.
2. These images are changed into the digital form, and it is known as the frame of the vision data.
3. A frame grabber is incorporated for taking digitized image continuously at 30 frames per second. Instead of scene projections, every frame is divided as a matrix.
4. By performing sampling operation on the image, the number of pixels can be identified. The pixels are generally described by the elements of the matrix.
5. A pixel is decreased to a value for measuring the intensity of light. As a result of this process, the intensity of every pixel is changed into the digital value and stored in the memory.

B. Image processing and analysis :

1. In this function, the image interpretation and data reduction processes are done.
2. The threshold of an image frame is developed as a binary image for reducing the data.
3. The data reduction will help in converting the frame from raw image data to the feature value data. The feature value data can be calculated via computer programming.
4. This is performed by matching the image descriptors like size and appearance with the previously stored data on the computer.
5. The image processing and analysis function will be made more effective by training the machine vision system regularly.
6. There are several data collected in the training process like length of perimeter, outer & inner diameter, area, and so on.
7. Here, the camera will be very helpful to identify the match between the computer models and new objects of feature value data.

C. Application :

1. The current applications of machine vision in robotics include inspection, part identification, location, and orientation.
2. Research is ongoing in advanced applications of machine vision for use in complex inspection, guidance, and navigation.

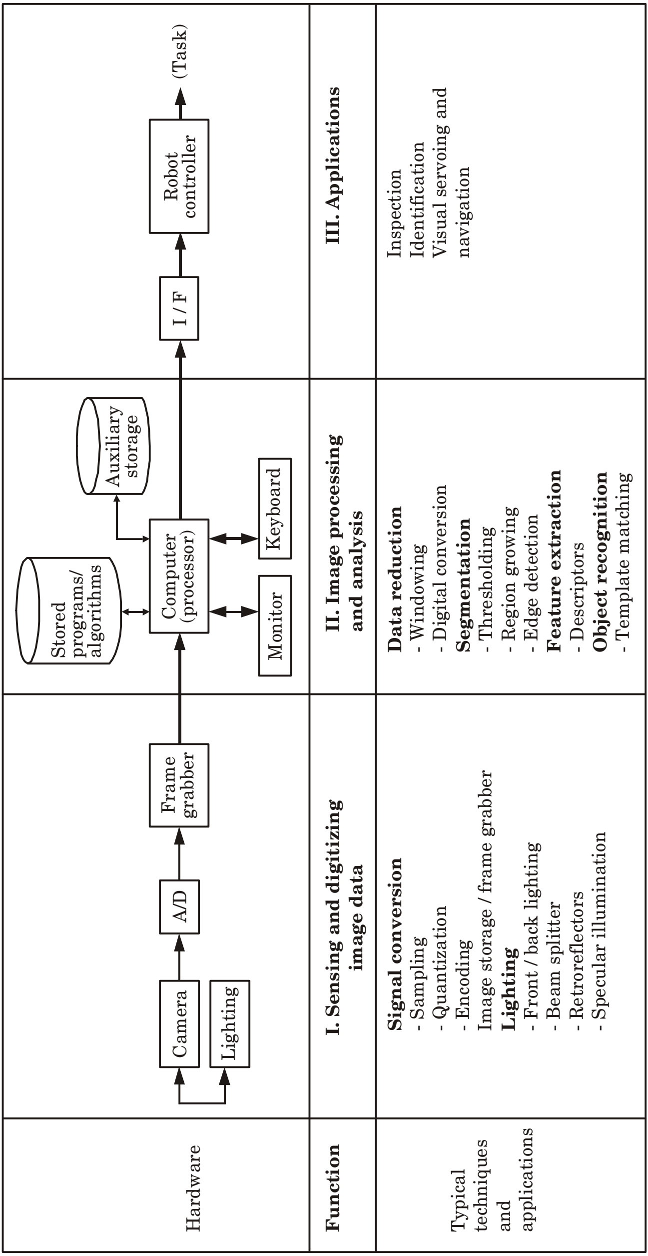


Fig. 3.7.1. Functions of a machine vision system.

PART-5

Training the Vision System in a Pick and Place Robot.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.8. What is VGR ?

Answer

1. In industrial pick and place applications, Vision Guided Robot (VGR) is typically robotic arms with integrated machine vision systems.
2. The machine vision system helps the robot discover the location of an object in order to guide the robot to a desired point for pick and place.

Que 3.9. Give the applications of VGR systems.

Answer

VGR systems are typically used for high-volume, highly repeatable processes. Some of the more common applications include :

1. Loading/unloading parts from conveyors and feeding systems.
2. Loading/unloading nested parts from trays or boxes.
3. Part placement, assembly and packaging.
4. Racking and de-racking.
5. Palletizing and de-palletizing.
6. Bin picking of random parts.

Que 3.10. Discuss about training a robot architecture using the Animal (AT) Model.

Answer

1. The AT robot design model consists of a robot with useful behaviours and tasks programmed by a human user and that executes those tasks on verbal command.
2. Physically, it is a mobile platform carrying a camera for object recognition and an arm for grasping and manipulating. A robot architecture that can implement this model consists of :

i. A behaviour manager
ii. A task manager
iii. A dialog manager.

3. The behaviour manager processes sensor data to drive actuators, such as the motors in the wheels (or legs) and arms of the robot.
4. The task manager converts behaviours into tasks that achieve a goal, and it selects and executes tasks given to it by the dialog manager.
5. The dialog manager is the interface between the human user and the task manager. It communicates with the task manager to select tasks and to create new tasks.
6. The behaviour manager uses the identities and relative locations of objects to control the various actuators of the robot, as determined by the active behaviours.
7. It consists of sensor processors (e.g. the vision system) to identify and locate objects, an analog logic system to convert this information into actuator control signals, and actuator processors for local control of actuator motors.
8. The task manager executes tasks previously supplied by the human user.
9. The task manager also determines when the task is done and whether it was successful.
10. Because the robot operates in an unpredictable environment, tasks can succeed or fail, and they can succeed in more than one way. If a task fails, the task manager must know what to do.
11. The dialog manager provides structured natural language communication between the task manager and the human user.
12. The robot only contains what we put in it. We enter the phrases and sentences we want it to recognize, and we enter the responses to those sentences.
13. Initially, only a small number of sentences and tasks may be required for the robot to be useful. This number can grow easily and incrementally with time.
14. Speech recognition - typically a difficult problem - can be aided by the finite nature of the vocabulary and dialog. The dialog manager includes an episodic memory.
15. This memory records task information from the task manager, such as tasks completed and objects recognized as part of task execution. The episodic memory remembers tasks executed and information specific to the task.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Give the difference between computer and machine vision.

Ans. Refer Q. 3.2.

Q. 2. Explain Charge-Coupled Device (CCD) imaging sensors with suitable example.

Ans. Refer Q. 3.4.

Q. 3. Discuss Complementary Metal Oxide Semiconductor (CMOS) imaging sensors with suitable example.

Ans. Refer Q. 3.5.

Q. 4. Explain the tasks included in machine vision system.

Ans. Refer Q. 3.7.

Q. 5. Give the applications of VGR systems.

Ans. Refer Q. 3.9.

☺☺☺

4
UNIT

Signal Conditioning & Data Acquisition Systems

CONTENTS

PART- 1

Signal Conditioning : Introduction, Functions of Signal Conditioning Equipment.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. What is signal conditioning ?

Answer

1. Signal conditioning is the manipulation of a signal in a way that prepares it for the next stage of processing.
2. Signal conditioning is the technique of making a signal from a sensor or transducer suitable for processing by data acquisition equipment.

Que 4.2. Give the various functions of signal conditioners.

Answer

A. Signal conversion :

1. The main function of a signal conditioner is to pick up the signal and convert it into a higher level of electrical signal.
2. Signal conversion is often used by industrial applications that use a wide range of sensors to perform measurements.
3. Due to the different sensors being employed, the signals generated may need to be converted to be usable for the instruments they are connected to.

B. Linearization :

1. Certain signal conditioners can perform linearization when the signals produced by a sensor do not have a straight-line relationship with the physical measurement.
2. This is the process of interpreting the signal from the software and it is common for thermocouple signals.
3. This method is used to reach higher accuracy because every sensor is not completely linear.

C. Amplifying :

1. The next step is signal amplification and the process of increasing the signal for processing or digitization.

2. There are two ways that signal amplification can be performed, by increasing the resolution of the input signal, or by increasing the signal-to-noise ratio.
3. Signal conditioning uses a range of different amplifiers for different purposes :

i. **Instrumentation amplifiers :** These are optimized for use with DC signals, and are characterized by high input impedance, High Common Mode Rejection Ratio (CMRR), and high gain.

ii. **Isolation amplifier :** These are designed to isolate high DC levels from the device while passing small AC or differential signal.

D. Filtering :

1. Another important function of a signal conditioner is filtering, and this is where the signal frequency spectrum is filtered to only include the valid data and block any noise.
2. The filters can be made from either passive and active components or digital algorithm.
3. A passive filter only uses capacitors, resistors, and inductors with a maximum gain of one.
4. An active filter uses passive components in addition to active components such as operational amplifiers and transistors.
5. State of the art signal conditioners use digital filters because they are easy to adjust and no hardware is required.
6. A digital filter is a mathematical filter used to manipulate a signal, such as blocking or passing a particular frequency range.
7. They use logic components such as ASICs, FPGAs or in the form of a sequential program with a signal processor.

E. Evaluation and smart-functions :

1. To provide additional benefits for the user and the process, modern signal conditioners have extra functions for signal evaluation and measurement data pre-processing.
2. This helps to monitor and evaluate warning and alarms directly via an electrical switching output rapidly.
3. Additional smart-functions like an internal calculated channel can handle mathematical functions, like adding of sensor-signals, up to technological operations like a PID-controller.
4. These functions help to get a fast reacting system and reduce the load from the machine control.

F. Interfaces :

1. Signal converters have to transmit the sensor signals via standard interfaces and protocols to the machine control.

2. These interfaces can be analog or digital. Common analog interfaces are voltage (+/– 10 V) or current signals (+/– 20 mA) which are easy to handle but every signal needs a separate wiring.
3. Modern digital interfaces are designed as Ethernet-based bus-interfaces (PROFINET, EtherCAT, EtherNet/IP) and allow the connection of several components with only one wire.
4. This reduces the wiring and also allows additional information to be transmitted, such as diagnostic information of the components, which is very important for reducing down-times and speed up maintenance.

Que 4.3. **What are various types of signal conditioning ?**

Answer

1. Amplification
2. Excitation
3. Linearization
4. Cold-junction compensation
5. Filtering
6. Isolation
7. High Impedance
8. RMS signal conditioning.

Que 4.4. **Give the types of signal conditioners according to measurement.**

Answer

A. Temperature signal conditioner :

1. A temperature signal conditioner is used with sensors that measure temperature or variations in temperature.
2. Sensors that measure temperatures are called thermocouples. Usually, thermocouple outputs are in the range of ± 80 mV.
3. Such a low output voltage is difficult for digital readers to record and display. This is where signal conditioners are helpful.
4. These devices amplify the signals, filter the noise, and send it for further analysis/display.

i. Thermocouple signal conditioner :

a. Signal conditioning necessary for cold junction compensation also.
b. When a thermocouple is connected to the instrument for temperature measurement, the material difference between the two generates a voltage at junctions known as cold junctions.

c. This voltage change affects the actual output of the thermocouple, giving out erroneous results.

d. A signal conditioner compensates for such variations and also filters out the power line noise.

e. Additionally, the device also performs linearization so that the output voltage of the thermocouple is linear with temperature.

ii. Thermistors signal conditioner :

a. Thermistors require current and voltage excitation as these are active temperature sensors.

b. Amplification and low pass filtering are also used for thermistors to modify the signals so that they can be easily read by the digital devices.

c. A signal conditioner for the thermistor performs these operations effectively.

iii. RTD signal conditioner :

a. Resistance Temperature Devices (RTDs) are temperature monitors that use the variation in resistance to calculate the temperature.

b. Similar to thermistors, RTDs also require excitation voltage, amplification, and filtering.

c. The RTD signal conditioner helps to meet such requirements while also eliminating unwanted signals from line resistance, non-linearity, and self-healing.

B. Pressure sensor signal conditioner :

1. Pressure sensing works by monitoring the strain or stress experienced by a bridge.
2. The pressure signal conditioner excites the bridge by providing constant voltage and amplifying the output signals.
3. The output of the pressure sensor varies in millivolts along with high common-mode signals.
4. The pressure sensor signal conditioner eliminates common-mode signals while retaining pressure variation values.

C. Load cell signal conditioner :

1. Strain gauges are extremely sensitive and they produce output in the range of millivolts.
2. The load cell signal conditioner is necessary to pick up these small variations to ensure accurate measurement.
3. Strain gauges also require excitation voltage in the range between 2.5 V to 10 V and this is achieved through a signal conditioner.

D. LVDT signal conditioner :

1. Linear Variable Differential Transformers (LVDTs) measure the position of a subject.

2. A sinusoidal excitation wave (between 400 kHz and 10 kHz) is required to excite the LVDT sensor.
3. The output is then passed through a low pass filter to ensure that the noise levels are kept to a minimum.
4. The final signal sent by the signal conditioner is easy to recognize for the digital reading device.

E. Torque signal conditioner : Torque signal conditioners follow the suite of the load and pressure signal conditioner as it can produce low or high output voltage based on the excitation voltage of the sensor.

F. Strain gauge signal conditioner :

1. Strain gauge signal conditioners require excitation voltage (around 10 V) and amplification.
2. The output of a standard strain gauge is in millivolts. A strain gauge signal conditioner modifies this output signal to scale it and make it readable for the modern digital recorders.

G. DC and AC signal conditioner :

1. The choice between AC and DC signal conditioner is made based on the measurement setup.
2. Resistance transducer setups like strain gauge use DC signal conditioners with amplification and filtering circuits.
3. AC signal conditioners are used in conjunction with variable reactance transducers and in setups where there is a considerable length between the transducers and the signal conditioning devices.

H. Frequency signal conditioner : Frequency signal conditioners or frequency transducers convert frequency into a standard output signal that can be easily measured using popular measurement devices.

PART-2

Need for Amplification of Signals, Types of Amplifiers.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.5. Explain amplification process.

Answer

1. Amplification is a process which increases (amplifies) the signal for possessing or digitization.

2. Signal amplifiers often include electronic components that amplify signals without producing significant amounts of thermal noise.
3. In some applications a signal must be amplified or attenuated in order to drive a circuit or a system.

Que 4.6. What are the various types of amplifiers ?

Answer

There are many types of amplifiers used in signal conditioning including the following :

1. **Voltage amplifiers :** They have a unity gain, so the output signal is a reproduction of the input signal. This type of amplifier is mainly used as an impedance matching device.
2. **Isolation amplifiers :** These are designed specifically to isolate high DC levels from the data acquisition device while passing the relatively small AC or differential signal. The inputs and outputs are electrically isolated.
3. **Instrumentation amplifiers :** These are differential amplifiers that have been optimized for use with DC signals. They are characterized by high gain, high Common Mode Rejection Ratio (CMRR), and high input impedance.
4. **Sample-and-hold amplifiers :** These amplifiers freeze the analog voltage instantly. During this process the HOLD command is issued and analog voltage is available for an extended period.
5. **Current amplifier :** As the name suggests, an amplifier that makes the given input current higher. It is characterized by a low input impedance and high output impedance.
6. **Voltage amplifier :** An amplifier that amplifies given voltage for a larger voltage output. It is characterized by a high input impedance and low output impedance.
7. **Transconductance amplifier :** An amplifier that changes output current according to changing input voltage.
8. **Transresistance amplifier :** An amplifier that changes output voltage according to changing input current. It is also known as a current-to-voltage converter.
9. **Operational amplifiers (Op-Amps) :**

i. An op-amp is an integrated circuit that acts as a voltage amplifier, and has differential input.

ii. It has a positive and negative input, but a single output with very high gain. Originally, op-amps were created using valves.

10. **Valve (or) vacuum tube amplifiers :**

i. An amplifier that uses vacuum tubes to provide an increased power or voltage output is known as a valve (or) vacuum tube amplifier.

ii. Op-amps were originally of the valve type, but were replaced by ICs once they got cheaper, in smaller applications at least.

iii. In high power applications, they're still in use because of their cost effectiveness and output quality. They are used in radar, military, high power radio and UHF transmitter applications.

11. Transistor amplifiers :

i. A transistor amplifier is a multi-configuration high output amplifier that uses transistors as the working base.

ii. These include Bipolar Junction Transistors (BJTs) and Metal Oxide Semiconductor Field-Effect Transistors (MOSFETs).

12. Klystron :

i. A special type of linear beam vacuum tube, used as an amplifier in high radio frequencies.

ii. It is highly precise and used in large scale operations, usually comes under microwave amplifiers.

13. Instrument amplifiers : Specially designed amplifiers to amplify sound, voice or music. Used mainly in musical instrument applications.

14. Distributed amplifiers : Amplifiers that use transmission lines to temporarily split the input and amplify each segment individually are called distributed amplifiers. They're commonly found in oscilloscopes.

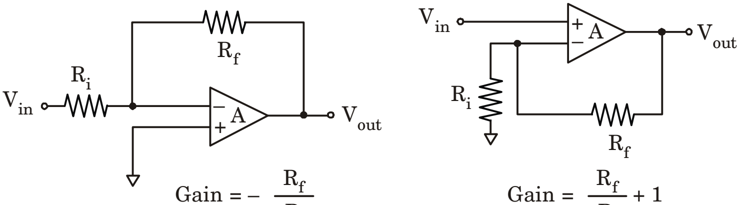
Que 4.7. Discuss operational amplifiers in detail with suitable diagram.

Answer

Operational amplifiers :

1. Most data acquisition systems use a number of different types of circuits to amplify the signal before processing.
2. Modern analog circuits intended for these data acquisition systems comprise basic integrated operational amplifiers, which are configured easily to amplify or buffer signals.
3. Integrated operational amplifiers contain many circuit components, but are typically portrayed on schematic diagrams as a simple logical functional block.
4. A few external resistors and capacitors determine how they function in the system.
5. Their extreme versatility makes them the universal analog building block for signal conditioning.
6. Most operational amplifier stages are called inverting or non-inverting as shown in Fig. 4.7.1.

7. A simple equation relating to each configuration provides the idealized circuit gains as a function of the input and feedback resistors and capacitors.
8. Also, special cases of each configuration make up the rest of the fundamental building blocks, namely the unity-gain follower and the difference amplifier.



$$\text{Gain} = -\frac{R_f}{R_i}$$

(a) Inverting

$$\text{Gain} = \frac{R_f}{R_i} + 1$$

(b) Non-inverting

Fig. 4.7.1.

Inverting amplifier stages :

1. The inverter stage is the most basic operational amplifier configuration.
2. It simply accepts an input signal referenced to common, amplifies it, and inverts the polarity at the output terminals.
3. The open-loop gain of a typical operational amplifier is in the hundreds of thousands.
4. But the idealized amplifier used to derive the transfer function assumes a gain of infinity to simplify its derivation without introducing significant errors in calculating the stage gain.
5. With such a high stage gain, the input voltage sees only the voltage divider composed of R_f and R_i.
6. The negative sign in the transfer function indicates that the output signal is the inverse polarity of the input.
7. Without deriving the transfer function, the output is calculated from,

$$V_o = -V_{in}(R_f/R_i)$$

where,
V_o = Output signal, (V)
V_{in} = Input signal, (V)
R_f = Feedback resistor, (Ω)
R_i = Input resistor, (Ω)

Non-inverting amplifier stages :

1. The non-inverting amplifier is similar to the previous circuit but the phase of the output signal matches the input.
2. Also, the gain equation simply depends on the voltage divider composed of R_f and R_i.

3. The simplified transfer function is,

$$V_o = V_{in}(R_f + R_i)/R_i$$

Que 4.8. **Explain differential amplifiers.**

Answer

1. Differential-input amplifiers offer some advantages over inverting and non-inverting amplifiers.
2. It appears as a combination of the inverting and non-inverting amplifiers as shown in Fig. 4.8.1.

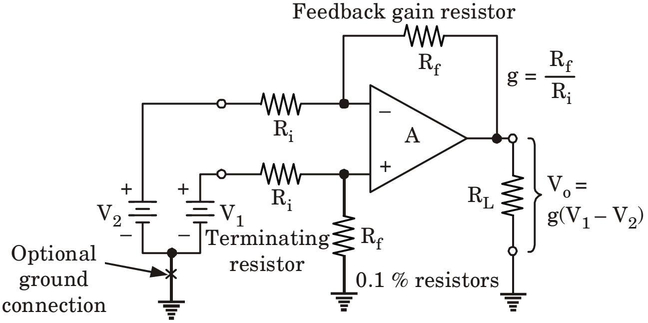


Fig. 4.8.1.

3. The input signal is impressed between the operational amplifier's positive and negative input terminals and can be isolated from common or a ground pin.
4. The optional ground pin is the key to the amplifier's flexibility. The output signal of the differential input amplifier responds only to the differential voltage that exists between the two input terminals.
5. The transfer function for this amplifier,

$$V_o = (R_f / R_i)\,(V_1 - V_2)$$

6. The major benefit of the differential amplifier is its ability to reject any voltages that are common to both inputs while amplifying the difference voltage.
7. The voltages that are common to both inputs are appropriately called common mode voltages (V_{cm} or CMV).
8. The common-mode voltage rejection quality can be demonstrated by connecting the two inputs together and to a voltage source referenced to ground.
9. Although a voltage is present at both inputs, the differential amplifier responds only to the difference, which in this case is zero.
10. The ideal operational amplifier, then, yields zero output volts under this arrangement.

Que 4.9. **Discuss programmable-gain amplifiers in detail with suitable diagram.**

Answer

1. Programmable gain amplifiers are typically non-inverting operational amplifiers with a digitally controlled analog switch connected to several resistors in its feedback loop.
2. An external computer or another logic or binary signal controls the addressable inputs of the analog switch so it selects a certain resistor for particular gain as shown in Fig. 4.9.1.

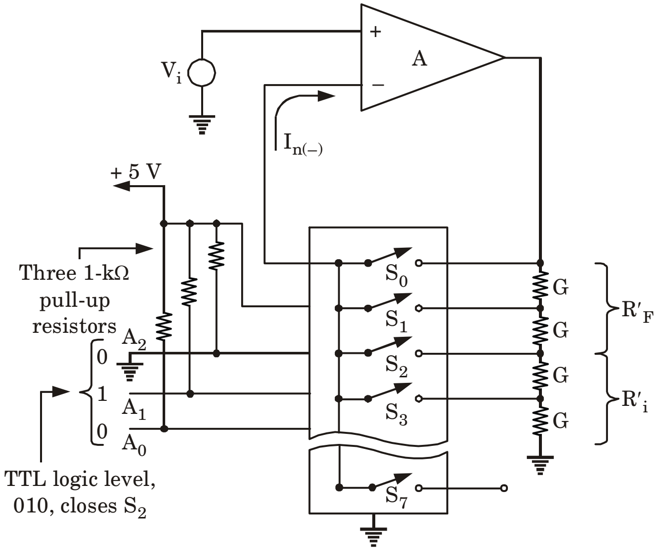


Fig. 4.9.1.

3. The data acquisition system's signal conditioners sense the input signal amplitude and automatically send the proper binary code to the Programmable Gain Amplifier (PGA) to increase the gain for a low signal, or decrease the gain for a large signal.
4. The input signal then can be measured and displayed without distortion.

PART-3

Data Acquisition Systems and Conversion: Introduction, Objectives & Configuration of Data Acquisition System.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.10. **What is data acquisition ? Give its components.**

Answer

A. Data acquisition (DAQ) :

1. Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, vibration or sound with a computer.
2. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with application software.

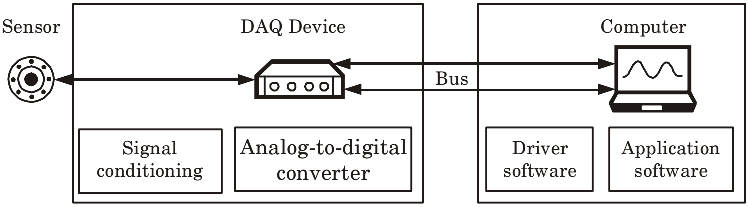


Fig. 4.10.1.

B. Components :

1. **Sensor :** A sensor, also called a transducer, converts a physical phenomenon like temperature or vibration, into a measurable electrical signal like voltage or resistance.
2. **DAQ device :** A DAQ device acts as the interface between a computer and signals from the outside world by digitizing incoming analog signals to be computer readable. DAQ devices include three key components :
   a. **Signal conditioning circuitry :** Transforms noisy real-world signals into forms that can be effectively and accurately measured.
   b. **Analog-to-digital converters (ADCs) :** Digitize real-world analog data into digital representations that can be manipulated by computers.
   c. **Computer bus :** Enables the DAQ device to transmit data to a computer. Examples include USB, PCIe, or Ethernet.
3. **Computer and software :** A computer with DAQ software is required to process, visualize, and store measurement data.
   a. **Driver software :** Gives application software the ability to control your DAQ device with menu-based configuration or a programmable API.

b. **Application software :** Gives the user a ready-made experience for acquiring, analyzing, and presenting data. Configuration is done using menu-based interfaces.

c. **Programming environment :** Allows users to develop their own application to acquire, analyze, and present data, using libraries of functions (APIs) to access and control their DAQ device.

PART-4

Analog & Digital IO, Need of Data Conversion.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.11. Explain analog to digital converter.

Answer

1. Analog to Digital Converter (ADC) is an electronic integrated circuit used to convert the analog signals such as voltages to digital or binary form consisting of 1s and 0s.
2. Most of the ADCs take a voltage input as 0 to 10 V, – 5 V to + 5 V, etc., and correspondingly produces digital output as some sort of a binary number.
3. Analog to digital converter samples the analog signal on each falling or rising edge of sample clock.

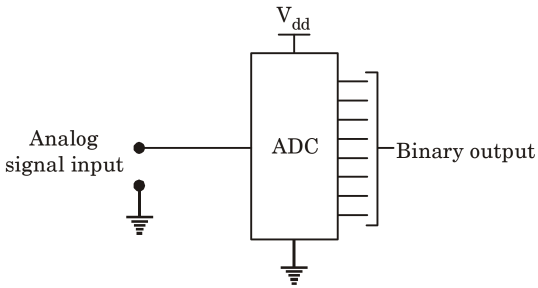


Fig. 4.11.1. ADC converter.

4. In each cycle, the ADC gets of the analog signal, measures and converts it into a digital value.
5. The ADC converts the output data into a series of digital values by approximates the signal with fixed precision.

6. In ADCs, two factors determine the accuracy of the digital value that captures the original analog signal. These are quantization level or bit rate and sampling rate as shown in Fig. 4.11.2.
7. Bit rate decides the resolution of digitized output and you can observe as shown in Fig. 4.11.2 where 3-bit ADC is used for converting analog signal.
9. Assume that one volt signal has to be converted from digital by using 3-bit ADC.
10. Therefore, a total of 2^3 = 8 divisions are available for producing 1 V output. This results 1/8 = 0.125 V is called as minimum change or quantization level represented for each division as 000 for 0 V, 001 for 0.125, and likewise upto 111 for 1 V.

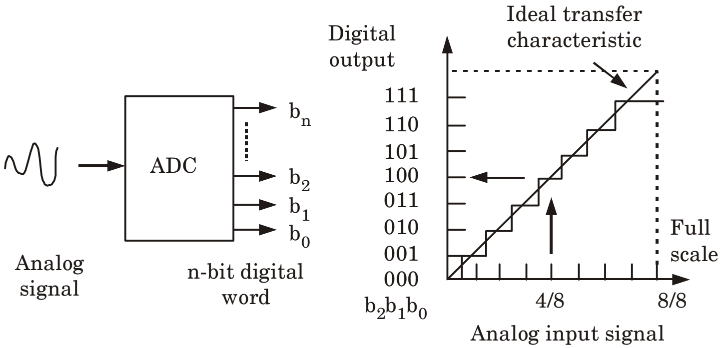


Fig. 4.11.2. Analog to digital conversion process.

11. If we increase the bit rates like 6, 8, 12, 14, 16, etc., we will get a better precision of the signal.
12. Thus, bit rate or quantization gives the smallest output change in the analog signal value that result from a change in the digital representation.

Que 4.12. **Discuss the different types of analog to digital converter.**

Answer

Types of analog to digital converters :

A. Dual Slope A/D Converter :

1. In this type of ADC converter comparison voltage is generated by using an integrator circuit which is formed by a resistor, capacitor and operational amplifier combination.
2. By the set value of V_{ref}, this integrator generates a sawtooth waveform on its output from zero to the value V_{ref}.
3. When the integrator waveform is started correspondingly counter starts counting from 0 to 2^n – 1, where n is the number of bits of ADC.

4. When the input voltage V_{in} equal to the voltage of the waveform, then control circuit captures the counter value which is the digital value of corresponding analog input value.
5. This dual slope ADC is relatively medium cost and slow speed device.

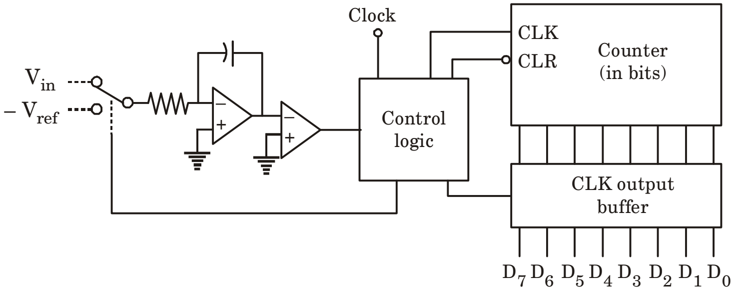


Fig. 4.12.1. Dual slope A/D converter.

B. Flash A/D converter :

1. This ADC converter IC is also called as parallel ADC, which is a most widely used efficient ADC in terms of its speed.
2. This flash analog to digital converter circuit consists of a series of comparators where each one compares the input signal with a unique reference voltage.
3. At each comparator, the output will be high state when the analog input voltage exceeds the reference voltage.
4. This output is further given to priority encoder for generating binary code based on higher order input activity by ignoring other active inputs. This flash type is a high-cost and high-speed device.

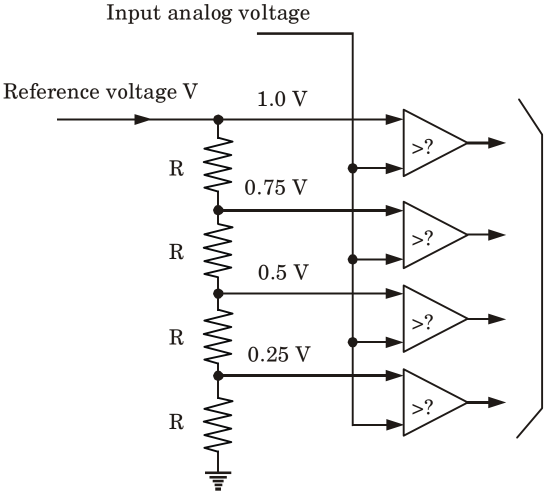


Fig. 4.12.2. Flash A/D converter.

C. Successive approximation A/D converter :

1. The SAR ADC is a modern ADC IC and much faster than dual slope and flash ADCs since it uses a digital logic that converges the analog input voltage to the closest value.
2. This circuit consists of a comparator, output latches, successive approximation register (SAR) and D/A converter.

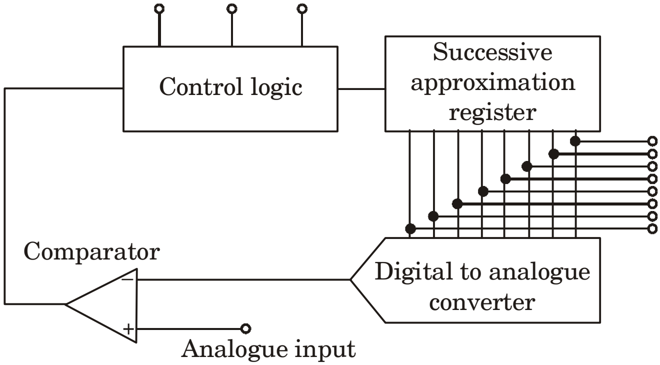


Fig. 4.12.3. Successive approximation A/D converter.

3. At the start, SAR is reset and as the LOW to HIGH transition is introduced, the MSB of the SAR is set.
4. Then this output is given to the D/A converter that produces an analog equivalent of the MSB, further it is compared with the analog input V_{in}.
5. If comparator output is LOW, then MSB will be cleared by the SAR, otherwise the MSB will be set to the next position.
6. This process continues till all the bits are tried and after Q_0, the SAR makes the parallel output lines to contain valid data.

Que 4.13. **Give the applications of ADC.**

Answer

1. They are used in computer to convert the analog signal to digital signal.
2. They are used in cell phones.
3. They are used in microcontrollers.
4. They are used in digital signal processing.
5. They are used in digital storage oscilloscopes.
6. They are used in scientific instruments.
7. They are used in music reproduction technology etc.

Que 4.14. **Explain Digital to Analog Converter (DAC).**

Answer

1. Digital to Analog Converter (DAC) is a device that transforms digital data into an analog signal.
2. According to the Nyquist-Shannon sampling theorem, any sampled data can be reconstructed perfectly with bandwidth and Nyquist criteria.
3. A DAC can reconstruct sampled data into an analog signal with precision.
4. The digital data may be produced from a microprocessor, Application Specific Integrated Circuit (ASIC), or Field Programmable Gate Array (FPGA), but ultimately the data requires the conversion to an analog signal in order to interact with the real world.

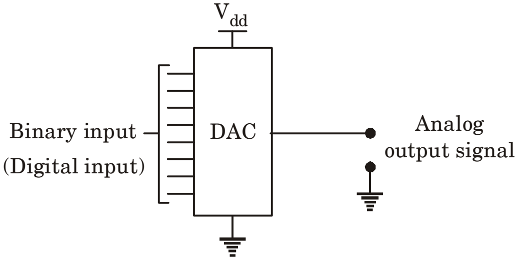


Fig. 4.14.1. Basic digital to analog converter.

Que 4.15. **Discuss the different types of Digital to Analog Converter (DAC).**

Answer

There are two methods commonly used for digital to analog conversion :

A. R-2R ladder network method :

1. The R-2R ladder DAC constructed as a binary-weighted DAC that uses a repeating cascaded structure of resistor values R and 2R.
2. This improves the precision due to the relative ease of producing equal valued-matched resistors (or current sources).

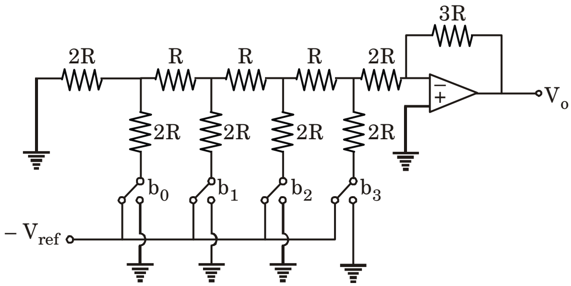


Fig. 4.15.1. 4-bit D/A converter using an R-2R ladder circuit.

3. Fig. 4.15.1 shows the 4-bit R-2R ladder DAC. In order to achieve high-level accuracy, we have chosen the resistor values as R and 2R.
4. Let the binary value $b_3b_2b_1b_0$, if $b_3 = 1$, $b_2 = b_1 = b_0 = 0$, then the simplified form of Fig. 4.15.1 DAC circuit is shown in Fig. 4.15.2. The output voltage is $V_0 = 3R(i_3/2) = V_{ref}/2$.

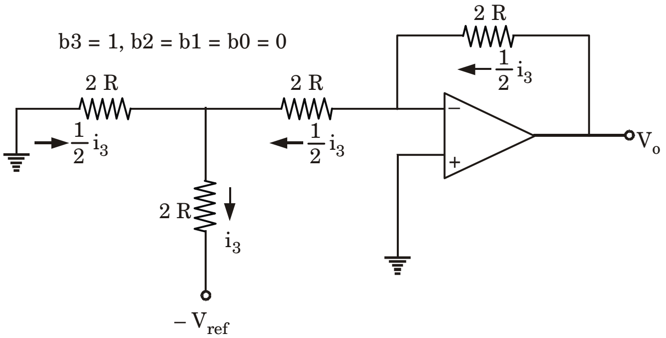


Fig. 4.15.2.

5. Similarly, If $b_2 = 1$, and $b_3 = b_1 = b_0 = 0$, then the output voltage is $V_0 = 3R\,(i_2/4) = V_{ref}/4$ and the simplified circuit is shown in Fig. 4.15.3.

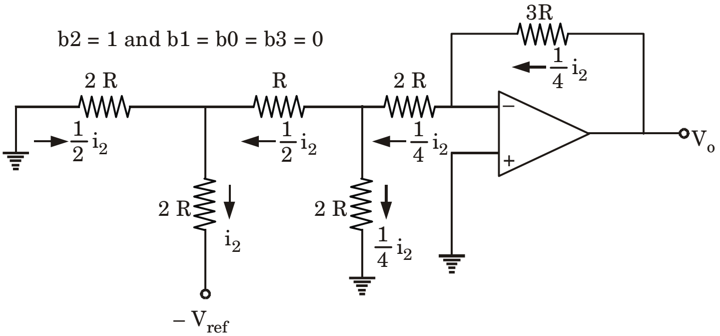


Fig. 4.15.3.

6. If $b_1 = 1$ and $b_2 = b_3 = b_0 = 0$, then the simplified form of Fig. 4.15.3 DAC circuit is shown in Fig. 4.15.4. The output voltage is $V_0 = 3R\,(i_1/8) = V_{ref}/8$.

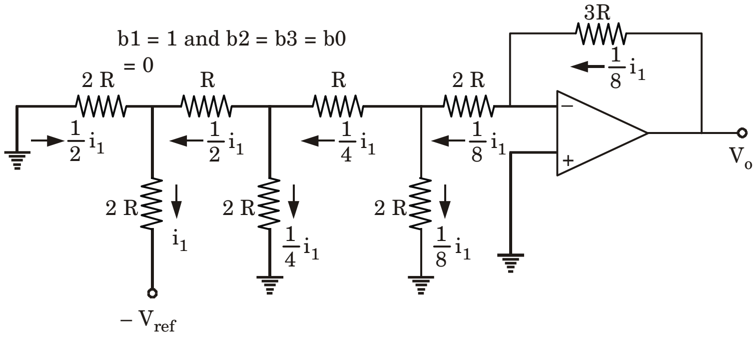


Fig. 4.15.4.

7. Finally, the circuit is shown in Fig. 4.15.5 corresponding to the case where $b_0 = 1$ and $b_2 = b_3 = b_1 = 0$. The output voltage is $V_0 = 3R\,(i_0/16) = V_{ref}/16$.

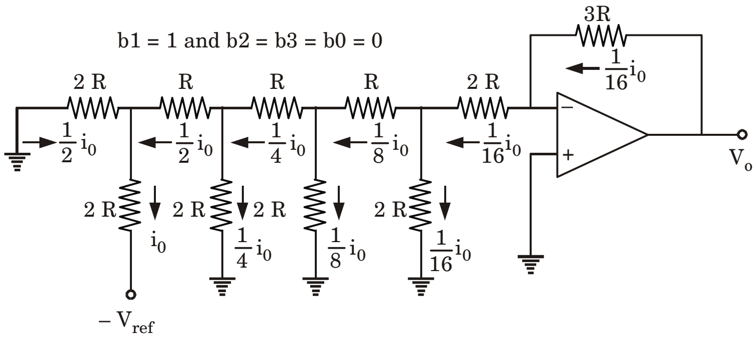


Fig. 4.15.5.

8. In this way, we can find that when the input data is $b_3\, b_2\, b_1\, b_0$(where individual bits are either 0 or 1), then the output voltage is,

$$V_0 = \left(\frac{1}{2}b_3 + \frac{1}{4}b_2 + \frac{1}{8}b_1 + \frac{1}{16}b_0\right)V_{ref}$$

$$= \frac{1}{2}\left(b_3 + \frac{1}{2}b_2 + \frac{1}{4}b_1 + \frac{1}{8}b_0\right)V_{ref}$$

B. Weighted resistors method :

1. The basic operation of DAC is the ability to add inputs that will ultimately correspond to the contributions of the various bits of the digital input.
2. In the voltage domain, that is if the input signals are voltages, the addition of the binary bits can be achieved using the inverting summing amplifier as shown in Fig. 4.15.6.

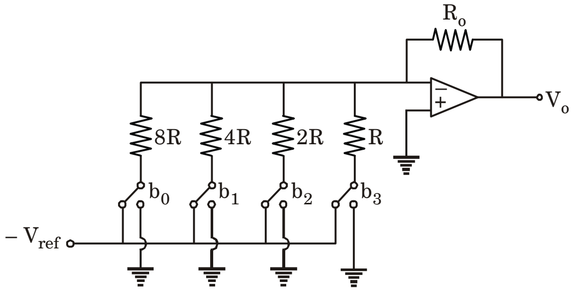


Fig. 4.15.6. Binary weighted resistors DAC.

3. In the voltage domain, that is if the input signals are voltages, the addition of the binary bits can be achieved using the inverting summing amplifier.
4. The input resistors of the op-amp have their resistance values weighted in a binary format.
5. When the receiving binary 1 the switch connects the resistor to the reference voltage.
6. When the logic circuit receives binary 0, the switch connects the resistor to ground. All the digital input bits are simultaneously applied to the DAC.
7. The DAC generates analog output voltage corresponding to the given digital data signal.
8. For the DAC the given digital voltage is b_3, b_2, b_1, b_0 where each bit is a binary value (0 or 1). The output voltage produced at output side is,

$$V_0 = R_0 / R\ (b_3 + b_2 / 2 + b_1 / 4 + b_0 / 8)\ V_{ref}$$

9. As the number of bits is increasing in the digital input voltage, the range of the resistor values becomes large and accordingly, the accuracy becomes poor.

Que 4.16. **Give the applications of digital to analog converter.**

Answer

1. **Audio amplifier :** DACs are used to produce DC voltage gain with microcontroller commands. Often, the DAC will be incorporated into an entire audio codec which includes signal processing features.
2. **Video encoder :** The video encoder system will process a video signal and send digital signals to a variety of DACs to produce analog video signals of various formats, along with optimizing of output levels. As with audio codecs, these ICs may have integrated DACs.
3. **Display electronics :** The graphic controller will typically use a lookup table to generate data signals sent to a video DAC for analog outputs such as Red, Green, Blue (RGB) signals to drive a display.

4. **Data acquisition systems :** Data to be measured is digitized by an Analog-to-Digital Converter (ADC) and then sent to a processor. The data acquisition will also include a process control end, in which the processor sends feedback data to a DAC for converting to analog signals.
5. **Calibration :** The DAC provides dynamic calibration for gain and voltage offset for accuracy in test and measurement systems.
6. **Motor control :** Many motor controls require voltage control signals, and a DAC is ideal for this application which may be driven by a processor or controller.
7. **Data distribution system :** Many industrial and factory lines require multiple programmable voltage sources, and this can be generated by a bank of DACs that are multiplexed. The use of a DAC allows the dynamic change of voltages during operation of a system.
8. **Digital potentiometer :** Almost all digital potentiometers are based on the string DAC architecture. With some reorganization of the resistor/switch array, and the addition of an I2C compatible interface, a fully digital potentiometer can be implemented.
9. **Software radio :** A DAC is used with a Digital Signal Processor (DSP) to convert a signal into analog for transmission in the mixer circuit, and then to the radio's power amplifier and transmitter.

Que 4.17. **Why do we need analog to digital converters ?**

Answer

1. In the real world, most data is characterized by analog signals. In order to manipulate the data using a microprocessor, we need to convert the analog signals to the digital signals, so that the microprocessor will be able to read, understand and manipulate the data.
2. Consider a temperature monitoring system wherein acquiring, analyzing and processing temperature data from sensors is not possible with digital computers and processors.
3. Therefore, this system needs an intermediate device to convert the analog temperature data into digital data in order to communicate with the digital processors like microcontrollers and microprocessors.

Que 4.18. **Why we use data acquisition system ?**

Answer

1. **Improves the efficiency and reliability of processes or machinery :**

i. Steel mills, utilities, or a research lab have some kind of data acquisition device that silently monitors some parameter.

ii. These collected data can be used to improve efficiency, ensure reliability or ensure that machinery operates safely.

2. **Problems are analyzed and solved faster :**
   i. With the use of real-time data acquisition systems, measurements are generated and displayed without delay.
   ii. A technician can intervene faster in any problem and make the machine reach optimum performance in less time.
3. **Data redundancy is reduced :** With the application of a system of this type, companies forget to have duplicate data and adopt a technology that facilitates the analysis of the information obtained, as it allows them to work without any noise that hinders the analysis.
4. **Decrease update errors :**
   i. This type of system automates data entry processes that were previously done by hand.
   ii. Automation reduces errors by eliminating human error and misplacement.
5. **Increased data integration and reliance on other programs :**
   i. The fewer programs that intervene in a more agile process, the more agile it will be.
   ii. It ensures that the information is complete and correct without having to rely on other types of applications.
6. **Improved access to data for users through the use of host and query languages :** With these systems it is easier to access the database and retrieve information for processing and analysis.
7. **Improves data security :** By automating the process of capturing data from reality, the human factor is no longer involved and the security risks associated with this procedure are reduced.
8. **Data entry, storage and retrieval costs are reduced :** These three processes are cheaper because data is entered faster, takes up less space, and can be retrieved in less time.
9. **Quality is controlled :**
   i. A system of this type can confirm that a system is meeting the design specifications and that a product meets the user's needs.
   ii. In addition, you can test whether a product has the quality required for marketing and detect those that are defective.
10. **Supervision of processes without human interaction :** With such a system, the company's various procedures are tracked and monitored to identify and resolve faults faster.

PART-5

Counters and Timers.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.19. **Discuss counters and timers.**

Answer

1. The counter and timer functions let users measure either the frequency or the period of an input signal, and the total number of pulses or cycles captured in a specified time period.
2. These functions are enabled when the digital I/O ports are set up as inputs.
3. Counter and timer functions can be programmed to start and stop external hardware (or software) when certain logical conditions in the data acquisition system have been met, such as turning on a valve after a specific number of pulses are counted in a particular time period.
4. Built-in timers also provide "pulse stream output" signals when the digital I/O ports are programmed as outputs.
5. These timers provide precise and stable output signals and should be used for all applications instead of any software generated timing signals.
6. The input to a counter is typically a pulse train. A counter measures the number of input pulses during a given time period and then determines the frequency of the signal as shown in Fig. 4.19.1.

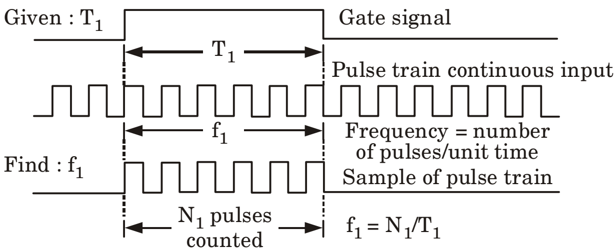


Fig. 4.19.1. Measure frequency.

7. Also a counter counts the absolute number of input events, pulses, or cycles during a given time period and outputs the results as a total number as shown in Fig. 4.19.2.

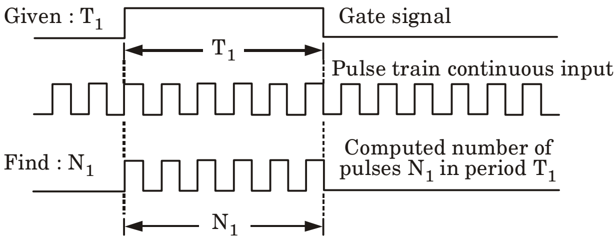


Fig. 4.19.2. Measure total count.

8. A timer measures the time period required for a preprogrammed number of cycles of input signals to occur as shown in Fig. 4.19.3.

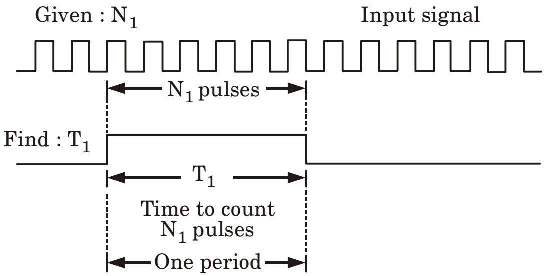


Fig. 4.19.3. Measure period or time.

9. Lastly, a trigger either initiates the start of a sequence or terminates a sequence of events or pulses as shown in Fig. 4.19.4.

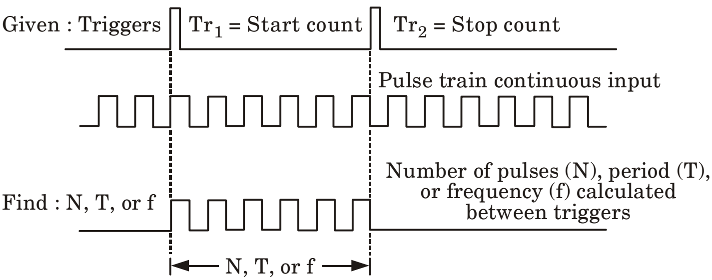


Fig. 4.19.4. Trigger signals.

10. The total count that the data acquisition system can handle depends on the counter circuit's number of bits.

11. For example, a 4-bit counter (2^4) can totalize only 16 pulses before resetting, but a 16-bit counter (2^{16}) can totalize 65,535 pulses, and a 24-bit counter (2^{24}) can totalize 16,777,216 counts.

12. Counters can be programmed to count up or down. Counter stages can be cascaded to increase the count by many powers of two with a carry bit.
13. That is, when the first counter reaches its maximum count, it outputs a carry bit to the next counter in the cascade which then increments its count by one.
14. For either cascaded or non-cascaded counter channels, each channel can be configured for:

i. **Pulse-counting mode :** Specifies that each counter should be cleared or reset to zero after being read and placed into the input scan list.

ii. **Totalize-counting mode :** Specifies that each counter is to free run and will not be cleared during the input acquisition.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What is signal conditioning ?

Ans. Refer Q. 4.1.

Q. 2. Give the various functions of signal conditioners.

Ans. Refer Q. 4.2.

Q. 3. What are the various types of amplifiers ?

Ans. Refer Q. 4.6.

Q. 4. Discuss operational amplifiers in detail with suitable diagram.

Ans. Refer Q. 4.7.

Q. 5. What is data acquisition ? Give its components.

Ans. Refer Q. 4.10.

Q. 6. Explain analog to digital converter.

Ans. Refer Q. 4.11.

Q. 7. Explain digital to analog converter (DAC).

Ans. Refer Q. 4.14.

Q. 8. Why we use data acquisition system ?

Ans. Refer Q. 4.18.

Q. 9. Discuss counters and timers.

Ans. Refer Q. 4.19.

☺☺☺

5
UNIT

Smart Sensors

CONTENTS

PART-1

Smart Sensors : General Structure of Smart Sensors and its Components.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. Explain smart sensors.

Answer

1. A smart sensor is simply expanded as "Sensing, Monitoring and Remote Transmission" sensor.
2. It can be of either analog type or digital type which can be combined with a processing unit and a communication interface. These sensors can provide an electrical output.
3. When they combined with suitable interfacing devices, these sensors are also called intelligent sensors.
4. It can be defined as a microprocessor-based sensor which can perform one or more number of the functions like logical functions, decision making, two-way communication, etc. It can be simply expressed as,

   Sensors + Suitable interfacing circuits = Smart sensors
5. Smart sensors are different from conventional type sensors due to their special functions such as ranging, calibration, communication with other devices, etc.

Que 5.2. Give the features of smart sensors.

Answer

1. Automatic ranging.
2. Auto calibration of data through an in-built system.
3. Automatic data acquisition system and storage of data in local memory of the field device.
4. Auto linearization of non-linear functions.
5. Auto correction of offsets, time and temperature drifts.
6. Self tuning control algorithms.
7. Easy communication through serial bus.

Que 5.3. **What are the advantages of smart sensors ?**

Answer

1. **No need of bulk cables and connectors :** Since smart sensors are of electronic circuits, there is no need to use any bulk cabling and connectors, and hence overall cost of the system gets reduced.
2. **Digital communication :** Due to the integrated manner, the smart sensors can provide digital communication. They also have an in-built self test or diagnostic facility.
3. **Enhanced features :** Smart sensors are having enhanced features like self-computation, fault diagnostics, duplex communication, multi sensing, etc. Hence, they will be preferred in all kinds of control system.
4. **Reliability :** Reduced wiring and ability to provide self-test and diagnostics make the sensors more reliable to use.
5. **Higher SNR :** The electrical characteristic problems with the conventional sensors are overcome by the use of smart sensors. There is no noise interference in smart sensors due to no usage of long transmission cables.
6. **Improved characteristics :** Improved linearity when compared with conventional non-linear characteristics, reduced cross-sensitivity, reduced offset and automatic are some of the important characteristics of a smart sensor.

Que 5.4. **Discuss the architecture of smart sensors.**

Answer

1. The simple structure of any smart sensor is shown in Fig. 5.4.1. The sensing element and signal conditioning are combined to develop a transduction element.

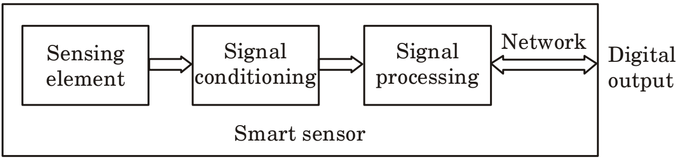


Fig. 5.4.1. Block diagram of a smart sensor.

2. The detailed architecture of a smart sensor is shown in Fig. 5.4.2.

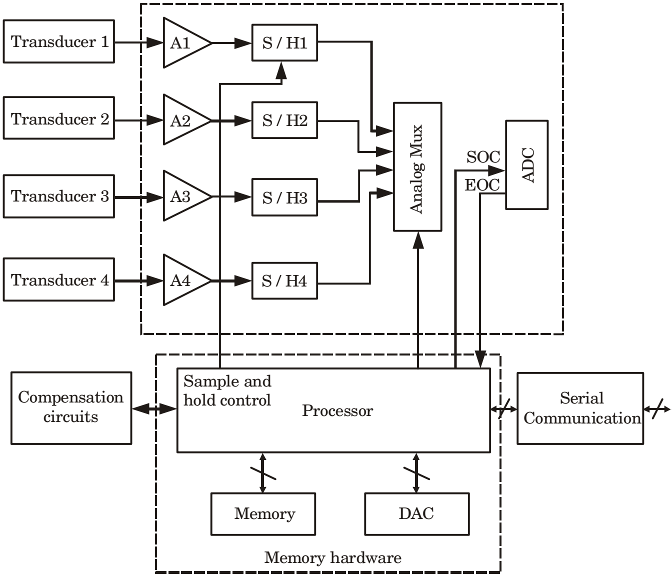


Fig. 5.4.2. Architecture of a smart sensor.

3. The components present in the architecture of a smart sensor are given as follows :

i. Transduction elements (transducers)

ii. Interfacing hardware (data acquisition system)

iii. Memory hardware

iv. Programming devices

v. Communication facilities

vi. Compensation facilities.

4. From the architecture, there are several amplifiers (A_1, A_2, A_3 and A_4) and sample and hold circuits (S/H_1, S/H_2, S/H_3 and S/H_4) corresponding to different transducers (Transducer 1, Transducer 2, Transducer 3 and Transducer 4) respectively.

5. To obtain the digital signal, the analog signals are sent to ADC via analog MUX. Any type of ADC like flash type, successive approximation type or dual slope type ADC can be preferred based on required conversion time constraint.

6. Offset compensation and correction circuits are also provided along with the processor.

7. These circuits are useful for the offset correction and zero compensation purpose against temperature drift. For the data storage and retrieval, memory is also available in the smart sensor.

Que 5.5. **Explain the components of smart sensors.**

Answer

A. Sensing elements :

1. Sensors along with the signal conditioning circuits or simply transducers are used as sensing purpose.
2. They are in contact with the real world signals or measuring systems. Any variables such as temperature, pressure, flow, level, etc., can be measured with them.
3. They are also called a primary sensing part of any measurement system.

B. Data acquisition system (DAS) :

1. It can be used for the measurement and processing of any real world signal, or the variable which is to be measured, before being monitored, displayed or recorded.
2. It consists of transducers, amplifiers, sample and hold devices, multiplexer and analog to digital conversion circuits.

C. Signal processing unit :

1. If sensors are available for transduction purpose, it is necessary to use signal processing units to process the output signals.
2. They will do the process of modifying or manipulating the input signal in such a way that they should meet the requirements for further processing.
3. The process of signal conditioning is carried out by the following steps:

i. Excitation :

a. For passive transducers, it is essential to supply the power.
b. Signal conditioning circuit itself generates excitation or power supply to the passive transducers such as strain gauge, RTD, and etc.
c. If RTD is used as sensor for temperature measurement, current excitation source can be used to convert change in resistance based on temperature variation into measurable voltage.

ii. Amplification : For the purpose of increasing the resolution and reducing the noise, amplifiers are used which will do boosting of input signals.

iii. Filtering : To remove the unwanted noise components present in the input signals, filters are required. Depending on the input signal, LPF or HPF can be preferred.

iv. **Linearization :** For better response, non-linear response can be converted into linear response by means of linearizing circuits.

v. **Sampling :** The process of conversion of continuous signal into discrete signal is called sampling.

vi. **ADC/DAC :** An analog to digital converter (ADC) can be used to convert physical quantity (continuous nature) into digital quantity, whereas the digital quantity can be converted into continuous analog quantity by means of a digital to analog converter (DAC).

vii. **Sample and Hold (S / H) circuit :**

1. Sample and hold circuit is a device which samples the voltage of continuously varying analog nature.
2. Further the value can be hold at a constant level for a specified period of time.
3. In any ADC circuit, sample and hold circuit can be used to eliminate the variation in the input signal which corrupts the conversion process.

D. Multiplexer :

1. It is selection device which selects one of the several analog or digital input signals and the selected signal will then be forwarded to a single line.
2. If there are 2^n inputs has n selector lines, a multiplexer is used to select a particular input signal to be sent to a single line.

E. Programming devices : After the process of data acquisition process, the processed output signal is fed to the programming device such as microprocessor unit for the purpose of programming.

F. Memory : For the purpose of storage and retrieval of programmed data, memory unit can be used.

Que 5.6. **What are the applications of smart sensors ?**

Answer

1. Smart accelerometers for the measurement of acceleration.
2. Smart optical sensors for object detection.
3. Smart IR detector array for the identification of presence of products.
4. Smart sensor for defect or fractures monitoring in structures or infrastructures.
5. Smart sensors to detect the minerals present in geological areas.
6. Food processing and preservation.

7. Biological hazard detection.
8. Health monitoring and medical diagnostics.

PART-2

Characteristic of Smart Sensors : Self-calibration, Self-testing and Self-communicating.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.7. **Explain the characteristics of smart sensors.**

Answer

A. Self-calibration :

1. Self-calibration means adjusting some parameter of sensor during fabrication, this can be either gain or offset or both.
2. Self-calibration is to adjust the deviation of the output of sensor from the desired value when the input is at minimum or it can be an initial adjustment of gain.
3. Calibration is needed because their adjustments usually change with time that needs the device to be removed and recalibrated.
4. If it is difficult to recalibrate the units once they are in service, the manufacturer over-designs, which ensure that device, will operate within specification during its service life.
5. These problems are solved by smart sensor as it has built in microprocessor that has the correction functions in its memory.

B. Computation :

1. Computation also allows one to obtain the average, variance and standard deviation for the set of measurements.
2. This can easily be done using smart sensor.
3. Computational ability allows to compensate for the environmental changes such as temperature and also to correct for changes in offset and gain.

C. Communication :

1. Communication is the means of exchanging or conveying information, which can be easily accomplished by smart sensor.
2. This is very helpful as sensor can broadcast information about its own status and measurement uncertainty.

D. Multi-sensing (Testing) :

1. Some smart sensor also has ability to measure more than one physical or chemical variable simultaneously.
2. A single smart sensor can measure pressure, temperature, humidity gas flow, and infrared, chemical reaction surface acoustic vapour etc.

Que 5.8. **Discuss the evolution of smart sensor.**

Answer

Evolution of smart sensors :

1. First generation devices had little, if any, electronics associated with them.
2. Second generation devices were part of pure analog systems. They have virtually connected to its associated electronics available in remote place from the sensor.
3. The block diagram of a third generation smart device is shown in Fig. 5.8.1.

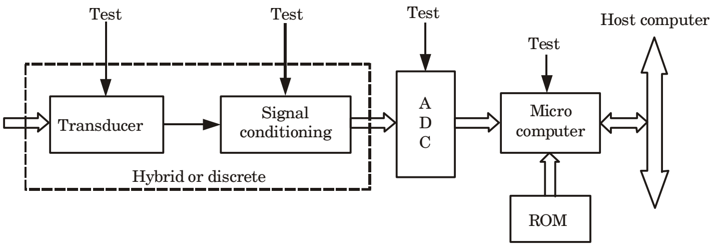


Fig. 5.8.1. Third generation smart sensor.

4. In the third generation devices, transducers and their associated signal conditioning circuits are used as discrete devices.
5. ADC can be used for the conversion of analog input signal into digital output signals.
6. Microcomputer was used for the programming purpose, and ROM was used for the storage and retrieval of data. With suitable communication

interface facility, communication with the host computer was carried out.

7. In the fourth generation of smart sensing devices, the transducer and signal conditioning devices have combined in a monolithic package.
8. The block diagram of fourth generation device is shown in Fig. 5.8.2.

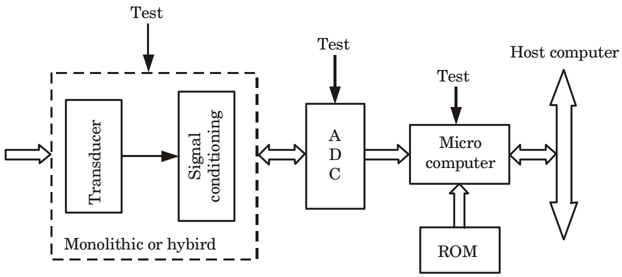


Fig. 5.8.2. Fourth generation smart sensor.

9. The block diagram of fifth generation smart sensor is shown in Fig. 5.8.3, along with and integrated sensor analog to digital conversion (ADC) device.
10. PROM memory can be combined with sensing and conversion unit in monolithic form. The functioning of the overall unit can also be carried out easily.

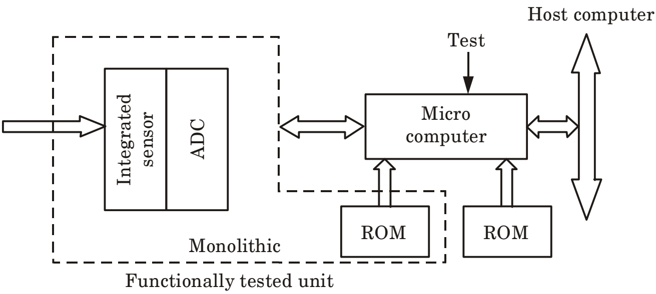


Fig. 5.8.3. Fifth generation smart sensor.

PART-3

Application of Smart Sensors : Smart City, Industrial Robots and Electric Vehicles.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.9. Explain the application of smart sensors in smart cities.

Answer

Applications :

A. Water management :

1. At present, the major cities waste up to 50 % of water due to pipe leakages. With sensors fitted on each pipes, water leaks can be easily detected and corrected before any heavy loss.
2. Besides this, the irrigation systems in public parks can automatically turn OFF whenever rain is detected to save water.

B. Energy management :

1. Sensors have also enabled the concept of "Advanced Metering Infrastructure (AMI)" underpinning energy management in cities.
2. Cities are considering use of "Smart meters" embedded with Phase Measurement Unit (PMU) sensors and communication module which facilitates a two-way communication between the consumer and the supplier.
3. For utility service providers, it helps check meter status prior to sending a repair crew in response to a customer call.
4. These checks prevent needless field crew dispatch to customer sites.
5. For consumers, it can provide the real-time energy usage detail in a way which a user can understand quite easily.
6. Based upon this data, users can change the preferences and make more informed decisions about their usage without waiting for their energy bill at the end of month.

C. Smart street lights :

1. In cities street lights remain ON even when there's no activity in the area.
2. Additionally, it becomes very difficult for authorities to detect any fault and theft of street lights.

3. With sensors, lights can go dim when they aren't needed and authorities can get a text message almost instantly whenever there is a fault or tampering in street lights.

D. Waste management :

1. With sensors fitted in the garbage bins, the municipal authorities can be notified when they are close to being full.
2. The Netherlands became the first ever to produce "Intelligent Bins" that report to the officials via text messages whenever the bins are either full or if there is any damage.

E. Transport management (smart parking) :

1. Traffic can be reduced with sensors that detect where the nearest available parking slot is.
2. Motorists get timely information via text messages so they can locate a free parking slot quickly, saving time and fuel.

F. Real-time pollution management :

1. Sensors mounted on poles can monitor the Ambient Air Quality (AAQ) of cities.
2. Citizens can monitor the pollution concentration in each street of the city or they can get automatic alarms when the pollution level rises beyond a certain level.

Que 5.10. Discuss the smart sensor application of traffic control, public safety, digital signage, EV charging and WiFi in smart cities.

Answer

A. Traffic control :

1. Data collected by optical sensor, radar, or infrared distance sensors can be used to count cars and estimate traffic flow on roads.
2. Machine vision is designed to recognize and categorize specific shapes in order to perform analysis on the optical data collected by smart cameras.
3. These video analytics can be manipulated to perform an enormous range of applications including people counting, traffic counting, wrong way driver detection and more.
4. Similar applications can be performed using radar detectors and infrared distance sensors.

5. Smart cities commonly use video analytics to monitor and track real time traffic patterns.
6. This data can be used to optimize signal timing or traffic patterns.
7. Data driven traffic system optimization can significantly reduce the amount of time drivers spend in their car thereby reducing greenhouse gas emissions as well as wear and tear on public roadways.

B. Public and campus safety :

1. Cameras, microphones and other security devices become more effective when paired with analytics.
2. Public safety applications use video and audio detection along with edge-based signal processing to identify suspicious or unlawful activity like, gunshots, glass-breaks, suspicious packages, wrong way drivers and more.
3. Using smart city communication networks, security events are instantly communicated to the designated security centre.

C. Digital signage :

1. Digital signage can easily be deployed around smart cities.
2. These signs can be used to improve way finding or to communicate emergency information like weather warnings or amber alerts.
3. Additionally, advertisements displayed on digital signs can generate new revenue for smart cities.
4. Digital signage transforms community engagement, enhances public safety and fosters economic development.

D. Electric vehicle charging :

1. Smart city hubs allow electricity from a street light pole to be tapped to power electric vehicle chargers.
2. That power can be metered and billed to end users.
3. Optical sensors use artificial intelligence to detect license plate information, that information and the power consumption data can be relayed over the smart city communication network to bill the end user.

E. Public Wi-Fi access :

1. Internet infrastructure is crucial for cities to attract business investment and new residents.
2. Public Wi-Fi access points can be deployed with or in LED streetlights.

3. This approach ensures low costs and ubiquitous coverage by utilizing existing streetlight infrastructure.
4. A widely available Wi-Fi network also enables smart city applications with greater communications requirements like video streaming for security purposes.

Que 5.11. **Explain the use of smart sensor in industrial robots.**

Answer

A. Force torque sensor :

1. While vision gives eyes to the robot, force torque sensors give touch to the robot wrist.
2. Here the robot uses a Force Torque Sensor (FT sensor) to know the force that the robot is applying with its end of arm tooling.
3. Most of the time, the FT sensor is located between the robot and the tool. This way, all the forces that are applied on the tool are monitored.
4. Applications such as assembly, hand-guiding, teaching and force limitation can be done with this device.

B. Collision detection sensor :

1. The main applications of these sensors is to provide a safe working environment for human workers, the collaborative robots are most likely to use them.
2. Some sensors can be some kind of tactile recognition systems, where if a pressure is sensed on a soft surface, a signal will be sent to the robot to limit or stop its motions.
3. You can also see this kind of sensor directly built into the robot. Some companies use accelerometers, some use current feedback.
4. In either case, when an abnormal force is sensed by the robot the emergency stop is released. This provides a safer environment.

C. Safety sensors :

1. With the introduction of industrial robots in collaborative mode, industry has to react with a way to protect its workers.
2. These sensors can really appear in a lot of different shapes. From cameras to lasers, a safety sensor is designed to tell the robot that there is a presence around it.
3. Some safety systems are configured to slow down the robot once the worker is in a certain area/space and to stop it once the worker is too close.

4. A simple example of safety sensors would be the laser on your garage door. If the laser detects an obstacle, the door immediately stops and goes backwards to avoid a collision.

D. Part detection sensors :

1. For applications that require you to pick parts, you probably have no clue if the part is in the gripper or if you just missed it.
2. Well, a part detection application gives you feedback on your gripper position.
3. For example, if a gripper misses a part in its grasping operation, the system will detect an error and will repeat the operation again to make sure the part is well grasped, adaptive gripper object detection.
4. Our adaptive grippers have part detection systems that don't need any sensors.
5. In fact, our grippers are designed to grasp parts with a given force.
6. So the gripper doesn't need to know that the part is there or not, it will only apply enough force to get the best grip on the object.
7. Once the required force is reached, you know that the object is in the gripper and that it is ready for the next step in the operation.

E. 2D vision :

1. 2D is vision is basically a video camera that can perform a lot of different things, from detecting movement to localization of a part on a conveyor.
2. Many smart cameras out there can detect parts and coordinate the part position for the robot so that it can then adapt its actions to the information it receives.

F. 3D vision :

1. 3D vision is much more recent phenomenon as compared to 2D vision.
2. A tri-dimensional vision system has to have 2 cameras at different angles or use laser scanners. This way, the third dimension of the object can be detected.
3. For example, Robot can use 3D vision to detect objects in a bin and recreate the part in 3D, analyze it and pick it the best way possible.

G. Others :

1. Of course there are a lot of other sensors that can be fitted to your robotic cell that are very specific to your application.
2. Sensors that are capable to do seam tracking in welding operations are a good example where a specific sensor is necessary.

3. Tactile sensors are also becoming more popular these days. This kind of sensor is, most of the time, fitted on a gripper to detect and feel.
4. Sensors are usually able to detect forces and draw an array of vectors with the force distribution.
5. This shows the exact position of an object and allows you to control the position and the grasping force of the end effector. Some tactile sensors can also detect heat variation.
6. Finally, sensors are key components to leveraging software intelligence. Without such sensors, advanced operations wouldn't be possible.
7. They bring a lot of complexity to the operation, but they also insure good control during the process.

Que 5.12. **Discuss the use of smart sensors in electric vehicle.**

Answer

A. Displacement/LVDT sensors :

1. LVDT (Linear Variable Differential Transformer) sensors to measure pouch and prismatic cell swelling during battery validation testing.
2. Because batteries bulge and expand over time, this testing helps to determine durability of each cell and the appropriate type and size of battery housing.
3. These sensors should be with high accuracy and resolution over wide temperature range, low drift over time and suitable for use in harsh fluids and hostile environments.

B. Inertial sensors :

1. Inertial sensors are used to measure translational and rotational accelerations.
2. By combining several inertial sensors in an inertial measurement unit, the accelerations and rotations around the three axes can be measured in six dimensions while driving.
3. Consequently, an inertial measurement unit can be used for a multitude of automotive applications as well as for future advanced driver assistance systems functions and automated driving.
4. The inertial measurement unit measures up to six dimensions :

i. Yaw

ii. Roll

iii. Pitch rate

iv. Lateral

v. Longitudinal

vi. Vertical accelerations.

5. The inertial measurement unit contributes to the functionality of the airbag control unit as well as to driver assistance systems like the adaptive cruise control, and improves the offset performance with an integrated microcontroller.

C. Wireless sensor networks :

1. From design qualification, production and to real-time vehicle health monitoring, wireless sensor networks are everywhere in the EV world.
2. Wireless temperature and voltage sensors on EV batteries and components are used as safety systems during manufacturing and testing of EVs.
3. They are used to detect quality defects, determine the crashworthiness of the vehicle and battery systems and protect test operators.
4. Wireless vibration, shock and strain sensors are used to characterize and optimize vehicle performance and to inform structural analysis.
5. These wireless sensor networks must be easy to deploy and should come with full-featured, time-synchronized sensor data aggregation and visualization tools.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Explain smart sensors.

Ans. Refer Q. 5.1.

Q. 2. Discuss the architecture of smart sensors.

Ans. Refer Q. 5.4.

Q. 3. Explain the components of smart sensors.

Ans. Refer Q. 5.5.

Q. 4. Explain the characteristics of smart sensors.

Ans. Refer Q. 5.7.

Q. 5. Discuss the evolution of transducer.

Ans. Refer Q. 5.8.

Q. 6. Discuss the smart sensor application of traffic control, public safety, digital signage, EV charging and WiFi in smart cities.

Ans. Refer Q. 5.10.

Q. 7. Explain the use of smart sensor in industrial robots.

Ans. Refer Q. 5.11.

☺☺☺

1 UNIT

Sensors & Transducers-I (2 Marks Questions)

1.1. Define sensor.

Ans.

1. It is defined as an element which produces signal relating to the quantity being measured.
2. It can also be defined as "A device which provides a usable output in response to a specified measurand."

1.2. What is transducer ?

Ans.

1. It is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measurand into a usable output by using a transduction principle.
2. It can also be defined as a device that converts a signal from one form of energy to another form.

1.3. Give the classification of sensors based on displacement and position.

Ans.

1. Potentiometer
2. Strain-gauged element
3. Capacitive element
4. Differential transformers
5. Eddy current proximity sensors
6. Inductive proximity switch
7. Optical encoders
8. Pneumatic sensors
9. Proximity switches
10. Hall effect sensors.

1.4. Classify sensors based on temperature.

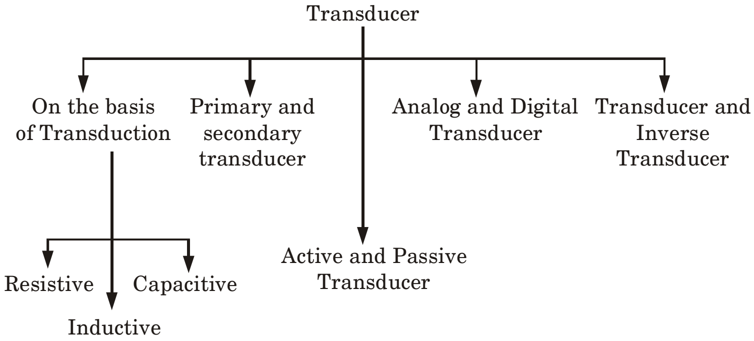
Ans.

1. Bimetallic strips
2. Resistance temperature detectors
3. Thermistors
4. Thermo-diodes and transistors

5. Thermocouples
6. Light sensors
7. Photo diodes
8. Photo resistors
9. Photo transistor.

1.5. Give the classification of transducers.

Ans.



1.6. What are the various advantages of transducers ?

Ans.

1. Electrical amplification and attenuation can be done easily.
2. No moving mechanical parts.
3. Very small electric power required.

1.7. Give the various disadvantages of transducers.

Ans.

1. Design is complicated.
2. The electrical transducer is sometimes less reliable than mechanical type.

1.8. What are the factors to be considered while selecting transducer ?

Ans.

1. High input impedance and low output impedance.
2. Highly sensitive.
3. Small in size.
4. High degree of accuracy and repeatability.
5. Free from errors.

1.9. What are the applications of transducers in various fields ?

Ans.

1. **Electromagnetic :**
   a. Antennas
   b. Hall-effect sensors
   c. Disk read and write heads
   d. Magnetic cartridges.
2. **Electromechanical :**
   a. Accelerometers
   b. Pressure sensors
   c. Galvanometers
   d. LVDT
   e. Load cells
   f. Potentiometers.

1.10. What is potentiometer ?

Ans. An instrument for measuring an electromotive force by balancing it against the potential difference produced by passing a known current through a known variable resistance is known as potentiometer.

1.11. What is an optical encoder ?

Ans.

1. An optical encoder is an electromechanical device which has an electrical output in digital form proportional to the angular position of the input shaft.
2. Optical encoders enable an angular displacement to be converted directly into a digital form. An optical encoder is an angular position sensor.

1.12. What are load cells ?

Ans. A load cell is a force gauge that consists of a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured.

1.13. How strain gauge load cell works ?

Ans.

1. In strain gauge load cells strain gauge assembly is positioned inside the load cell housing to convert the load acting on them into electrical signals.
2. The resistance of a strain gauge varies with applied force and, it converts parameters such as force, pressure, tension, weight, etc. into a change in resistance that can be measured later on.

1.14. Explain the characteristics of strain gauges.

Ans.

1. They are highly precise.
2. They are ideal for long distance communication.
3. They require easy maintenance and have a long operating life.
4. They require certain precautions while installing.

1.15. Give the applications of strain gauges.

Ans.

1. They are used in diagnosis on machines and failure analysis.
2. They are used for multi-axial stress fatigue testing and proof testing.
3. They are primarily used as sensors for safety in automotive.

1.16. What is piezoelectric sensor or transducer ?

Ans.

1. A piezoelectric transducer (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.
2. When pressure is applied to a crystal, it is elastically deformed. This deformation results in a flow of electric charge (which lasts for a period of a few seconds).

1.17. What are the advantages of piezoelectric sensor or transducer ?

Ans.

1. No need for an external force.
2. Easy to handle and use as it has small dimensions.
3. High-frequency response.

1.18. Give the disadvantages of piezoelectric sensor or transducer.

Ans.

1. It is not suitable for measurement in static condition.
2. It is affected by temperatures.
3. The output is low so some external circuit is attached to it.

1.19. What are the applications of piezoelectric sensor or transducer ?

Ans.

1. In microphones.
2. It is also used in medical diagnostics.
3. It is used in electric lighter used in kitchens.
4. It is used infertility treatment.
5. It is used in inkjet printers.

☺☺☺

2 UNIT

Sensors & Transducers-II (2 Marks Questions)

2.1. Explain the thermistors.

Ans.

1. A thermistor (or thermal resistor) is defined as a type of resistor whose electrical resistance varies with changes in temperature.
2. Although all resistors' resistance will fluctuate slightly with temperature, a thermistor is particularly sensitive to temperature changes.
3. Thermistors follow the principle of decrease in resistance with increasing temperature.

2.2. Give the relationship between resistance and temperature of thermistors.

Ans. The relationship governing the characteristics of a thermistor is given below as,

$$R_1 = R_2 e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

where :

R_1 = Resistance of the thermistor at absolute temperature T_1[K]

R_2 = Resistance of the thermistor at temperature T_2[K]

β = Constant depending upon the material of the transducer.

2.3. What are the applications of thermistors ?

Ans.

1. To monitor the coolant temperature and/or oil temperature inside the engine.
2. To monitor the temperature of an incubator.
3. To monitor the temperature of battery packs while charging.
4. To monitor temperature of hot ends of 3D printers.

2.4. Discuss RTD.

Ans. A resistance thermometer or Resistance Temperature Detector (RTD) is a device which used to determine the temperature by measuring the resistance of pure electrical wire. This wire is referred to as a temperature sensor.

2.5. Give the characteristics of RTD.

Ans.
1. If we want to measure temperature with high accuracy, RTD is the only one solution in industries.
2. It has good linear characteristics over a wide range of temperature.

2.6. What is thermal imaging ?

Ans. Thermal imaging is a method of improving visibility of objects in a dark environment by detecting the object's infrared radiation and creating an image based on that information.

2.7. Give the types of thermal imaging.

Ans. There are two common types of thermal-imaging devices:
a. Un-cooled
b. Cryogenically cooled.

2.8. What is Hall Effect sensors ?

Ans. A Hall Effect sensor is a device that is used to measure the magnitude of a magnetic field. Its output voltage is directly proportional to the magnetic field strength through it.

2.9. What capacitive proximity sensors can detect ?

Ans. Capacitive proximity sensors can detect both metallic and non-metallic targets in powder, granulate, liquid, and solid form.

2.10. Explain photoelectric sensors.

Ans. These sensors use light sensitive elements to detect objects and are made up of an emitter (light source) and a receiver.

2.11. What are the types of vibration sensor ?

Ans.
1. Accelerometer
2. Strain gauge
3. Eddy-current.

2.12. How ultrasonic flow sensors work ?

Ans. Ultrasonic flow sensors use sound waves to determine the velocity of a fluid flowing in a pipe.

2.13. What are the advantages of ultrasonic flow sensors ?

Ans.
1. It does not block the path of liquid flow.
2. The flow of liquid is bidirectional.
3. The dynamic response of this meter is good.
4. The output of this meter is in analog form.

2.14. Give the disadvantages of ultrasonic flow sensors.

Ans.
1. It is expensive as compared with other mechanical flow meters.
2. Design of this meter is complex.
3. It cannot measure cement or concrete pipes one they rusted.
4. It doesn't work once the pipe contains holes or bubbles in it.

2.15. What are the applications of ultrasonic flow sensors ?

Ans.
1. These meters are used in wastewater and dirty liquid applications.
2. These meters are used wherever less maintenance and low-pressure drop are required.
3. These meters are used to measure the velocity.

2.16. What are the advantages of ultrasonic level sensors ?

Ans.
1. Non-contact with product.
2. Reliable performance in difficult service.
3. No moving parts.
4. Measurement without physical contact.

2.17. Give the disadvantages of ultrasonic level sensors.

Ans.
1. Product must give a good reflection and not absorb sound.
2. Not suitable for higher pressures or in a vacuum.
3. The temperature is limited to 170 °C.

2.18. What are the advantages of capacitive level sensors ?

Ans.
1. Relatively inexpensive
2. Versatile
3. Requires minimal maintenance
4. Reliable
5. Contains no moving parts
6. Easy to clean.

2.19. Give the application of capacitive level sensors.

Ans.

1. Powered and granular solids
2. Liquefied gases at very low temperature
3. Very high pressure industrial processes.

2.20. What are the disadvantages of capacitive level sensors ?

Ans. This system cannot work with materials having varying dielectric materials.

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3 UNIT

Machine Vision (2 Marks Questions)

3.1. What is machine vision ?

Ans.

1. Machine vision systems analyse images from cameras to generate image feature data that guides robotic and automation machines in their understanding of the physical world.
2. Vision is a sensory input capable of producing detailed data that in many instances could only be obtained by means of vision.

3.2. Give the difference between computer and machine vision.

Ans.

S. No.	Computer vision	Machine vision
1.	It doesn't depend on machine vision.	It can't exist without computer vision.
2.	It is a scientific domain	It is an engineering one.
3.	It has a much greater processing capability of acquired visual data.	It has lesser processing capability of acquired visual data as compared to computer vision.

3.3. What are the applications of computer vision.

Ans.

1. This process is used to detect abnormalities in medical scans.
2. Computer vision differentiates between intentional and accidental damage based on pattern recognition.
3. Surveillance may be automated with computer vision.

3.4. Give the applications of machine vision.

Ans.

1. Automatic inspection
2. Quality control
3. Robot guidance.

3.5. What are Charge-Coupled Device (CCD) imaging sensors.

Ans.
1. The charge-coupled device (CCD) is a technology for capturing images, from digital astrophotography to machine vision inspection.
2. The CCD sensor is a silicon chip that contains an array of photosensitive sites.

3.6. What is full form of CMOS ?

Ans. **CMOS :** Complementary metal oxide semiconductor.

3.7. Compare CCD and CMOS.

Ans.

Sensor	CCD	CMOS
Pixel signal	Electron packet	Voltage
Chip signal	Analog	Digital
Speed	Moderate - High	High
Power Consumption	Moderate - High	Low

3.8. Explain the tasks included in machine vision system.

Ans.
A. Sensing and digitizing image data
B. Image processing and analysis
C. Applications function.

3.9. What is VGR ?

Ans.
1. In industrial pick and place applications, Vision Guided Robots (VGR) are typically robotic arms with integrated machine vision systems.
2. The machine vision system helps the robot discover the location of an object in order to guide the robot to a desired point for pick and place.

3.10. Give the applications of VGR systems.

Ans.
1. Loading/unloading parts from conveyors and feeding systems
2. Part placement, assembly and packaging
3. Racking and de-racking
4. Bin picking of random parts.

3.11. What is Animal (AT) Model ?

Ans. The AT robot design model consists of a robot with useful behaviours and tasks programmed by a human user and that executes those tasks on verbal command.

☺☺☺

4 UNIT

Signal Conditioning & Data Acquisition Systems (2 Marks Questions)

4.1. What is signal conditioning ?

Ans.

1. Signal conditioning is the manipulation of a signal in a way that prepares it for the next stage of processing.
2. Signal conditioning is the technique of making a signal from a sensor or transducer suitable for processing by data acquisition equipment.

4.2. Give the various functions of signal conditioners.

Ans.

A. Signal conversion
B. Linearization
C. Amplifying
D. Filtering.

4.3. What are various types of signal conditioning ?

Ans.

1. Amplification
2. Excitation
3. Linearization
4. Filtering.

4.4. Give the types of signal conditioners.

Ans.

1. Temperature signal conditioner
2. Thermocouple signal conditioner
3. Thermistors signal conditioner
4. RTD signal conditioner.

4.5. Explain amplification process.

Ans. Amplification is a process which increases (amplifies) the signal for possessing or digitization.

4.6. What are the various types of amplifiers ?

Ans.

1. Isolation amplifiers

2. Current amplifier
3. Voltage amplifier
4. Operational amplifiers (Op-Amps).

4.7. Give the names of the stages in operational amplifiers.

Ans.
1. Inverting amplifier stages
2. Non-inverting amplifier stages.

4.8. What is the benefit of differential amplifier ?

Ans. The major benefit of the differential amplifier is its ability to reject any voltages that are common to both inputs while amplifying the difference voltage.

4.9. What is data acquisition ?

Ans. Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, vibration or sound with a computer.

4.10. What are the components of DAQ ?

Ans.
1. Sensor
2. DAQ device
3. Computer and software.

4.11. Explain analog to digital converter.

Ans. Analog to Digital Converter (ADC) is an electronic integrated circuit used to convert the analog signals such as voltages to digital or binary form consisting of 1s and 0s.

4.12. What are the types of analog to digital converter ?

Ans.
A. Successive approximation A/D converter
B. Dual slope A/D converter
C. Flash A/D converter.

4.13. What is digital to analog converter (DAC).

Ans. Digital to Analog Converter (DAC) is a device that transforms digital data into an analog signal.

4.14. Give the types of digital to analog converter.

Ans.
A. R-2R ladder network method.
B. Weighted resistors method.

4.15. Why do we need analog to digital converters ?

Ans.

1. In the real world, most data is characterized by analog signals.
2. In order to manipulate the data using a microprocessor, we need to convert the analog signals to the digital signals, so that the microprocessor will be able to read, understand and manipulate the data.

4.16. Why we use data acquisition system ?

Ans.

1. It improves the efficiency and reliability of processes or machinery.
2. It increases data integration and reliance on other programs.
3. It improves data security.
4. Data entry, storage and retrieval costs are reduced.

4.17. Discuss counters and timers.

Ans.

1. The counter and timer functions measure either the frequency or the period of an input signal, and the total number of pulses or cycles captured in a specified time period.
2. Also a counter counts the absolute number of input events, pulses, or cycles during a given time period and outputs the results as a total number.
3. A timer measures the time period required for a preprogrammed number of cycles of input signals to occur.

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5 UNIT

Smart Sensors (2 Marks Questions)

5.1. Explain smart sensors.

Ans.

1. A smart sensor is simply expanded as "Sensing, Monitoring And Remote Transmission" sensor.
2. It can be defined as a microprocessor-based sensor which can perform one or more number of the functions like logical functions, decision making, two-way communication, etc. It can be simply expressed as:
   Sensors + Suitable interfacing circuits = Smart sensors

5.2. Give the features of smart sensors.

Ans.

1. Automatic ranging
2. Auto calibration of data through an in-built system
3. Auto linearization of non-linear functions
4. Easy communication through serial bus.

5.3. What are the advantages of smart sensors ?

Ans.

1. No need of bulk cables and connectors
2. Enhanced features
3. Reliability
4. Higher SNR.

5.4. Give the block diagram of smart sensors.

Ans.

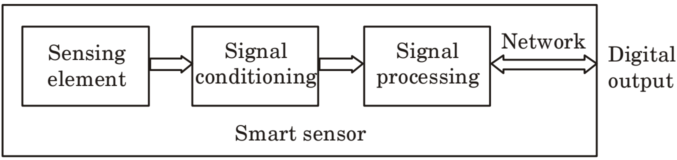

Fig. 5.4.1. Block diagram of a smart sensor.

5.5. What are the applications of smart sensors ?

Ans.

1. Smart accelerometers for the measurement of acceleration
2. Smart optical sensors for object detection
3. Food processing and preservation
4. Biological hazard detection.

5.6. What are the characteristics of smart sensors ?

Ans.

1. Self-calibration
2. Computation
3. Communication
4. Multi-sensing.

5.7. Give the applications of smart sensors in smart cities.

Ans.

1. Water management
2. Energy management
3. Smart streetlights
4. Traffic control.

5.8. Which smart sensors used in industrial robots ?

Ans.

1. Force torque sensor
2. Collision detection sensor
3. Safety sensors
4. Part detection sensors.

5.9. Which smart sensors are used in electric vehicle ?

Ans.

1. Displacement/LVDT sensors
2. Inertial sensors
3. Wireless sensor networks.

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