University of Dhaka
Department of Computer Science and Engineering
CSE-2205: Introduction to Mechatronics

Lec-2: Basics of Sensors and Transducers

Mechatronics: Electronic Control Systems in Mechanical Engineering by W. Bolton

Md. Ariful Islam
Assistant Professor
Dept. of Robotics and Mechatronics Engineering
University of Dhaka

Sensor

A sensor is a device that *detects and responds to physical stimuli* (such as light, heat, motion, pressure, etc.) and *converts that input into a signal* (often electrical) that *can be read or interpreted*.

1. Temperature Sensor

Example: Thermocouple

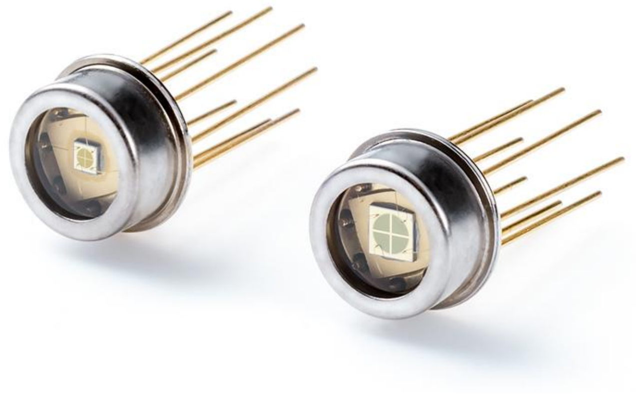
Function: Measures temperature *by generating a voltage* based on the *temperature difference* between two junctions.

2. Pressure Sensor

Example: Piezoelectric Pressure Sensor

Function: Measures pressure by converting *pressure changes into an electrical signal* using piezoelectric materials.

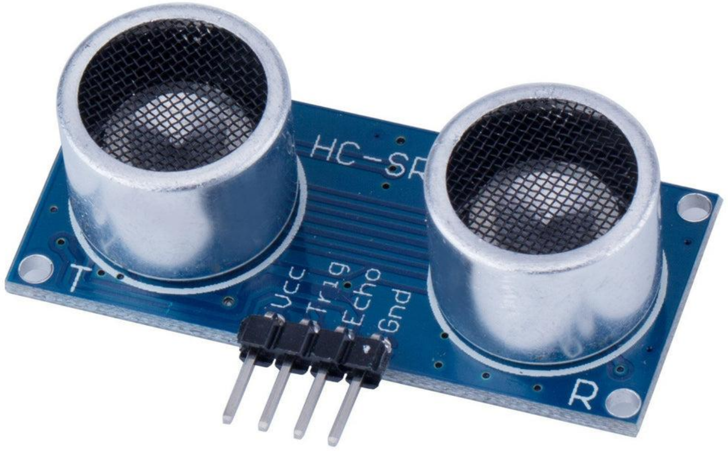
3. Light Sensor



Example: Photodiode

Function: *Detects light intensity* and converts it into a *current or voltage signal*.

4. Proximity Sensor



Example: Ultrasonic Sensor

Function: *Measures the distance* to an object by *emitting ultrasonic waves* and *detecting the time* taken for *the echo to return*.

5. Motion Sensor

Example: Passive Infrared (PIR) Sensor

Function: Detects motion by *measuring changes in infrared radiation* emitted *by objects* in its field of view.

6. Humidity Sensor

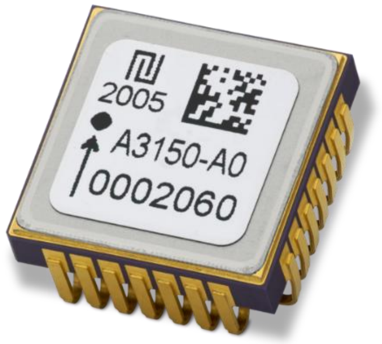
Example: Capacitive Humidity Sensor

Function: Measures humidity levels by *detecting changes in capacitance* caused by *moisture in the air*.

7. Acceleration Sensor

Example: MEMS* Accelerometer

Function: Measures acceleration forces *to detect motion or orientation changes*.



*MEMS: micro electro mechanical system

8. Gas Sensor

Example: MQ Gas Sensor

Function: Detects the *presence of specific gases* (like CO_2 methane) by measuring *changes in resistance*.

9. Flow Sensor

Example: Turbine Flow Sensor

Function: Measures the flow rate of liquids or gases by *counting the rotation of a turbine*.

Transducer

A transducer is a device that *converts one form of energy into another*. This conversion can be between various types of energy, such as electrical, mechanical, thermal, acoustic, or optical.

Examples of Transducer

1. Microphone:

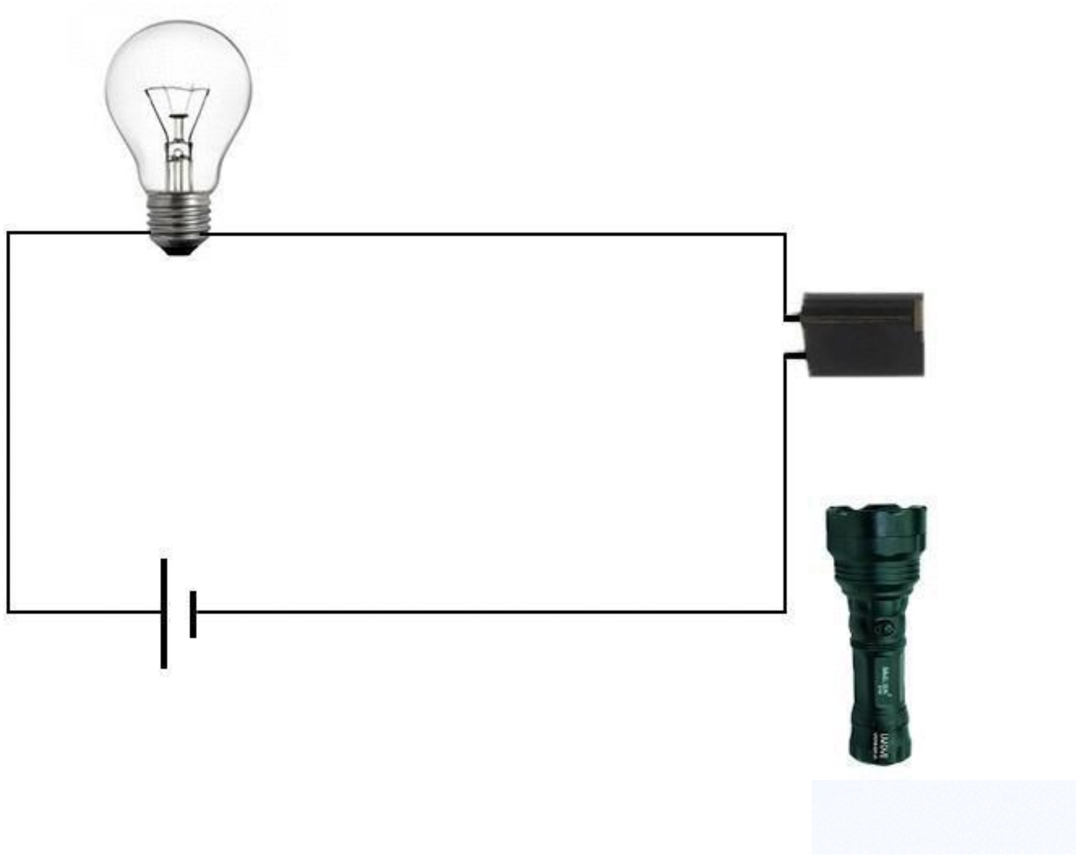
Converts *sound (acoustic energy) into an electrical signal*.

2. Speaker:

Converts *electrical signals into sound* (acoustic energy).

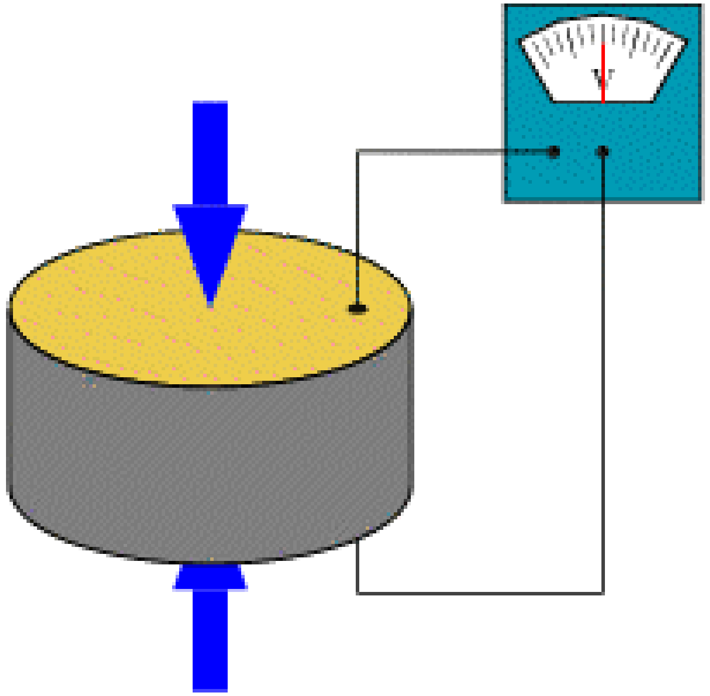
3. Photodiode

Converts *light (optical energy) into an electrical signal.*



4. Piezoelectric Sensor

Converts *mechanical stress (mechanical energy) into an electrical signal*.



$$\sigma = \frac{F}{A}$$

Where:

σ is stress

F is force

A is cross sectional area

$$\varepsilon = \frac{\Delta L}{L}$$

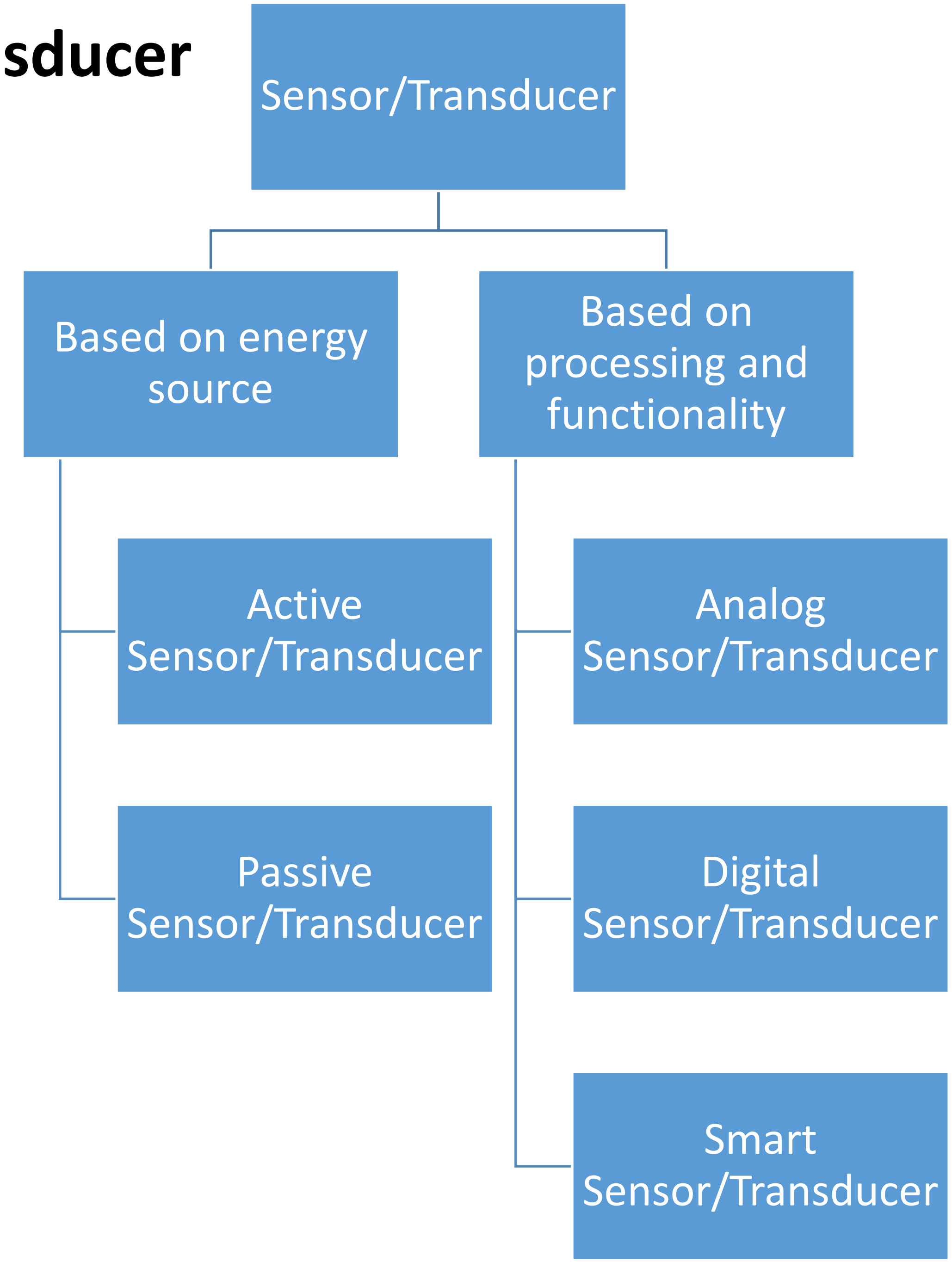
Where:

ε is the strain

ΔL is the change in length

L is the original length

Classification of Sensor / Transducer



Types of Sensors based on energy source

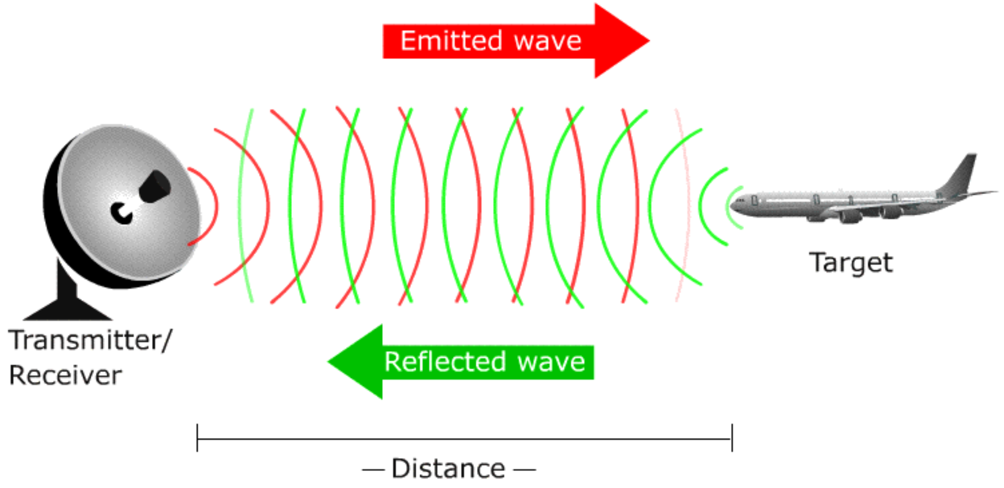
1. Active Sensor

Active sensors *require an external power source* to operate and often *emit energy (such as light or sound)* to *detect changes* in the environment.

1.1 RADAR* Sensors:

Emit radio waves and detect objects by *analyzing the reflected signals*.

Used in *speed detection, weather monitoring, and aircraft navigation*.

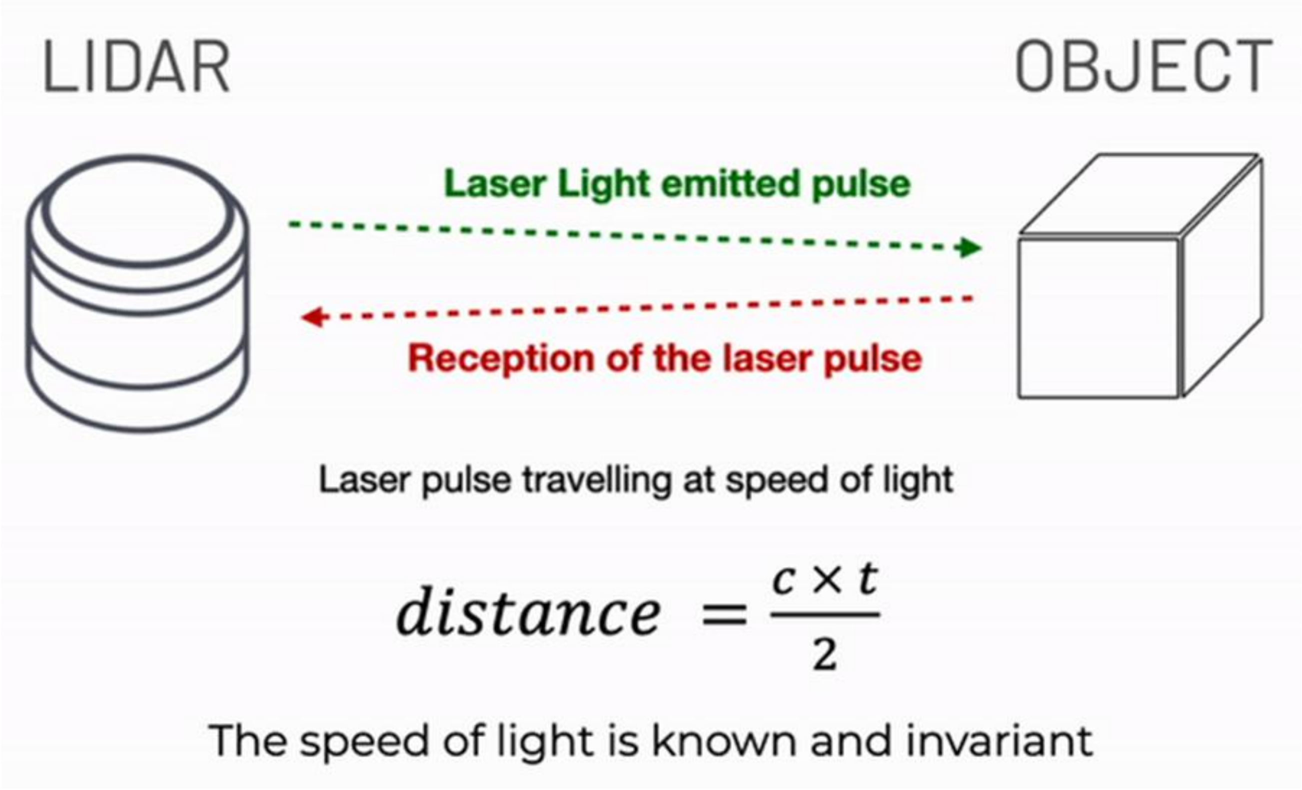


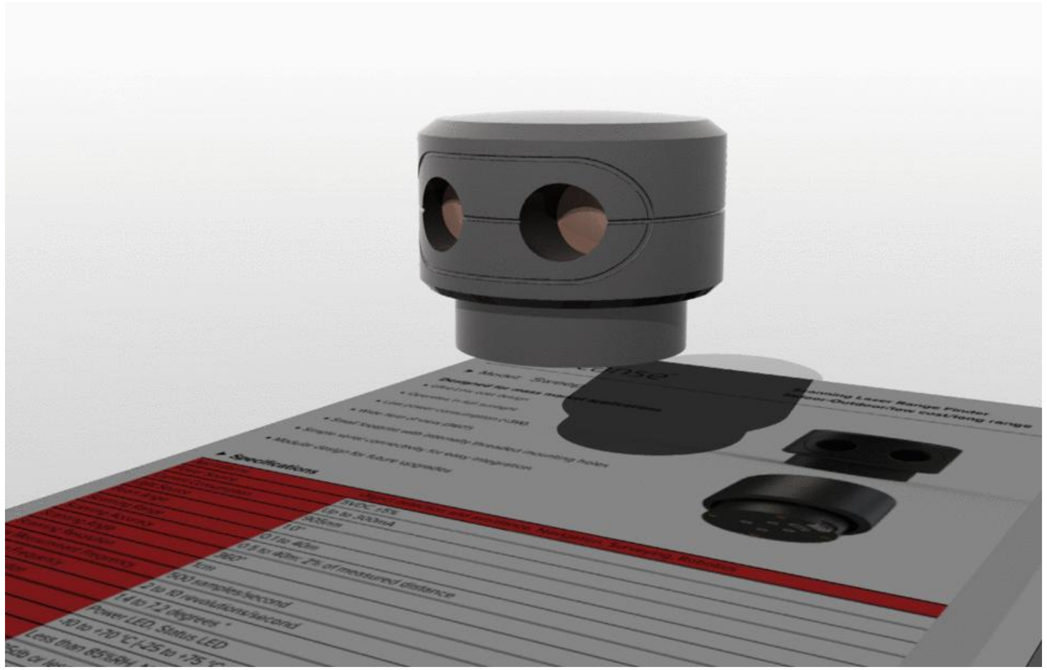
*Radio Detection And Ranging

1.2 LIDAR* Sensors:

Emit laser beams and *measure the reflection* to determine *distance* and *create 3D maps*.

Used in *autonomous vehicles, surveying, and environmental monitoring*.



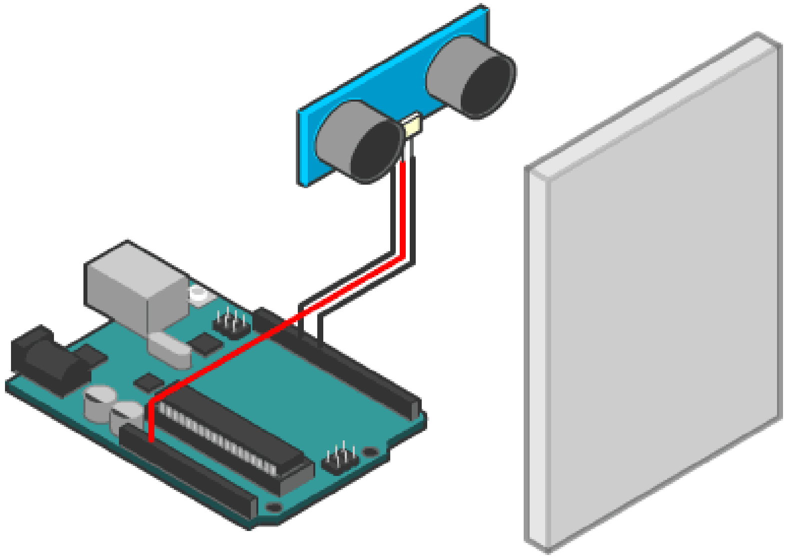


*Light Detection and Ranging

1.3 Ultrasonic Sensors:

Emit high-frequency sound waves and *measure the time* it takes for the *echo to return*.

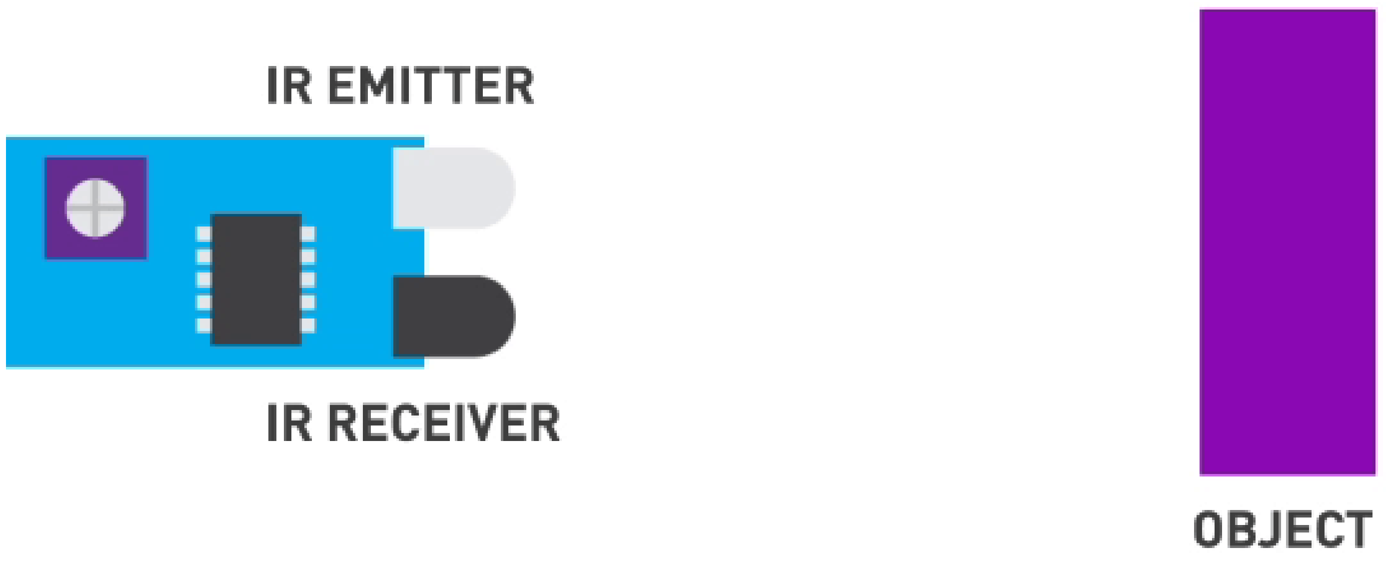
Used in *parking sensors, object detection, and distance measurement*.



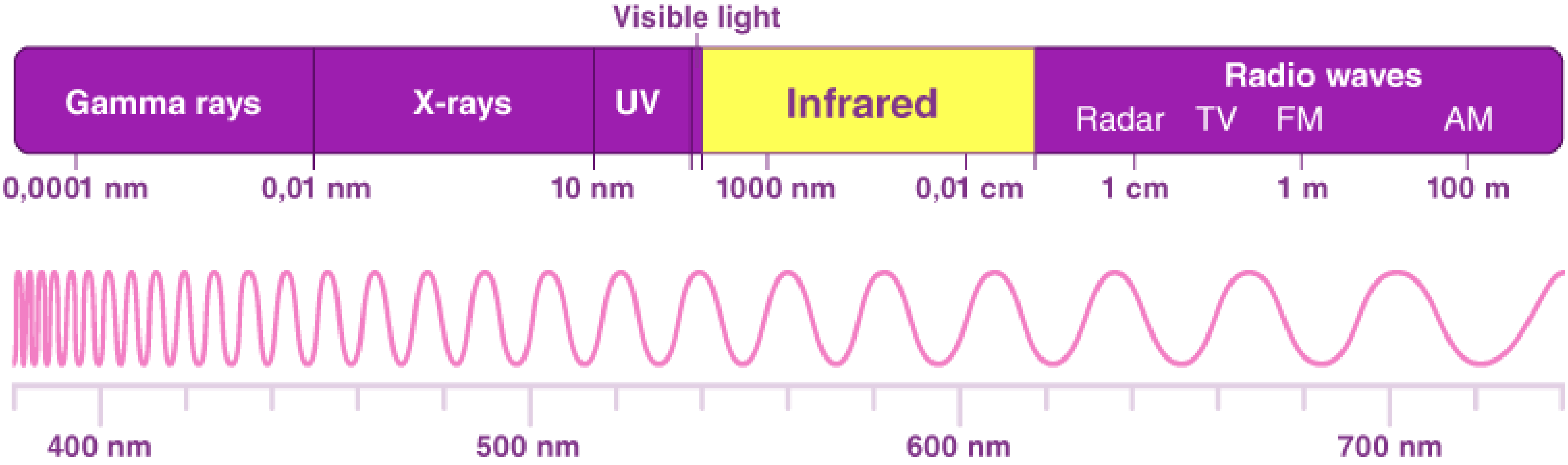
1.4 Infrared (IR) Sensors:

Emit infrared light and *detect the reflected signal* to determine the *presence of objects*.

Used in *motion detectors, remote controls, and night-vision equipment*.



Electromagnetic spectrum (Not for Exam)



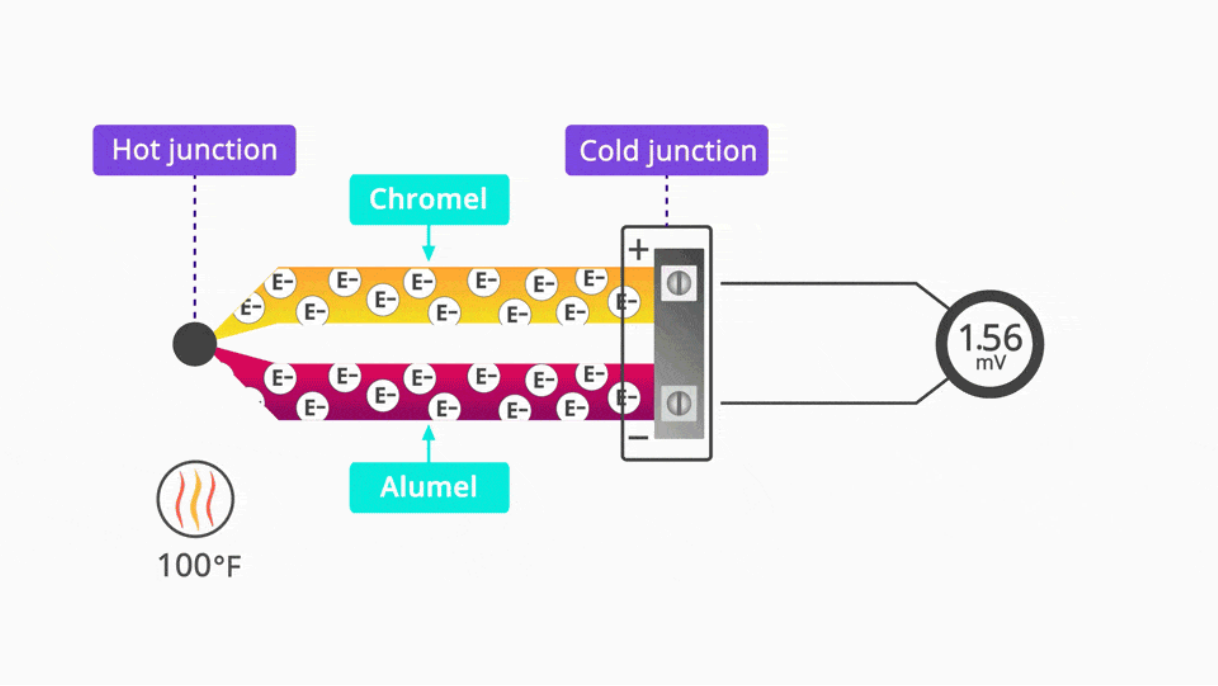
2. Passive Sensor

Passive sensors *do not emit any energy* but *detect and measure existing environmental* energy or signals.

2.1 Temperature Sensors

Measure temperature *without emitting any energy*.

Examples include *thermistors and thermocouples*.

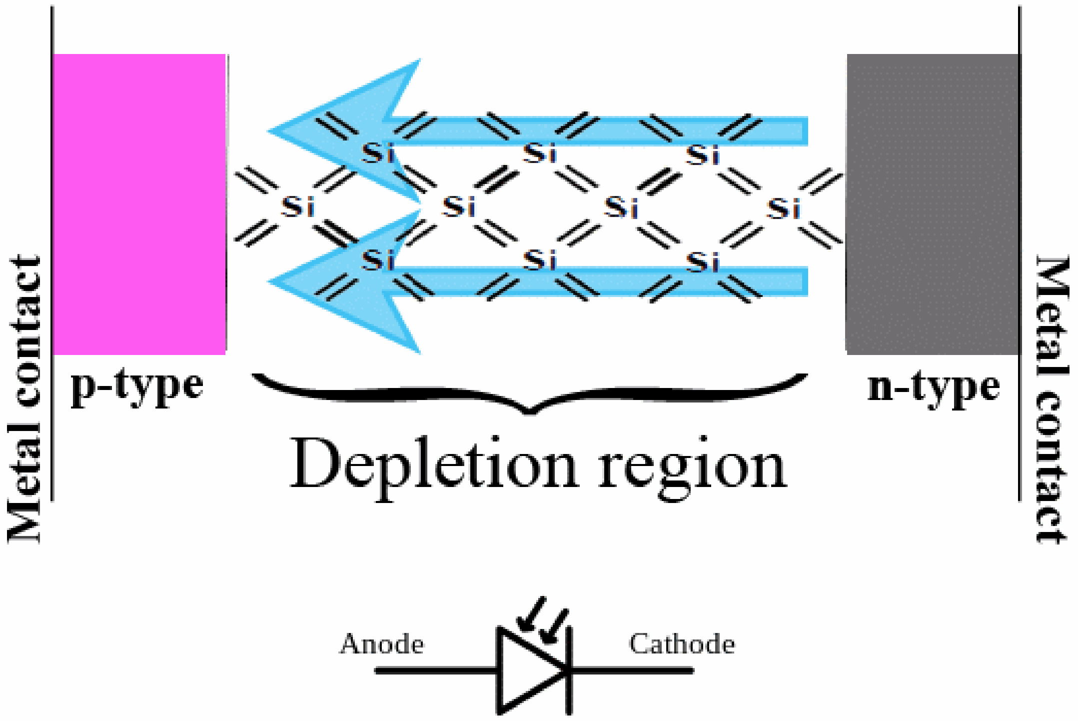


thermocouples

2.2 Photodiodes

Detect light intensity without emitting light.

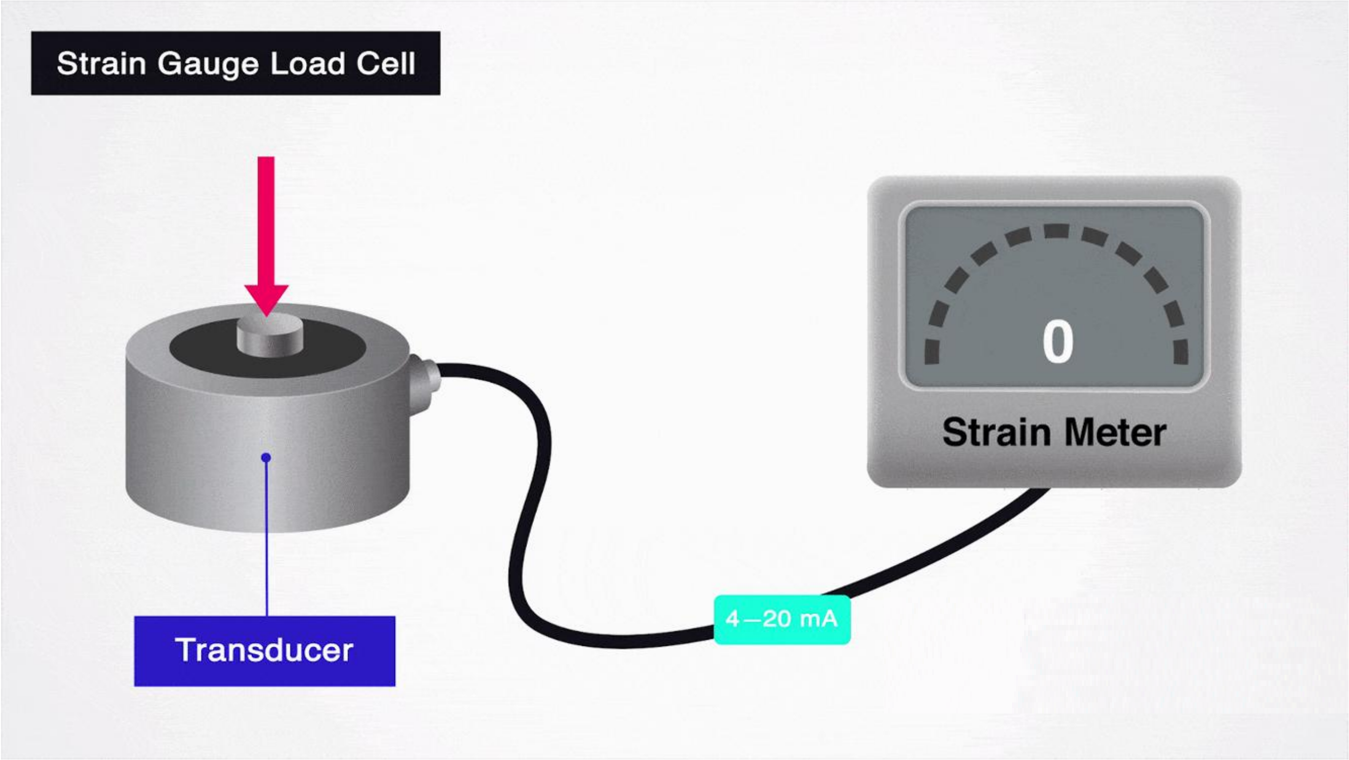
Used in *cameras, light meters, and optical communication*.



2.3 Strain Gauges

Measure deformation (strain) in materials without emitting energy.

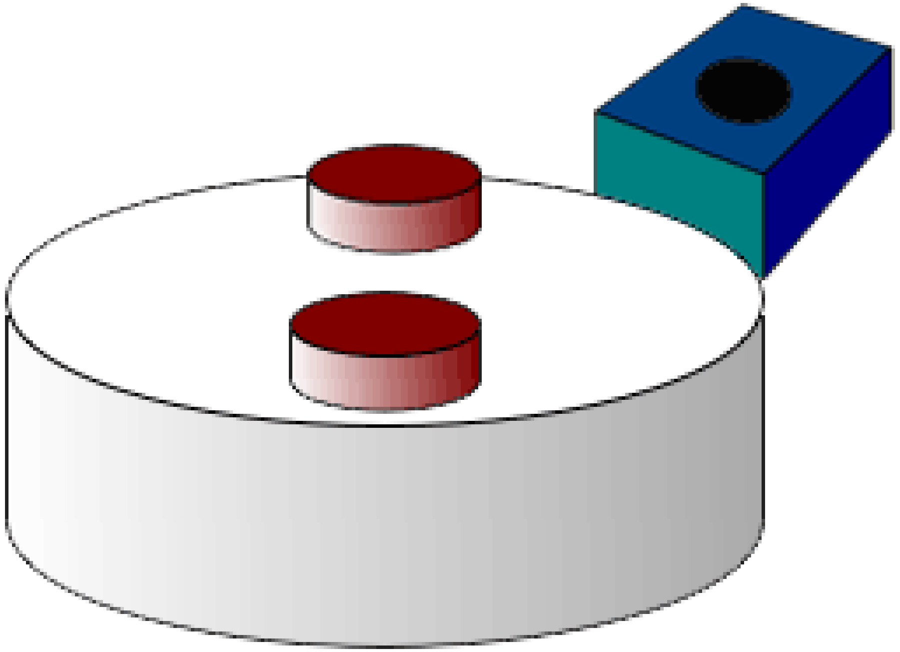
Used in *structural health monitoring and weight measurement*.



2.4 Magnetometers

Detect magnetic fields without emitting magnetic waves.

Used in *compasses, smartphones, and metal detectors*.

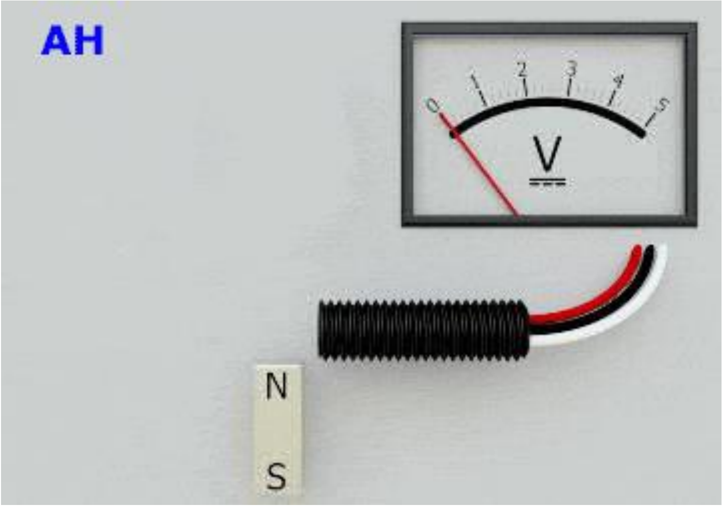


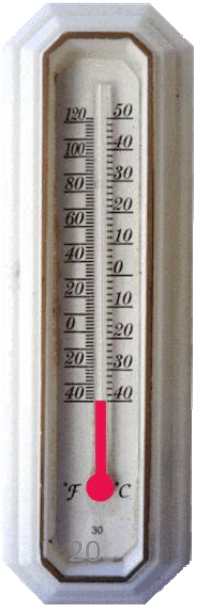
Types of Sensors based on their signal processing and functionality

1. Analog Sensor

An analog sensor *produces a continuous output signal* (usually voltage or current) that is directly proportional to the measured physical quantity. The output is a continuous signal that *varies over time*.

Example: A temperature sensor that outputs a voltage that changes continuously with temperature changes.

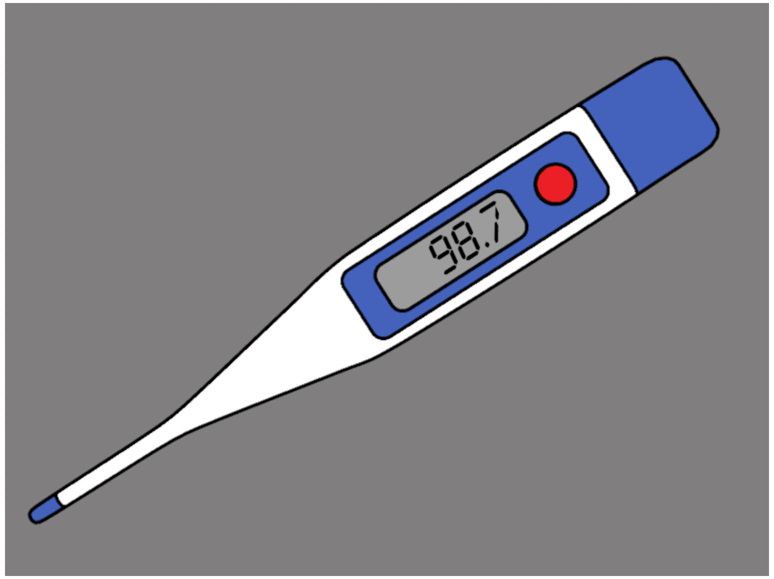




2. Digital Sensor

A digital sensor *provides a discrete output signal*, typically in binary form (0s and 1s). It *converts the analog signal into a digital signal* that can be easily read and *processed by digital systems*, such as microcontrollers or computers.

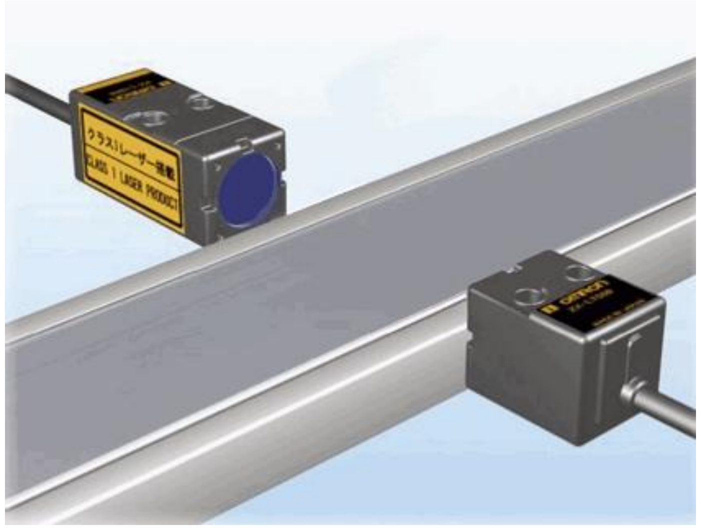
Example: A digital temperature sensor that outputs a temperature reading as a binary number.



3. Smart Sensor

A smart sensor includes *additional processing capabilities* beyond basic sensing. It typically combines *sensing, signal conditioning, and data processing* within the same unit. Smart sensors can perform functions such as self-calibration, self-diagnostics, and data communication.

Example: A smart temperature sensor that not only measures temperature but also *processes the data, calibrates itself, and communicates* the temperature reading *over a network*.



3.1 Key features of smart sensors:

Integrated Signal Processing:

Perform data processing tasks such as *filtering, amplification, and noise reduction* within the sensor itself.

Self-Calibration:

Automatically *calibrate themselves to maintain accuracy* over time without external intervention.

Self-Diagnostics:

Monitor their own performance and health, detecting and reporting any faults or malfunctions.

Data Storage:

Include memory to *store measurement data, calibration information*, and other relevant data.

Communication Capabilities:

Transmit data to other devices or systems using *communication protocols* like Bluetooth, Wi-Fi, Zigbee, or other wireless

Efficiency:

Optimize power consumption for longer battery life or reduced energy usage in energy-constrained applications.

Advanced Algorithms:

Implement complex algorithms for tasks such as <u>*pattern recognition, machine learning, or predictive analysis*</u>.

Multiple Sensing Modalities:

Integrate multiple sensing elements to measure different types of physical phenomena (e.g., <u>*temperature, pressure, humidity*</u>) within a <u>*single device*</u>.

Compact Size and Integration:

Combine sensing, processing, and communication components <u>*into a compact and integrated package*</u>, making them suitable for a wide range of applications.

Adaptability:

Adjust to changing environmental conditions or application requirements in real-time.

Enhanced Security:

Implement security features to protect data integrity and privacy, ensuring secure communication and data handling.

User-Friendly Interfaces:

Provide easy-to-use interfaces for configuration, monitoring, and data retrieval, often through mobile apps or web dashboards.

4. Static Characteristics of Sensor

The static characteristics of a sensor refer to its *behavior and performance* under specific static or *steady-state conditions*.

4.1 Range

The limits within which the *input can vary*.

For example, a temperature sensor might have a range of -10°C to 100°C, meaning it can measure temperatures within this range.

4.2 Span

$$\text{Span} = \text{Maximum Value} - \text{Minimum Value}$$

The *maximum value of the input minus the minimum value*. In the case of the temperature sensor, the span would be 100°C - (-10°C) = 110°C.

Problem: A temperature sensor has a range of -40°C to 80°C. If the current temperature is 20°C, what percentage of the full range is this temperature?

Span = 80°C - (-40°C) = 120°C

Percentage of range = $\frac{20-(-40)}{120} \times 100$

Percentage of range = $\frac{60}{120} \times 100 = 50$

Problem: A temperature sensor operates within the range -50°C to 150°C. If the sensor is currently reading 75°C, how much of the total span (in °C) has been covered?

Span = 150°C - (-50°C) = 200°C

Covered span = 75°C - (-50°C) = 75°C + 50°C = **125°C**

Problem 1: A pressure sensor has a range of 50 kPa to 500 kPa. What is the span of the sensor?

Problem 2: A humidity sensor has a range of 0% to 100%. If the sensor reads 60%, what fraction of the full range does this value represent?

Problem 3: A displacement sensor has a range of 0 cm to 10 cm. If the sensor is reading a displacement of 7.5 cm, what percentage of the range has been covered?

Problem 4: A strain gauge pressure transducer has a range from 200 Pa to 6000 Pa. If the transducer measures 3500 Pa, what fraction of the range is this reading? Express the answer as a percentage.

Problem 5: A temperature sensor has a minimum measurable value of -20°C and a maximum measurable value of 80°C. What is the span of this sensor?

Problem 6: A pressure transducer has a range from 150 psi to 1200 psi. Calculate the span.

Problem 7: A flow sensor operates between 2 liters/min and 15 liters/min. What is the span for this flow sensor?

4.3 Error

$$\text{Error} = \text{Measured Value} - \text{True Value}$$

The *difference* between the *measured value and the true value* of the quantity being measured.

For instance, if a *thermometer reads 25°C* when the *actual temperature is 24°C*, the *error is +1°C*. If the actual temperature were 26°C, the error would be -1°C.

Problem 1: A temperature sensor shows a reading of 45°C, but the actual temperature is 50°C. What is the error?

Problem 2: A pressure gauge reads 180 psi, while the actual pressure is 175 psi. Calculate the error.

Problem 3: A flow meter measures 12 liters/min, but the true flow rate is 10 liters/min. What is the error in the measurement?

Problem 4: A distance sensor records a value of 5.5 meters, but the actual distance is 5.0 meters. Determine the error.

Problem 5: A speedometer shows 60 km/h, but the actual speed is 58 km/h. Calculate the error.

Problem 6: A thermometer measures -10°C, but the true temperature is -8°C. What is the error in the measurement?

4.4 Accuracy

Accuracy refers to *how close a measured value* is to the *true or accepted value* of the quantity being measured.

It indicates the *reliability or correctness* of the measurement.

Problem: A pressure sensor has an accuracy of ±2%. If the true pressure is 500 psi*, what is the range of possible measured values for the sensor?

Accuracy range = 2% of 500 psi = $0.02 \times 500 = 10$ psi

So, the range is 500 psi ± 10 psi = 490 psi to 510 psi

*Pound-force per square inch

Problem 1:
A thermometer has an accuracy of ±1°C. If the actual temperature is 30°C, what is the range within which the thermometer's reading might fall?

Problem 2:
A scale has an accuracy of ±0.5 kg. If the actual weight is 75 kg, what are the possible upper and lower limits of the scale's reading?

Problem 3:
A voltmeter has an accuracy of ±1.5%. If the true voltage is 220 V, calculate the possible range of values the voltmeter might display.

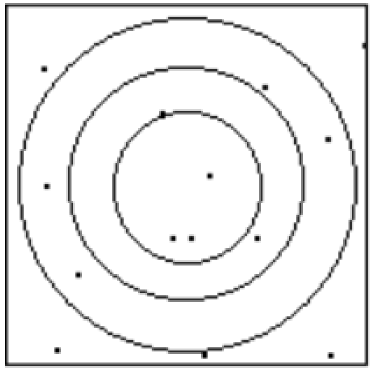
Problem 4:
A flow meter has an accuracy of ±0.05 liters/min. If the actual flow rate is 10 liters/min, what range of readings would the flow meter give?

4.5 Precision

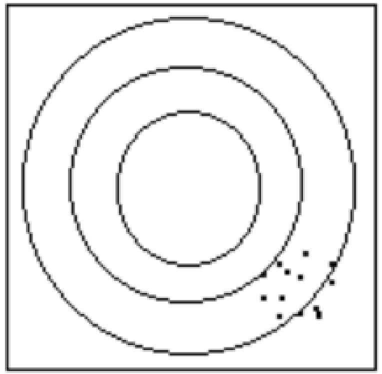
Precision refers to the *degree of consistency and repeatability* of measurements. It describes the *ability* of a measurement system *to reproduce the same result multiple times* under the *same conditions*.

Problem: A laboratory balance has a precision of ±0.01 grams. If you measure the same object 5 times and get the following readings: 5.01 g, 5.00 g, 5.02 g, 5.01 g, and 5.00 g, calculate the range of the measurements. Is the precision maintained?

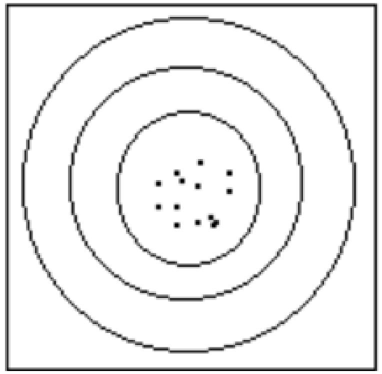
Solution: The range of the measurements is from 5.00 g to 5.02 g.
Precision range: ±0.01 g, so all the measurements should lie within 5.00 g ± 0.01 g (i.e., 4.99 g to 5.01 g). Since some measurements (e.g., 5.02 g) fall outside this range, the precision is not maintained.



Low Accuracy, Low Precision



Low Accuracy, High Precision



High Accuracy, High Precision

Problem 1:

A voltmeter has a precision of ±0.5 V. If you measure the same voltage five times and get values like 12.1 V, 12.2 V, 12.0 V, 12.1 V, and 12.2 V, is the voltmeter maintaining its precision?

Problem 2:

A thermometer has a precision of ±0.1°C. After measuring the temperature of water several times, you record the following values: 37.1°C, 37.2°C, 37.2°C, 37.0°C, and 37.1°C. Does the thermometer show good precision?

Problem 3:

A pressure gauge with a precision of ±1 psi is used to measure pressure multiple times, with the following readings: 150 psi, 151 psi, 149 psi, 150 psi, and 151 psi. What is the precision range, and is it maintained in these readings?

Problem 4:

A flow meter has a precision of ±0.02 liters/min. If repeated measurements of the same flow rate give 8.10 liters/min, 8.11 liters/min, 8.12 liters/min, and 8.10 liters/min, does the flow meter show good precision?

4.6 Sensitivity

The relationship indicating *how much output there* is *per unit input*.

$$\text{Sensitivity} = \frac{\Delta\text{Output}}{\Delta\text{Input}}$$

For example, a strain gauge might have a sensitivity of 2 mV/V, meaning it produces a *2-millivolt change in output voltage* per volt change in input.

Problem 1:

A pressure sensor has a sensitivity of 0.5 mV/kPa. If the pressure applied to the sensor changes from 50 kPa to 100 kPa, calculate the change in output voltage.

$$\Delta V = \text{Sensitivity} \times \Delta\text{Pressure} = 0.5\,\text{mV}/\text{kPa} \times (100 - 50)\,\text{kPa} = 0.5 \times 50 = 25\,\text{mV}$$

Problem 2:

A temperature sensor has a sensitivity of **10 mV/°C**. If the sensor output changes by **30 mV**, how much has the temperature changed?

Problem 3:

A strain gauge has a sensitivity of **2 mV/V**. If an input voltage of **5V** is applied, what is the change in output voltage?

Problem 4:

A light sensor has a sensitivity of **0.8 mV/lux**. If the light intensity increases by **200 lux**, calculate the increase in sensor output.

Problem 5:

A force sensor has a sensitivity of **1.5 mV/N**. If the output voltage increases by **9 mV**, what is the applied force?