1. Introduction to Sensors, Transducers & Actuators

Sensor

A **sensor** is a device that detects physical parameters (such as temperature, pressure, humidity, light, etc.) and converts them into a readable signal, usually electrical.
Example: A temperature sensor in a weather station converts thermal energy into a voltage signal.

Transducer

A **transducer** is a broader term that includes sensors. It **converts one form of energy into another**. A sensor is a type of transducer, but not all transducers are sensors.
Example: A microphone is a transducer that converts sound energy into electrical signals.

Relation:

- Sensor: physical input → electrical signal (output)
- Actuator: electrical signal (input) → physical action (output)

Actuator

An **actuator** is the reverse of a sensor: it receives an electrical signal and performs a **mechanical action** such as movement or control.
Example: An electric motor receives a signal and rotates a wheel.

2. Principles of Sensing

Sensors work based on various physical principles, depending on the type of input they are measuring. The **conversion of physical quantity to electrical signal** is the core principle.

Common Principles:

Physical Input	Sensor Type	Sensing Principle
Temperature	Thermistor, RTD	Resistance changes with temperature
Light	Photodiode	Light intensity changes electric current
Pressure	Piezoelectric	Pressure generates voltage
Displacement	LVDT	Magnetic induction due to movement
Sound	Microphone	Acoustic waves generate electrical signal

3. Sensor Classification

Sensors can be classified based on **energy domain**, **signal type**, and **contact type**.

A. Based on Energy Domain

1. **Mechanical Sensors**
   - Measure: Force, displacement, pressure
   - Example: Strain gauge, pressure sensor
2. **Thermal Sensors**
   - Measure: Temperature
   - Example: Thermistor, thermocouple
3. **Electrical Sensors**
   - Measure: Voltage, current
   - Example: Current sensors in power meters
4. **Optical Sensors**
   - Measure: Light
   - Example: Photodiodes, LDRs (Light Dependent Resistors)
5. **Magnetic Sensors**
   - Measure: Magnetic field
   - Example: Hall effect sensor

B. Based on Output Signal

1. **Analog Sensors**
   - Output: Continuous signal
   - Example: Thermistor (voltage changes continuously with temperature)
2. **Digital Sensors**
   - Output: Discrete signal (e.g., High/Low, 1/0)
   - Example: IR Obstacle Sensor

C. Based on Contact Type

1. **Contact Sensors**
   - Require physical contact to detect changes
   - Example: Switch-type proximity sensor
2. **Non-contact Sensors**
   - Work remotely
   - Example: Ultrasonic distance sensor, IR sensor

4. Sensor Characteristics

Key Characteristics:

1. **Range:**
    - The minimum and maximum values the sensor can measure.
    - Example: A temperature sensor with a range of -50°C to +150°C
2. **Sensitivity:**
    - How much the output changes in response to a unit change in input.
    - High sensitivity = small changes detected easily.
3. **Resolution:**
    - The smallest change a sensor can detect.
    - Example: A sensor that can detect 0.01°C change.
4. **Accuracy:**
    - How close the output is to the true value.
    - $\text{Accuracy} = |\text{Measured Value} - \text{Actual Value}|$
5. **Precision (Repeatability):**
    - The ability of the sensor to give the same output under the same conditions.
6. **Linearity:**
    - Degree to which output is directly proportional to input.
    - Perfect linearity means a straight-line graph of input vs. output.
7. **Hysteresis:**
    - Difference in output when input is increasing vs. decreasing.
8. **Response Time:**
    - Time taken by the sensor to reach 90% of its final value after a change in input.
9. **Drift:**
    - A slow change in output without a change in input.
    - Often due to aging or temperature effects.