# Contents:

# Sensors:



- Sensor is a device that produces an output signal for the purpose of sensing of a physical phenomenon
- A sensor is a device that receives and responds to a signal.
- This signal must be produced by some type of energy, such as heat, light, motion, or chemical reaction.
- Once a sensor detects one or more of these signals (an input), it converts it into an analog or digital representation of the input signal.
- Based on this explanation, sensors are used in all aspects of life to detect and/or measure different conditions.
- Typically sensors convert a recognized signal into an electrical – analog or digital – output that is readable.

# Sensors:

- A good sensor obeys the following rules:

1. It is sensitive to the measured property
2. It is insensitive to any other property likely to be encountered in its application, and
3. It does not influence the measured property.

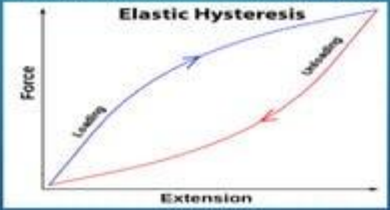
- Sensors suffer from the following deviations:

1. Sensitivity Error
2. Hysteresis Error
3. Offset Error or Bias
4. Non-linearity
5. Quantization error
6. Aliasing Error
7. Noise
8. Drift

# Sensitivity & Hysteresis:

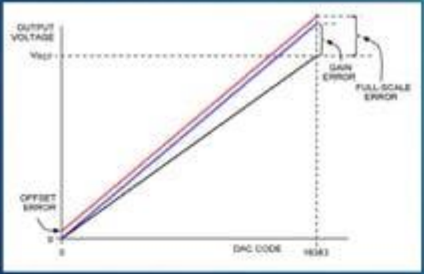


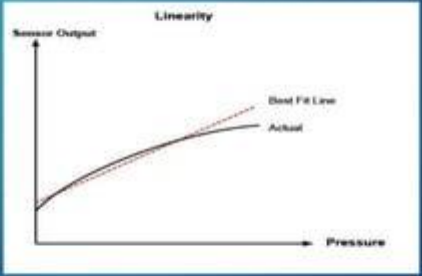
- Sensitivity is the ability of the measuring instrument to respond to changes in the measured quantity.
- It is also the ratio of the change of output to the change of input.
- E.g., for a sensor measuring temperature and having a voltage output, the sensitivity is a constant with the unit [V/K]; this sensor is linear because the ratio is constant at all points of measurement.
- Hysteresis is an error caused when the measured property reverses direction, but there is some finite lag in time for the sensor to respond, creating a different offset error in one direction than in the other.



# Offset Error & Non-linearity:

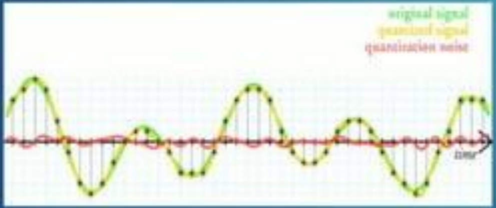
- Offset Error: If the output signal differs from the correct value by a constant, the sensor has an offset error or bias. This is an error in the y-intercept of a linear transfer function.
- Nonlinearity is deviation of a sensor's transfer function from a straight line transfer function. Usually, this is defined by the amount the output differing from the ideal behavior over the full range of the sensor, often noted as a percentage of the full range.

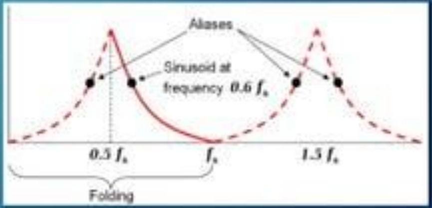


# Quantization Error & Aliasing Error:

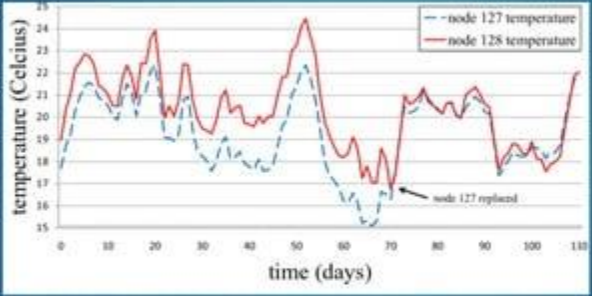
- If the sensor has a digital output, the output is essentially an approximation of the measured property. This error is also called quantization error.
- If the signal is monitored digitally, the sampling frequency can cause a dynamic error, or if the input variable or added noise changes periodically at a frequency near a multiple of the sampling rate, aliasing errors may occur.



# Noise & Drift:

- Noise is a random deviation of the signal that varies in time.
- If the output signal slowly changes independently of the measured property, this is defined as drift. Long term drift over months or years is caused by physical changes in the sensor.




P.C: Themistoklis Bourdenas; Jan 2009 Architecting Dependable Systems VII

# Types of Sensors:

- Classification of Sensors

1. Active and Passive Sensors
2. Analog and Digital Sensors

- The sensors are also classified into the following criteria:

1. Primary Input quantity (Measurand)
2. Transduction principles (Using physical and chemical effects)
3. Material and Technology
4. Property
5. Application

# Active & Passive Sensors:



- Active Sensors: The type of sensors that produces output signal without the help of external excitation supply. The own physical properties of the sensor vary with respect to the applied external effect. Therefore, it is also called as Self Generating Sensors. Any sensor which requires to input energy to the environment in order to retrieve the measurement is active.
- Examples: Photovoltaic cells, Thermocouples, Piezoelectric device.

- Passive Sensors: The type of sensors that produces output signal with the help of external excitation supply. They need any extra stimulus or voltage. Sensors are able to retrieve a measurement without actively interacting with the environment.
- Example: Strain Gauge, Magnetometer, Barometer.

# Analogue & Digital Sensors:

- Analog Sensors: The sensor that produces continuous signal with respect to time with analog output is called as Analog sensors. The analog output generated is proportional to the measured or the input given to the system. Generally, analog voltage in the range of 0 to 5 V or current is produced as the output. The various physical parameters like temperature, stress, pressure, displacement, etc. are examples for continuous signals.

- Digital Sensors: When data is converted and transmitted digitally, it is called as Digital sensors. Digital sensors produce discrete output signals. Discrete signals will be non-continuous with time and it can be represented in "bits" for serial transmission and in "bytes" for parallel transmission. Digital output can be in form of Logic 1 or Logic 0 (ON or OFF). A digital sensor consists of sensor, cable and a transmitter. The measured signal is converted into a digital signal inside the sensor itself without any external component. Cable is used for long distance transmission.

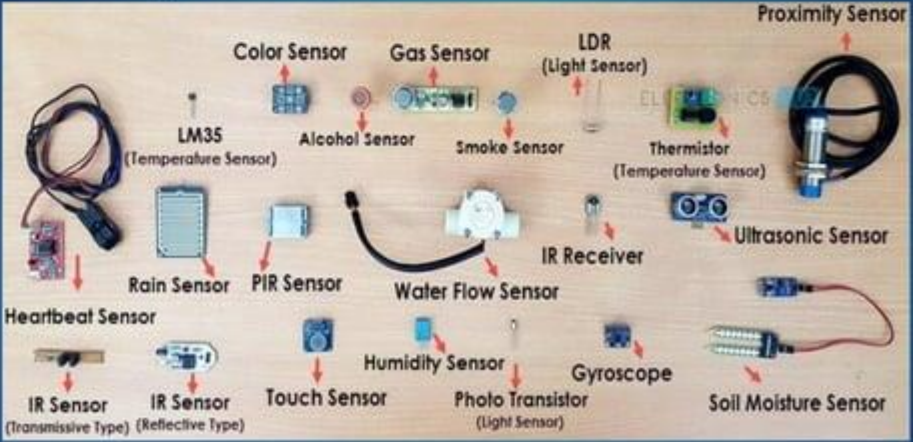
# Applications of Digital Sensors:

- Detection of leaks in gas pipes and cables using pressure sensor
- Pressure monitoring in tires.
- Monitoring airflow
- Measuring level
- Inhalers (medical device)

# Pictorial Depiction of Few Sensors:



- Few Sensor Types



# Sensor Types:

- Light Sensor
  1. IR Sensor (IR Transmitter / IR LED)
  2. Photodiode (IR Receiver)
  3. Light Dependent Resistor
- Temperature Sensor
  1. Thermistor
  2. Thermocouple
- Pressure/Force/Weight Sensor
  1. Strain Gauge (Pressure Sensor)
  2. Load Cells (Weight Sensor)
- Bio-Sensor
- Chemical Sensor

# Sensor Types:



- Position Sensor
  1. Potentiometer
  2. Encoder
- Hall Sensor (Detect Magnetic Field)
- Flex Sensor
- Sound Sensor
- Microphone
- Ultrasonic Sensor
- Touch Sensor
- PIR Sensor
- Tilt Sensor
- Accelerometer
- Gas Sensor

# Transducers:

- A transducer is a device that converts energy from one form to another. Usually a transducer converts a signal in one form of energy to a signal in another.

- Requirements of a good transducers
  1. Smaller in size and weight.
  2. High sensitivity.
  3. Ability to withstand environmental conditions.
  4. Low cost.

# Transducers:



- Factor to be considered while selecting a transducer are:

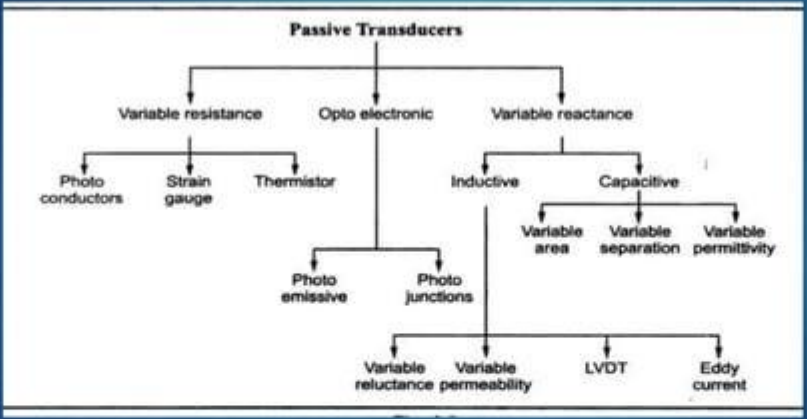
1. It should have high input impedance and low output impedance, to avoid loading effect.
2. It should have good resolution over the entire selected range.
3. It must be highly sensitive to desired signal and insensitive to unwanted signal.
4. Preferably small in size.
5. It should be able to work in 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 transducers must be free from errors.
9. The transducer circuit should have overload protection so that it will withstand overloads.

# Classification of Transducers:

1. As active and passive transducer
2. According to transduction principle
3. As analog and digital transducer
4. As primary and secondary transducer
5. As forward transducer and inverse transducer

# Classification of Transducers:

- Forward Transducers convert non-electrical quantity into electrical quantity whereas Inverse Transducer converts electrical quantity into non-electrical quantity.



# Resistive Transducer:





- The most commonly used type of transducer is variable resistance transducer.
- It is otherwise called as resistive sensors.
- It measures temperature, pressure, displacement, force, vibrations, etc.
- Resistive sensors works on the principle that, the conductor length is directly proportional to resistance of the conductor and it is inversely related with area of the conductor.
- L denotes conductor length, A for area of the conductor and R for resistance of conductor. ρ is the resistivity and it is constant for all the materials used for conductor construction.

$$R = \rho \frac{L}{A}$$

# Resistive Transducer:

- The resistance of the transducer varies due to external environmental factors and physical properties of the conductor.
- AC or DC devices are used to measure the resistance change.
- This transducer acts as both primary and secondary transducer.
- As a primary transducer, it converts physical quantity into mechanical signal.
- As a secondary transducer, the obtained mechanical signal is converted into electrical signal.

# Resistive Transducer:

1. Resistance Strain Gauge – The change in value of resistance of metal semi-conductor due to elongation or compression is known by the measurement of torque, displacement or force.
2. Resistance Thermometer – The change in resistance of metal wire due to the change in temperature known by the measurement of temperature.
3. Resistance Hygrometer – The change in the resistance of conductive strip due to the change of moisture content is known by the value of its corresponding humidity.
4. Hot Wire Meter – The change in resistance of a heating element due to convection cooling of a flow of gas is known by its corresponding gas flow or pressure.
5. Photoconductive Cell – The change in resistance of a cell due to a corresponding change in light flux is known by its corresponding light intensity.
6. Thermistor – The change in resistance of a semi-conductor is known by its corresponding measure of temperature.
7. Potentiometer Type – The change in resistance due to the movement of the slider as a part of an external force applied is known by its corresponding pressure or displacement.

# Capacitive Transducer:





- A capacitor consists of two conductors (plates) that are electrically isolated from one another by a nonconductor (dielectric).
- When the two conductors are at different potentials (voltages), the system is capable of storing an electric charge. The storage capability of a capacitor is measured in Farads.
- The principle of operation of capacitive transducers is based upon the equation for capacitance of a parallel plate capacitor as shown below:

$$\text{Capacitance } C = \frac{\varepsilon A}{d}$$

A = Overlapping area of plates; d = Distance between two plates; ε = Permittivity (dielectric constant); F/m.

- The capacitive transducers are commonly used for measurement of linear displacement, by employing the following effects.
  1. Change in capacitance due to change in overlapping area of plates.
  2. Change in capacitance due to change in distance between the two plates.
  3. Change in capacitance due to change in dielectric between the two plates.

# Capacitive Transducer:



- Variable Capacitance Pressure Gauge: Distance between two parallel plates is varied by an externally applied force.

  Applications: Measurement of Displacement, pressure.

- Capacitor Microphone: Sound pressure varies the capacitance between a fixed plate and a movable diaphragm.

  Applications: Speech, music, noise.

- Dielectric Gauge: Variation in capacitance by changes in the dielectric.

  Applications: Liquid level, thickness.

# Inductive Transducer:

- An inductive sensor is a device that uses the principle of electromagnetic induction to detect or measure objects.
- An inductor develops a magnetic field when a current flows through it alternatively; a current will flow through a circuit containing an inductor when the magnetic field through it changes.
- This effect can be used to detect metallic objects that interact with a magnetic field.
- The inductive sensor is based on Faraday's law of induction.
- The temporal variations of the Magnetic Flux $\phi$ through a N turns circuit will induce a voltage e which is denoted as:

$$e = -N\frac{d\phi}{dt} = -N \cdot S\frac{dB}{dt}$$

B = Induced Magnetic Field; S = homogeneous Section; R = Reluctance of magnetic circuit.

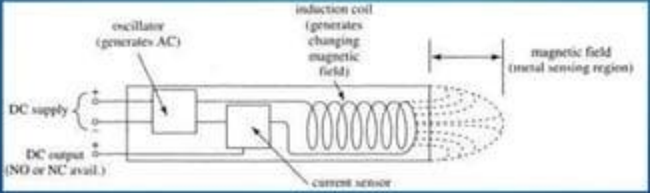
$$Self\ Inductance\ L = \frac{N^2}{R};\quad Mutual\ Inductance\ M = K\sqrt{L_1 L_2}$$

# Inductive Transducer:



- One form of inductive sensor drives a coil with an oscillator. A metallic object approaching the coil will alter the inductance of the coil, producing a change in frequency or a change in the current in the coil. These changes can be detected, amplified, compared to a threshold and use to switch an external circuit. The coil may have a ferromagnetic core to make the magnetic field more intense and to increase the sensitivity of the device. A coil with no ferromagnetic core ("air core") can also be used, provided the oscillator coil must cover a large area.

- Another form of inductive sensor uses one coil to produce a changing magnetic field, and a second coil (or other device) to sense the changes in the magnetic field produced by an object, for example, due to eddy currents induced in a metal object.



# Inductive Transducer:



- Inductance is the phenomenon where a fluctuating current, which by definition has a magnetic component, induces an electromotive force (EMF) in a target object.
- To amplify a device's inductance effect, a sensor manufacturer twists wire into a tight coil and runs a current through it.
- An inductive proximity sensor has four components;

  A) Coil, B) Oscillator, C) Detection circuit and D) Output circuit.
- The oscillator generates a fluctuating magnetic field in the shape of a doughnut around the winding of the coil that is located in the device's sensing face.
- When a metal object moves into the inductive proximity sensor's field of detection, Eddy circuits build up in the metallic object, magnetically push back, and finally reduce the Inductive sensor's own oscillation field.
- The sensor's detection circuit monitors the oscillator's strength and triggers an output from the output circuitry when the oscillator becomes reduced to a sufficient level.

# Inductive Transducer:



- Magnetic Circuit Transducer: Self inductance or mutual inductance of AC-excited coil is varied by changes in the magnetic circuit. Applications: Pressure, displacement.
- Reluctance Pickup: Reluctance of the magnetic circuit is varied by changing the position of the iron core of a coil. Applications: Pressure, displacement, vibration, position.
- Differential Transformer: The differential voltage of two secondary windings of a transformer is varied by positioning the magnetic core through an externally applied force. Applications: Pressure, force, displacement, position.
- Eddy Current Gauge: Inductance of a coil is varied by the proximity of an eddy current plate. Applications: Displacement, thickness.
- Magneto-striction Gauge: Magnetic properties are varied by pressure and stress. Applications: Force, pressure, sound.

# Voltage and Current Transducer:



- Hall Effect Pickup: A potential difference is generated across a semiconductor plate (germanium) when magnetic flux interacts with an applied current.

  Applications: Magnetic flux, current.

- Ionization Chamber: Electron flow induced by ionization of gas due to radioactive radiation.

  Applications: Particle counting, radiation.

- Photo-emissive Cell: Electron emission due to incident radiation on photo-emissive surface.

  Applications: Light and radiation.

- Photomultiplier Tube: Secondary electron emission due to incident radiation on photosensitive cathode.

  Applications: Light and radiation, photo-sensitive relays.

# Self – Generating Transducer:



- They do not require an external power, and produce an analog voltage or current when stimulated by some physical form of energy.

1. Thermocouple and Thermopile: An EMF is generated across the junction of two dissimilar metals or semiconductors when that junction is heated.

   Applications: Temperature, heat flow, radiation.

2. Moving-Coil Generator: Motion of a coil in a magnetic field generates a voltage.

   Applications: Velocity, vibration.

3. Piezoelectric Pickup: An EMF is generated when an external force is applied to certain crystalline materials, such as quartz.

   Applications: Sound, vibration. acceleration, pressure changes.

4. Photovoltaic Cell: A voltage is generated in a semi-conductor junction device when radiant energy stimulates the cell.

   Applications: Light meter, solar cell.

# Difference between Active & Passive Transducers:



| Active Transducer | Passive Transducer |
|---|---|
| The active transducer is also called as self generating type transducer. | The passive transducer is also called as externally powered transducer. |
| The active transducer does not require any auxiliary (external) power supply. | The passive transducer requires auxiliary (external) power supply for transduction. |
| The signal conversion is simpler. | The signal conversion is more complicated. |
| The energy required to produce output is obtained from the physical quantity. | They also derived part of the power required for conversion from physical quantity under measurement. |
| Example of active transducer is bourdon tube. | Example of passive transducer is LVDT (linear variable differential transformer). |
| It generates electric current or voltage directly in response to environmental stimulation. | It gives a change in some passive electrical quantity, such as capacitance, resistance or inductance, as a result of stimulation. |