Electrical and Electronic Measurements, Part 2

Lecture 3: Sensors and Transducers

Displacement, Position and Proximity

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Lecture Outline:

1. Introduction to Sensors and Transducers.
2. Analog vs. Digital Sensors.
3. Signal Conditioning and Smart Sensors.
4. Displacement, Position and Proximity Sensors.

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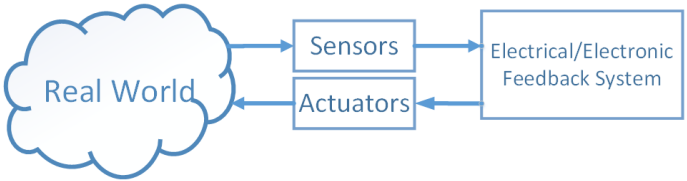
Introduction to Sensors and Transducers:

Electrical and Electronic systems need to **sense** and **react** with the **real world** either by:

- Reading (**sensing**) an input quantity, or:
- Activating (**actuating**) some form of output devices.



Sensor:

A sensor is a device that measures/detects a signal or stimulus to acquire information from the real world.

Actuator:

An actuator is a device that generates a signal or stimulus to affect the state of the real world.

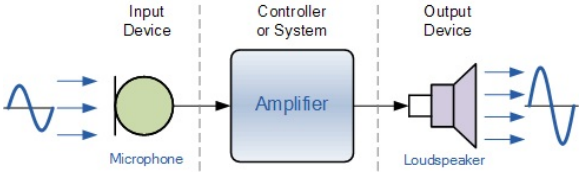
Introduction to Sensors and Transducers:

Transducer:

- It is a collective word used for both sensors and actuators.
- It is a device that converts a form of energy into a different form of energy.

Electrical Transducers:

Devices that are used to convert types of energy to/from electrical energy.



A microphone (input device) converts **sound waves into electrical signals** for the amplifier. Also, a loudspeaker (output device) converts these **electrical signals back into sound waves**.

Introduction to Sensors and Transducers:

Types of Electrical Transducers:

- In this part of the course, some types of **electrical sensors** will be discussed.
- There are many different types of sensors available in the marketplace.
- The **choice** of which sensor to use depends **upon the quantity to be measured**:

- **Position and Displacement**:
  - Potentiometers.
  - Encoders.
  - Linear Variable Differential Transformer (LVDT).
  - etc.
- **Force**:
  - strain gauge.
  - Load cells.
  - etc.
- **Speed**:
  - Tachogenerators.
  - Slotted optocoupler.
  - Doppler Effect Sensors.
  - etc.
- **Temperature**:
  - Thermocouple.
  - Resistive Temperature Detector (RTD).
  - etc.
- **etc..**

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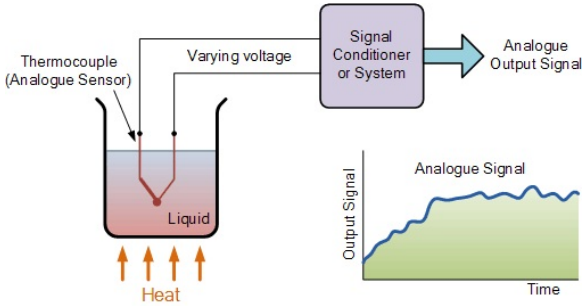
Analog vs. Digital Sensors:

Analog Sensors:

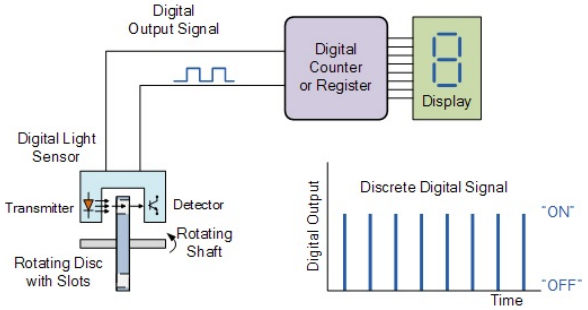
- Analog sensors produce a continuous output signal or voltage which is generally proportional to the quantity being measured.
- Physical quantities (such as Temperature, Speed, Pressure, Displacement, etc.) are all analog or continuous in nature.
- For example, the fluid temperature could be measured by a thermometer which responds continuously to the temperature change.



Analog vs. Digital Sensors:

Digital Sensors:

- Digital sensors produce a discrete digital output signal or voltage which is a digital representation of the quantity being measured.
- Digital sensors produces Binary output signal in the form of logic "High" or logic "Low".
- The digital representation of the measured quantity could be sent to the controlling device in **serial** (bit-by-bit) or in **parallel** (combination of bits) .
- For example, a shaft encoder is used to measure the speed of a shaft.



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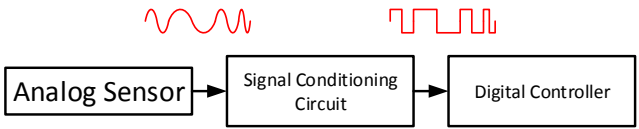
Signal Conditioning and Smart Sensors:

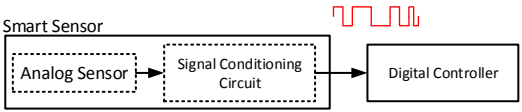
- Signal conditioning is defined as the operations done over an analog signal in such a way that it meets the requirements of the next stage for further processing.



- Signal conditioning includes: **amplification**, **filtering**, **range changing** and **analog-to-digital conversion**.

Smart Sensors:

The sensors that come combined with their signal conditioning in the same package.



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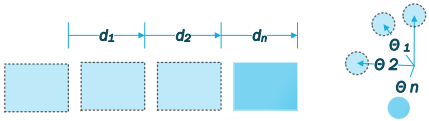
Displacement, Position and Proximity Sensors:

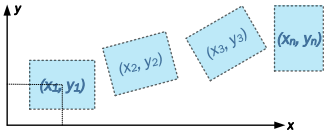
Displacement Sensors:

Sensors that are concerned with the measurement of the **amount by which some object has been moved**.



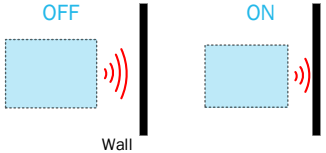
Position Sensors:

Sensors that are concerned with the determination of the **position of some object in relation to some reference** point.

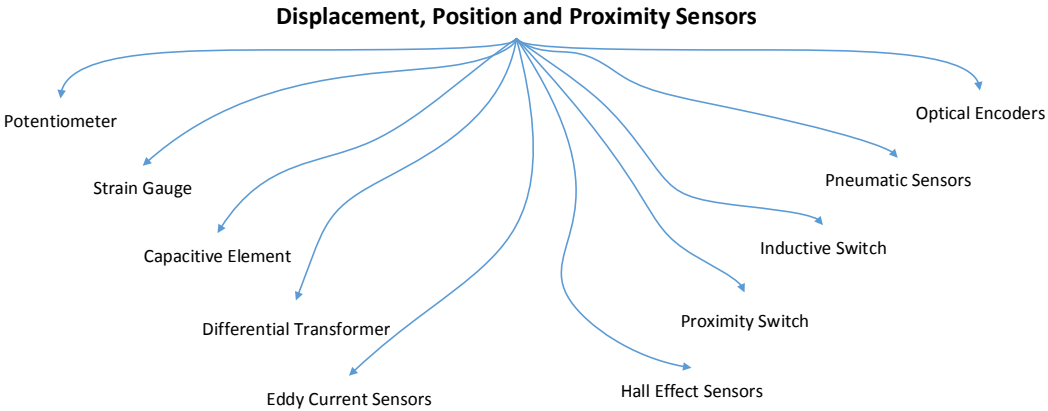


Proximity Sensors:

Sensors that are used to determine **if an object is within some particular critical distance** of the sensor. They give ON/OFF outputs.



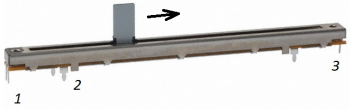
Displacement, Position and Proximity Sensors:

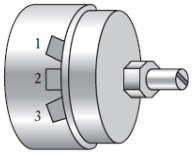


Displacement, Position and Proximity Sensors:

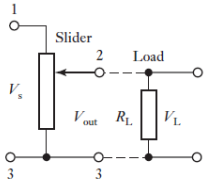
[1] Potentiometer Sensors:

- A potentiometer consists of a resistance element with a sliding contact that can move over the length of the resistance element.
- The moving object could be connected to the sliding contact to indicate the object **displacement** as a change in resistance.



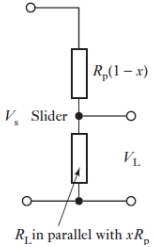


A rotary potentiometer



The circuit when connected to a load

The circuit as a potential divider



R_L in parallel with xR_p

Displacement, Position and Proximity Sensors:

[1] Potentiometer Sensors:

The effect of R_L connected across the output:

- Without load resistance R_L, the V_o is:

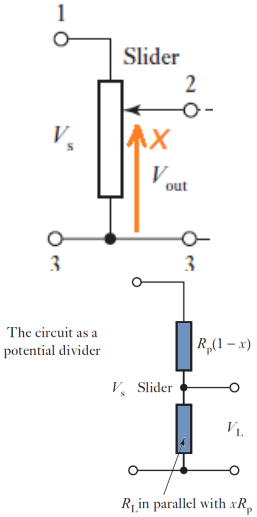
$$\frac{V_o}{V_s} = \frac{R_{23}}{R_{13}} = \frac{xR_p}{R_p} = x \qquad \text{linear}$$

where, R_p is the total pot resistance.
x is the displacement.

- Inserting R_L will convert the relationship between V_o and V_s into a non-linear relationship:

$$\frac{V_L}{V_s} = \frac{x}{(R_p/R_L).x.(1-x)+1} \qquad \text{non-linear}$$

$$Error = xV_s - V_L = Vs\frac{R_p}{R_L}(x^2 - x^3)$$



Displacement, Position and Proximity Sensors:

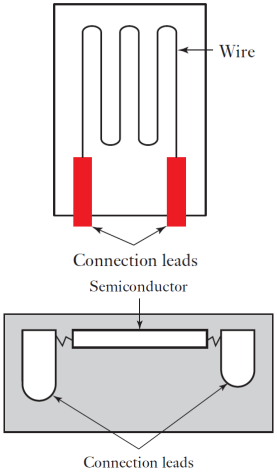
[2] Strain-Gauged Element:

- **Strain** is defined as the ratio of the change in length to the original length of an elastic material.
- **Strain gauge** is a metal wire or a strip of semiconductor that when subject to strain or elongation, its resistance R changes.
- The change in strain-gauge resistance, $\Delta R/R$, is proportional to the applied strain, ε.

$$\frac{\Delta R}{R} = G\varepsilon$$

where G is the gauge factor constant.

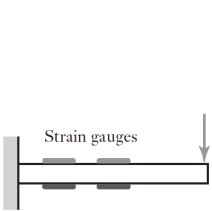
- A problem with all strain gauges is that **their resistance changes with temperature**.

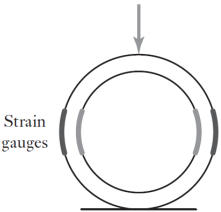


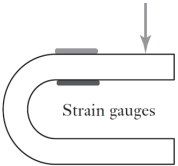
Displacement, Position and Proximity Sensors:

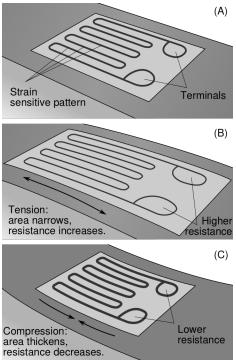
[2] Strain-Gauged Element:

- To monitor a displacement by a strain gauge, the moving object is attached a flexible to form either a **cantilevers**, **rings** or **U-shape**.
- When the flexible element is deformed as a result of moving object, the resistance of the strain gauges will change. The change in resistance is thus a measure of the **displacement** or deformation of the flexible element.









Displacement, Position and Proximity Sensors:

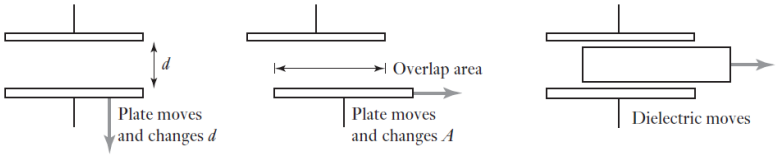
[3] Capacitive Elements:

- The capacitance C of a parallel plate capacitor is:

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

ε_r: Relative permittivity of the dielectric.
ε_o: Permittivity of free space.
A: Overlap area between the two plates.
d Plates separation distance.

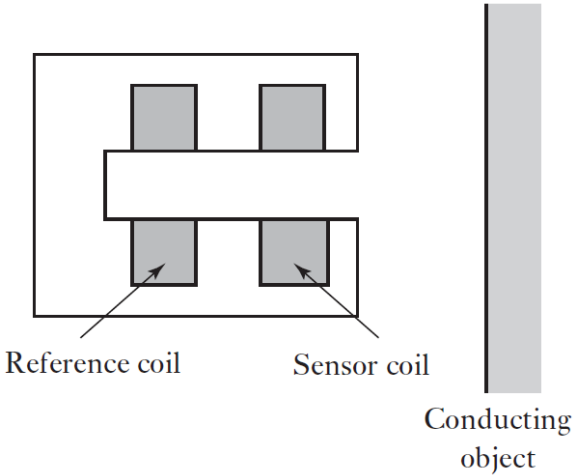
- To monitor a linear displacement, capacitive sensors is arranged in such a way that the displacement is either:
  1. Change of the plate separation distance.
  2. Change the plates overlap area.
  3. Change of the dielectric between plates.



Displacement, Position and Proximity Sensors:

[4] Eddy Current Proximity Sensors:

- A coil is supplied with an AC current that produces an AC magnetic field.
- If there is a metal object in close proximity to this AC magnetic field, then eddy currents are induced in the metal.
- The eddy currents themselves produce a magnetic field that distorts the original magnetic field
- As a result, the impedance of the coil changes which could be an indication for a presence of a metallic object.



End of Lecture

Best Wishes

Reference videos:

Robotic hand with glove.

Eddy current sensor.