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Types of Sensors and their Characterization

J. K. Dongre
Department of Physics, Prime Minister College of Excellence, Government Autonomous Post Graduate College Chhindwara (M.P.) 480001

Abstract: Sensor is a device that receives and responds to a signal or stimulus. The sensor is based on transducer principle that converts any type of energy into electrical energy. Based on the different types of signals they receive and respond to, sensors are classified into microelectromechanical systems (MEMS), optical, mechanical, electrochemical, semiconductor, and biosensing types. In the present article static and dynamic characteristics are discussed for a sensor.
Keywords: Sensor, Transducer, MEMS, Optical, Mechanical, Electrochemical, Semiconductor, Static Characteristic

I. INTRODUCTION

A sensor is an electronic device that converts the signal received from an instrument into some specific signal. Actually, a sensor is a transducer which converts the quantity into other signals which contain the required information. The most important requirements of a sensor are diversity, sensitivity, accuracy of the extracted information, selectivity and stability. Modern sensors are believed to have begun with the emergence of the first thermostat in 1883. Initially manufactured sensors were simple devices that produced mechanical, electrical or optical output signals. But in recent years the capabilities of sensors have greatly increased. Sensors can be used to measure proteins, bacteria, chemicals, gases, sound and many other physical and chemical variations.

II. CLASSIFICATION OF SENSORS

A. Mechanical Sensor

Mechanical sensors work by converting information about mechanical deformations into electrical signals. They use resistive materials or structures that change electrical resistance when stressed. The mechanical deformation that results in motion, velocity, acceleration and displacement that can be measured [1]. The common mechanical and electromechanical sensors as described by the IEEE Sensors Council are Strain Gauge, Pressure, Accelerometer, Gyroscope, Potentiometer, Displacement, Force, Acoustic Wave, Ultrasonic and Flow.

B. MEMS Sensor

The term MEMS refers to the process of manufacturing the sensing probe and the sensor. The term MEMS is used to describe both these methods. MEMS are three-dimensional, and fabricated using standard semiconductor manufacturing techniques. It combines mechanical microstructures, microsensors, microactuators, and microelectronics on a single silicon chip.MEMS sensors are used in the car industry, smartphones, tablets, game console controllers, portable gaming devices, digital cameras, and camcorders. Apart from this, there are also applications in the healthcare sector.

C. Optical Sensor

The principle of optical sensor is based on detection of photons of light of visible, infrared and ultraviolet (UV) spectral regions. These can be operated by measuring changes in light intensity. They are commonly used in the automatic doors, stepper motors and in measurement of level of liquids and materials in tanks.

D. Semiconductor Sensor

The working mechanism of semiconductor sensors is that when semiconductors come in contact with gases, their resistance goes varies.

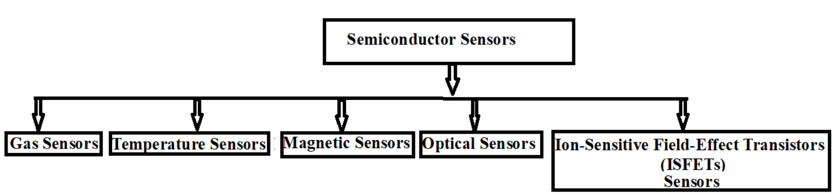

Fig. 1 classification of Semiconductor sensors

This change in resistance or electrical conductivity is due to the adsorption of gaseous species on the surface atoms of the semiconductor film by a chemical reaction [2]. Semiconductor sensors have grown in popularity due to their low cost, reliability, low power consumption, long operational lifespan, and small form factor [3]. Semiconductor sensors are classified as Gas Sensors, Temperature Sensors, Magnetic Sensors, Optical Sensors and in Ion-Sensitive Field-Effect Transistors (ISFETs) sensor as depicted in the figure 1.

E. Electrochemical Sensor

Electrochemical sensors work by reacting with a gas to generate an electrical signal. These electrical signals are proportional to the gas concentration. Electrochemical sensors consist of a sensing or working electrode, and a counter electrode, separated by a liquid or solid electrolyte. A typical electrochemical sensor is shown in the figure 2. At low temperatures (< 140 °C), liquid electrolyte sensors are used to measure pH, conductivity, dissolved ions, and dissolved gases. For measurements at high temperatures (> 500 °C), such as exhaust gases and molten metals, solid electrolyte sensors are used [4].

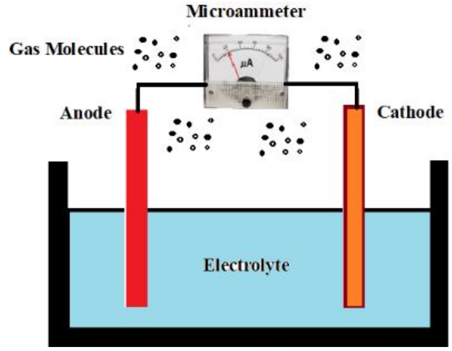

Fig. 2 Illustration of an electrochemical sensor

F. Biosensor

A biosensor is a device that combines a biological component (biologically derived recognition molecules) with a transducer. Transducer converts the biological signal into an electrical signal that detect and measure biological analytes (like biomolecules, structures, or microorganisms). Thus, it is also known as analytical devices. Here, biological component could be an enzyme, antibody, nucleic acid, or hormone, in a self-contained device.It is one of the most commonly used sensors to detect cancer and various other diseases. Biosensors are also used to detect specific types of DNA [5].

III.SENSOR CHARACTERISTICS

The performance of the sensor is determined by its characteristics. Sensor characteristics are categorized as static and dynamic. The static characteristic of a sensor indicates how accurately the sensor signal represents the measured quantity after it has stabilized. Thus, when a sensor is in stable state, then the static characteristics can be measured. Important static characteristics of sensors are range, sensitivity, resolution, linearity, drift, precision, errors, hysteresis (backslash), repeatability and reproducibility.

A. Static Characteristics

1) *Range:* It describes both the lower and upper values of the input or output.
2) *Accuracy:* It measures the difference between the sensor output and the standard value. In other words is the capacity of a measuring instrument to give results close to the true value of the measured quantity. Inaccuracy (ε) is usually described as follows:

$$\varepsilon = \frac{X_{meas} - X_{true}}{X_{true}} \qquad \text{.......................... (1)}$$

3) *Precision:* Describes how exactly and reproducibly an unknown value is measured [6]. Precision is a necessary but not sufficient condition for accuracy.
4) *Drift or zero drift:* When the sensor is in a stable state, then drift exhibits the deviation from the actual reading of the sensor.
5) *Life time:* When a sensor in given time duration remains active under ideal stable condition is known as life time of sensor.

6) *Resolution:* It is the minimal change of the input necessary to produce a detectable change at the output. When the increment is from zero, it is known as Threshold. To put it simply when a sensor can continuously measure and show the smallest changes in an object, it is called the resolution of the sensor. For example, a transmission electron microscope can detect and show a particle of 1 nm size in the object, so it is called high resolution TEM.

If the temperature sensor gives an increment of output voltage ΔV with change of temperature of an object ΔT, then the maximum resolution R_{max} is expressed as [6]

$$\frac{\Delta T_{min}}{T_{max} - T_{min}} \quad \text{.................................(2)}$$

The spam T_{max} -T_{min} describes the operating range of a sensor.

7) *Sensitivity:* sensitivity (S) of a sensor defined as

$$S = \frac{Measure\ of\ output\ signal\ change\ (\Delta Y)}{Measure\ of\ input\ property\ (\Delta X)} \quad \text{........................ (3)}$$

In a sensor response plot, if sensitivity is constant over the range of the sensor it is called linear response of an ideal sensor and estimated from the slope of the straight-line plot. In case of non-linearity, the sensitivity will vary over the sensor range and can be equal to derivative of S with respect to x.

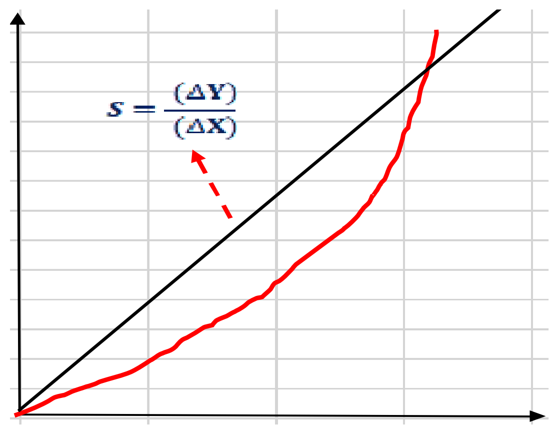

Fig. 3 Sensor sensitivity plot

8) *Hysteresis:* The difference between two output values that correspond to a given input value X when X is reached from two opposite directions, that is from X negative and X positive as depicted the in figure-4. This phenomenon is known as hysteresis.

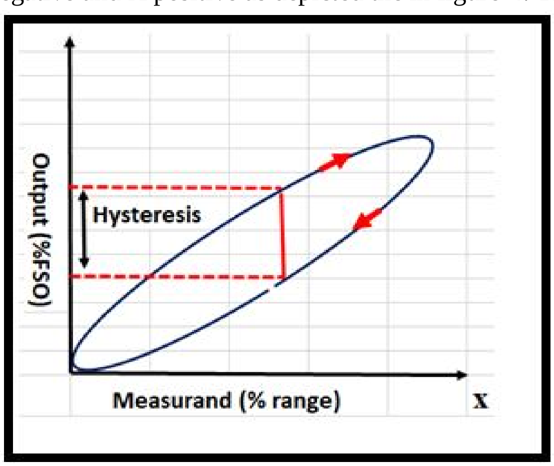

Fig. 4 Hysteresis curve, illustrating the different responses of a sensor to input value X reached from opposite directions of X negative and X positive.

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B. Dynamic Characteristics

It represents the time response of the sensor system i.e. it is a time dependent. The dynamic characteristics of the sensor are represented by rise time, delay time, peak time, settling time, percentage error and steady-state error as shown in the figure-5.

Rising time (T_r) is the steady-state response of a sensor which is pass between 5% to 80% sensitivity [7]. The peak time (T_p) refers to the time required for the sensor to reach peak accuracy. The settling time (T_s) is the time when the sensor's response value settles down to a steady-state value (say ± 1%).

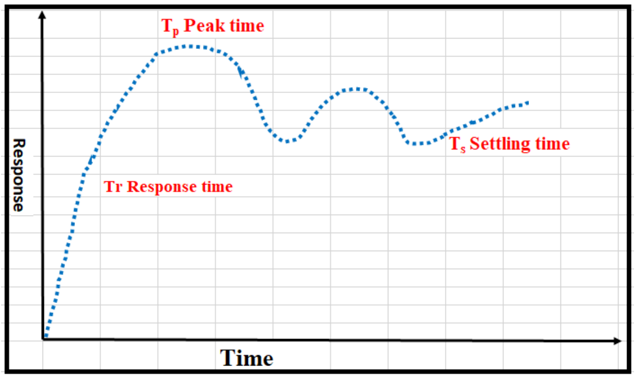

Fig. 5 Dynamic Characteristics of a sensor

IV. CONCLUSIONS

In recent years, nano-sensors especially gas sensors, temperature sensors, biosensors and electrochemical sensors are undergoing intensive research work in laboratories around the world. Sensors can measure variety of quantities such as chemical, biological, and physical using a wide range of sensing techniques as mechanical, MEMS, optical, semiconductor, electrochemical and biosensors. The respective advantages of the sensing techniques are discussed. Various important parameters are also discussed to characterized a sensor i.e. static and dynamic characteristics.

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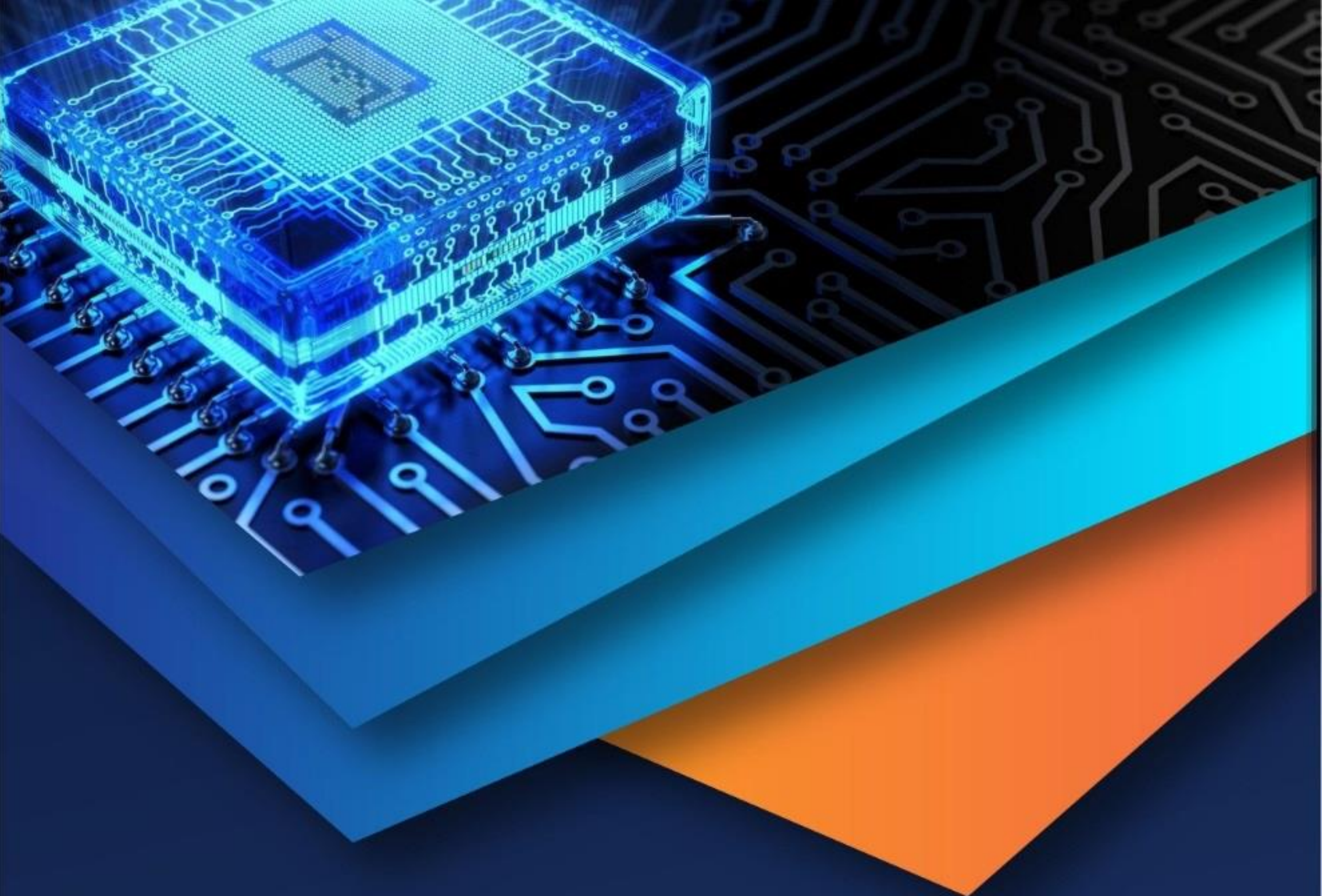

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