INSTRUMENTATION AND MEASUREMENT-1

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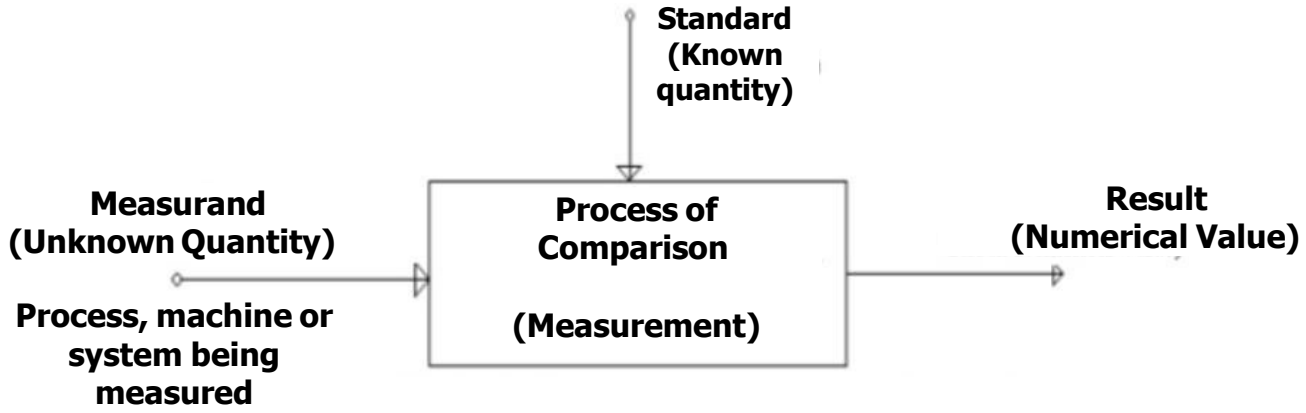
ME 3109: INSTRUMENTATION AND MEASUREMENT

"What is not measured does not exist."

Max Born, 1926

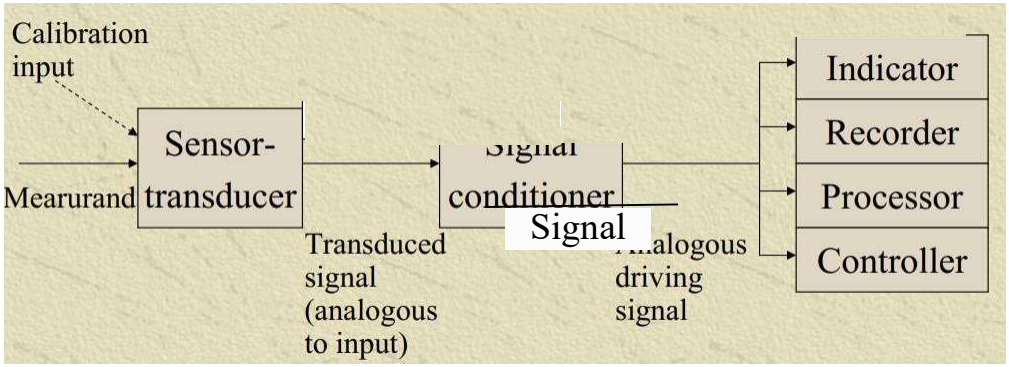
Generic scheme of a measurement

The measurement of a given quantity is essentially an act or result of comparison between a quantity, whose magnitude is unknown with a similar quantity whose magnitude is known, the latter is called standard.



Essential Elements of Scientific Instruments

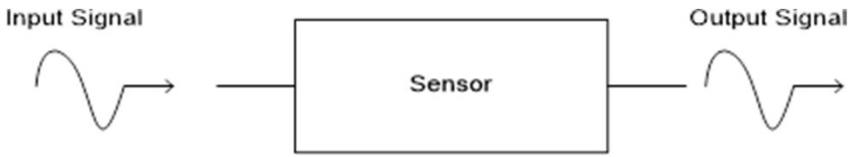
- A Detector (Sensor –Transducer) – Senses desired input to exclusion of all others and provides analogous output
- An intermediate transfer device (Signal Conditioner) – Modifies transduced signal into form usable by final stage. Usually increases amplitude and/or power, depending on requirement. May also selectively filter unwanted components and convert signal into pulsed form.
- An indicator, recorder or a storage device – Provides an indication or recording in form that can be evaluated by an unaided human sense or by a computer or controller.



Sensors (Detectors/Transducers)

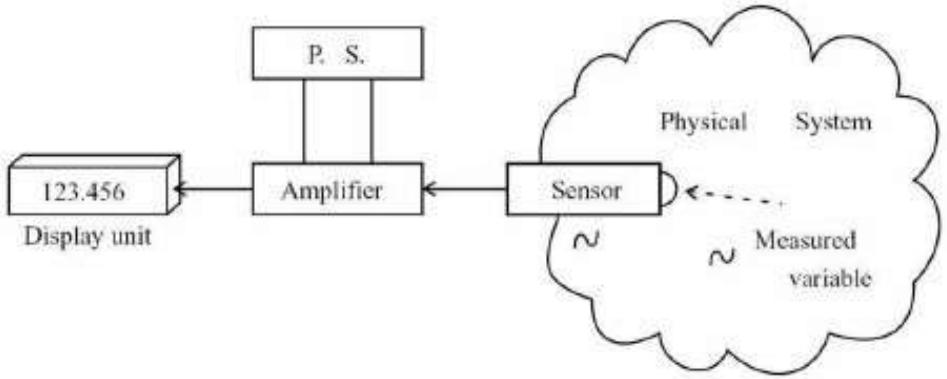
American National Standards Institute (ANSI) Definition:

A device which provides a usable output in response to a specified measurand



A sensor acquires a physical parameter and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical)

Basic Phenomenon in Effect in Sensor Operation



1. Change (or the absolute value) in the measured physical variable (i.e. pressure, temperature, displacement) is translated into change in sensor property (resistance, capacitance, magnetic coupling). This is called the *transduction*.
2. Change in the sensor property is translated into low-power-level electrical signal in the form of electrical voltage or current.
3. Low-level-power sensor signal is conditioned and transmitted for processing i.e. display or for use in control systems.

Detectable Phenomenon (Physical Parameters)

Stimulus/Measurand	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Classification of Sensors and Actuators

- Based on physical laws
- Based on any convenient distinguishing property
- Active and Passive sensors
- Contact and non-contact sensors
- Absolute and relative sensors
- Other schemes

1. Active and passive sensors

Active sensor: a sensor that requires external power to operate. Examples: the carbon microphone, thermistors, strain gauges, capacitive and inductive sensors, etc.

Other name: parametric sensors (output is a function of a parameter - like resistance)

Passive sensor: generates its own electric signal and does not require a power source. Examples: thermocouples, magnetic microphones, piezoelectric sensors.

Other name: self-generating sensors

Note: some define these exactly the other way around

2. Contact and noncontact sensors

Contact sensor: **a sensor that requires physical contact with the stimulus. Examples: strain gauges, most temperature sensors**

Non-contact sensor: **requires no physical contact. Examples: most optical and magnetic sensors, infrared thermometers, etc.**

3. Absolute and relative sensors

Absolute sensor: **a sensor that reacts to a stimulus on an absolute scale: Thermistors, strain gauges, etc., (thermistor will always read the absolute temperature)**

Relative scale: **The stimulus is sensed relative to a fixed or variable reference. Thermocouple measures the temperature difference, pressure is often measured relative to atmospheric pressure.**

Classification by broad area of detection

- Electric sensors
- Magnetic
- Electromagnetic
- Acoustic
- Chemical
- Optical
- Heat, Temperature
- Mechanical
- Radiation
- Biological

Classification by physical law

- Photoelectric
- Magnetoelectric
- Thermoelectric
- Photoconductive
- Photomagnetic
- Thermoelastic
- Thermomagnetic
- Thermooptic
- Electrochermical
- Magnetoresistive
- Photoelastic
- Etc.

Classification by specifications

- Accuracy
- Sensitivity
- Stability
- Response time
- Hysteresis
- Frequency response
- Input (stimulus) range
- Resolution
- Linearity
- Hardness (to environmental conditions, etc.)
- Cost
- Size, weight,
- Construction materials
- Operating temperature
- Etc.

Classification by area of application

- Consumer products
- Military applications
- Infrastructure
- Energy
- Heat
- Manufacturing
- Transportation
- Automotive
- Avionic
- Marine
- Space
- Scientific

SENSORS AND TRANSDUCERS

A sensor detects a specific physical change in its environment. It converts it into a measurable output signal. At the same time, a transducer is a broader term that refers to any device capable of converting one form of energy into another, meaning all sensors are considered transducers, but not all transducers are sensors. Essentially, a sensor is a specialized transducer focused on detecting specific physical parameters like temperature or pressure.

Key points to remember:

Function: A sensor is designed to detect and respond to a specific physical phenomenon, while a transducer can convert various types of energy, not just physical changes.

Output: A sensor typically outputs a signal directly related to the measured parameter, whereas a transducer may output a signal in a different form of energy entirely.

Example: A temperature sensor is a specific type of transducer that detects temperature changes and outputs an electrical signal proportional to that change.

SENSOR BASICS

Sensor Calibration

- Calibration afford the opportunity to check the instrument against a known standard and subsequently to reduce errors in accuracy.
- Calibration process involves adjustment to compensate for the variation in:
  - Gain
  - Offset
  - Saturation
  - Hysteresis
  - Dead band
  - Drift in time

SENSOR BASICS

Gain: Gain in a sensor is the degree to which a signal's amplitude or power increases from the input to the output.

Offset/zero shift error: A sensor offset is the difference between a sensor's output and its expected value when the input is zero.

Saturation: This refers to the point at which the sensor can no longer accurately measure the input signal. Sensor saturation occurs when the input signal to a sensor exceeds the maximum value that the sensor can measure or detect. When a sensor saturates its output signal becomes fixed at the maximum value, even if the input signal continues to increase. This can lead to measurement errors and loss of accuracy.

Dead band: Sensor hysteresis also known as sensor lag or dead band, refers to a phenomenon observed in sensors where the output value of the sensor does not change immediately as the input value crosses a particular threshold. Instead, there is a delay or a range of input values within which the sensor output remains unchanged, even though the input value is changing.

SENSOR BASICS

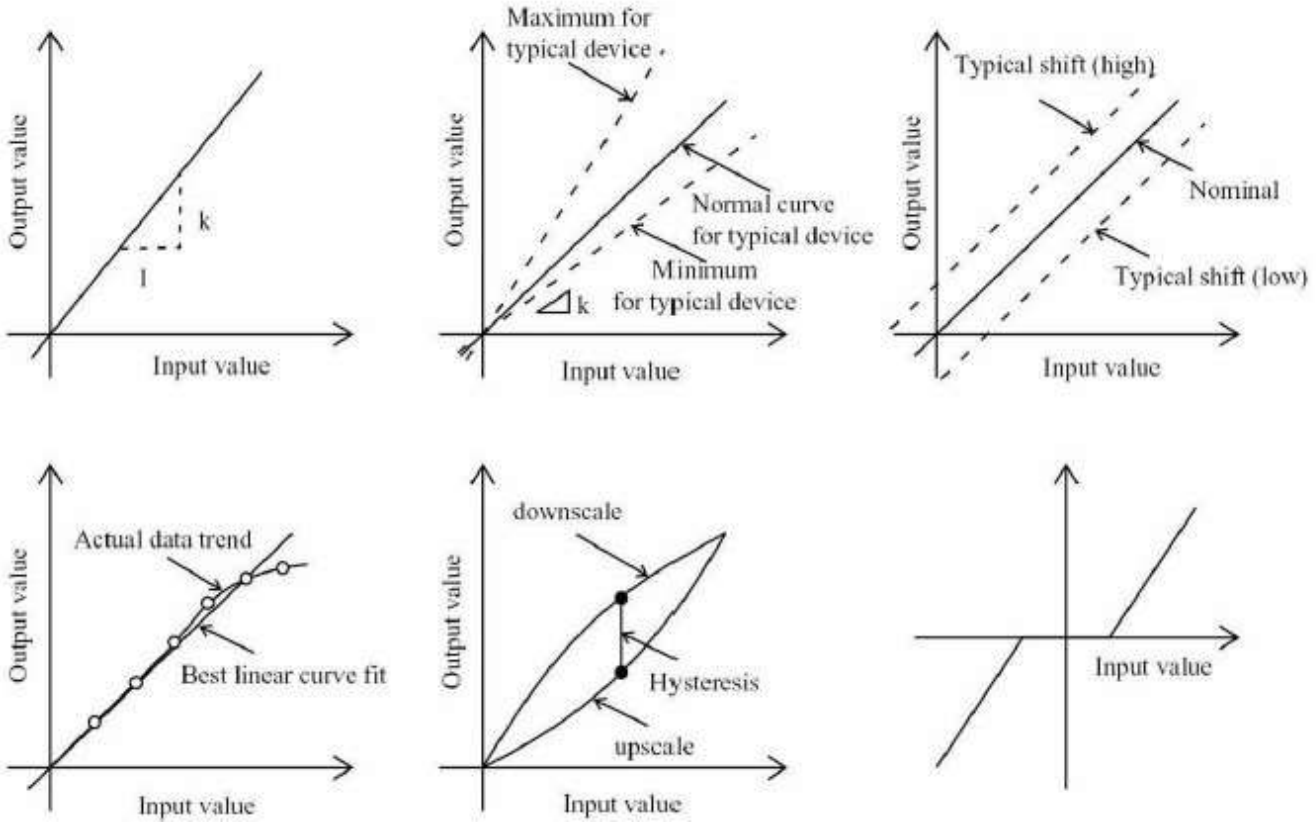
Drift in time: Drift in time in sensors is a gradual change in a sensor's output over time even when the input signal remains constant.

Hysteresis: The hysteresis is an error of a sensor which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter.

Sensitivity error: Sensitivity error is a deviation from the ideal slope of a sensor's characteristic curve.

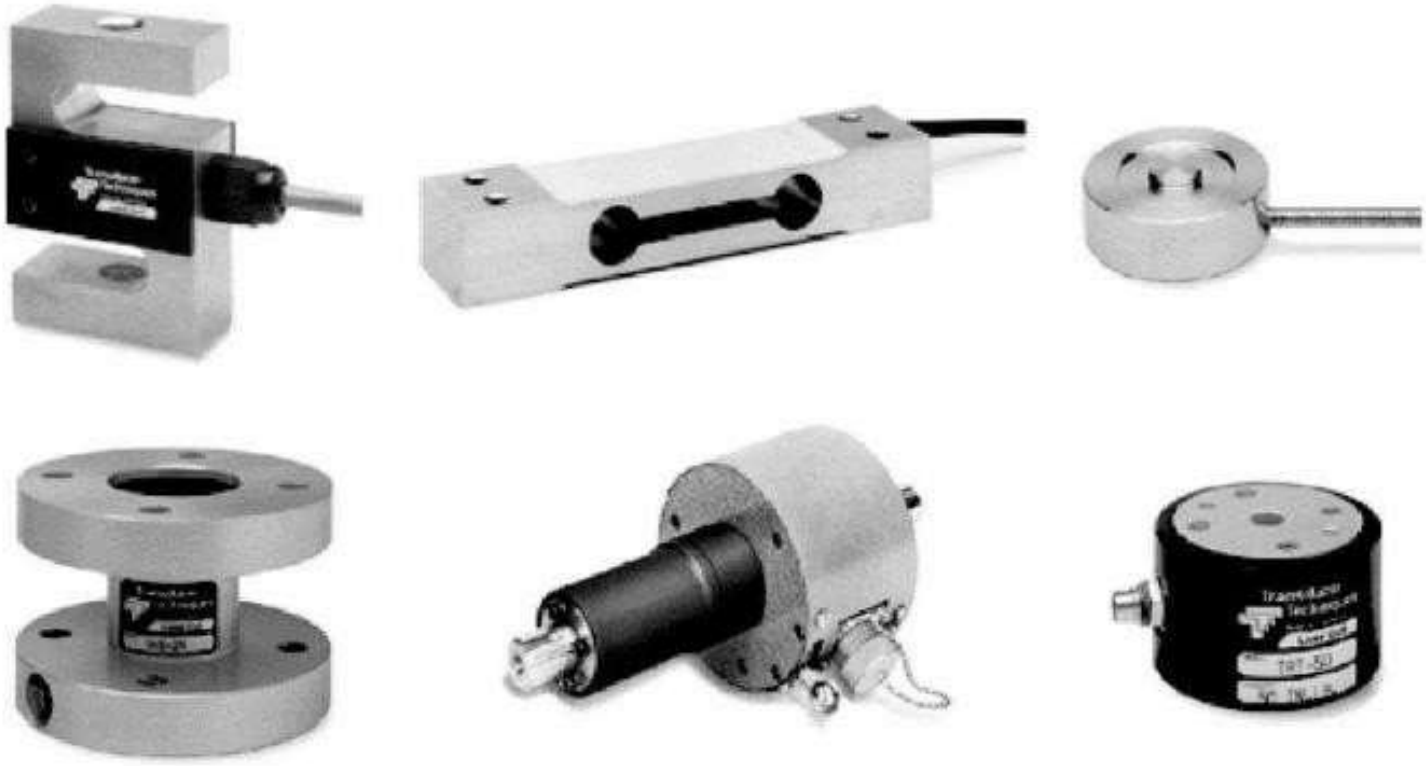
SENSOR BASICS

Non-linear Variation of Input-Output Relationship



SENSOR BASICS

Resistive Sensors



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Various load cells using strain gauges for force and torque measurements