Instrumentation-Sensors

Dr. Ahmed Taibi

ahmed_env26@outlook.com

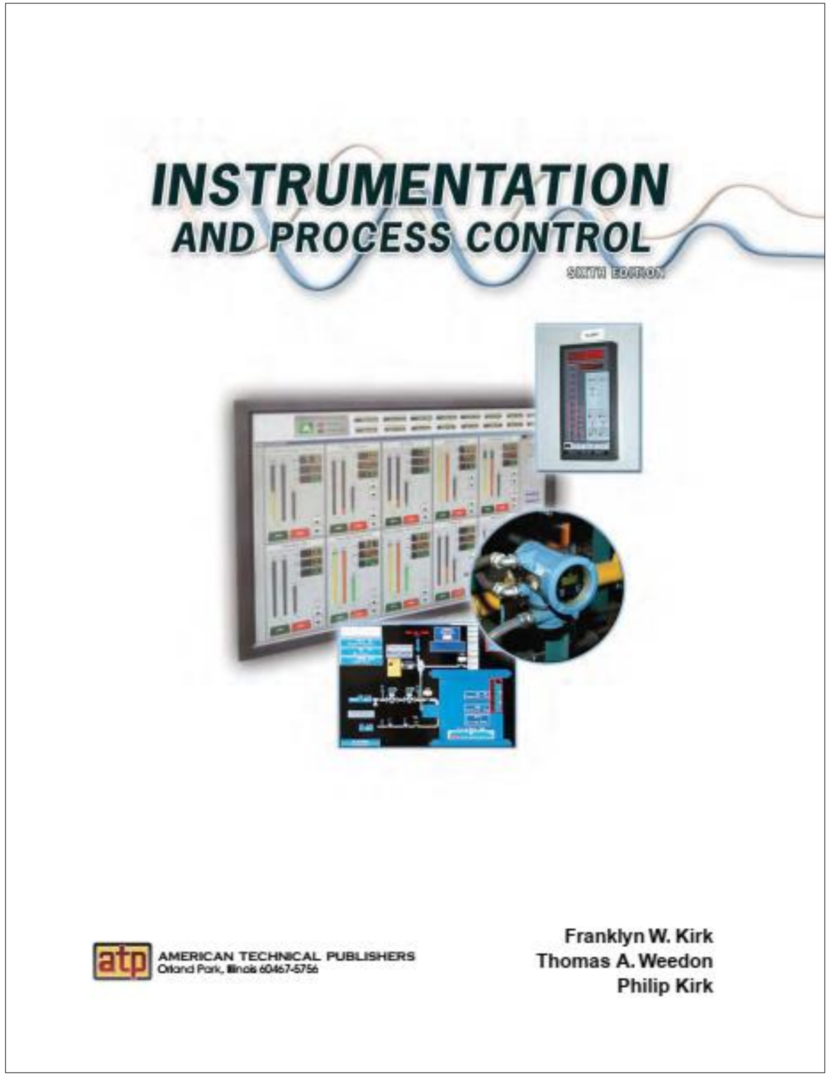
Instrumentation-Sensors

Course : 1h30

Evaluation method

Exam	100%
Credit	2
Coefficient	1

Instrumentation-Sensors



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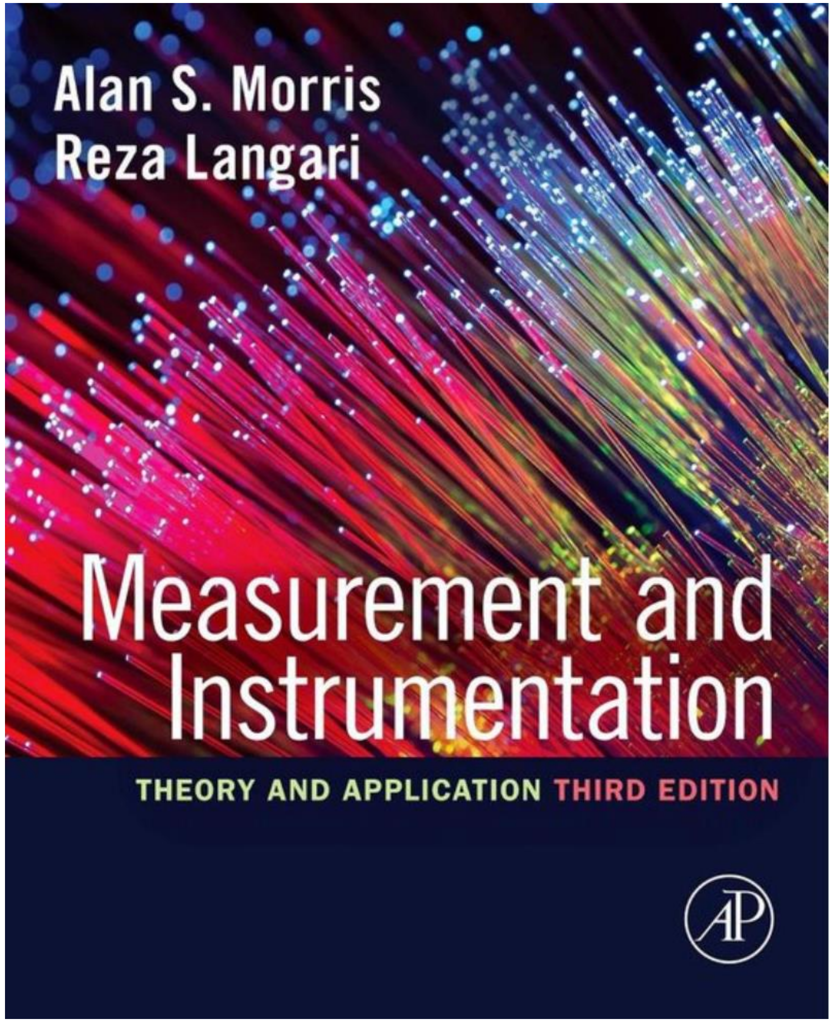

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Instrumentation-Sensors

Patrick Prouvost
Agrégé en génie mécanique
au Lycée Val de Murigny
à Reims

**Instrumentation
et régulation
en 30 Fiches**

DUNOD

DUNOD

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What you will learn from this course?

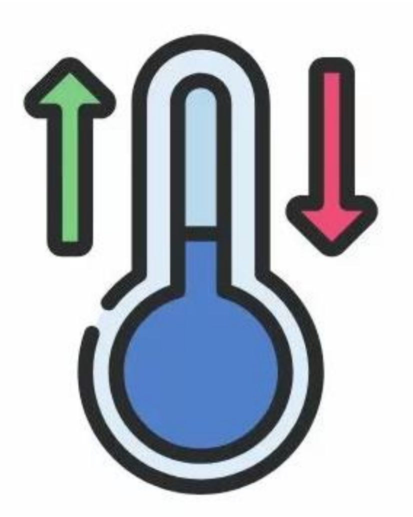
- **Learn about** measurement Instruments and methodologies,
- **Learn about** measurement of different parameters: flow,

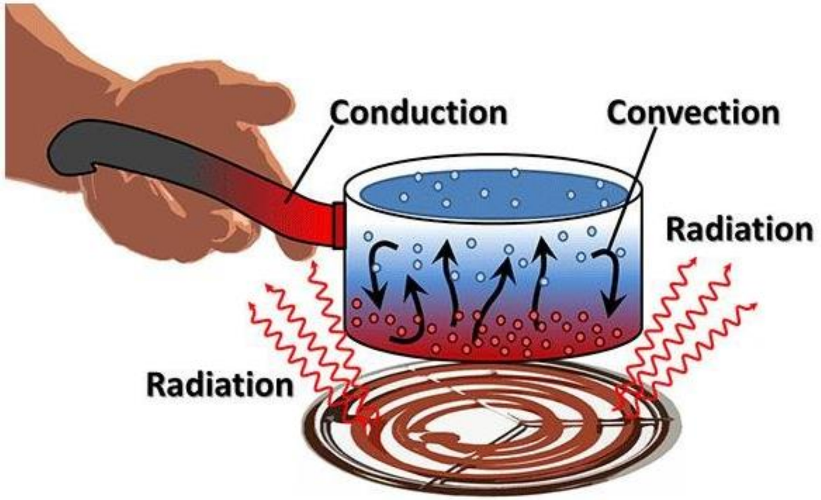
  temperature, pressure, and level,
- Different types of Sensors
- State of the art in different measurement sensors.

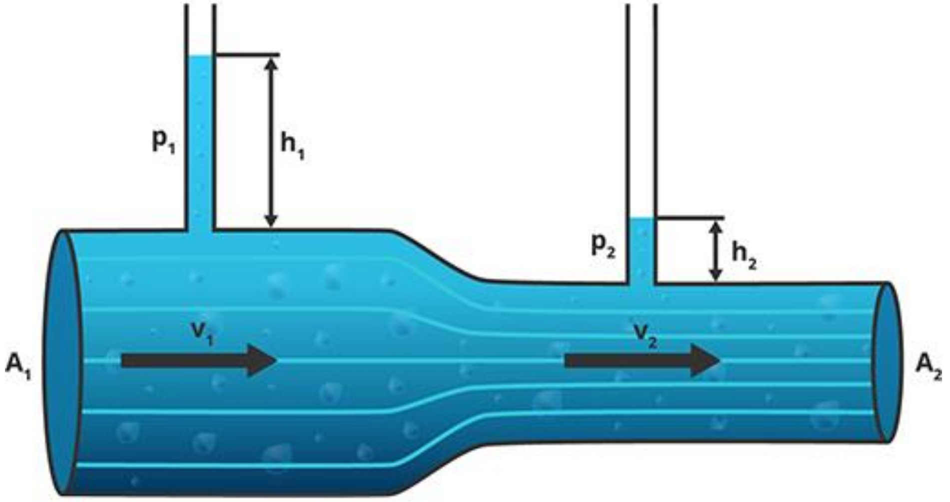
Course Information

Pre-requisites

- Thermodynamics
- Fluid mechanics
- Transfer phenomena







Instrumentation-Sensors (what)

- Introduction: principles and fundamentals of Process Measurement and Instrumentation **(2 weeks)**
- Pressure Measurement **(2 Weeks)**
- Flow Measurement **(2 Weeks)**
- Level Measurement **(2 Weeks)**
- Temperature Measurement **(2 Weeks)**
- Sensors **(5 Weeks)**

Introduction

Introduction

What comes to your mind when you hear the words

Instrumentation

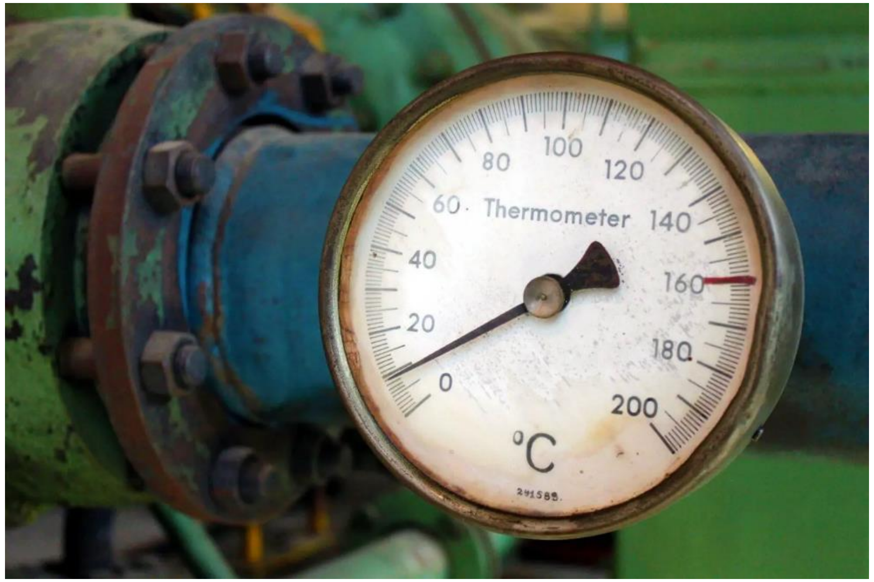
&

Measurement

Introduction

History

Humans always needed to measure certain things for which they developed certain methods



Introduction

History

- The industrial revolution of the nineteenth century demanded new and huge variety of measurement instrument and techniques
- With the developing word, accuracy and cost effectiveness are the two major areas of research in instrumentation

Introduction

Measurement units

Table 1: Fundamental SI units.

Quantity	Standard unit	Symbol
(a) Fundamental units		
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	candela	cd
Matter	mole	mol
(b) Supplementary fundamental units		
Plane angle	radian	rad
Solid angle	steradian	sr

Introduction

Applications:

- ✓ Monitoring of process and operations
- ✓ Control of processes and operations
- ✓ Experimental engineering analysis

Exemple

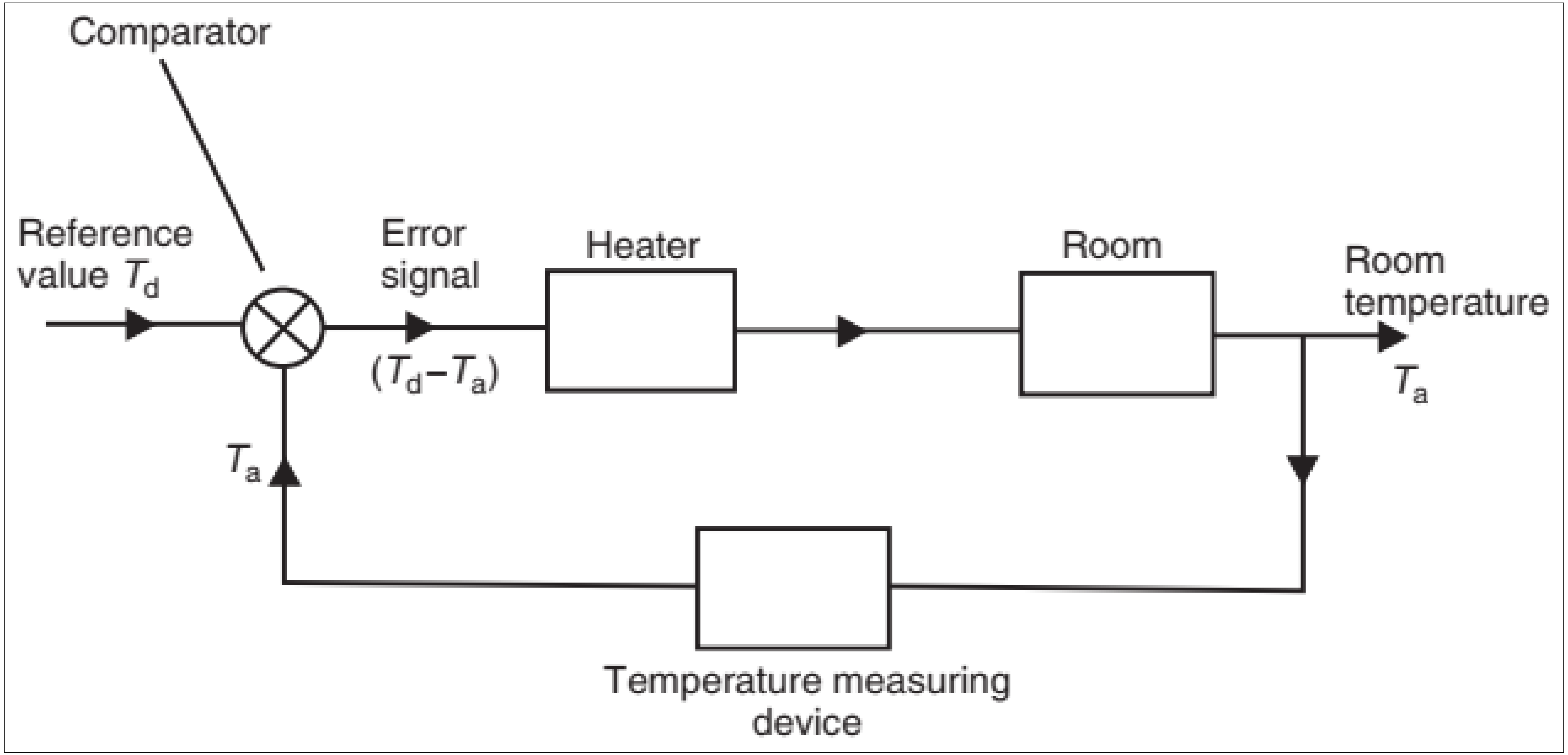


Figure 2: Elements of a simple closed-loop control system.

Introduction

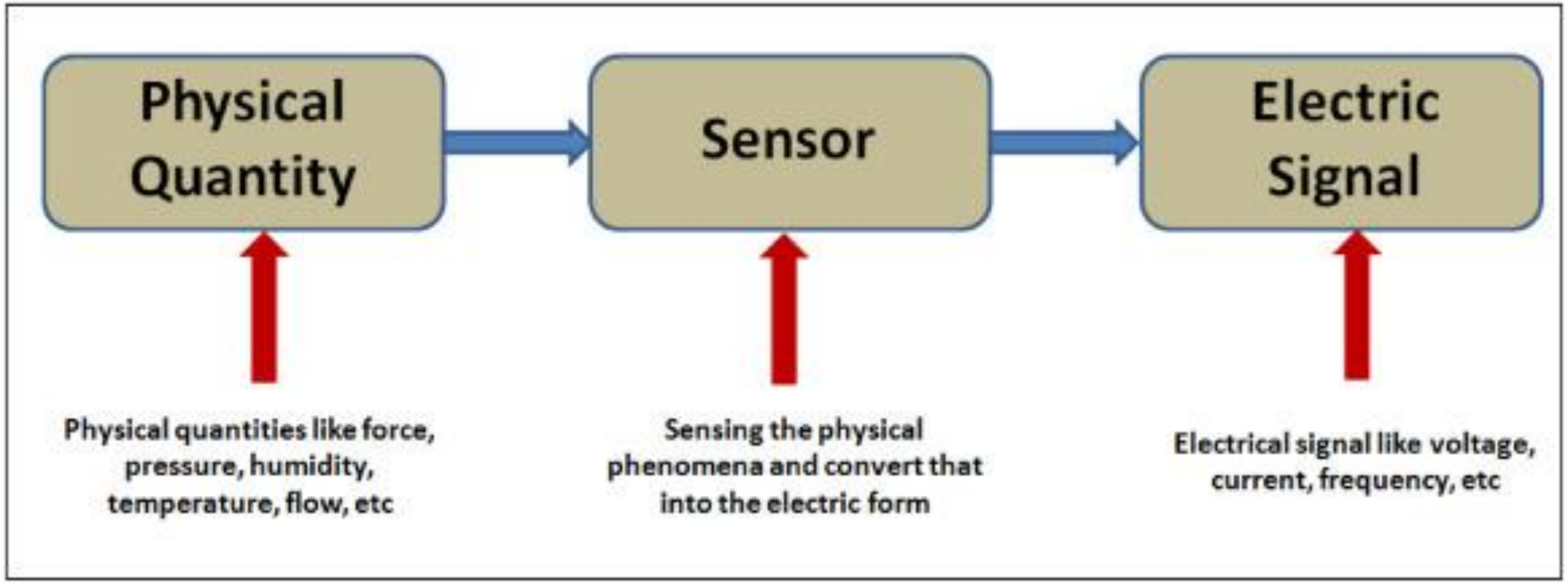
Sensor

- Human senses
    - 5 senses

Introduction

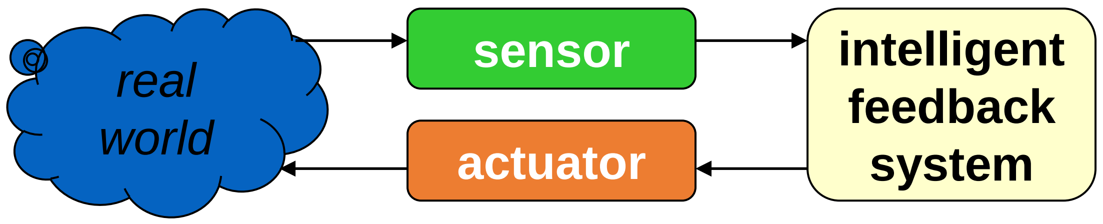
Sensor

- Collect information about the world
- Just like we do as humans
- **Sensor:** an electrical/mechanical/chemical device that maps an environmental attribute to a quantitative measurement



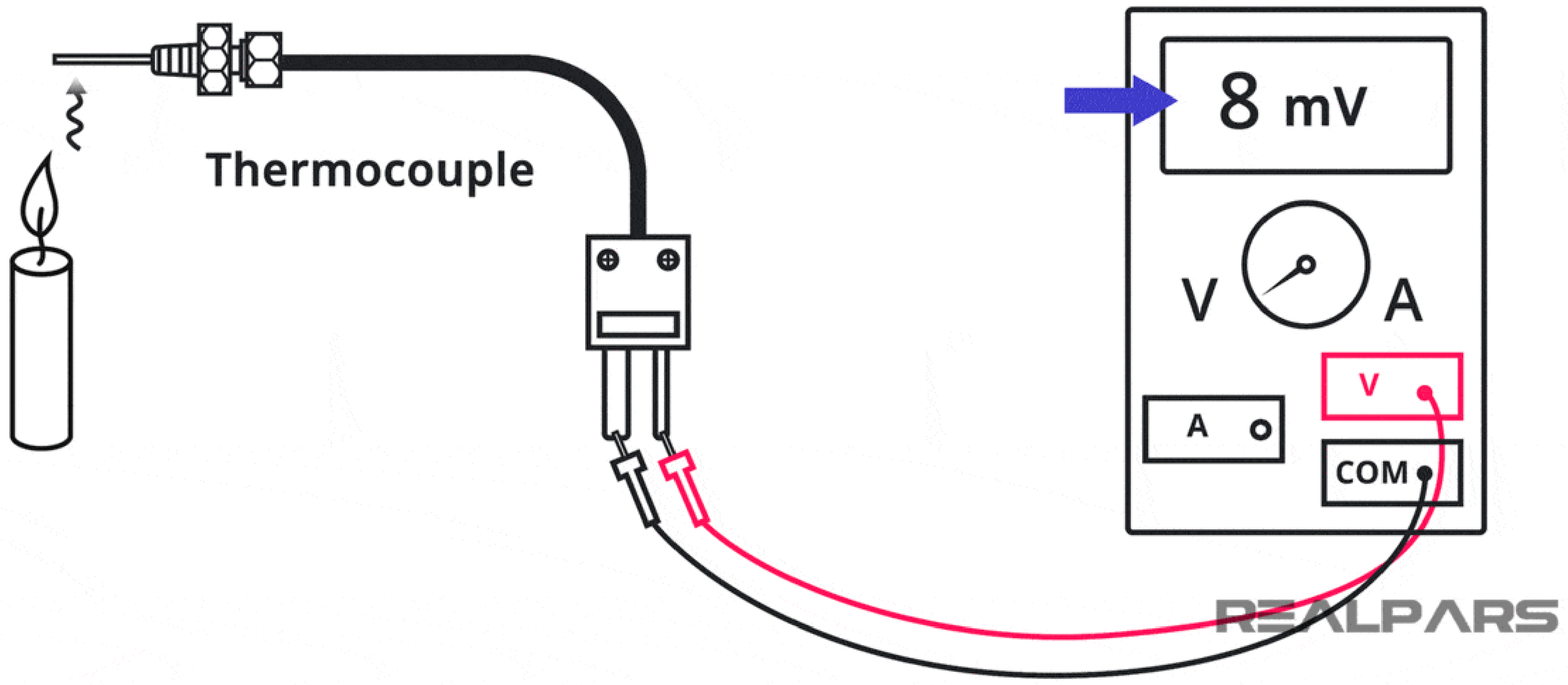
Introduction

- **Transducer**
  - a device that converts a primary form of energy into a corresponding signal with a different energy form
    - Primary Energy Forms: mechanical, thermal, electromagnetic, optical, chemical, etc.
  - take form of a **sensor** or an **actuator**
- **Sensor** (e.g., thermometer)
  - a device that detects/measures a signal or stimulus
  - acquires information from the "real world"
- **Actuator** (e.g., heater)
  - a device that generates a signal or stimulus



Exemple

Active



Fundamental of Measurement and Instrumentation

Introduction

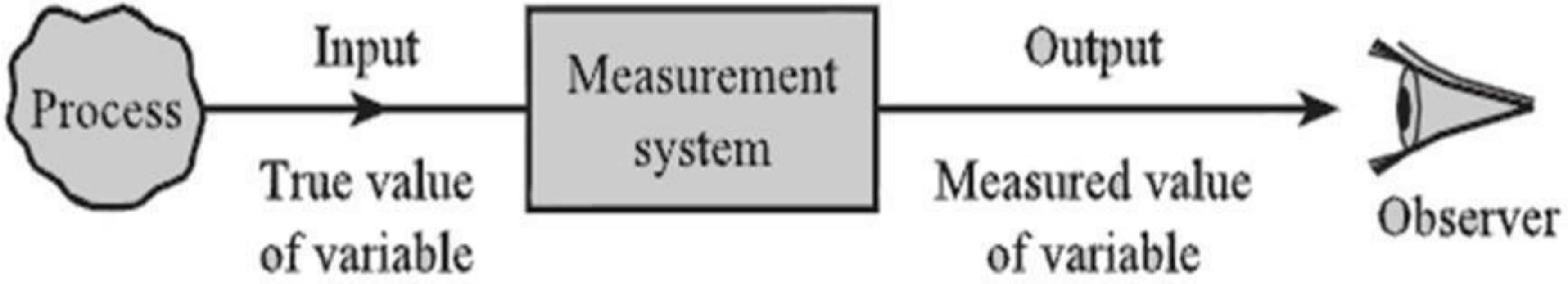
- **Measurement:** This refers to the process of collecting information from the physical world and comparing it to agreed-upon standards, converting physical properties or phenomena into meaningful numerical values. For accuracy, these standards must be well-defined, widely accepted, and traceable to established reference points.

- **Instrumentation:** This involves the use of measuring tools or devices to monitor, measure, and control process variables, particularly in fields such as production, laboratories, and manufacturing. The primary focus is on ensuring precise measurement and regulation of variables such as temperature, pressure, flow, and others to ensure process efficiency and quality control.

Purpose and performance of measurement systems

A measurement system links an observer to a process that generates information.

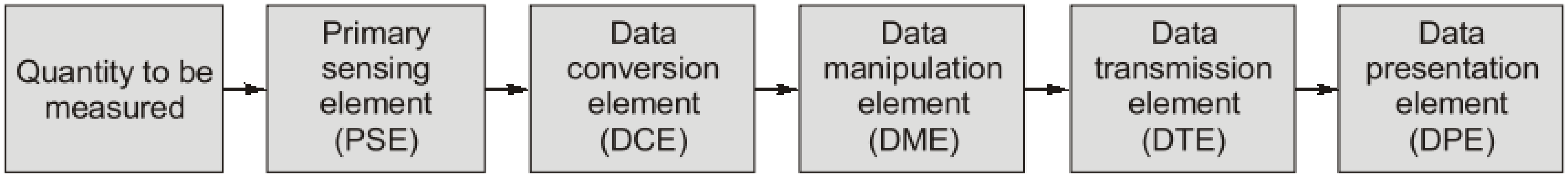
- **Process:** Any system that produces data (e.g., chemical reactor, car, human heart, weather system).
- **Observer:** The person or system needing the information (e.g., plant operator, driver, nurse, engine control system).
- **The measurement system** captures, processes, and presents information to the observer for decision-making.



Basic Requirements for a Meaningful Measurement

- The **standards** used for comparison must be **precisely defined** and **widely accepted**.
- The **apparatus used** and the method adopted must be **verifiable** and **reliable**.

Elements of Generalized Measurement System



- **Primary Sensing Element (PSE):** These elements are in direct contact with quantity under measurement. It is used to sense the quantity to be measured.

  e.g. transducer and other sensing element.
- **Data Conversion Element (DCE):** This element converts one form of the data to another form, but the basic information carried over by the data is preserved.

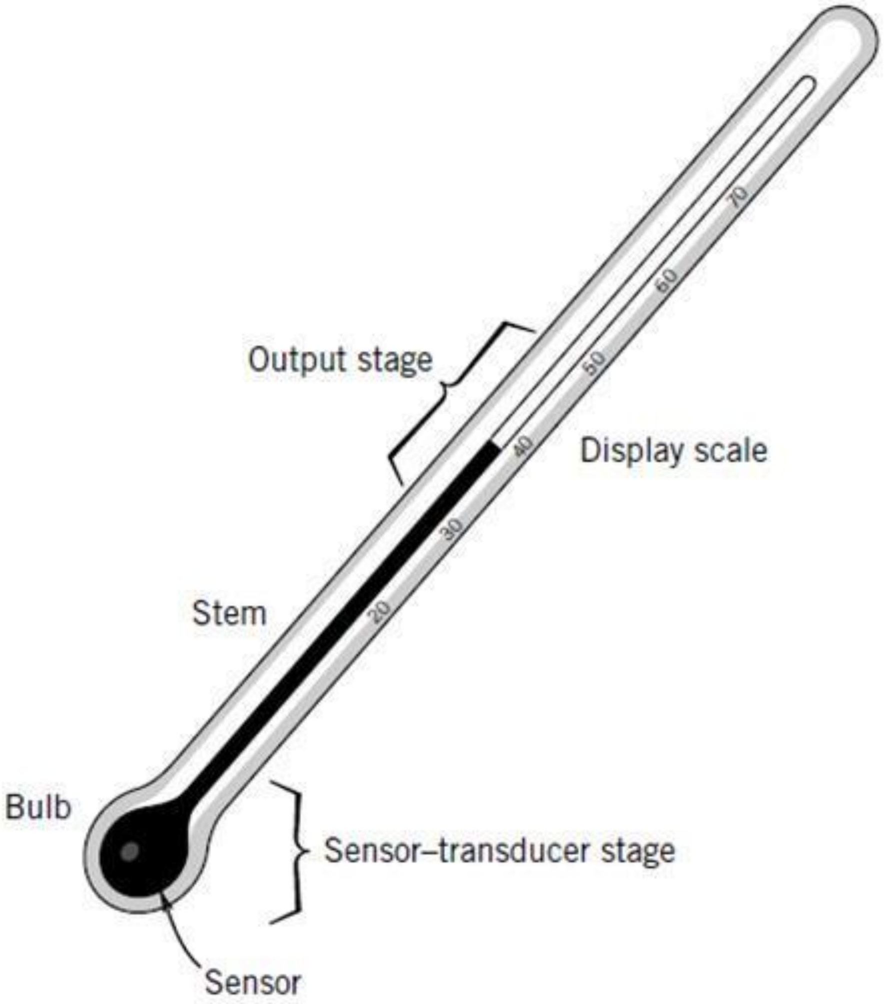
  e.g. voltage to frequency converter, voltage to current converter, ADC, DAC.
- **Data Manipulation Element (DME):** This element changes the level of signal preserving its basic nature.

  e.g. amplification, modulation, attenuation etc.
- **Data Transmission Element (DTE):** This element provides transmission channel.

  e.g. optical fibres, coaxial cables, transmission lines etc.
- **Data Presentation Elements (DPE):** This element is used either to store or to display the signal receiver.

  e.g. CRO, recorder, digital display, plotters etc.

Examples of Measurement System



Components of bulb thermometer equivalent to sensor, transducer, and output stages.

Choosing Appropriate Measuring Instruments

- **Performance Characteristics:** The instrument’s ability to provide accurate, sensitive, and responsive measurements.

- **Ruggedness and Durability:** How well the instrument withstands harsh conditions and physical stress.

- **Maintenance Requirements:** The frequency and cost of upkeep needed to maintain accuracy and functionality.

- **Purchase Cost:** The initial cost, balanced against long-term operational and maintenance expenses.

Factors affecting measurements

1. Environmental Conditions: Variations in temperature or humidity can affect materials and measurement equipment, reducing accuracy.

2. Inferior Measuring Equipment: Poorly maintained, damaged, or uncalibrated equipment leads to unreliable results.

3. Poor Measuring Techniques: Inconsistent measurement procedures can reduce precision and reliability.

4. Inadequate Staff Training: Lack of proper training, confidence, or willingness to seek advice can negatively impact measurement accuracy.

Standards in Measurement

- During calibration, the indicated value of a measurement system is compared to a reference value.

- This reference value is called the **standard**.

- A standard can come from equipment output, an object with a well-defined physical attribute, or a well-accepted technique that provides a reliable value for comparison.

Methods of Measurements

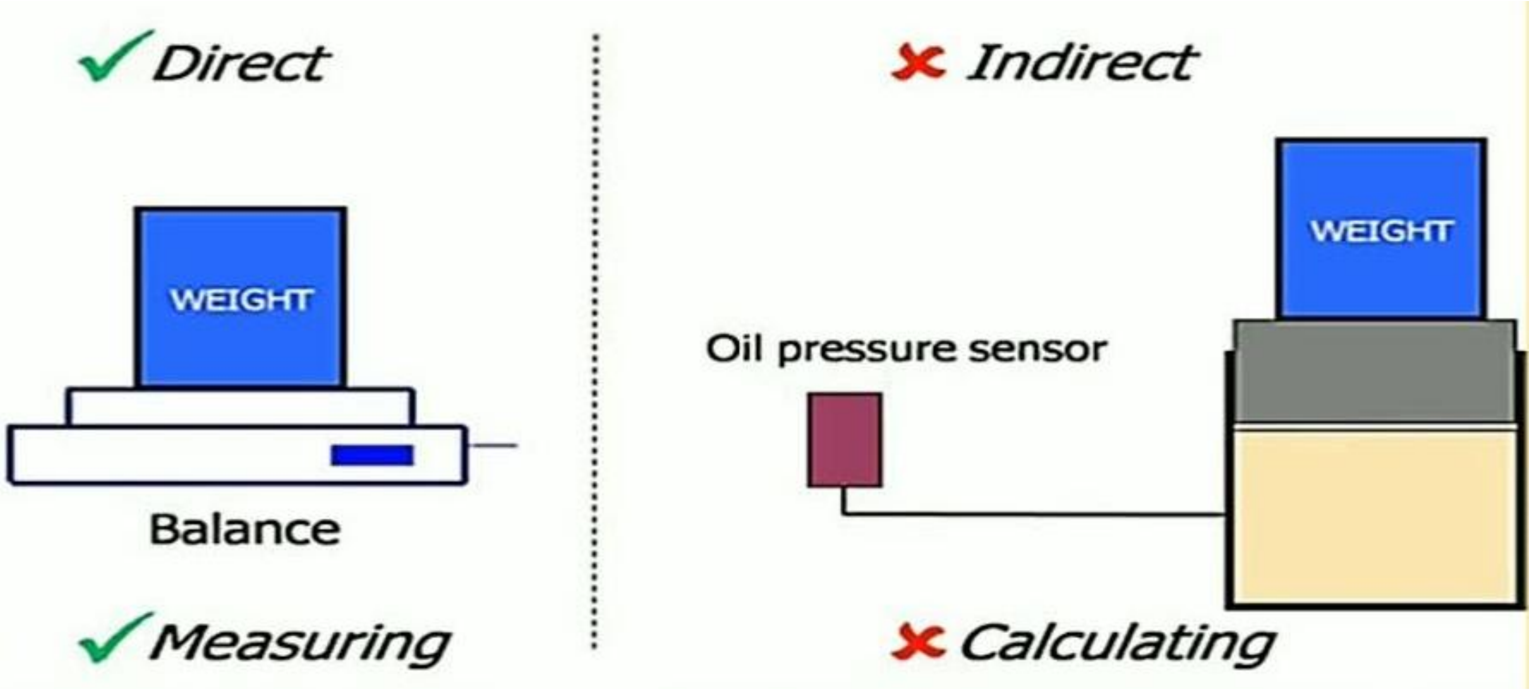
The methods of measurements are classified into two categories:

(a) Direct methods

(b) Indirect methods

Methods of Measurements

'**Direct measurement**' refers to measuring exactly the thing that you are looking to measure, while '**indirect measurement**' means that you're measuring something by measuring something else.



Classification of Instruments

Active vs Passive Instruments

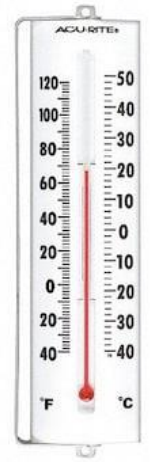
Active Instruments:

•Require external power to function.

•Generate an output signal based on the measured quantity.

•**Example:** Electronic thermometers, which need power to measure temperature and display results.

Passive Instruments:



•Do not require external power.

•Operate by relying on the measured quantity to produce a response

•**Example:** Mercury thermometers, which directly respond to temperature changes without external energy.

Null-Type and Deflection-Type Instruments

Null-Type Instruments:

- Measure by **balancing against a known reference**, aiming for zero deflection.
- More precise but slower.
- **Example:** Balance scale.

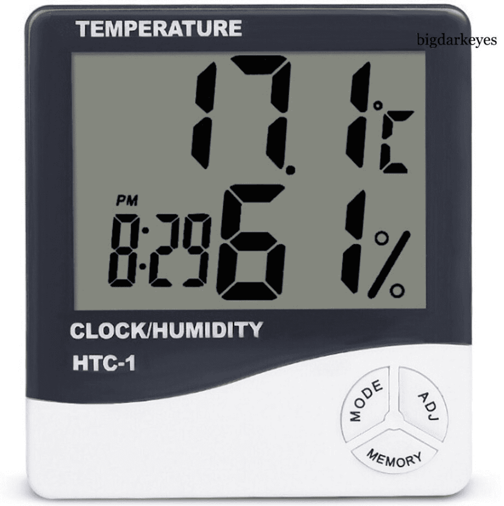
Deflection-Type Instruments:

- Measure by the deflection of a **pointer** or **indicator** in response to the measured value.
- Faster but potentially less accurate.
- **Example:** Pressure gauge.

Analogue and Digital Instruments

Analogue Instruments:

- Continuous signal with a scale or pointer.
- Less precise and prone to reading errors.
- Example: Analog voltmeter.



Digital Instruments:

- Display numerical values.
- More accurate and easier to read.
- Example: Digital thermometer.

Evolution of Instruments

<u>Mechanical Instruments:</u>

- Operate using mechanical parts like gears, levers, and springs.
- Example: Pressure gauges, mechanical clocks.

<u>Electrical Instruments:</u>

- Use electrical properties like voltage or current for measurement.
- Example: Analog voltmeters, ammeters.

<u>Electronic Instruments:</u>

- Use electronic components such as transistors and integrated circuits.
- Example: Digital multimeters, electronic thermometers.

Performance Characteristics of Instruments

Static Characteristics of Instruments

The **Static Characteristics** of instruments and measurement systems describe how an instrument behaves under steady conditions. Here are the key static characteristics with brief explanations:

1. **Accuracy**:
2. **Precision**:
3. **Resolution**:
4. **Sensitivity**:
5. **Range**:
6. **Linearity**:
7. **Repeatability and Reproducibility**:
8. **Drift**:
9. **Stability**

Accuracy الدقة

- **Accuracy** refers to how closely the **measured value** aligns with the **true value**.

- To maintain **high accuracy**, select instruments with a range that closely matches the values being measured. Using a wide-range instrument, like a 0–10 bar gauge to measure 1 bar, may reduce accuracy due to potential errors.

- Instruments with a narrower range (closer to the expected measurement) will provide better accuracy.

Precision الضبط او الاحكام

- **Precision:** the degree to which repeated measurements under the same conditions yield consistent results, showing minimal variation between readings.
- **High Precision:** Small spread in results, showing good repeatability.
- **Precision vs. Accuracy:** Precision does not imply accuracy; they are distinct concepts.
- **High Precision, Low Accuracy:** Can occur due to systematic bias, correctable by recalibration.
- **Confusion:** Precision is often mistakenly equated with accuracy.

Accuracy vs Precision

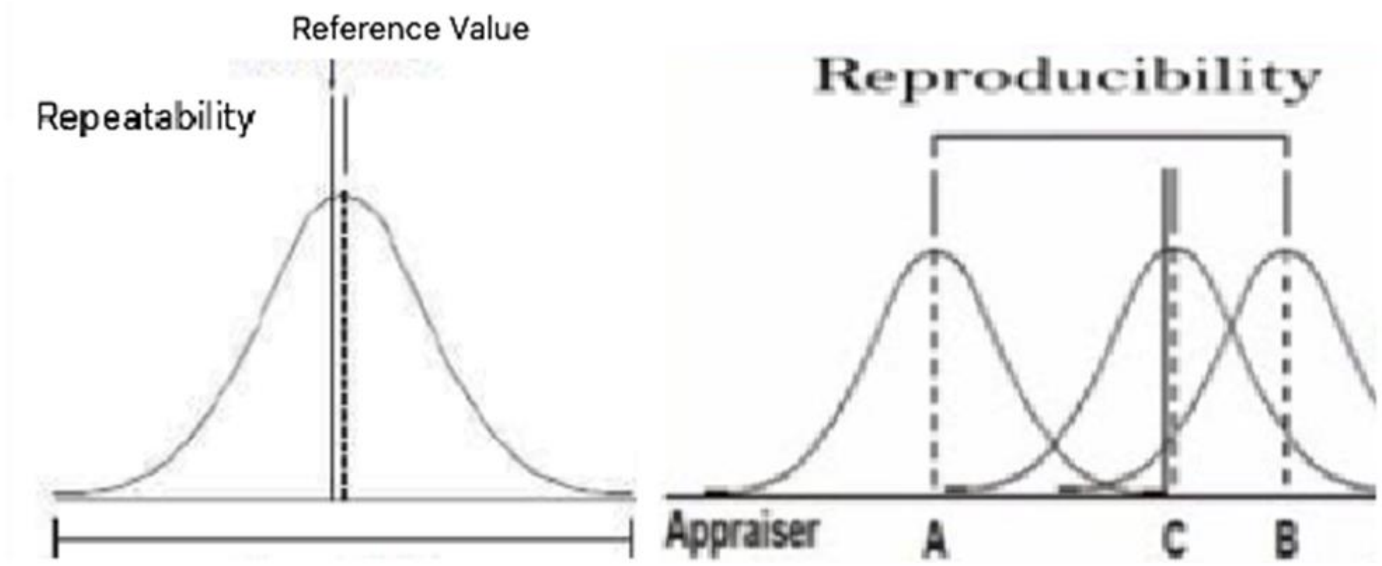
•**Accuracy** is about getting close to the correct value.

•**Precision** is about getting consistent results, regardless of whether they are correct.

Low accuracy, but high precision | Higher accuracy, but low precision | High accuracy and high precision

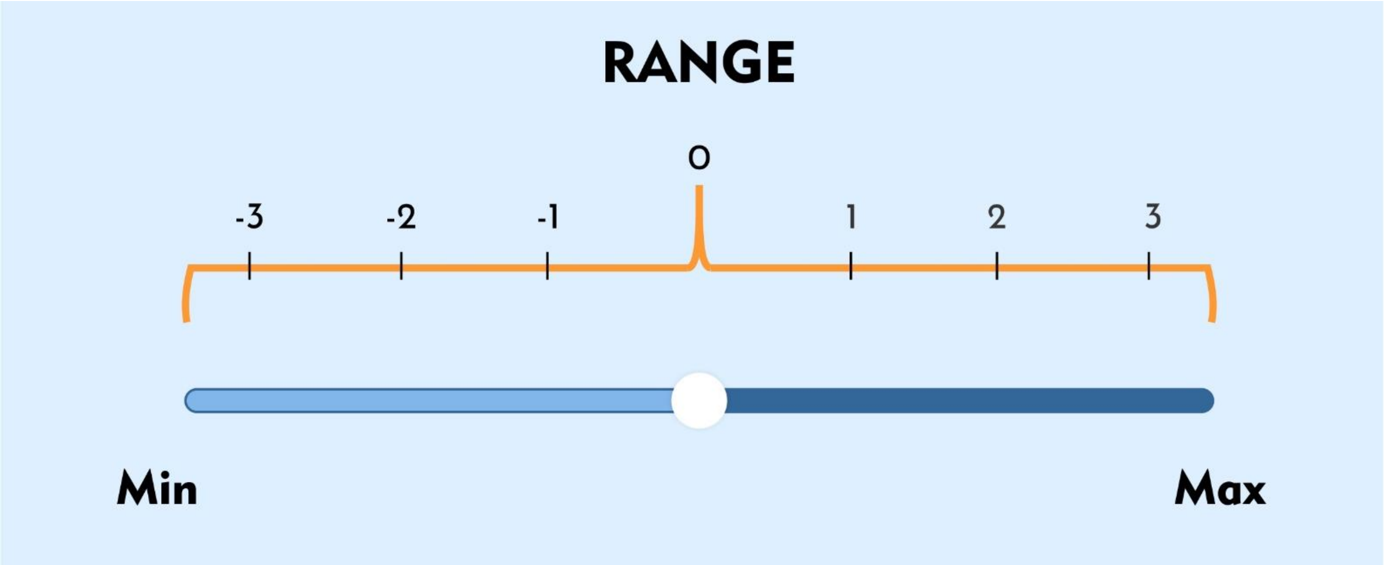
Repeatability and Reproducibility

- **Repeatability:** Refers to how closely output readings align when the same input is measured repeatedly under identical conditions—same instrument, observer, location, and time.
- **Reproducibility:** Refers to how closely output readings align when the same input is measured under varying conditions—different instruments, observers, locations, methods, and times.



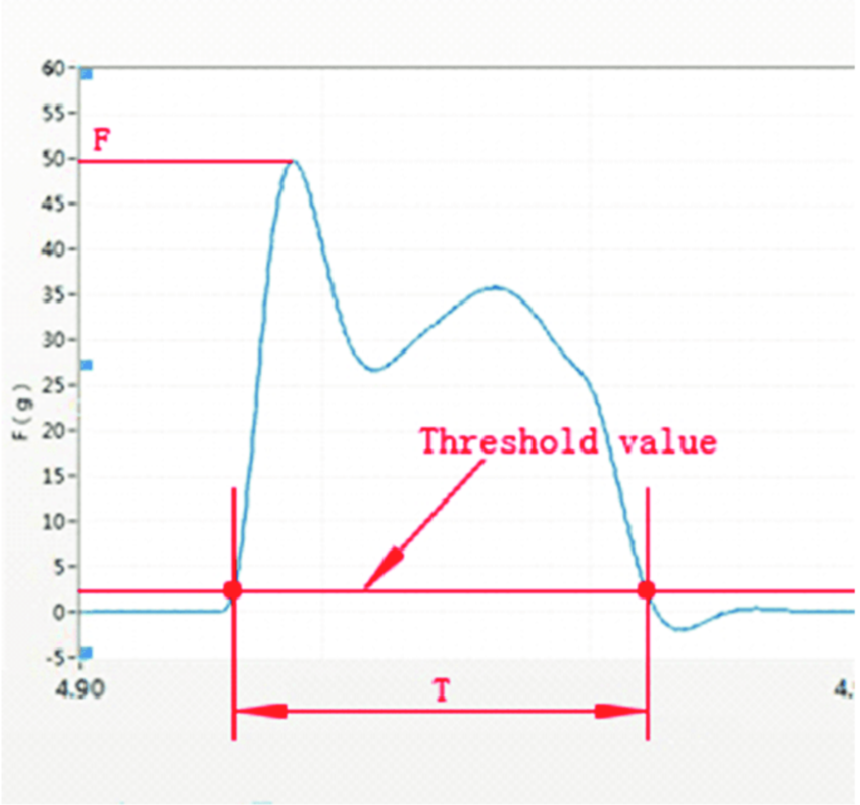
Range or span النطاق

- The span between the minimum and maximum values that an instrument can measure accurately.



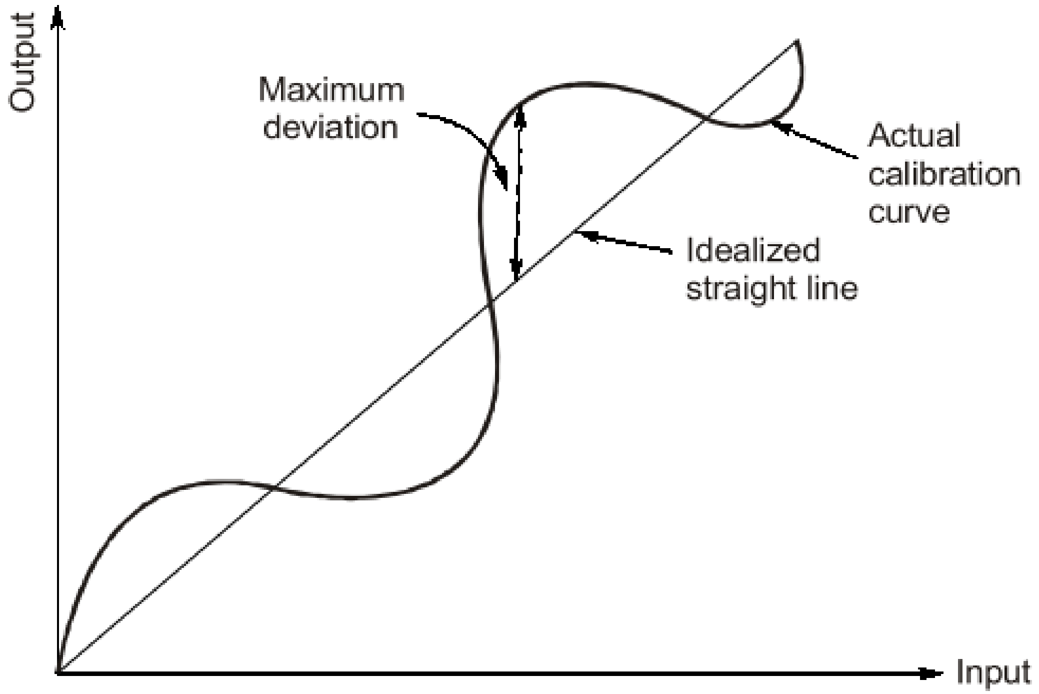
Threshold الحد الأدنى

- In measurement, a **threshold** is the minimum level at which a signal, stimulus, or effect can be detected or measured. It defines the point below which a system, sensor, or human perception cannot reliably identify the presence of the signal or effect.



Linearity الخطية

The degree to which the output of the instrument changes proportionally with the input. A linear instrument produces results that are directly proportional to the measured quantity.



(Linearity w.r.t. actual calibration curve and idealized straight line)

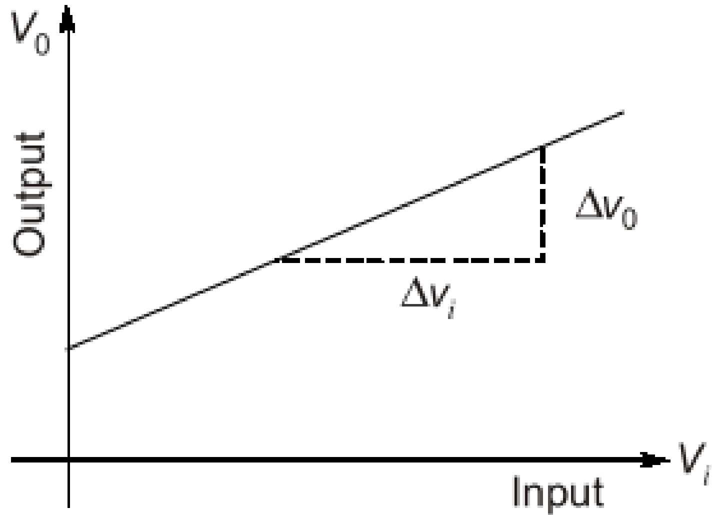
Sensitivity حساسية

- The ability of an instrument to respond to small changes in the input signal. More sensitivity allows the detection of smaller variations in the measured quantity.

$$\text{Sensitivity} = \frac{\text{Small change in output}}{\text{Small change in input}}$$

$$= \frac{\Delta V_0}{\Delta V_i}$$

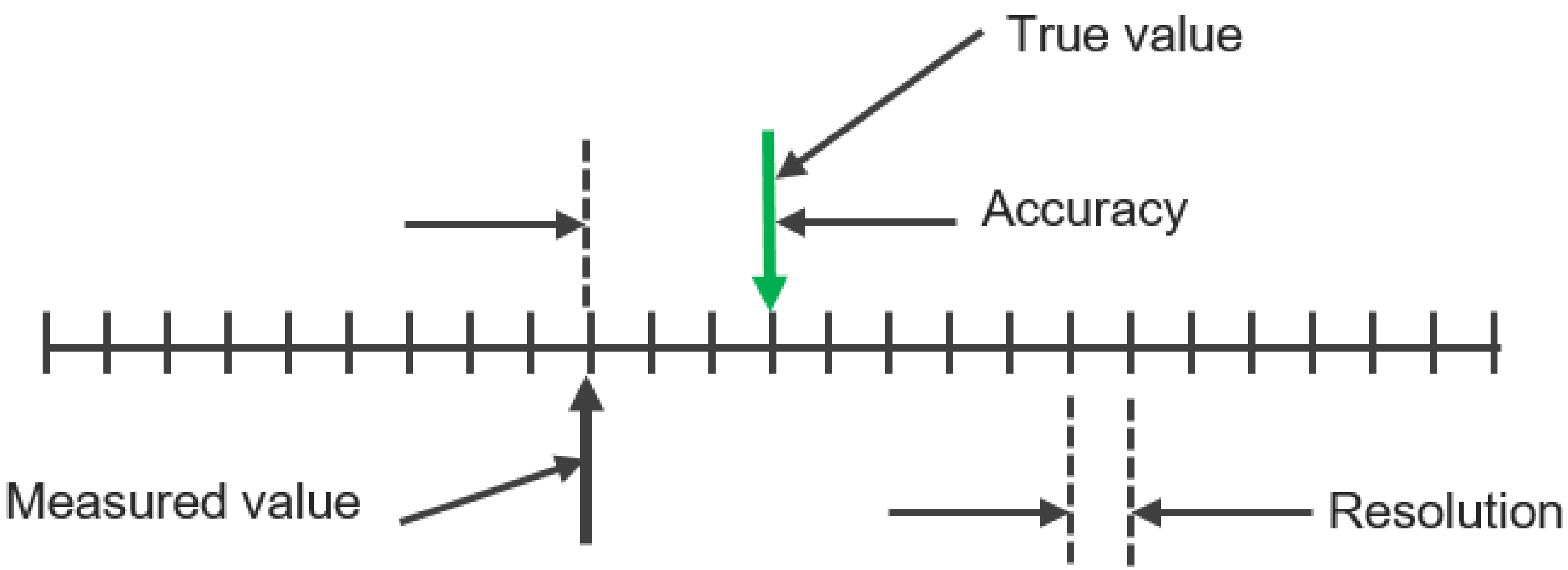
$$\text{Deflection Factor} = \frac{1}{(\text{Static Sensitivity})}$$



(Sensitivity)

Resolution

- The smallest change in a measured quantity that an instrument can detect. Higher resolution means the instrument can detect smaller changes.



Stability الثبات

- The ability of an instrument to maintain its performance characteristics over time. An instrument with good stability will not vary significantly in its readings.

Dynamic Characteristics of Instruments

The dynamic characteristics of instruments describe how a measuring system or instrument responds to changes in the quantity being measured over time.

1. **Speed of Response:** How quickly an instrument reacts to a change in the input.
2. **Dead Time:** The delay before the instrument starts responding to a change in input.
3. **Lag:** The slow or gradual response after the instrument begins to react.
4. **Dynamic Error:** The difference between the true value and the measured value during changing conditions.
5. **Damping:** The ability to avoid oscillations or overshoot when responding to input changes.

Errors in Measurements

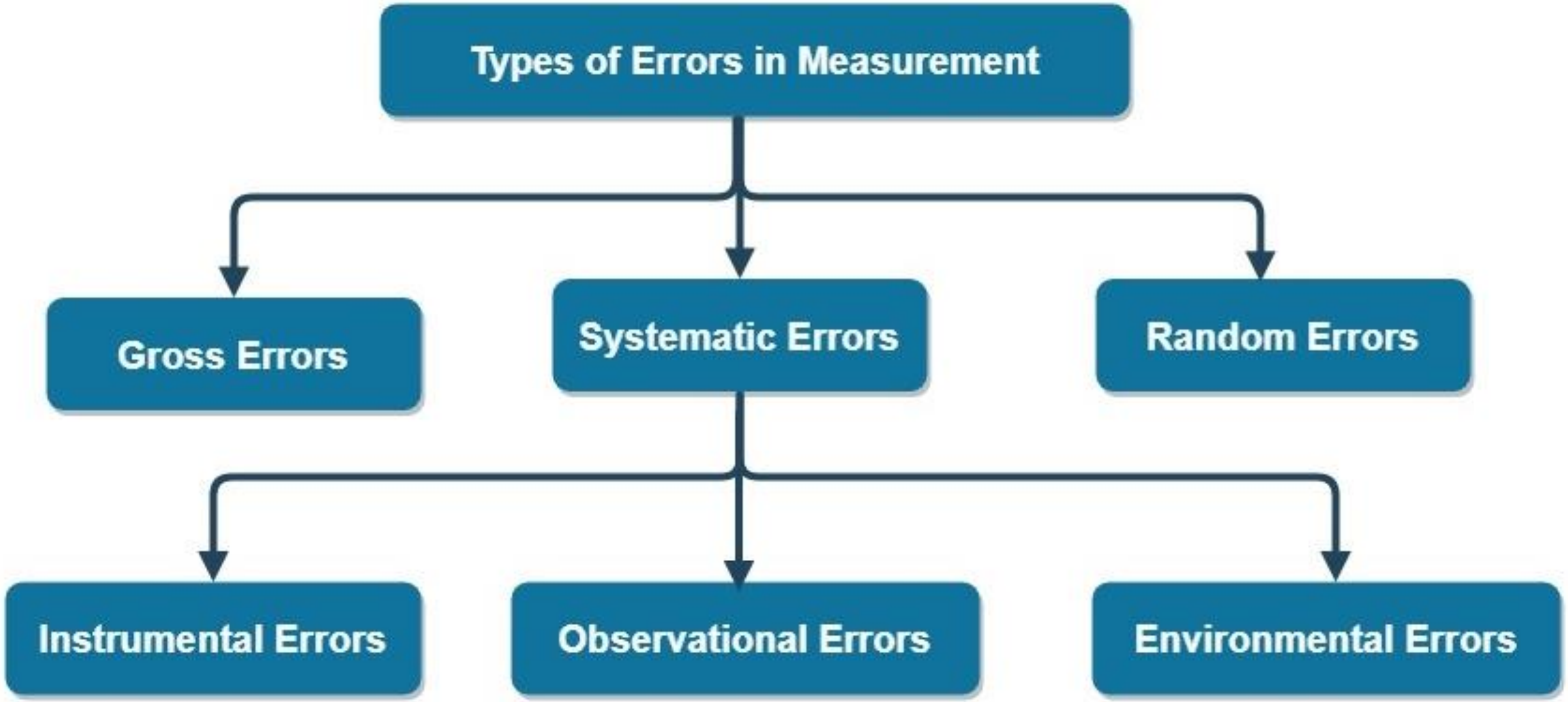
Definition of Error

- **Error:** Difference between measured value and true value.

$$e = \text{measured value} - \text{true value}$$

CLASSIFICATION OF ERRORS

- No measurement can be made with perfect accuracy
- It is important to find out the accuracy rate and errors occurred
- A study of errors is a first step in finding ways to reduce them.



Gross Errors

- Human mistakes in reading instruments and recording and calculating measurement result.

Ex: The temperature is 31.50C, but it will write as 21.50c

This can be avoided by adopting two means

1. Great care should be taken in reading and recording the data.
2. Two, three (or) even more readings should be taken for quantity under measurement

Systematic Errors

Systematic Errors in measurements can be classified into three categories:

1. **Instrumental Errors:** Caused by inherent limitations or misuse of the instrument.
2. **Environmental Errors:** Result from changes in environmental conditions surrounding the instrument.
3. **Observational Errors:** Caused by the observer's habits, such as parallax error.

Random Errors

These errors occur due to unknown or unpredictable factors during measurements, including:

a. Human errors,

b. Disturbances اضطراب to the equipment,

c. Fluctuating تذبذب experimental conditions.

MCQ questions

MCQ questions

1- The ratio of the output to input change for a given measuring system is referred to as

(a) sensitivity

(b) linearity

(c) stability

(d) none of these

MCQ questions

1- The ratio of the output to input change for a given measuring system is referred to as

(a) sensitivity

(b) linearity

(c) stability

(d) none of these

MCQ questions

2- The Conformity of the output to the true value of the measurement is called

(a) precision

(b) accuracy

(c) sensitivity

(d) none of these.

MCQ questions

2- The Conformity of the output to the true value of the measurement is called

(a) precision

(b) accuracy

(c) sensitivity

(d) none of these.

MCQ questions

3- The resolution of a system refers to

(a) smallest change in the measured that can be measured

(b) true value of the input

(c) retardation of the response

(d) none of these

MCQ questions

3- The resolution of a system refers to

(a) smallest change in the measured that can be measured

(b) true value of the input

(c) retardation of the response

(d) none of these

MCQ questions

4- State which of the following describes the linearity of instrument

(a) range of inaccuracy which can be tolerated

(b) largest change in the measured value which produces no instrument response

(c) relationship between output and the input

(d) one of these

MCQ questions

4- State which of the following describes the linearity of instrument

(a) range of inaccuracy which can be tolerated

(b) largest change in the measured value which produces no instrument response

(c) relationship between output and the input

(d) one of these

MCQ questions

5- Environmental errors may be due to changes in

(a) Pressure and temperature

(b) wind velocity and gravity

(c) humidity

(d) any of the above

MCQ questions

5- Environmental errors may be due to changes in

(a) Pressure and temperature

(b) wind velocity and gravity

(c) humidity

(d) any of the above

MCQ questions

6- The dead time of an instrument refers to

(a) large change of input quantity for which there is not output

(b) the time encountered when the instrument has to wait for some reactions to take place

(c) the time before the instrument begins to respond after the quantity has altered

(d) retardation or delay in the response of an instrument to a change in the input signal

MCQ questions

6- The dead time of an instrument refers to

(a) large change of input quantity for which there is not output

(b) the time encountered when the instrument has to wait for some reactions to take place

(c) the time before the instrument begins to respond after the quantity has altered

(d) retardation or delay in the response of an instrument to a change in the input signal

MCQ questions

7- Precision is the

(a) closeness of the instrument output to true value of the measured quantity

(b) ratio of difference between measured value and the true value of the measurand

(c) smallest increment in measurand that can be detected with certainty by the instrument

(d) degree of repeatability of several independent measurements of the desired input at the same reference conditions

MCQ questions

7- Precision is the

(a) closeness of the instrument output to true value of the measured quantity

(b) ratio of difference between measured value and the true value of the measurand

(c) smallest increment in measurand that can be detected with certainty by the instrument

(d) degree of repeatability of several independent measurements of the desired input at the same reference conditions

MCQ questions

8- Smallest change in which an instrument can detect ,

(a) Resolution

(b) Accuracy

(c) Precision

(d) Scale

MCQ questions

8- Smallest change in which an instrument can detect ,

(a) Resolution

(b) Accuracy

(c) Precision

(d) Scale

MCQ questions

9- Which of the following results from careless handling?

(a) Systematic Error

(b) Gross Error

(c) Random Error

(d) None of the above

MCQ questions

9- Which of the following results from careless handling?

(a) Systematic Error

(b) Gross Error

(c) Random Error

(d) None of the above

MCQ questions

10- Which of the following defines measurement error?

(a) True value - Measured value

(b) Precision - True value

(c) Measured value – Precision

(d) None of the above

MCQ questions

10- Which of the following defines measurement error?

(a) True value - Measured value

(b) Precision - True value

(c) Measured value – Precision

(d) None of the above