# Chapter 1

# INTRODUCTION TO INSTRUMENTATION

# OBJECTIVES

- At the end of this chapter, students should be able to:
  1. Explain the static and dynamic characteristics of an instrument.
  2. Calculate and analyze the measurement error, accuracy, precision and limiting error.
  3. Describe the basic elements of electronic instrument.

# INTRODUCTION

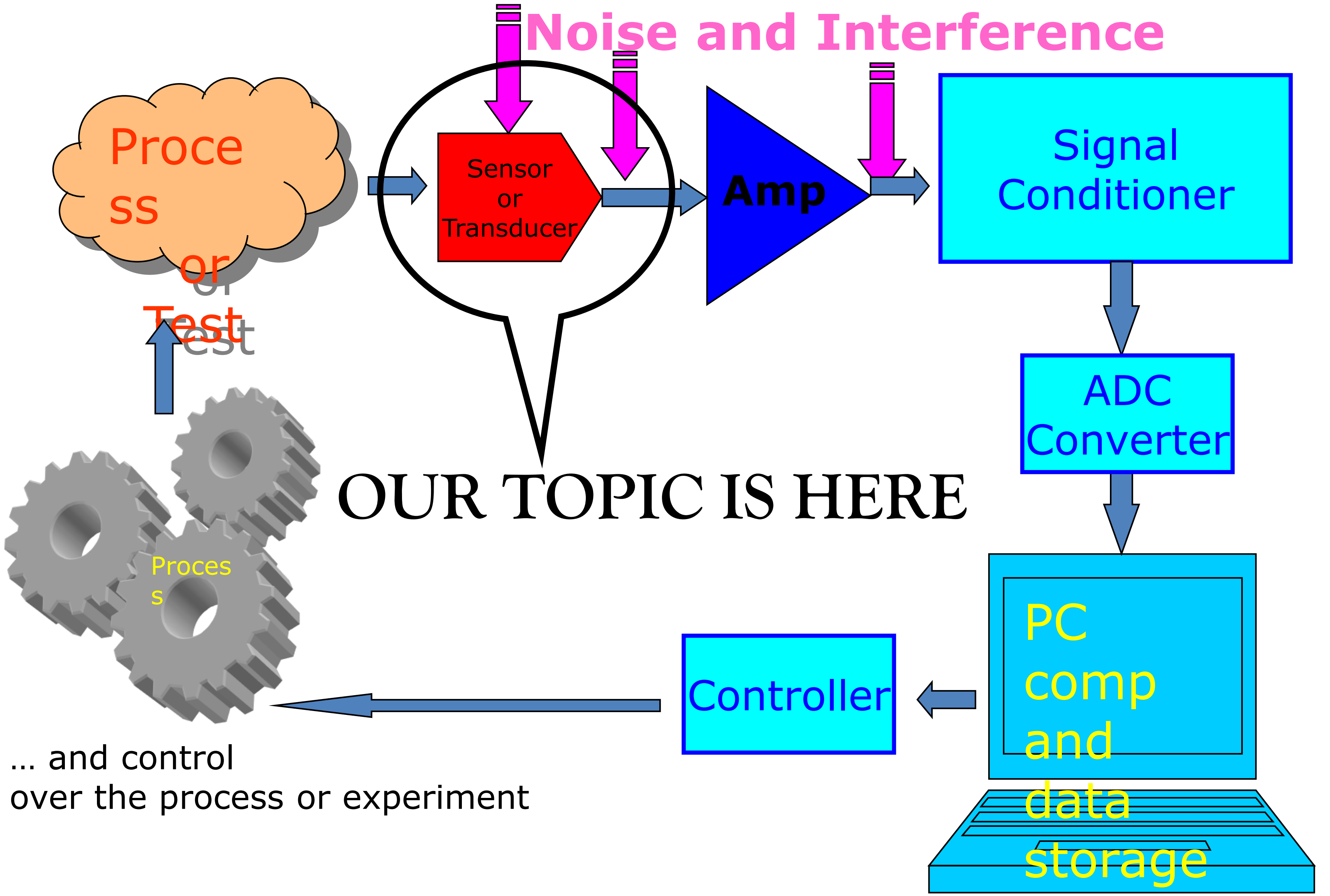
- Instrumentation is a technology of measurement which serves sciences, engineering, medicine and etc.
- Measurement is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.
- Instrument is a device for determining the value or magnitude of a quantity or variable.
- Electronic instrument is based on electrical or electronic principles for its measurement functions.

# FUNCTION AND ADVANTAGES

- The 3 basic functions of instrumentation :-
  - **Indicating** – visualize the process/operation
  - **Recording** – observe and save the measurement reading
  - **Controlling** – to control measurement and process

- Advantages of electronic measurement
  - Results high sensitivity rating – the use of amplifier
  - Increase the input impedance – thus lower loading effects
  - Ability to monitor remote signal

# Typical Measurement System Architecture



# Examples of Electronic Sensor applications


New Solar Power Faucet by Sloan Valve
•0.5 gpm aerator regulates water flow
•Electronic sensor automatically turns water on/off
•Integral temperature control

Uses infrared optical sensor

# PERFORMANCE CHARACTERISTICS

- Performance Characteristics - characteristics that show the performance of an instrument.
  - Eg: accuracy, precision, resolution, sensitivity.
- Allows users to select the most suitable instrument for a specific measuring jobs.
- Two basic characteristics :
  - Static – measuring a constant process condition.
  - Dynamic - measuring a varying process condition.

# PERFORMANCE CHARACTERISTICS

- Accuracy – the degree of exactness (closeness) of measurement compared to the expected (desired) value.
- Resolution – the smallest change in a measurement variable to which an instrument will respond.
- Precision – a measure of consistency or repeatability of measurement, i.e successive reading do not differ.
- Sensitivity – ratio of change in the output (response) of instrument to a change of input or measured variable.
- Expected value – the design value or the most probable value that expect to obtain.
- Error – the deviation of the true value from the desired value.

# ERROR IN MEASUREMENT

- Measurement always introduce error
- Error may be expressed either as absolute or percentage of error

Absolute error, e = $Y_n - X_n$

where $Y_n$ – expected value

$X_n$ – measured value

% error = $\left|\dfrac{Y_n - X_n}{Y_n}\right| \times 100$

# ERROR IN MEASUREMENT

Relative accuracy, $A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right|$

% Accuracy, a = 100% - % error

= $A \times 100$

Precision, P = $1 - \left| \frac{X_n - \overline{X}_n}{\overline{X}_n} \right|$

where $X_n$ - value of the n$^{th}$ measurement

$\overline{X}_n$ - average set of measurement

The precision of a measurement is a quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurements.

**Example 1.1**

Given expected voltage value across a resistor is 80V. The measurement is 79V. Calculate,

i. The absolute error
ii. The % of error
iii. The relative accuracy
iv. The % of accuracy

# Solution (Example 1.1)

Given that , expected value = 80V
measurement value = 79V

i. Absolute error, e = $Y_n - X_n$ = 80V – 79V = 1V

ii. % error = $\left|\dfrac{Y_n - X_n}{Y_n}\right| \times 100 = \dfrac{80-79}{80} \times 100$ = 1.25%

iii. Relative accuracy, $A = 1 - \left|\dfrac{Y_n - X_n}{Y_n}\right|$ = 0.9875

iv. % accuracy, a = A x 100% = 0.9875 x 100%=98.75%

# Example 1.2

From the value in table 1.1 calculate the precision of 6th measurement?

Table 1.1

| No | $X_n$ |
|---|---|
| 1 | 98 |
| 2 | 101 |
| 3 | 102 |
| 4 | 97 |
| 5 | 101 |
| 6 | 100 |
| 7 | 103 |
| 8 | 98 |
| 9 | 106 |
| 10 | 99 |

Solution

the average of measurement value

$$\overline{X}_n = \frac{98+101+....+99}{10} = \frac{1005}{10} = 100.5$$

the 6th reading

Precision = $1-\left|\frac{100-100.5}{100.5}\right| = 1-\frac{0.5}{100.5} = 0.995$

# LIMITING ERROR

- The accuracy of measuring instrument is guaranteed within a certain percentage (%) of full scale reading
- E.g manufacturer may specify the instrument to be accurate at $\pm 2$ % with full scale deflection
- For reading less than full scale, the limiting error increases

# LIMITING ERROR (cont)

Example 1.6

Given a 600 V voltmeter with accuracy ±2% full scale.

Calculate limiting error when the instrument is used to measure a voltage of 250V?

Solution

The magnitude of limiting error, 0.02 x 600 = 12V

Therefore, the limiting error for 250V = 12/250 x 100 = 4.8%

# LIMITING ERROR (cont)

Example 1.7

Given for certain measurement, a limiting error for voltmeter at 70V is 2.143% and a limiting error for ammeter at 80mA is 2.813%. Determine the limiting error of the power.

Solution

The limiting error for the power = 2.143% + 2.813%

= <u>4.956%</u>

# Exercise

- A voltmeter is accurate 98% of its full scale reading.
  i. If the voltmeter reads 200V on 500V range, what is the absolute error?
  ii. What is the percentage error of the reading in (i).

# Significant Figures

- Significant figures convey actual information regarding the magnitude and precision of quantity
- More significant figure represent greater precision of measurement

## Example 1.3

Find the precision value of $X_1$ and $X_2$?

$$X_n = 101$$

$$X_1 = 98 \quad ===>> 2\ s.f$$

$$X_2 = 98.5 \quad ===>> 3\ s.f$$

# Solution (Example 1.3)

$$\overline{X_n} = 101$$

$$X_1 = 98 ====>> \textit{2 s.f}$$

$$X_2 = 98.5 ====>> \textit{3 s.f}$$

$$X_1 = \text{Precision} = 1 - \left|\frac{98-101}{101}\right| = 0.97$$

$$X_2 = \text{Precision} = 1 - \left|\frac{98.5-101}{101}\right| = 0.975 \quad \textit{===>more precise}$$

# Significant Figures (cont)

**Rules regarding significant figures in calculation**

1) For adding and subtraction, all figures in columns to the right of the last column in which all figures are significant should be dropped

Example 1.4

$$V_1 = 6.31 \text{ V}$$

$$+ \quad V_2 = 8.736 \text{ V}$$

Therefore $$V_T = 15.046 \text{ V}$$

$$\cong \underline{15.05 \text{ V}}$$

# Significant Figures (cont)

2) For multiplication and division, retain only as many significant figures as the least precise quantity contains

## Example 1.5

From the value given below, calculate the value for $R_1$, $R_2$ and power for $R_1$?

$I = 0.0148$ A ===> 4 s.f

$V_1 = 6.31$ V ===> 2 s.f

$V_2 = 8.736$ V ===> 3 s.f

# Solution (Example 1.5)

$$R_1 = \frac{V_1}{I} = \frac{6.31V}{0.0148A} = 426.35 = 426\Omega \text{ ===> 3 s.f}$$

$$R_2 = \frac{V_2}{I} = \frac{8.736V}{0.0148A} = 590.27 = 590\Omega \text{ ===> 3 s.f}$$

$$P_1 = V_1 \times I = (6.31V) \times (0.0148\,A)$$

$$= 0.09339$$

$$= 0.0934 \text{ ===> 3 s.f}$$

# Significant Figures (cont)

3) When dropping non-significant figures

0.0148 ==> 0.015 (2 s.f)

==> 0.01 (1 s.f)