Instrumentation & Measurements

Chapter 1: Introduction to Instrumentation & Measurements

by
Ahmad Afif Mohd Faudzi
Faculty of Electrical & Electronics Engineering
afif@ump.edu.my

Chapter Description

- Expected Outcomes
  - Understand the principle of Instrumentation & Measurement
  - Applying the error calculation for different problem
  - Recognize the standard of measurement and
  - Applying the statistical analysis for measurement

Chapter Outline

1. Principle of Instrumentation and Measurements
2. Error in Measurement
3. Measurement Standard

1.1 PRINCIPLE OF INSTRUMENTATION & MEASUREMENTS

1.1 Principle of Instrumentation & Measurements (1/8)

Instrumentation:

- A technology of measurement which serves not only science but all branches of engineering, medicine, and etc.
- serve three (3) basic functions
  - **Indicating**: provide information regarding the variable quantity under measurement and most of the time this information are provided by the deflection of the pointer.
  - **Recording**: usually use the paper in order to record the output.
  - **Controlling**: widely used in industrial world. In this these instruments controls the processes

source: https://www.electrical4u.com/

- The knowledge of any parameter largely depends on the measurement

1.1 Principle of Instrumentation & Measurements (2/8)

Measurements:

- The process of obtaining the magnitude of a quantity relative to an agreed standard by using appropriate instrument.

source: https://www.sciencelearn.org.nz

- Basically used to monitor a process or operation as well as the controlling process

1.1 Principle of Instrumentation & Measurements (3/8)

Measurements:

- The major problem encountered with any measuring instrument is the error.
- Therefore, it is necessary to select the appropriate measuring instrument & measurement method which minimises error
- To avoid errors in any experimental work, careful planning, execution & evaluation of the experiment are es
  - Before the measurement
  - During the measurement
  - After the measurement

1.1 Principle of Instrumentation & Measurements (4/8)

Before the measurement:

- Methods/procedures of measurement.
- Characteristics of the parameter
- Quality: time and cost, instrument
- To avoid errors in any experimental work, careful planning, capabilities, knowledge of measurement, acceptable result
- What instrument to use?

1.1 Principle of Instrumentation & Measurements (5/8)

During the measurement:

- Quality: best instrument chosen, suitable position when taking the data, etc.
- Safety: electric shock, overloaded, instrument limits, read instrument manual
- Sampling: observe parameter changing, taking enough sample

After the measurement:

- Analyse the data mathematically/statistically
- Full result must be reported completely and accurately

1.1 Principle of Instrumentation & Measurements (6/8)

The SI Units: International System of Units:

- Performing a measurement means comparing an unknown physical (or chemical) quantity with a quantity of the same type taken as reference using an instrument.
- In 1960, during the eleventh Conférence Générale des Poids et Mesures (CGPM), the International System of Units, the SI, was developed.
- Two classes of units :
  - The seven base units ;
  - The derived units.

source: http://www.french-metrology.com/

1.1 Principle of Instrumentation & Measurements (7/8)

The seven base units	
metre (m)	The metre is **the length** of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
kilogram (kg)	The kilogram is **the mass** of the platinum-iridium prototype which was approved by the Conférence Générale des Poids et Mesures, held in Paris in 1889, and kept by the Bureau International des Poids et Mesures.
second (s)	The second is **the duration** of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.
ampere (A)	The ampere is t**he intensity of a constant current** which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 x 10-7 newton per metre of length.
kelvin (K)	The kelvin is **the fraction 1/273,16 of the thermodynamic temperature** of the triple point of water.
candela (cd)	The candela is **the luminous intensity**, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 1012 hertz and that has a radiant intensity in that direction of 1/683 watt per steradian
mole (mol)	The mole **is the amount of substance** of a system which contains as many elementary entities as there are atoms in 0,012 kilogram of carbon 12.

source: http://www.french-metrology.com/

1.1 Principle of Instrumentation & Measurements (8/8)

The derived units:

- There are numerous derived units that are complementary to the base units. They may have special names (e.g. hertz, pascal, becquerel, etc.) but can always be expressed in terms of the base units.

source: http://www.french-metrology.com/

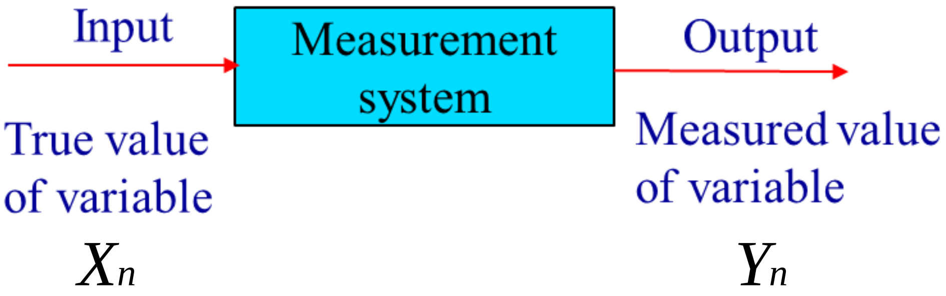
Quantity	Symbol	Unit	Unit abbre.
voltage	V	volt	V
charge	Q	coulomb	C
resistance	R	Ohm	Ω
capacitance	C	farad	F
inductance	L	henry	H

1.2 ERROR IN MEASUREMENT

1.2 Error in Measurement (1/15)

Error:

- Definition: the difference between the measured value and the expected value (true value) of the measured parameter



Types of error:

- Absolute error
- Gross error
- Systematic error
  - Instrumental error
  - Environmental error
  - Observational error
- Random error
- Limiting error

1.2 Error in Measurement (2/15)

a) Absolute error:

- The difference between the expected value of the variable and the measured value of the variable, or

$$e = \left| X_n - Y_n \right|$$

where

e = absolute error

X_n = expected value

Y_n = measured value

1.2 Error in Measurement (3/15)

a) Absolute error:

- Absolute error in percentage

$$\% \text{ error} = \frac{e}{X_n} \times 100$$

- Relative accuracy, A

$$A = \left| 1 - \frac{e}{X_n} \right|$$

e	= absolute error
X_n	= expected value
Y_n	= measured value

- Accuracy in percentage,
  % accuracy, a

$$a = 100\% - \% error$$

or

$$a = A \times 100\%$$

1.2 Error in Measurement (4/15)

b) Gross error:

- Caused by human mistake due to
  - Incorrect reading,
  - Incorrect recording,
  - Improper use of instrument and etc.
- Minimize it by
  - Take at least three (3) separate reading
  - Take proper care in reading and recording

1.2 Error in Measurement (5/15)

c) Systematic error (Instrumental error):

- Due to
  - Incorrect spring tension,
  - Incorrect in meter movement,
  - Improper calibration,
  - Faulty instrument and etc.
- Minimize it by
  - proper maintenance,
  - proper use and handling of instruments.

1.2 Error in Measurement (6/15)

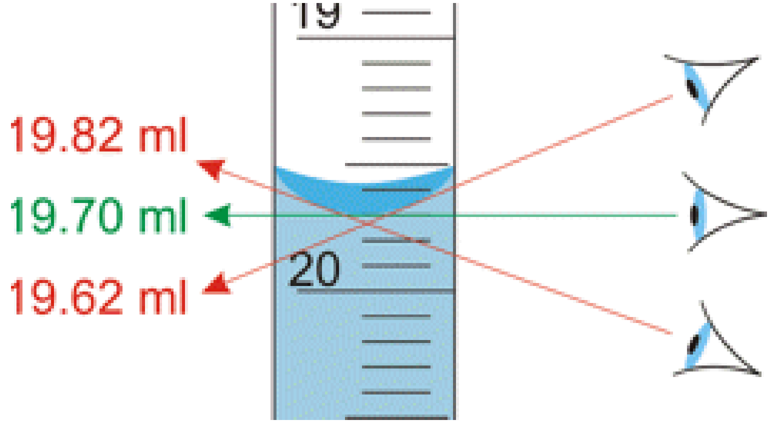
c) Systematic error (Environmental error):

- Due to
  - external condition of the measuring.
- E.g.: effects of change in temperature, humidity, barometric pressure, electrostatic fields and etc.
- Minimize it by using
  - air conditioning,
  - hermetically sealing certain components in the instrument and
  - using magnetic shields.

1.2 Error in Measurement (7/15)

c) Systematic error (Observational error):

- Introduced by the observer, due to
  - parallax error introduced in reading a meter scale
  - error of estimation when obtaining a reading from a meter scale



source: https://chem.libretexts.org/

1.2 Error in Measurement (8/15)

d) Random error:

- Errors that remain after gross and systematic errors have been substantially reduced
- Are generally the accumulation of a large number of small effects
- May be of real concern only in measurements requiring a high degree of accuracy
- such errors can only be analysed statistically
- Due to unknown causes

e) Limiting error:

- Most manufacturers of instrument state that an instrument is accurate within a certain percentage of a full-scale reading.
- E.g. a voltmeter is accurate within ±2% at full-scale deflection (limiting errors)
- Reading with less than full-scale, the limiting error will increase
- Minimize it by
  - obtain measurements as close as possible to full scale

1.2 Error in Measurement (10/15)

Statistical Analysis of Measurement Data:

- Important because it allows an analytical determination of the uncertainty of the final result
- Requires a large number of measurements
- Analysis
  - Precision
  - Arithmetic Mean / Average, $\bar{x}$
  - Deviation, d_n
  - Average deviation, D
  - Standard deviation, σ

1.2 Error in Measurement (11/15)

Precision:

- A measure of the consistency or repeatability of measurements

$$\text{precision} = 1 - \left| \frac{Y_n - \overline{Y_m}}{\overline{Y_m}} \right|$$

where

Y_n = the value of the n-th measurement

$\overline{Y_m}$ = the average of the **set** of m measurements

1.2 Error in Measurement (12/15)

Arithmetic Mean/Average:

- The most probable value of measured variable.

$$\text{Average, } \bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \sum_{\mathrm{i}=1}^{n} \frac{x_i}{n}$$

n = total number of reading

x_n = n-th reading taken

x_i = set of number

1.2 Error in Measurement (13/15)

Deviation, d_n:

- The difference between each piece of data and arithmetic mean.

deviation, $d_n = x_n - \bar{x}$

- Algebraic sum of deviation

$$d_{total} = d_1 + d_2 + \cdots + d_n = 0$$

1.2 Error in Measurement (14/15)

Average deviation, D:

- precision of a measuring instrument
- High D, mean low precision
- Low D, mean high precision

$$D = \frac{|d_1| + |d_2| + \cdots + |d_n|}{n}$$

1.2 Error in Measurement (15/15)

Standard deviation, σ:

- also known as root mean square deviation
- the most important factor in statistical analysis
- reduction means improvement in measurement

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 \cdots + d_n^2}{n-1}}$$

1.3 MEASUREMENT STANDARDS

1.3 Measurement Standards (1/5)

Measurement standards are defined in four (4) categories:

1. International Standard
2. Primary Standard
3. Secondary Standard
4. Working Standard

1.3 Measurement Standards (2/5)

1. International Standard

- Defined by international agreements
- These standards are maintained at the International Bureau of Weight and Measures in Paris, Frances
- They are periodically evaluated and checked by absolute measurements in term of the fundamental units of physics
- They represent certain units of measurement to the closest possible accuracy attained by the science and technology of measurement and used for comparison with primary standards

1.3 Measurement Standards (3/5)

2. Primary Standard

- Are maintained at institution in various countries around the world, such as the National Bureau of Standard on Washington D.C, SIRIM in Malaysia
- The primary standards are not available for use outside the national laboratories
- Their principle function is to calibrate and verify the secondary standards
- Also known as National Standard

1.3 Measurement Standards (4/5)

3. Secondary Standard

- Used as the basic reference standards used by measurement & calibration laboratories in the industry
- Each industrial laboratory is completely responsible for its own secondary standards
- Each laboratory sends its secondary standards to the national standards (primary standards) laboratory for calibration
- After calibration, the secondary standards are returned to the industrial uses with the certification and checked periodically

1.3 Measurement Standards (5/5)

4. Working Standard

- Working standard is the principle tools of a measurement laboratory and the lowest level of standards
- Used to check and calibrate the instruments used in the laboratory or to make comparison measurement in industrial application
- Example: the standard resistor, capacitors, inductor which usually found in an electronics laboratory are classified as working standards.

The End of Chapter 1

Thank you

Thank you to all past lecturers of

Instrumentation & Measurement

Faculty of Electrical & Electronics Engineering