BIRZEIT UNIVERSITY

Faculty of Engineering and Technology

Electrical and Computer Engineering Department

ENEE4304
Instrumentation and Measurements

Instructor: Nasser Ismail

Second Semester 2019-2020

ENEE4304 Instrumentation and Measurements L1

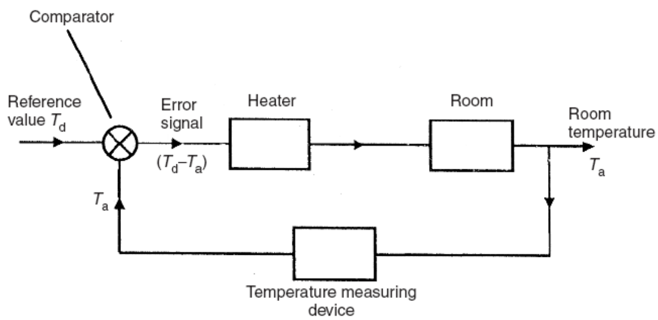
Introduction

Introduction to Measurements

- Measurement techniques have been of immense importance ever since the start of human civilization,
- When measurements were first needed to regulate the transfer of goods in barter trade to ensure that exchanges were fair.
- The industrial revolution during the nineteenth century brought about a rapid development of new instruments and measurement techniques to satisfy the needs of industrialized production techniques.

Applications of Measurement Systems

1. Regulating trade
2. Monitoring to allow human beings to take some action accordingly
3. Use as part of automatic feedback control systems

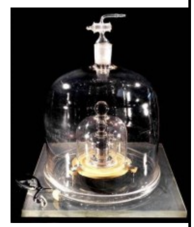


Standardization of Units

- ❑ Establishment of standards for the measurement of physical quantities proceeded in several countries at broadly parallel times, and in consequence, several sets of units emerged for measuring the same physical variable.
- ❑ An internationally agreed set of standard units (SI units or Syst`emes Internationales d’Unit´es) has been defined, and strong efforts are being made to encourage the adoption of this system throughout the world.

Standard Units

Physical quantity	*Standard unit*	*Definition*
Length	metre	The length of path travelled by light in an interval of 1/299 792 458 seconds
Mass	kilogram	The mass of a platinum–iridium cylinder kept in the International Bureau of Weights and Measures, Sèvres, Paris
Time	second	9.192631770×10^9 cycles of radiation from vaporized caesium-133 (an accuracy of 1 in 10^{12} or 1 second in 36 000 years)
Temperature	kelvin	The temperature difference between absolute zero and the triple point of water is defined as 273.16 kelvin
Current	ampere	One ampere is the current flowing through two infinitely long parallel conductors of negligible cross-section placed 1 metre apart in a vacuum and producing a force of 2×10^{-7} newtons per metre length of conductor
Luminous intensity	candela	One candela is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz (Hz $\times 10^{12}$) and with a radiant density in that direction of 1.4641 mW/steradian. (1 steradian is the solid angle which, having its vertex at the centre of a sphere, cuts off an area of the sphere surface equal to that of a square with sides of length equal to the sphere radius)
Matter	mole	The number of atoms in a 0.012 kg mass of carbon-12



Fundamental Units and Supplementary Fundamental Units

(a) Fundamental units

Quantity	*Standard unit*	*Symbol*
Length	metre	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

Quantity	*Standard unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Standard unit*	*Symbol*	*Derivation formula*
Area	square metre	m^2	
Volume	cubic metre	m^3	
Velocity	metre per second	m/s	
Acceleration	metre per second squared	m/s^2	
Angular velocity	radian per second	rad/s	
Angular acceleration	radian per second squared	rad/s^2	
Density	kilogram per cubic metre	kg/m^3	
Specific volume	cubic metre per kilogram	m^3/kg	
Mass flow rate	kilogram per second	kg/s	
Volume flow rate	cubic metre per second	m^3/s	
Force	newton	N	$kg\,m/s^2$
Pressure	newton per square metre	N/m^2	
Torque	newton metre	N m	
Momentum	kilogram metre per second	kg m/s	
Moment of inertia	kilogram metre squared	$kg\,m^2$	
Kinematic viscosity	square metre per second	m^2/s	
Dynamic viscosity	newton second per square metre	$N\,s/m^2$	
Work, energy, heat	joule	J	Nm

- The ***Mars Climate Orbiter*** (formerly the **Mars Surveyor '98 Orbiter**) was a 338-kilogram (745 lb) robotic space probe launched by NASA on December 11, 1998 to study the Martian climate, Martian atmosphere, and surface changes and to act as the communications relay in the Mars Surveyor '98 program for Mars Polar Lander. However, on September 23, 1999, communication with the spacecraft was lost as the spacecraft went into orbital insertion, due to ground-based computer software which produced output in non-SI units of pound-force seconds (lbf·s) instead of the SI units of newton-seconds (N·s) specified in the contract between NASA and Lockheed. The spacecraft encountered Mars on a trajectory that brought it too close to the planet, and it was either destroyed in the atmosphere or re-entered heliocentric space after leaving Mars' atmosphere.[1][2]

NASA's metric confusion caused Mars orbiter loss

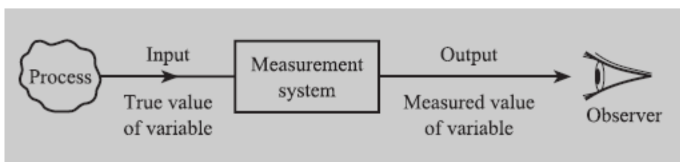
- http://edition.cnn.com/TECH/space/9909/30/mars.metric/index.html
- NASA lost a $125 million Mars orbiter because one engineering team used metric units while another used English units for a key spacecraft operation, according to a review finding.
- For that reason, information failed to transfer between the Mars Climate Orbiter spacecraft team at Lockheed Martin in Colorado and the mission navigation team in California.

Purpose and performance of measurement systems

- We begin by defining a **process** as a system which generates **information**.
- Examples are a chemical reactor, a jet fighter, a gas platform, a submarine, a car, a human heart, and a weather system.
- Table lists **information variables** which are commonly generated by processes:
- For example: a car generates displacement, velocity and acceleration variables

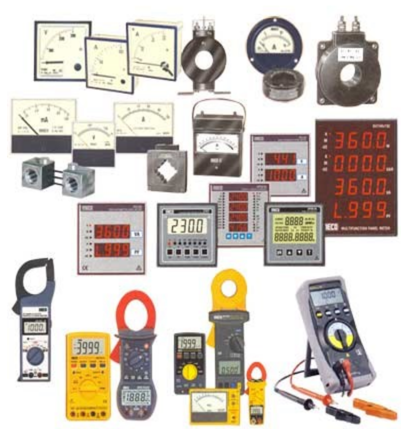
Acceleration	Density
Velocity	Viscosity
Displacement	Composition
Force–Weight	pH
Pressure	Humidity
Torque	Temperature
Volume	Heat/Light flux
Mass	Current
Flow rate	Voltage
Level	Power

- We then define the **observer** as a person who needs this information from the process.
- This could be the car driver, the plant operator or the nurse.
- The purpose of the **measurement system** is to link the observer to the process,
- Here the observer is presented with a number which is the current value of the information variable.
- We can now refer to the information variable as a **measured variable**.
- The input to the measurement system is the **true value** of the variable; the system output is the **measured value** of the variable.
- In an ideal measurement system, the measured value would be equal to the true value.



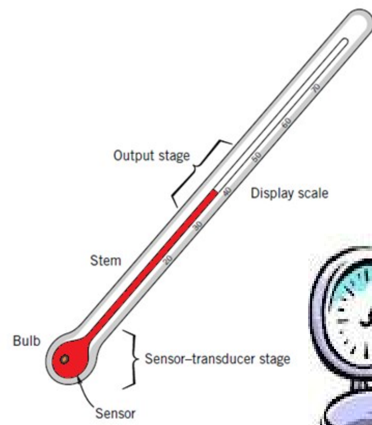
Elements of a Measurement Systems

- In simple cases, the system can consist of only a single unit that gives an output reading or signal according to the magnitude of the unknown.
- However, in more complex measurement situations, a measuring system consists of several separate elements.
- These components might be contained within one or more boxes, and the boxes holding individual measurement elements might be either close together or physically separate.



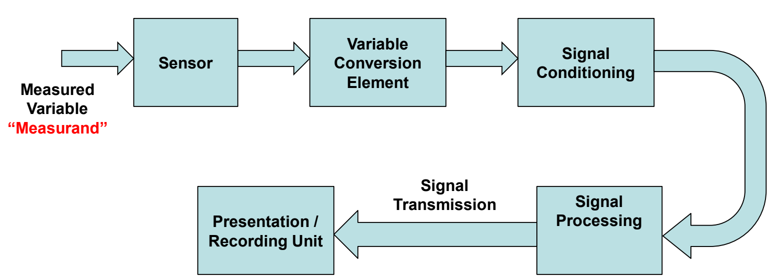
Elements of a Measurement Systems

- In simple cases, the system can consist of only a single unit that gives an output reading or signal according to the magnitude of the unknown.
- However, in more complex measurement situations, a measuring system consists of several separate elements.
- These components might be contained within one or more boxes, and the boxes holding individual measurement elements might be either close together or physically separate.



Elements of a Measurement Systems

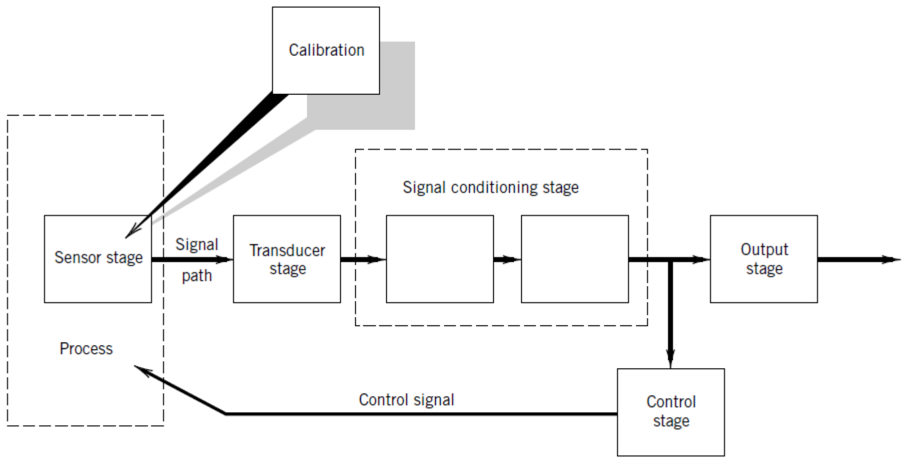
Comparison from different references



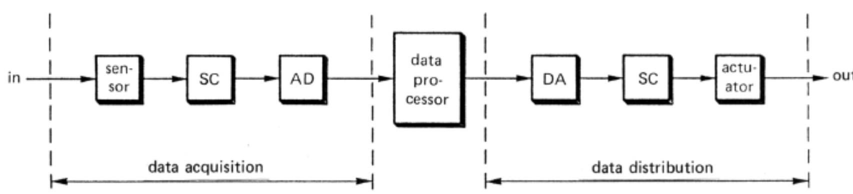
Allan Morris

Elements of a Measurement Systems

[Figliola, Theory and Design of Mechanical Measurements]

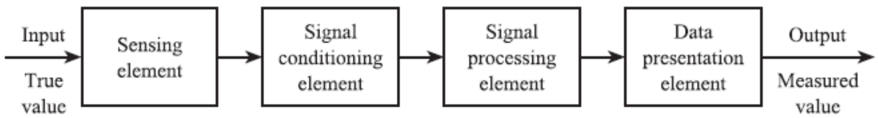


Single Channel Measuring System



- Sensor
- SC - Signal Conditioning
- AD - Analog to Digital Converter
- DA – Digital to Analog Converter
- Actuator (such as motor, pump…etc)

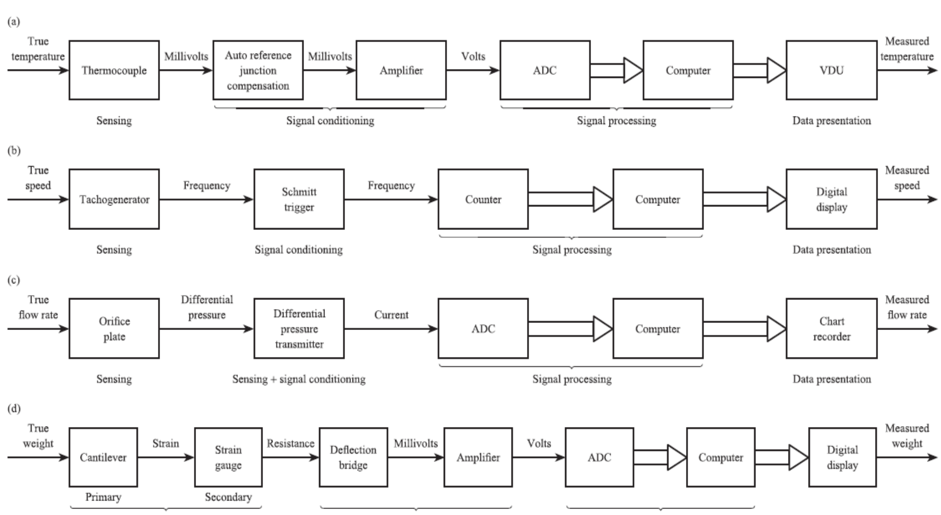
Structure of Measuring System



- ➢ Sensing Element (Sensor):
- ➢ This is in contact with the process and gives an output which depends in some way on the variable to be measured (measurand)
- ➢ If there is more than one sensing element in a system, the element in contact with the process is termed the **primary sensing element**, the others **secondary sensing elements**.
- ➢ For most but not all sensors, this function is approximately linear

(sensor output is linearly proportional to the input measured variable)

Different measurement systems



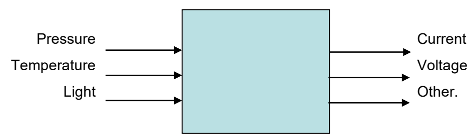
20

Sensing Principles

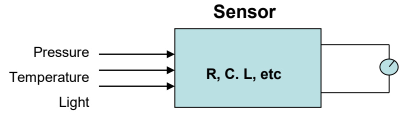
The interaction of physical parameters with each other—most notably electricity with stress, temperature and thermal gradients, magnetic fields, and incident light—yields a multitude of sensing techniques which may be applied in measurements

- ❑ Transductive (تحويلي)
  - ❑ Piezoelectric
  - ❑ Thermoelectric
  - ❑ Photoelectric
  - ❑ etc.
- ❑ Constitutive (تاسيسي)
  - ❑ Resistive
  - ❑ Capacitive
  - ❑ Inductive
  - ❑ Etc.

Transducer



Sensor

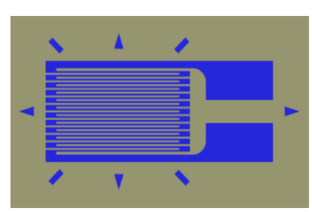


Examples Sensors

Liquid Mercury
Input: Temperature
Output: Mercury volume

Thermocouple
Input: Temperature
Output: Voltage

Strain gauge
Input: Strain
Output: Electric resistance



Are these linear sensors?

Examples Sensors

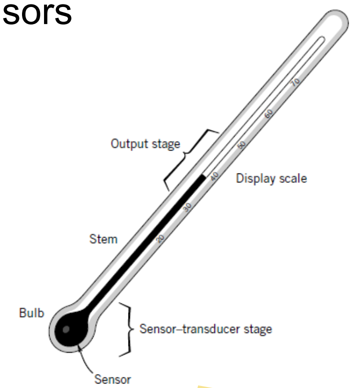
Liquid Mercury Thermometer

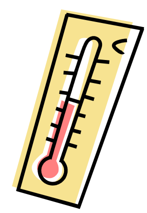
Measured Variable: Temperature

Sensor: Liquid Mercury

Variable Conversion Element: Stem

Signal Presentation Element: Display Scale





Signal conditioning element

- This takes the output of the sensing element and converts it into a form more suitable for further processing, usually a d.c. voltage, d.c. current or frequency signal.
- Improve the quality of the output of a measurement system.
- Examples are:
  - Deflection bridge which converts an impedance change into a voltage change
  - Amplifier which amplifies millivolts to volts
  - Oscillator which converts an impedance change into a variable frequency voltage.
- Other signal processing element are those that filter out induced noise and remove mean levels etc. In some devices, signal processing is incorporated into a transducer, which is then known as a transmitter.

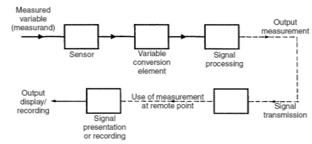
Signal processing element

- This takes the output of the conditioning element and converts it into a form more suitable for presentation.
- Examples are:
  - Analogue-to-digital converter (ADC) which converts a voltage into a digital form for input to a computer
  - Computer (digital signal processor “DSP” , Microcontroller , Field Programmable Gate Array “FPGA”)which calculates the measured value of the variable from the incoming digital data.
- Typical calculations are:
  - Computation of total mass of product gas from flow rate and density data Integration of chromatograph peaks to give the composition of a gas stream
  - Correction for sensing element non-linearity.

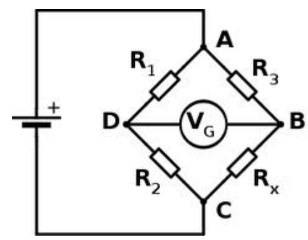
Data presentation element

- This presents the measured value in a form which can be easily recognized by the observer.
- It may be omitted altogether when the measurement is used as part of an automatic control system.
- It takes the form either of a signal presentation unit or of a signal-recording unit.
- Examples are:
  - Simple pointer–scale indicator
  - Chart recorder
  - Alphanumeric display
  - Visual display unit (VDU) such as an LCD display

Elements of a Measurement Systems: Variable Coversion Element

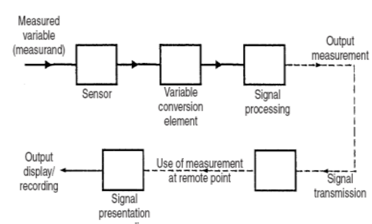


- ❑ Needed where the output variable of a primary sensor is in an inconvenient form and has to be converted to a more convenient form.
- ❑ The displacement-measuring strain gauge has an output in the form of a varying resistance. The resistance change cannot be easily measured and so it is converted to a change in voltage by a bridge circuit, which is a typical example of a variable conversion element.
- ❑ In some cases, the primary sensor and variable conversion element are combined, and the combination is known as a transducer.

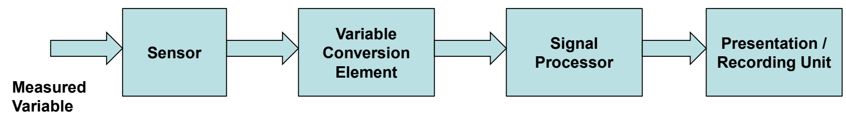


Elements of a Measurement Systems: Signal Transmission

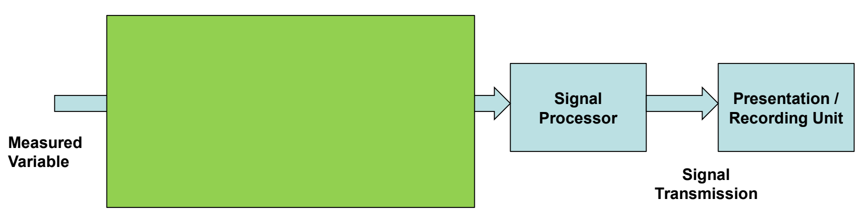
- ➢ Needed when the observation or application point of the output of a measurement system is some distance away from the site of the primary transducer.
- ➢ It has traditionally consisted of single or multi-cored cable, which is often screened to minimize signal corruption by induced electrical noise.
- ➢ Fibre-optic cables are being used in ever increasing numbers in modern installations because of their low transmission loss and imperviousness to the effects of electrical and magnetic fields.



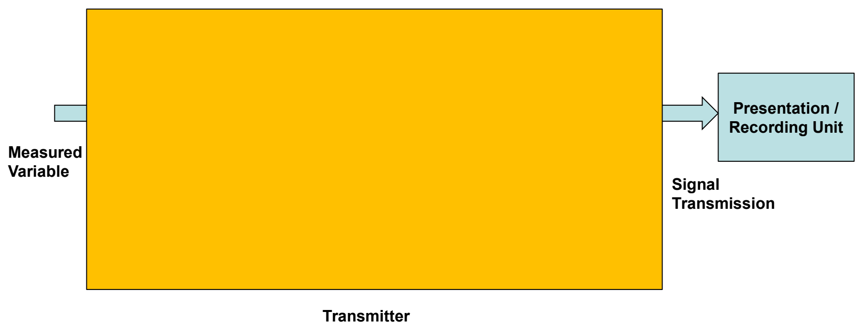
Elements of a Measurement System



Elements of a Measurement Systems



Elements of a Measurement Systems



Choosing appropriate measuring instruments

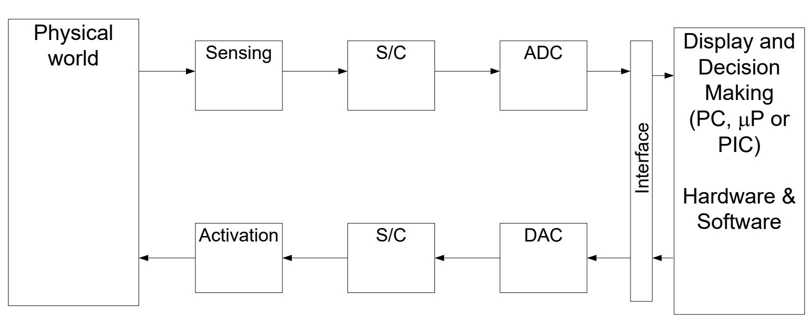
- Accuracy, resolution, sensitivity and dynamic performance.
- Environmental conditions that the instrument will be subjected to.
- Measurement systems and instruments should be chosen that are as insensitive as possible to the operating environment.
- The extent to which the measured system will be disturbed during the measuring process is another important factor in instrument choice.
- For example, significant pressure loss can be caused to the measured system in some techniques of flow measurement.

Data Acquisition and Control

- **<u>Data acquisition</u> is the process by which physical phenomena from the real world are transformed into electrical signals that are measured and converted into a digital format for processing, analysis, and storage by a computer**.
- **In a large majority of applications, the data acquisition (DAQ) system is designed not only to acquire data, but to act on it as well. In defining DAQ systems, it is therefore useful to extend this definition to include the control aspects of the total system**.
- **<u>Control</u>** is the process by which digital control signals from the system hardware are convened to a signal format for use by control devices such as actuators and relays. These devices then control a system or process. Where a system is referred to as a data acquisition system or DAQ system, it is possible that it includes control functions as well.

Instrumentation 33

Data Acquisition and Control



Instrumentation 34