BCSE420L

SENSORS, ACTUATORS AND SIGNAL CONDITIONING

Course Introduction

Course Code : BCSE420L

Course Name : Sensors, Actuators and Signal Conditioning

Total credits : 2 0 0 2

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MODULE 1

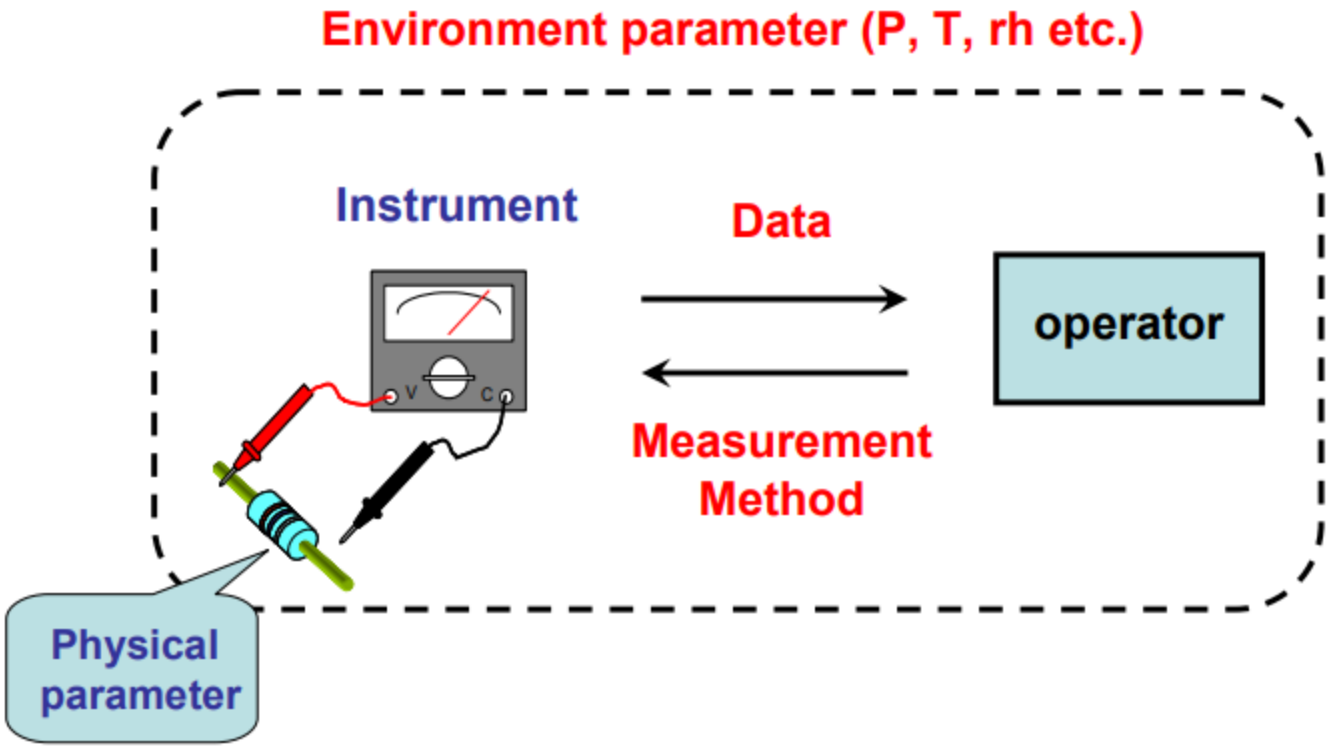
Basics of Energy Transformation

- Introduction to sensors and transducers
- Principle of sensing and transduction
- Classification of sensors.

INTRODUCTION TO MEASUREMENT

Measurement:

an estimation of a physical (chemical or biological) variable by a measurement device.

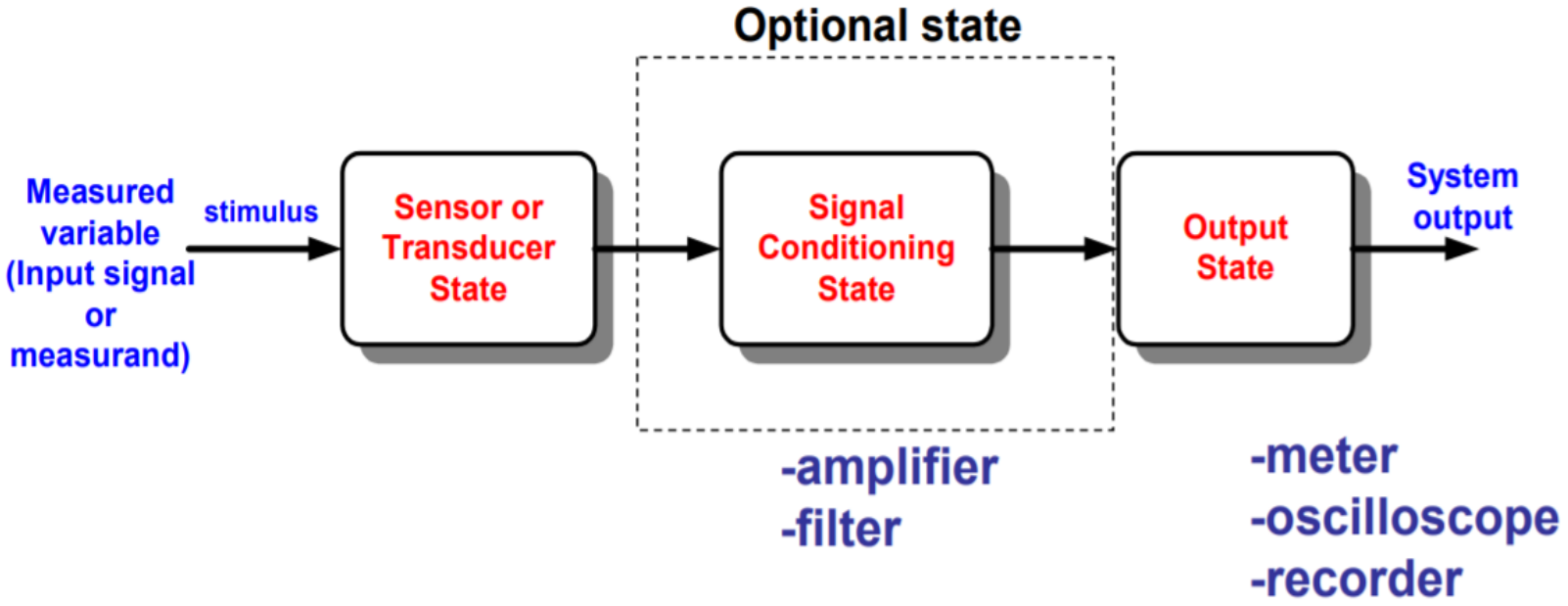


Significance of Measurement

Importance of Measurement is simply expressed in the following statement of famous physicist Lord Kelvin:

" I often say that when you can measure what you are speaking about and can express it in numbers, you know something about it; when you cannot express in it numbers your knowledge is of meager and unsatisfactory kind "

Measurement System



A system is a combination of two or more elements, subsystems, and parts necessary to carry out one or more functions

Measurement System

Measurand:

The physical quantity or the characteristic condition which is the object of measurement in an instrumentation system is variously termed as measurand, Measurement variable, instrumentation variable or process variable

The measurand may be:

-fundamental quantity(Length, mass, time, temperature, electric current, amount of substance.)

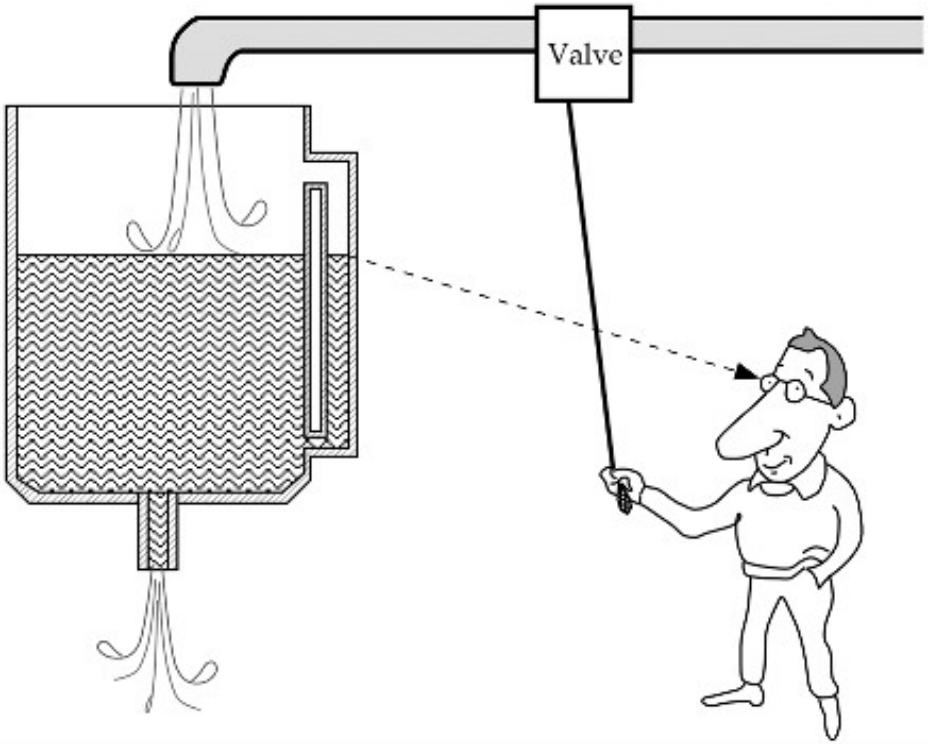
-derived quantity(force, density, volume, momentum)

The word measurand is used to designate the particular physical parameter being observed and quantified.

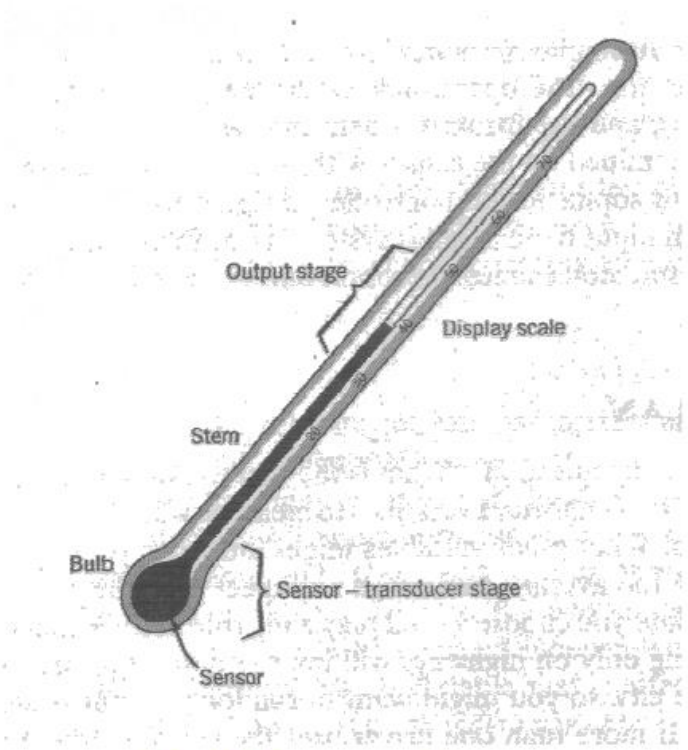
- **Sensor or transducer** is an input device convert the quantity under measurement into a detectable signal form: electrical, mechanical, optical etc.
- **Signal conditioning** modifies the transducer signal into a desired form e.g. amplification, noise reduction.
- Output State provides an indication of the value of the measurement (readout device or recording)

Sensor

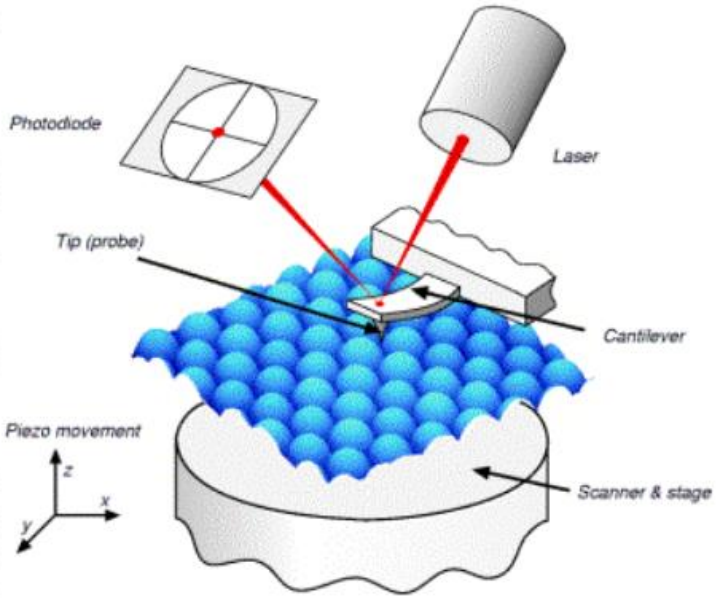
A device that receives and respond to a signal or stimulus



Example of Measurement System



A bulb thermometer



Atom Force Microscope: example of a complicated system

Signal Domains with example

Mechanical	Length, area, volume, all time derivatives such as linear/angular velocity/acceleration, mass flow, force , torque, pressure, acoustic wavelength and intensity
Thermal	Temperature, (specific) heat, entropy, heat flow, state of matter
Electrical	Voltage, current,charge, resistance, inductance, capacitance, dielectric constant, polarization, electric field, frequency, dipole moment
Magnetic	Field intensity, flux density, magnetic moment, permeability
Radiant	Intensify, phase, wavelength, polarization, reflectance, transmittance, refractive index
Chemical	Composition, concentration, reaction rate, pH, oxidation/reduction potential

SENSOR AND TRANSDUCER-DEFINITIONS

- 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**

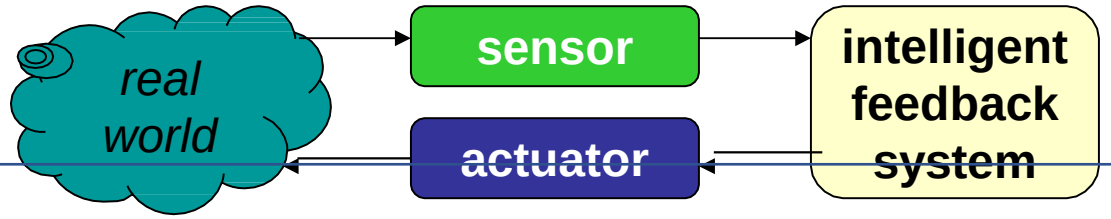
Sensor (e.g., thermometer)

– 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



- **Transducer** a device which converts a signal from one physical form to a corresponding signal having a different physical form. (energy converter).
- Since **transducers** can convert between any forms of energy, they can be used to provide feedback to the system.

- **Sensor (input transducer)** a device converts the physical or non-physical signal which is to be measured into an electrical signal which can be processed or transmitted electronically. (physical signal/electrical signal).
- A **sensor** merely measures a quantity and cannot, by itself, give feedback to the system.
- produces an electric signal based on the strength of the quantity measured

- Output from a sensor may or may not be meaningful i.e most of the times it needs to be conditioned and converted into various other forms.

- The transducer output is always meaningful.
  - The output of a motor is meaningful.
  - The output of a loudspeaker is meaningful. They are transducers.

- A sensor is nothing but just a primary element which senses any physical phenomenon or it gives an indication in any change of the physical phenomenon.
- **Every transducer is also(or has) a sensor but every sensor need not be a transducer**.

- Sometimes in a sensor, there is no conversion at all. Ex. Thermometer, where the temperature is sensed and is directly measured.
- In a transducer there is always a conversion i.e transduction. Ex. RTD, Thermocouple etc where the temperature is sensed and the measurement is made in terms of voltage.

Thus a SENSOR may or may not have a conversion and it only senses. A TRANSDUCER always involves a conversion and also has signal conditioning involved.

- 'Sensor' is `a device that detects a change in a physical stimulus and turns it into a signal which can be measured or recorded.

  E.g. : Thermistor

- 'Transducer' is 'a device that transfers power from one system to another in the same or in the different form'.

  E.g. Thermistor with it associate circuit convert heat to electricity.

As a comparison.....

'Sensor' for the sensing element itself and 'transducer' for the sensing element plus any associated circuitry. All transducers would thus contain a sensor and most (not all) sensors would also be transducers.

SENSING PROCESS

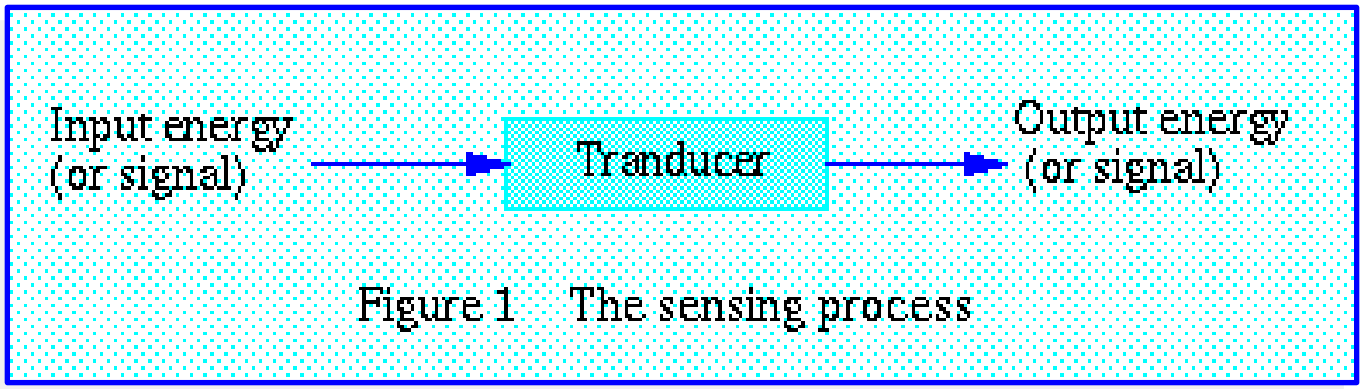


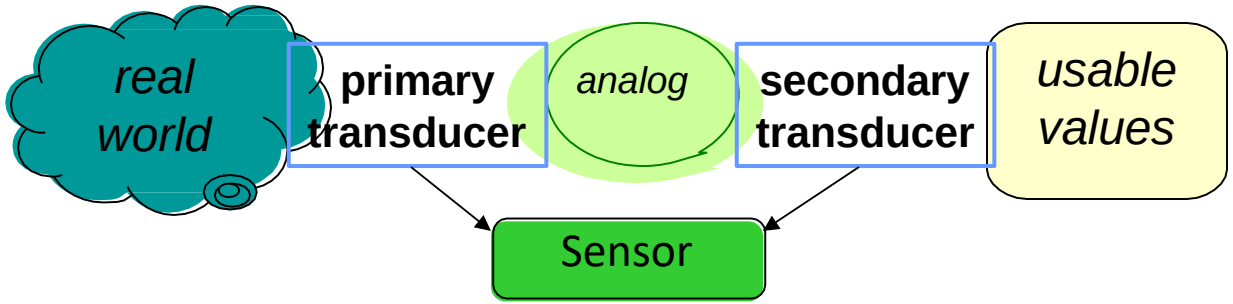
Figure 1 The sensing process

SENSOR SYSTEMS

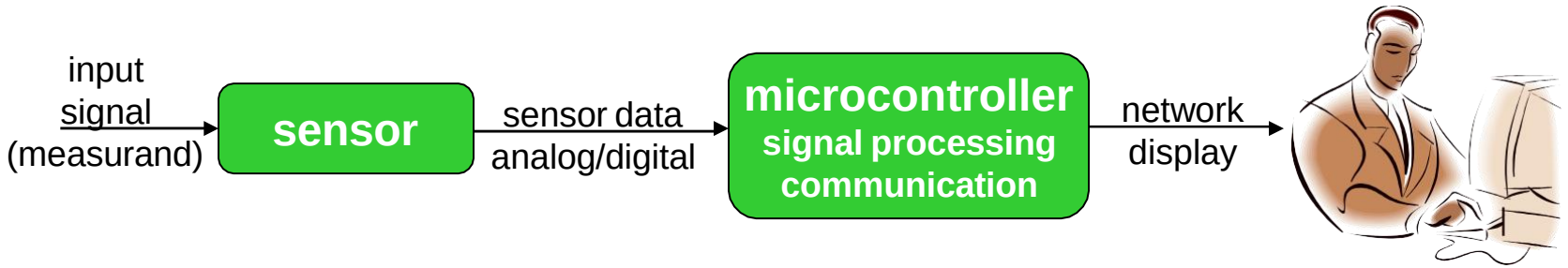
*Typically interested in **electronic sensor***

- convert desired parameter into electrically measurable signal

- General Electronic Sensor
  - primary transducer: changes "real world" parameter into electrical signal
  - secondary transducer: converts electrical signal into analog or digital values



- Typical Electronic Sensor System

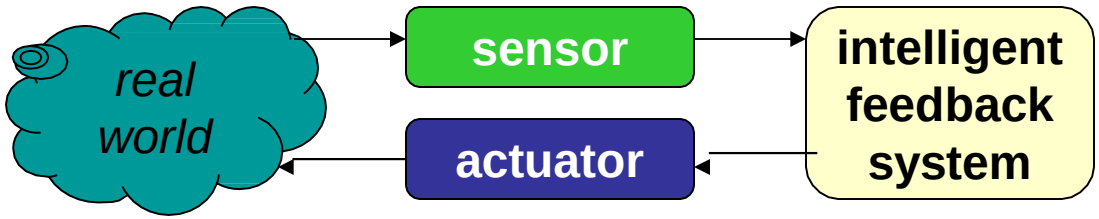


ACTUATORS-DEFINITIONS

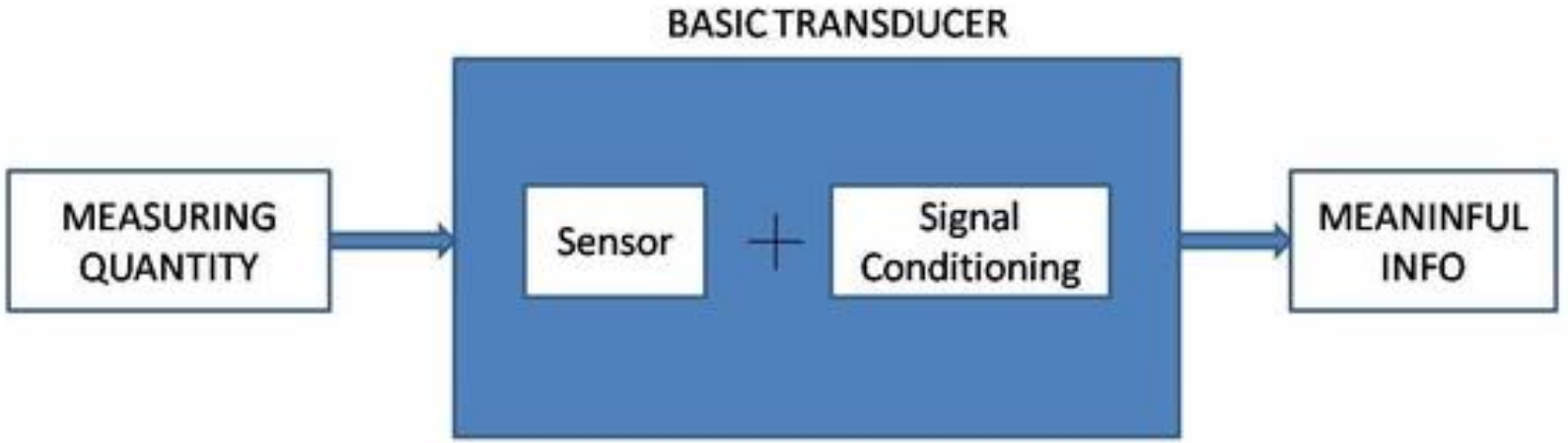
Actuator (output transducer) a device converts the modified electrical signal into a nonelectrical signal. (electrical signal/physical signal). A device or mechanism capable of performing a physical action.

–Actuator (e.g., heater)

– a device that generates a signal or stimulus



Block Diagram-Basic Transducer



Signal conditioners

Are electronic circuits performing any of following functions: amplification, level shifting, filtering, impedance matching, modulation, and demodulation.

Signal Conditioning

- Signal conditioners are measuring system elements that start with an electric sensor output signal and then yield a signal suitable for transmission, display, or recording, or that better meet the requirements of a subsequent standard equipment or device.
- They normally consist of electronic circuits performing any of the following functions:
  - amplification,
  - level shifting, filtering,
  - impedance matching,
  - modulation, and
  - demodulation.
- Some standards call the sensor plus signal conditioner subsystem a transmitter.

Display

- The display of measured results can be in an analog (optical, acoustic, or tactile) or in a digital (optical) form.
- The recording can be magnetic, electronic, or on paper, but the information to be recorded should always be in electrical form.

Applications of Sensors

Sensors used to measure:

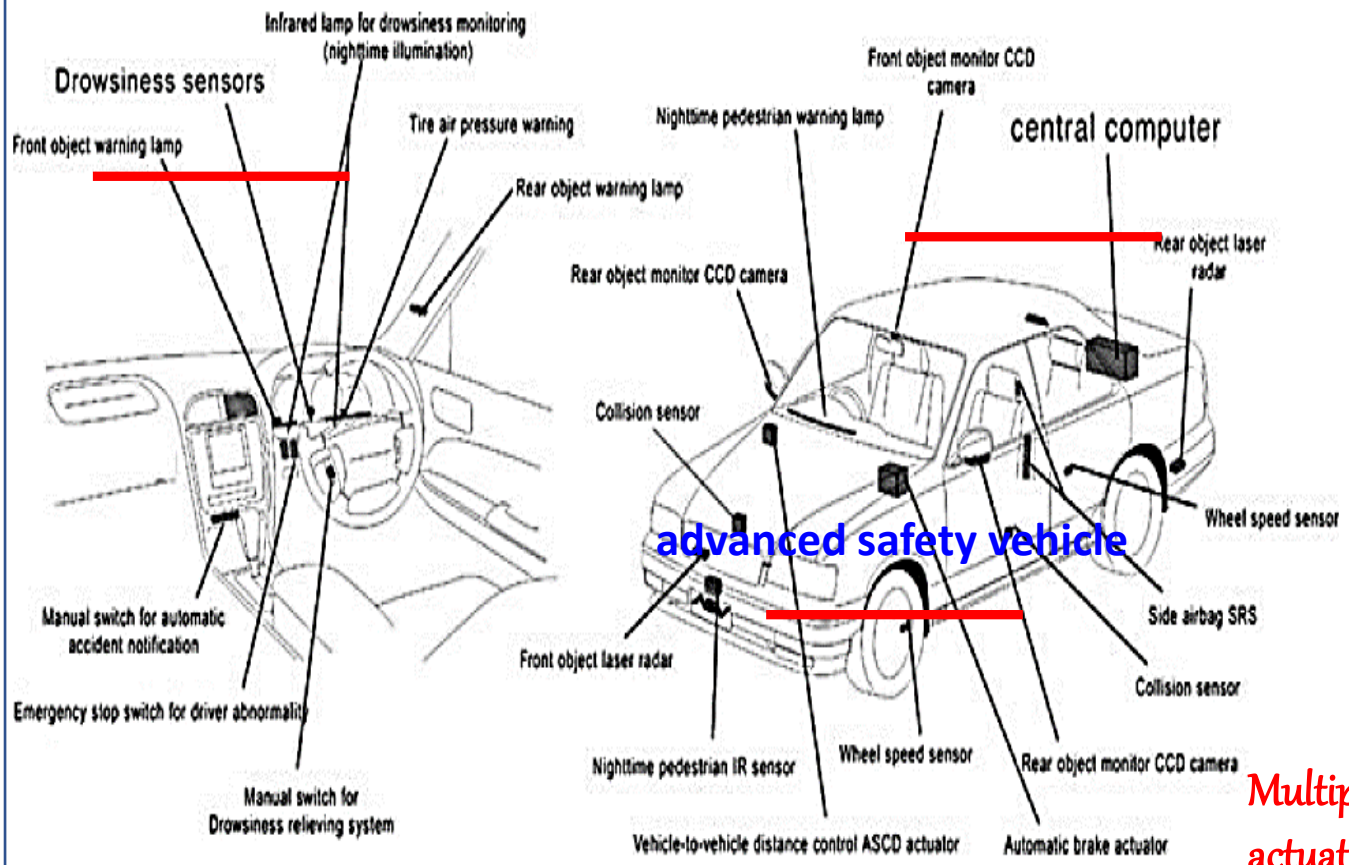
- *Temperature*
- *Pressure*
- *Flow*
- *Gases and Chemicals*
- *Motion detector*
- *Light*
- *Image sensor*

USE CASES OF SENSORS

Where are all are SENSORS commonly used?

- Mobiles?
- At home?
- In cars?
- In markets?
- In Hospitals?
- Traffic and Environment monitoring?

Advanced safety Cars



Multiple sensors, actuators, and warning signals are parts of the advanced safety vehicle

Washing Machine

Two Important Sensors:

Temperature Sensors-

THERMISTOR- Made of solid Semiconducting material showing

- Shows positive temperature coefficient & negative temperature coefficient
- High Sensistivity (~ 44,000 ppm/ °C @ 25 °C
- Small response time

Water level Sensor-

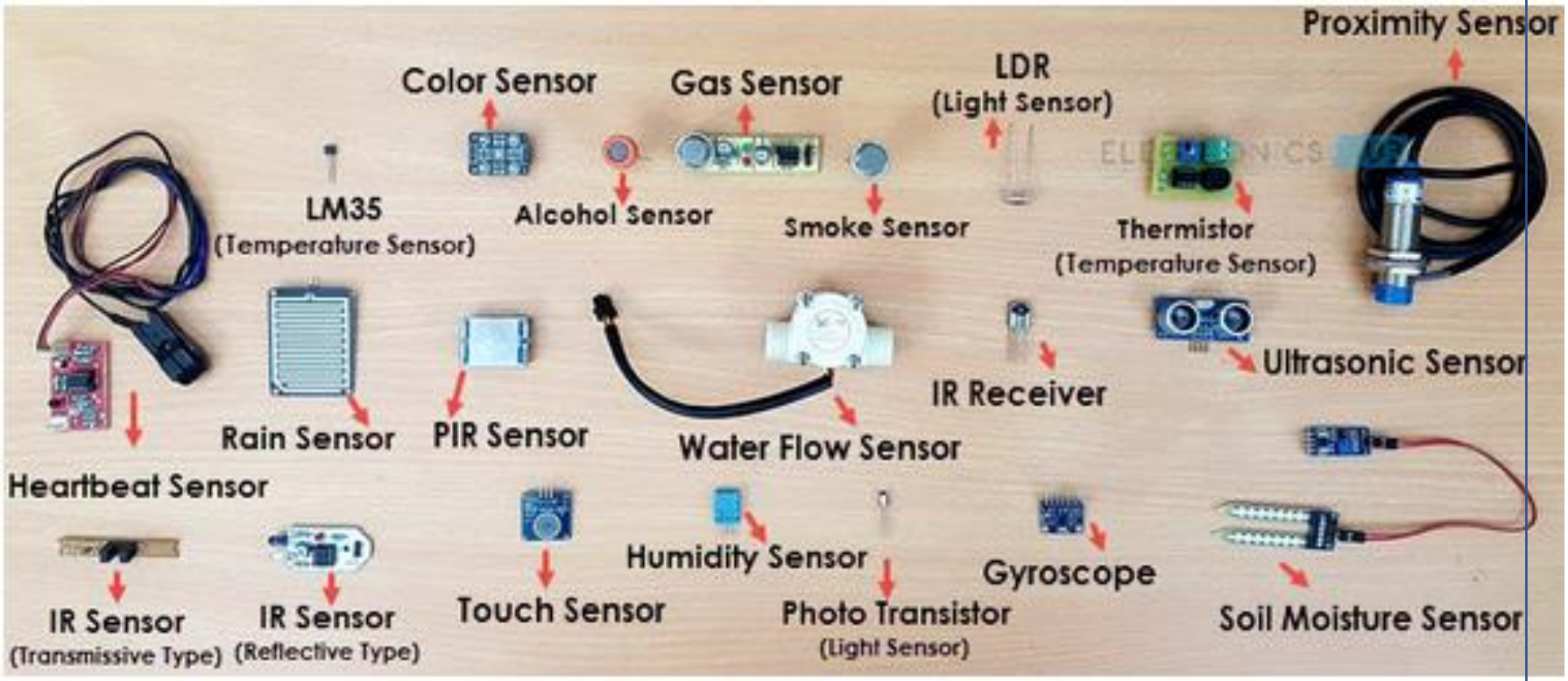
Based on switch to control how high tub fills...

Geysers

Thermostat is used as a ***control switch*** to regulate the temperature of the water by adjusting the heating duration of the element.

Principle: When the *temperature is close to the set-point* on the thermostat, the *element is switched off.*

When the temperature of the geyser drops below the set point, the *element is switched on* and the water heated to the set point .


Proximity Sensor
Color Sensor
Gas Sensor
LDR
(Light Sensor)
LM35
(Temperature Sensor)
Alcohol Sensor
Smoke Sensor
Thermistor
(Temperature Sensor)
Ultrasonic Sensor
IR Receiver
Rain Sensor
PIR Sensor
Water Flow Sensor
Heartbeat Sensor
IR Sensor
(Transmissive Type)
IR Sensor
(Reflective Type)
Touch Sensor
Humidity Sensor
Photo Transistor
(Light Sensor)
Gyroscope
Soil Moisture Sensor

SENSOR CLASSIFICATION

- Modulating (active) or self-generating (passive)
- Absolute and Relative Sensors
- Analog and Digital
- Deflection and Null type

SENSOR CLASSIFICATION

According to the need of power supply

- **Modulating (active) or self-generating (passive)**

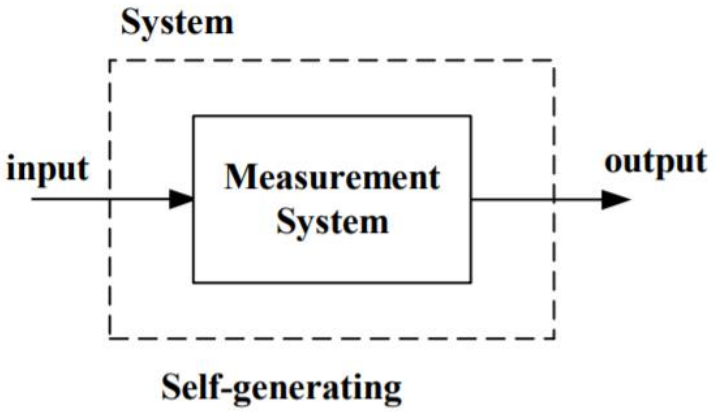
Passive

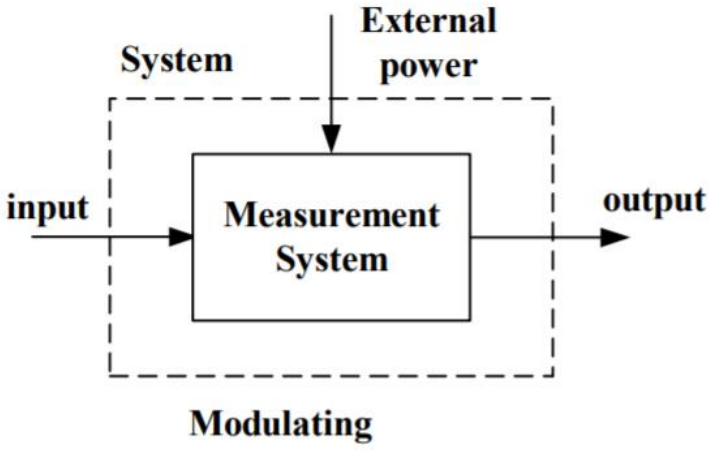
- Doesn't need any additional energy source
- Directly generate an electric signal in response to an external stimuli
- E.g. Thermocouple, photodiode, Piezoelectric sensor

Active

- Require external power called excitation signal Sensor modify excitation signal to provide output
- E.g. thermistor, resistive strain gauge

Modulating (active) or self-generating (passive)





Absolute and Relative Sensors

SENSORS can be CLASSIFIED
(based on selection of Reference)

ABSOLUTE SENSORS
Detects a stimulus in reference to an absolute physical scale that is independent of the measurement conditions

RELATIVE SENSORS
Produces a signal that relates to some special case

Examples:

TEMPERATURE SENSOR Click to add text

Absolute sensor: THERMISTOR- 'R' directly relates to the absolute temperature scale of Kelvin

Relative sensor: THERMOCOUPLE- Produces a 'V', which is a function of a temperature gradient across the thermocouple wires

PRESSURE SENSOR

* ***Absolute pressure sensor*** produces *signal in reference to vacuum* – (an absolute zero on a pressure scale.)

Analog and Digital

- According to the output
- Analog : -output changes continuously

  -This continuous output signal produced by the analog sensors is proportional to the measurand.

- Digital : -output is discrete steps or states (binary)
  - do not require an ADC
  - output is easier to transmit
  - more repeatable and reliable and oftenmore accurate.
  - cannot measure many physical quantities
  - Digital sensor consists of sensor itself, cable and a transmitter.

Deflection and Null type-According to output mode

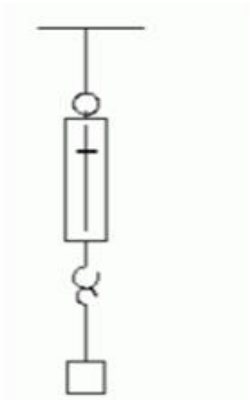
Deflection-type:

- The measured quantity produced some physical effects that engenders a similar but opposing effect in some part of the instrument. The opposing effect increases until a balance is achieved, at which point the "deflection" is measured.

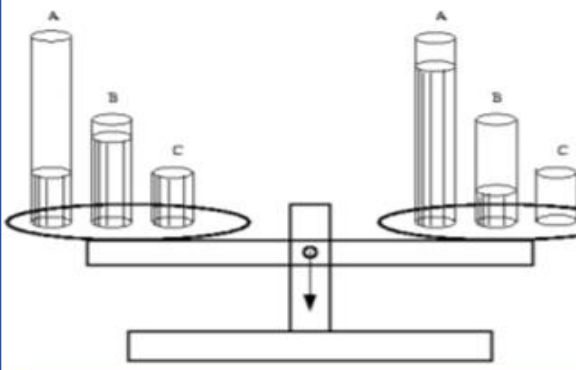
Null-type Method:

- a null-type device attempts to maintain deflection at zero by suitable application of a known effect opposing the generated by the measured quantity. (a null detector and a means of restoring balancing are necessary).

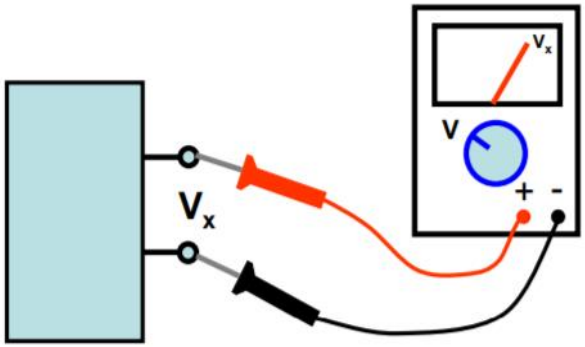
Deflection and Null type



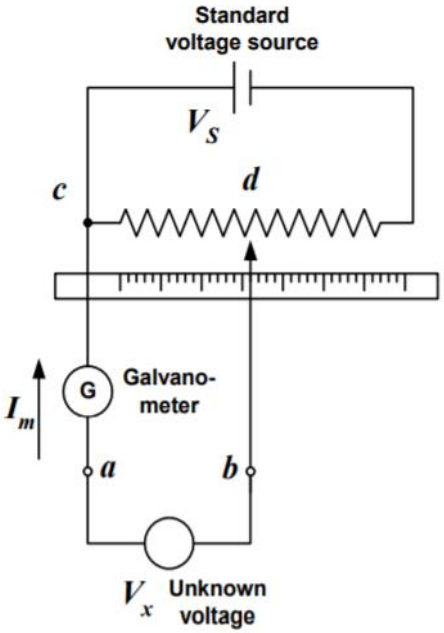
A spring balance



An equal arm balance



Measuring unknown voltage using a voltmeter



Potentiometer voltage measurement

Signal Classification

TABLE 1.1 Sensor Classifications According to Different Exhaustive Criteria

Criterion	Classes	Examples
Power supply	Modulating	Thermistor
	Self-generating	Thermocouple
Output signal	Analog	Potentiometer
	Digital	Position encoder
Operation mode	Deflection	Deflection accelerometer
	Null	Servo-accelerometer

Different Types of Sensors

- Temperature Sensor
- Proximity Sensor
- Accelerometer
- IR Sensor (Infrared Sensor)
- Pressure Sensor
- Light Sensor
- Ultrasonic Sensor
- Smoke, Gas and Alcohol Sensor
- Touch Sensor
- Humidity Sensor
- Tilt Sensor
- Flow and Level Sensor

Displacement, Position & Proximity

- Displacement sensors are concerned with the measurement of the amount by which some object has been moved.
- Position sensors are concerned with the determination of the position of some object in relation to some reference point.
- Proximity sensors are a form of position sensor and are used to determine when an object has moved to within some particular critical distance of the sensor. They are essentially devices which give on/off outputs.

PIR Sensor

- All objects with a temperature above absolute zero emit heat energy in the form of radiation. Usually this radiation isn't visible to the human eye because it radiates at infrared wavelengths, but it can be detected by electronic devices designed for such a purpose.
- A PIR-based motion detector is used to sense movement of people, animals, or other objects.
- They are commonly used in burglar alarms and automatically-activated lighting systems.
- They are commonly called simply "PIR", or sometimes "PID", for "passive infrared detector".

Ultrasonic sensors

- As the name indicates, ultrasonic sensors measure distance by using ultrasonic waves.
- The sensor head emits an ultrasonic wave and receives the wave reflected back from the target.
- Ultrasonic Sensors measure the distance to the target by measuring the time between the emission and reception.

Pressure Sensors

- A pressure sensor is a device for pressure measurement of gases or liquids.
- Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area.
- A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed.

Light Sensors

- The **light sensor** is a passive devices that convert this "**light** energy" whether visible or in the infra-red parts of the spectrum into an electrical signal output.
- **Light sensors** are more commonly known as "Photoelectric Devices" or "Photo **Sensors**" because the convert **light** energy (photons) into electricity (electrons).

Touch sensor

- A **touch sensor** is a type of equipment that captures and records physical **touch** or embrace on a device and/or object.
- It enables a device or object to detect **touch**, typically by a human user or operator.
- A **touch sensor** may also be called a **touch** detector.
- For example, when navigating through a smartphone or using an application, the touch sensor captures the human touches or the applied pressure across the screen.
- Each interaction with the user across the screen might have a different meaning for the device and/or the application.

Tilt Sensors

- A tilt sensor can **measure** the tilting in often two axes of a reference plane in two axes.
- In contrast, a **full** motion would use at least three axes and often additional sensors.
- Example
  - Digital **Tilt** Motion **Sensor**.
  - The 507M Digital **Tilt Sensor** is ideal for protecting a **vehicle** from theft by detecting when the **vehicle** is being raised by a tow truck or lifted using a jack, in an attempt to remove the wheels or tow the **vehicle**.

Flow and Level Sensors

- A level sensor is a device for determining the level or amount of fluids, liquids or other substances that flow in an open or closed system.
- There are two types of level measurements, namely, continuous and point level measurements.
- Continuous level sensors are used for measuring levels to a specific limit, but they provide accurate results.
- Point level sensors, on the other hand, only determine if the liquid level is high or low.

Proximity Sensor

- A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact.
- Proximity sensors are used in phones, recycling plants, self-driving cars, anti-aircraft systems, and assembly lines.
- For example, during a telephone call, proximity sensors play a role in detecting (and skipping) accidental touchscreen taps when mobiles are held to the ear.

GPS (Global Positioning System) sensor

- GPS short form of Global Positioning System, originally developed and setup for military operations and was made available for everyone in 1980s by Government.
- GPS is a system which tracks the target or 'navigate' the things by map or picture with the help of GPS satellites.
- Nowadays smartphones come with assisted GPS or A-GPS which does the same work with the help of intermediate server in case of disconnection with main GPS satellite.

GPS to VPS

Ambient Light Sensor

- This sensor optimize the light of screen when it exposed to normal light with different intensity.
- Ultimate function of ambient light sensor is to adjust the display brightness, which at the end saves the battery power and life too.
- Ambient light sensor senses and adjust the light based on principle of "superposition".
- They contain photo diodes which are sensitive to different spectrum of light and combined mathematical effect adjusts the gain and output changes of the light intensity on the screen.

Accelerometer

- Accelerometer sensor senses the change in orientation by 3D (X,Y & Z axis) measurement of acceleration of the device with respect to free fall.
- For example, when working on a web-page with increased width, the landscape view can be obtained from changing the orientation of phone to horizontal.
- Similarly camera mode also changes the portrait to landscape or landscape to portrait mode when we change the orientation of phone/camera.
- The main function of accelerometer is to sense the changes in the orientation with respect to datum and adjust the orientation to suit the viewing angle of operator.