https://www.indiawaterportal.org/articles/ngt-orders-100-percent-treatment-sewage-entering-rivers

Outline

- Definitions
- **Sensor Classification**
- **<u>Sensor Characteristics</u>**
- **Sensor Working Principles**

Classification: Field of applications

Agriculture	Automotive	Civil engineering, construction	Domestic, appliances	Distribution, commerce, finance	Environment, meteorology, security
Energy, power	Information, telecommunication	Health, medicine	Marine	Manufacturing Recreation, toys	Military
	Space	Scientific measurement	Transportation (excluding automotive)	Other	

Classification : Stimuli

Stimulus	Stimulus	
Acoustic	*Mechanical*	Position (linear, angular)
Wave amplitude, phase		Acceleration
Spectrum polarization		Force
Wave velocity		Stress, pressure
Other		Strain
Biological		Mass, density
Biomass (types, concentration states)		Moment, torque
Other		Speed of flow, rate of mass transport
Chemical		
Components (identities, concentration, states)		Shape, roughness, orientation
Other		
Electric		Stiffness, compliance
Charge, current		Viscosity
Potential, voltage		Crystallinity, structural integrity
Electric field (amplitude, phase, polarization, spectrum)		Other
Conductivity	*Radiation*	Type
Permittivity		Energy
Other		Intensity
Magnetic		Other
Magnetic field (amplitude, phase, polarization, spectrum)	*Thermal*	Temperature
		Flux
Magnetic flux		Specific heat
Permeability		Thermal conductivity
Other		Other
Optical		
Wave amplitude, phase, polarization, spectrum		
Wave velocity		
Refractive index		
Emissivity, reflectivity, absorption		
Other		

Handbook of Modern Sensors; Physics, Designs, and Applications
Fifth Edition – Jacob Fraden

Classification : Sensing element material

- Inorganic/Organic
- Conductor /Insulator
- Semiconductor
- Liquid gas or plasma
- Biological substance
- Other….

Sensor Characteristics

Sensor specifications

- Sensitivity
- Stimulus range (span)
- Stability (short and long term)
- Resolution
- Accuracy
- Selectivity
- Speed of response
- Environmental conditions
- Overload characteristics
- Linearity
- Hysteresis
- Dead band
- Operating life
- Output format
- Cost, size, weight Other

https://www.signaguard.com/case-studies-in-bridge-health-monitoring/

Range and Span

- **Range**
  Minimum and Maximum value of a physical quantity that a sensor can measure
  Example: A Resistance Temperature Detector (RTD) for the measurement of temperature has a range of -200 to 800˚C

- **Span**
  Difference between maximum and minimum values of input measured
  In the above example, span of RTD = 800 – (-200) = 1000˚C

Accuracy and Resolution

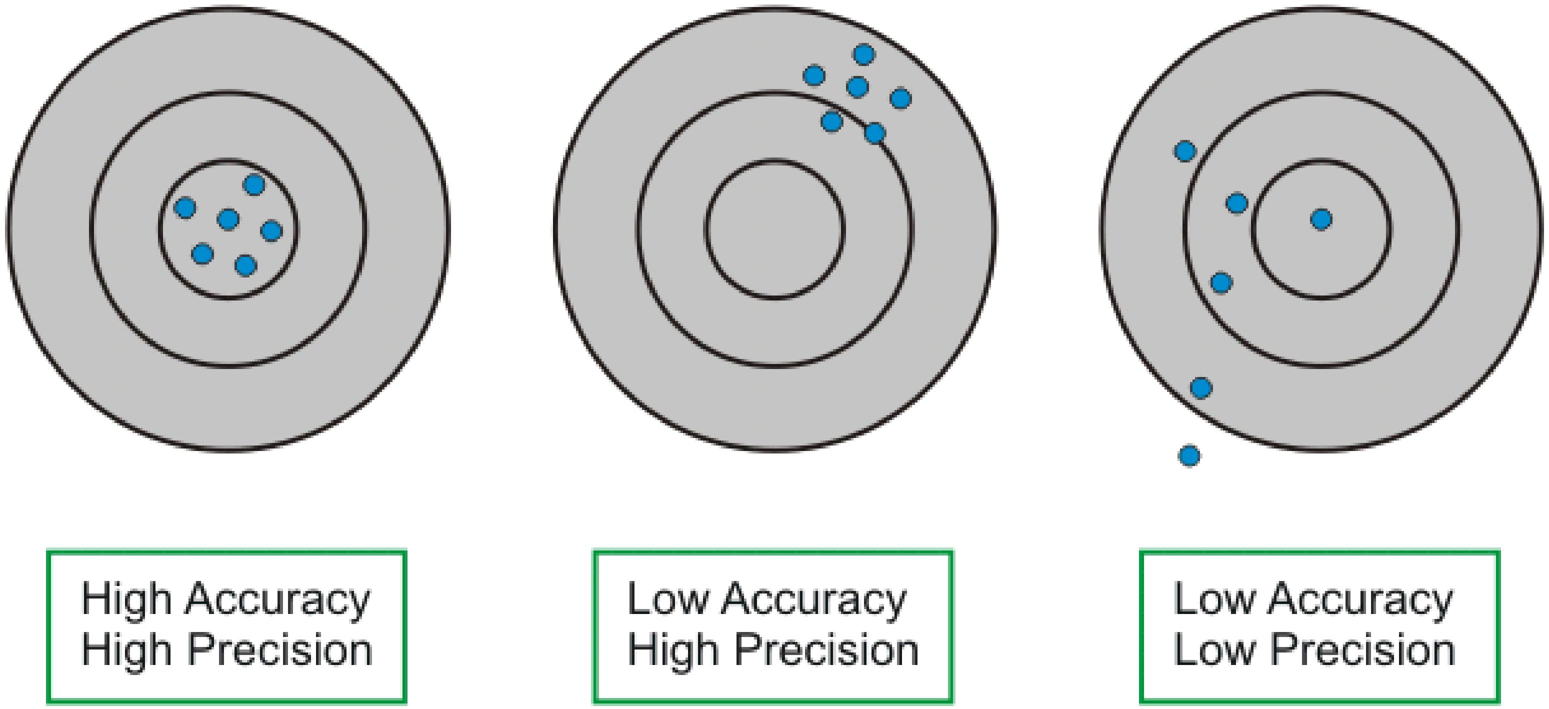
- **Accuracy** is the capacity of a sensor to give results close to the **TRUE VALUE** of the measured quantity
  - ➢ Measured by absolute and relative errors

    ABSOLUTE ERROR = RESULT – TRUE VALUE (measured value to a known absolute true value)

    RELATIVE ERROR = ABSOLUTE ERROR / TRUE VALUE (how close is the value to a standard value in relative terms)
- **Resolution** is the minimal change of the input necessary to produce a detectable change at the output

Precision

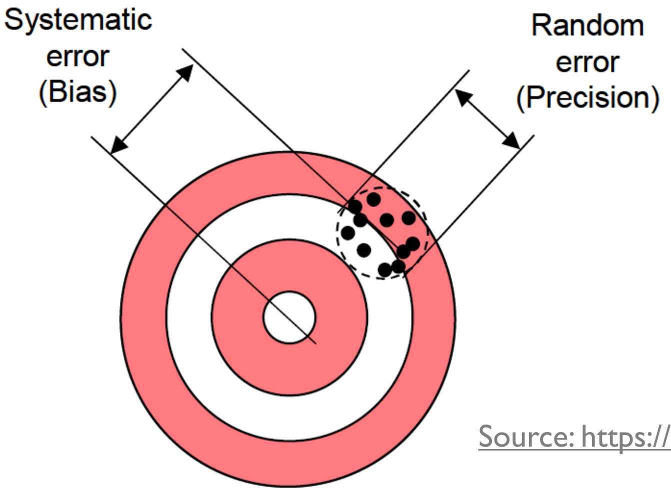
- Capacity of a sensor to give same reading when repetitively measuring the same quantity under the same prescribed conditions



Source: https://www.electrical4u.com/characteristics-of-sensors/

Errors

- Systematic Errors
  Due to interfering or modifying variables (e.g., temperature), loading, attenuation, etc.
- Random Errors
  A signal that carries no information such as environmental noise



Source: https://www.philadelphia.edu.jo/academics/kaubaidy/uploads/Sensor-Lect2.pdf

Sensing

Sensitivity

- Ratio of change in output to change in input.
  If Y is the output quantity in response to input X, then sensitivity S can be expressed as

$$S = \frac{dY}{dX} = \frac{\Delta Y}{\Delta X}$$

It is also the slope of the calibration curve

Measurement – mathematical models

- Linear (simplest model)

$E = A + Bs$

B = slope & is the sensitivity

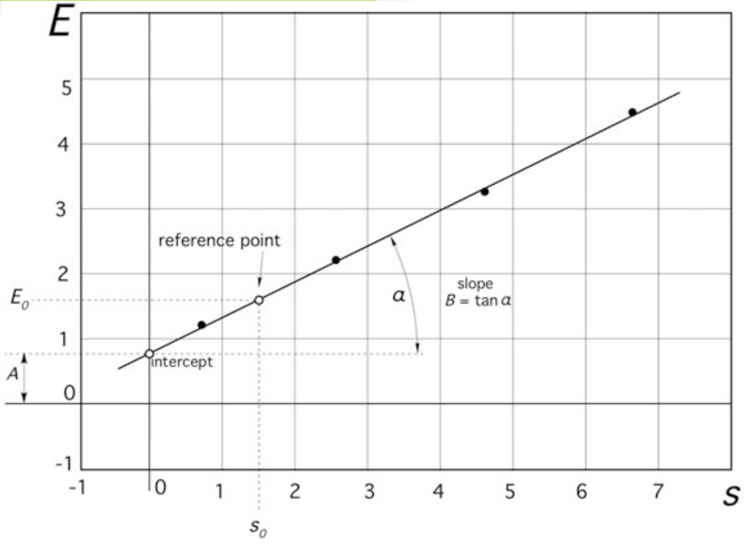
- Output signal

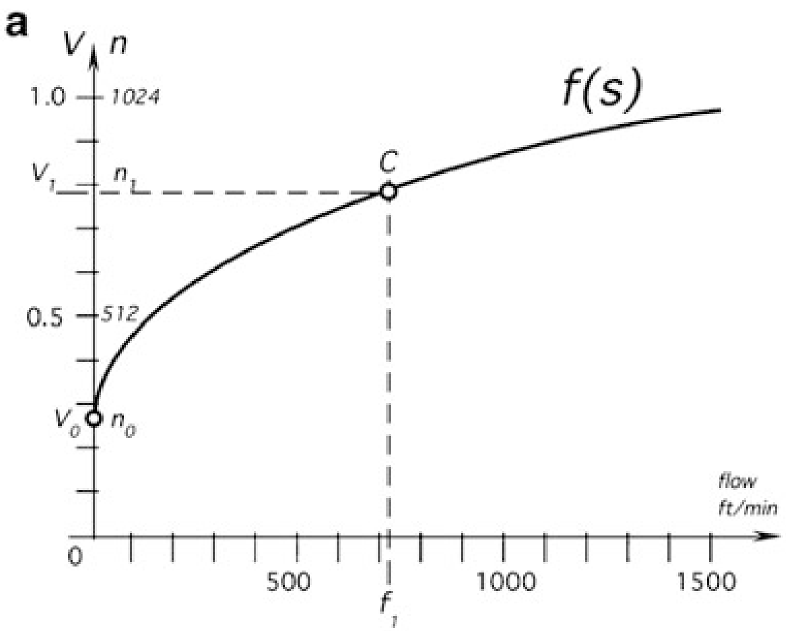
$E = f(s)$

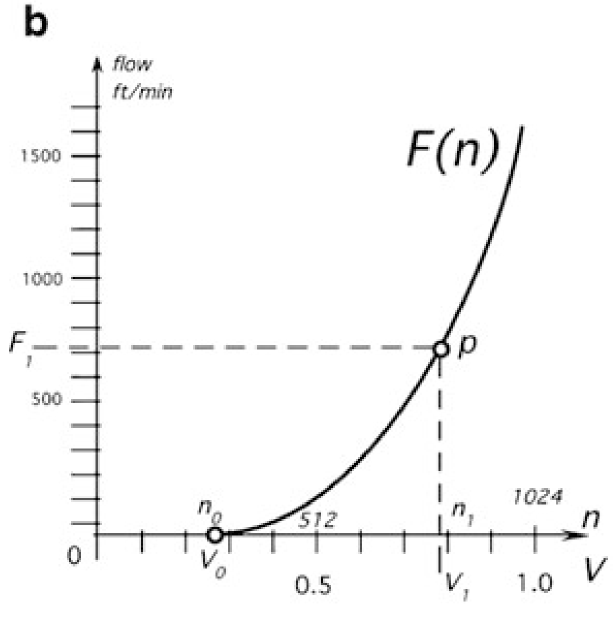
To get 's'

$s = f^{-1}(E)$

- transfer function

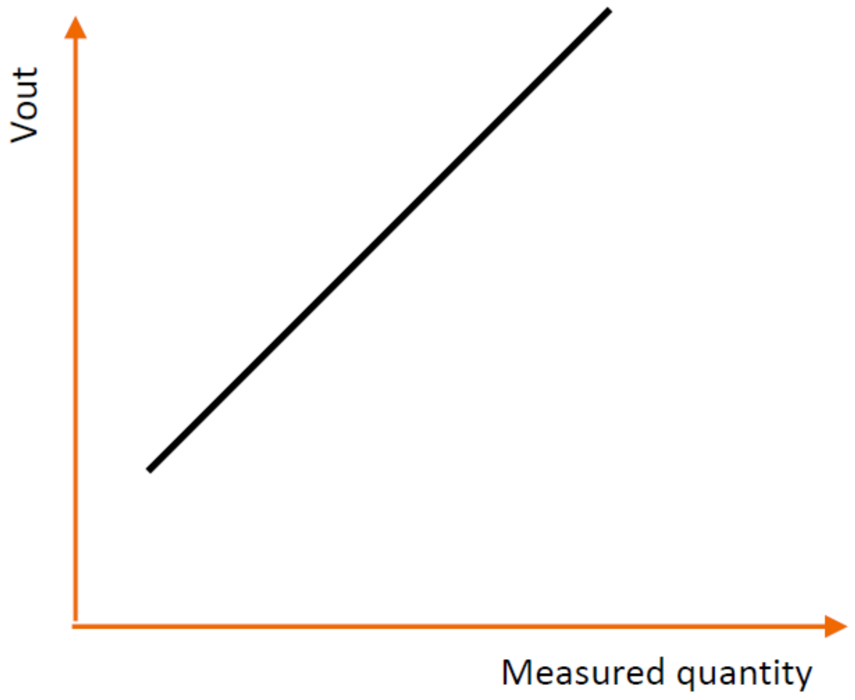






Linearity

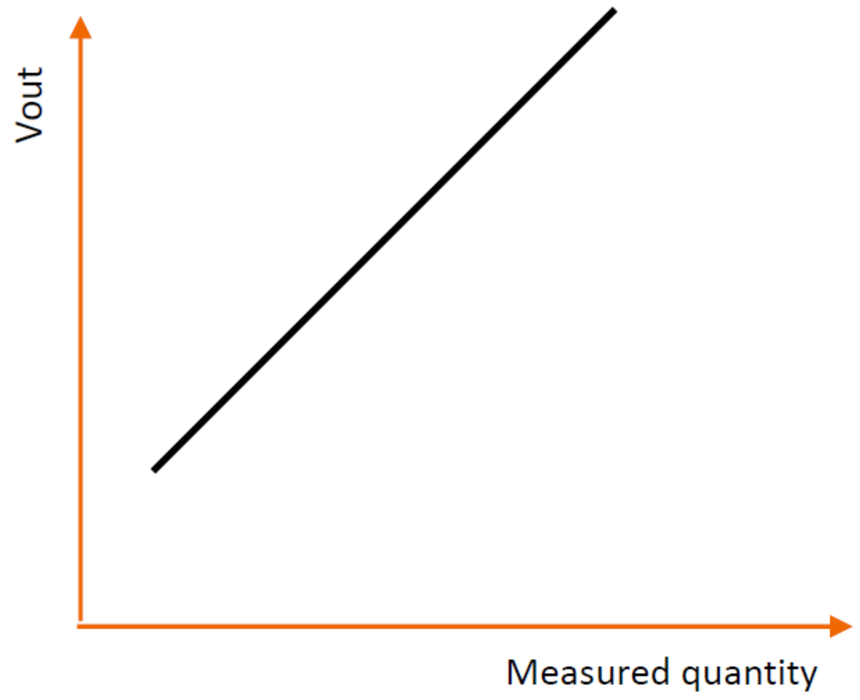
- Assume we can successfully convert the physical quantity into electrical and proportional voltage
- Characteristics of this sensor can be plotted as measured quantity in X axis and output voltage in Y axis
- Hope is that we get a linear characteristic – but why is this so important?



Sensor Characteristic

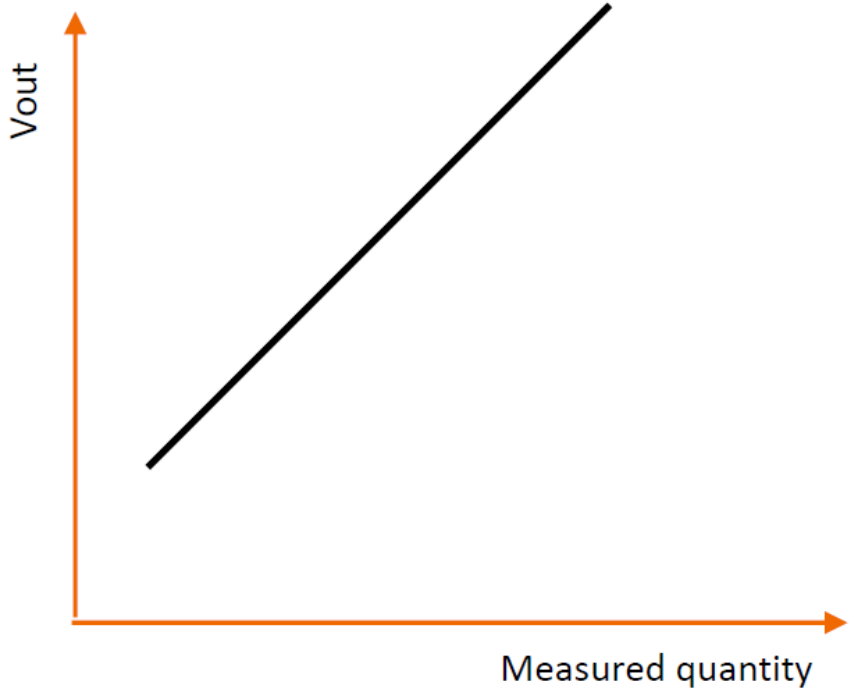
- Need to find the value of measured quantity (MQ) based on the reading of voltage
- Need a function which maps Vout to the MQ
- Easiest to have a linear equation as below

$$MQ = \frac{V_{out}}{slope} + C$$



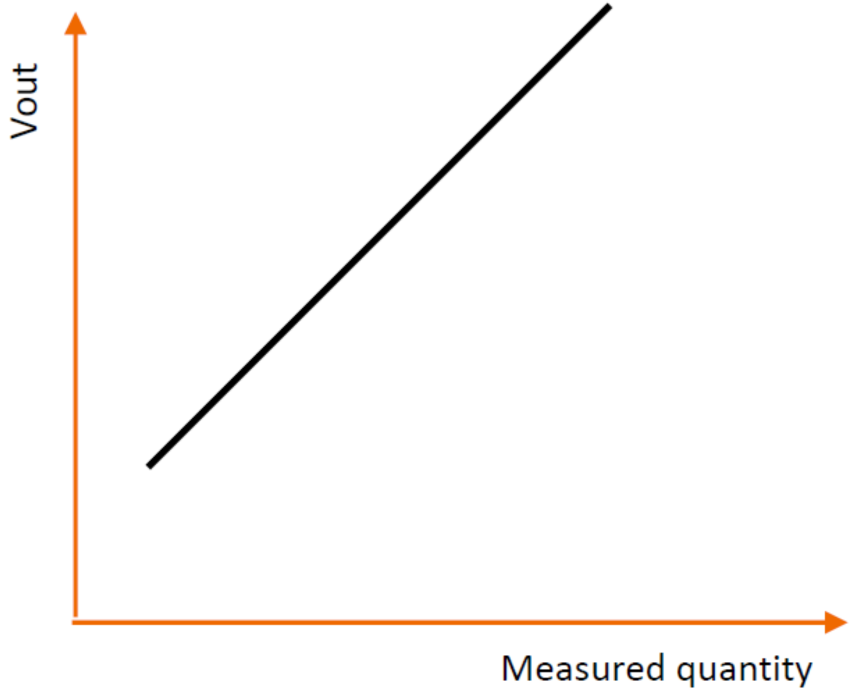
Sensor Calibration

- Two unknown quantities, once known, can calculate MQ for any Vout
- Provided by sensor manufacturer, but the problem is these values shift over time
- Calibration involves finding these values or verifying already given values
- One method → Subject the sensor to a known stimulus and measure Vout
- Two points are sufficient to get the function



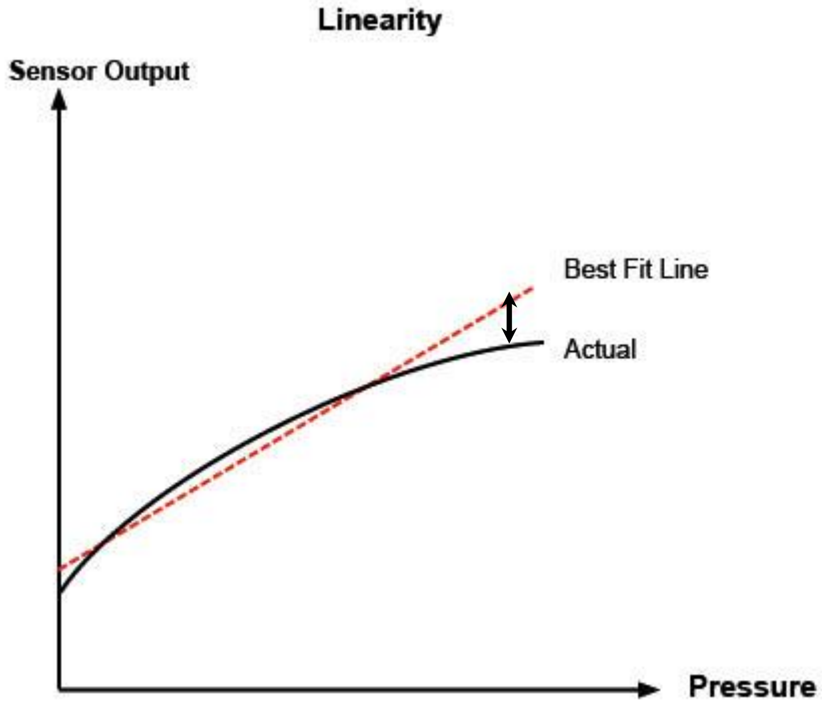
Sensor Calibration

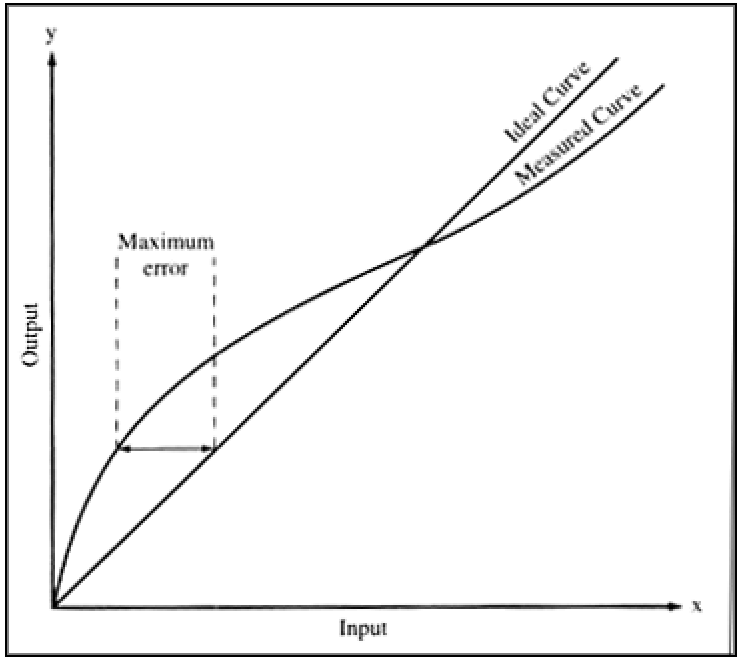
- Biggest challenge in IoT deployments → Sensor calibration drifts with time, i.e., value of C and slope are functions of time
- Strategies to address this
  - Know the drift in advance and program into system logic
  - Recalibrate the sensor over the air based on a gold standard
  - Recalibrate by bringing the sensor to a conditioned ambient



Linearity

- Maximum deviation between the measured values of a sensor from ideal curve



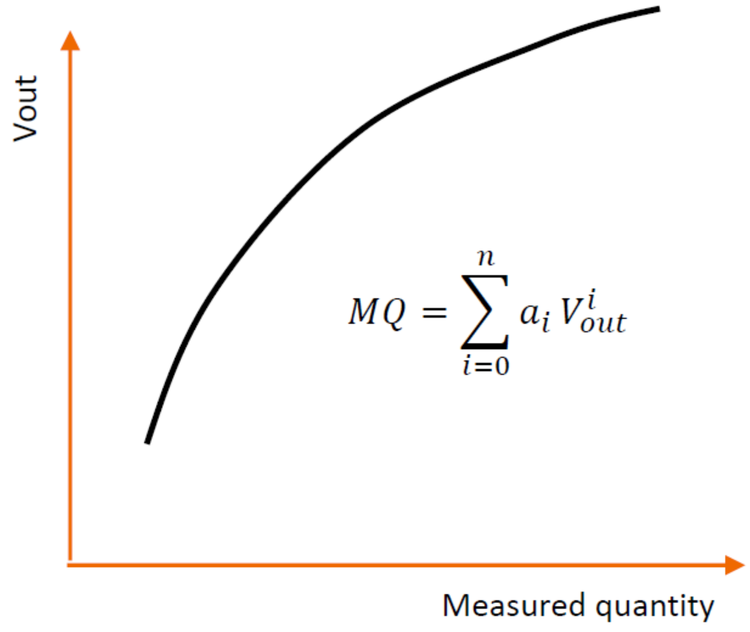


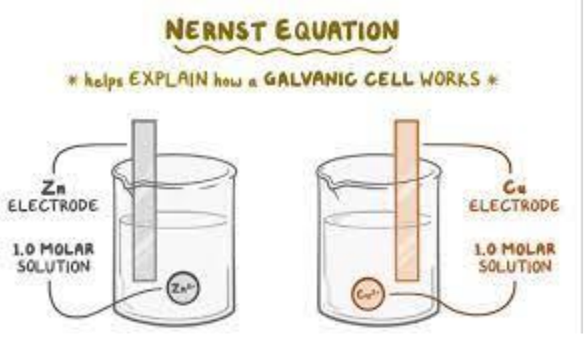
Source: https://appmeas.co.uk/resources/pressure-measurement-notes/linearity-or-nonlinearity/

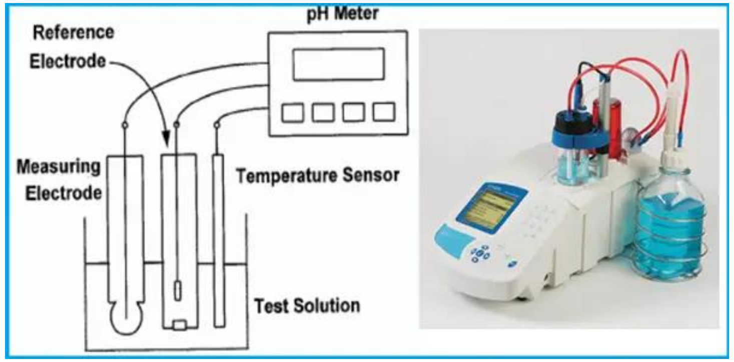
Non-linear systems

- Some systems give non-linear response
- Require multiple parameters to determine the calibration
- Strategies:
  - Use of ML algorithms to determine the sensed quantity

Examples: photodiodes, thermistors, pH sensors



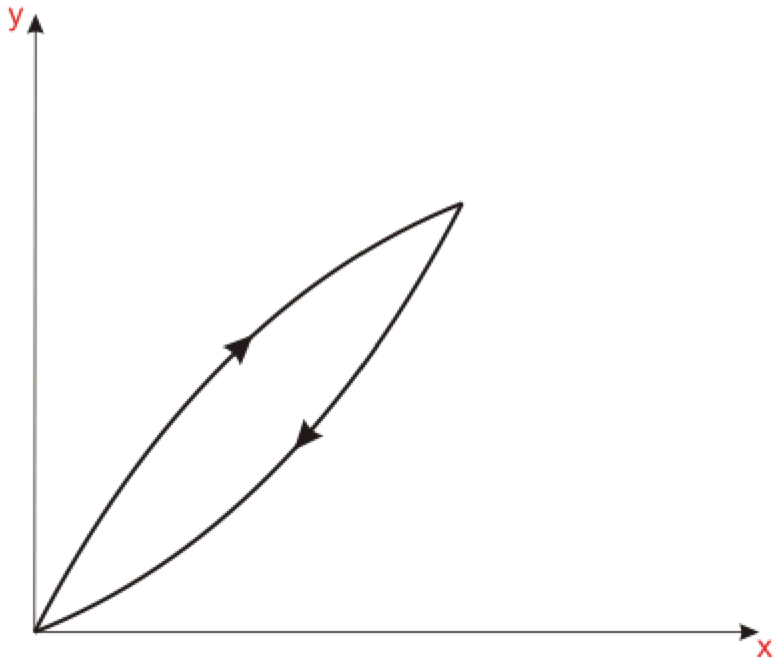




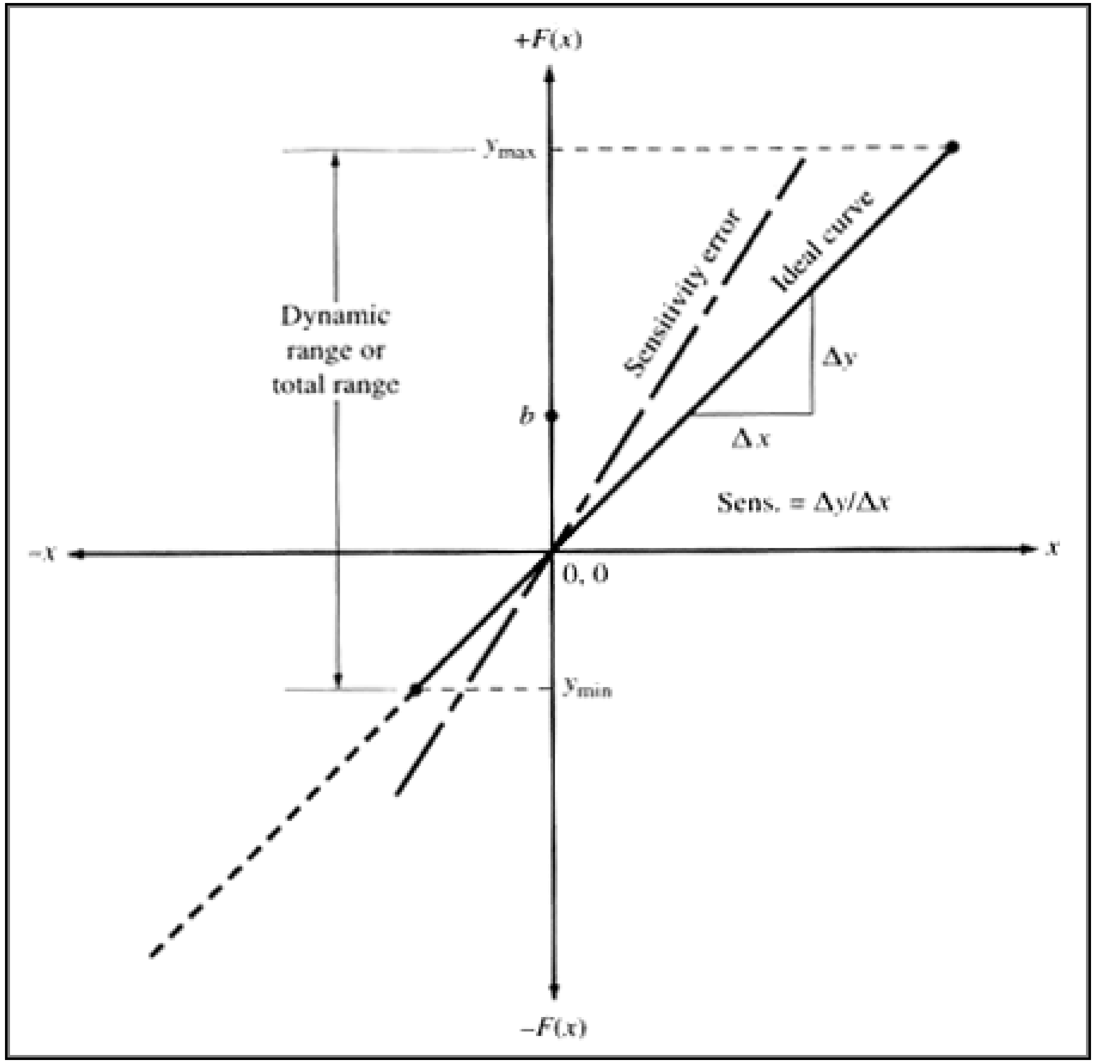
Nernst equation: **E = E0 + 2.303 (RT/nF) log aH+** where slope, also called sensitivity, is denoted by -2.303 RT/nF and pH is equal to -log aH+

Hysteresis

- Difference in output for same input when the input is reached at from different trajectories



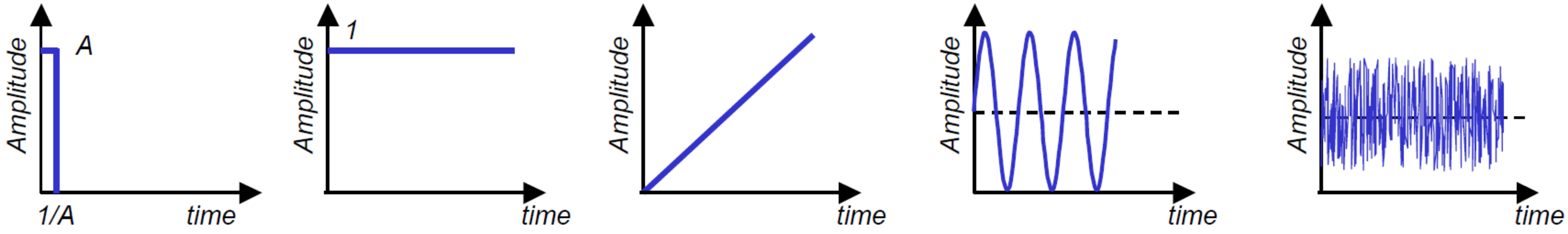
Source: https://www.electrical4u.com/characteristics-of-sensors/



+F(x)
y_{max}
Dynamic range or total range
Sensitivity error
Ideal curve
Δy
b
Δx
Sens. = Δy/Δx
−x
x
0, 0
y_{min}
−F(x)

Dynamic Characteristics

- Sensor response to a variable input is different from what is seen when the input signals are constant (described by static characteristics)
- Dynamic Characteristics are determined by analyzing the response of the sensor to a family of variable input waveforms



Source: https://www.philadelphia.edu.jo/academics/kaubaidy/uploads/Sensor-Lect2.pdf

Summary

- Sensitivity :The *minimum input of physical parameter that will create a detectable output change.*
- Range :The range of the sensor is the maximum and minimum values of applied parameter that can be measured
- Precision : reproducibility
- Resolution : smallest/small change measurable (0.001 or 0.01)
- Accuracy :max. diff between actual value & indicated value
- Offset :The offset error of a transducer is defined as the output that will exist when it should be zero
- Linearity
- Hysteresis
- Response Time :*time required for a sensor output to change from its previous state to a final settled value within a tolerance band of the correct new value*
- Dynamic Linearity :The dynamic linearity of the sensor is a measure of its ability to follow rapid changes in the input parameter.

Examples of different types of sensors

Conversion phenomena

Physical

- Thermoelectric
- Photoelectric
- Photomagnetic
- Magnetoelectric
- Electromagnetic
- Thermoelastic
- Electroelastic
- Thermomagnetic
- Thermo-optic
- Photoelastic
- Other

Chemical

- Chemical transformation
- Physical transformation
- Electrochemical process
- Spectroscopy
- Other

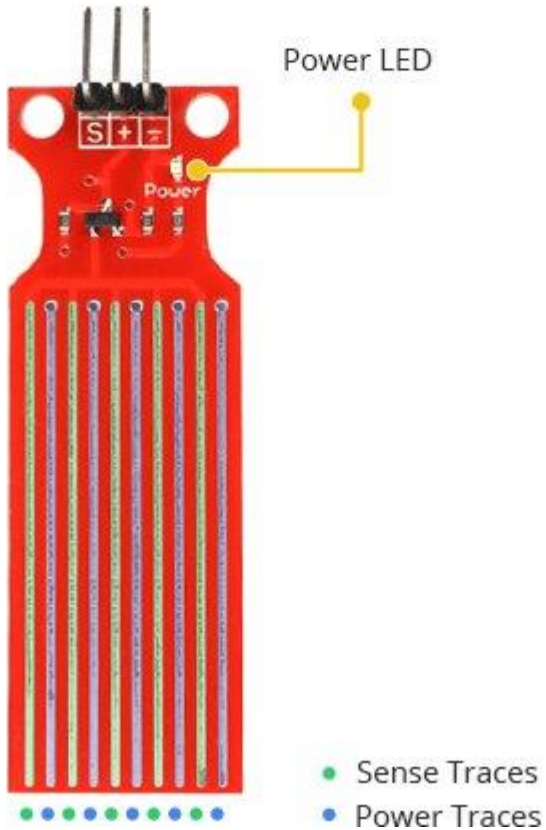
Biological

- Biochemical transformation
- Physical transformation
- Effect on test organism
- Spectroscopy

Other

Water Level Sensor

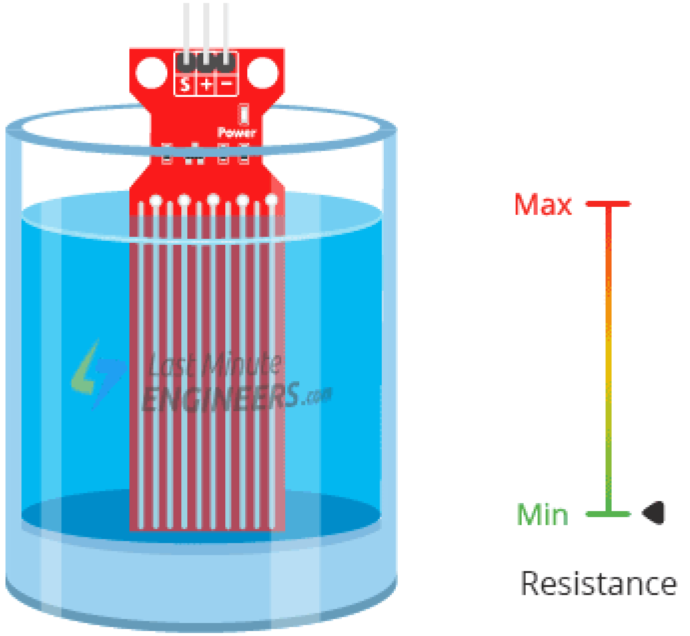
- Presence of 10 exposed copper traces – 5 are power traces and 5 are sense traces
- One sense trace in between every two power traces
- These traces are bridged when submerged in water



Source: https://lastminuteengineers.com/water-level-sensor-arduino-tutorial/

Water Level Sensor working principle

- The parallel conductors act as a variable resistor and resistance varies according to water level
- Resistance inversely proportional to the height of the water
- More the immersion, better the conductivity and lower the resistance and vice versa
- Produces an output voltage according to resistance
- Issue: short lifespan as exposed to moist environment



Source: https://lastminuteengineers.com/water-level-sensor-arduino-tutorial/

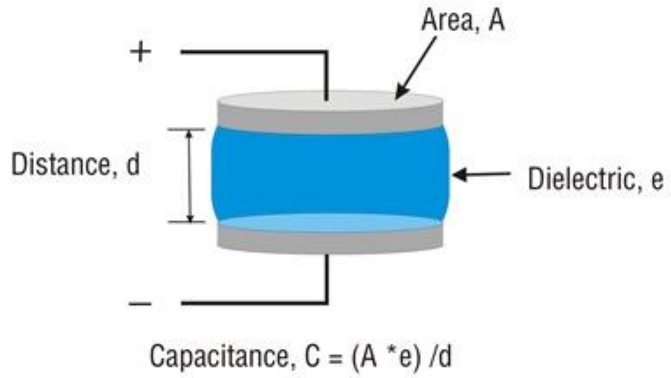
Optical water level sensor

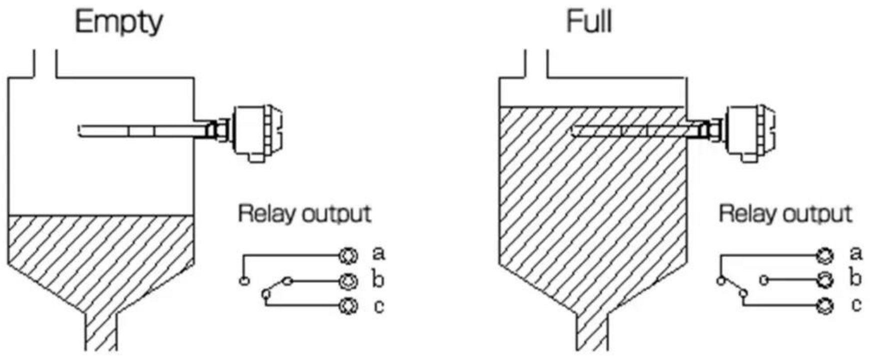
infrared LEDs and phototransistors

Advantages: non-contact measurement, high accuracy, and fast response.
Disadvantages: Do not use under direct sunlight, water vapor will affect the measurement accuracy.

https://www.renkeer.com/

Capacitance liquid level sensor



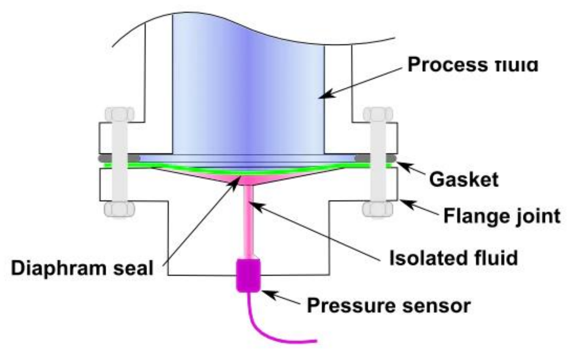


Advantages: can be used to determine the rise or fall of the liquid in the container. By making the electrode and the container the same height, the capacitance between the electrodes can be measured. No capacitance means no liquid. A full capacitance represents a complete container.

Disadvantages: The corrosion of the electrode will change the capacitance of the electrode, and it needs to be cleaned or recalibrated.

https://www.renkeer.com/

Tuning fork level sensor
&
Diaphragm liquid level sensor



resonant frequency.

Advantages: It can be truly unaffected by flow, bubbles, liquid types, etc., and no calibration is required.
Disadvantages: Cannot be used in viscous media.

Advantages: There is no need for power in the tank, it can be used with many types of liquids, and the switch will not come into contact with liquids.
Disadvantages: Since it is a mechanical device, it will need maintenance over time.

Float water level sensor
&
Ultrasonic liquid level sensor

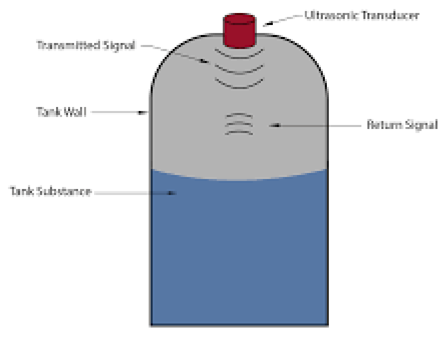


Figure 1: "Top-Down" Ultrasonic Sensor

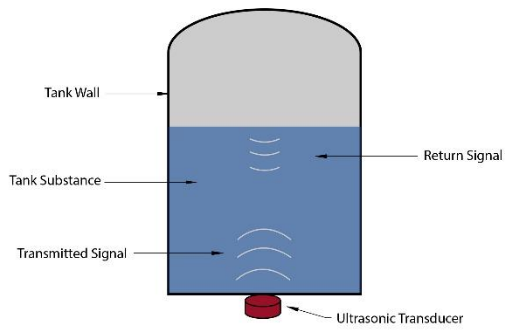


Figure 2: "Bottom-Up" Ultrasonic Sensor

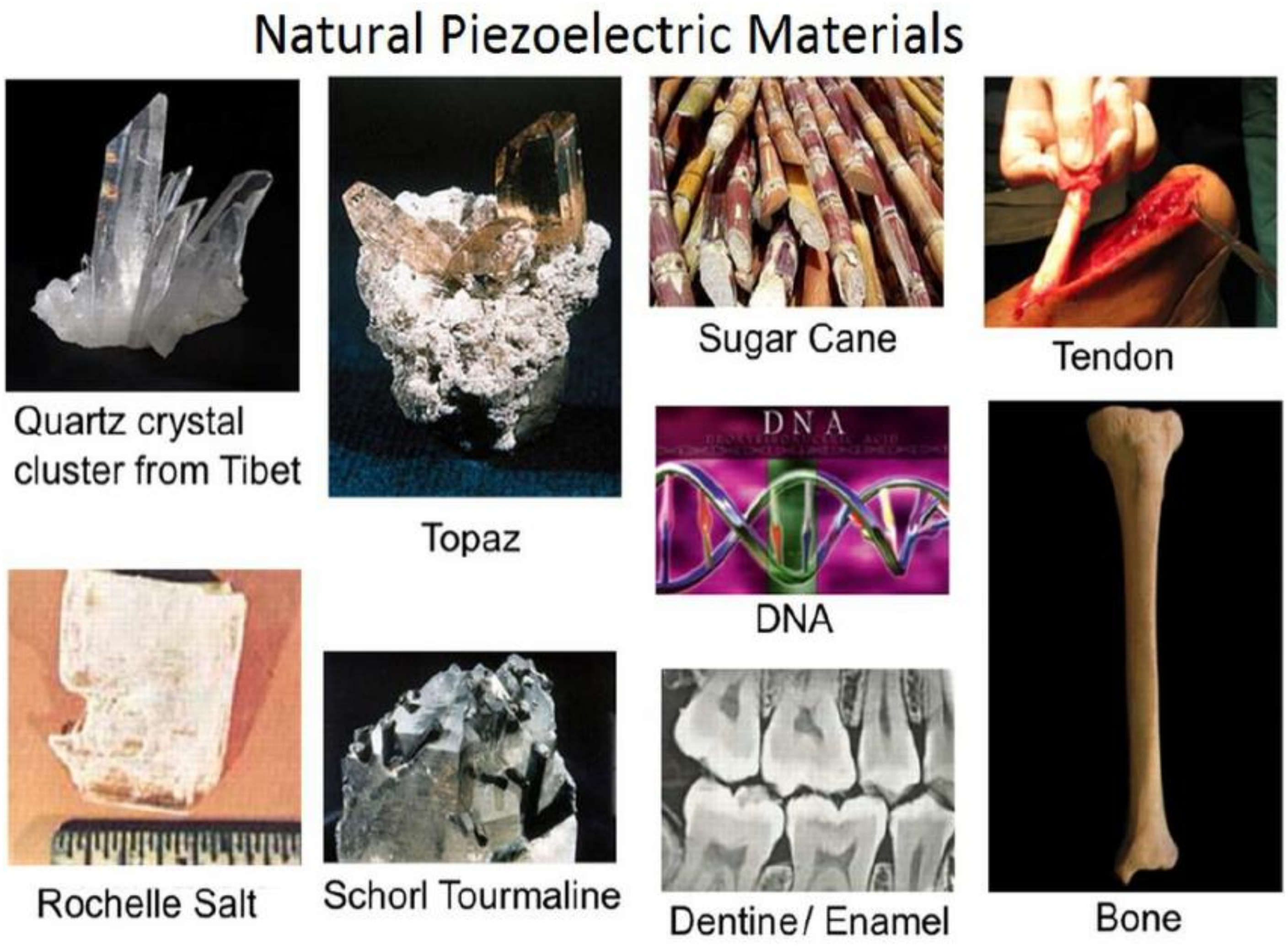
Advantages: non-contact measurement, the measured medium is almost unlimited, and it can be widely used for measuring the height of various liquids and solid materials.
Disadvantages: The measurement accuracy is greatly affected by the temperature and dust of the current environment.

Advantages: The float switch can measure any type of liquid and can be designed to operate without any power supply.
Disadvantages: They are larger than other types of switches, and because they are mechanical, they must be used more frequently than other level switches.

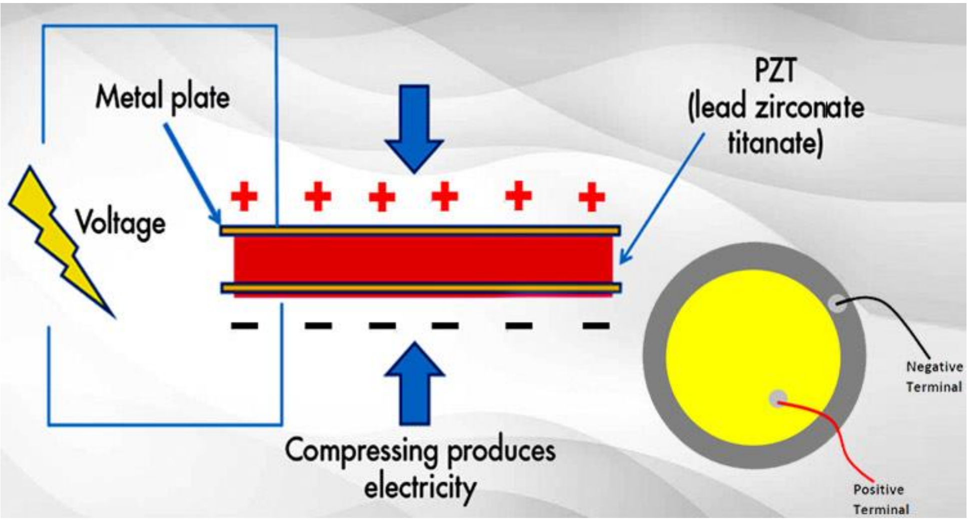
Radar level gauge

Advantages: wide application range, not affected by temperature, dust, steam, etc.
Disadvantages: It is easy to produce interference echo, which affects the measurement accuracy.

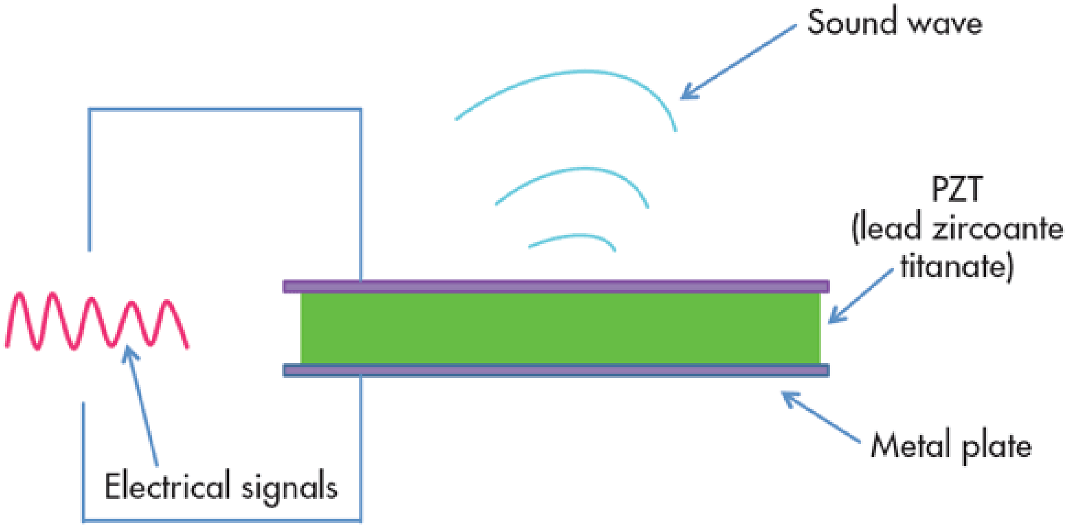
Ultrasonic



Natural Piezoelectric Materials
Quartz crystal cluster from Tibet
Topaz
Sugar Cane
Tendon
DNA
DNA
Bone
Rochelle Salt
Schorl Tourmaline
Dentine / Enamel

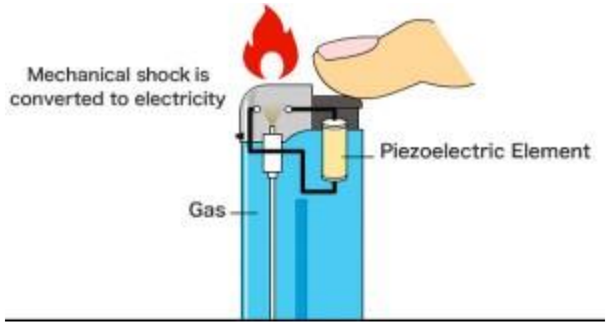


Applying mechanical energy to a crystal is called a direct piezoelectric effect which forces the excess negative and positive charges appear on opposite sides of the crystal face. The metal plate collects these charges, which can be used to produce a voltage and send an electrical current through a circuit.



Electrical energy applied to the crystal, shrinks and expands the crystal's structure.
As the crystal's structure expands and contracts, it converts the received electrical energy and releases mechanical energy in the form of a sound wave.

- Actuators use piezoelectricity to power devices - video cameras, and smartphones.
- Piezo sensors are used in a variety of applications such as microphones, amplified guitars, and medical imaging equipment.



Pressing the button of the lighter releases a spring-loaded hammer into a piezoelectric crystal. This produces an electrical current that crosses a spark gap to heat and ignite gas

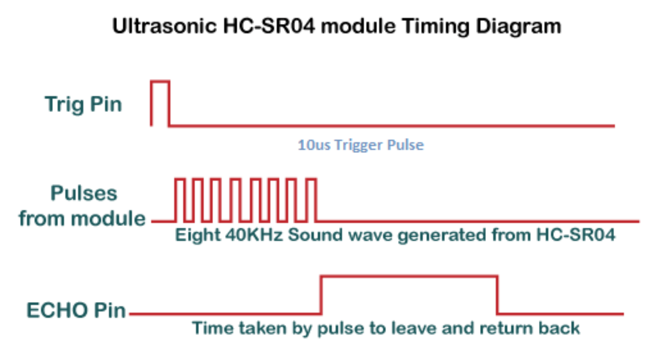
HC-SR04 Ultrasonic Sensor

- Ultrasound is high-pitched sound wave with inaudible frequencies – Frequency of over 20000 Hz
- Consists of 2 ultrasonic transducers – one acts as a transmitter and another as a receiver
- Transmitter converts electrical signal to 40 KHz ultrasonic sound pulses
- Receiver listens for the pulses and produces output pulses with width corresponding to distance
- Non contact range of 2 cm to 400 cm with an accuracy of 3 mm

HC-SR04 Ultrasonic Sensor

- Trig (Trigger): Pin to trigger ultrasonic sound pulses
- Echo: Output pulse produced at this pin when reflected signal is received

HC-SR04 Ultrasonic Sensor working principl



- Principle of the SONAR and RADAR system
- A pulse of at least 10 microsecond applied to Trigger pin
- Sensor transmits burst of 8 ultrasonic sound pulses at 40 KHz
- 8-pulse pattern makes an ultrasonic signature allowing receiver to differentiate from ambient ultrasonic noise
- As the ultrasonic pulses travel, the ECHO pin goes high
- If the pulses are not reflected, then ECHO signal will timeout in 38 msec and become low → indicates no obstruction or obstacle in the range
- If the pulses are received, the ECHO signal becomes low as soon as the signal is received
- A pulse produced whose width varies between 150 microseconds and 25 msec depending upon the time it took.

Other applications….