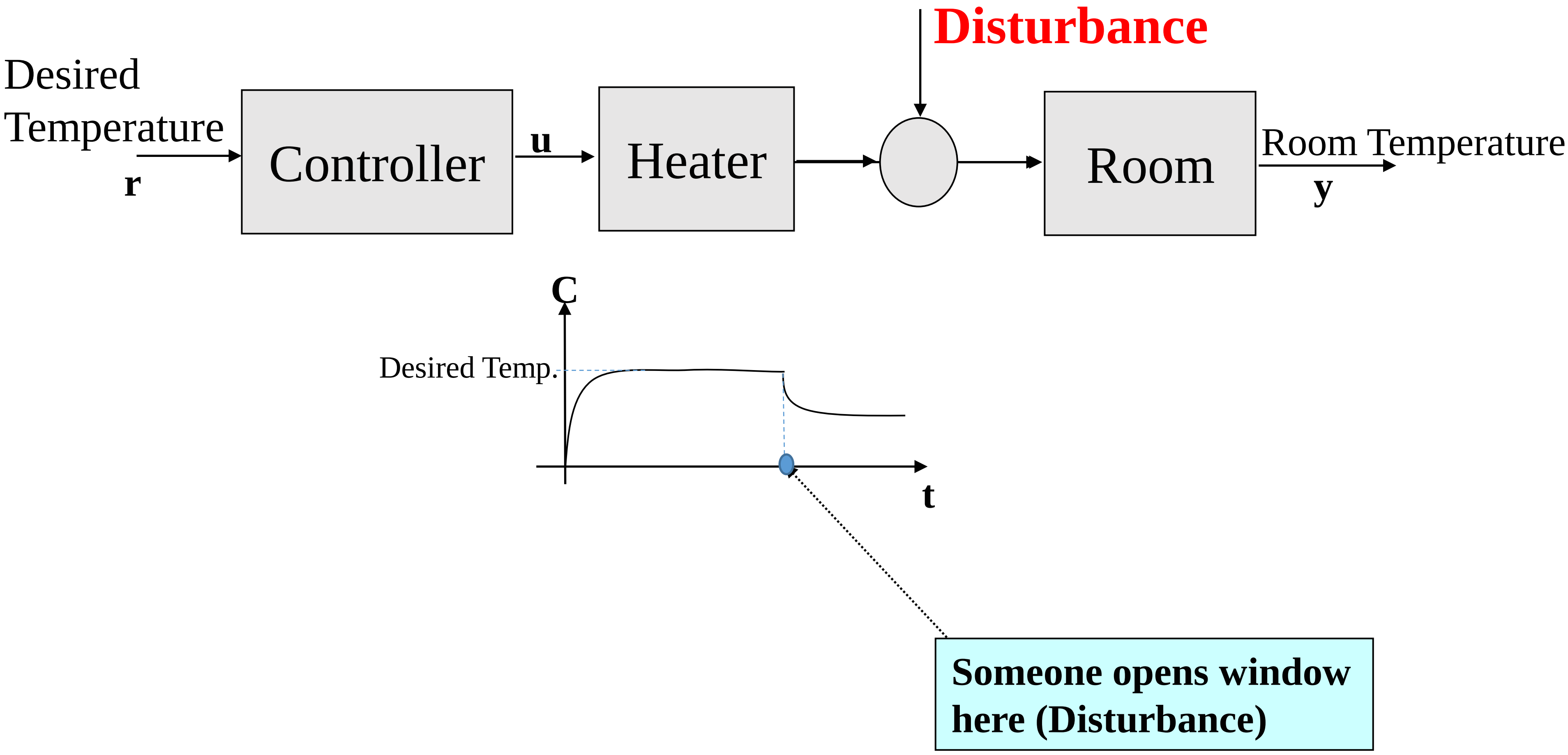
Introduction to Measurement

Week 2

Mechatronic System Components

Prof. Dr. Volkan Sezer

Why We Measure?



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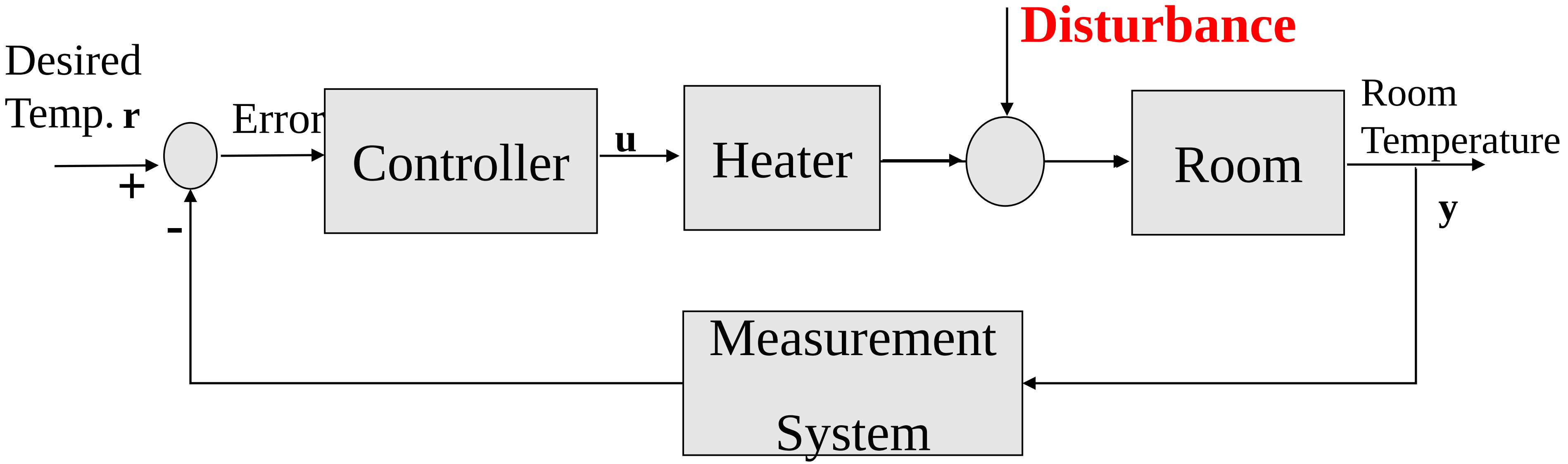
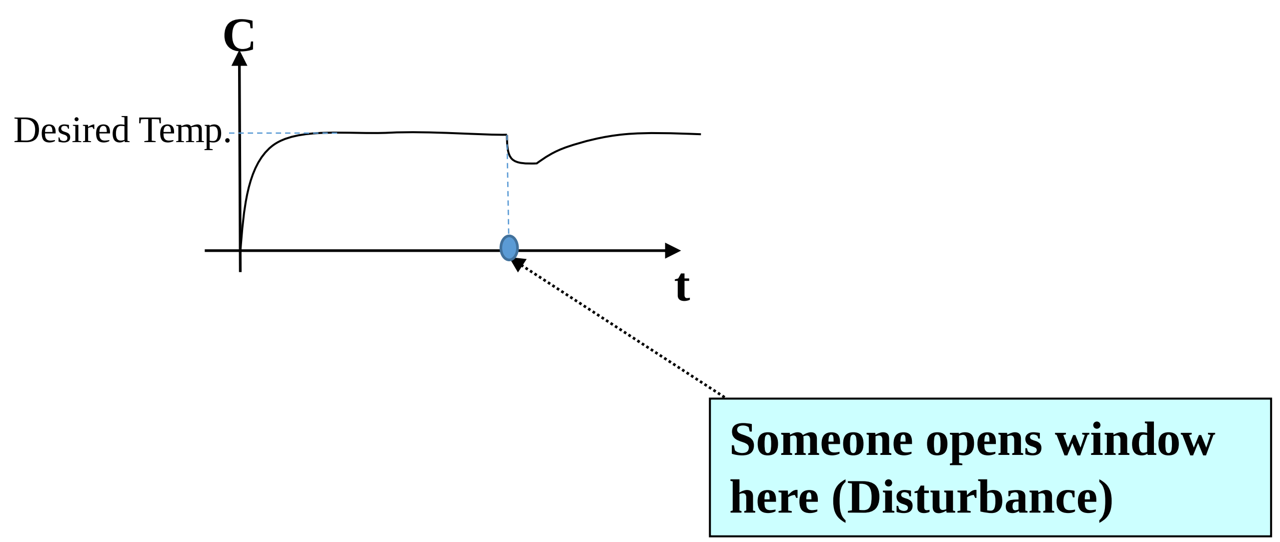
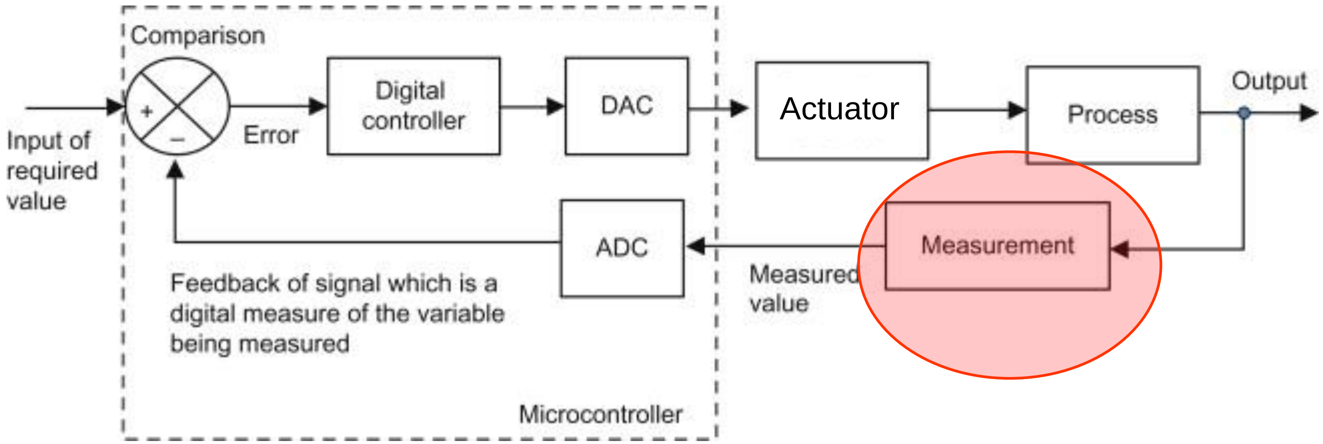




Introduction to Measurement

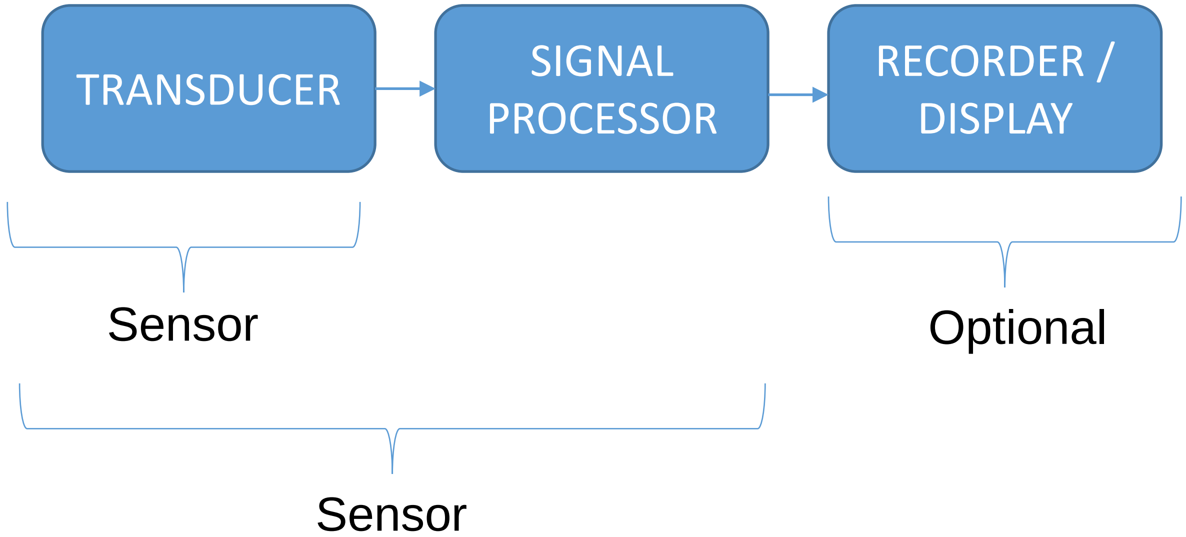


A simple closed loop system with Measurement (Digital World)

Measurement: 'The process of associating numbers with physical quantities'

Measurement System and Their Principles

- A fundamental part of many mechatronic systems is a measurement system which is composed of 3 basic parts.



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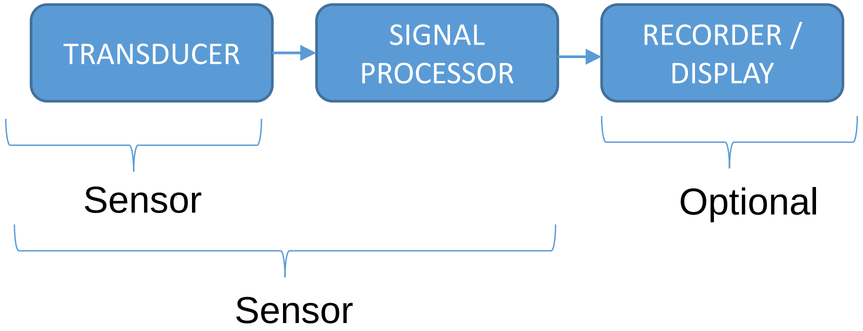
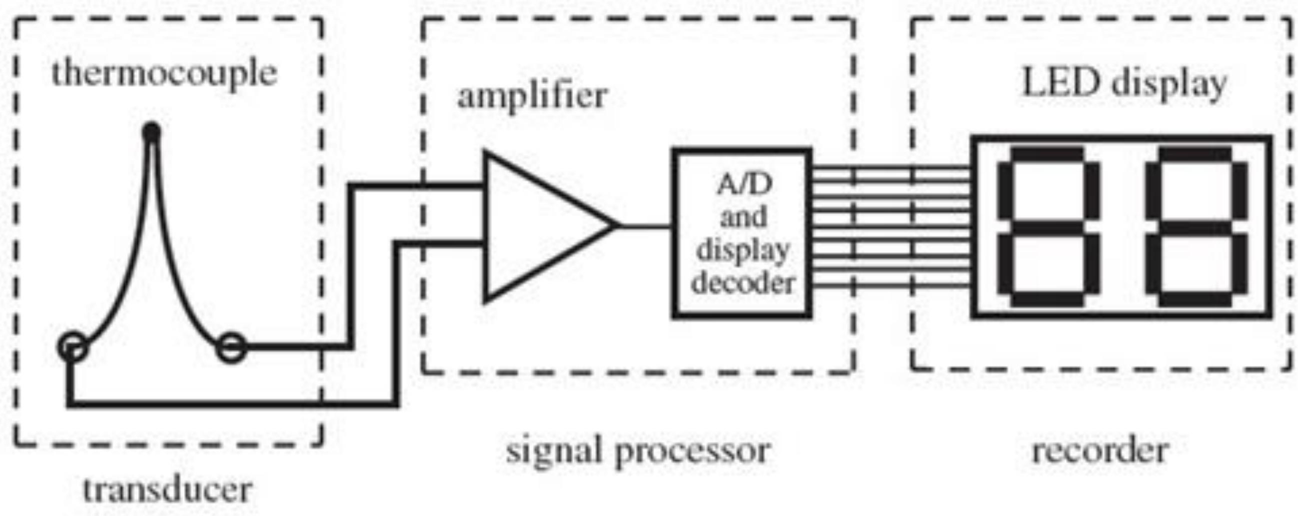


Transducer: Sensing device that converts a physical input into an output, generally a voltage (strain gauge, thermocouple..)

Signal Processor: It performs filtering, amplification or other signal conditioning on transducer output.

Recorder/Display: This might be simple display or a computer for online monitoring or subsequent processing.

Measurement System and Their Principles



https://joshigirish.wordpress.com/lecture-notes/mechatronics/introduction-to-sensors-and-transducers/

Converts Temperature to Small Voltage

- At the core of a sensor, there is a transducer. Transducer is a device which transforms energy from one type to another, even if both energy types are in the same domain.
  - Typical energy domains are mechanical, electrical, chemical, magnetic, optical and thermal.
  - Sensors are devices which monitor a parameter of a system, hopefully without disturbing that parameter.

Measurement System and Their Principles

Various types of sensors and their measurement objectives

Measurement Objective	Sensor
Distance: Linear/Rotational	
	Linear/rotational variable differential transducer (LVDT/RVDT)
	Optical Encoder
	Electrical tachometer
	Hall effect sensor
	Capacitive transducer
	Strain gauge elements
	Interferometer
	Gyroscope
Acceleration	Seismic accelerometer
	Piezoelectric accelerometer
Force, torque and pressure sensors	Strain gauge
	Dynamometers/ load cells
	Piezoelectric load cells
	Tactile sensor
	Ultrasonic stress sensor

Measurement System and Their Principles

Continued list of sensors:

Measurement Objective	Sensor
Flow	Pitot tube
	Orifice plate
	Flow nozzle, veturi tubes
	Rotameter
	Ultrasonic type
	Turbine flowmeter
	Electromagnetic flowmeter
Temperature	Thermocouples
	Thermistors
	Thermodiodes, thermo transistors
	RTD- resistance temperature detector
	Infrared type
	Infrared thermography
Proximity	Inductance, eddy current, hall effect, photoelectric etc.
Light	Photoresistors, photodiodes,phototransistors, photoconductors, etc.
	Charge-coupled device

Measurement System and Their Principles

Measurement 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

Safety Systems

- SIL: Safety Integration Level

It is the degree of confidence that a safety system will operate correctly. (IEC6150: Functional safety standards of electrical/electronic/programmable electronic safety related systems)

SIL	*Probability of dangerous failure per hour*	*Probability of dangerous failure per year*
4	10^{-9} to 10^{-8}	10^{-5} to 10^{-4}
3	10^{-8} to 10^{-7}	10^{-4} to 10^{-3}
2	10^{-7} to 10^{-6}	10^{-3} to 10^{-2}
1	10^{-6} to 10^{-5}	10^{-2} to 10^{-1}

Elements of a safety system.

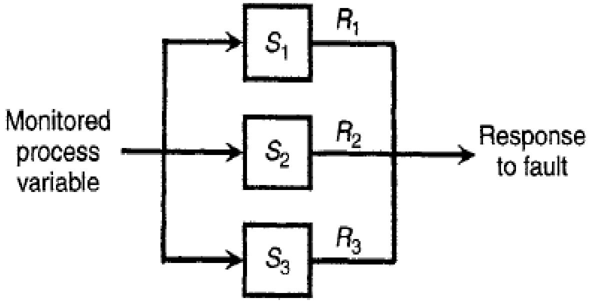
Safety Systems

- SIL: Safety Integration Level

It is the degree of confidence that a safety system will operate correctly. (IEC6150: Functional safety standards of electrical/electronic/programmable electronic safety related systems.

Two out of Three Voting Ex:

Shutdown action is taken if at least two out of three system indicate the requirement!



$$\begin{aligned} R_S &= \text{Probability of all three systems operating correctly} \\ &\quad + \text{Probability of any two systems operating correctly} \\ &= R_1R_2R_3 + (R_1R_2F_3 + R_1F_2R_3 + F_1R_2R_3) \end{aligned}$$

where R_1, R_2, R_3 and F_1, F_2 and F_3 are the reliabilities and unreliabilities of the three systems respectively. If all of the systems are identical (such that $R_1 = R_2 = R_3 = R$ etc.):

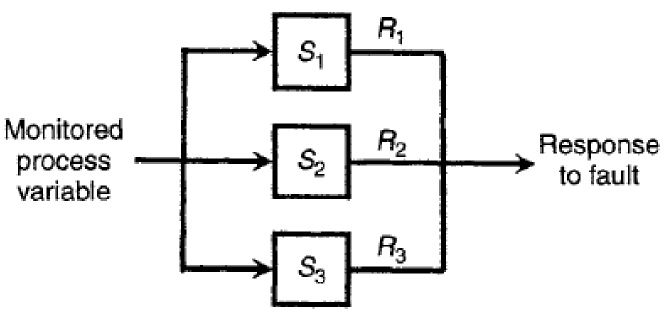
$$R_S = R^3 + 3R^2F = R^3 + 3R^2(1 - R)$$

Safety Systems

- SIL: Safety Integration Level

It is the degree of confidence that a safety system will operate correctly. (IEC6150: Functional safety standards of electrical/electronic/programmable electronic safety related systems.)

In a particular protection system, three safety systems are connected in parallel and a two-out-of-three voting strategy is applied. If the reliability of each of the three systems is 0.95, calculate the overall reliability of the whole protection system.



$$R_S = 0.95^3 + [3 \times 0.95^2 \times (1 - 0.95)] = 0.993.$$

Instrument Classification

1) Instrument Classification

- 1.1) Active/Passive Instruments

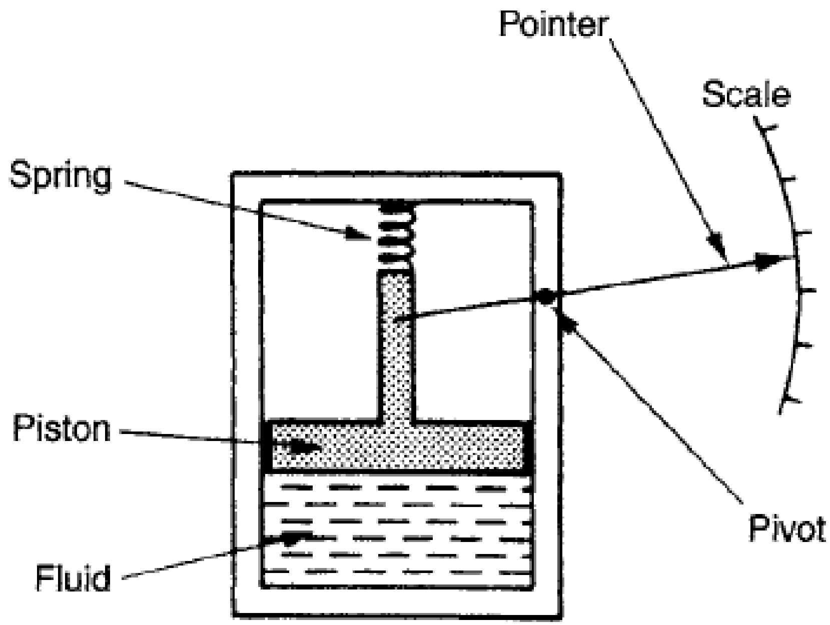
Passive Instrument: Output is entirely produced by the quantity measured.

Active Instrument: It modulates the magnitude of the quantity being measured.

1) Instrument Classification

- 1.1) Active/Passive Instruments

Passive Instrument: Output is entirely produced by the quantity measured.



Ref: Morris, Alan S., and Reza Langari. *Measurement and instrumentation: theory and application*. Academic Press, 2012.

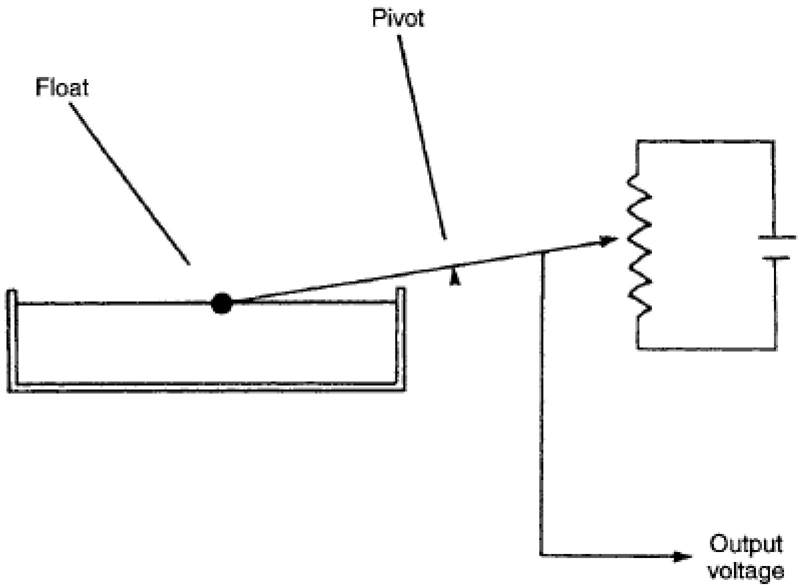
Passive pressure gauge.

The pressure of the fluid is translated into a movement of a pointer against a scale. The energy expended in moving the pointer is derived entirely from the change in pressure measured: there are no other energy inputs to the system.

1) Instrument Classification

- 1.1) Active/Passive Instruments

Active Instrument: It modulates the magnitude of the quantity being measured.

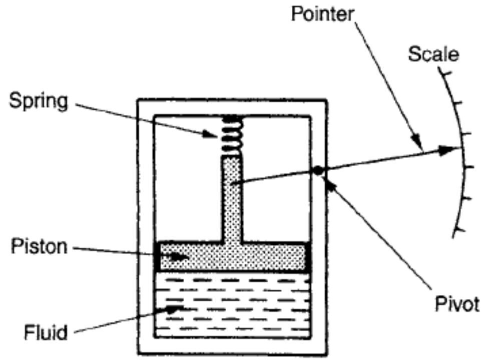


Ref: Morris, Alan S., and Reza Langari. *Measurement and instrumentation: theory and application*. Academic Press, 2012.

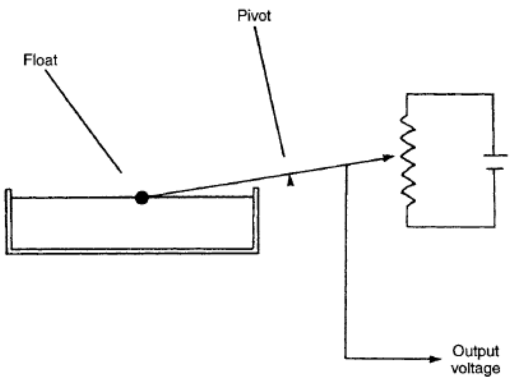
Petrol-tank Level Indicator

Here, the change in petrol level moves a potentiometer arm, and the output signal consists of a proportion of the external voltage source applied across the two ends of the potentiometer. The energy in the output signal comes from the external power source: the primary transducer float system is merely modulating the value of the voltage from this external power source.

1) Instrument Classification



Passive pressure gauge.



Petrol-tank Level Indicator

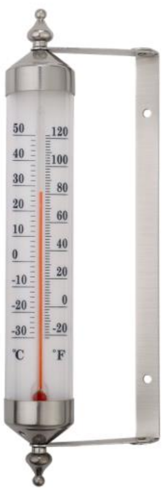
Passive instruments are normally of a simpler construction that active ones, which make them cheaper to manufacture.

The choice between active and passive instruments involves carefully balancing measurement resolution againist cost.

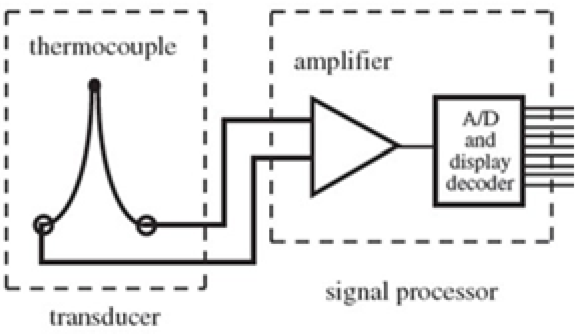
1) Instrument Classification

- 1.2) Monitoring/Control Instruments

This distinction comes from whether the instrument is suitable only for monitoring functions or whether their output is in a form that can be directly included as part of an automatic control system.



Monitoring Instrument



Control Instrument

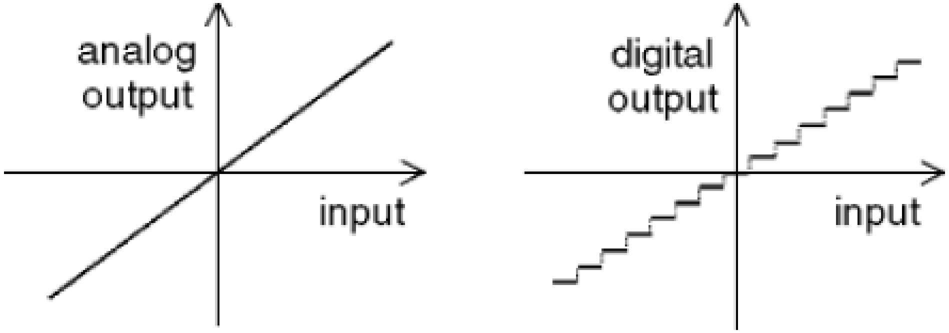
1) Instrument Classification

- 1.3) Analog/Digital Instrument

An analog instrument gives an output which varies continiously as the quantity being measured changes. (Pressure gauge, liquid level indicator..)

A digital instrument has an output which varies in discrete steps and so can only have a finite number of values (A digital thermometer, digital encoder..)

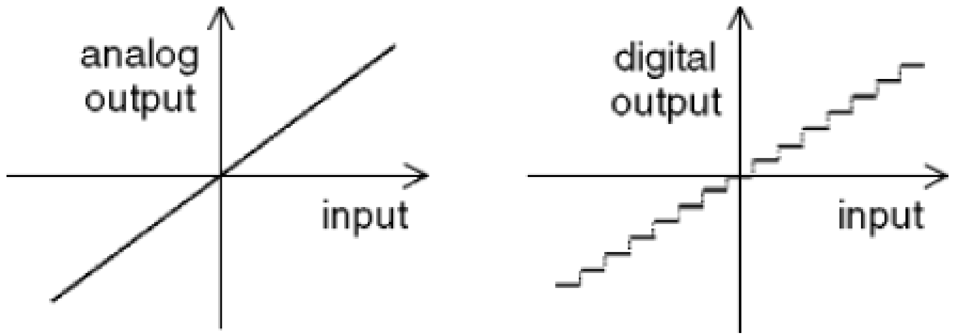
Analog instruments must be interfaced to the microprocessor by an analog-digital converter (ADC).



Sensor Characteristics/2

Analog vs Discrete:

- Analog sensors have an output that is continuous over a finite region of inputs.
- Examples of analog sensor include potentiometers, LVDTs (linear variable differential transformers), load cells, and thermistors.
- Digital sensors have a fixed or countable number of different output values. A common digital sensor often found in mechatronic systems is the incremental/absolute encoder.



2) Static Characteristics of Instruments

Accuracy, sensitivity, linearity and etc.. are critical datasheet properties for instruments.

It is important to note that the related values on datasheets are obtained under specified conditions. The real performance expectations should be quite lower.

Static characteristics are obtained in steady-state conditions!

2) Static Characteristics of Instruments

- 2.1) Accuracy

Accuracy is the degree of closeness between a measurement and its true value.

It is generally given as percentage of the full scale.

Example:

Let's say the inaccuracy of a pressure instrument is $\pm 1\%$ and its range is 0-10 bar.

If we measure 1bar, the real value is between 0,9bar and 1,1bar. The error is $\pm 10\%$ for 1bar measurement.

This means maximum error to be expected in any reading is 0,1 bar.

Result: If we are measuring pressures with expected values between 0 and 1 bar, we should not use an instrument with a range of 0-10bar.

!

2) Static Characteristics of Instruments

- 2.2) Precision

Precision is a term which describes an instrument's degree of freedom from random errors.

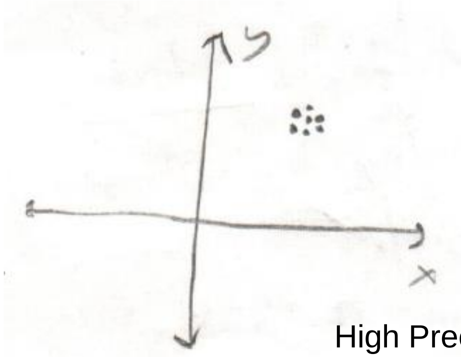
Precision must not be confused with accuracy.

High precision does not imply anythig about measurement accuracy.

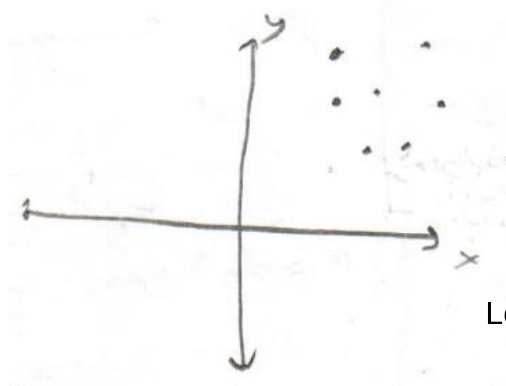
2) Static Characteristics of Instruments

- Accuracy-Precision Example

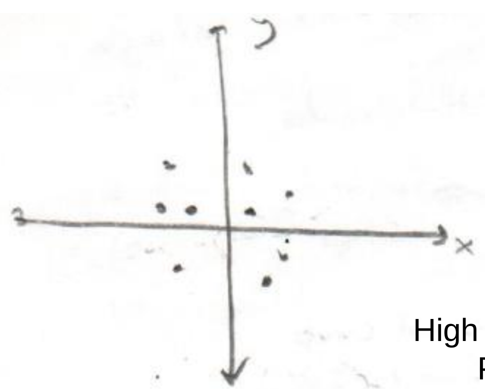
Let say our instrument provides a robot's position in 2D and the real postion is **origin.**



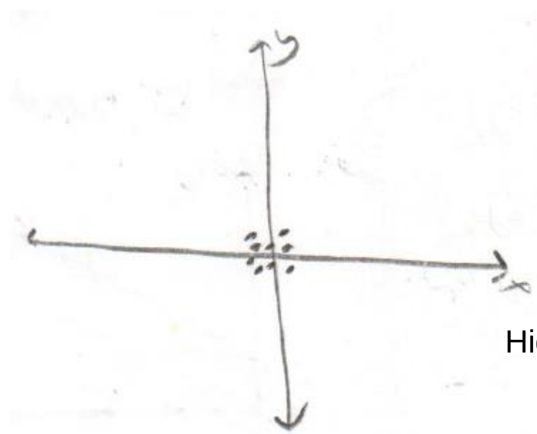
High Precision low accuracy



Low accuracy, low precision



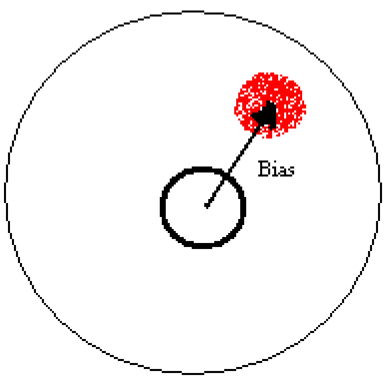
High Accuracy low Precision



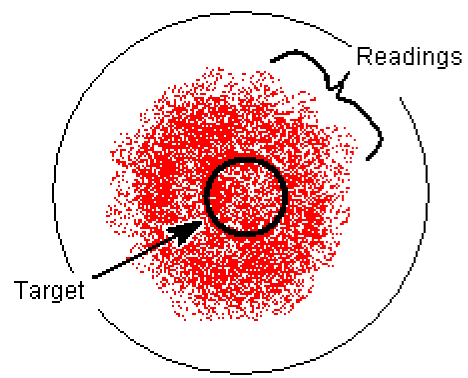
High Accuracy, high precision

2) Static Characteristics of Instruments

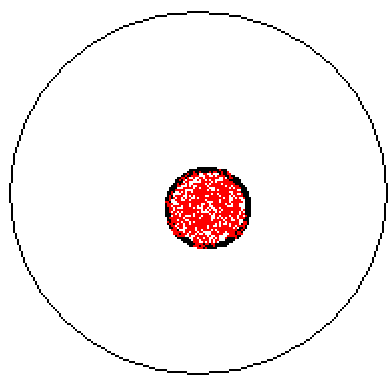
- Accuracy-Precision Example



High Precision low accuracy



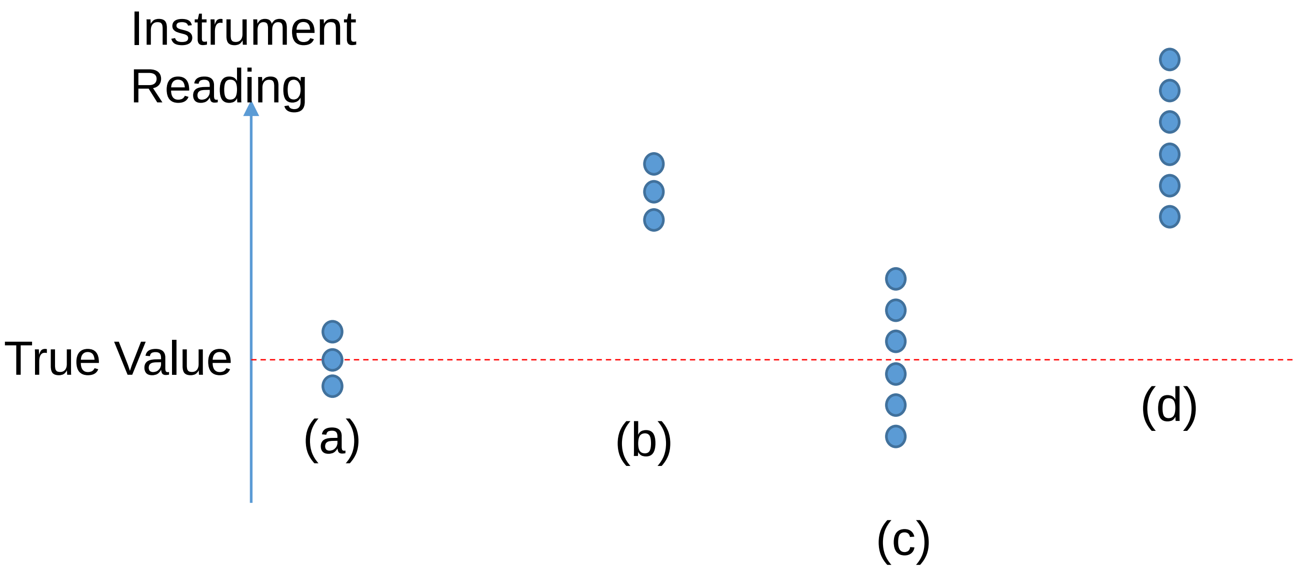
High accuracy low precision



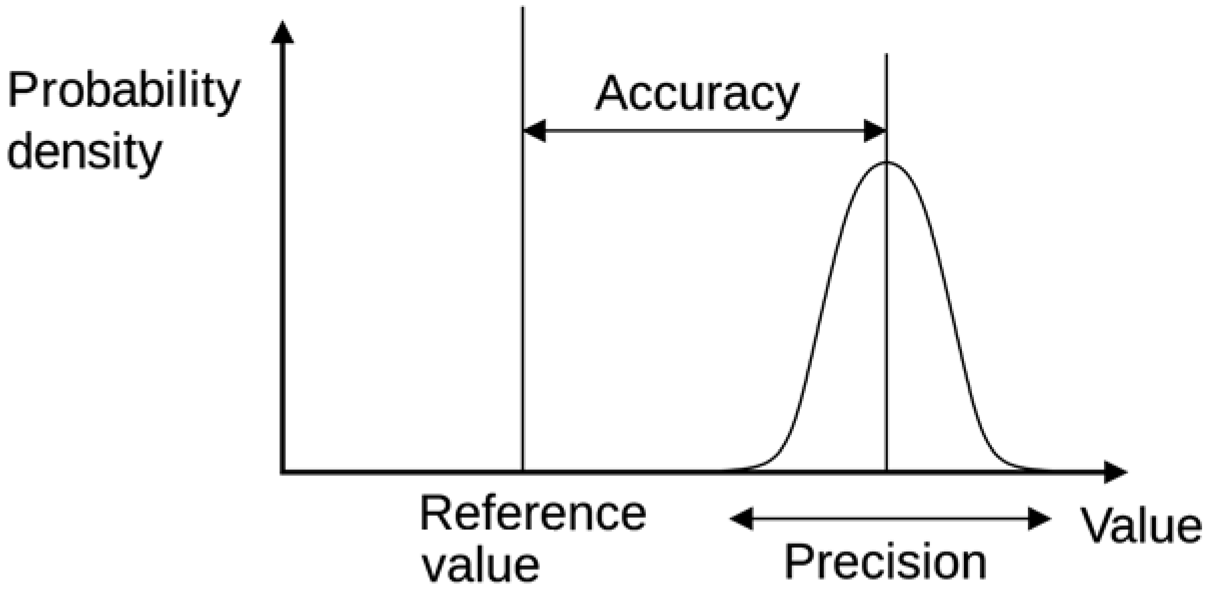
High precision high accuracy

2) Static Characteristics of Instruments

- Accuracy-Precision Example (1D)

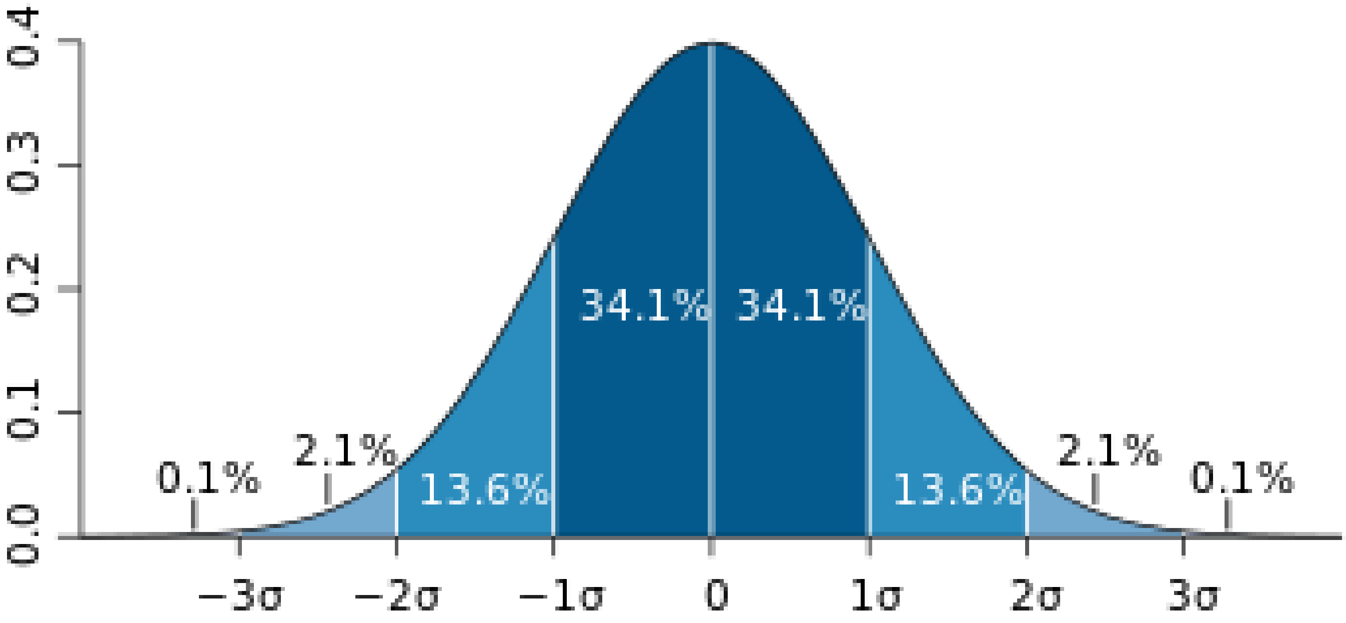


2) Static Characteristics of Instruments



‘In engineering, precision is often taken as three times Standard Deviation of measurements taken, representing the range that 99.73% of measurements can occur within’.

2) Static Characteristics of Instruments



https://en.wikipedia.org/wiki/Normal_distribution

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2) Static Characteristics of Instruments

- 2.3) Tolerance

Tolerance is a term which is closely related to accuracy and defines the maximum error which is to be expected in same value.

Example:

Diameter tolerance of crankshaft is 10^{-6} .
Resistor's tolerance is 5%. (This means 1000ohm labeled resistor should be expected to be between 950ohm and 1050ohm.)

Tolerance is mostly used for products, instead of a measurement.

2) Static Characteristics of Instruments

- 2.4) Range or Span

- The range or span of an instrument defines the maximum values of a quantity that the instrument is designed to measure. (Algebraic difference between maximum and minimum)

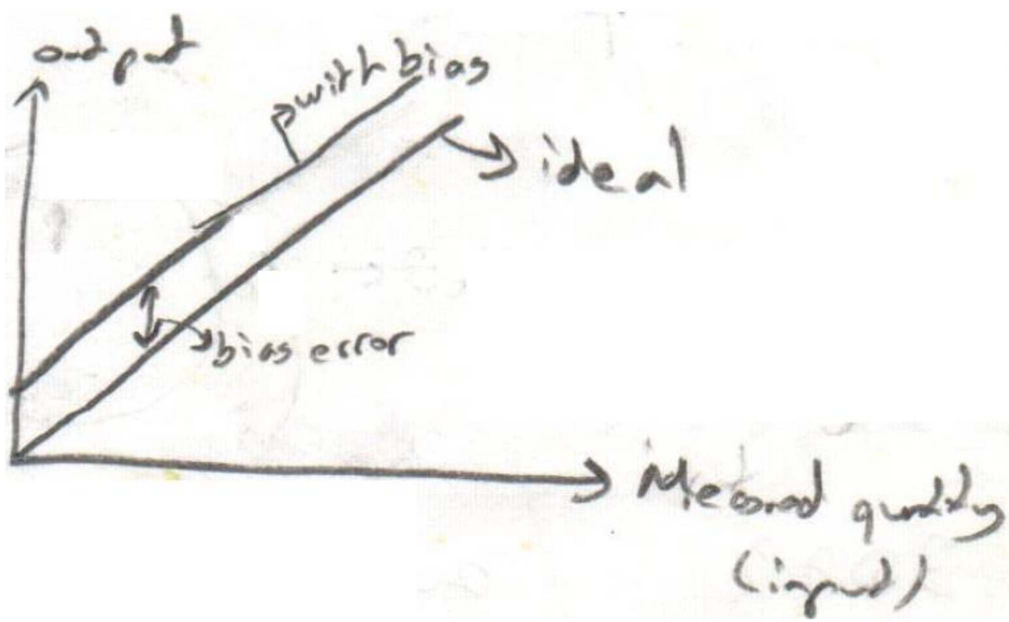
- **An instrument which has a reading range of –100°C to 100 °C.**

  span is 200 °C

2) Static Characteristics of Instruments

- 2.5) Bias

Bias describes a constant error which exists over the full range of measurement of an instrument.

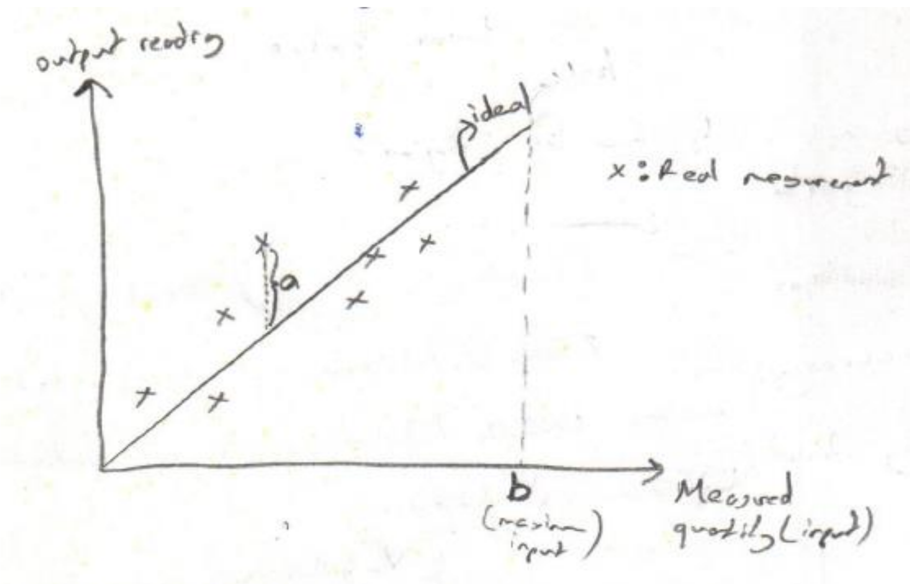


It is easily removable by calibration.

2) Static Characteristics of Instruments

- 2.6) Linearity

It is normally desirable that the output readings of an instrument is linearly proportional to the quantity being measured.



We can get a good fit straight line through the crosses, using least-squares line fitting technique.

2) Static Characteristics of Instruments

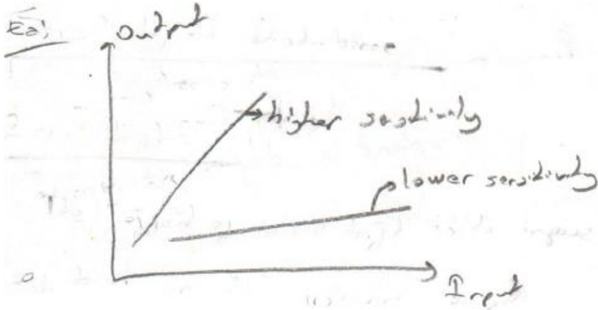
- 2.7) Sensitivity

Sensitivity is defined as the slope of the output characteristics. It is the measure of change in instrument output for a given amount of input.

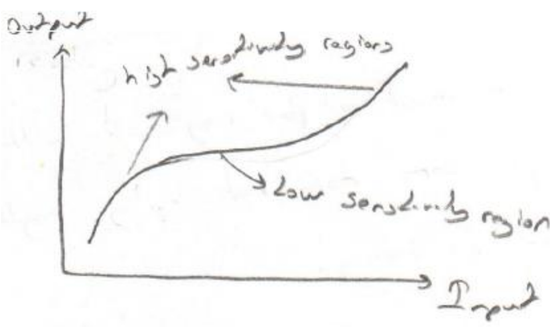
Example

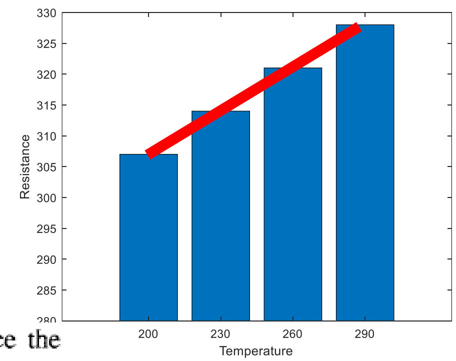
The following resistance values of a platinum resistance thermometer were measured at a range of temperatures. Determine the measurement sensitivity of the instrument in ohms/°C.

Resistance (Ω)	*Temperature* (°C)
307	200
314	230
321	260
328	290



If these values are plotted on a graph, the straight-line relationship between resistance change and temperature change is obvious.





For a change in temperature of 30°C, the change in resistance is 7 Ω. Hence the measurement sensitivity = 7/30 = 0.233 Ω/°C.

2) Static Characteristics of Instruments

- 2.8) Zero Drift and Sensitivity Drift

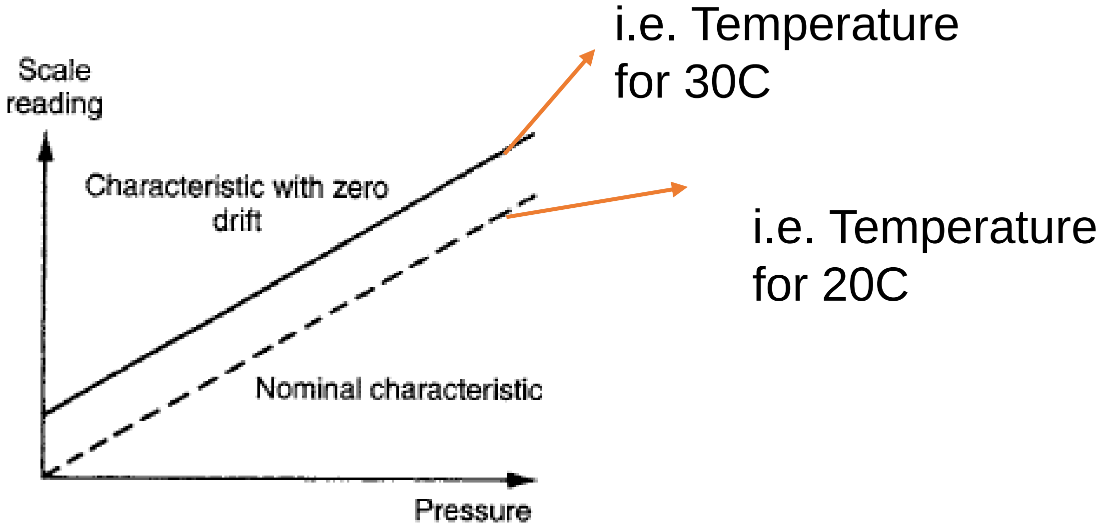
Drift is a variation in the output of a measurement device which is not caused by any changes in the input signal.

It generally happens when the ambient condition changes. (i.e. When the ambient temperature/humidity/pressure.. are different from the calibration values)

2) Static Characteristics of Instruments

- 2.8) Zero Drift and Sensitivity Drift

Zero Drift: In this case, zero reading of instrument changes and this change constantly affects all inputs.

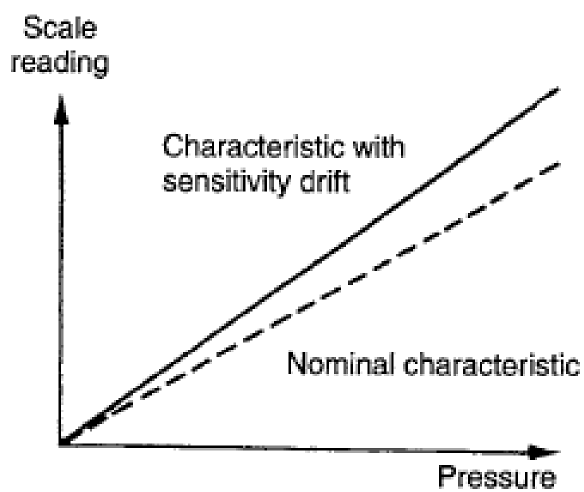


Zero drift is bias and normally removable by a recalibration.

2) Static Characteristics of Instruments

- 2.8) Zero Drift and Sensitivity Drift

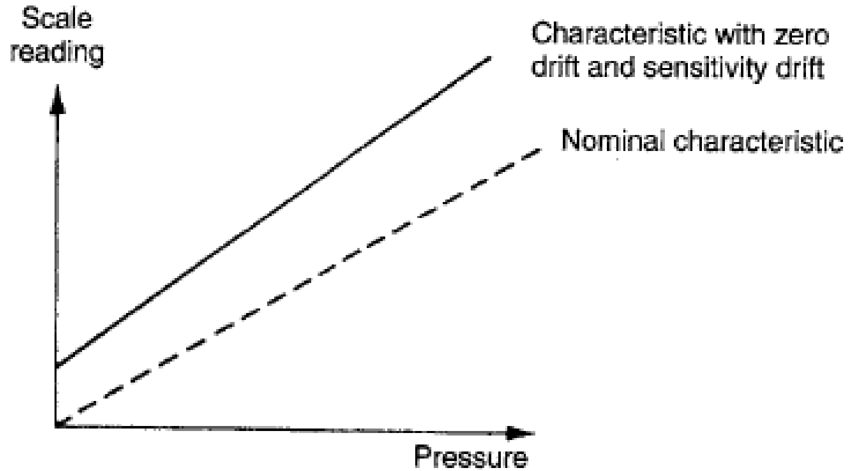
Sensitivity Drift: It defines the amount by which an instrument's sensitivity of measurement varies as ambient condition's change.



2) Static Characteristics of Instruments

- 2.8) Zero Drift and Sensitivity Drift

An instrument may suffer from both zero drift and sensitivity drift at the same time.



2) Static Characteristics of Instruments

- 2.8) Zero Drift and Sensitivity Drift

Example

A spring balance is calibrated in an environment at a temperature of 20°C and has the following deflection/load characteristic.

Load (kg)	0	1	2	3
Deflection (mm)	0	20	40	60

It is then used in an environment at a temperature of 30°C and the following deflection/load characteristic is measured.

Load (kg):	0	1	2	3
Deflection (mm)	5	27	49	71

Determine the zero drift and sensitivity drift per °C change in ambient temperature.

2) Static Characteristics of Instruments

- 2.8) Zero Drift and Sensitivity Drift

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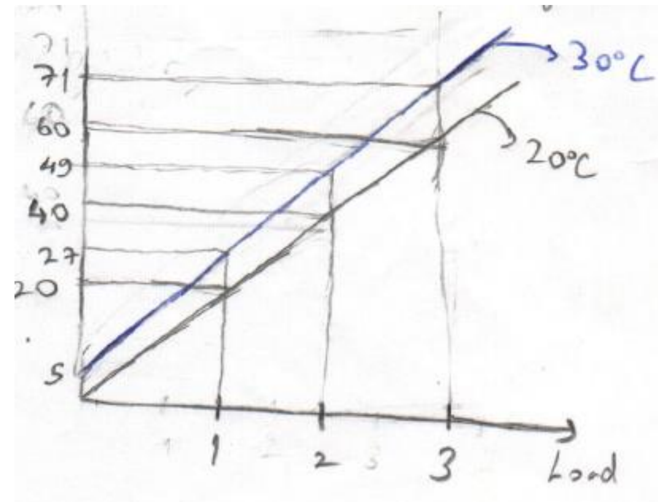
Determine the zero drift and sensitivity drift per °C change in ambient temperature.

Solution



At 20°C, deflection/load characteristic is a straight line. Sensitivity $= 20$ mm/kg.

At 30°C, deflection/load characteristic is still a straight line. Sensitivity $= 22$ mm/kg.

Bias (zero drift) $= 5$ mm (the no-load deflection)

Sensitivity drift $= 2$ mm/kg

Zero drift/°C $= 5/10 = 0.5$ mm/°C

Sensitivity drift/°C $= 2/10 = 0.2$ (mm per kg)/°C