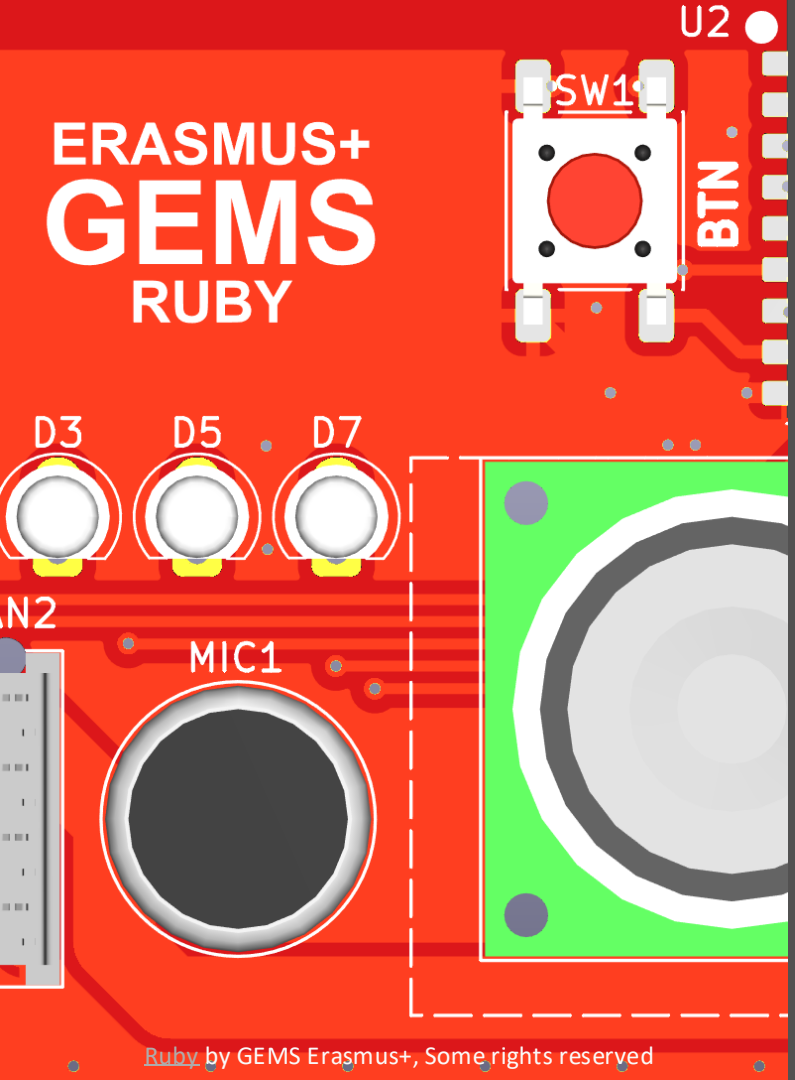

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Electronic Support for Sensing

From transducers to digital signals

Marta Marrón-Romera (University of Alcala)

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This lecture is focused on

- **Understanding the electronics** related to generic sensor modules
- Knowing the **general block diagram** of sensor electronics:

  basic **architectures**, **requirements** for processing, calibration and **errors**

This lecture is not focused on … go to further reading to know more

- Analyzing specific characteristics of each specific sensor
- Analyzing errors related to each specific sensor

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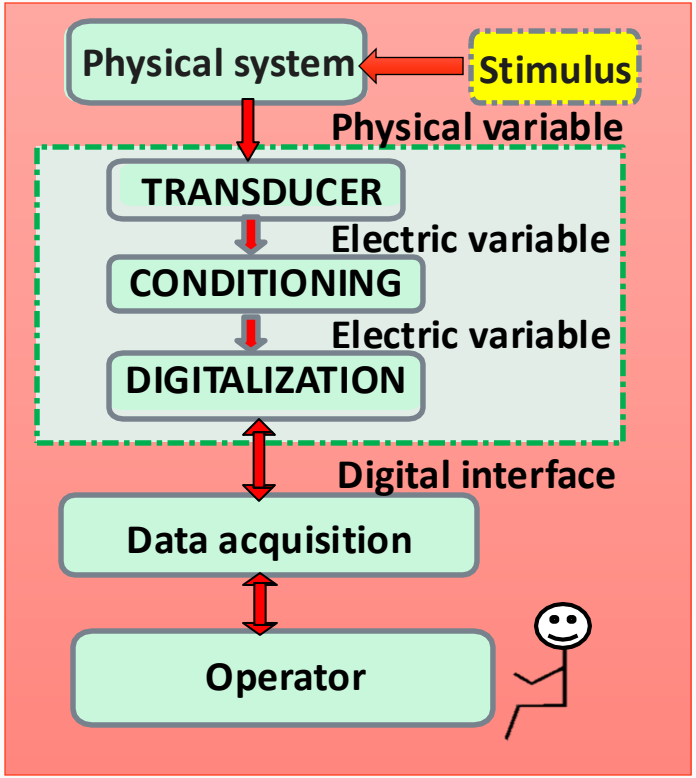
An **instrumentation system** is a collection of electronic devices designed to measure a physical variable in a specific environment or process

These systems provide
valuable data to help engineers
make informed decisions
in complex electronic devices,
and optimize their performance



Basic architecture for that instrumentation process

Notice:
Data acquisition is detailed in the following module

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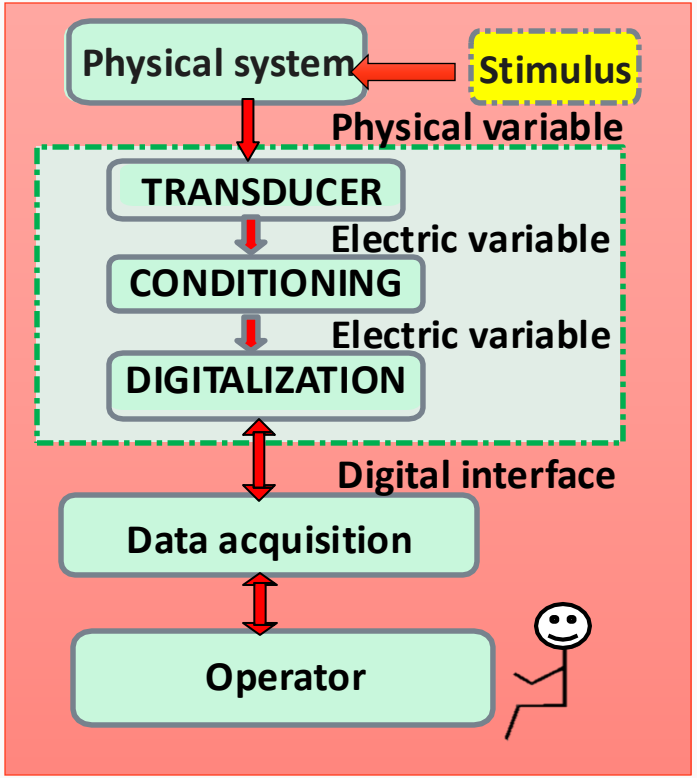
The **block diagram of a sensorial system** includes the following elements:

- **TRANSDUCER**: That captures and converts the sensor physical variable into electrical
- **CONDITIONING:** That optimizes the electric variable to process
- **DIGITALIZATION**: To convert the electric variable into a digital signal to later be processed in a microcontroller



Basic architecture for that instrumentation process

Notice:
Data acquisition is detailed in the following module

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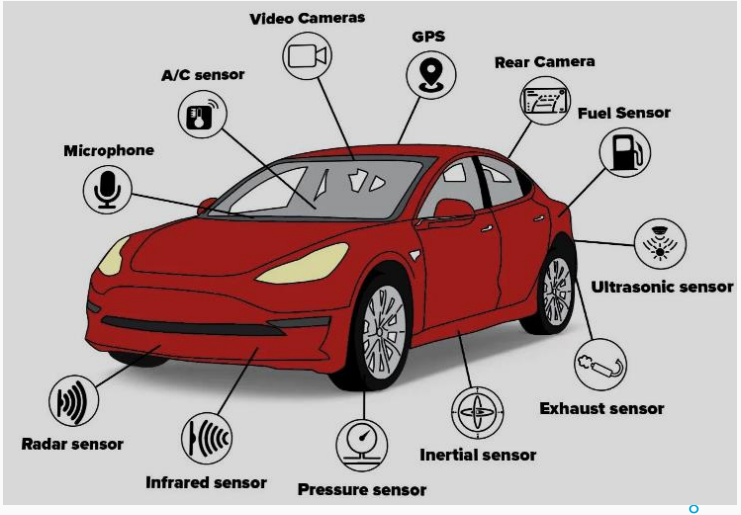
Key Components of a Sensorial System

1. **Sensors** and transducers: Devices that **detect physical phenomena** (e.g. temperature, pressure, light) and **convert them into electrical signals**
2. **Conditioning**: Circuits that **prepare sensor signals for further processing**, including amplification and filtering
3. **Data Acquisition** for digitalization: **Digitalize signals** for analysis

Some other Key Components

1. **Processing Units**: **Microcontrollers or Processors** that analyze the data and make decisions
2. **Communication Interfaces**: **Protocols / Hardware** to enable data transfer other systems
3. **Actuators**: Devices that **perform actions** based on sensed signal



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Practical Demonstration Ideas

- **Temperature Monitoring:** Use a temperature sensor connected to a microcontroller to display in real-time temperature readings on an LCD screen

- **Motion Detection:** Implement a motion sensor to trigger an alarm, photo or light when movement is detected

- **Health Monitoring:** Using a pulse sensor and a microcontroller to show heart rate on a display

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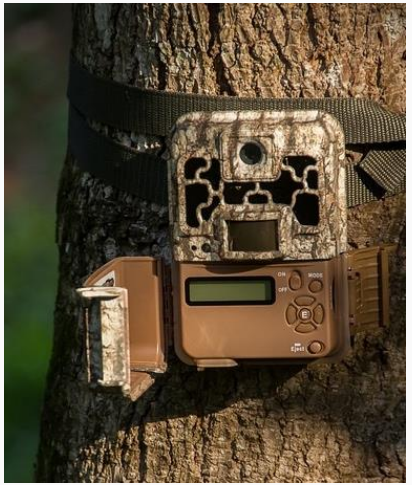

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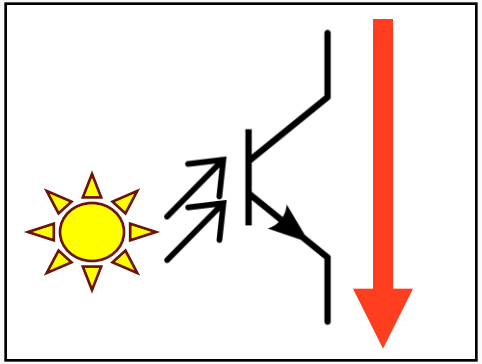
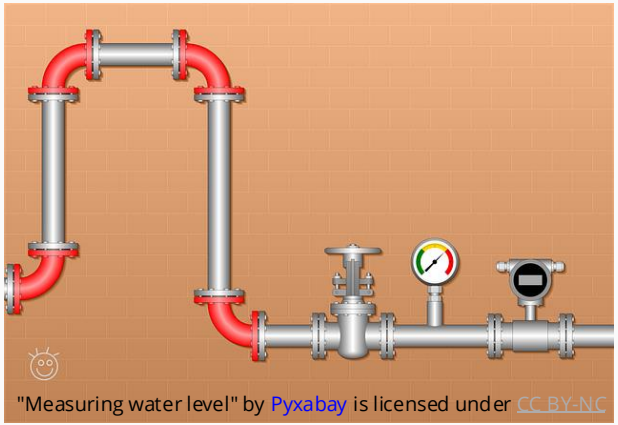
What is a transducer?

It is a device that **transforms a physical magnitude** (mechanical, thermal, magnetic, electrical, optical, etc.) in other magnitude, **usually electrical**

His name indicates the type of transformation,
i.e. electromechanical, photoelectric…

This stage is the part prior to conditioning one





"Measuring water level" by Pyxabay is licensed under CC BY-NC

Example: Solution for measuring the height of the water in a deposit

Transducer: potentiometer that converts the displacement in a variation of electrical resistance

Transducers Classification:

a) According to output variation:

- **Detectors**: Output is 2 levels (1/0)
  Depending on whether a physical magnitude is over a threshold
- **Sensors**: Output takes different values depending on the magnitude value

b) According to the energy they require:

- **Active**: Do not need polarization, as it is provided by the measured signal
  e.g. microphone electrodynamic
- **Passive**: They need a power source to work
  e.g. thermistor

c) Physical magnitude to be measured: According to the one to which it is sensitive

Transducers Static Characteristics

They describe its **performance in permanent regime** or with very slow changes in the variable to be measured

They give rise to fixed errors. **BUT Errors can be corrected**

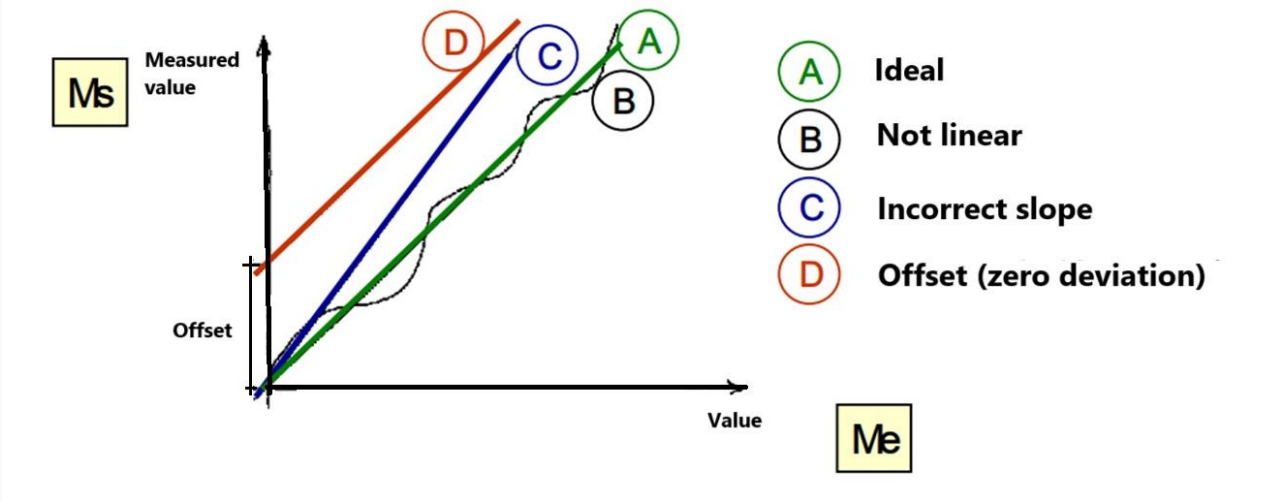
Basic characteristics of the sensors:

- **Overrange**: Maximum operating range (depending transducer power supply)
- **Hysteresis**: Output behavior difference when measurement increases or decreases
- **Repeatability**: Maximum variation in output, obtained measuring the same input several times with the same sensor in identical environmental conditions

Transducers Static Characteristics

In a measurement process there may be errors, giving rise to differences between the output obtained (Ms) and its ideal value (Me)

MOST of these errors can be corrected, if THEY ARE CONSTANT AND KNOWN by the transducer characterization



Transducers Static Characteristics

- **Offset**: Deviation from zero (D example)
- **Linearity**: Deviation from a straight line in the response (B example)

- **Sensitivity**: Ratio of output variation with a magnitude one
- **Resolution**: Minimum variation of input magnitude that can be observed at output
- **Response speed:** Capacity of the measurement to follow the variations of the input

- **Accuracy:** Maximum expected error
- **Measurement range:** Range of the magnitude with certain output precision assured
- **Error band:** Zone around the ideal output with expected error as a % of full scale

Calibration: **Test to adjust accuracy**. Known outputs for specific inputs are applied

Transducers Dynamic Characteristics

They describe the **behavior** of the sensor **in the transient period**
Characterize the system when the measurement varies

- **Rise time:** It is the time necessary for the response to go from 10% to 90% of its final output value
- **Response time:** Time that elapses to reach 90% of its output final value
- **Delay time:** It is the time necessary for the response to reach 50% of its final output value

Therefore, the transducer **time constant** shows the speed of the system for a given input to reach steady state

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What is a conditioning stage?

This block includes all transformations performed on the electrical signals in the output of the transducer

Reasons for the transducer's output to be conditioned:

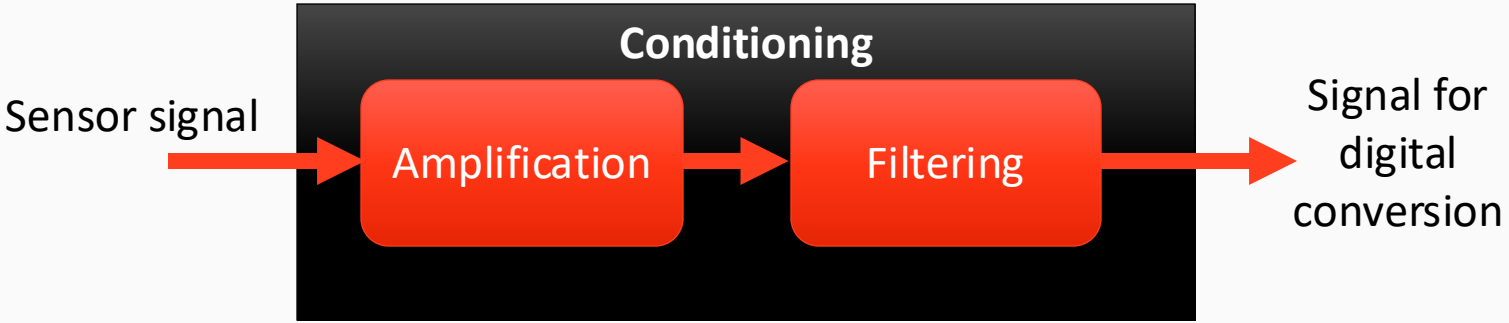
- To transform the electrical signal provided by the transducer into a voltage

  E.g. in resistive transducers, to convert the resistance value into voltage
  E.g. with capacitive or inductive transducers, they are usually mounted as part of an oscillator, where the output magnitude is a frequency

- To increase the **relationship sign-noise** up suitable levels

Conditioning

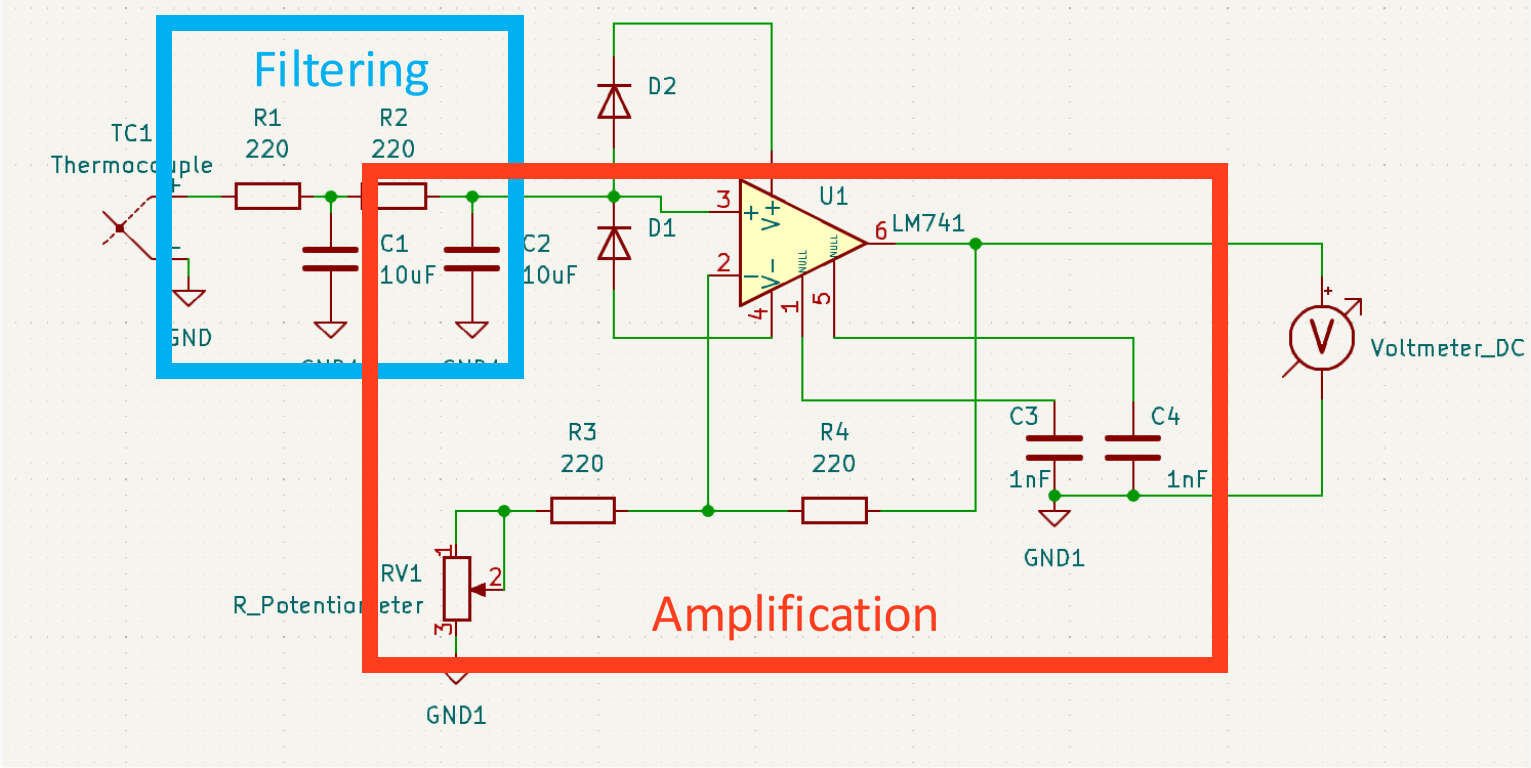
- **Amplification**: Increases the signal power level
- **Filtering**: Eliminates unwanted signal components



NOTICE: What comes first?... It depends…

Conditioning

Involves additional electronics after the transducer and before the digital output



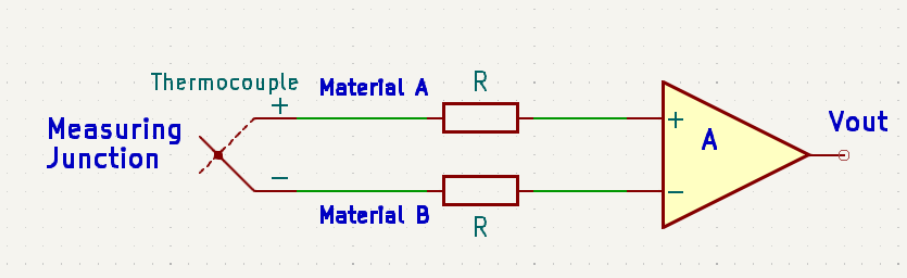
Amplification

Signals from physical transducers usually have a small amplitude, which makes them difficult to be used directly

Amplifying at higher values may also to help separate and eliminate noise without altering the original sensor data

The amount of amplification depends on the gain values needed

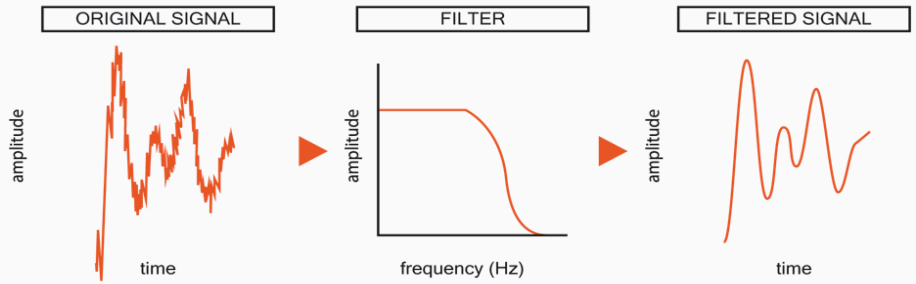
An operational amplifier is an option for this function

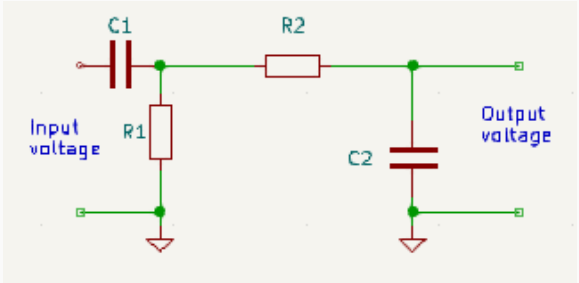


Amplification can be beneficial in thermocouple where the output signal is in the millivolts

Filtering

It consists of filtering the signal's frequency spectrum, **preserving valid data** and blocking all noise





Filters can consist of passive and active components or a digital algorithm

- **A passive filter** uses exclusively capacitors, resistors and inductors with a maximum gain of one
- **An active filter** uses passive components combined with active components, such as operational amplifiers and transistors

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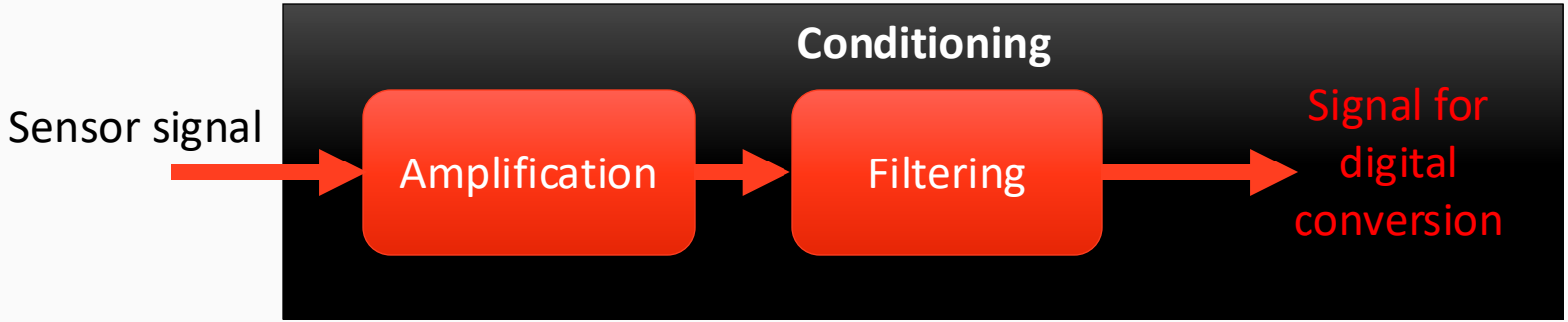
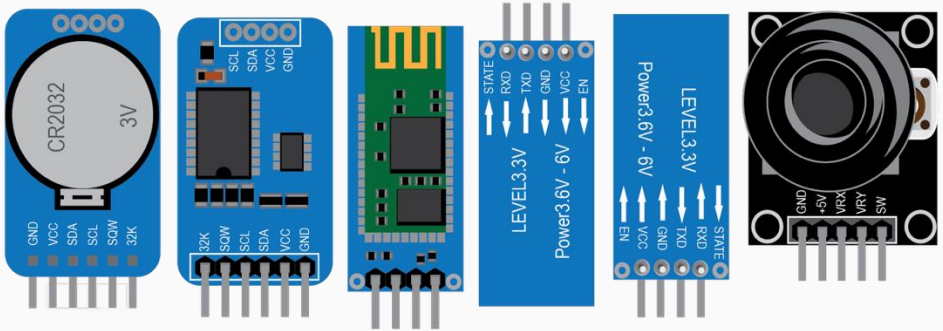
An **integrated sensor** refers to the set of **sensors and electronic components** designed to collect and process data from the physical variable to the digital signal

These systems are completely **manufactured to work in a specific environment** (communication, functionality, ranges, etc.)



This is the case of HC-SR04 module in GEMS



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Types of errors

Systematic error: it **occurs in the same way in all measurements**

It may be **caused by a defect** in the instrument
It **can be qualitatively modeled** and avoided through calibration

Random or accidental error: inevitable error that occurs due to unique events that are impossible to model nor control during the measurement process

Sources of random errors **are difficult to identify**
They are **numerous and small,** but **their accumulation may be dangerous**
Cause **measurements to fluctuate around an average**
Thus, **defined by a statistical criteria**, generally with Gaussian distribution
Can be **reduced by statistical processes,** increasing the number of samples

Uncertainty: **Error** is the difference between the real and measured value
Meanwhile the **uncertainty** is the estimation of error

The **absolute uncertainty** is **difference between the highest and lowest** meas
I.e. uncertainty is the **margin of error in which this measurement occurs**

Example:

We measure a resistance of 3.4Ω and, by measuring the resistance twice, we obtain the results 3.35Ω and 3.41Ω

The errors produced the values of 3.35Ω and 3.41Ω, while the range between 3.35 and 3.41 is the uncertainty range

As **statistically modeled,** uncertainty is usually defined with **% probability**
I.e. Vo=10V±10mV/95%

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What and why?

- **Comparison of an instrument reliability** with another of known quality, to validate / improve / adjust it
- Calibration must be done **periodically**
- **All commercial sensorial systems are subject to calibration regulations**

European Union

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum:2403020211_2

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[1] Automation Forum. What is Instrumentation & Control?
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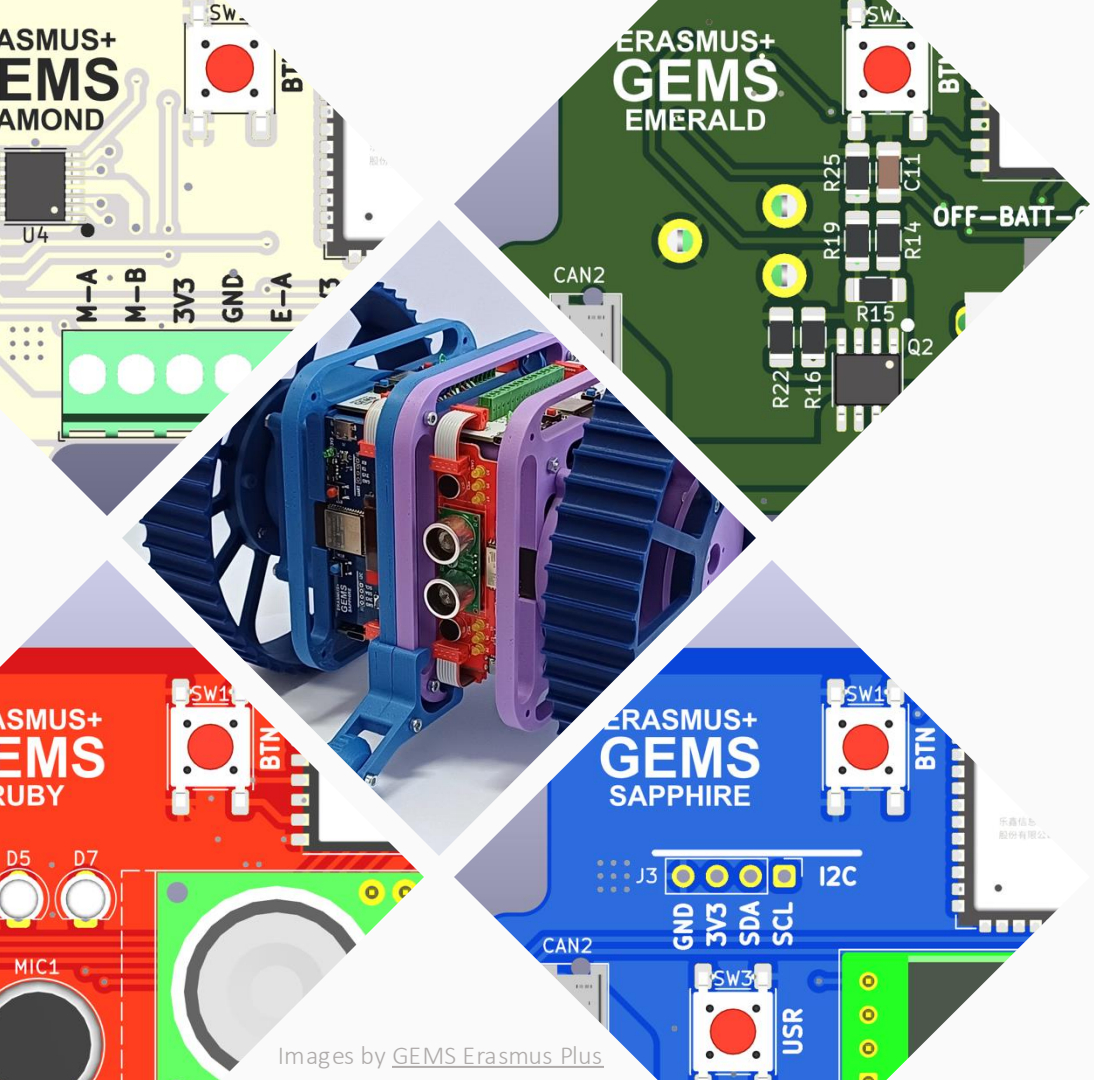

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