POLITECNICO
MILANO 1863

Introduction about sensors

SENSOR SYSTEMS

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termal → optical

TRANSDUCER = **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.

Transducer can be further divided into **Sensors** and **Actuators**

SENSOR is a transducer = **device which monitor a parameter of a system, hopefully without disturbing that parameter.**

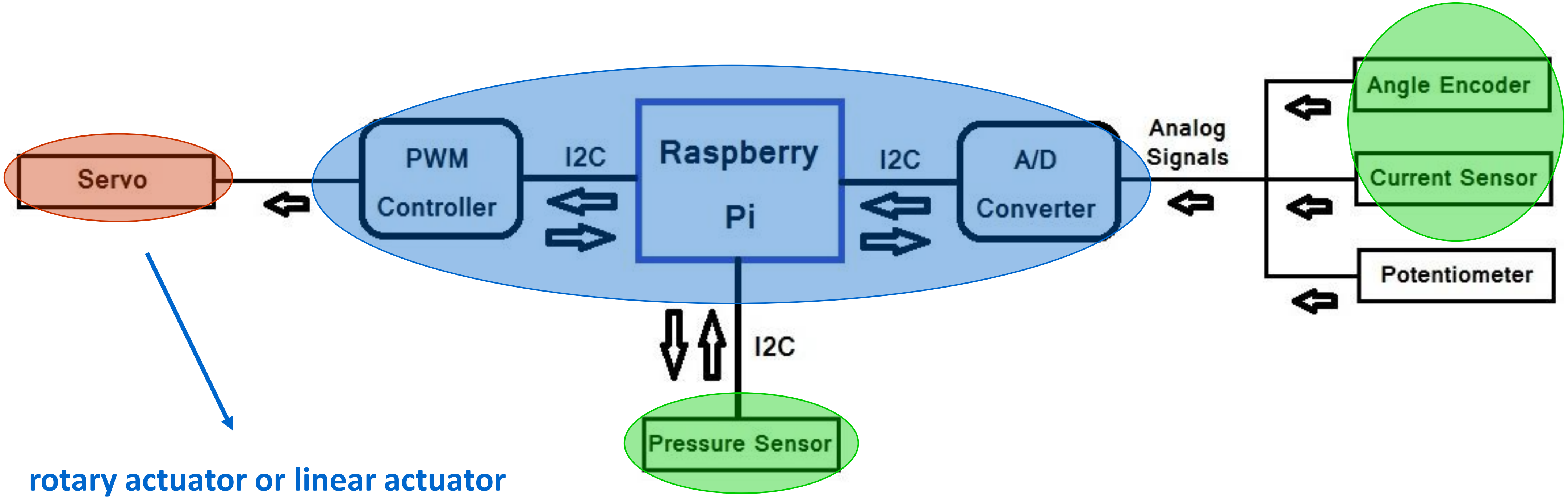
from physical to electrical

The specific input could be light, heat, motion, moisture, pressure,
or any one of a great number of other environmental phenomena.
The output is generally a signal that is converted to human-readable
display at the sensor location or transmitted electronically over a network
for reading or further processing.

from electrical to control moving parts

ACTUATOR = **component of machines which is responsible for moving or controlling a mechanism or system.**

actuator ⇐ electronics ⇐ sensors



rotary actuator or linear actuator
that allows for precise control
of angular or linear position,
velocity and acceleration

Classification based on **physical phenomena**

active pixel sensors

- Optical: visible/IR light (photodiode, CCD, CMOS APS, infrared sensor)
- Thermal: temperature (RTD, thermistor, thermocouple…)
- Magnetic: magnetic field (Hall effect sensor, magneto-resistive sensor)
- Mechanical: strain (strain gauge), force (piezo-electric sensor), displacement and distance (capacitive, inductive, acoustic, optical), acceleration and orientation (MEMS), viscosity, pressure, etc.
- Chemical: pH (pH-meter) (not treated)

Classification based on **measuring mechanism**

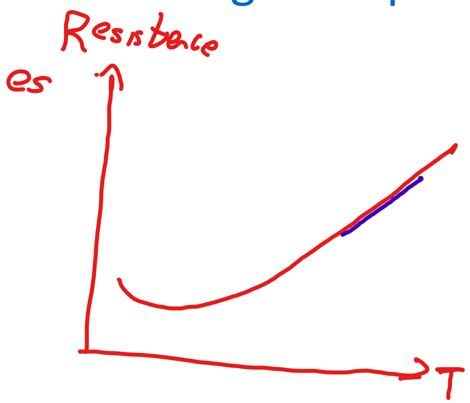
- Resistive sensing
- Capacitive sensing mic, accelerometer
- Inductive sensing proximitive, mic
- Piezoelectricity force sensors
- Hall Effect magnetic field
- MEMS mycro elettro mechanical sensors

Which sensors will we study?

Physical phenomena	Sensor
Sound	- Microphone
Light and images	- Photodiode - CCD - CMOS sensor
Temperature	- Resistance Temperature Detectors (RTD) - Thermistors (NTC and PTC) - Thermocouple - Infrared thermometer
Magnetic Field	- Hall effect sensors - Magneto-resistances
Strain, force, pressure	- Strain gauges - Piezoelectric sensors
Displacement, proximity, distance and rotation	- Capacitive sensors - Inductive sensors - Acoustic sensors - Optical sensors
Acceleration and Orientation	- Accelerometers (MEMS) - Gyroscopes (MEMS)

Sensitivity: the ratio between the change in the output signal to a small change in input physical signal. Slope of the input-output fit line.

$$\boxed{S = \frac{\partial\, out}{\partial\, in}}$$



Resolution (LSB): the smallest increment of measure that a device can make (Least Significant Bit).

Resolution of ADC in the sensor (mV) expressed in terms of the measure you want to take

Full Scale Range (FSR): the maximum interval of measure that a device can cover.

Number of bits (n): in sensors with digital output 2^n is the number of levels in which the FSR is divided.

↳ bits of ADC

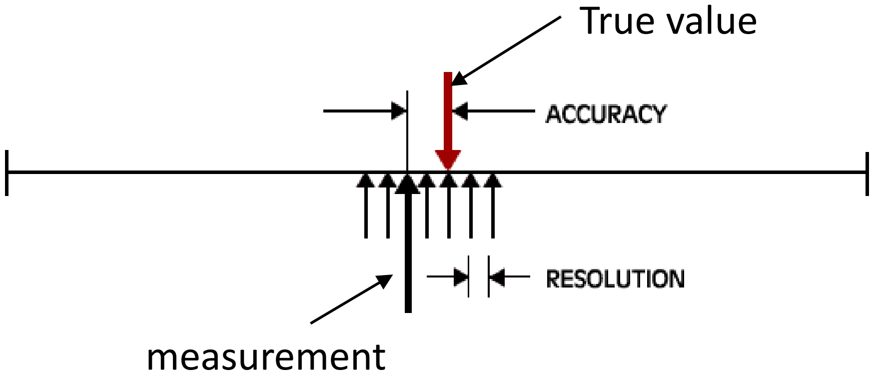
$$2^n = \frac{FSR}{LSB}$$

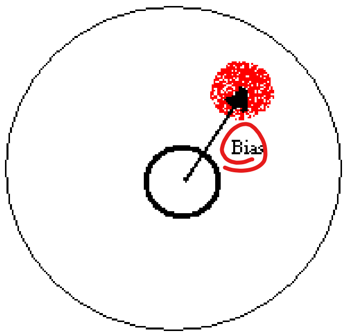
Sensors' characteristics (2)

Accuracy: error between the result of a measurement and the true value being measured.

Repeatability/Precision: the ability of the sensor to output the same value for the same input over a number of trials.

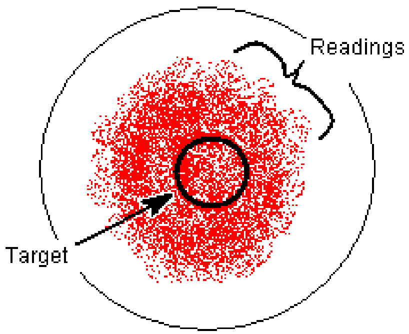
ripetibilità



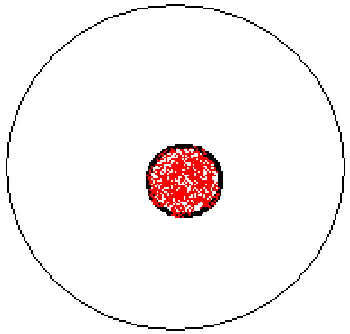


Precision without accuracy

correct for the bias



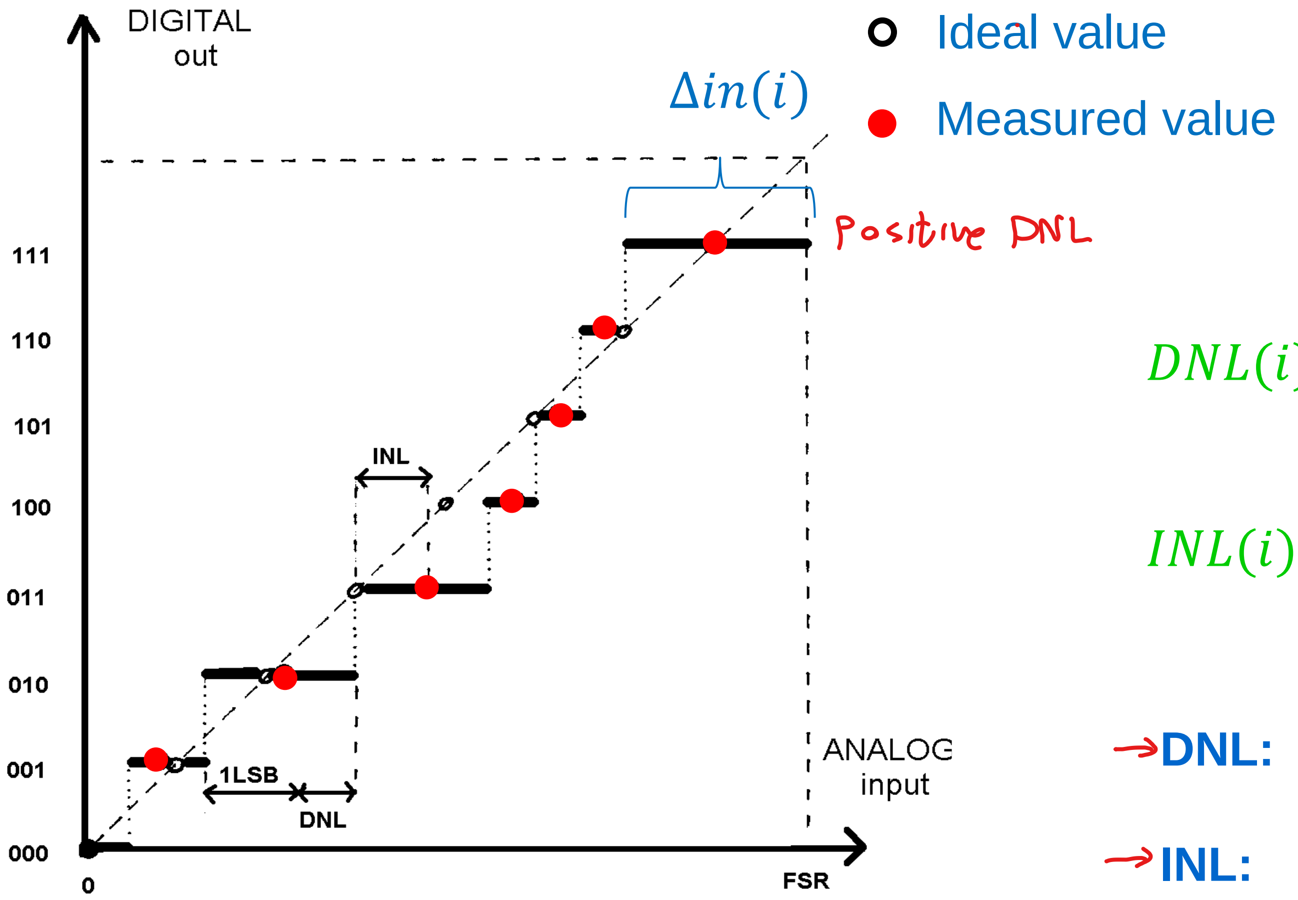
Accuracy without precision



Precision and accuracy

Linearity: the deviation of the output from a best-fit straight line for a given range of the sensor.

Differential Non-Linearity (DNL) and Integral Non-Linearity (INL)



$$DNL(i) = \Delta in(i) - LSB$$

$$INL(i) = \sum_{k=1}^{i} DNL(k)$$

distance between ideal linear center (white) and real center (red)

far from linear andamento

→**DNL:** Differential Non-Linearity

difference of the real step, compared to the ideal one (i.e. 1 LSB)

→**INL:** Integral Non-Linearity

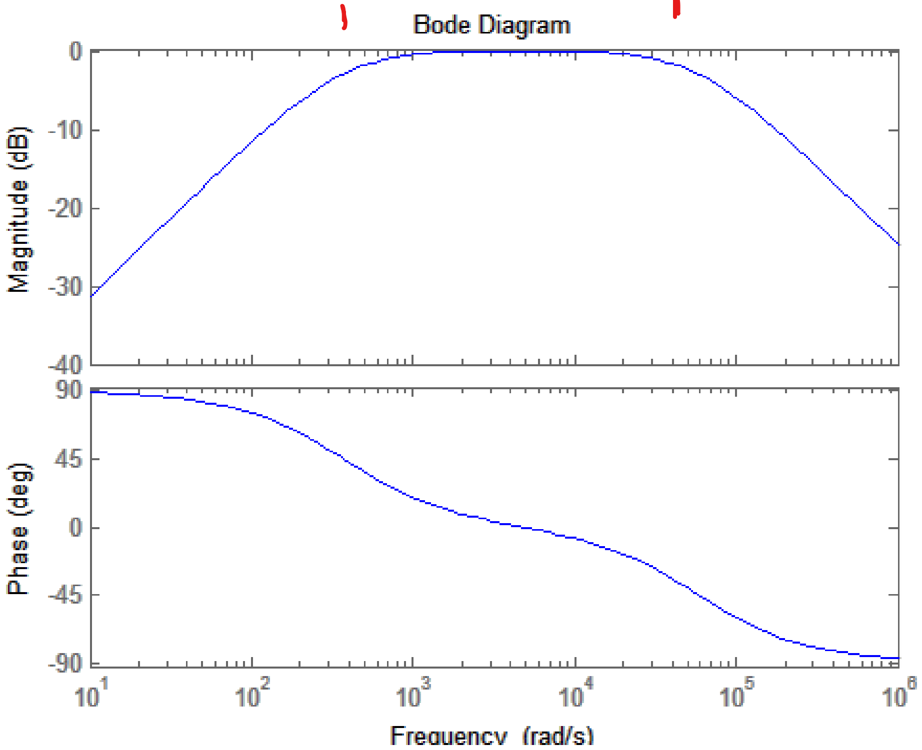
distance between real and ideal output voltage

Sensors' characteristics (4)

- **Transfer Function** (Frequency Response): The relationship between physical input signal and electrical output signal, which may constitute a complete description of the sensor characteristics as a function of frequency.

- **Bandwidth**: the frequency range between the lower and upper cutoff frequencies, within which the sensor transfer function is constant gain or linear.

bw1 bw2 bw3 (?)



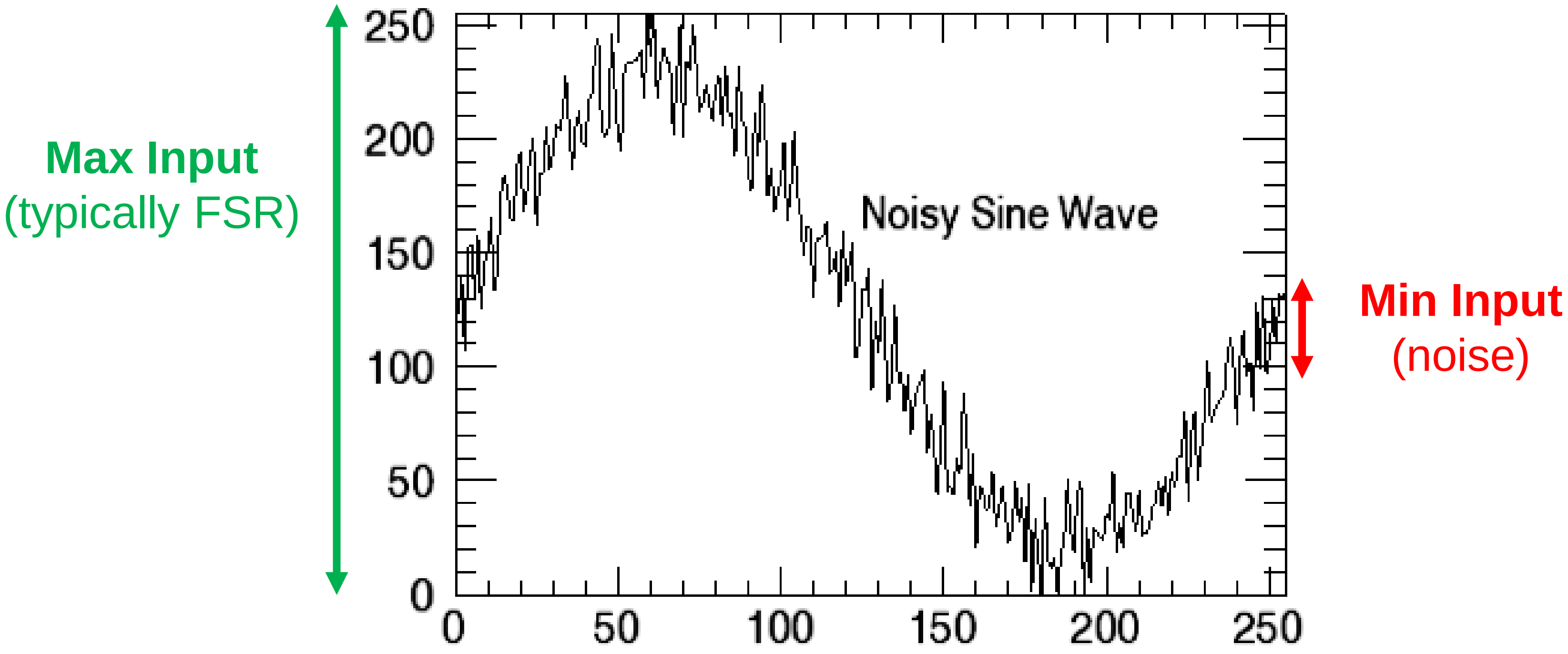
Sensors' characteristics (5)

→ average ø and RMS (root mean square)

Noise: random fluctuation in the measured value. It is quantified with its rms (root mean square) value.

Dynamic Range: the ratio of maximum recordable input amplitude to minimum input amplitude:

$$DR = 20 \cdot Log\left(\frac{Max\ Input\ Amplitute}{Min\ Input\ Amplitude}\right)$$ (expressed in dB)

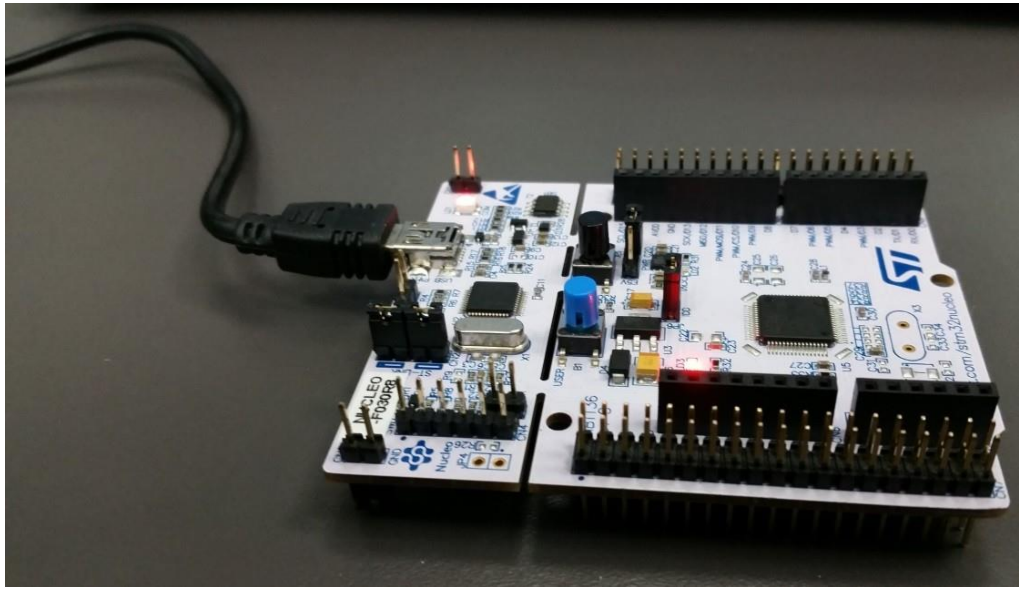


Analog sensor readout

- ADC + microcontroller
  many microcontrollers have a built-in ADC
  (typically 8-bit to 12-bit or even 16-bit)

- Data Acquisition Cards (DAQ)
  - ✓ PC card or external devices with analog and digital I/O
  - ✓ interface through LabVIEW or user-generated code

    software to display data analog



Smart sensor

= sensor with built-in signal processing & communication
(e.g., combining a “dumb sensor” and ADC / processing)

Digital output:

- parallel bus

- serial I/O

  synchronous (with clock): SPI, I^2C
  (must match byte format, stop/start bits, parity check, etc.)

  - Serial Peripheral Interface (SPI)
    1 clock + 1 bidirectional data + 1 chip select/enable

  - Inter Integrated Circuit (I^2C)
    1 clock + 1 data

  UART (slower) ← asynchronous (no clock): one wire
  (must match baud rate and bit width, transmission protocol, etc.)

  - frequency encoded
    use timing port, measure pulse width or pulse frequency

Sensors can exhibit non-ideal effects

- offset: nominal output ≠ nominal parameter value, with a fixed difference
- nonlinearity: output not linear with parameter changes
- cross parameter sensitivity: secondary output variation with other parameters (e.g., temperature drifts)

Calibration = adjusting output to match parameter

- analog signal conditioning
- look-up table
- digital calibration

  $T = a + bV + cV^2$,

  - T= temperature; V=sensor voltage;
  - a,b,c = calibration coefficients