Robotics
Intelligent sensors (intro)

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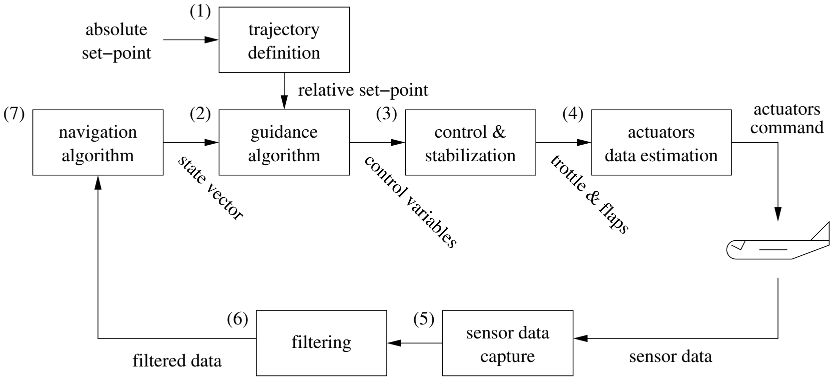
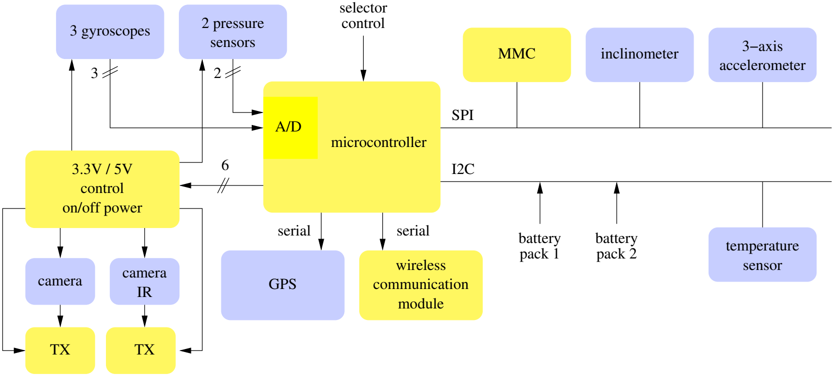
http://robot.unipv.it/toolleeo

Example of control loop



control system scheme of an autonomous aerial vehicle

Example of multi-sensor platform



enhanced inertial measurement unit (IMU) and other components for the autonomus navigation of an aerial vehicle often the terms **transducer**, **sensor** and **actuator** are used ambiguously

- a **transducer** is a device that converts a type of energy (mechanical, chemical, etc.) into electric signals – or vice versa
- alternatively, a transducer is sometimes defined as any device that converts between two types of energy
- an **actuator** is a device used to produce some actions on the controlled physical system
- a **sensor** is a component that transforms a physical quantity (mechanical, chemical, etc.) into an electrical signal, to be used as input of a control system
- sensors and actuators ARE transducers

Examples of sensors

- proximity : ultrasound, radar, capacitive sensor
- angular position : encoder, switch, potentiometer
- absolute position : GPS
- light level : photo cell, camera
- sound level : microphone
- deformation : strain gauge
- temperature : thermometer
- gravity : inclinometer (accelerometer)
- acceleration (linear) : accelerometer
- rotational speed : gyroscope
- contact : switch
- current : current transformer, Hall effect
- time : clock

the distinction is based on different use of energy

1. **passive sensors**: part or all the output power from the sensor is provided by the sensor itself
2. **active sensors**: an external source of energy must be provided to power some sensor components

input and output signals may or may not have the same form of energy (electrical, mechanical, chemical, etc.).

examples:

- passive sensors: speedometer, some accelerometers, pressure sensors, thermometers
- operational amplifier, servo-mechanism

Analog vs digital sensors

the distinction is based on the type of output signal

1. **analog sensors**: the output is an analog quantity, often a variable voltage
2. **digital sensors**: the output is a digitally encoded value

Analog vs digital sensors

- in case of analog sensors, the output value *is* the output voltage
- in case of digital sensors, the physical output is a voltage that represents the two binary values (e.g. 0 if $0V < v < 2.2V$ and 1 if $2.8V < v < 5V$); this makes the voltage sampling more immune to disturbs
- the output value is encoded as a binary number, i.e., sequence of binary digits (e.g. 01010001)
- the sampling rate (the frequency of the measurements) of an analog sensor is determined by the sampling system; for digital sensors it depends on the sensor and the adopted digital interface
- a digital sensor is often built around an analog sensor (e.g., the digital inclinometer is based on the analog accelerometer)

Type of processing

distinction based on the component that
performs the processing of the information

- **digital electronics** : e.g., the voltage level changes abruptly when an object interrupts the light flow of a photo cell
- **analog signal processing** : e.g., filtering is needed to separate the voice from the noise in the signal coming from a microphone
- **computing** : e.g., image processing to recognize entities of interest

Deflection vs null sensors

the distinction is based on working characteristics

1. **deflection**: some physical effect is produced on sensor elements by the measured quantity
2. **null**: the sensor uses some energy to counterbalance the effect of the measured quantity; the measurement is based on the required amount of energy

Deflection vs null sensors: examples

deflection sensor
spring scale balance

null sensor
double-pan balance

in general, null sensors are more accurate, since they can work in a close interval of the equilibrium point, improving the linearity

Range

defined by lower and upper limits of the measurement interval

examples:

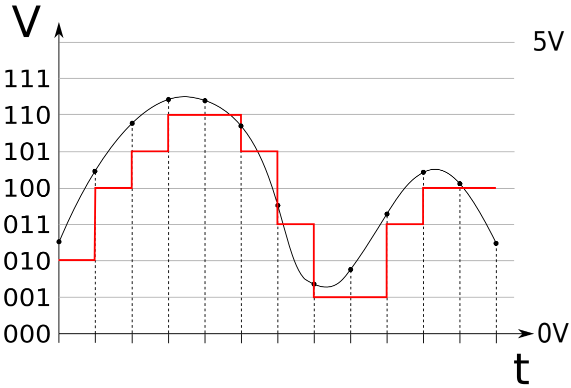
- some IR (infrared) proximity sensors have a sensing range spanning from 1 to 10 cm
- some acoustic proximity sensors have a sensing range spanning from 40 to 300 cm
- some LIDAR (Laser Imaging Detection and Ranging) sensors have a sensing range spanning from 0.1 to 30 m (e.g., Hokuyo UTM-30LX-EW)
- sonars (SOund Navigation And Ranging) can have a sensing range of several kilometers

Resolution

- minimum difference between two measurements
- for digital sensors, it depends from the resolution of the integrated A/D converter

examples:

range [volt]	resolution [bit]	# intervals	resolution [mV/sample]
5	3	7 (i.e., $2^3 - 1$)	710
5	10	1023 (i.e., $2^{10} - 1$)	4.88



sampling and quantization of an analog signal

- measurement range: $0 - 5$ volts
- A/D resolution: 3 bit

Dynamic range

- indicates the spread between lower and upper limits of sensor inputs
- it is expressed as the ratio between the maximum and minimum measurable input, expressed in decibels (dB)

$$\text{Dynamic Range} = 10 \log \frac{\text{Upper Limit}}{\text{Lower Limit}}$$

example:

- an acoustic proximity sensor having sensing range between 40 and 300 cm has a dynamic range of

$$\text{Dynamic Range} = 10 \log \frac{300}{40} = 8.75 \quad \text{dB}$$

Bandwidth

the frequency at which the sensor can provide a sequence of samples

the upper limit of sensor sampling frequency depends on

- the physical phenomenon leveraged by the transducer
- the sampling rate of the A/D

examples:

- a sonar may take some seconds to get the return signal
- the GPS returns a measurement every 1s (frequency 1 Hz)
- a rapidly changing physical quantity (e.g., acceleration or rotational velocity) may be sampled at 100 Hz or more

Sensitivity

ratio of output variation to input variation

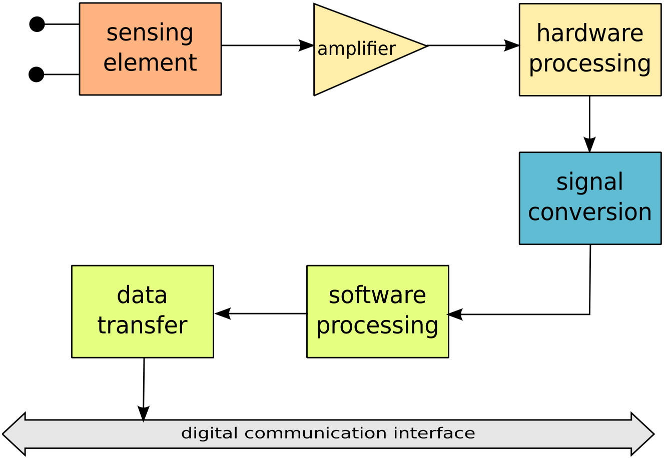
example:

- for acoustic proximity sensors: input is a distance, output is a voltage
- a sensitivity of 0.01 [volt/cm] means that there is a variation of 0.01 volts for each cm distance measured

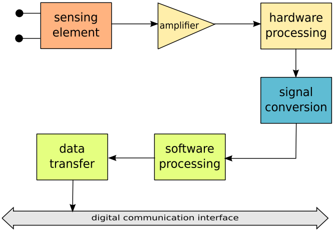
NOTE: cross-sensitivity is a different thing: it means that a sensor measurement may be influenced by other environmental factors higher sensitivity allows better measurements

- consider to have a given resolution of the A/D (e.g. 10 bits)
- the sampling range is $0 - 5$ volts
- therefore, the voltage sampling resolution is 4.88 [mV/sample]
- sensitivity 0.01 [volt/cm] : $0.01/0.00488 \sim 2$ samples/cm
- sensitivity 0.1 [volt/cm] : $0.1/0.00488 \sim 20$ samples/cm

general scheme of an intelligent sensor



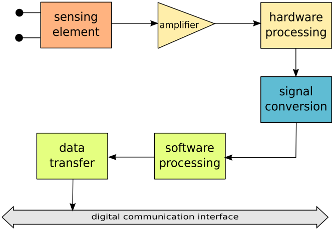
Intellingent sensors



sensing element

- usually made by an analogue sensor
- preferably, it should be possible to integrate it in silicon
- primary topic of upcoming lessons

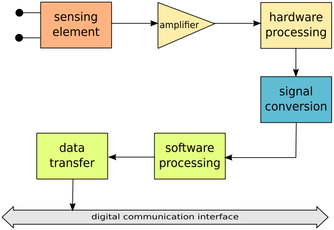
Intellingent sensors



amplifier

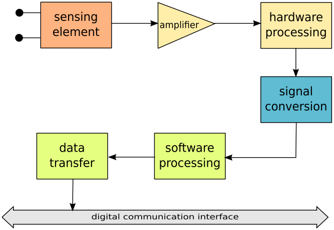
- required to increase the analog voltage level
- important issue: signal-to-noise ratio
- amplification also increases the noise level

Intellingent sensors



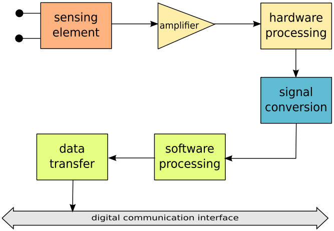
hardware processing

- usually this is synonymous to analog filtering
- analog filtering may be needed since
  - signal aliasing must be reduced
  - digital filtering may take too much computation time



signal conversion

- voltage sampled by an Analog-to-Digital converter
- issues:
  - non-linear distortion
  - quantization error
  - sampling frequency

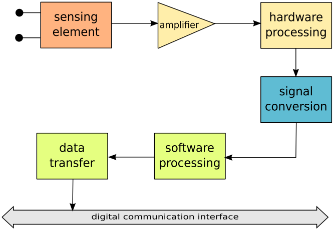


software processing

- digital filtering
- data aggregation
  (many samples are aggregated into one or more value)

peculiar feature of intelligent sensors

Intellingent sensors



data transfer

- information encoding and trasmission
- represents the actual interface of the intelligent sensor
- bottleneck of the sensor reading rate