SMART SENSORS FOR DOMOTICS AND HEALTH CARE

- Sensors and Smart sensors

A.A. 2018 / 2019

Alessandra Flammini

ELECTRICAL QUANTITIES: A SUMMARY

ELECTRICAL CHARGE Q

Electrical charge [measured in Coulombs] is a property of electrons and atoms. Electrons have small negative charge. Energizing (heating, radiating,..) a specimen can extract or add electrons, charging it

CURRENT I

Current [Ampere] is a flow of electrical charges (e.g. electrons). Sign of current is the opposite of the sign of electrons flow.

VOLTAGE V

An electric field (electrical charge distribution) generates a differential voltage $V_{AB}=V_A-V_B$. Measured in Volt [V] voltage is related to: the discharge of a lightning, $220V_{AC}$ at the domestic electrical plugs, the signal furnished by a battery

RESISTANCE R

Resistance [Ohm] of a material is the property to oppose to the current flow when a differential voltage is applied. $V=R\cdot I$. Metals and sea water have low resistance, plastic or wood has high resistance

CODES: A SUMMARY

BINARY CODING

A bit is an information that can assume two states only:

- True or false, on or off, positive or negative, 1 or 0

DECIMAL CODING

A decimal code is an information that can assume ten states only:

- 0,1,2,3,4,5,6,7,8,9 (e.g integer decimal coding: $381,2 = 3\cdot10^2+8\cdot10^1+1\cdot10^0+ 2\cdot10^{-1}$ floating point decimal coding $3,812\cdot10^2$)

FINITE INTEGER CODING

- a string of bit can code integer

$$b_7b_6b_5b_4b_3b_2b_1b_0 = b_7 2^7+ b_6 2^6+ b_5 2^5+ b_4 2^4+ b_3 2^3+ b_2 2^2+ b_1 2^1+ b_0 2^0$$

this code can express integer numbers from 0 to 2^8-1

$b_{n-1}b_{n-2}\ldots b_1b_0 2$ can express integer numbers from 0 to 2^n-1

FINITE REAL CODING

- a real coding allow to express number in floating point. Computer real numbers are expressed in terms of mantissa f and exponent e (Number = $1.f*2^e$) where f and e are finite and, typically, {f,e} is contained in 32 or 64 bit

THE CONCEPTS OF SENSOR AND OF ACTUATOR

SENSOR

An element with a physical (or chemical or other) input, the Measurand, and a “readable” output

Physical or chemical quantity (e.g. temperature, light intensity, length, heart rate, weight, …) → Sensor →

Readable output
- readable by humans
- readable by machines (voltage [V], current [A])

ACTUATOR

An element with an electrical or an “actionable” input (command) and a physical output

Command
- by humans (light switch, bicycle)
- by machines (voltage, current)

→ Actuator →

Physical output
- motion, heat, light,…

EXAMPLES OF SENSORS AND OF ACTUATORS

SENSORS for humans

Special materials that change their color or their volume or their shape
- Thermometer, sundial
- Wind direction and intensity (Flag)

SENSORS for machines

Materials or devices that change an electrical characteristic (voltage, current, resistance, capacitance, …)
- Thermometers, barometers, Humidity sensors, light sensors, gas sensors
- position/velocity sensors
- magnetic field sensors
- Video cameras and infrared cameras
- sensors for human body (e.g. heart rate sensor)

ACTUATORS by humans

A touch or a pressure or a movement affects the physical quantity
- Light switch and other switches (produce or interrupt current flow)
- Hand mixer, Bicycle
- Heating wind or by contact

ACTUATORS by machines

A voltage or a current command modify the speed of a motor or the flow of a fluid, and so on
- Oven, fans, air conditioners
- Motors
- Electromagnets for lifting or moving
- Lamps, Laser
- Pumps and valves

EXAMPLES OF SENSORS AND OF ACTUATORS

DIGITAL or BINARY SENSORS

Sensors whose output has only 2 states

- True or False, Good or no good, 0 or 1
- Easy to be managed

ANALOG SENSORS

Sensors whose output has more than two states

- Discrete sensors

The number of possible states is finite (eg. A sensor whose output is a color –red, yellow, blue or green-)

- Continuous sensors

The number of possible states in infinite (e.g. a sensors whose output is between 0 and 5 V)

DIGITAL or BINARY ACTUATORS

Actuators whose command has only 2 states

- True or False, open or closed, left or right, on or off, 0 or 1
- Easy to be managed

ANALOG ACTUATORS

Actuators whose input has more than two states

- Discrete actuators

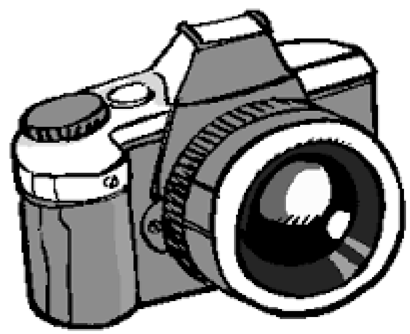
The number of possible states is finite (eg. A heater with three possible speed of the fan –knob with 3 positions-)

- Continuous actuators

The number of possible states in infinite (e.g. a motor with variable speed)

SENSORS AND ACTUATORS: tests

CLASSIFY (Sensor/Actuator, Binary/Discrete/Continuous, humans/machine)



- Thermometer
- Lamp
- Camera
- Webcam
- Defibrillator

SENSORS AND ACTUATORS: tests

CLASSIFY (Sensor/Actuator, Binary/Discrete/Continuous, humans/machine)

<u>Solutions</u>

• Thermometer

Sensor, continuous, readable by humans

• Lamp

Actuator, binary, controlled by humans and by machine (both)

• Camera

Sensor, continuous, readable by humans

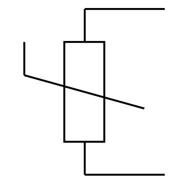
• Webcam

Sensor, continuous, readable by machine

• Defibrillator (semiautomatic)

Sensor and actuator (it is a system!), the sensor is continuous and readable by machine (the black box that records the ECG), the actuator is binary and auto-controlled

“ROUGH” SENSORS



“ROUGH” SENSOR

A material or an element that changes its output C (resistance, capacitance,..) according to the measurand M.

It should have:

- High repeatability $\quad C = f(M)$ and not $C = f(M, time)$
- High linearity $\quad C = \alpha \cdot M + \beta \quad$ for $\quad M_{min}<M<M_{max} \rightarrow M = (C-\beta)/\alpha$
- High sensitivity $\partial C/\partial M$ large $\rightarrow$ small values of ∂M can be revealed
- High selectivity $C = f(M)$ and not $C = f(M, temperature, other\ quantities)$

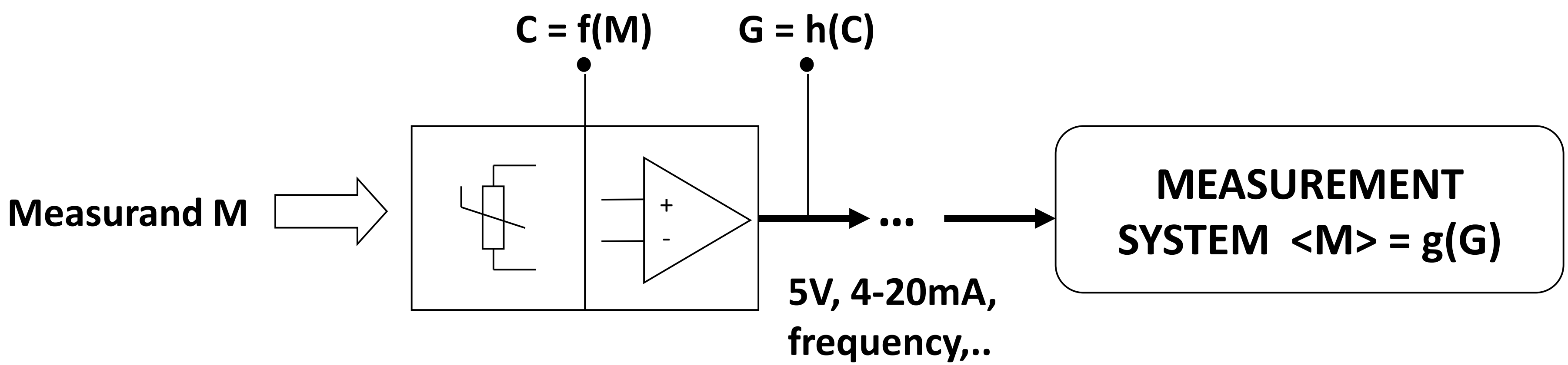
… and, generally speaking, it should be easy to retrieve the value of M starting from the measure of the sensor.
It is easy to measure voltage or current, so…

“ROUGH” SENSOR ⇒ **“CONDITIONED” SENSOR**

"CONDITIONED" SENSORS

"CONDITIONED" SENSOR

A "rough" sensor that, thanks to electronic circuits, provides an output G (voltage, current, frequency, digital output, …) that is easier to be measured than its characteristic C (resistance R, capacitance C,..).



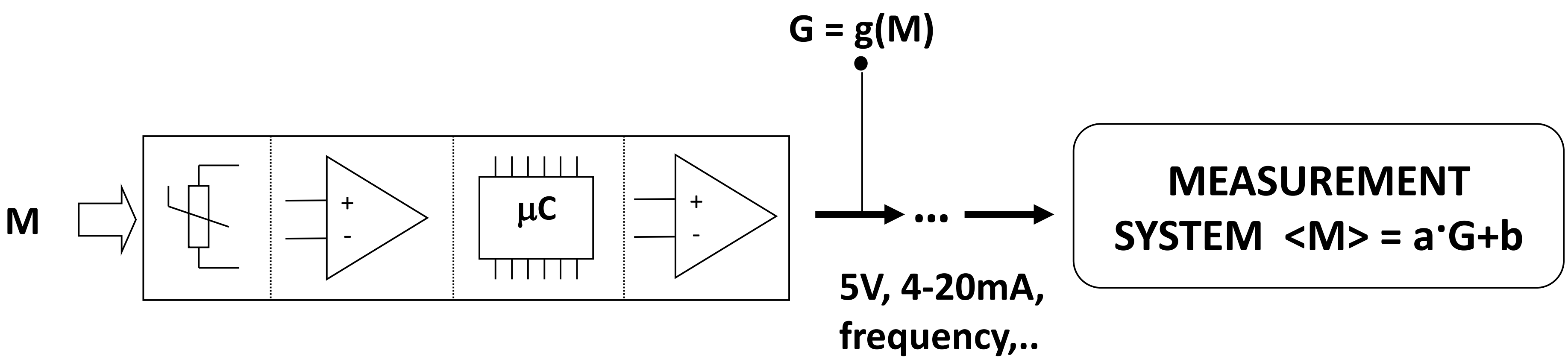
A microprocessor can be useful to compensate sensor non-idealities (e.g. to improve linearity)

"CONDITIONED" SENSOR ⇨ "ENHANCED" SENSOR

“ENHANCED” SENSORS

“ENHANCED” SENSOR

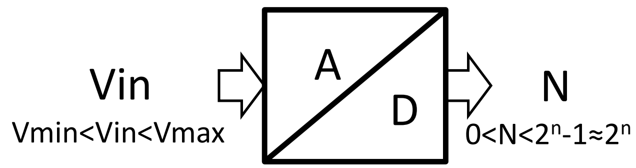
A “conditioned” sensor that includes a microcontroller to compensate sensor non-idealities. It simplify calculations of the measurement system.
Its output is still one analog information (no diagnostic, no identification,...)



... IT IS NOT A “SMART” SENSOR

"ENHANCED" SENSORS: Analog to Digital conversion

A signal in Volt should be converted in a number N



An Analog-to-digital Converter (ADC) with n bits translates a Voltage range [Vmin – Vmax] in a finite number of states, from 0 to Nmax, whit $Nmax=2^n-1\approx 2^n$

If a signal of voltage V is applied to the ADC with n bits, the output N can be computed according to the proportion

$$\frac{N}{2^n} = \frac{V-Vmin}{Vmax-Vmin} \qquad N = 2^n(V-Vmin)/(Vmax-Vmin)$$

The ADC is also characterized by a sampling rate fs, that is the maximum number of outputs per second (1 Hz = 1 output per second).

Typical values are:

- audio: n=16, fs=100kHz
- video: n=8, fs=10MHz

“ENHANCED” SENSORS: tests

Tests

1) A temperature sensor has an output of 1V if T=0°C and 3V if T=100°C. If I measure 2,5V which is the temperature? [75°C]

2) An ADC with 10 bit and Vmin=0V and Vmax=5V is used to convert a voltage signal. Which is the number N corresponding to a signal of 2.1V? [N=430]

3) An ADC with 8 bit and Vmin=0V and Vmax=5V is used to convert the signal of the temperature sensor (output of 1V if T=0°C and 3V if T=100°C). Which is the relation that, starting from the number N, output of the ADC, allows to estimate the temperature T in °C? [$<T>=100°C((5N/256)-1)/(3-1)$]

3a) Which is the value of N when the sensor Vmin is applied to the ADC? [256/5]

3b) Which is the value of N when the sensor Vmax is applied to the ADC? [3*256/5]

4) Which is the time elapsed between two consecutive measurements of an ADC with sampling rate of 50ksample/s? [20µs]

"ENHANCED" SENSORS: tests

Tests, Solutions

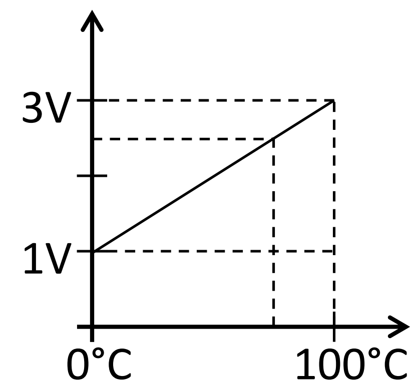
1) A temperature sensor has an output of 1V if T=0°C and 3V if T=100°C. If I measure 2,5V which is the temperature? [75°C]

It is sufficient to apply the proportional relation

(T-Tmin)/(Tmax-Tmin) = (V-Vmin)/(Vmax-Vmin)

T/100 = (V-1)/2   T/100=1,5/2   T=75°C

Or solve with a graphical approach



2) An ADC with 10 bit and Vmin=0V and Vmax=5V is used to convert a voltage signal. Which is the number N corresponding to a signal of 2.1V? [N=430]

It is sufficient to apply the proportional relation

$(N)/(2^n)$ = (V-Vmin)/(Vmax-Vmin) $N/2^{10}$ = V/5   N/1024 = 2,1/5   N=430

4) Which is the time elapsed between two consecutive measurements of an ADC with sampling rate of 50ksample/s? [20µs]

If I can obtain 50000 samples in 1 second, the time distance is 1/50000 = 20µs

"ENHANCED" SENSORS: tests

Tests, Solutions

3) An ADC with 8 bit and Vmin=0V and Vmax=5V is used to convert the signal of the temperature sensor (output of 1V if T=0°C and 3V if T=100°C). Which is the relation that, starting from the number N, output of the ADC, allows to estimate the temperature T in °C? [<T>=100°C((5N/256)-1)/(3-1)]

It is sufficient to apply the proportional relations

(T-Tmin)/(Tmax-Tmin) = (V-Vmin)/(Vmax-Vmin) for the sensor and

(N)/(2^n) = (V-Vmin)/(Vmax-Vmin) for the ADC

T/100 = (V-1)/2   for the sensor and N/2^8 = V/5, that is V=5N/256

Replacing V in the equation for the sensor we obtain

T/100 = ((V=5N/256) -1)/2

The estimated value of T, that is <T> is   <T>=100°C((5N/256)-1)/2

3a) Which is the value of N when the sensor Vmin is applied to the ADC? [256/5]

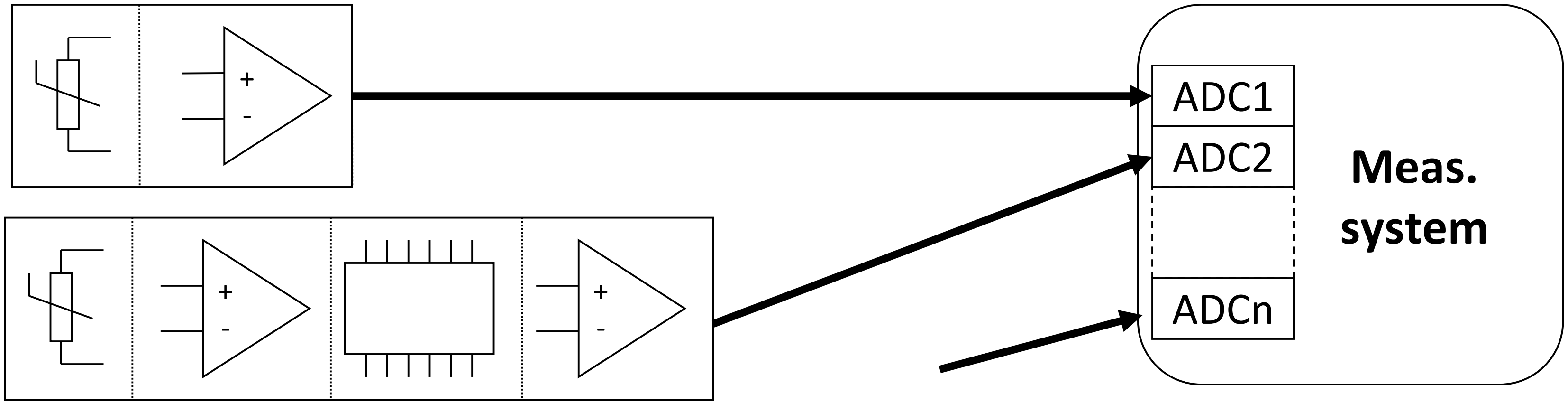
If I apply Vmin=1V to the ADC it is (N)/(2^n)=(1V-0V)/(5V-0V)   N/256=1/5   N=256/5

3b) Which is the value of N when the sensor Vmax is applied to the ADC? [3*256/5]

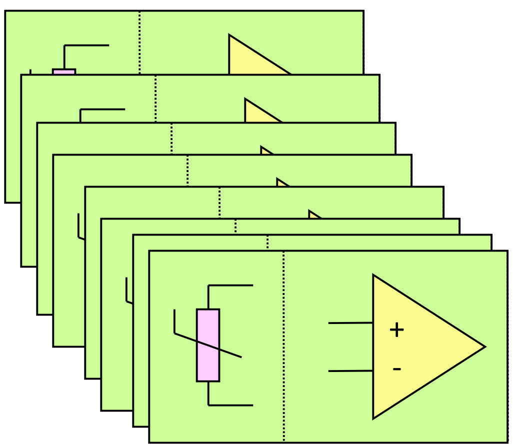
If I apply Vmax=3V to the ADC it is (N)/(2^n)=(3V-0V)/(5V-0V)   N/256=3/5

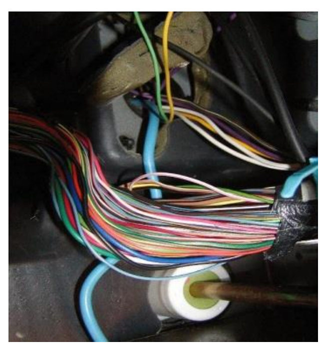
N=3*256/5

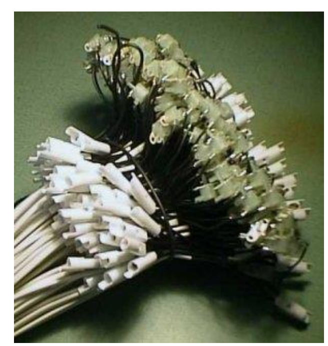
SENSORS WITH ANALOG OUTPUT

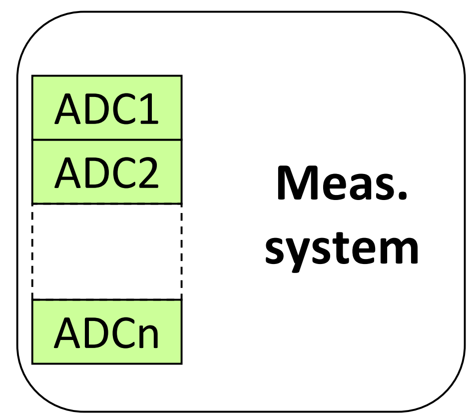


One information = one wire → **a lot of wires**

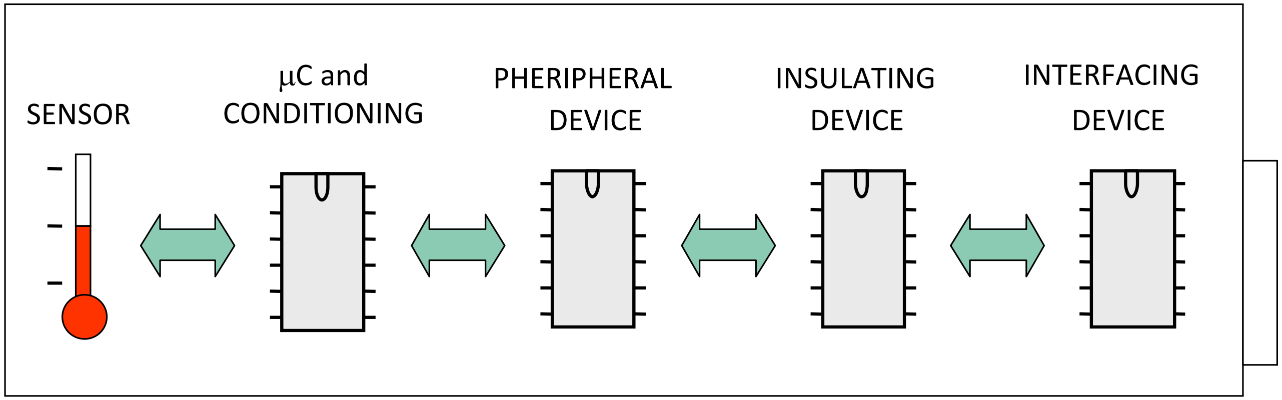








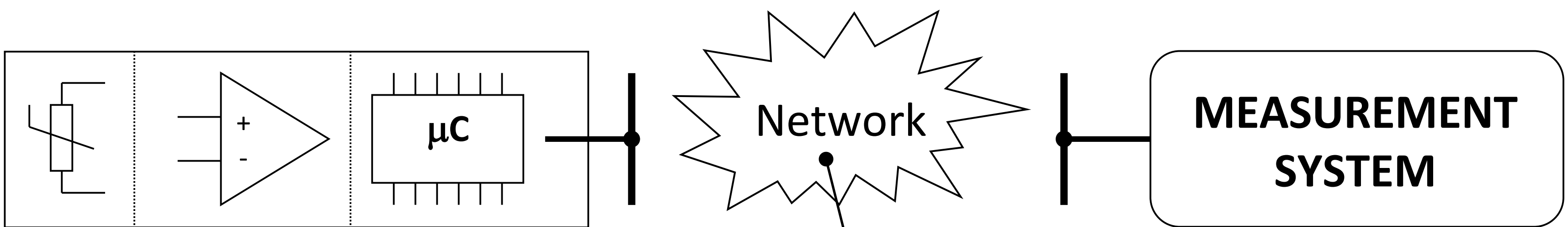
SMART SENSORS: not a wire but a communication link



SMART SENSOR

- More devices (costs)
- Powerful µC (stack)
- Diagnostics
- “Plug&play”
- Industrialized units

<u>One communication link = more information</u> **few “wires”**



- **USB, Ethernet – TCP/IP, RTE…**
- **Bluetooth, WiFi, 4G**
- **Wireless sensor networks**

SMART SENSORS: PROS and CONS

Pros

• a communication link allow to use 1 “wire” to transfer more information (diagnostics, a buffer of consecutive measurements, communicate a new measure only if the value is changed,….)
• the information is available at the user side, not a signal that requires calculations
    • A thermal sensor with output 0V @ 0°C and 5V @ 100°C (enhanced)
    • A thermal sensor with USB that communicate Temperature XXX.XX°C (smart)

Cons

• more expensive
• more complex
• the problem of coupling one or more smart wireless sensors to a network (image a room with 4 thermal wireless sensors: how you can distinguish them?)

NEW AVAILABLE SMART SENSORS: characteristics

Smart sensors

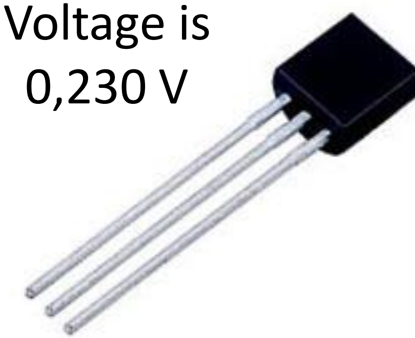
- are very small and quite inexpensive (cost is for norms compliance, e.g. compare the cost of a belt with heart rate readout with a digital Holter or an equipment for telemedicine: sensors and electronic devices are almost the same)
- Include a processor and memory functions for data recording and processing
- may have wireless interface (typ. Bluetooth or WiFi)
- may be battery powered (battery life depends on required data rate)
- require a coupling procedure to correctly communicate with the selected smart device (Tablet or PC or Smartphone)
- offer information about the Measurand, but also other information (time and place, battery status, quality of the communication link, and so on)
- may offer a single information or a trace (buffer) triggered according to user need
- many measurements and identification functions are made by sensors similar to human sense (smart cameras, microphones, probes for dimensional control, electronic noses and tongues) together with a lot of elaboration
- Smart sensors allow data fusion, online adding and removing sensors

RESUMING: sensors and smart sensors

Resistance is 109,0 Ω

Current is 0,296 mA

Voltage is 0,230 V



Code is 0A9Bh, for you is 2715 ;-)

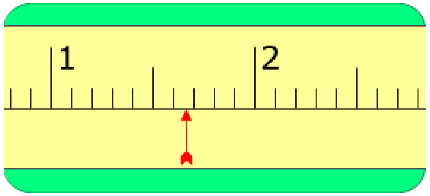
Temperature is 23°C, I've recorded for you every minute

Temperature is 23,0 °C and you know everything about me

© Rosemount

Temperature? Sensor, please give me a **smart** response

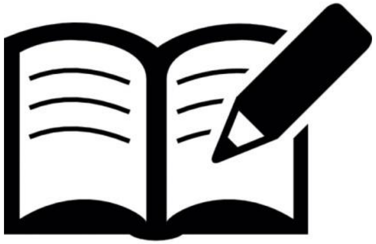
RESUMING: information from a smart sensor



VALUE (value of input sampling. Characterized by resolution, uncertainty, measurement unit,…)

TIME (time instant of input sampling)

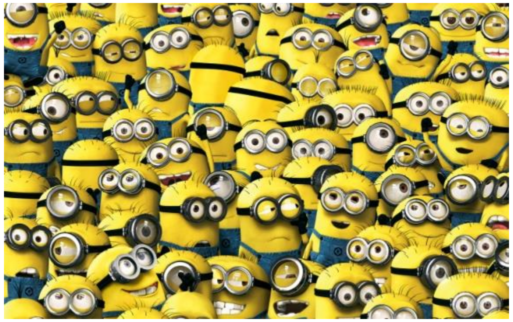
PLACE/CONTEST
(place or contest –rest, motion,..- of input sampling)



QUALITY (reliability of the measurement)

STATIC INFORMATION
(producer; HW FW identifier; …)

LOOK AHEAD: sensors can be arranged in a network



SENSOR NETWORK (more sensors are managed according to a hierarchical topology)
SMART SENSOR NETWORK (more sensors cooperate and contribute to a <u>distributed information system</u>)

WIRED NETWORKS: Ethernet, Real-Time Ethernet, Fieldbus, USB
- place/context is meaningless (fixed sensors, static information)
- normally no power problems

WIRELESS NETWORKS: ZigBee, Bluetooth, GPRS, Wi-Fi, Z-Wave, wMBus, wireless fieldbus,..
- real-time behavior is difficult to achieve (air is an unreliable medium)
- power (sensing, communicating) is the main concern
  - battery
  - power harvesting

SENSORS AND SMART SENSORS: tests

Tests

1) A smart sensor, with respect to other sensors (rough or conditioned or enhanced) is characterized by [c]:

a. Includes a microprocessor
b. it has a voltage output
c. Supports a digital communication link
d. is has high repeatability

2) A smart temperature sensor furnishes as the readout [a]:

a. Number indicating °C and more information
b. A voltage indicating temperature
c. A resistance indicating temperature
d. Numbers indicating °C in a display

3) The …. Is the characteristic of a sensor to produce a high variation of the output if a small variation of the Measurand is performed [c]

a. repeatability
b. linearity
c. sensitivity
d. selectivity

4) The …. Is the characteristic of a sensor to produce a significant variation of the output if a variation of the Measurand is performed and a negligible variation of the output if a variation of other quantities are applied [d]

a. repeatability
b. linearity
c. sensitivity
d. selectivity

SENSORS AND SMART SENSORS: tests

Tests

5) A …. Sensor can communicate on the same wire the result of the measurement and other diagnostic information [a]

a. Smart b. Enhanced c. Conditioned d. Rough

6) A …. Sensor is the one with the lowest cost, but it is also the most complicated to be managed [d]

a. Smart b. Enhanced c. Conditioned d. Rough

7) A …. Can be considered as a motion actuator controlled by humans [b]

a. Robot b. Bicycle c. Train d. Elevator

8) A humidity sensors has an output voltage of 0,5V at 10% and 4,5V at 90%. If an Analog to Digital Converter (ADC) with 12 bit and input range of 0…5V is used and the Humidity is 25%, which is the number at the ADC? [b]

a. 250 b. 1024 c. 1200 d. 4096

8bis) Which is the Humidity if the readout is 3071? [d]

a. 0% b. 10% c. 50% d. 75%

SMART SENSORS FOR DOMOTICS AND HEALTH CARE

- Mobile systems

A.A. 2017 / 2018

Alessandra Flammini

MOBILE SYSTEMS

Smart sensors are normally managed by a mobile system or by a PC or by remote systems connected with an infrastructure

Mobile systems:

• Portable PC
(powerful, WiFi connected, heavy, cumbersome, about 4h of battery life)

• Tablets
(quite powerful, WiFi or 4G connected, light, about 8h of battery life)

• Smartphone
(quite powerful, WiFi or 4G connected, light, about 24h of battery life)

PC-based SYSTEMS

Smart sensors are all external (PC does not have sensors with the exception of a low-performance fix camera and a microphone)

Smart sensors are managed by WiFi or by wired connections (USB, Ethernet)

USB

USB

USB

Many PC peripherals are sensors (e.g. mouse)

It's easy to find many cheap sensors for USB
e.g. http://www.vernier.com/products/sensors/usb-sensors/

- Many sensors have USB interface (webcam, microphones, environmental sensors, & so on)
- There are USB modules to directly connect sensors (USB Data Acquisition, DAQ)

WiFi

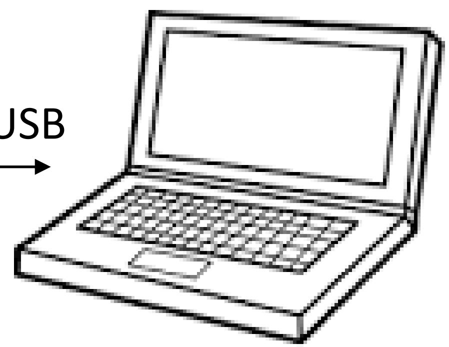
Ethernet

Normally used for systems (e.g. vision) connection (not smart sensors).
Used for Internet enabled sensors (web sensors)

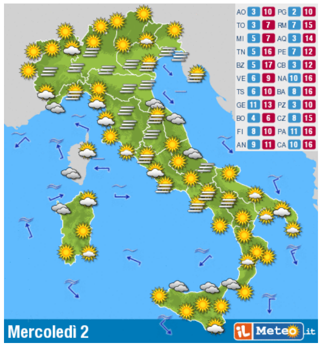
PC-based SYSTEMS and VIRTUAL SENSORS

VIRTUAL SENSORS (WEB-SENSORS)
A program running on a PC get information from a web server providing a streaming of data in a real-time fashion

ETHERNET/USB



INTERNET



Real sensor (weather station)
- Data every ms
- Costly
- Single probe

Virtual sensor (www.ilmeteo.it)
- Data every 15 minutes
- Free (weatheronline)
- A lot of data

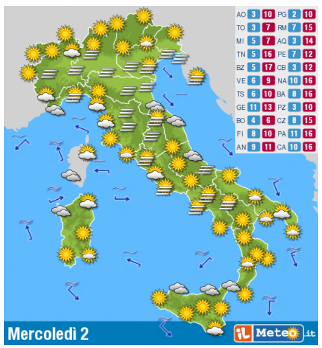
MOBILE DEVICES: INTERNAL AND VIRTUAL SENSORS

A SMARTPHONE OR A TABLET HAVE WIRELESS SENSORS ONLY
***Android supports USB on-the-go but it is not very much used (battery)**

BUT THEY HAVE INTERNAL SENSORS (cameras, GPS, accelerometers)

Bluetooth

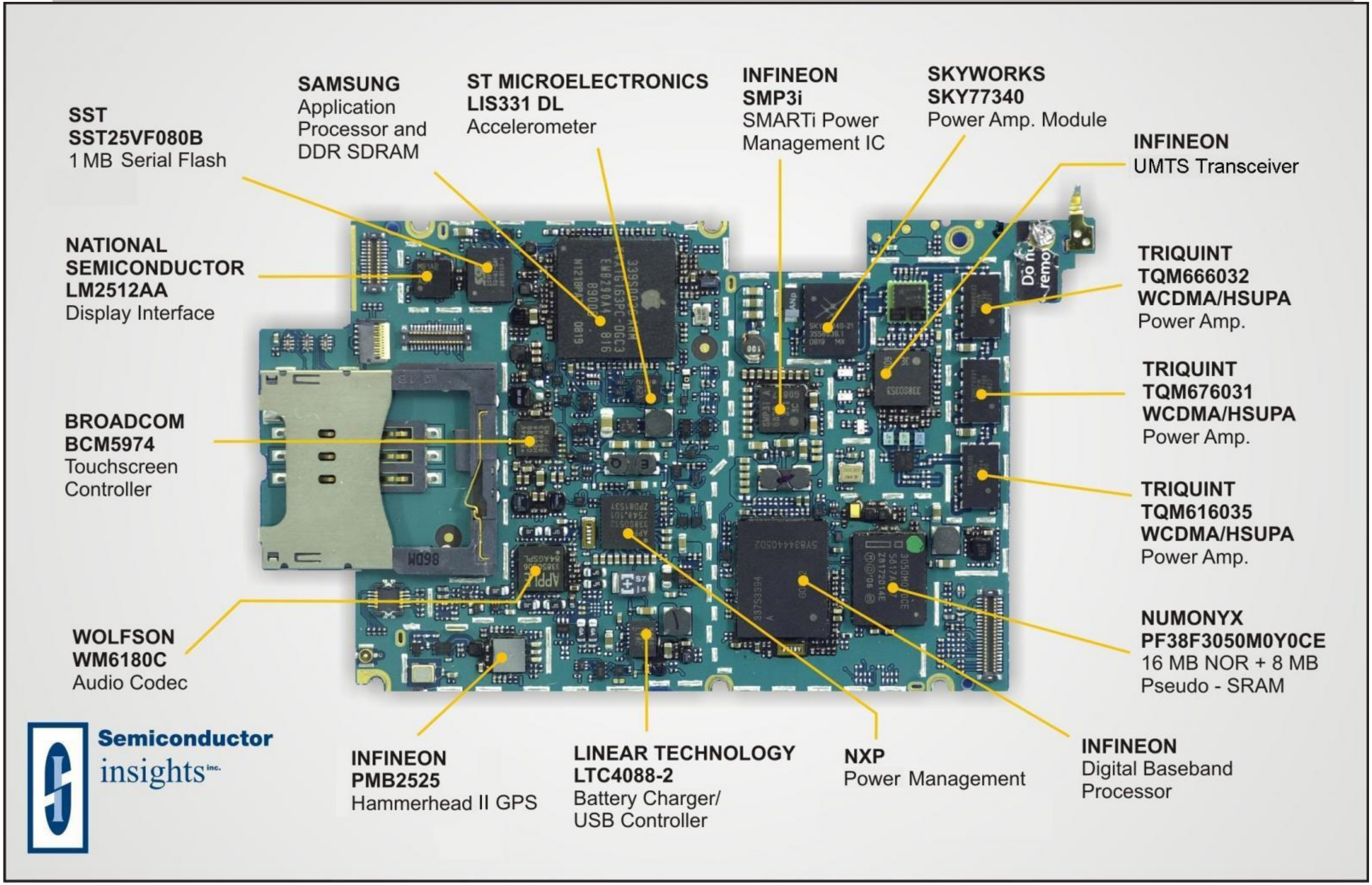
INTERNET



Real sensor (weather station)
- Data every s
- Quite costly
- Single probe

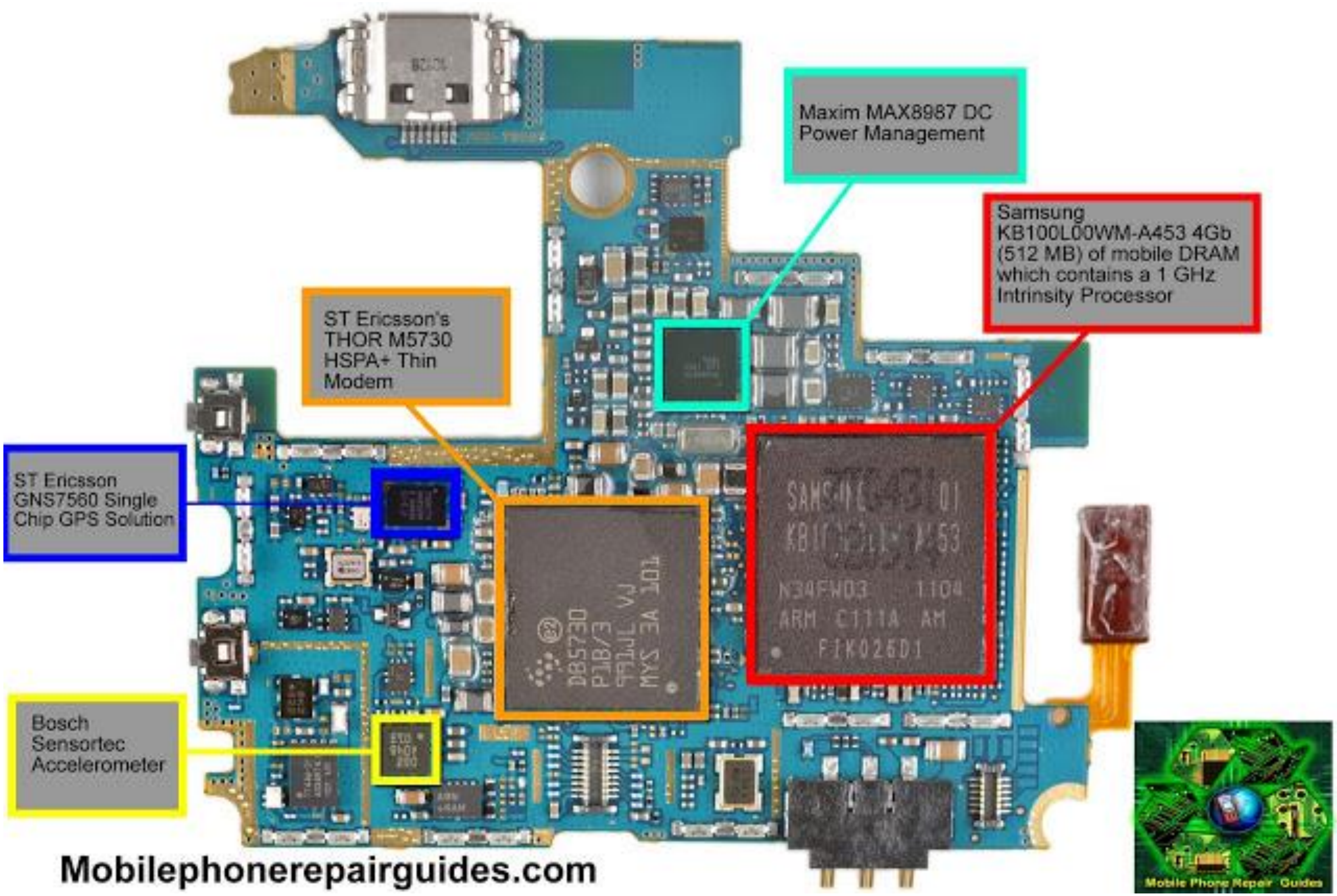
Virtual sensor (www.ilmeteo.it)
- Data every 15 minutes
- Free (weatheronline)
- A lot of data

SMARTPHONE: INTERNAL STRUCTURE (simplified)



SMARTPHONE: INTERNAL STRUCTURE (simplified)

Samsung Galaxy S4: few big devices (cameras and other components on different boards)



SMARTPHONE: INTERNAL STRUCTURE (simplified)

Processors (CPU, Central Processing Unit)

• Digital Baseband Processor: for radio communications (WiFi, Bluetooth) and Operative Systems (OS). It's a system, with CPU, memories and firmware

• Application processor: for OS and applications. Normally at 32 or 64 bit (floating points operations), but low power consumption is mandatory

Memories

• DDR SDRAM (Double Data Rate Synchronous Dynamic Random Access Memory) very fast, transfers 64bits 2 times every clock cycle. Used for OS and applications

• NOR Flash non-volatile memory for binary code of programs (wireless stack), accompanied with PSRAM (Pseudostatic RAM, memory for data)

• Serial FLASH non-volatile memory for slow data storage (Typ. configuration data)

Many device relating Power

• Battery life is one of the main concern (sensors, wireless communications, applications –processors and memories- are responsible of power dissipation)

Human interface and peripherals

• Touchscreen, display, audio, cameras (they could also be considered as sensors)

Sensors

• GPS, accelerometers, other

GPS (position and time) and UTC

Universal Time Coordinated (UTC)

- Introduced in 1972
  - In 1955 the cesium atomic clock replaced astronomic observation
  - 1 January 1972 00:00:00 UTC = 1 January 1972 00:00:10 TAI (same tick rate)
  - UTC Format: 1970-01-01T00:00:00Z (“zulu” format)
  - This is “the starting point” for Unix time (Posix time), that counts the number -32bit- of seconds elapsed (not counting leap seconds)
  - Overflow at 03:14:07 UTC 2038-01-19 (2^{31} seconds)
  - 32 bit for fractional part (0,4 ns as the resolution)

- Used in Internet and WWW (NTP or SNTP protocol)

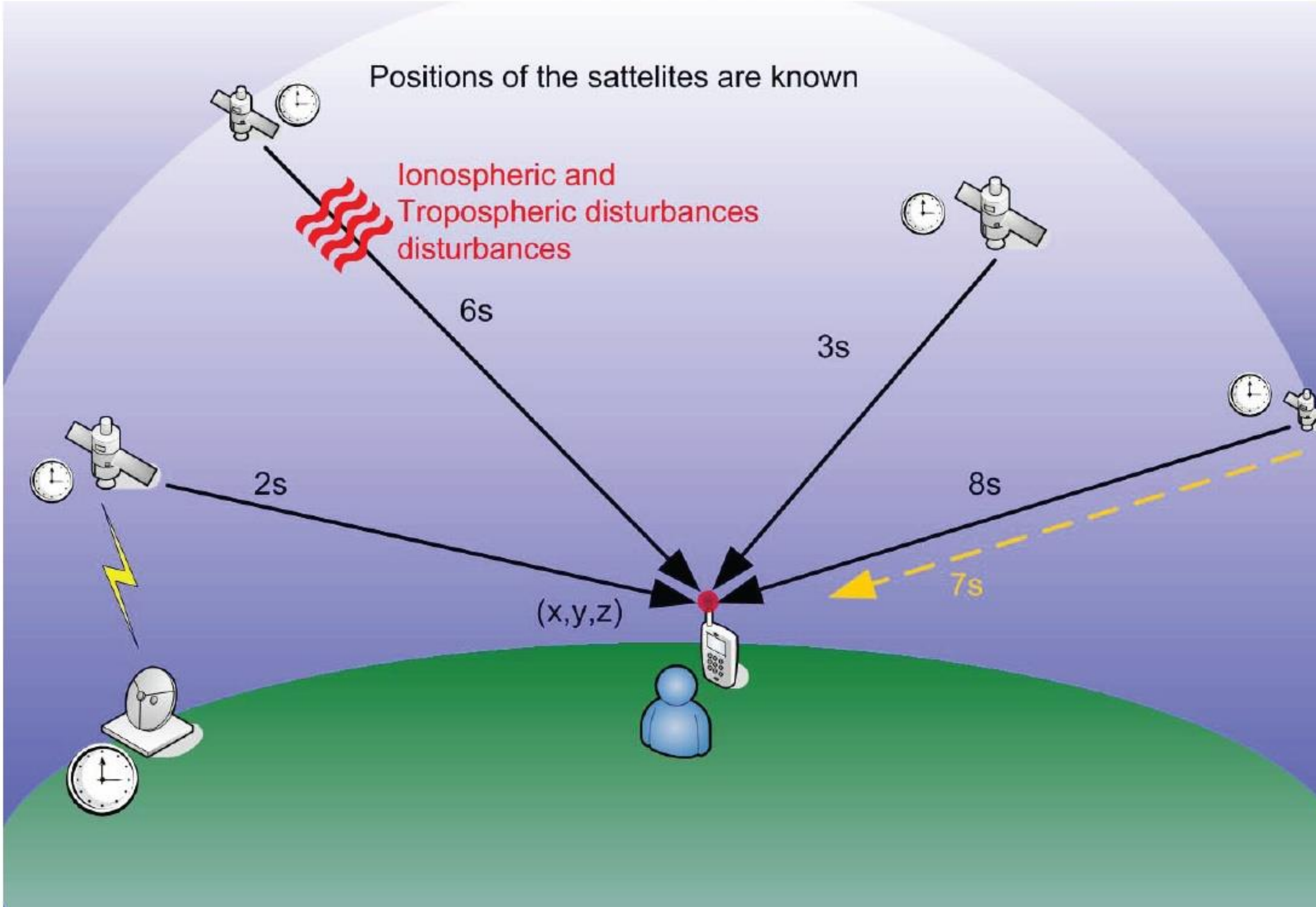
- Defined by Int. Telecom. Union Recommendation (ITU-R TF.460-6)

GPS: Global Positioning System

Kept by US Naval Observatory

- Reference: two cesium and two rubidium atomic clocks
- is kept as closely as possible to UTC
- offset to UTC is given in messages
- each GPS satellite continuously broadcasts a navigation message (50bits/s) composed of 5 subframes (37500bits) and sent at a precise time (start of a second)
- Position of the satellites are known
- The GPS device inside the smartphone receives messages from several satellites and, computing starting from the arrival time of the messages, it understand its own position by triangulation (**it localizes itself**) and the time the message has been sent (**it synchronizes itself**)
- Assisted GPS is when computation uses also signals from 4G or WiFi infrastructures
- GPS does not work indoor and decreases the battery life

GPS: Global Positioning System

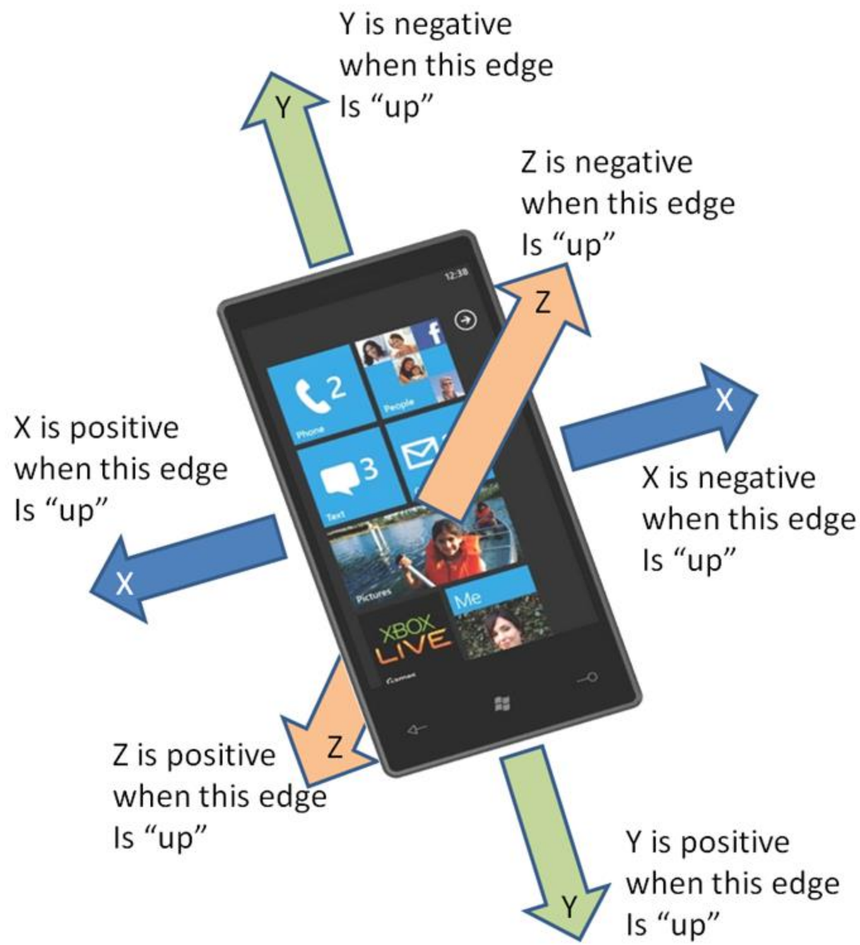


Accelerometers

Accelerometer

• is a sensor of acceleration, but not intended as the variation of the speed, but referred to the surface of the Earth. An accelerometer measures proper acceleration, which is the acceleration it experiences relative to freefall and is the acceleration felt by people and objects (at rest it measures 1g).

• A smartphone includes a 3axes accelerometer and, thanks to it, the Smartphone can manage the vertical or horizontal view of the screen.



Accelerometers and other sensors

Accelerometer within the smartphone can be used to detect
- human activities – walking, running, dancing or posture
- vehicles collisions or vibrations
- The Smartphone includes gyroscopes (orientation –yaw, pitch, roll- and their variation) and magnetometers (the strength of earth's magnetic field)

Proximity sensor, touchscreen
- during a call, if the phone is close (in touch) to the ear, the touchscreen is disabled. The touchscreen can be considered as another sensor

Microphones
- is a sensor for word and/or noise detection and identification, but also a sensor for acoustic pollution measurement, a sensor for traffic measurement, weapon shot detection, and so on

Cameras, luxmeter
- A smartphone includes two cameras with sometimes a luxmeter for automatic flash management. The camera can be used as a heart rate detection. New possible cameras for pulsiossimeter or glucose detection

MOBILE SYSTEMS: tests

Tests

1) In a PC-based(/Smartphone-based) system, smart sensors are normally connected by [a(/d)]:

a.USB b. Ethernet c. WiFi d. Bluetooth

2) The web-sensors or virtual sensors strongly depends on availability of …. connection [c]

a.USB b. Ethernet c. Internet d. Bluetooth

3) Thanks to the GPS(/accelerometers) the smartphone can…. [c(/d)]

a. Localize itself b. Synchronize itself

c. Both localize and synchronize itself d. Allow vertical and Horizontal view

4) … is the number of second elapsed since 1 Jan 1972 [a]

a. UTC b. GPS c. NTP d. CPU

5) The accelerometer within a Smartphone has … axes [c]

a. 1 b. 2 c. 3 d. 4