Sensors:

From atom to bits

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Sensors

Sensors are the bridge between the physical world made of atoms and the abstract world of data.
Humans have sensors that perceive many physical quantities whose output is transmitted by the nervous system and then processed by the brain to transform it in meaningful data.
Man made sensor extend this capability to many other variables.

Electrical Sensors

Electrical sensors are devices that convert a physical variable into an electrical signal.
The electrical signal is then converted into a number for further processing in the digital world.
The output of digital sensor is a binary number
The output of an analog sensor must be applied to an analog to digital converter (ADC) before processing.

Actuators: “Bits to atoms”

Actuators are the counterpart of sensors, they use electrical signals at their input to perform a specific operation in the physical world, for instance opening/closing a valve, turning on a light or blasting a horn. Unlocking a car doors is a familiar application of actuators.

Example of variables to be sensed

- Temperature
- Humidity, soil moisture
- Light intensity, insolation
- Sound, sound int.
- Pressure, barometer, force
- Wind (speed, direction)
- Position, pushbutton,GPS
- Proximity
- Displacement
- Acceleration
- Orientation (magnetic, gyroscope)
- Heath (infrared)
- Smoke
- Motion, landslide
- Vibration, seismic
- RF intensity
- Water Level, flow, quality
- Turbidity, PH
- Pollution
  - Particulates
  - Gas sensors
- Radioactivity

A typical smart phone has a number of sensors already built in:

- Temperature
- Accelerometer, Gravity
- Proximity
- Motion,vibration, screen orientation
- Light intensity
- Barometric pressure, altitude
- Sound level
- Position (GPS or Cellular based)
- RF intensity in certain bands (WiFi, Cell)

As well as some actuators:

Buzzer, Alarm
LED
Vibration
Loudspeaker
Tone generator

Calibration

All sensor must be calibrated.

Some might be calibrated at the factory or at a specialized laboratory.

Calibration consists in checking the reading of the sensor when exposed to a known reference.

Most sensors will be affected by temperature, atmospheric pressure and other factors which must be accounted for calibration to be accurate.

Examples: a thermometer can be calibrated by submerging in boiling water, a barometer can be used to measure altitude only after proper calibration.

Power consumption

All sensor consume power to some extent.

Some will consume more power than the controller to which they are attached.

It is advisable to avoid making measurements more often that what is necessary for a given application, making use of timers or interrupts to save energy.

Beware of sensors that have a heating element: they usually consume a lot of power

Power consumption of some sensors

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Table 3. Features of Typical Sensors

Name	Type	Sensing time	Active current
SLG64-0075	Liquid-Flow	30ms	5.1mA
SFM4100	Gases- Flow	4.6ms	12.5mA
VTISCA3000	Acceleration	10ms	120μA
VTISCP1000	Airpressure	110ms	25μA
SensorionSHT15	Humidity	210ms	300μA
AvagoAPDS-9002	Illumination	1.0ms	2.0mA
HitachiHM55B	Magneticfield	30ms	9.0mA
FastraxiTRAX03	Position	4.0s	32mA
DallasDS620U	Temperature	200ms	800μA

Sensor requirements

Linearity

Sensitivity

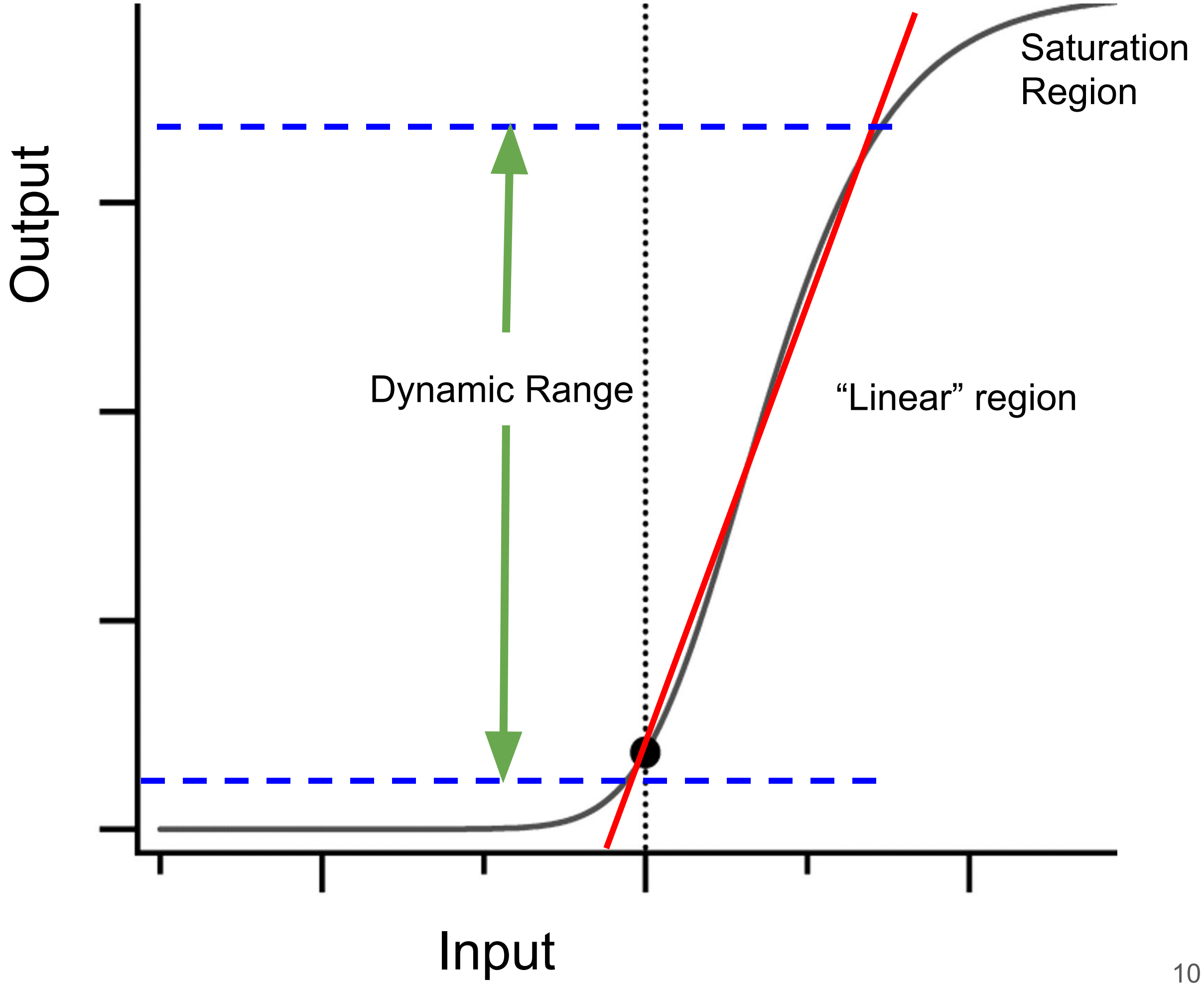
Adequate dynamic range

Reproducibility

Robustness

Weather resistance

Low power consumption



Water quality sensor specifications example

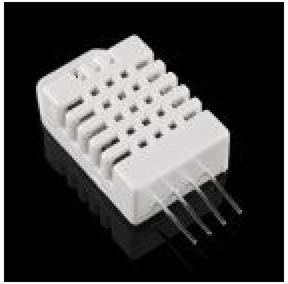
Parameter	Range	Resolution	Fidelity	Maintenance	Precision	Response time
Active chlorine	0–2.5 mg/L	0.01	±5 %	The multi-parameter probe should be replaced every year	±10 %	<30s
Conductivity	100–1000 µS/cm	1	±5 %		±5 %	Not reported
Pressure	1–10 bars	1 mbar	±2 %		±10 %	Not reported
Temperature	0–40 °C	0.1 °C	±5 %		±5 %	<15s/°C

Sensor examples

Temperature

Proximity

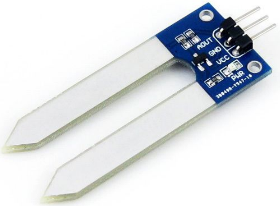
Radioactivity



Humidity and
temperature

Carbon
monoxide

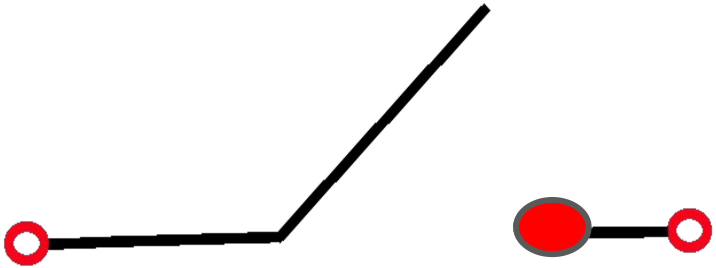
LPG gas



Soil Moisture

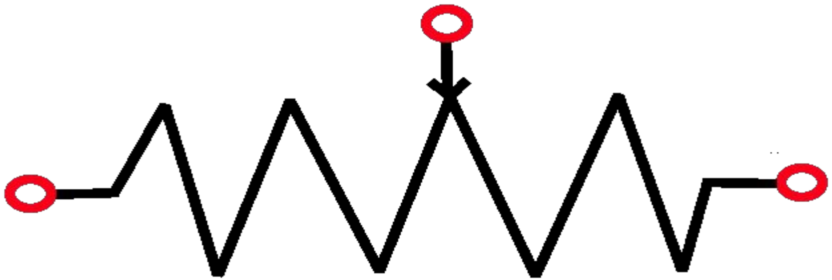
Input devices: pushbutton

For digital input a pull-up resistor is often required to close the circuit.



Input devices: potentiometer

ADC input. Acts as a voltage divider



Output devices: LED

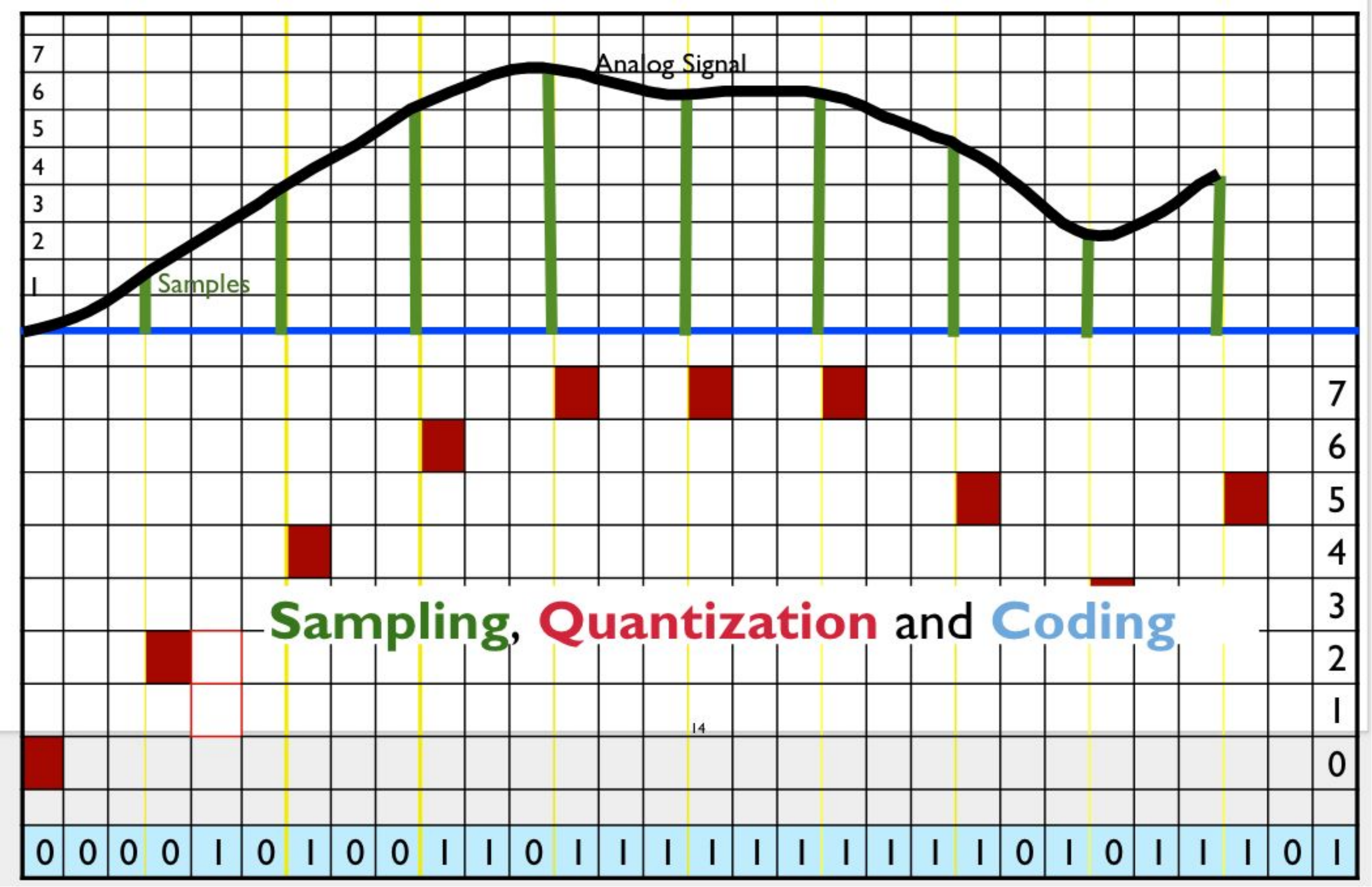
An LED operating point is determined by the voltage applied and the current flowing

Excessive current can damage the LED so often a current limiting resistor is inserted in series

Three LEDs emitting at Red, Green and Blue

can produce white light

Analog to Digital Conversion (ADC)



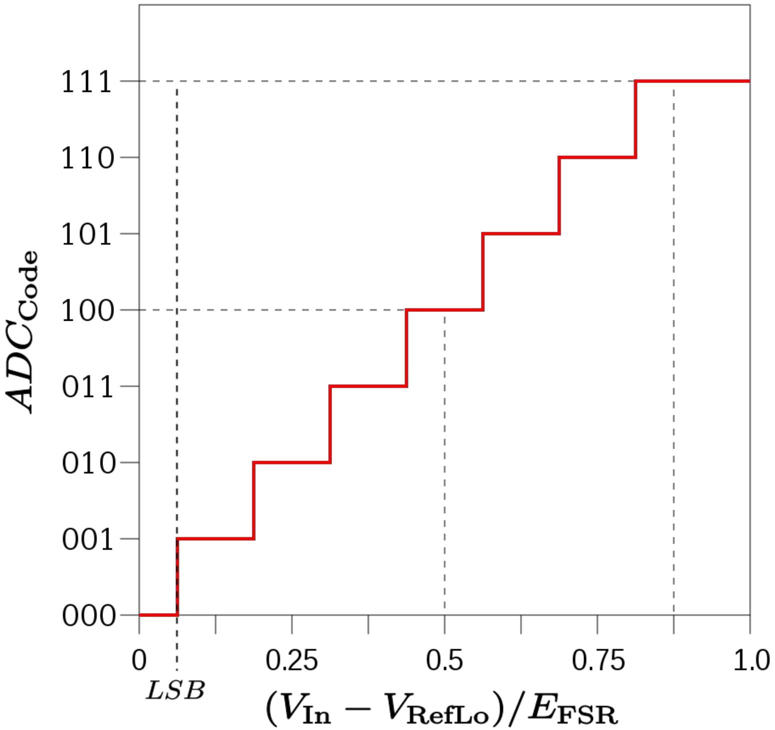
Quantization and Coding: Analog input, Digital Output

The continuous input signal is converted into a discrete one in both amplitude and time.

The sampling rate must be at least twice the bandwidth of the input.

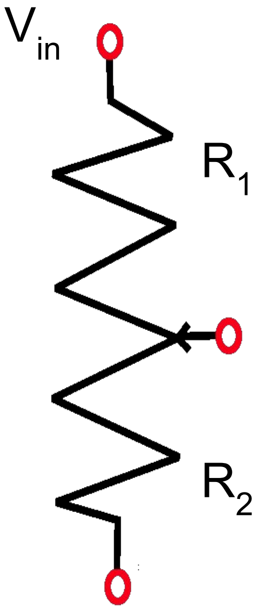
Quantization error is inevitable but can be made as low as required.

Dynamic range determined by Effective Number of Bits (ENOB).



Analog to Digital Conversion, voltage scaling

If the analog voltage exceeds the maximum input allowed in the ADC, it must be scaled using a voltage divider as the one shown:



$$V_{out} = V_{in} * R_1/(R_1+R_2)$$

Digital Sensors

Normally interfaced by means of a specific communications protocol, like:

- I^2C
- SPI
- 1-Wire

They allow for an extended set of commands (turn on, turn off, configure interrupts).

One can set a threshold value and have the sensor send an interrupt when it is reached, without the need for continuous polling.

I^2C

The Inter-integrated Circuit (I^2C) specification is a serial protocol intended to allow multiple “slave” digital integrated circuits to communicate with one (or more) “master” device which generates the clock.

Requires only two bidirectional wires: Serial Data Line (SDA) and Serial Clock Line (SCL) that must be connected to pull-up resistors.

It is meant for low speed and very short distances (intra-board).

Serial Peripheral Interface Bus (SPI)

SPI is a synchronous serial 4 wires communication interface for short distance communication, normally in embedded systems.
It employs a full duplex mode master-slave architecture with a single master.
Master device originates the frame for reading and writing. Multiple slave devices are supported by activating individual slave select (SS) lines.

Slaves use the master's clock and do not need precision oscillators nor a unique address.

Higher throughput and lower consumption than I^2C, no maximum clock speed specified.

1-Wire

1-Wire is a device communications bus system that provides low-speed data, signaling, and power over a single conductor. It is similar to I²C, but with lower data rates and longer range.

Typically used to communicate with small devices such as digital thermometers and weather instruments using only two wires, data and ground. An 800 pF capacitor is used to power the device when the line is active.

A network of 1-Wire devices with an associated master device is called a MicroLAN.

Each 1-Wire chip has a unique 64 bit identifier code.

Digital Sensor example: accelerometer

ADLX345: 3 axis accelerometer able to read up to 16 g

- Measures static acceleration of gravity in tilt sensing applications
  - Resolution of 4 mg/LSB allows inclination measurements changes < 1.0º
- Measures dynamic acceleration resulting from motion or shock. Three types of interrupts:
  - Single tap
  - Double tap
  - Free fall

g= 9.8 m/s^2
LSB: Least significant bit

Conclusions

- Sensor are the interface between the physical world made of atoms and the the abstract world of data amenable to computer processing.
- Actuators allow for the manipulation of physical objects by means of electrical signals.
- Analog signal must be converted to digital ones for processing, incurring in an unavoidable quantization error, which nevertheless can be made as small as desired by increasing the number of bits per sample.
- Calibration is a fundamental step for reliable measurement of any variable.