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EUROSENSORS XXXV CONFERENCE LECCE 10-13 SEPTEMBER 2023

EUROSENSORS School 2023

Sensors and Sensor Networks for Air Quality Monitoring

Dr. Stefano Zampolli

IMM Istituto per la Microelettronica e Microsistemi BOLOGNA
Consiglio Nazionale delle Ricerche

Missione 4 Istruzione e Ricerca

Soggetto Attuatore del Progetto “**Ecosystem for Sustainable Transition in Emilia-Romagna**”
Codice: ECS_00000033 – CUP: B33D21019790006
Missione 04 Istruzione e ricerca – Componente 2
Dalla ricerca all’impresa Investimento 1.5, –
NextGenerationEU

Introduction on CNR-IMM Bologna

Devices, materials and processes

- Microelectronics
- Sensors and microsystems
- Photovoltaic and optoelectronic devices
- Carbon-based nanomaterials and devices

Diagnostic and characterization techniques

- Electron microscopy
- X-ray diffraction
- Ion-beam analysis
- Electrical measurements
- Functional measurements

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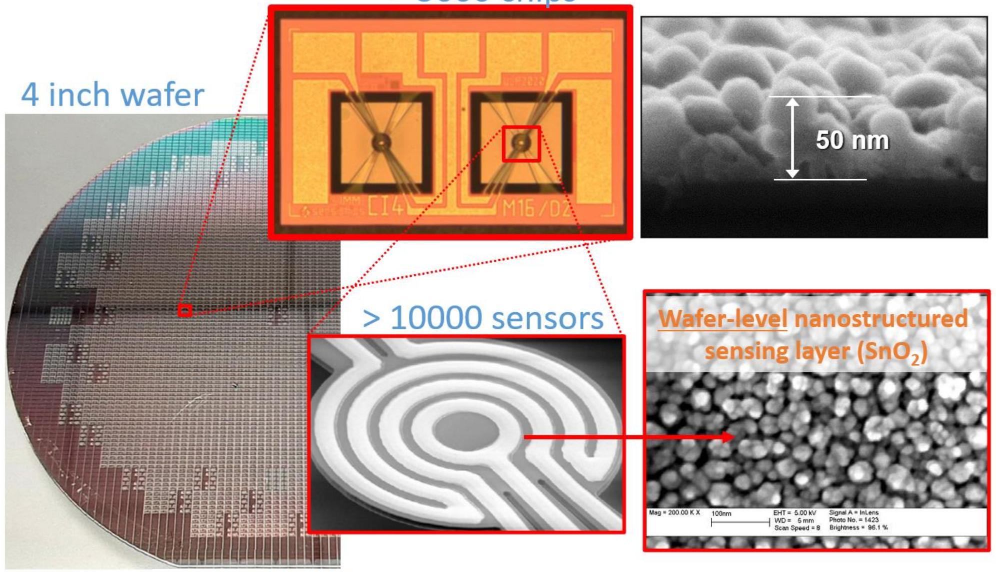
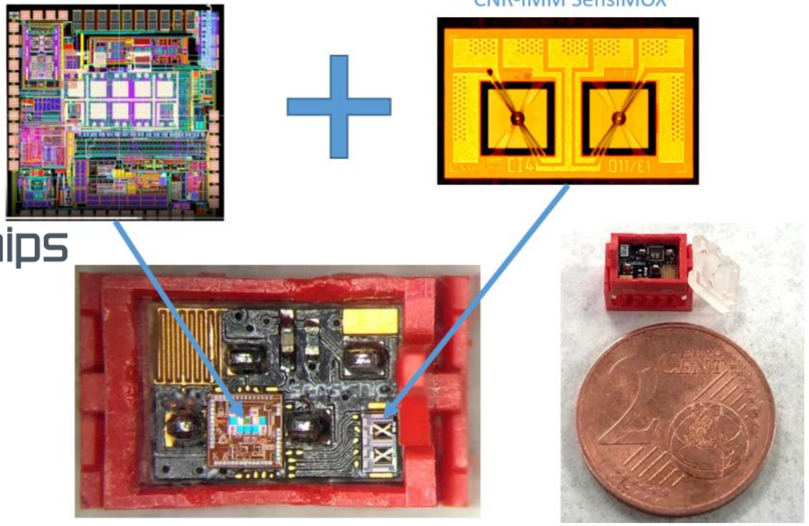
Introduction on CNR-IMM Bologna: gas sensors and microsystems

Wafer-level MEMS MOX gas sensors and SIP





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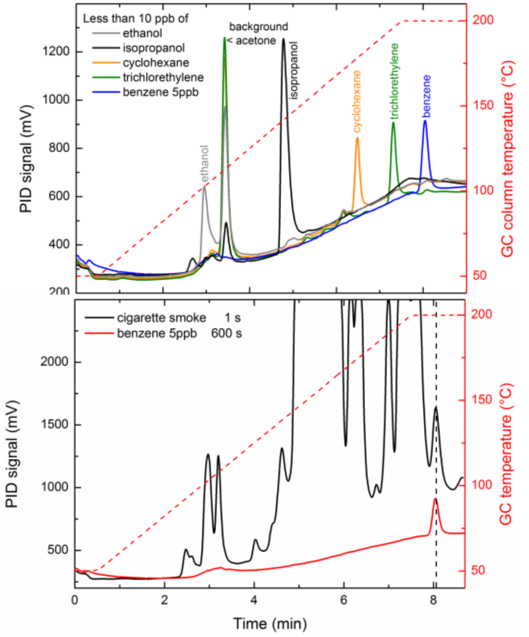
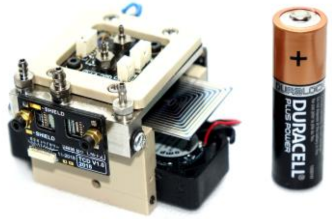
MEMS-based gas chromatographic systems



POLLUTION
ANALYTICAL EQUIPMENT
PyxisGC BTEX
CARRIER FREE ANALYSER



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Presentation outline

- The evolution of commercial MOX sensors
- Other commercially available digital environmental sensors
- About commercial low-cost sensors for environmental monitoring: are they any good?
- Sensor networks: available hardware, software and protocols
- (Hands-on) examples of implementations
- Conclusions: outlook and take-away messages

The evolution of commercial MOX sensors

1968-1969: mass production of Taguchi's «MOS-type» gas sensor and foundation of Figaro Engineering Inc.

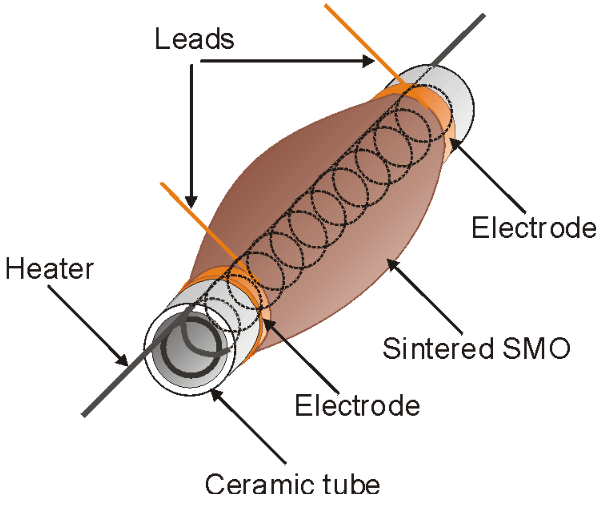


Image source: Tomchenko, Alexey. (2006). Printed Chemical Sensors: from Screen-Printing to Microprinting.

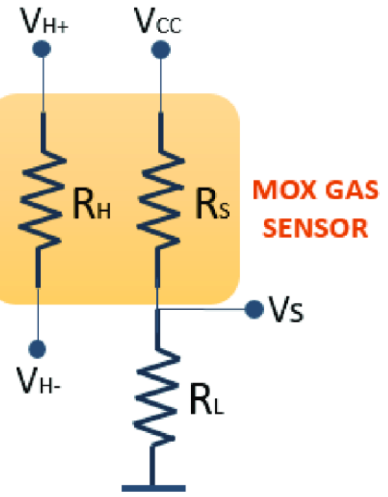


Image source: Arroyo, Patricia (2018). Electronics. 7. 342

Commercial MOX sensor consisting essentially of two resistors:

1. Heater resistor (Joule heating)
2. Sensing layer «resistor» (?)

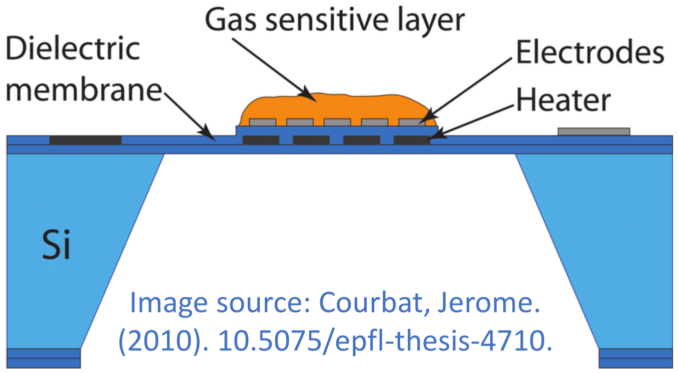
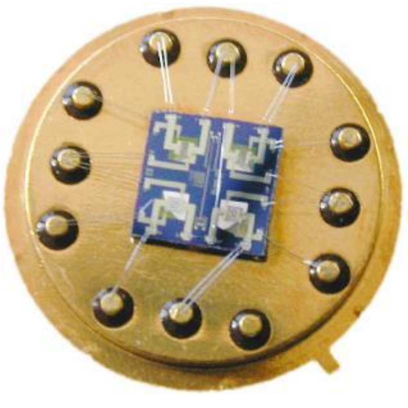


Image source: Courbat, Jerome. (2010). 10.5075/epfl-thesis-4710.

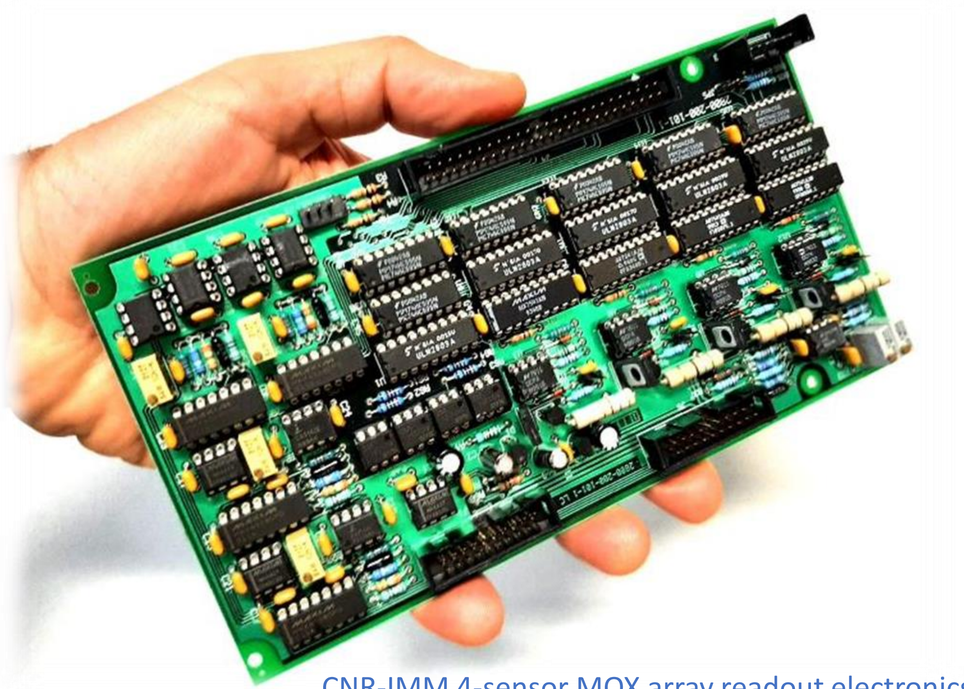
Late 1990s: use of MEMS technology for miniaturization and reduction of power consumption. Still: two resistors!

The evolution of commercial MOX sensors

Until mid 2010s, MOX sensors were still analog devices requiring some more or less complex readout electronics. The most complex electronic circuits enabled constant temperature control of the heater (feedback from temperature sensor) and different sensing layer "resistance" readout mechanisms (constant voltage, constant current, AC readout, …)



CNR-IMM MEMS-based
4-sensor MOX array (1997)

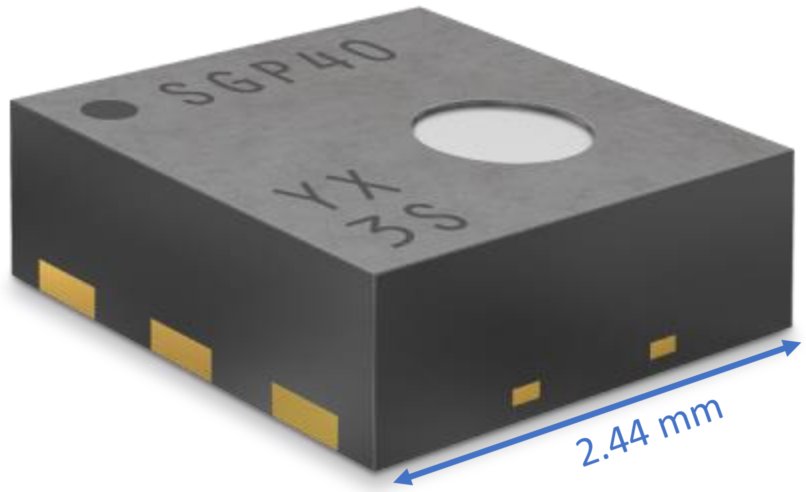


CNR-IMM 4-sensor MOX array readout electronics
with proprietary digital communication interface (1999)

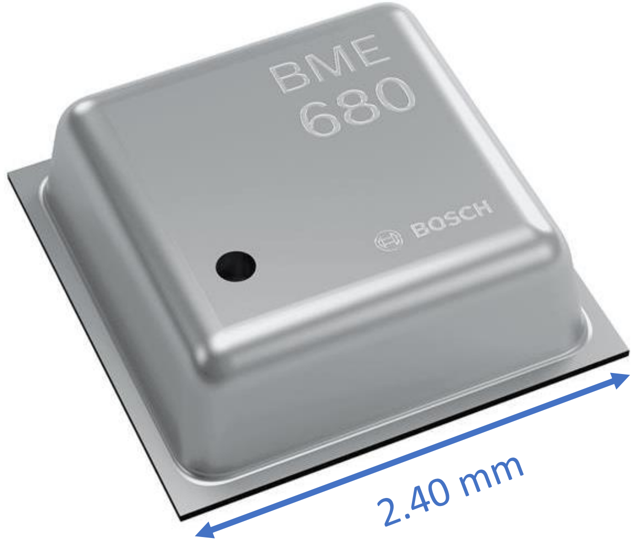
CNR-IMM 4-sensor MOX array readout electronics
USB dongle (2007)

The evolution of commercial MOX sensors

More recently, the first **digital MOX sensors** were released, in particular:



Price range:
<10€



Sensirion SGP30/40/41 multipixel gas sensor

Bosch Sensortec BME680 gas and pressure sensor

“Digital” MOX sensors have all the necessary control and readout electronics integrated (in-package) and expose a <u>digital communication interface</u> for pre-processed data.

The evolution of commercial MOX sensors

Advantages of digital (MOX) (gas) sensors:

- No need to design and optimize sensor readout electronics
- Sensor control and acquisition strategies already studied and optimized by the manufacturer
- Pre-processed data output, up to air quality indices or even machine learning algorithms
- Easy integration into digital datalogging systems
- Fast firmware and software development using smart communication libraries provided by the manufacturer

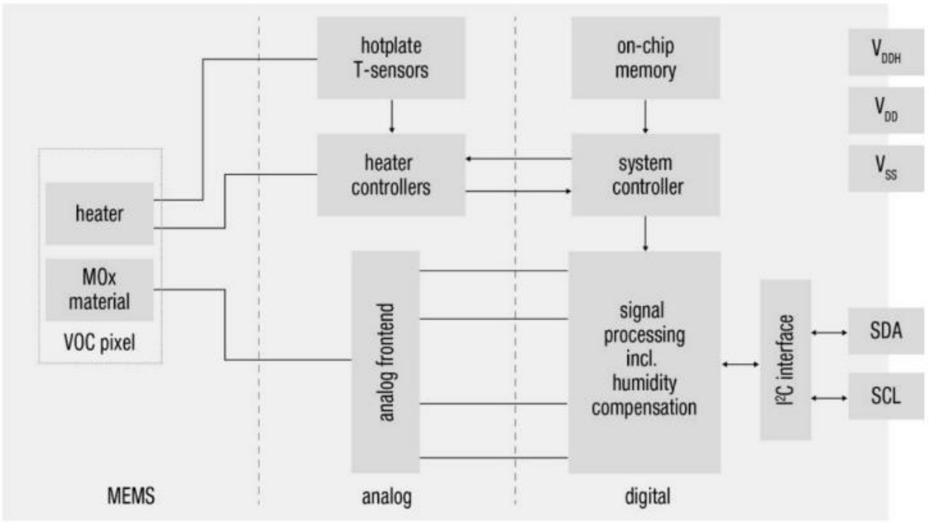
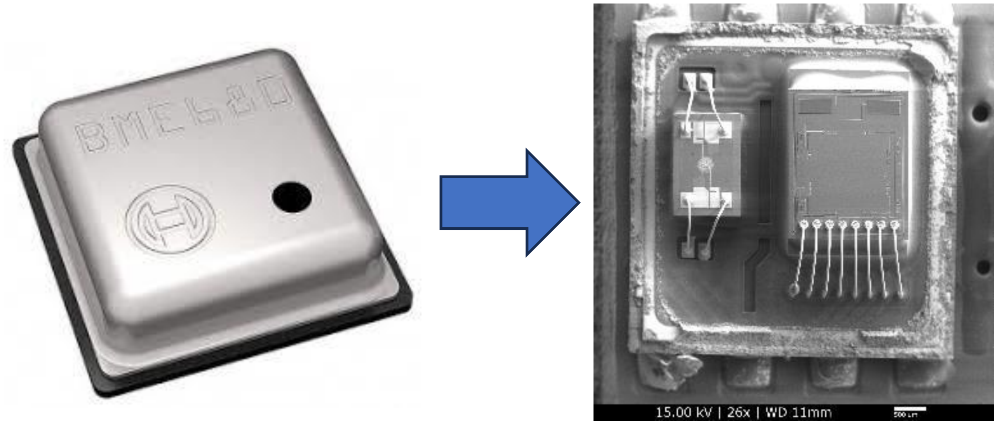


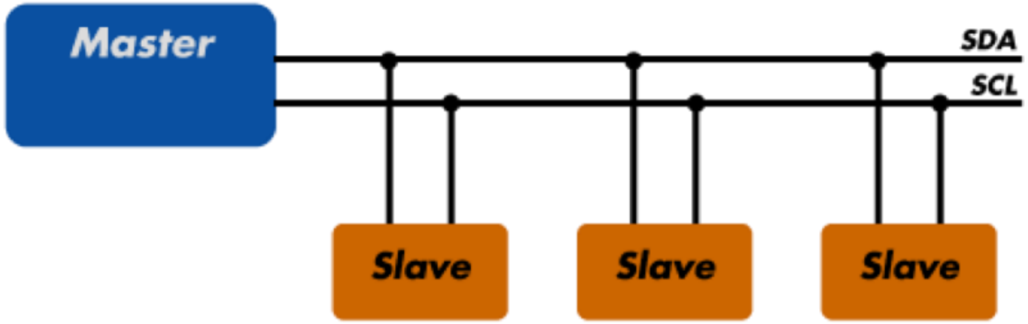
Figure 1 Functional block diagram of the SGP40.

Image source: Sensirion SGP40 datasheet



The evolution of commercial MOX sensors

Example of the most common digital sensor interface: the I2C bus



Pin	Name	Comments
1	V_{DD}	Supply voltage
2	V_{SS}	Ground
3	SDA	Serial data, bidirectional
4	n/a	Connect to ground (no electrical function)
5	V_{DDH}	Supply voltage, hotplate
6	SCL	Serial clock, bidirectional

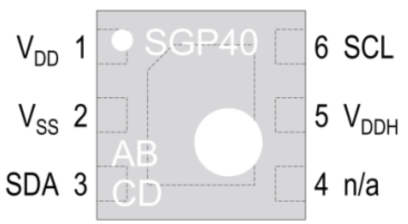


Image source: Sensirion SGP40 datasheet

I2C is a 2-wire communication bus allowing the connection of up to 128 slave devices to a master.

Generally, a I2C sensor has just 4 connections: Power supply, ground, SDA and SCL (I2C signals).

I2C is a very user friendly but rather “slow” communication bus, although:
is 400kbit/s a slow speed for gas sensor data?

The evolution of commercial MOX sensors

Firmware libraries for digital gas sensors: everything is available on-line, free to download!

For different platforms/languages

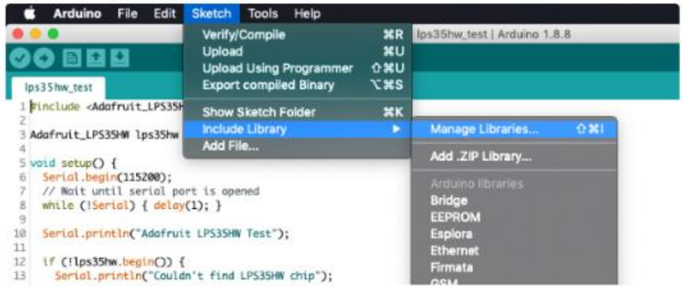
- Arduino C/C++
- CircuitPython
- Raspberry-Pi: whatever!

We will see these in more detail later…

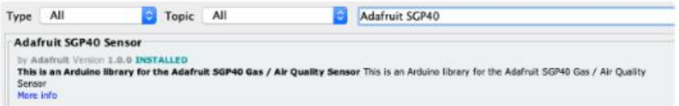
Source of screenshots: Adafruit website

Library Installation

You can install the **Adafruit SGP40** library for Arduino using the Library Manager in the Arduino IDE.



Click the **Manage Libraries ...** menu item, search for **Adafruit SGP40** , and select the **Adafruit SGP40** library:



Follow the same process for the **Adafruit BusIO** library.

Finally follow the same process for the **Adafruit SHT31 Library**:

CircuitPython Installation of BME680 Library

Next you'll need to install the Adafruit CircuitPython BME680 library on your CircuitPython board.

First make sure you are running the latest version of Adafruit CircuitPython for your board.

Next you'll need to install the necessary libraries to use the hardware--carefully follow the steps to find and install these libraries from Adafruit's CircuitPython library bundle. Our introduction guide has a great page on how to install the library bundle for both express and non-express boards.

Remember for non-express boards like the, you'll need to manually install the necessary libraries from the bundle:

- **adafruit_bme680.mpy**
- **adafruit_bus_device**

You can also download the **adafruit_bme680.mpy** from its releases page on Github.

Before continuing make sure your board's lib folder or root filesystem has the **adafruit_bme680.mpy,** and **adafruit_bus_device** files and folders copied over.

Next connect to the board's serial REPL so you are at the CircuitPython >>> prompt.

Python Installation of BME680 Library

You'll need to install the Adafruit_Blinka library that provides the CircuitPython support in Python. This may also require enabling I2C on your platform and verifying you are running Python 3. Since each platform is a little different, and Linux changes often, please visit the CircuitPython on Linux guide to get your computer ready!

Other commercially available digital environmental sensors

Other commercially available digital environmental sensors

Particulate matter (PM): optical particle counters working principle

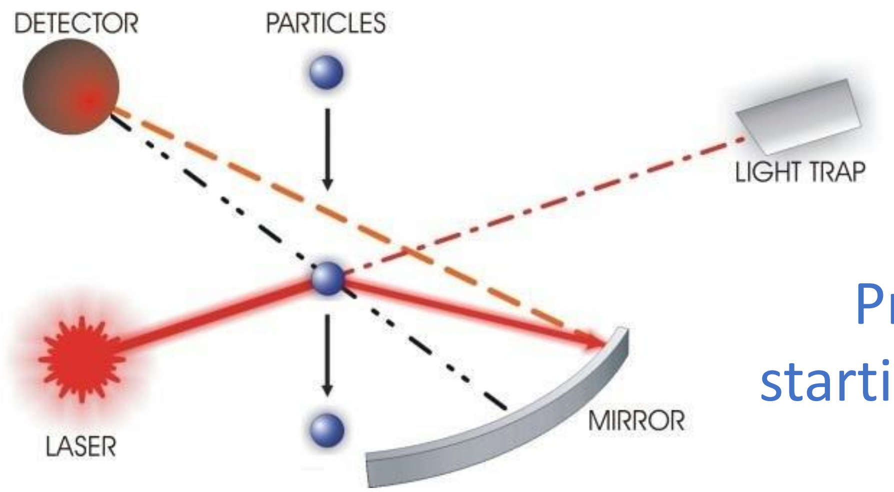


Image source: Weber, Konradin et al (2010).
Proceedings of SPIE - The International Society for Optical Engineering.
7827. 10.1117/12.869629.

Price range:
starting around 20€

Alphasense

Plantower

Sensirion

Novasense

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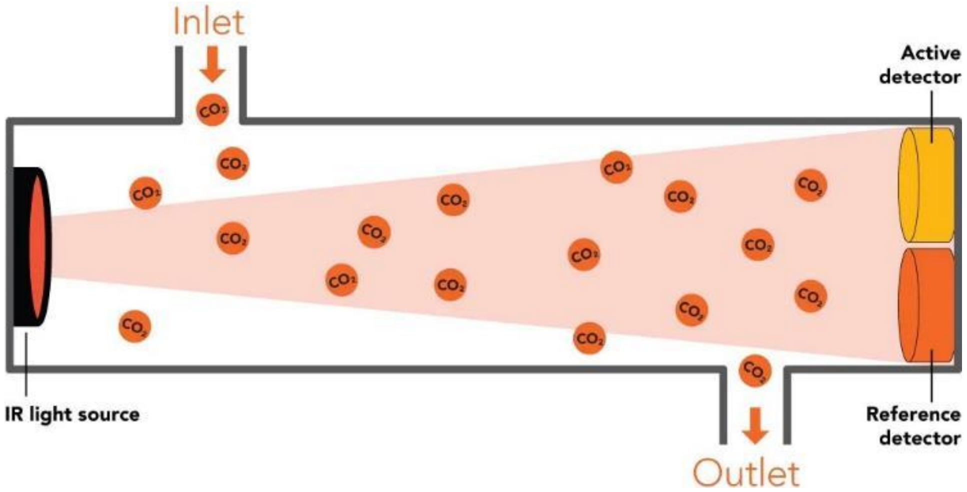
Other commercially available digital environmental sensors

Carbon Dioxide (CO_2) sensors: infrared absorption

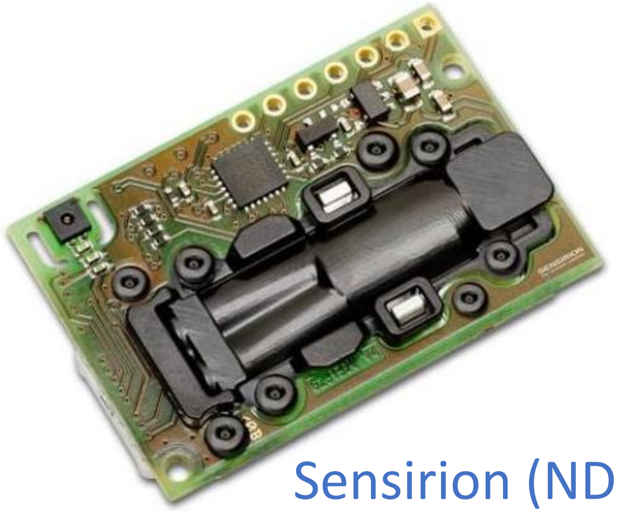
Working principle (NDIR)



https://atlas-scientific.com/blog/how-does-an-ndir-co2-sensor-work/

Price range:
starting around 30€

Senseair



Sensirion (NDIR)

Sensirion (photoacoustic)

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Other commercially available digital environmental sensors

Sensirion TVOC, NO_2, PM, T and RH sensor all-in-one: SEN55

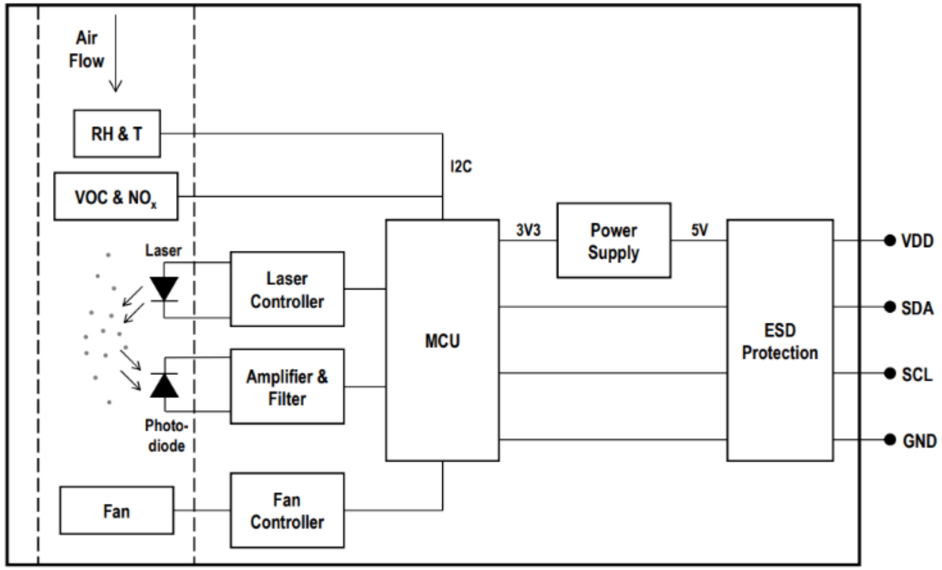
This device integrates:

- Sensirion SGP41 multi-pixel MOX sensor for TVOC and NO_2
- Sensirion OPC for PM
- Relative humidity and temperature sensors

with a simple 4-wire connection (power supply + I2C).

Sensirion SEN55

+ firmware libraries for the calculation of TVOC and NO_2 indoor air quality indices are provided for all platforms…



Price range:
20€

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Other commercially available ~~digital~~ environmental sensors

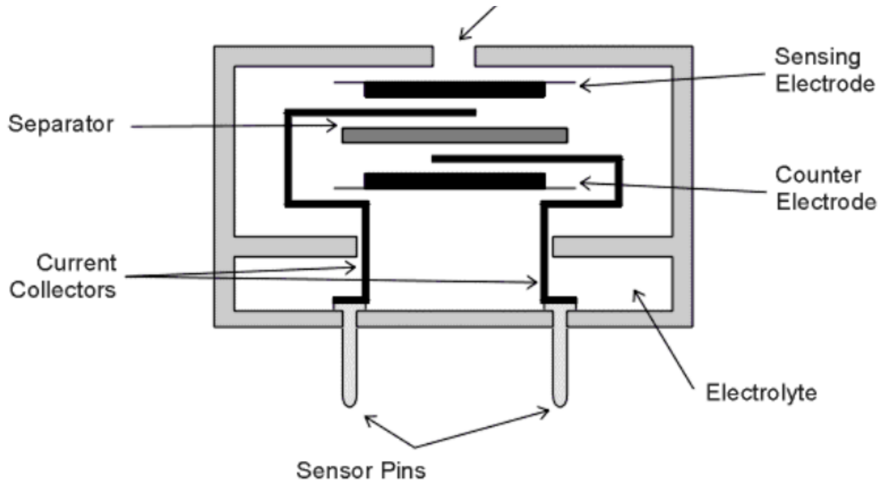
Electrochemical gas sensors

Working principle: the gas to be detected undergoes a chemical reaction on the 2 functionalized sensor electrodes. The reactions generate a small current. Example of reaction (CO sensor):

Working Electrode: $CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$

Counter Electrode: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Overall: $CO + \frac{1}{2}O_2 \rightarrow CO_2$



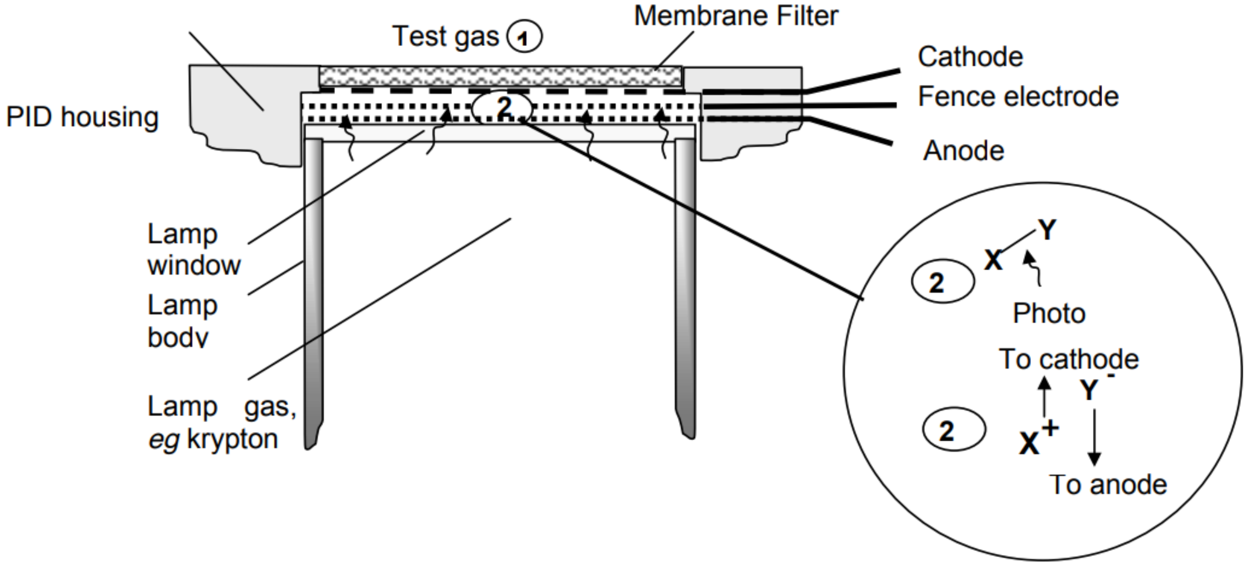
https://www.sgxsensortech.com/content/uploads/2014/08/Introduction-to-Electrochemical-EC-Gas-Sensors1.pdf

Image source: SGX sensortech website

Other commercially available ~~digital~~ environmental sensors

Photoionization detector (PID)

PID sensors use high energy (10.6eV) ultraviolet (UV) light from a lamp to ionize the gas molecules. The two resulting ions (one positive and one negative ion) are attracted by two electrodes, resulting in an ion current. The current is pre-amplified to a voltage in the range [50 – 3300] mV.
All gases with ionization energies <= 10.6eV can be detected.



Copyright Ion Science Ltd, 2007

Image source: Alphasense website

Price range:
300-500€

Commercial environmental sensors: are they any good?

Commercial environmental sensors: are they any good?

These are personal considerations after >20 years experience on environmental sensing.

Are they any good?

Yes, they are! Some are better, others slightly worse.

Really good: NDIR CO2. Generally good: OPC PM.

You shouldn't expect the performance of reference environmental monitoring sensors costing €50.000 and more. But for that price, and considering the performance of sensors 10 years ago, the latest commercial sensors are really impressive, just out-of-the-box.

What are the main problems/drawbacks (1/3)?

There are problems, and the most common is: to expect too much from the sensors, or to use their data incorrectly.

Example: does it make sense to measure TVOC indoor? What is the source of indoor VOCs? Mostly detergents, cooking, perfume. Are these harmful?

Commercial environmental sensors: are they any good?

These are personal considerations after >20 years experience on environmental sensing.

What are the main problems/drawbacks (2/3)?

Other typical errors: where to use the sensors. Typically, these sensors are commercialized for indoor air quality monitoring. Remember that "*every sensors is also a temperature sensor*", this applies very much for gas sensors. You can try hard to compensate for temperature changes, but some effects will remain. Furthermore, outdoor environments generally have bigger variations of relative humidity, which changes with temperature (dew-point etc).

Just using indoor sensors in outdoor environments will generally fail!

You can work on pre-treating the environment (put sensors in a temperature-controlled housing, avoid condensation of humidity, etc.) but some effects will remain.

Big problem with RH: PM sensing. Humidity condenses on particulate, swells particulate, …

Commercial environmental sensors: are they any good?

These are personal considerations after >20 years experience on environmental sensing.

What are the main problems/drawbacks (3/3)?

Finally, few words on MOX sensors: the main drawbacks of MOX sensors are still unsolved. Selectivity is low, but even more: sensor signal drift is still the worst problem!

Commercial sensors (SGP3x, SGP4x, BME680) use algorithms to compensate for this drift. These algorithms make some assumptions, which are generally true in indoor environments: the "lowest" VOC reading over a certain period (days) probably corresponds to "clean" air.

This is not true in:

- **Applications different than indoor air quality monitoring. If you use such a sensor to measure a synthetically VOC-charged environment, after some days the reading may be "clean air".**
- **Indoor air quality monitoring in a very polluted city, in a house without pollution filters or scrubbers of any sort: the air will never be really "clean", but the algorithm will imply it.**

Commercial environmental sensors: are they any good?

These are personal considerations after >20 years experience on enviro

What are the main problems/drawbacks (3/3)?

Finally, few words on MOX sensors ... lved.
Selectivity is low, but even ...

Commerc...
T... environments:
... sponds to "clean" air.

... air quality monitoring. If you use such a sensor to measure
... ged environment, after some days the reading may be "clean air".
- ... ity monitoring in a very polluted city, in a house without pollution filters or
s... bers of any sort: the air will never be really "clean", but the algorithm will imply it.

But hey: they cost <10€.
What do you expect from them?
Just use them cleverly! That's our job.

Hardware for sensor networks

Hardware for sensor networks (in the 2020s)

We start from available digital sensors (most likely with I2C bus).

What do we use for sensor readout, datalogging, data transfer (wireless?), …

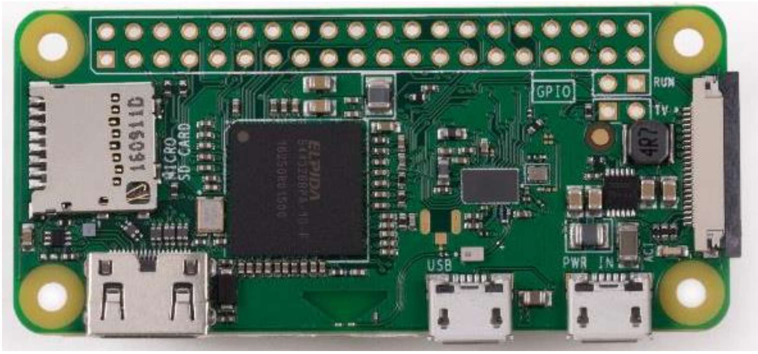
There are mainly 2 low-cost options:

1. Microcontrollers (e.g. Arduino, ESP32, …)
2. Embedded micro-PCs (e.g. Raspberry-Pi)

Both options have several versions.
They differ in capabilities (e.g. WiFi, Bluetooth, LAN, …) and cost.

Generally, with 5-20€ you can have all you need!

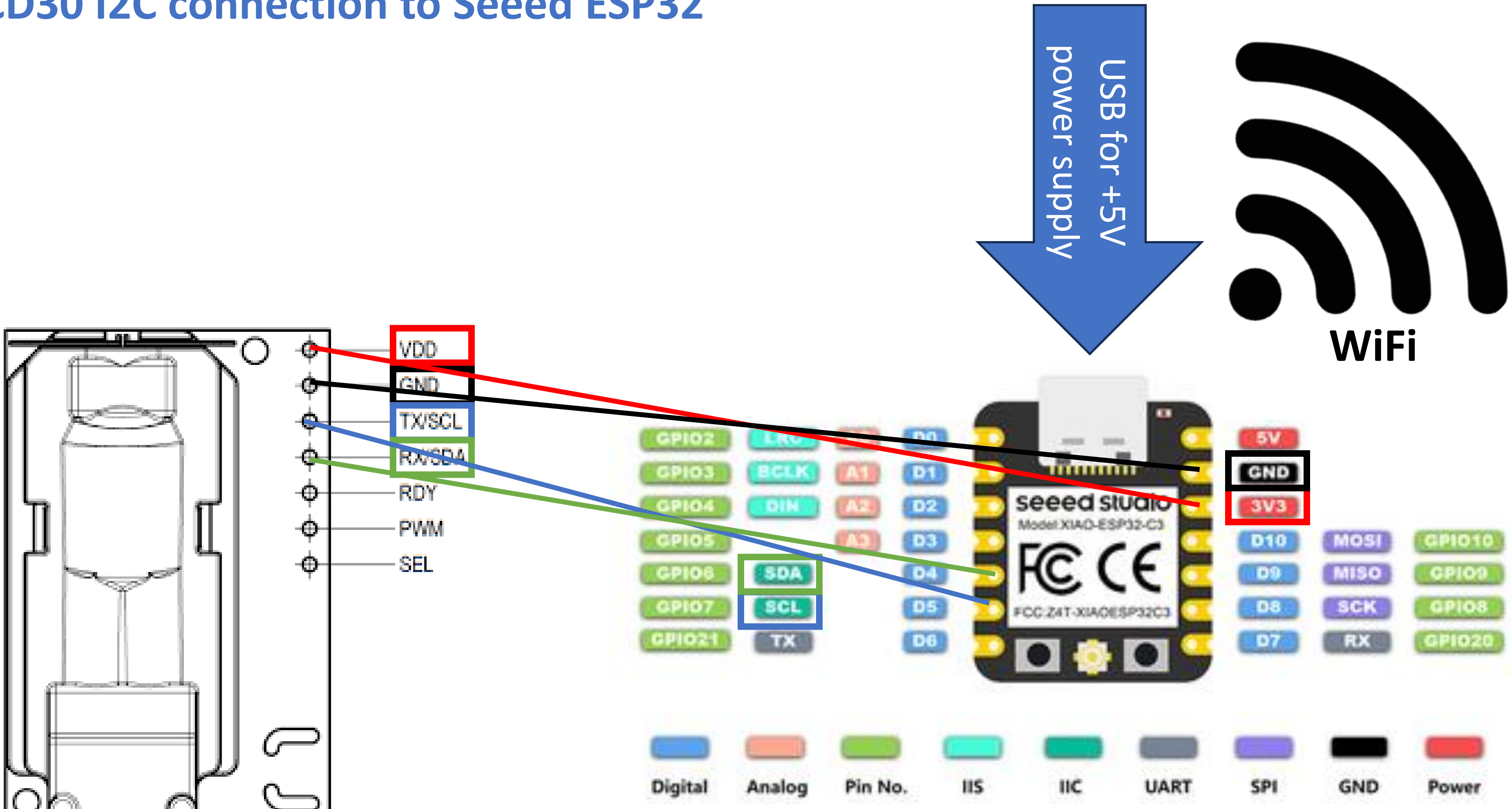
Seeed studio ESP32:
WiFi, BT, USB-C, **I2C**,
Arduino-IDE. € 5,41



Raspberry-Pi 0W:
WiFi, BT, **I2C**, USB-C, HDMI, SD-card,
+full Linux Debian-like OS. € 14,39

Hardware for sensor networks (in the 2020s)

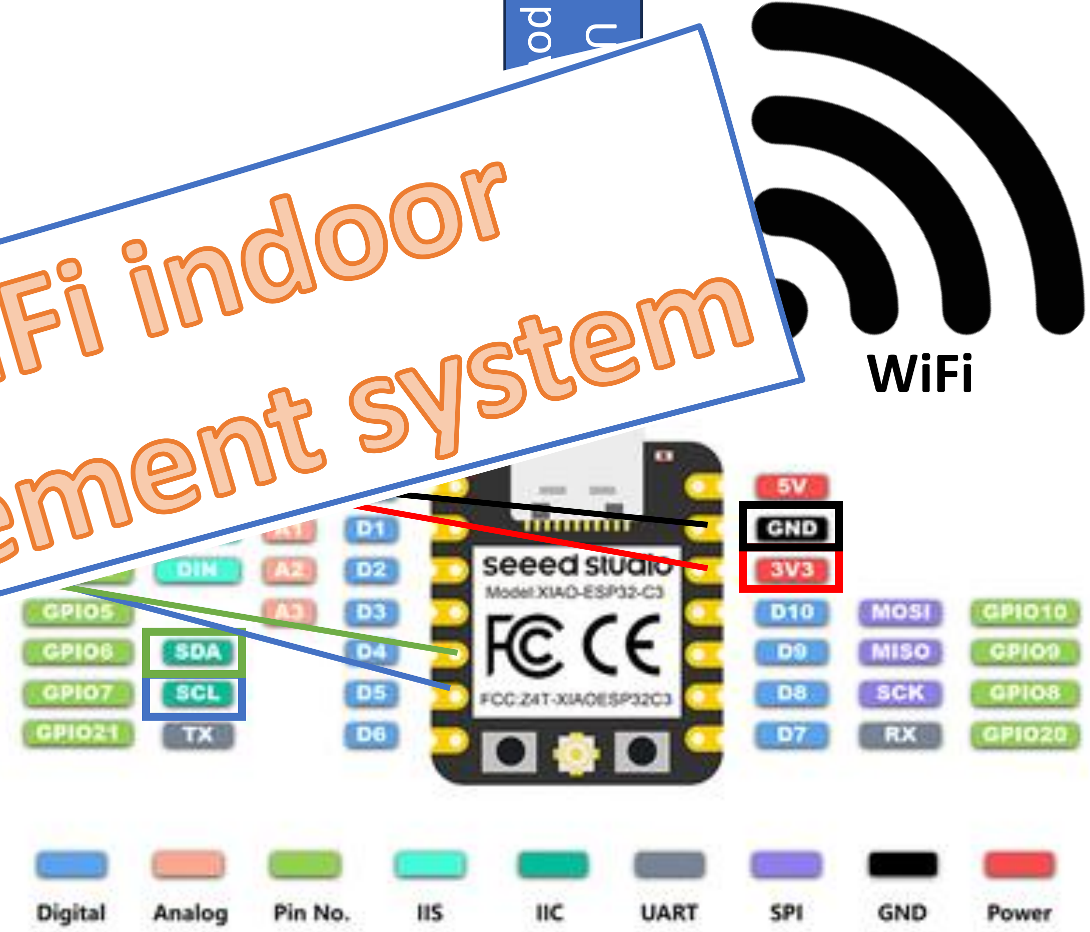
Example 1: CO_2 sensor SCD30 I2C connection to Seeed ESP32



* Aliexpress prices

Hardware for sensor networks (in the 2020s)

Example 1: CO_2 sensor SCD30 I2C connection to Seeed ESP32

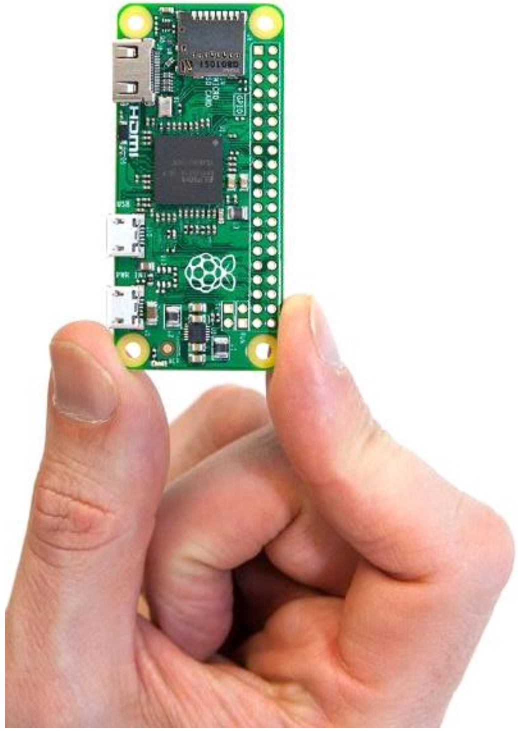


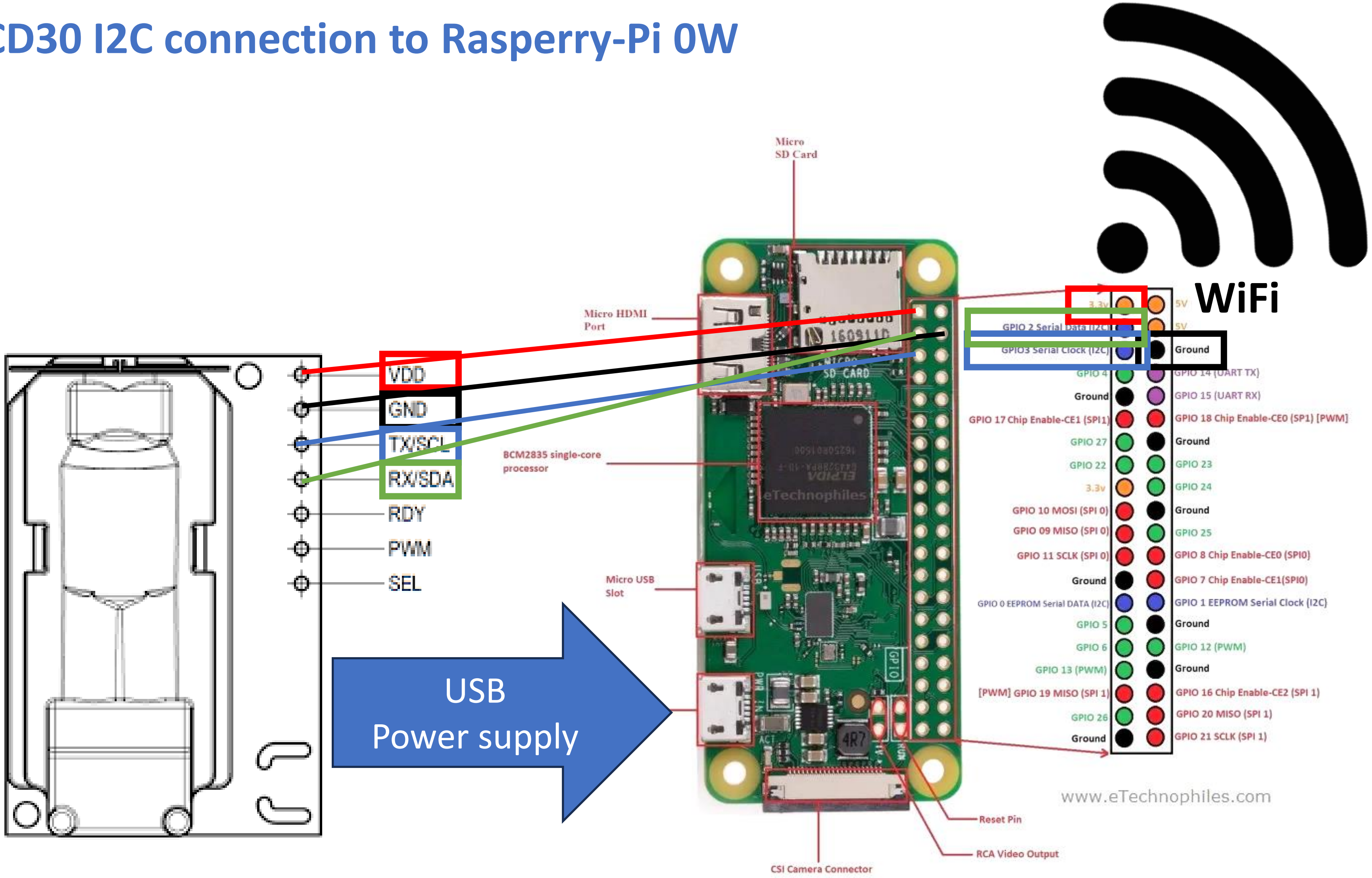
This is a €30* WiFi indoor air quality measurement system

* Aliexpress prices

Hardware for sensor networks (in the 2020s)

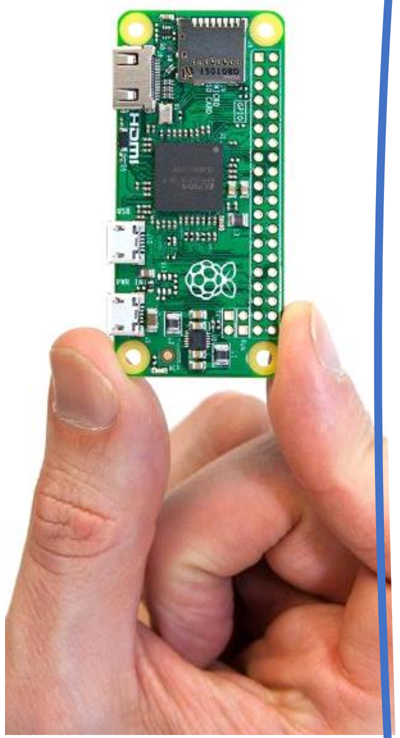
Example 2: CO_2 sensor SCD30 I2C connection to Rasperry-Pi 0W

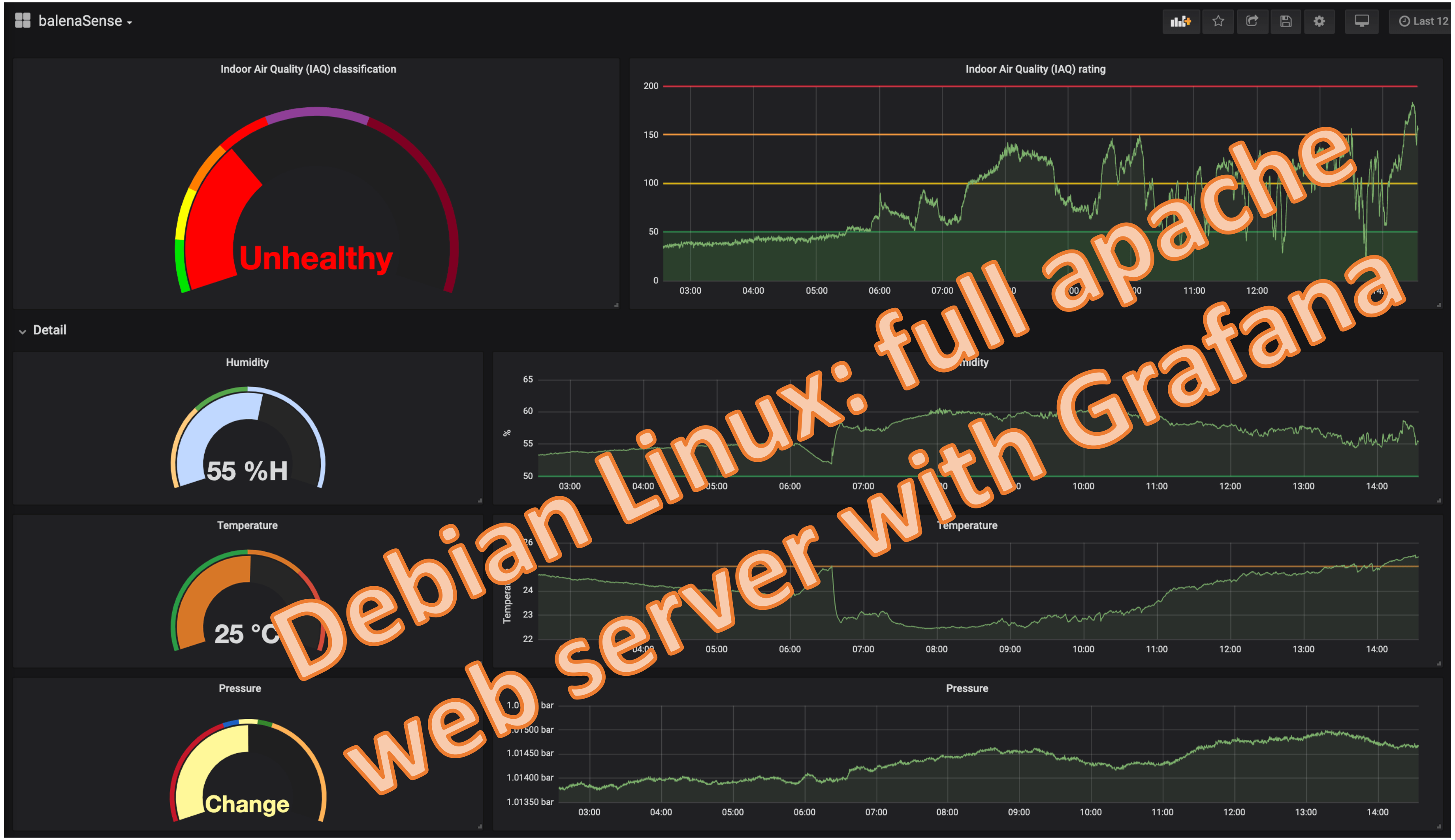




Hardware for sensor networks (in the 2020s)

Example 2: CO_2 s





Debian Linux: full apache web server with Grafana

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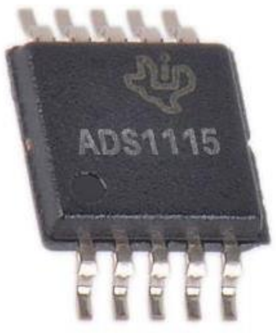
From analog sensor to digital sensor

Some sensors (e.g. electrochemical, photoionization) still provide analog signals.

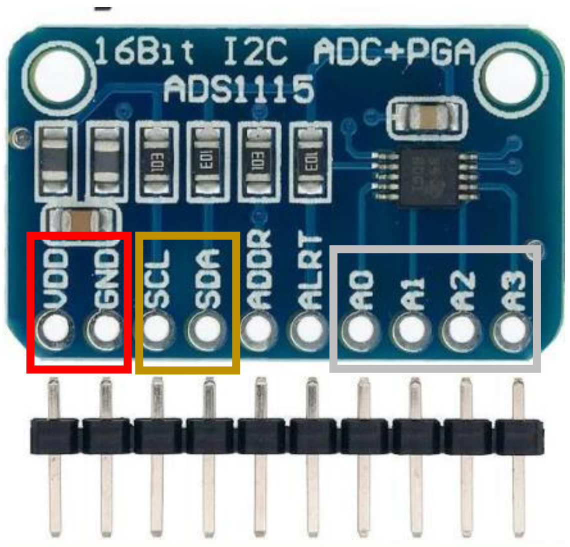
Acquisition of analog signals can be easily accomplished using A/D converters, and nowadays low-cost ADCs with I2C interfaces are available. Example: Texas Instruments ADS1115.

Main features of ADS1115:

- ✓ 16-bit resolution
- ✓ Up to 860 samples per seconds
- ✓ 4 single-ended or 2 differential inputs
- ✓ Internal voltage reference
- ✓ Programmable gain amplifier
- ✓ I2C interface, can be configured on 4 addresses
- ✓ Programmable comparator with alarm function



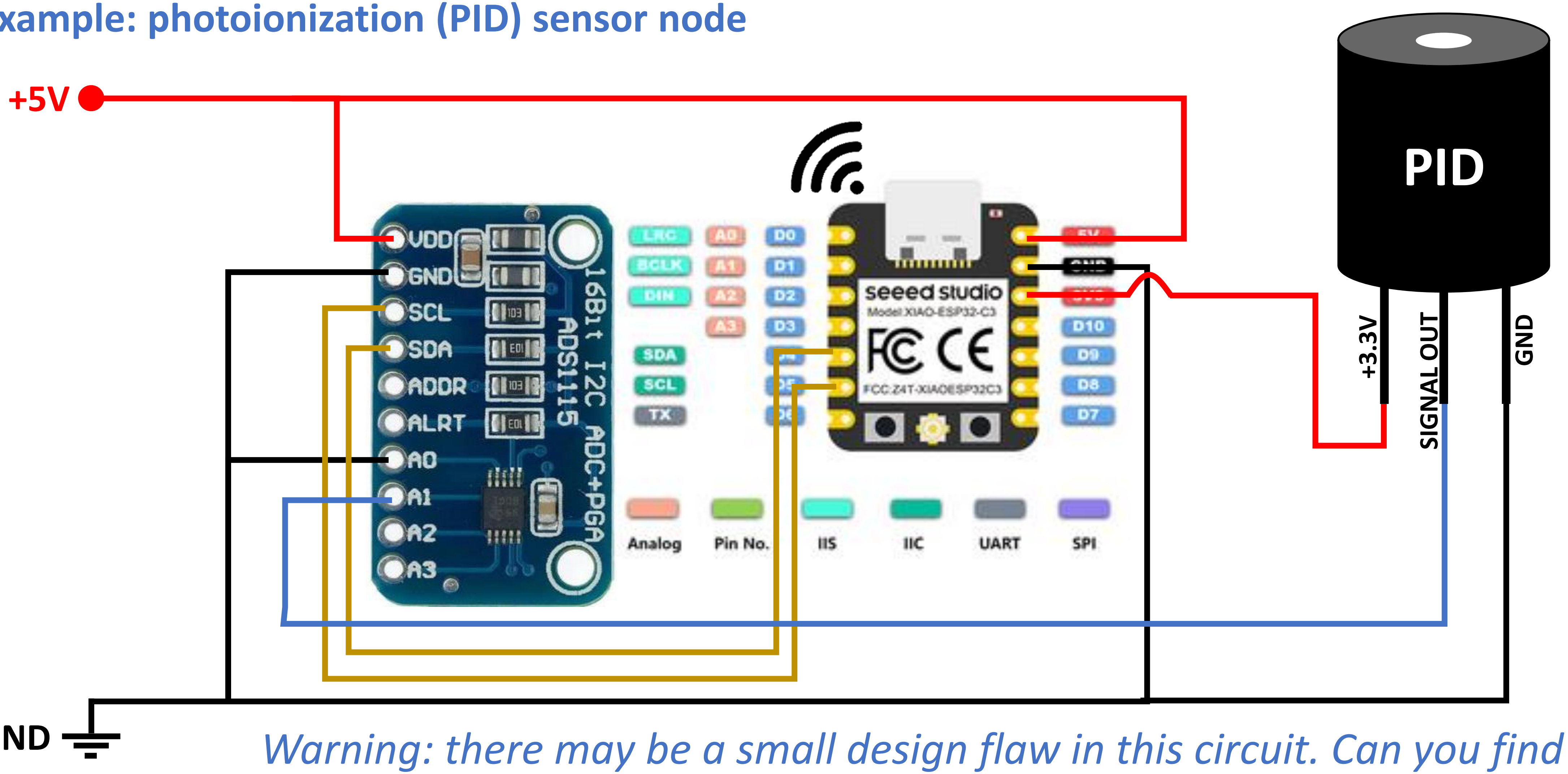
Price range:
<6€ (mouser)



Price range:
2.15€ (AliExpress)

From analog sensor to digital sensor

Example: photoionization (PID) sensor node



Warning: there may be a small design flaw in this circuit. Can you find it?

Hardware for sensor networks (in the 2020s)

On either Raspberry-Pi or Microcontroller you can choose between different programming languages!

Raspberry-Pi:

- C/C++
- Python / Circuitpython
- Simple graphical programming IDEs (for children!)
- …

getting easier…

Microcontrollers (ESP32, SAMD21, Arduino)

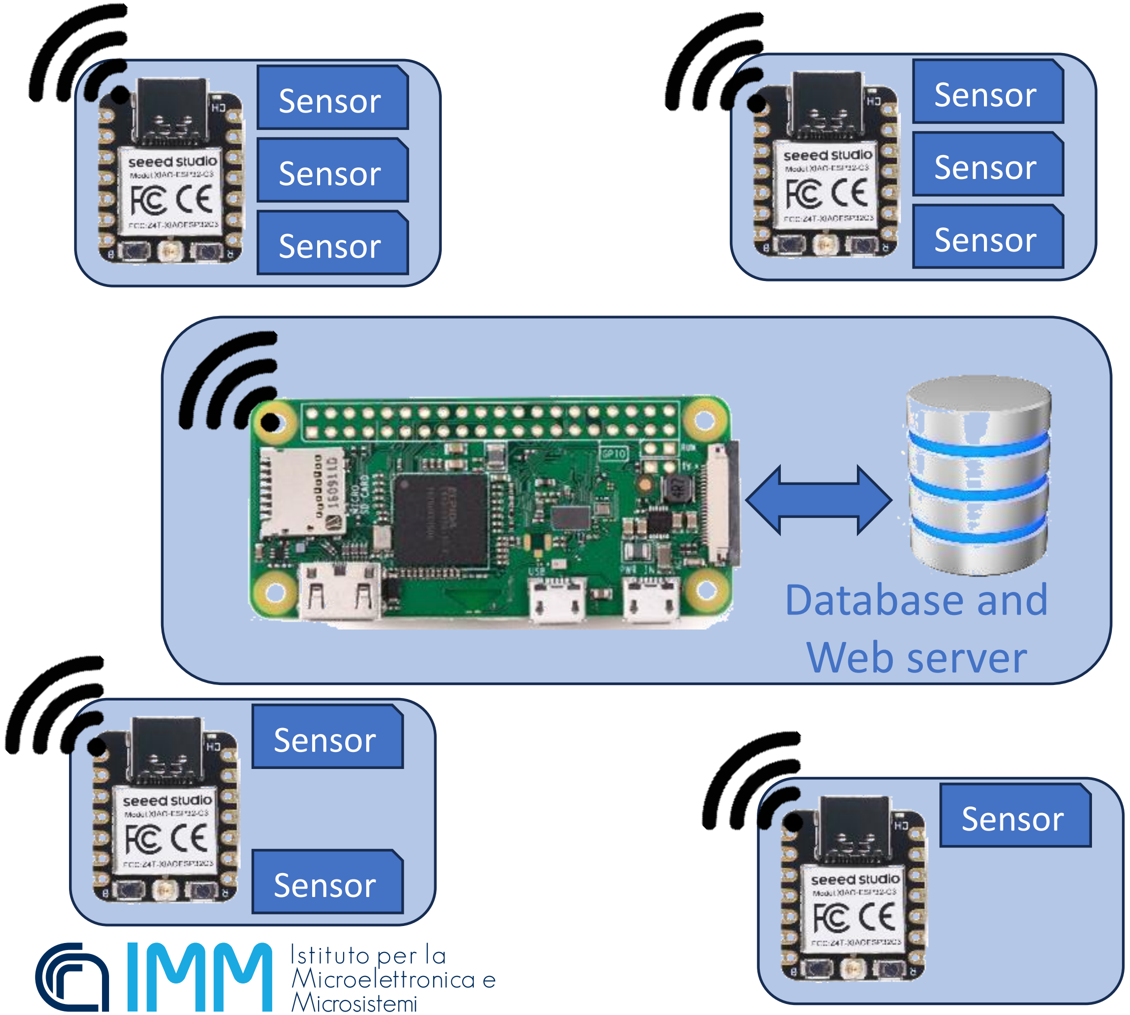
- Proprietary IDEs (Micorchip, Expressif, …)
- C/C++ in Arduino IDE
- Python / Circuitpython / Micropython
- …

The main difference is that, at a slightly higher cost and power consumption, on Raspberry-Pi you have a complete Linux distribution with web server, database, compilers for most programming languages, packages for data visualization like the excellent Grafana. **All freeware!**

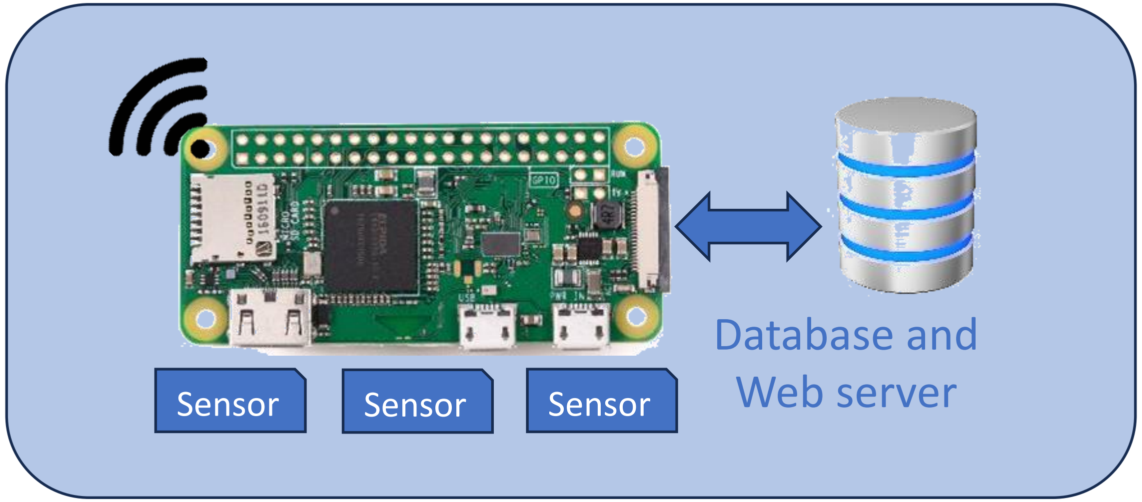
As a first approximation, you can consider the following 2 use-cases:

Hardware for sensor networks (in the 2020s)

A network of sensor nodes with one central server for data storage and visualization



A single stand-alone sensor node with integrated data storage and visualization



Hardware for sensor networks (in the 2020s)

Some words about sensor data transfer protocols.

A lightweight, easy and powerful standard protocol was already defined: **MQTT**.
No need to worry about coding protocols yourself.

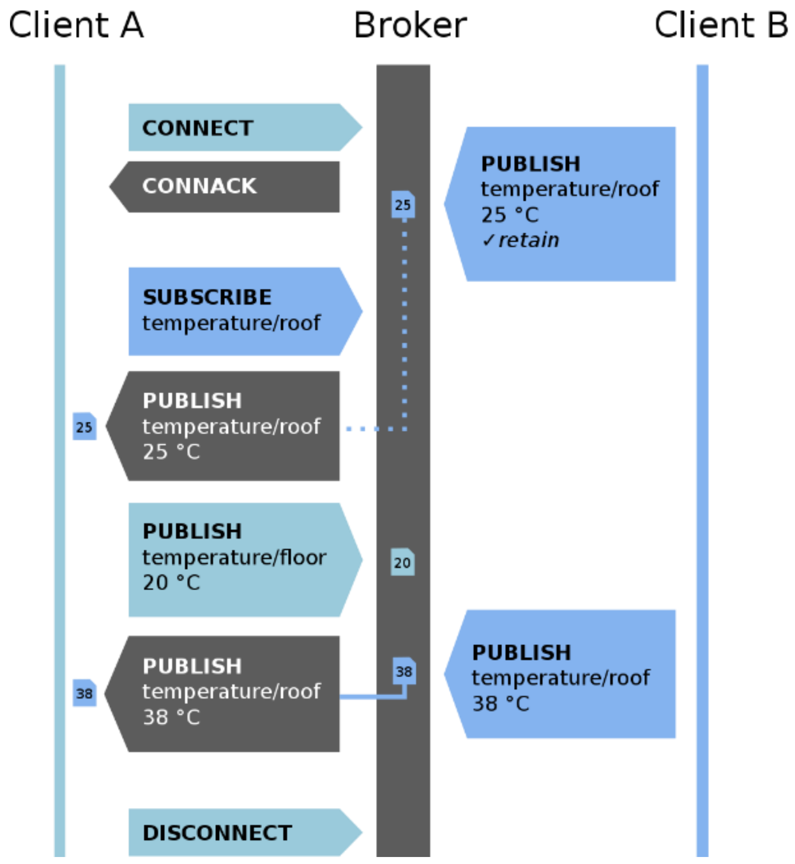
MQTT generally relies on a broker, which you could consider as some sort of "server", which could be a public and free server running on the cloud. The broker is accessible, has a known address (URL).

The sensor node is generally a MQTT client, which "publishes" data on the broker, on a given channel.

Other clients can connect to the broker and "listen" to the messages (=data) on a given channel.
This means that, for example, the database will get the sensor messages by "subscribing" to the channel on the MQTT broker, listening to and receiving the messages published by the clients, and storing the data from the messages in the database.

Hardware for sensor networks (in the 2020s)

Some words about sensor data transfer protocols: MQTT



Example of typical MQTT interactions, from Wikipedia.

MQTT libraries already exist, free to download, for most platforms and languages.
Both for broker and client side.

The protocol is very flexible: many nodes can publish on a channel, many nodes can listen to the data broadcast to that channel.
You can add your own IDs for the single sensors in the message body, you can even encrypt data.

There are also QOS (Quality of Service) measures, including acknowledgements for message reception on broker side.

Hands-on examples

Hands-on examples

Microcontroller programming has never been that easy: CirctuitPython!

Description of the workflow:

1. Find a microcontroller compatible with CircuitPython (best place to look: Adafruit website)
2. Write the CircuitPython loader to the Microcontroller NVRAM (instructions on the website)
3. Find and download the CircuitPython libraries for the sensor (e.g. SCD30 CO_2 sensor)
4. Connect the Microcontroller via USB to your PC: this will open an external storage drive (!)
5. Copy the libraries downloaded in 3) to the external drive
6. Create a file named main.py on the external drive and write the following code into the file:

Hands-on examples

Microcontroller programming has never been that easy: CircuitPython!

```
import time
import board
import busio
import adafruit_scd30

i2c = busio.I2C(board.SCL, board.SDA, frequency=50000)
scd = adafruit_scd30.SCD30(i2c)

while True:
    if scd.data_available:
        print("CO2: %d PPM" % scd.CO2)
        print("Temperature: %0.2f degrees C" % scd.temperature)
        print("Humidity: %0.2f %% rH" % scd.relative_humidity)
    time.sleep(0.5)
```

Source: https://learn.adafruit.com/adafruit-scd30/python-circuitpython

Hands-on examples

Microcontroller programming has never been that easy: CirctuitPython!

```
import time
import board
import busio
import adafruit_scd30

i2c...
s...

wh...

    ...0.2f degrees C" % scd.temperature)
    ...ity: %0.2f %% rH" % scd.relative_humidity)
    t...eep(0.5)
```

Just 11 lines of code to read CO_2, RH and T data from a digital sensor to a microcontroller!

Source: https://learn.adafruit.com/adafruit-scd30/python-circuitpython

Hands-on examples

OK, we talked about WiFi capabilities… but these are typically available indoors or in smart cities. What can we use for outdoor sensor networks data transfer?

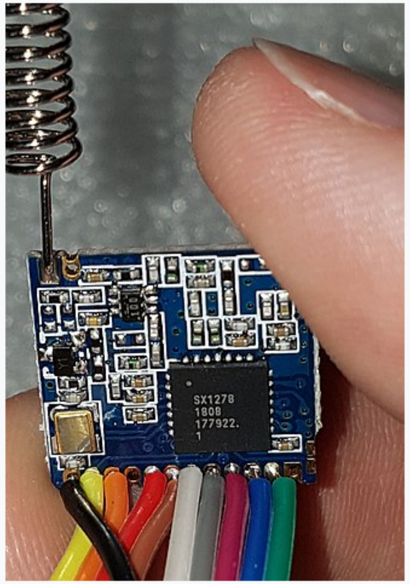
LoRa®

LoRa (from "long range") is a physical proprietary radio communication technique.[1] It is based on spread spectrum modulation techniques derived from chirp spread spectrum (CSS) technology.[2] It was developed by Cycleo (patent 9647718-B2), a company of Grenoble, France, later acquired by Semtech.[3][4]

LoRaWAN (Wide Area Network) defines the communication protocol and system architecture. LoRaWAN is an official ITU-T Y.4480 standard of the International Telecommunication Union (ITU).[5] The continued development of the LoRaWAN protocol is managed by the open, non-profit LoRa Alliance, of which SemTech is a founding member.

Together, LoRa and LoRaWAN define a Low Power, Wide Area (LPWA) networking protocol designed to wirelessly connect battery operated devices to the internet in regional, national or global networks, and targets key Internet of things (IoT) requirements such as bi-directional communication, end-to-end security, mobility and localization services. The low power, low bit rate, and IoT use distinguish this type of network from a wireless WAN that is designed to connect users or businesses, and carry more data, using more power. The LoRaWAN data rate ranges from 0.3 kbit/s to 50 kbit/s per channel.[6]

LoRa



A LoRa module

Developed by	Cycleo, Semtech
Connector type	SPI/I2C
Compatible hardware	SX1261, SX1262, SX1268, SX1272, SX1276, SX1278
Physical range	>10 kilometres (6.2 mi) in perfect conditions

Features [edit]

LoRa uses license-free sub-gigahertz radio frequency bands EU868 (863–870/873 MHz) in Europe; AU915/AS923-1 (915–928 MHz) in South America; US915 (902–928 MHz) in North America; IN865 (865–867 MHz) in India; and AS923 (915–928 MHz) in Asia;[7] and 2.4 GHz worldwide.[8] LoRa enables long-range transmissions with low power consumption.[9] The technology covers the physical layer, while other technologies and protocols such as LoRaWAN (Long Range Wide Area Network) cover the upper layers. It can achieve data rates between 0.3 kbit/s and 27 kbit/s, depending upon the spreading factor.[10]

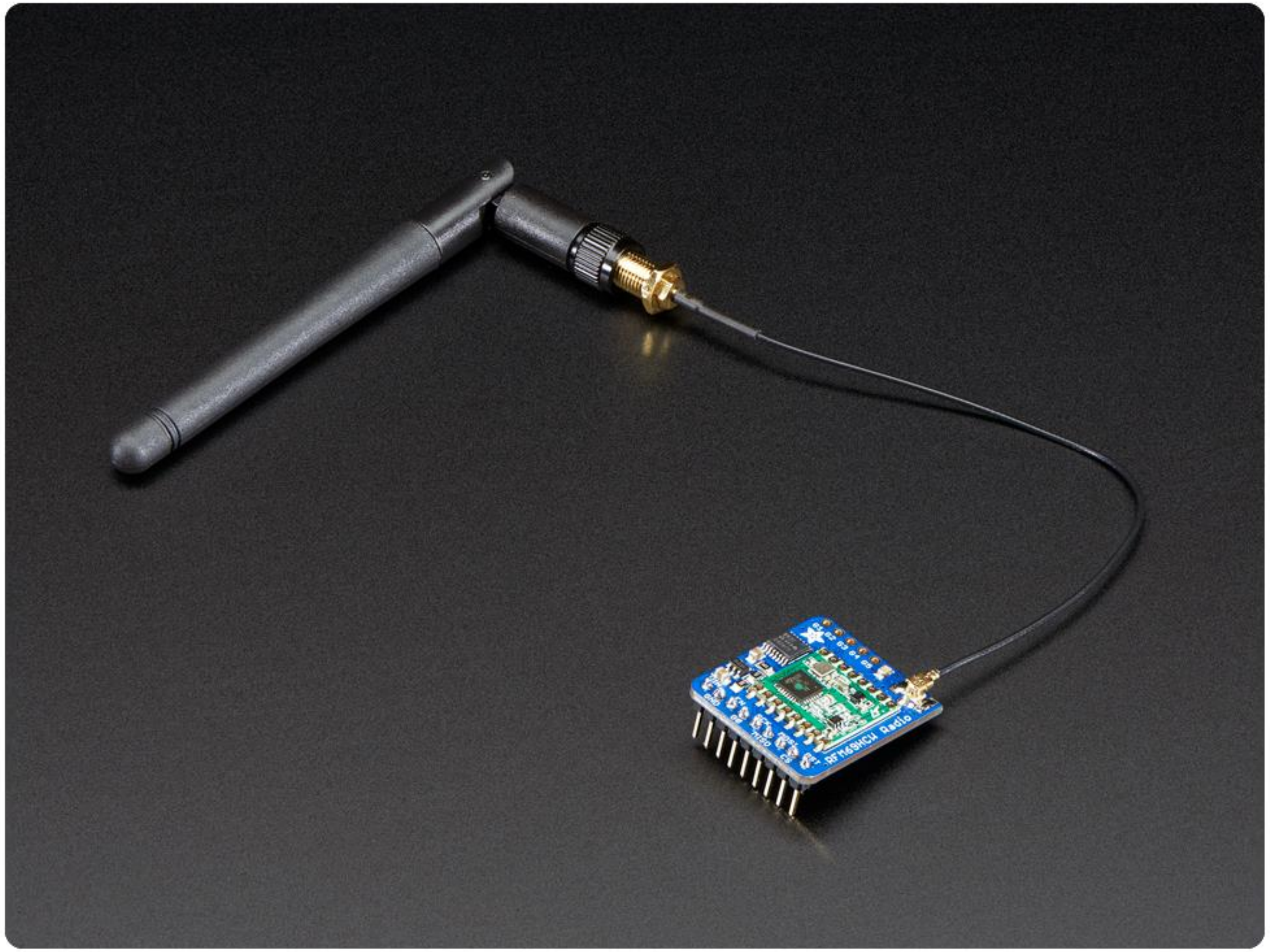
LoRa devices have geolocation capabilities used for trilaterating positions of devices via timestamps from gateways.[11]

Hands-on examples

LoRa® sounds great! But where can I get one?

adafruit Products Gift Ideas What's New

Wireless / RF / LoRa / LoRaWan / Adafruit RFM95W LoRa Radio Transceiver Breakout - 868 or 915 MHz



Adafruit RFM95W LoRa Radio Transceiver Breakout - 868 or 915 MHz - RadioFruit

Product ID: 3072

$19.95

In stock

Order now to ship today

1 Add to Cart

☐ Also include 1 x Edge-Launch SMA Connector for 1.6mm / 0.062" Thick PCBs ($2.50)

☐ Also include 1 x uFL SMT Antenna Connector ($0.75)

☐ Also include 1 x Simple Spring Antenna - 915MHz ($0.95)

Qty	Discount
1-9	$19.95
10-99	$17.96
100+	$15.96

Add to Wishlist

Description

Well, that could be Adafruit again. Or Amazon, eBay, AliExpress, Mouser, melopero®…

Hands-on examples

But how do I write the firmware for LoRa ? Do I need to implement RF layer, protocols, libraries?

```
import board
import busio
import digitalio
import adafruit_rfm9x


RADIO_FREQ_MHZ = 915.0
CS = digitalio.DigitalInOut(board.D5)
RESET = digitalio.DigitalInOut(board.D6)

spi = busio.SPI(board.SCK, MOSI=board.MOSI, MISO=board.MISO)
rfm9x = adafruit_rfm9x.RFM9x(spi, CS, RESET, RADIO_FREQ_MHZ)

rfm9x.tx_power = 23

rfm9x.send(bytes("Hello world!\r\n", "utf-8"))
```

Source: https://learn.adafruit.com/adafruit-rfm69hcw-and-rfm96-rfm95-rfm98-lora-packet-padio-breakouts/circuitpython-for-rfm9x-lora

Hands-on examples

But how do I write the firmware for LoRa ? Do I need to implement RF layer, protocols, libraries?

```
import board
import busio
import digitalio
import adafruit_rfm9x


RADIO_FREQ_MHZ =
CS = di
RE

sp                    board.MOSI, MISO=board.MISO)
rfm                 RFM9x(spi, CS, RESET, RADIO_FREQ_MHZ)

rfm9  x_power = 23

rfm9x.send(bytes("Hello world!\r\n", "utf-8"))
```

Just 11 lines of code to send a message up to 10km with a low-power radio link!

Source: https://learn.adafruit.com/adafruit-rfm69hcw-and-rfm96-rfm95-rfm98-lora-packet-padio-breakouts/circuitpython-for-rfm9x-lora

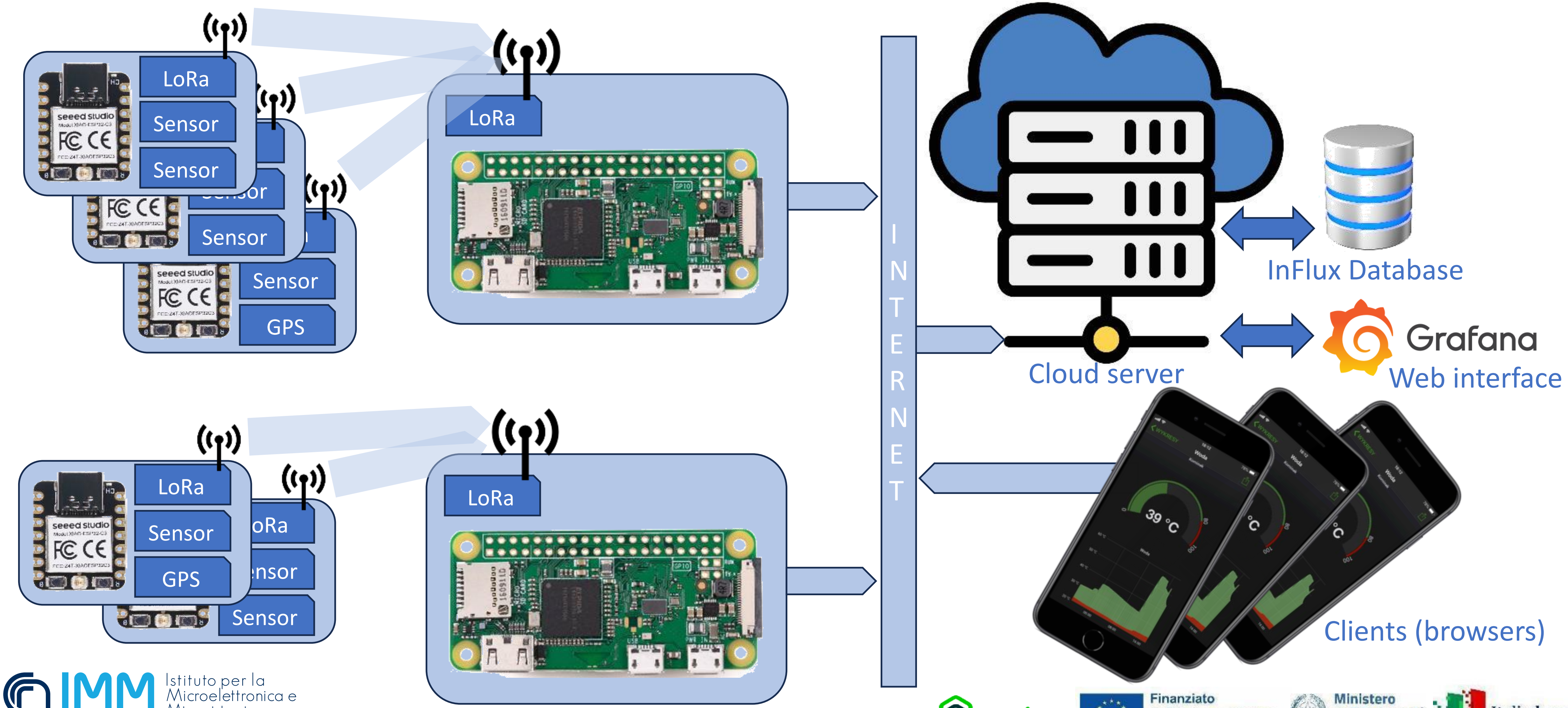
Hands-on examples

Let's write the entire software for a CircuitPython® compatible microcontroller with SCD30 CO_2 sensor and a LoRa® module for 10km data transfer, transmitting one measurement every 10s:

```
import time
import board
import busio
import digitalio
import adafruit_rfm9x
import adafruit_scd30

CS = digitalio.DigitalInOut(board.D5)
RESET = digitalio.DigitalInOut(board.D6)
spi = busio.SPI(board.SCK, MOSI=board.MOSI, MISO=board.MISO)
rfm9x = adafruit_rfm9x.RFM9x(spi, CS, RESET, 915.0)
rfm9x.tx_power = 23

i2c = busio.I2C(board.SCL, board.SDA, frequency=50000)
scd = adafruit_scd30.SCD30(i2c)

while True:
    if scd.data_available:
        DataString = "{:d}, {:.1f}, {:.1f}\n".format(scd.CO2, scd.temperature, scd.relative_humidity)
        rfm9x.send(bytes(DataString, "utf-8"))
        time.sleep(10)
```

Hands-on examples

A complete sensor network scheme: Sensor Nodes, LoRa gateways, cloud server, database, clients



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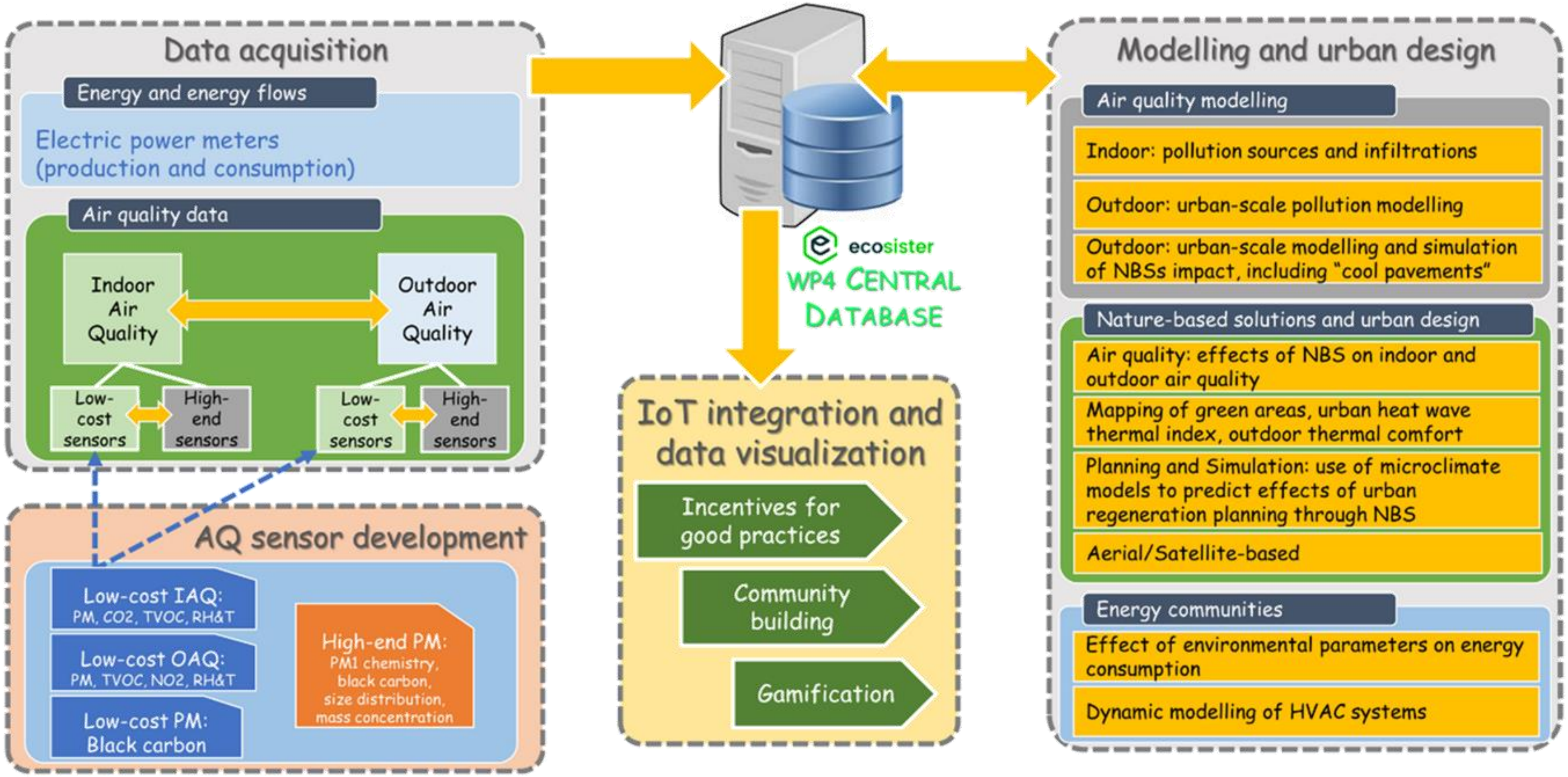
Conclusions: outlook and take-away messages

Ongoing research project on sensor networks for indoor and outdoor air quality:
Spoke4 WP4 or the Emilia-Romagna Next-Generation-EU Research Ecosystem



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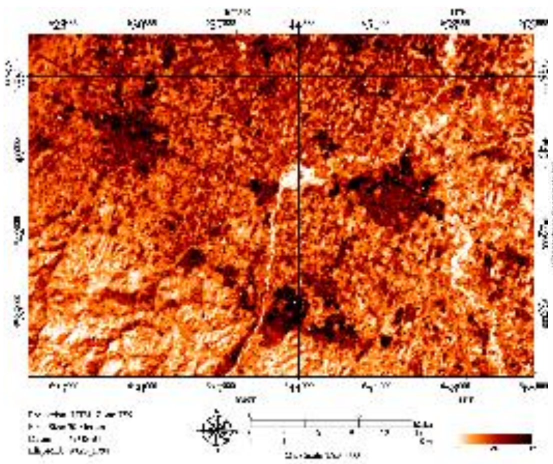
Ongoing research project on sensor networks for indoor and outdoor air quality:
Spoke4 WP4 or the Emilia-Romagna Next-Generation-EU Research Ecosystem

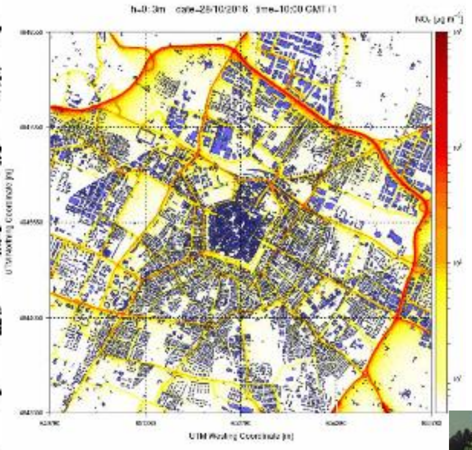
RPi 0W

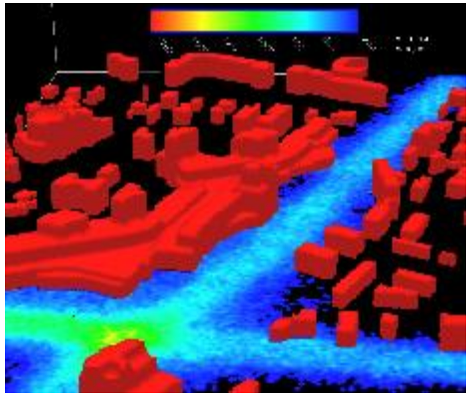
Plantower OPC (PM)

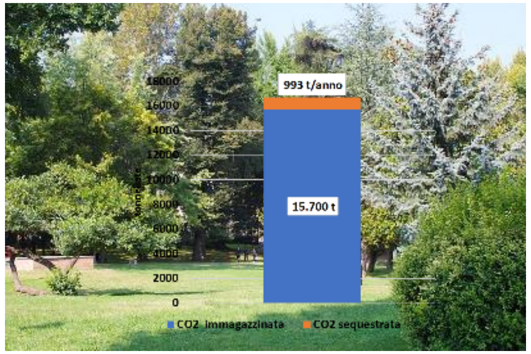
Sensirion SGP41
($TVOC\&NO_2$)

«Old» smartphone
as optional display
(sustainability)









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Conclusions: take-away messages

- ✓ Commercial sensors for environmental monitoring have made great progress in recent years
- ✓ This is especially true for indoor environments. For outdoor, there is still some work for you…

- ✓ Don't be afraid of electronics and firmware: in recent years incredible tools were developed
- ✓ Such "maker" environments are easy enough for kids to work with

- ✓ **Some names to keep in mind**… and read about on the Internet:
  - Any **digital sensor** with **I2C** (or SPI) bus will be rather easy to use
  - Microcontrollers (**ESP32**, SAMD21, Arduino) and **Raspberry-Pi** for sensor control and readout
  - **Circuitpython** as very powerful microcontroller programming language
  - **MQTT** as sensor data transfer protocol: libraries exist for every platform! No need to code it
  - **Grafana** as sensor data visualization tool (web server, data access from any browser, free!)
  - **InFluxDB** as database for sensor data (had no time to talk about it today, sorry…)

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at CNR-IMM
Francesco Suriano, Francesco Marucci
at Proambiente

Missione 4 Istruzione e Ricerca

Thank you for your attention.

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Dr. Stefano Zampolli
stefano.zampolli@cnr.it

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