

# DESIGNING AND DEPLOYING LOW-COST IOT: DIGITAL AGRICULTURE OPPORTUNITY FOR SMALLHOLDERS



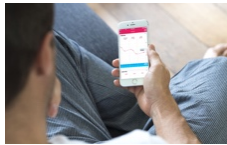
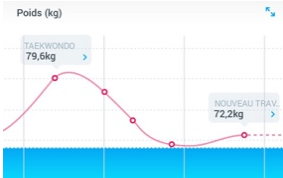
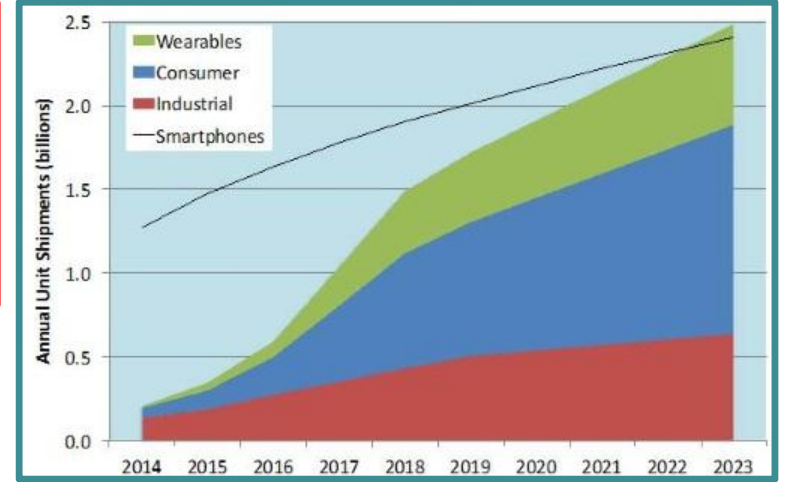
**Presented on May 26th, 2021**

Prof. Congduc Pham  
<http://www.univ-pau.fr/~cpham>  
Université de Pau, France





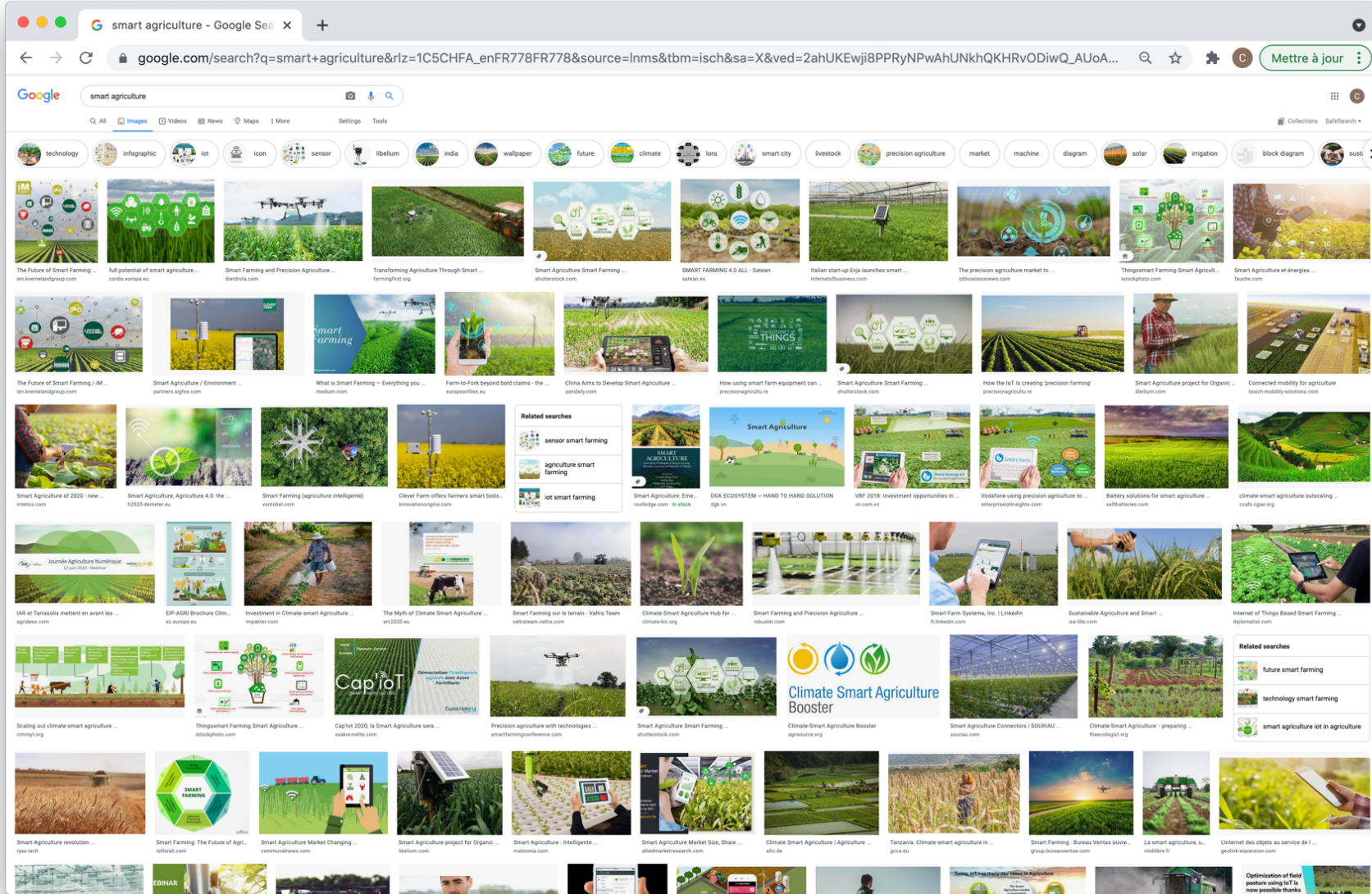
# ...shows communicating objects



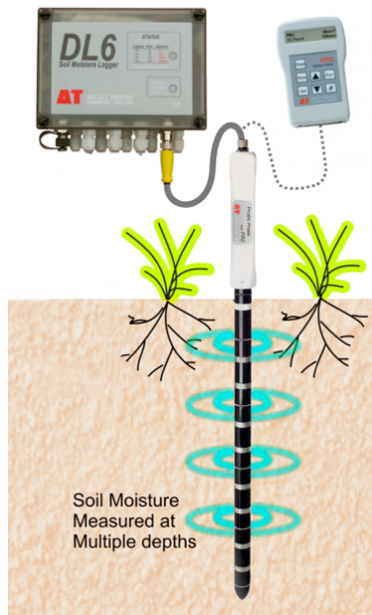
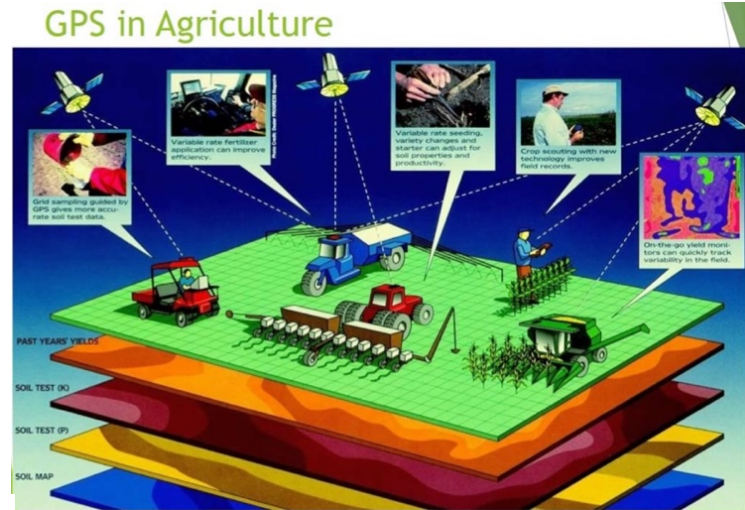
Prof. Congduc Pham  
<http://www.univ-pau.fr/~cpham>



# Googling for "Smart Agriculture"



# Smart Agriculture, a mature technology



# Sense, Monitor, Optimize & Control



**DATA ANALYSIS,  
 OPTIMIZATION & CONTROL**

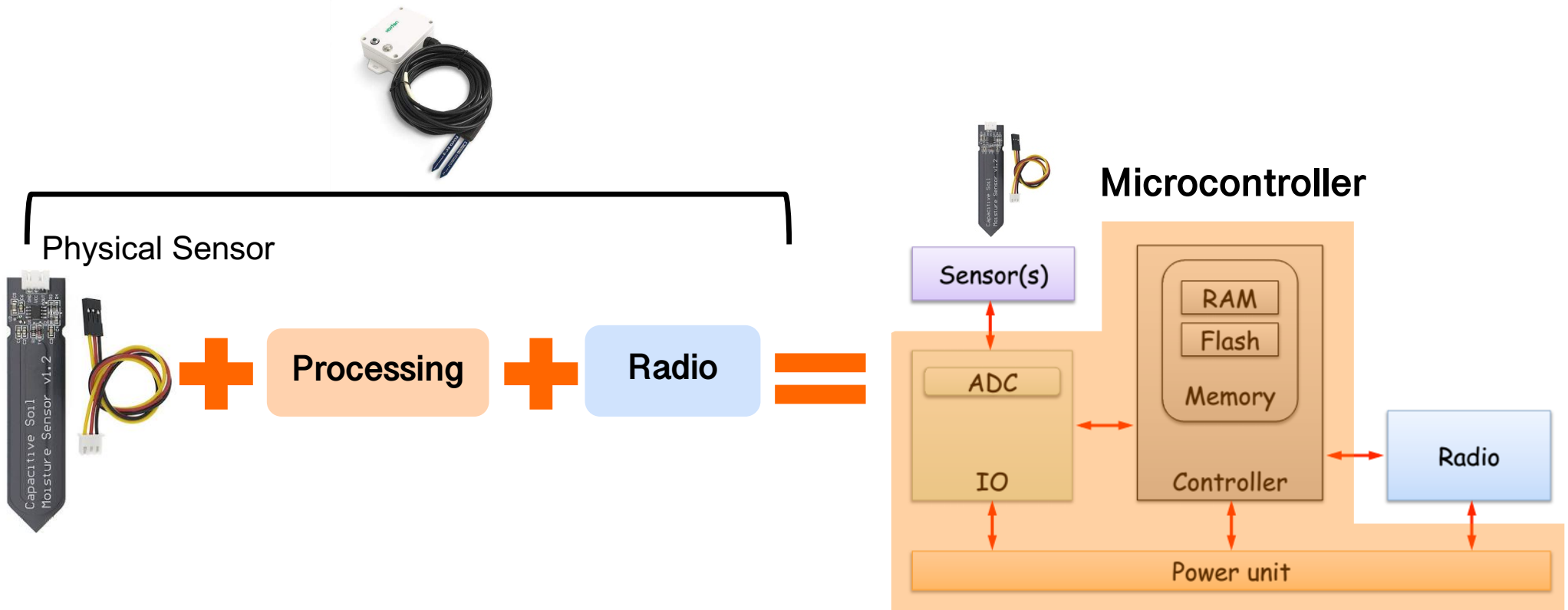
**MONITORING**

**SENSING  
 PHYSICAL WORLD INTERACTION**

**APPLICATION DOMAINS**



- IoT device can be viewed as a simple Embedded System



# Smart Agriculture Sensors





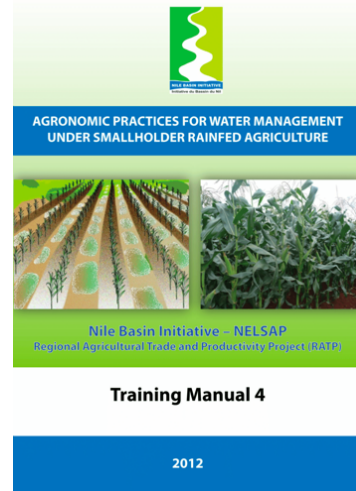
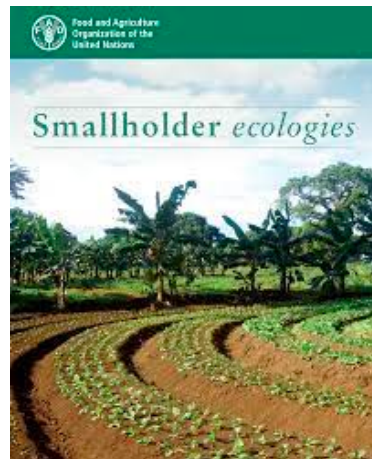
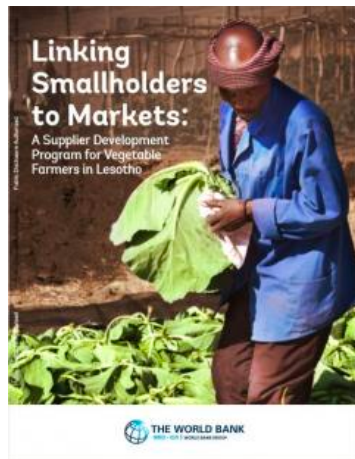
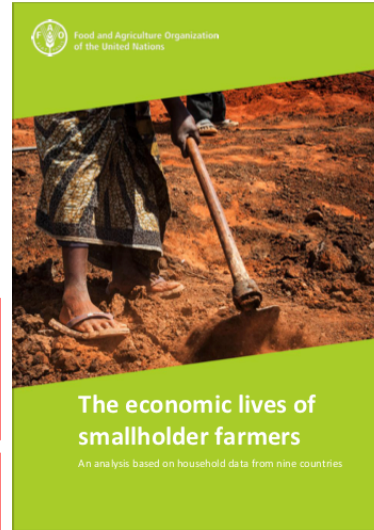


# Smallholders: the next decade challenge!



Smallholders are small-scale farmers, pastoralists, forest keepers, fishers who manage areas varying from less than one hectare to 10 hectares. Smallholders are characterized by family-focused motives such as favouring the stability of the farm household system, using mainly family labour for production and using part of the produce for family consumption.

Eighty percent of the farmland in sub-Saharan Africa and Asia is managed by smallholders (working on up to 10 hectares). While 75 percent of the world's food is generated from only 12 plants and 5 animal species, making the global food system highly vulnerable to shocks, biodiversity is key to smallholder systems who keep many rustic and climate-resilient varieties and breeds alive.



# Smart Agriculture for Smallholder?

**Many commercial systems are not adapted for developing countries, rural areas, smallholders**



Needs, cost, design approach, constraints & control mechanisms

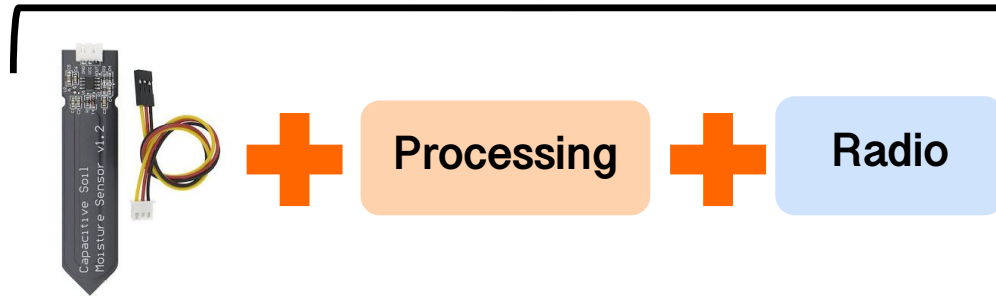
**Challenges:**  
 Low-cost, adaptation, digital inclusion, local economy

«WAZIUP» ABOUT » TECHNOLOGIES » COMMUNITY NEWS & EVENT » DOWNLOADS DEV KIT FAQ CONTACT

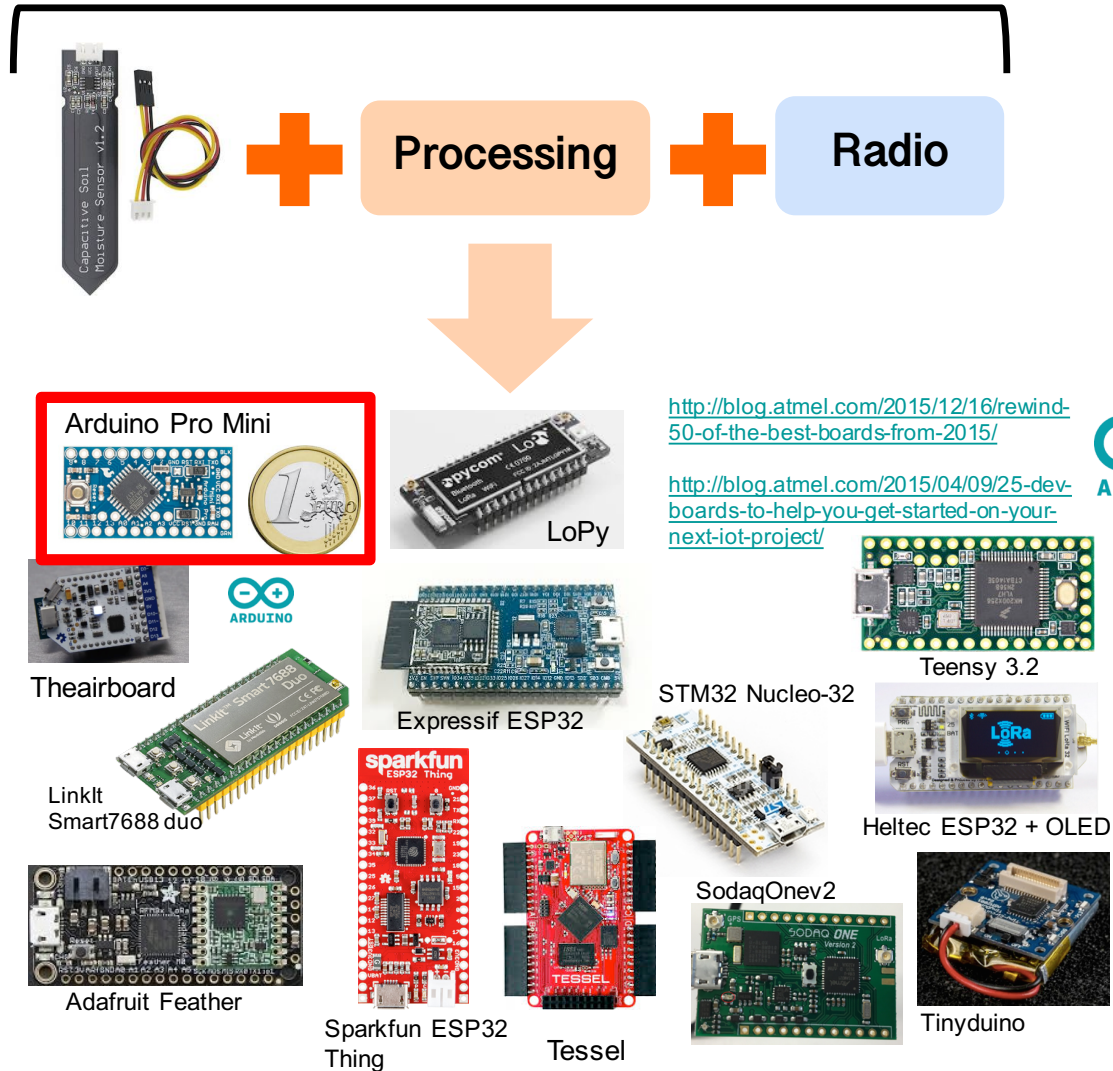
**HORIZON 2020**

**AFFORDABLE TECHNOLOGIES TO EMPOWER RURAL ECONOMIES**

# IoT device

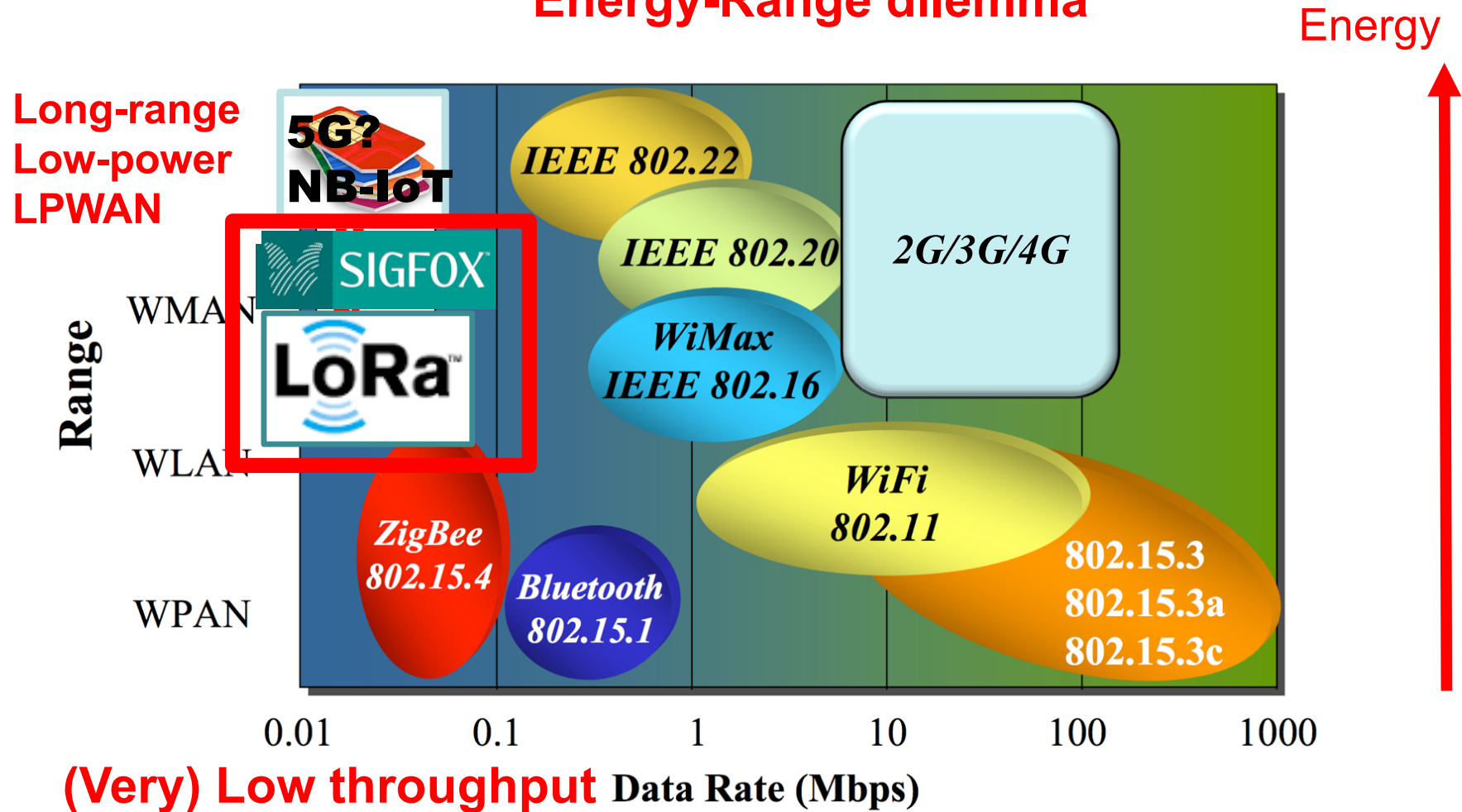


# Low-cost microcontroller boards



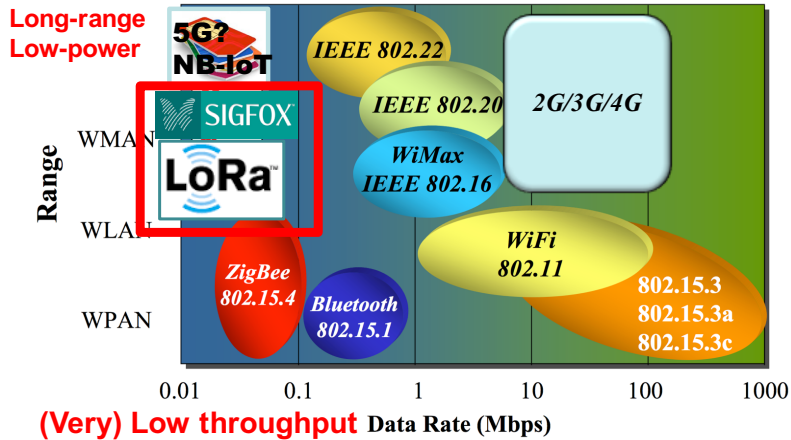
# Low-power & long-range radios

## Energy-Range dilemma



# Energy consumption comparison

## Energy-Range dilemma



Energy ↑

2G	3G	LAN	ZigBee	Lo Power WAN
N/A	N/A	O: 300m I: 30m	O: 90m I: 30m	Same as 2G/3G
200-500mA	500-1000mA	100-300mA	18mA	18mA-40mA
2.3mA	3.5mA	NC	0.003mA	0.001mA



2500mA

TX power: 500mA. Mean consumption:  $(8s \times 500 + 3592s \times 0.005) / 3600 = 1.11mA$

$2500 / 1.11 = 2252h = 93 \text{ days} = 3 \text{ months} \text{ ☹️}$

In most cellular networks, the device is still maintaining communication with BS even if it is inactive

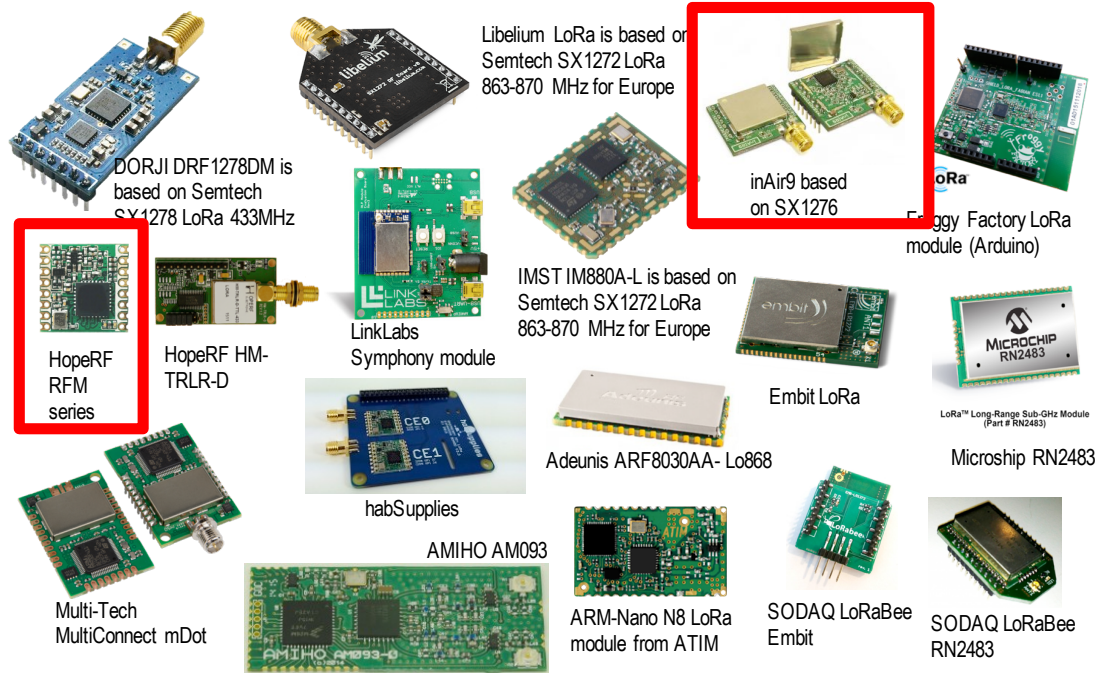
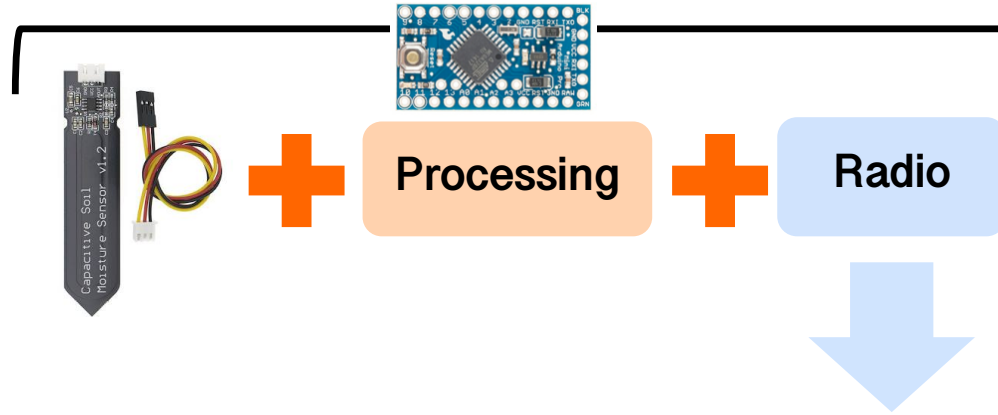
TX power: 40mA. Mean consumption:  $(2s \times 40 + 3598s \times 0.005) / 3600 = 0.027mA$

$2500 / 0.027 = 92592h = 3858 \text{ days} = 10 \text{ y.} \text{ 😊}$

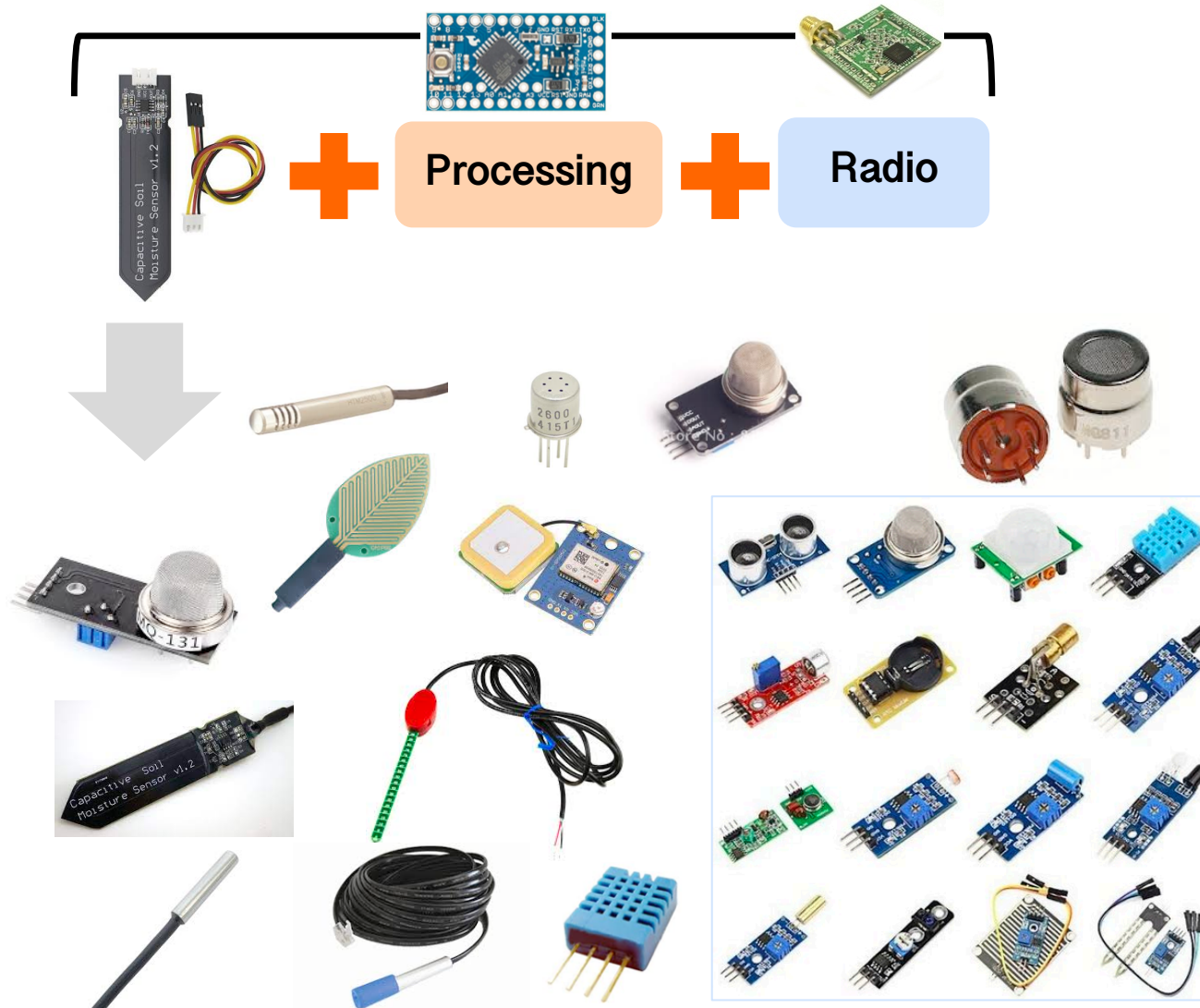
LPWAN does not need to maintain connection if not in used



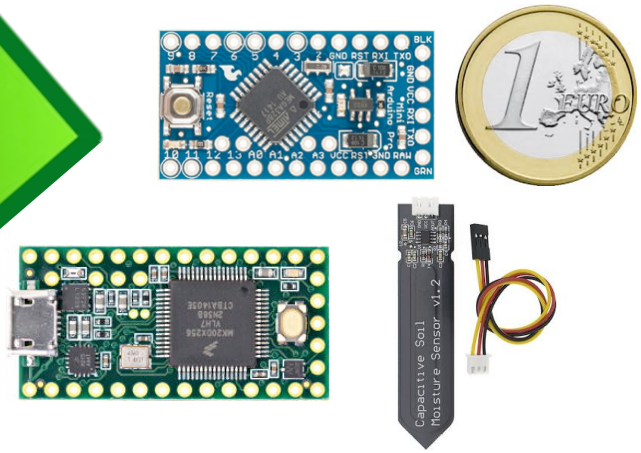
# Low-power, long-range radios



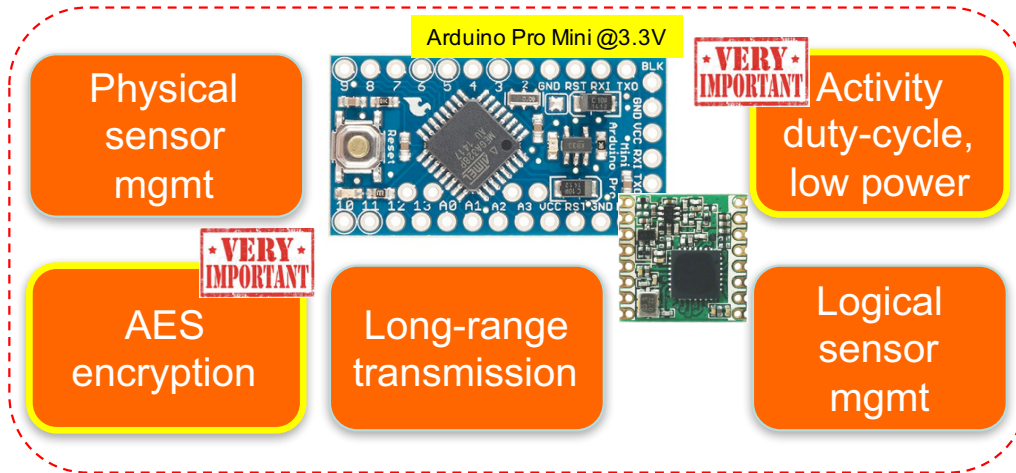
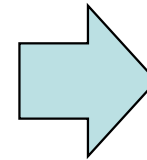
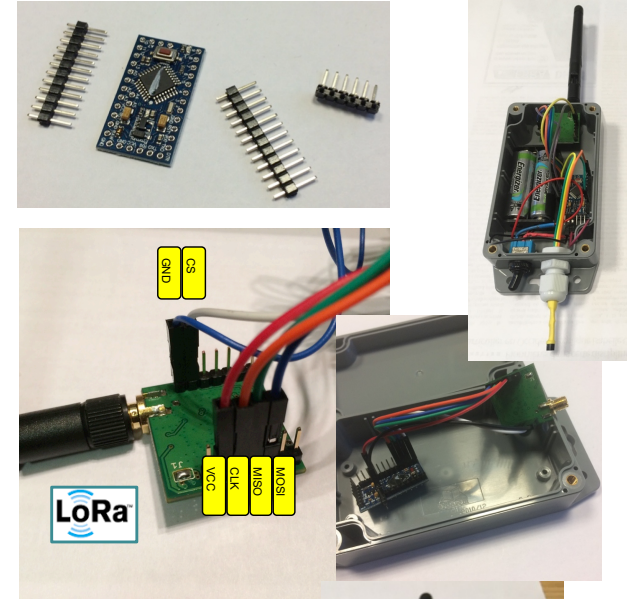
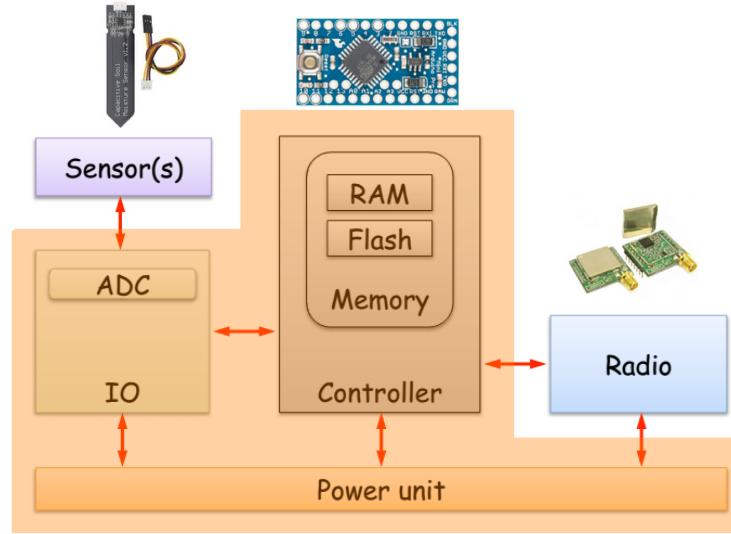
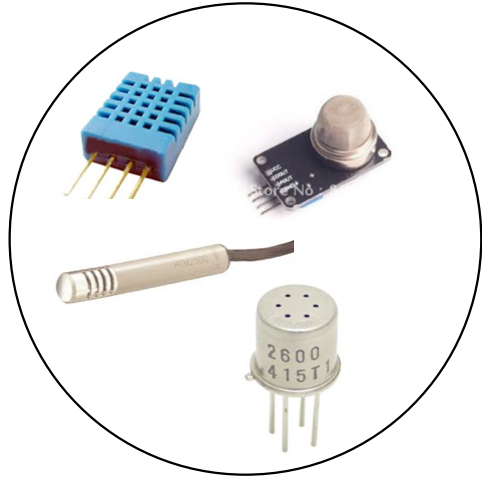
# Last but not least: low-cost sensors!



# IoT-for-All can become reality!



# Do-It-Yourself IoT

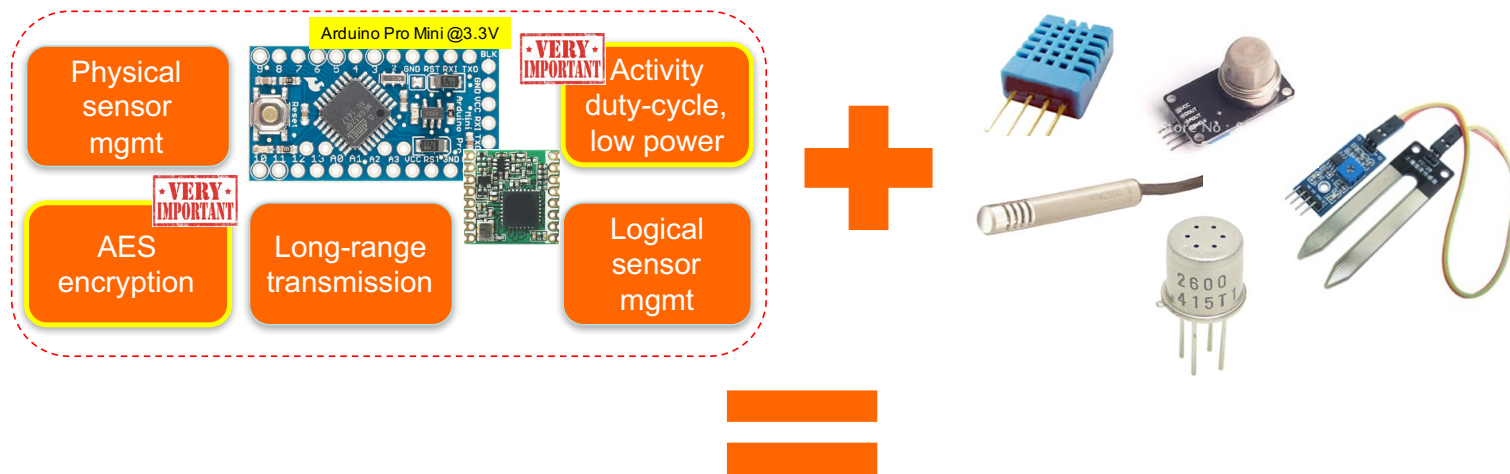


**WAZIUP**  
 IoT - from idea to reality  
**WAZIHUB**



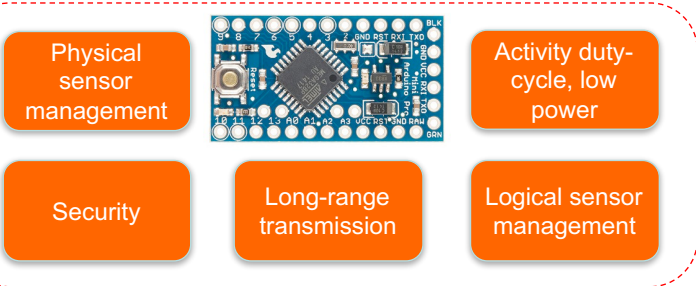
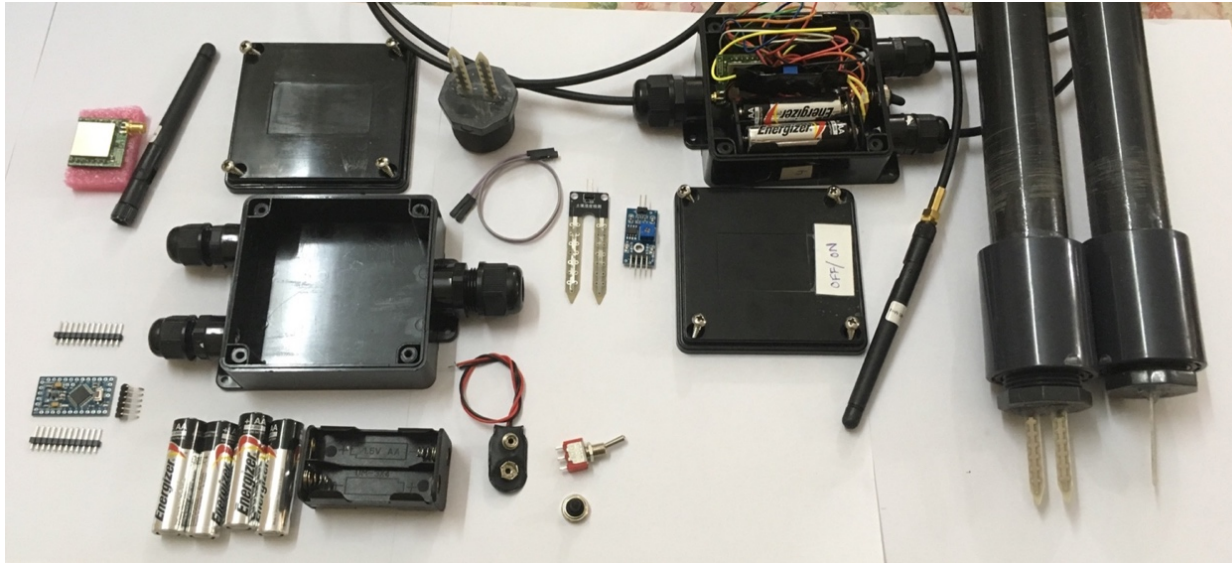
# Generic IoT v.s. highly specialized Intel-IrriS

- Build **low-cost**, **low-power**, **generic** IoT platform
- Methodology for low-cost platform design
- Technology transfers to user communities, economic actors, stakeholders,...

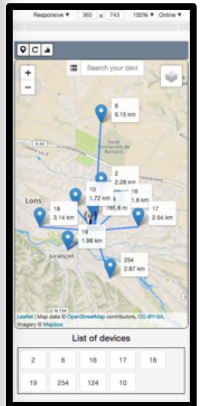
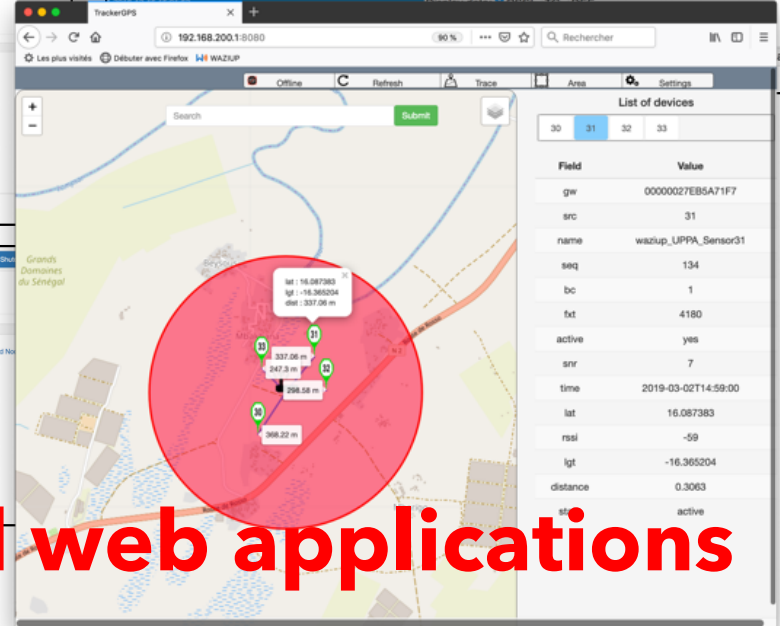
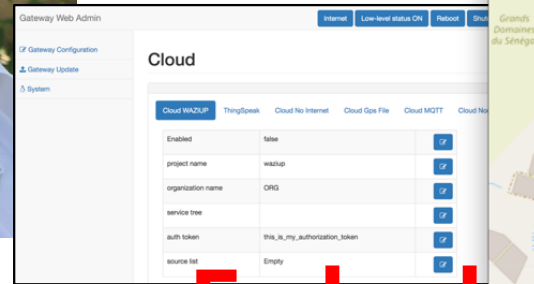
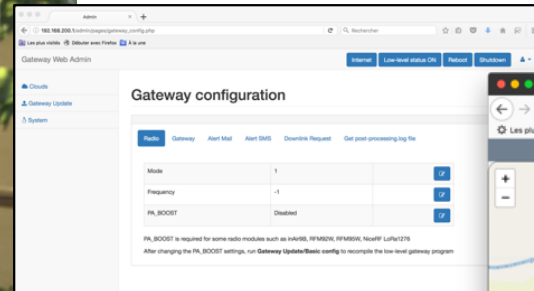
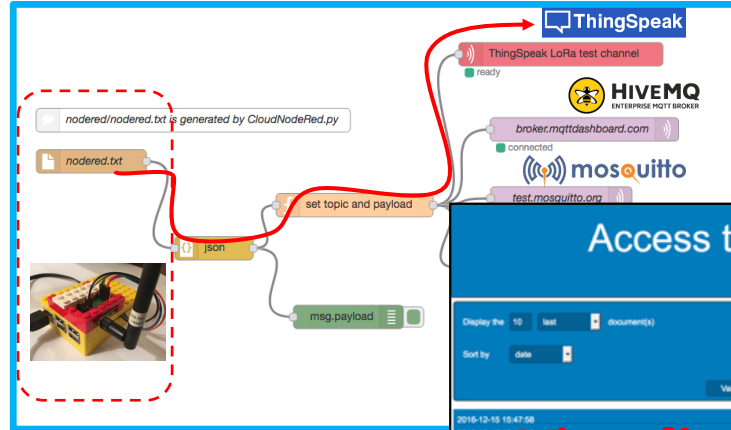




# A soil humidity sensor example



# Open, versatile IoT gateway



**Embed web applications**



# Deployment for Nestlé's WaterSense



# Minimum Viable Products (MVP)

## Soil moisture solutions



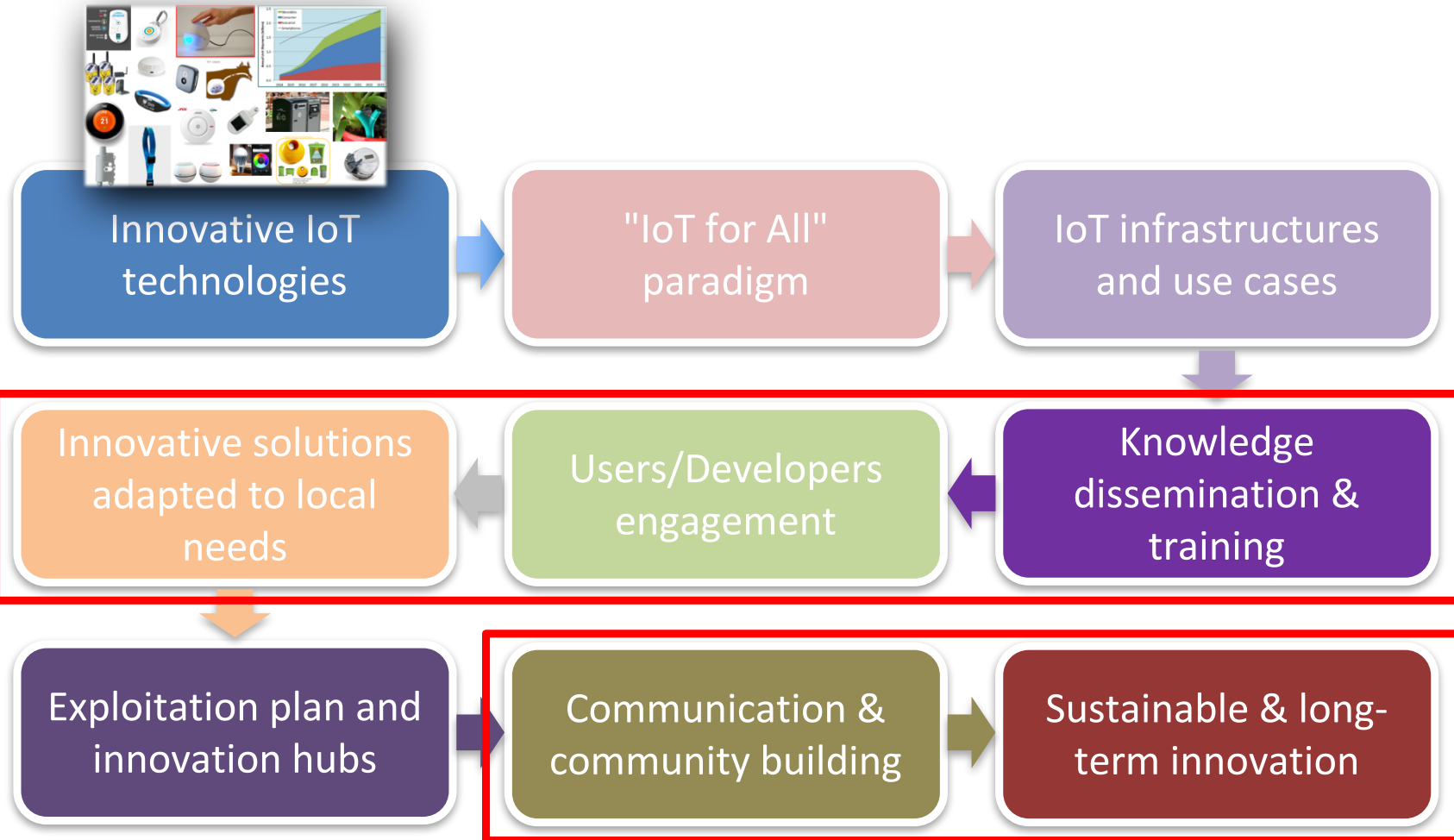
## Fish farming solutions



## Cattle rusting and location monitoring



# Making IoT happening!



# 100% open-source code templates

```

/*
 * temperature sensor on analog 8 to test the LoRa gateway
 *
 * Copyright (C) 2015 Congduc Pham, University of Pau, France
 *
 * This program is free software: you can redistribute it and/or modify
 * it under the terms of the GNU General Public License as published by
 * the Free Software Foundation, either version 3 of the License, or
 * (at your option) any later version.
 *
 * This program is distributed WITHOUT ANY WARRANTY;
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.
 * See the GNU General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License
 * along with this program.
 *
 * *****
 *
 * AN OPEN PROJECT WRITTEN, DEBUGGED,
 * AND SUPPORTED BY ARDUINO.CC AND
 * THE ARDUINO COMMUNITY WORLDWIDE
 *
 * LEARN MORE ABOUT THE CONTRIBUTORS
 * OF ARDUINO.CC on arduino.cc/credits
 *
 * *****
 */
// Include the SX1272
#include "SX1272.h"

// IMPORTANT
// please uncomment only :
// it seems that both HopeRF and
// boards we set the init

// uncomment if your radio is an HopeRF RFM92W or RFM95W
#define RADIO_RF92_95
// uncomment if your radio is a Modtronix inA19B (the one with +20dBm features), if inA19, leave comment
// #define RADIO_INA19B

// IMPORTANT
  
```

CongducPham / LowCostLoRaGw

Unwatch 62 Unstar 397 Fork 213

<> Code Issues 161 Pull requests 2 Projects 0 Wiki Insights Settings

Branch: master LowCostLoRaGw / Arduino / Create new file Upload files Find file History

Congduc Pham update SX1272.cpp Latest commit 114d06d 7 days ago

..		
Arduino_Encrypt_LSC_v2	update LSC lib and related examples	2 months ago
Arduino_GPS_ParseG_GGA	update Arduino examples	a month ago
Arduino_LoRa_Demo_Sensor	update Arduino examples	a month ago
Arduino_LoRa_GPS	update Arduino examples	a month ago
Arduino_LoRa_Gateway	update lora_gateway.cpp and SX1272.cpp	26 days ago
Arduino_LoRa_Gateway_1_4	improve management of transmission power, add channels in 863-865	2 years ago
Arduino_LoRa_Generic_DHT	update Arduino examples	a month ago
Arduino_LoRa_Generic_Simple_Mu...	update Arduino examples	a month ago
Arduino_LoRa_InteractiveDevice	update Arduino InteractiveDevice	a month ago
Arduino_LoRa_Ping_Pong	update Arduino examples	a month ago
Arduino_LoRa_Ping_Pong_LCD	update Arduino examples	a month ago
Arduino_LoRa_Radiohead_Example	update README and example sketch for RadioHead lib	a year ago
Arduino_LoRa_Simple_DHT	update Arduino examples	a month ago
Arduino_LoRa_Simple_temp	update Arduino examples	a month ago
Arduino_LoRa_temp	update Arduino examples	a month ago
Arduino_LoRa_ucaml	update image support	2 years ago

Many examples using various temp/hum sensors

<https://github.com/CongducPham/LowCostLoRaGw/tree/master/Arduino>

# Community building for sustainable innovation

**International Events**  
+ 20 organized & attended

**Workshop at the European Conference on Networks & Communications (Greece, CNET)**



**Launch event (Ghana, iSpace)**



**Launch event (Senegal, CTIC Dakar)**



**IoTWeek2016 (Belgrade, EGM)**

**IoTBigData2016 (Italy, EGM)**



**IoT Care Conference (Budapest, CNET)**

**WAZIUP Workshop on IoT (Togo, L'Africaine d'Architecture)**



**Workshop at the RESSACS 2016 (France, UPPA)**

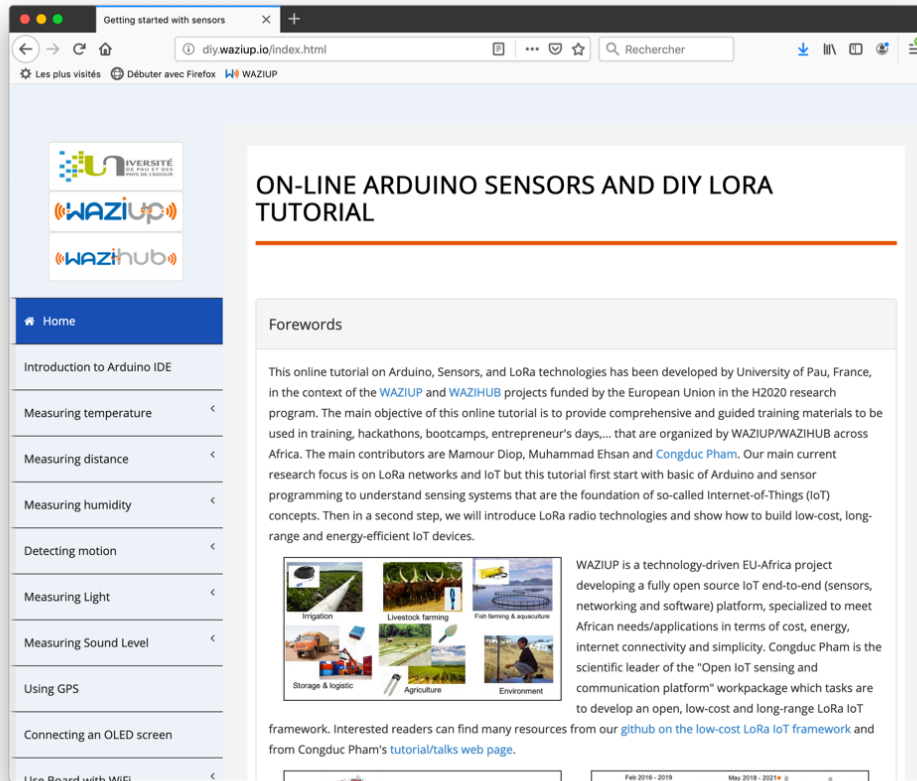
Credit: C. Vavasseur, CTIC Dakar

<http://diy.waziup.io>



# Training & hackathons

- ⦿ Technical training sessions
- ⦿ Hackathons, ...



Online Arduino & IoT step-by-step tutorial  
<https://diy.waziup.io>



# Tutorials/resources

<https://github.com/CongducPham/tutorials>

EU Horizon 2020 grant agreement number 101017427

**Low-cost LoRa IoT devices and gateway FAQ**

1) **What is Internet-of-Thing (IoT)?**

From ERC (European Research Cluster on the Internet of Things)

The ERC (European Research Cluster on the Internet of Things) is a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.

From <http://www.gartner.com/it-glossary/internet-of-things/>

"The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment"

From <http://internetofthingsagenda.techtarget.com/definition/Internet-of-Things-IoT>

"The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction."

2) **What is WAZIUP?**

The EU H2020 WAZIUP project, namely the Open Innovation Platform for IoT-Big Data in Sub-Saharan Africa is a collaborative research project using cutting-edge technology applying IoT and Big Data to improve the working conditions in the rural ecosystem of Sub-Saharan Africa. First, WAZIUP focuses on involving farmers and breeders in order to define the platform specifications in focused validation cases. Second, while tackling challenges which are specific to the rural ecosystem, it also engages the flourishing ICT and good practices, entrepreneur sector. WAZIUP proposes solutions that:

WAZIUP will deliver a connected gateway locally the know how farmers will need to create and to radically new paradigms for citizens by the following objectives:

1. Empower the African R&D to empower the African R&D of local innovation and support the necessary leadership on a new scale

Author : Congduc Pham, University of Pau  
Last update : 07/20/2018

**TUTORIAL ON HARDWARE & SOFTWARE FOR LOW-COST LONG-RANGE IOT**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**LOW-COST LORA IOT DEVICE: A STEP-BY-STEP TUTORIAL**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**BUILDING AN IOT DEVICE FOR OUTDOOR USAGE: A STEP-BY-STEP TUTORIAL**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**LOW-COST LORA IOT DEVICE: SUPPORTED PHYSICAL SENSORS**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**LOW-COST LORA GATEWAY: A STEP-BY-STEP TUTORIAL**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**LOW-COST LORA IOT: USING THE WAZIUP DEMO KIT**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**The generic hardware platform**

**The Arduino Pro Mini**

The Arduino Pro Mini is a compact form factor Arduino board based on the ATmega328P microcontroller. Use the **3.3v** and **5MHz** version of the Arduino Pro Mini for lower power consumption.

You can get the original board designed by Sparkfun or get one of the various clones available, mostly from Chinese manufacturers. The last solution is very cost-effective as the Pro Mini board can be purchased for a bit more than 4€ a piece.

Depending to connect pins may pin with a soldered

**The LoRa radio module**

There are various LoRa radio modules that are all based on the Semtech SX1272/127x.

**LoRa**

Fully tested LoRa radio modules

HopfRF R9M2095W Libelium LoRa Multisim v4A499B

Most of off-based LoRa radio modules are supported. We recommend the Multisim (v4) model if you don't have delicate soldering experience as this module can come with reader pins ready to be connected with DuPont wires.

The R9M2095W can be found assembled (Altium) or an adapter can be purchased (from Sparkfun for instance).

**Connect the LoRa radio module**

Connect the connector module to the SPI pins (blue) in pin 21, MISO pin 30 and CS pin (orange) Then connect also the of the radio module to board (right side). The VCC of the Pro Mini board gets 3.3v from the on-board voltage regulator.

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**LOW-COST LORA GATEWAY: WEB ADMIN INTERFACE**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**LOW-COST LORA IOT ANTENNA TUTORIAL FOR GATEWAY**

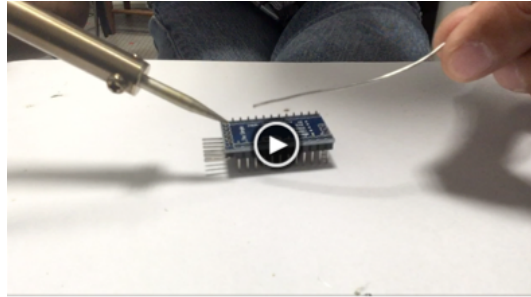
PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

**IOT DEPLOYMENT WITH WAZIUP \*\*\***

**GUIDELINES, BEST PRACTICES, TROUBLESHOOTING AND FAQ**

PROF. CONGDUC PHAM  
[HTTP://WWW.UNIV-PAU.FR/~CPHAM](http://www.univ-pau.fr/~cpham)

Low-cost LoRa IoT device



+94000 views

May2021

[https://www.youtube.com/watch?v=YsKbJeeav\\_M](https://www.youtube.com/watch?v=YsKbJeeav_M)

Low-cost LoRa IoT gateway



+22000 views

May2021

<https://www.youtube.com/watch?v=mj8ltKA14PY>

Extreme low-power LoRa IoT



+9000 views

May2021

[https://www.youtube.com/watch?v=2\\_VQpcCwdd8](https://www.youtube.com/watch?v=2_VQpcCwdd8)

Setting up a gateway in 5mins



+4600 views

May2021

<https://www.youtube.com/watch?v=CJbUFXLpSok>

# Is it enough?

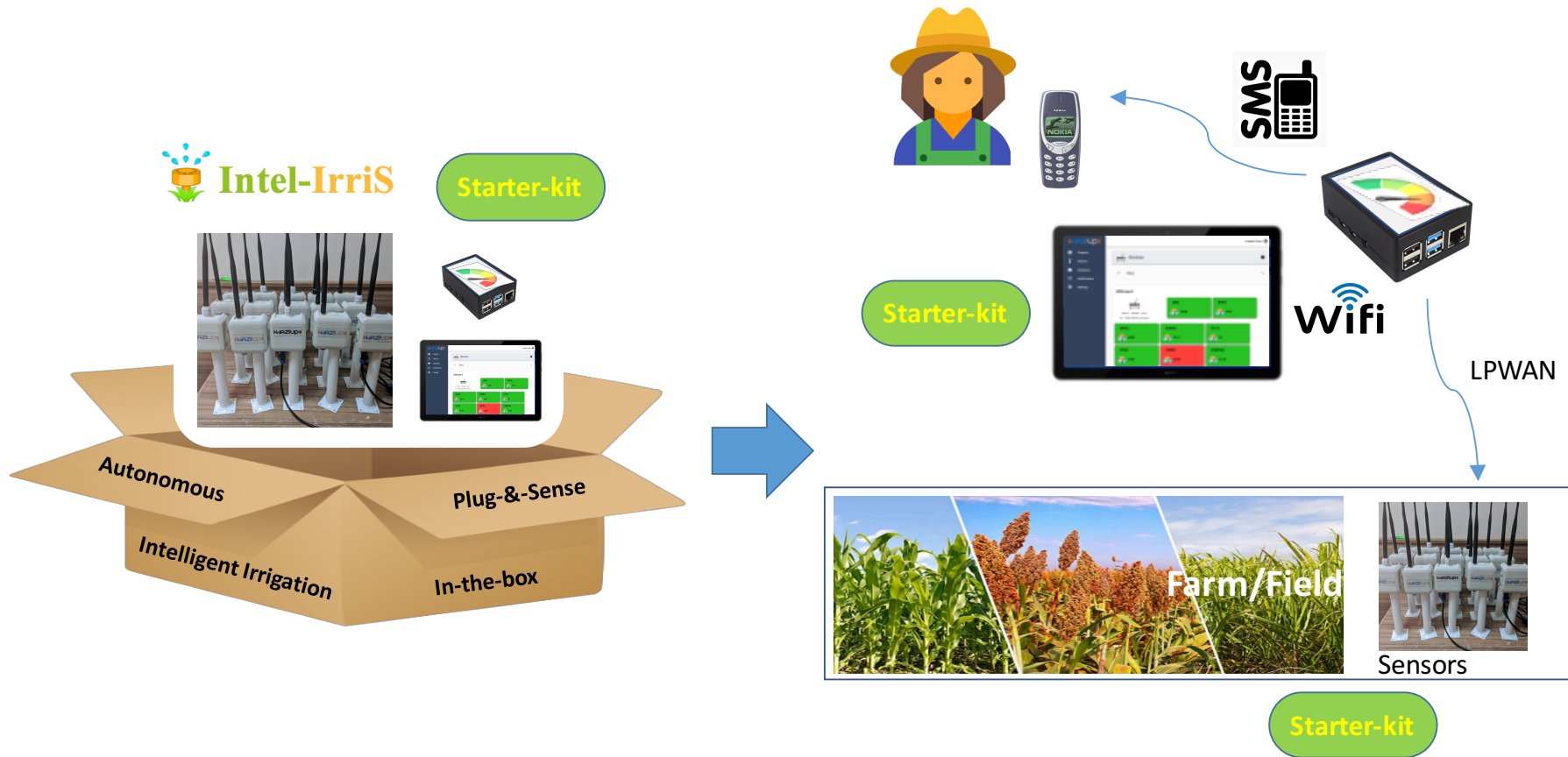


**Q: what's missing?**



**Accuracy? Simplicity?**

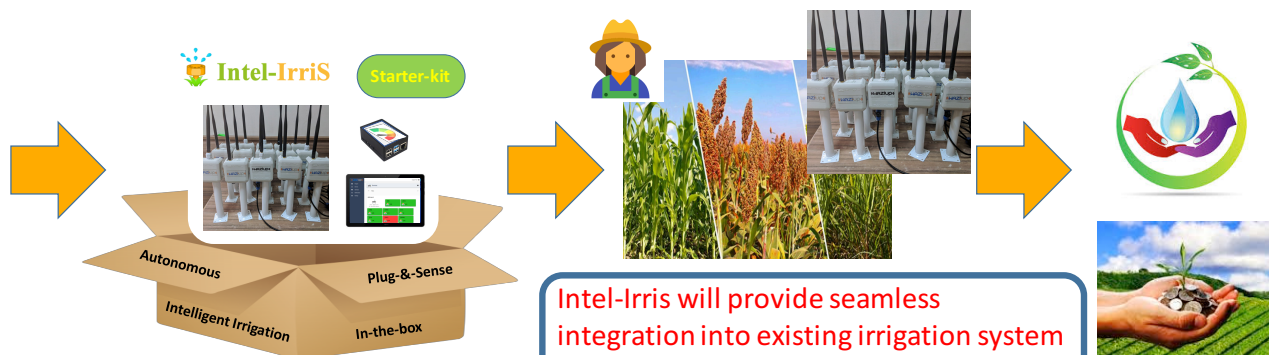
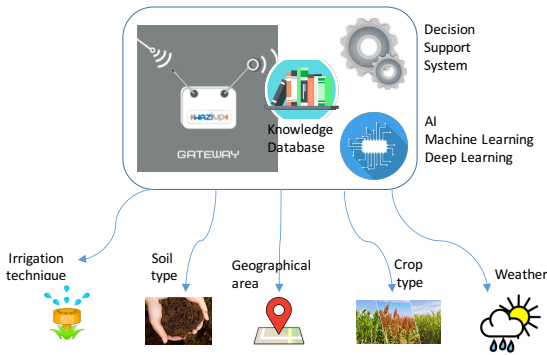
# Intel-IrriS: Intelligent Irrigation-in-a-box



# AI+Smart Agriculture=Win-Win!

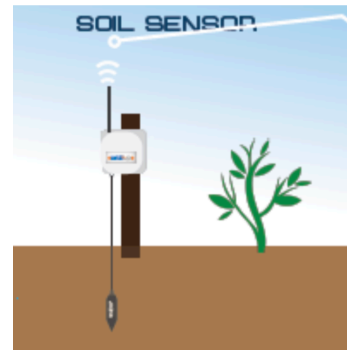



Low-cost system based on low-cost sensors and advanced water-soil-plants-climate interaction models for higher accuracy of collected measures



# Low-cost sensors: accuracy?

Sensor part

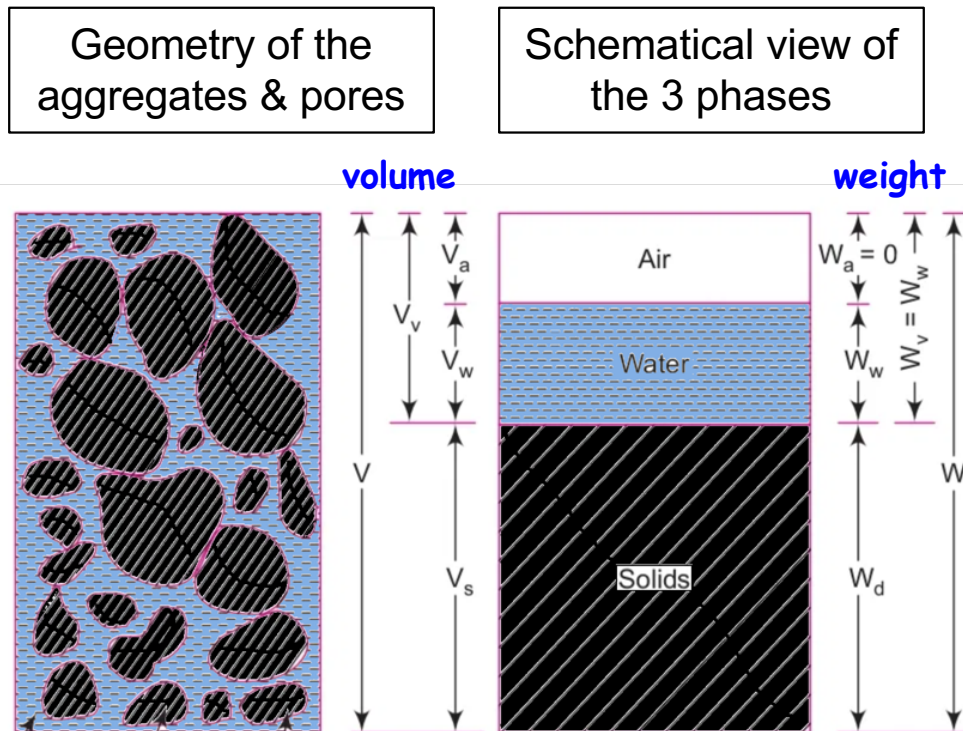


- Build on low-cost, low-power IoT expertise ()
- Increase accuracy of low-cost sensors by **advanced calibration**
- Enable deployment of several complementary low-cost sensors: soil conductivity, volumetric water content, ...
- Include **agricultural models / knowledge with corrective & predictive analytics**

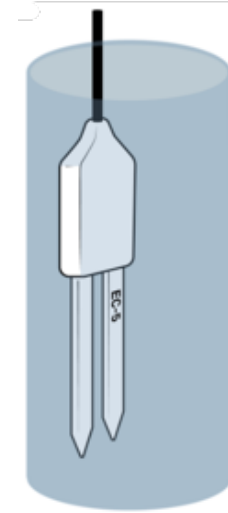
# Understanding soil water

Source: Christian Hartmann, IRD

- Low-cost sensors usually measure soil water content
- Soil = a pile of aggregates  $\rightarrow$  3 phases: solid + air & water



## water volume capacitive sensors



Decagon EC5  
**120 euros**

*accurate*



Gravity SEN193  
**6 euros**

*under test*

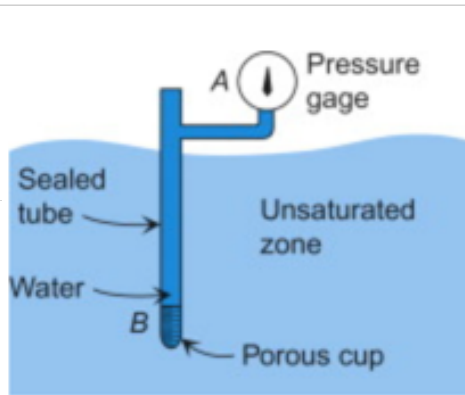
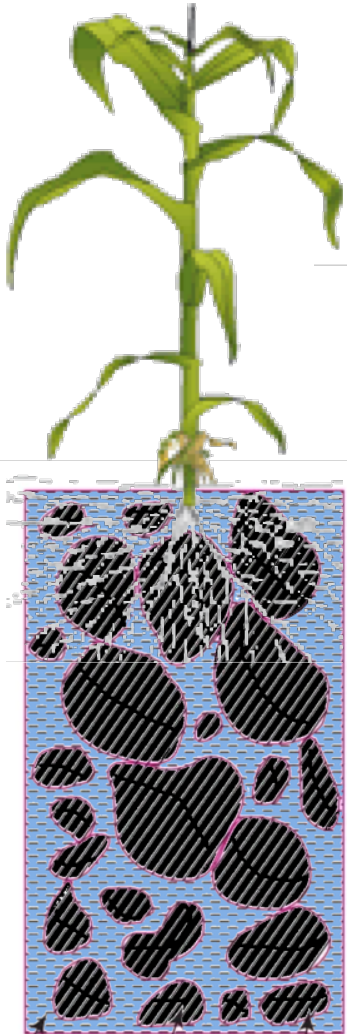
Saturated soil



# Soil water? Not enough!

Source: Christian Hartmann, IRD

- in the soil, the water is UNDER TENSION = it is hold by CAPILLARY FORCES
- Water tension is also needed!



**SDEC**  
**100 euros**



**WATERMARK**  
**40 euros**

**IRD**  
**< 5 euros?**



# Smart embedded control

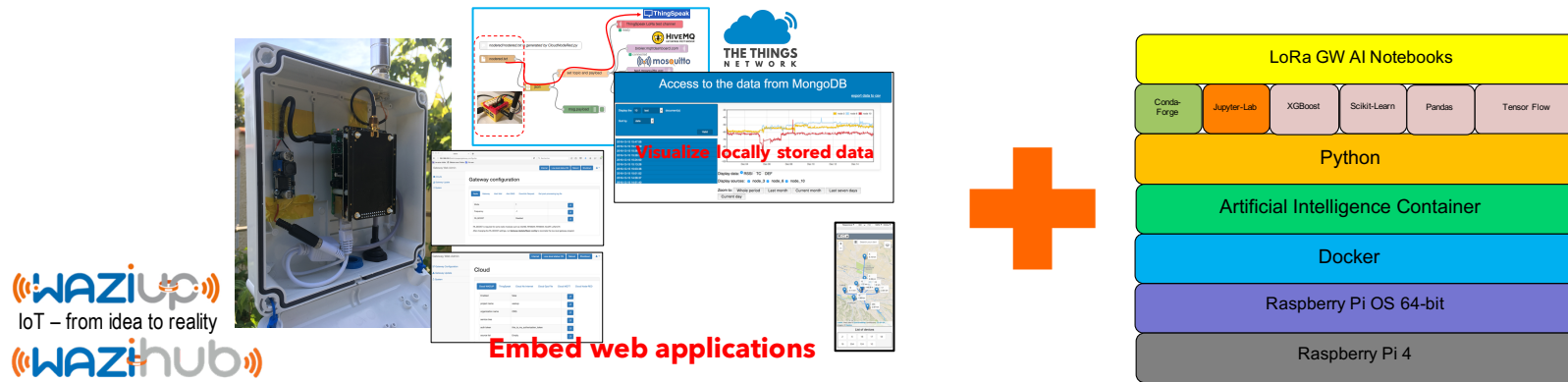


- Build on low-cost embedded & open IoT gateway expertise
- Implement the “Intelligent Irrigation in-the-box” vision
- Model **complex interactions**: water-soil-plant interaction, evapotranspiration,...
- Embed **Decision Support System (DSS)** and **disruptive Artificial Intelligence (AI)**
- Integration of **multiple knowledge streams**
- Fully **autonomous**

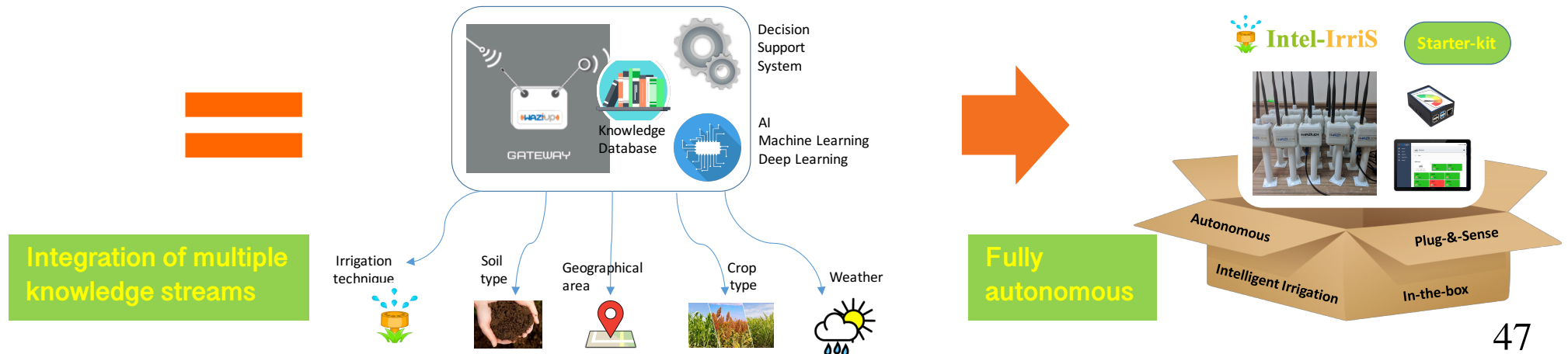


# Edge-AI for fully autonomous system

- Embed every thing on the IoT gateway to provide a fully autonomous system for the "Intelligent Irrigation-in-the-box"



Prof. Congduc Pham  
<http://www.univ-pau.fr/~cpham>



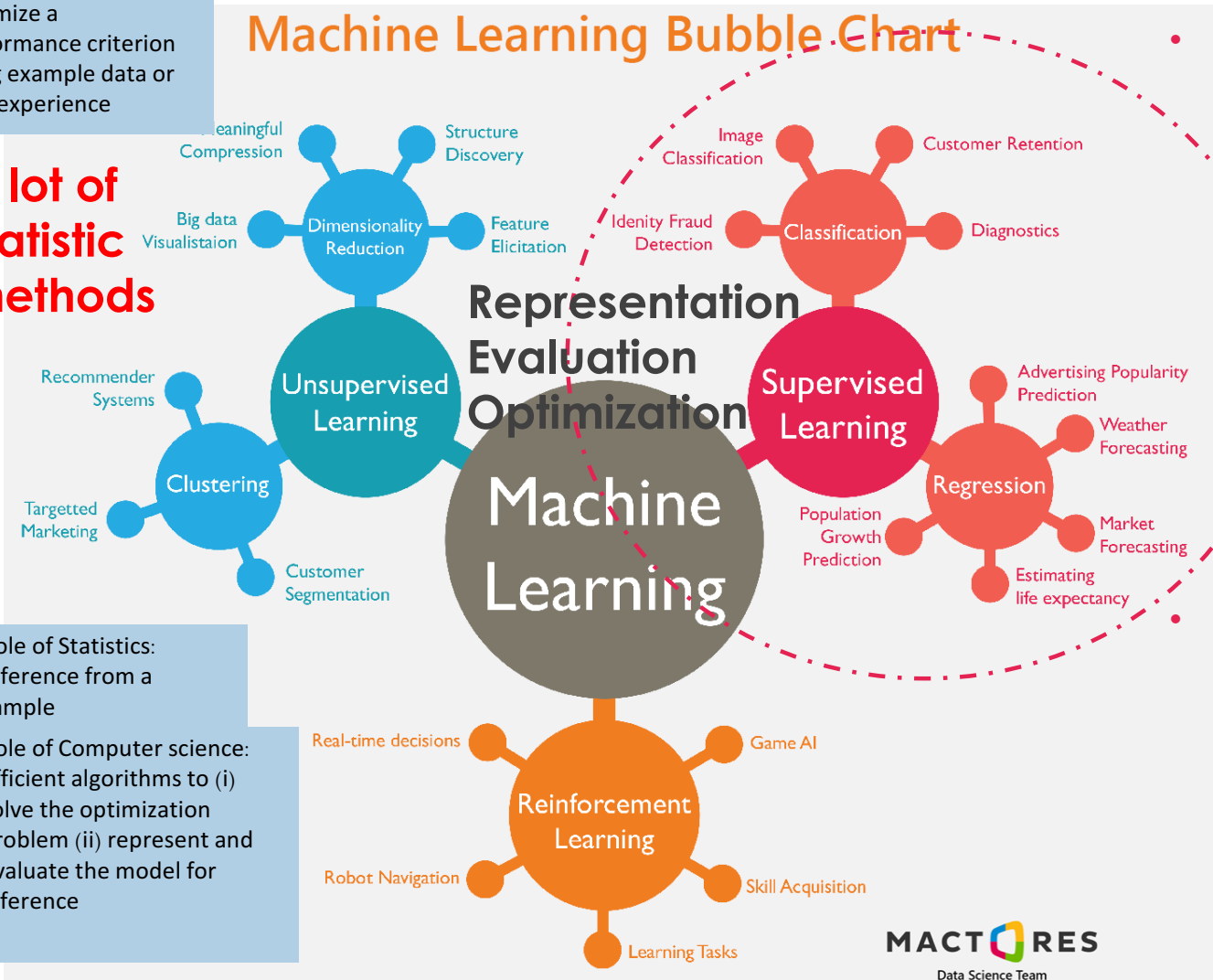
# Machine Learning Techniques

Optimize a performance criterion using example data or past experience

**A lot of statistic methods**

Role of Statistics: Inference from a sample  
Role of Computer science: Efficient algorithms to (i) solve the optimization problem (ii) represent and evaluate the model for inference

## Machine Learning Bubble Chart

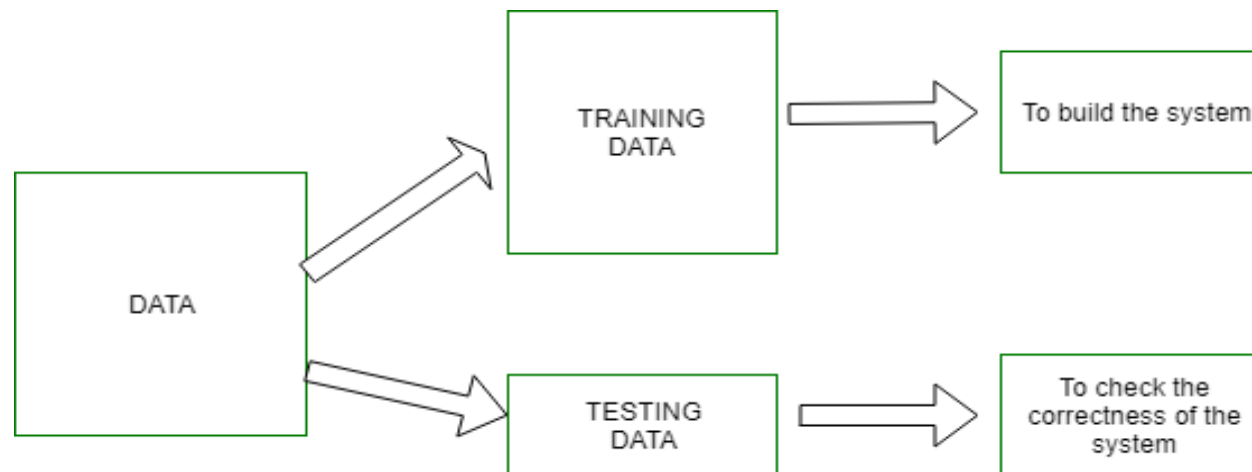


- Classification
  - Logic
  - SVM
  - Random Forest
  - Hidden Markov
  - ...

- Regression
  - Lasso
  - Ridge
  - Loes
  - KNN
  - Spline
  - XGBoost
  - ...

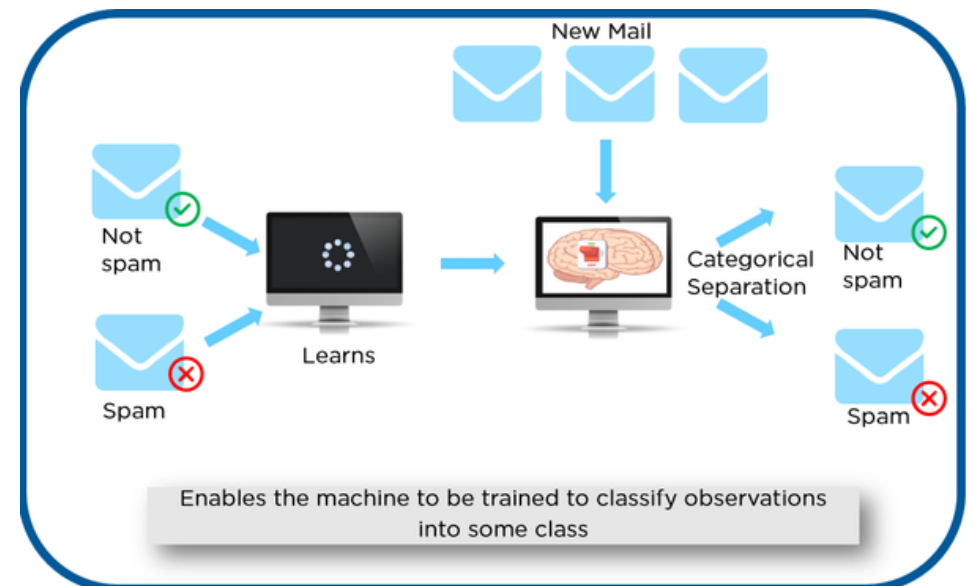
# Supervised Learning

- ⦿ ML model is presented with *input data* which is labeled
  - ⦿ Each *input data* is tagged with the correct label.
- ⦿ The goal is to approximate math operations in the ML model so well that when presented with new *input data*, the ML model can **predict** the output variables for that *input data*.



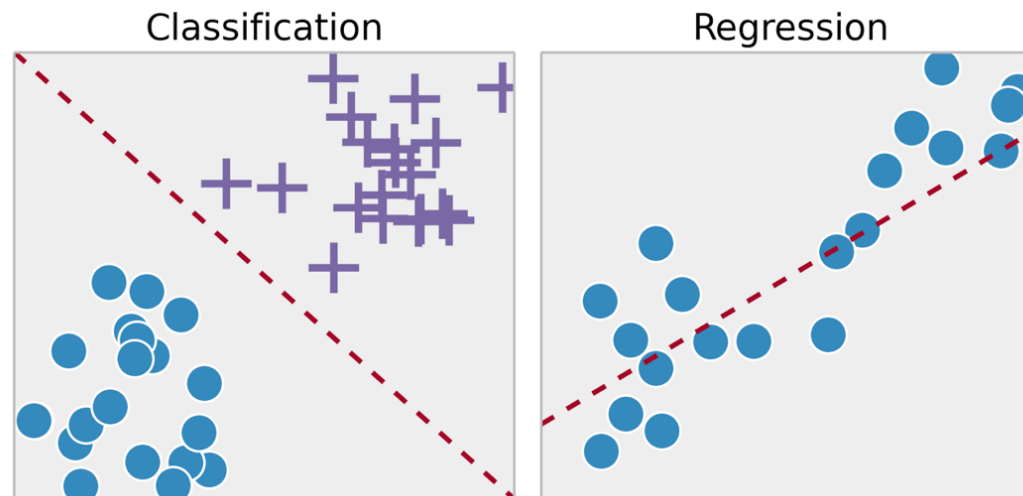
# Spam Mail Example

- ⦿ On the left side of the image, some data is marked as ‘Spam’ or ‘Not Spam’. This is *labeled data*. This data is used to train the supervised model, the *intelligent* program (at center of the image).
- ⦿ Trained model is tested with new mails (on the top of the image) and checking if the output of the supervised model is correct (on the right side of the image).



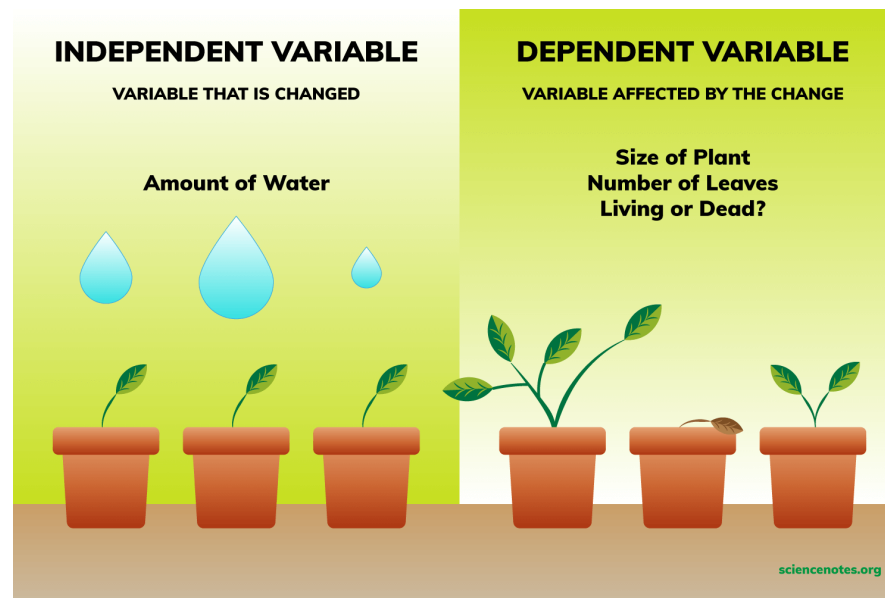
# Types of Supervised Learning

- ⦿ **Classification:** A classification problem is when the output is a category, such as “red” or “blue” or “disease” and “no disease”.
- ⦿ **Regression:** A regression problem is when the output is a real number, such as “dollars” or “weight”.



# Regression

- ⦿ **Dependent variables:** the main event or factor to understand or predict. Also known as *explanatory variable*.
- ⦿ **Independent variables:** the events or factors suspected to have an impact on the dependent variable. Also known as *response variable*.





# Types of Regression

- Simple regression:** single independent variable for a single dependent variable. It is very common to name the independent variable as  $x$  and  $Y$  as the dependent variable

$x$ : number of cricket chirps

$Y$ : temperature

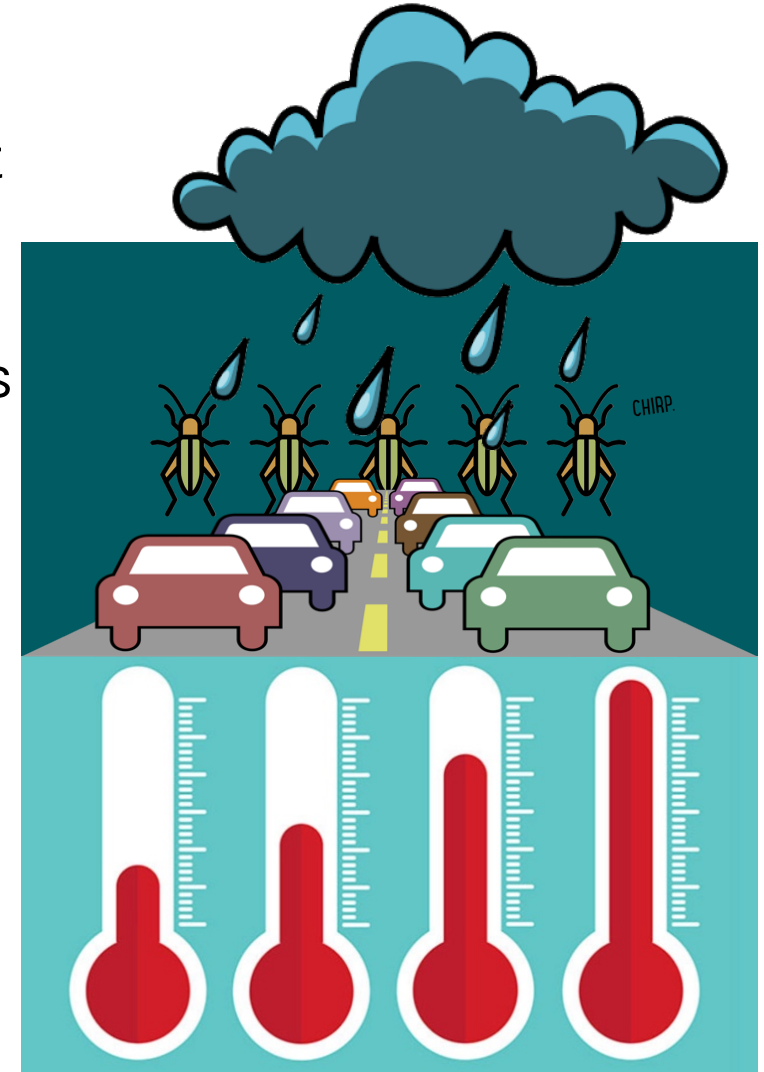
- Multivariable regression:** multiple independent variables,  $x_1, x_2, x_3$ , for a dependent variable  $Y$ .

$x_1$ : number of cricket chirps

$x_2$ : rainfall

$x_3$ : automobile traffic

$Y$ : temperature



# It is NOT ONLY about technology!



**4**

Improve farmer's knowledge on water-related issues, foster local adaptation of technologies, increase local innovation capacity and facilitate technology appropriation

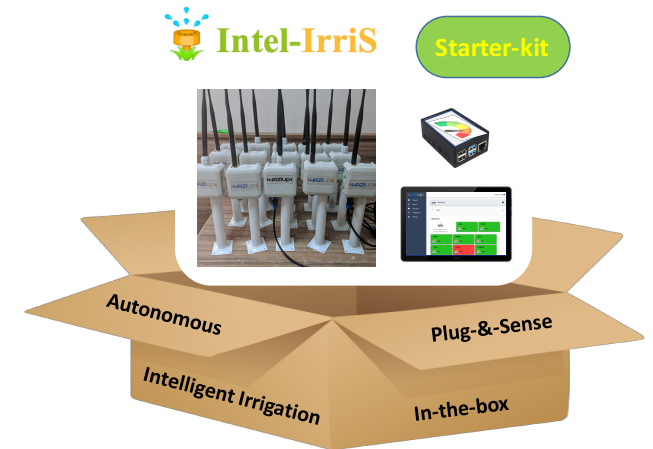


**5**

Large-scale adoption of low cost smart irrigation system by smallholders, stimulating synergies between various local actors

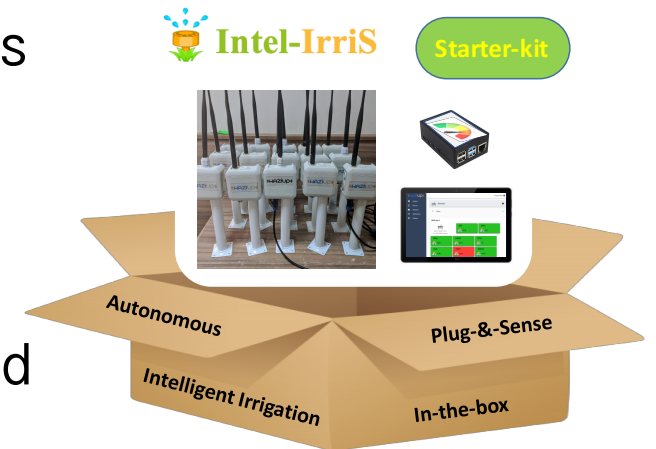
# Smallholder Piloting Program

- ⦿ Participatory approach to co-design & test the innovative solutions in fields
- ⦿ Take into account region-dependent technical, agricultural, social, climatic and environmental aspects
- ⦿ Will run for 30 months to ensure that the proposed irrigation systems are well tailored for the specificities of the regional context
- ⦿ 9 farms already enrolled to participate in the Piloting Program
- ⦿ Scale-up to involve at least 20 small-scale farms



# Farmer Training Program

- ⦿ Run in parallel to the Smallholder Piloting Program
- ⦿ Increase smallholders' knowledge so that they can familiarize with the proposed technologies, tools and practices
- ⦿ Specific training materials will be created for that purpose and dedicated training sessions will be organized in coordination with the Smallholder Piloting Program
- ⦿ Increase engagement of final users
- ⦿ Recruit for Smallholder Piloting Program and distribution of starter-kits



# Conclusions

- Internet-of-Things provides the unique feature to make things "talk" to us: localisation, surrounding environmental conditions,...
- It has unique capabilities in helping humanity to reach more sustainable development
- Adapting IoT solution for smallholders is the next decade challenge!**
- Next generation sensors such as cameras, spectrometers, hyperspectral cameras,... will provide possibilities to further optimize a number of complex processes
- We have more than 8 years expertise in developing & deploying low-cost IoT in Africa with 4 EU H2020/PRIMA projects



# DESIGNING AND DEPLOYING LOW-COST IOT: DIGITAL AGRICULTURE OPPORTUNITY FOR SMALLHOLDERS



**PRIMA**  
PARTNERSHIP FOR RESEARCH AND INNOVATION  
IN THE MEDITERRANEAN AREA



**Intel-Irris**

Presented on May 26th, 2021

Prof. Congduc Pham  
<http://www.univ-pau.fr/~cpham>  
Université de Pau, France



**WAZIup**  
IoT – from idea to reality  
**WAZIhub**