Intelligent Irrigation System for Low-cost Autonomous Water Control in Small-scale Agriculture

Deliverable D1.2b

Low-cost sensor generic platforms for connected irrigation system – v2

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Document revision history

Version	Date	Changes
V1.1	June 10th, 2022	Public release
V1.0	May 30th, 2022	First draft version for internal approval
V0.1	May 23rd, 2022	First release for review

Executive Summary

Deliverable D1.2b updates D1.2a and describes the “INTEL-IRRIS low-cost soil humidity sensor platform – v2”. The deliverable will present the various tests of the proposed generic hardware platform and the development to integrate the two selected soil moisture sensors: the capacitive SEN0308 sensor and the Watermark water tension sensor.

Table of Contents

1. Introduction

The INTEL-IRRIS low-cost sensor generic platforms for connected irrigation systems will essentially consist of a soil humidity sensor device, possibly coupled with a soil temperature device. It is part of the INTEL-IRRIS starter-kit that will be specifically addressed in D2.2a "Starter-kit for smart irrigation system – v1".

Here, D1.2b will present the design using the *DIY-PCB de development line* presented previously in D1.2a. The INTEL-IRRIS PCB will therefore be presented with the various tests of the generic hardware platform. We will also present the development of version 2 of the soil sensor device based on the Watermark water tension sensor.

2. The low-cost sensor generic platform

2.1. Review of hardware components

The final component list to build the low-cost soil sensor generic platform are shown below.

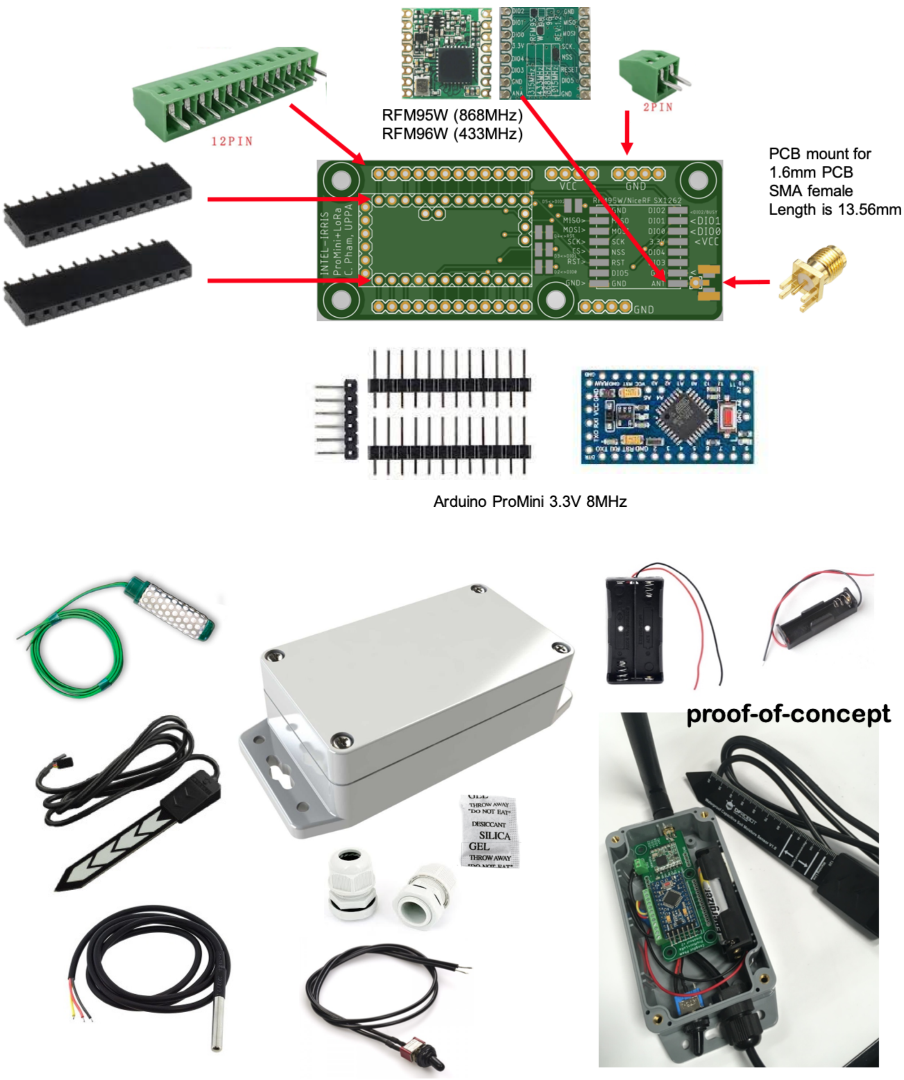


Figure 1 – All the parts of the soil sensor device

The microcontroller platform with all the components are illustrated below, showing the main steps of the assembly based on the DIY-PCB development line.

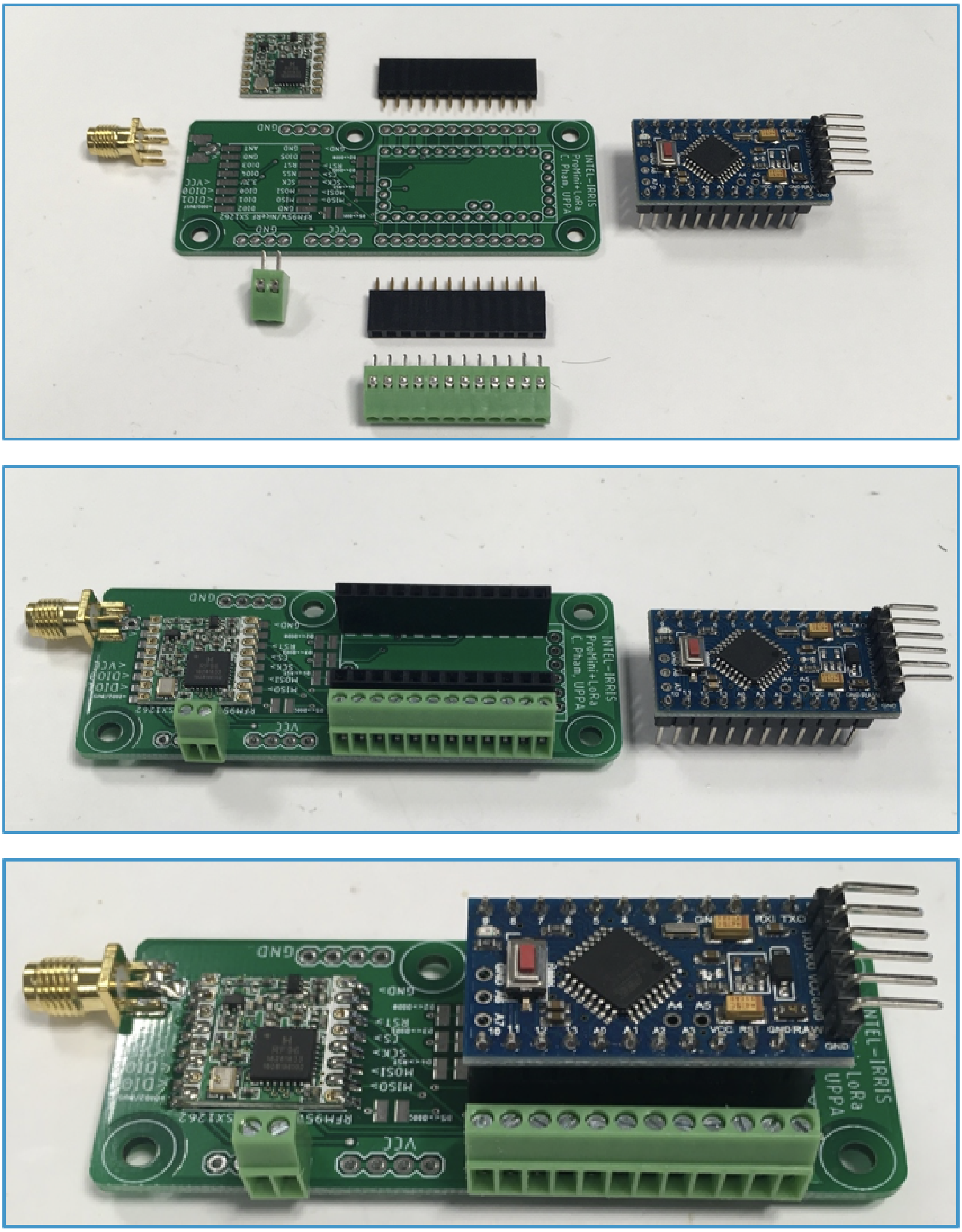


Figure 2 – The microcontroller platform

2.2. Versions of the low-cost soil sensor device

It was planned from the very beginning of the INTEL-IRRIS project that the starter-kit would come in 2 versions of the low-cost sensor platform:

Version 1 will use a low-cost (about 14 euro) capacitive soil moisture sensor (the waterproof Gravity SEN0308 from DFRobots) where the soil bulk density has to be known in order to provide the required level of accuracy. Calibration procedures on various soil types are currently developed in the laboratory by IRD.

Figure 3a – Capacitive SEN0308 sensor

Version 2 will use a medium-cost (about 40 euro) Watermark soil moisture sensor which measures the electrical resistance inside of a granular matrix to determine soil water tension. For simplicity, we will use the term “tensiometer” for the Watermark. The tensiometer approach is to measure directly the force holding water in the soil (thus avoiding the need of measuring the soil bulk density). The Watermark is a widely used tensiometer due to its high efficiency vs cost ratio, and numerous documentations and tutorials describing its installation can easily be found.

Figure 3b – Watermark water tension sensor

2.3. Estimated cost of the IoT platform

soil sensor device				remark
item	unit cost (€)	qt	total cost	
INTEL-IRRIS PCB	0.25	1	0.25	
RFM95W radio module	4.5	1	4.5	
12-pin terminal block	0.8	1	0.8	
2-pin terminal block	0.15	2	0.3	
12-pin female header	0.05	2	0.1	
Arduino ProMini 3.3V 8MHz	1.5	1	1.5	at time of proposal, now ~5€
SMA connector	0.2	1	0.2	
2 AA battery holder	0.25	1	0.25	
3dBi whip antenna	2.15	1	2.15	
toggle switch	0.65	1	0.65	
waterproof cap	0.25	1	0.25	
cable gland	0.15	1	0.15	
ABS enclosure	6	1	6	
SEN0308 for version 1	14	1	14	
Watermark for version 2	40	1	40	
version 1 cost	31.1			
version 2 cost	57.1			
gateway				remark
item				
Raspberry 3B	35	1	35	at time of proposal, now out-of-stock
LoRa hat PCB	0.15	1	0.15	
RFM95W radio module	4.5	1	4.5	
OLED	2.5	1	2.5	
SMA connector	0.2	1	0.2	
3dBi whip antenna	2.15	1	2.15	
RPI case	2.15	1	2.15	
gateway cost	46.65			

starter-kit miscelleanous				remark		
item						
starter-kit box	1.8	1	1.8			
RPI power adapter	6	1	6			
AA battery	0.5	2	1			
starter-kit miscelleanous cost	8.8					
	1 soil device	2 soil devices	3 soil devices	4 soil devices	5 soil devices	
starter-kit version 1 cost	86.55	117.65	148.75	179.85	210.95	
starter-kit version 2 cost	112.55	169.65	226.75	283.85	340.95	

The total cost of the soil sensor device with the capacitive SEN0308 (i.e. so-called version 1) is about 31€ while the total cost of the soil sensor device with the Watermark tensiometer (i.e. so-called version 2) is about 57€.

The cost of version 1 is greater than what we expected, about 25€ in the initial project proposal, because of the cost of the capacitive soil sensor itself.

KPI_1 (COST): Low-cost generic smart irrigation system	Obj.1 Obj.2 Obj.3	The cost of a connected sensor ready to be deployed does not exceed 25€. The cost of the smart control system able to handle hundredth of sensors to start at about 55€. **A starter-kit to start at about 80€.**

However we chose the SEN0308 because of its native water-proof property which would have been difficult and certainly less robust to achieve by adapting a lower cost sensor (such as the SEN0193 for instance that cost about 6€).

With version 1 of the soil sensor device, the starter-kit that adds the gateway and some miscellaneous parts is at about 86.5€. If the power adapter for the RPI gateway is removed because a smallholder can use an existing 5V, 2A USB adapter then the starter-kit estimated cost meets the one we estimated in the initial proposition: about 80€.

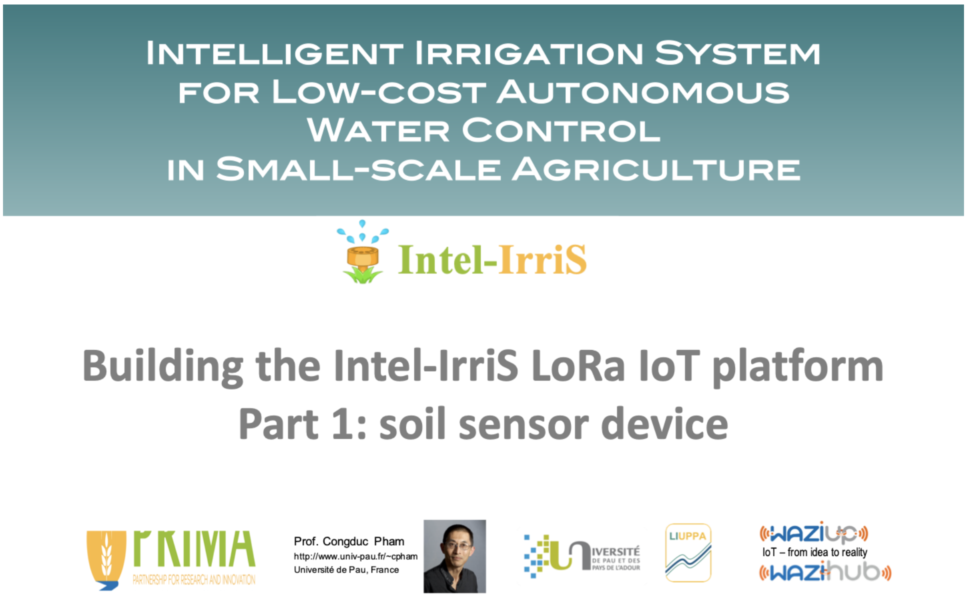
As can be seen from the remarks in the table, the cost of the Arduino ProMini and the RaspberryPI were taken at time of proposal. Now, due to COVID-19, the cost of many electronic components have dramatically increased. The Raspberry Pi single computer boards are even out-of-stock with an estimated date for availability in Dec. 2023! For INTEL-IRRIS, partners have taken from their existing stock of Raspberry 3B to build the starter-kit in order to not delay the deployment of the test program and the Smallholder Piloting Program.

However, we already foreseen that it will be difficult to meet the planned distribution of 100 starter-kit as the total existing stock of Raspberry Pi is about 30 units among all the partners.

2.4. Tutorial materials for the sensor platform

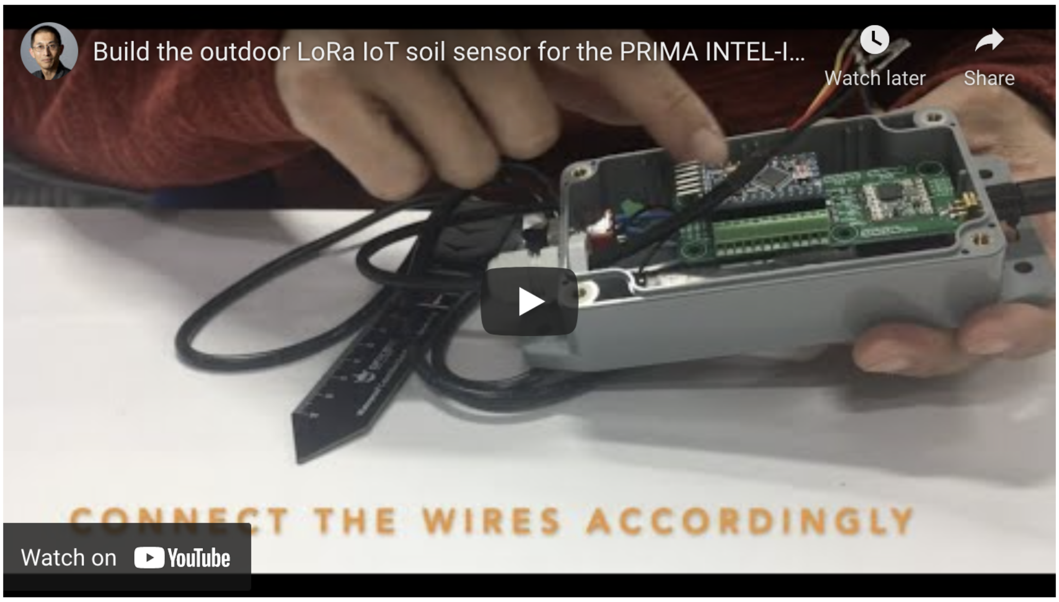
The “INTEL-IRRIS List of parts” to build the soil sensor device [1] and the tutorial slides on “Building the INTEL-IRRIS LoRa IoT platform. Part 1 soil sensor device” [2] have been updated accordingly, showing instructions for both soil moisture sensors.

- **Tutorial slides on Building the INTEL-IRRIS LoRa IoT platform. Part 1: soil sensor device**. Related videos are Video n°1, Video n°2 and Video n°3. https://github.com/CongducPham/PRIMA-Intel-IrriS/blob/main/Tutorials/Intel-Irris-IOT-platform.pdf



- **Video n°1. YouTube tutorial video showing how to build the IoT microcontroller platform for the LoRa IoT soil sensor device**. https://youtu.be/3jdQ0Uo0phQ

- **Video n°2. YouTube tutorial video showing how to build the outdoor LoRa IoT soil sensor device**. https://youtu.be/zcazzDbXvHk



- **Video n°3. YouTube tutorial video showing how to wire the SEN0308 capacitive sensor and test LoRa data transmission on the Edge IoT gateway**. https://youtu.be/n0YGan7_vUc

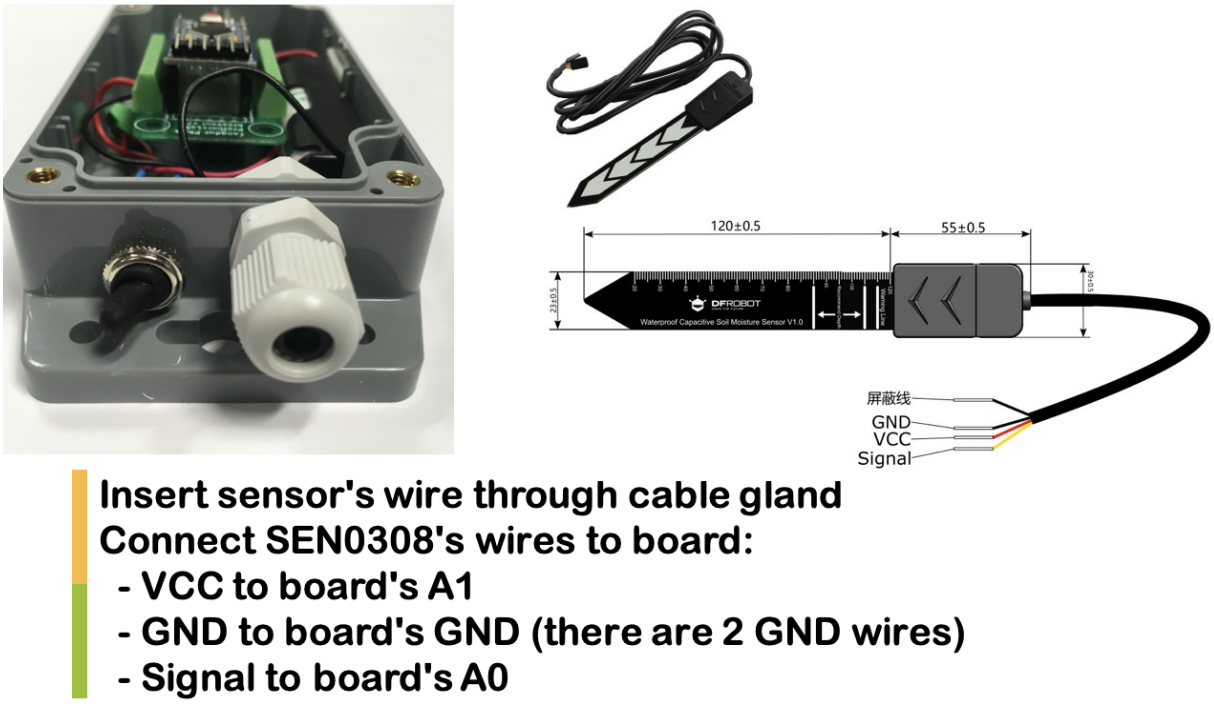


Figure 4 – Wiring diagram for the capacitive sensor

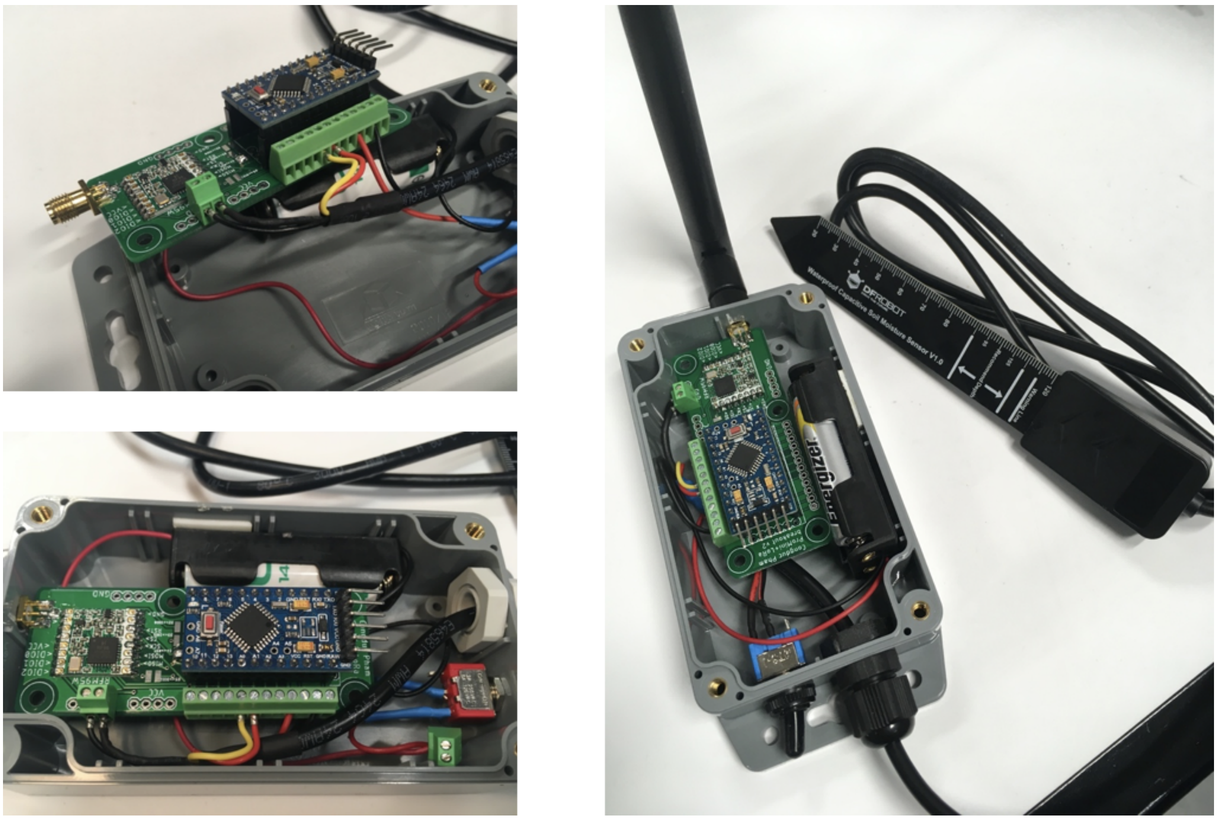


Figure 5 – The soil sensor device with the capacitive sensor

While Version 1 of the soil sensor device was already ready in D1.2a, version 2 with the Watermark is an update that will be described in more detail in this deliverable.

3. INTEL-IRRIS PCBs

3.1. Simple PCB for external antenna

INTEL-IRRIS PCBs designed by UPPA were received on Feb 3rd, 2022 (http://intel-irris.eu/news). Gerber files for the PCBs are available on INTEL-IRRIS GitHub [3].

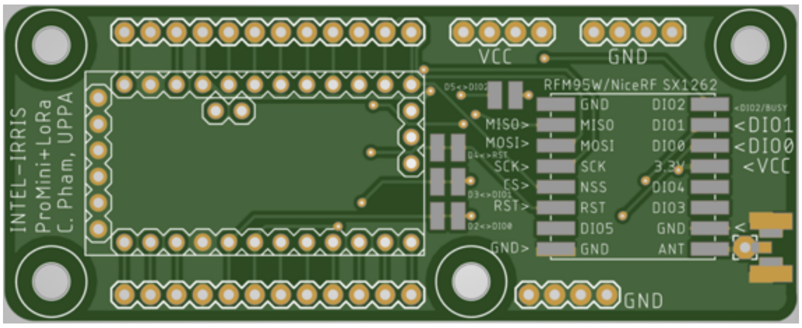


Figure 6a – The designed simple INTEL-IRRIS PCBs

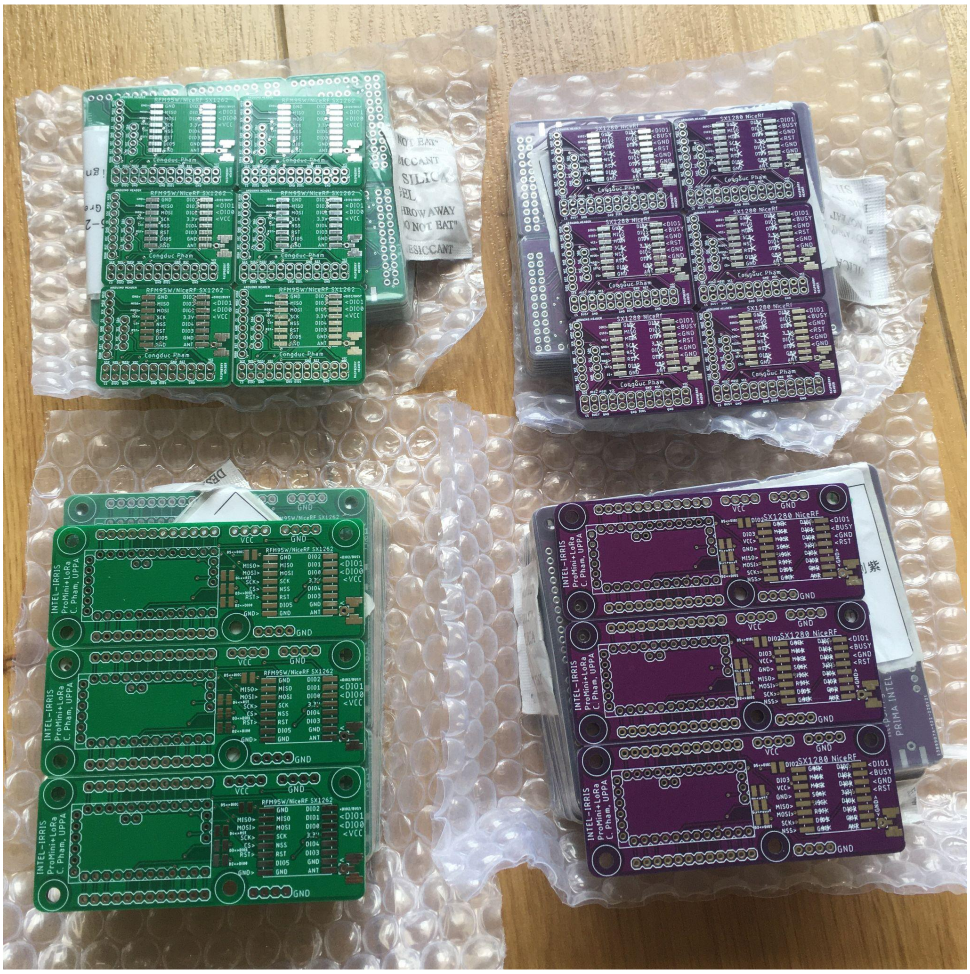


Figure 6b – The manufactured INTEL-IRRIS PCBs

A dedicated tutorial showing how to order INTEL-IRRIS PCBs has been produced:

- **Tutorial slides on ordering & manufacturing the INTEL-IRRIS PCBs to build the IoT microcontroller platform for the LoRa IoT soil sensor device**. https://github.com/CongducPham/PRIMA-Intel-IrriS/blob/main/Tutorials/Intel-Irris-PCB.pdf

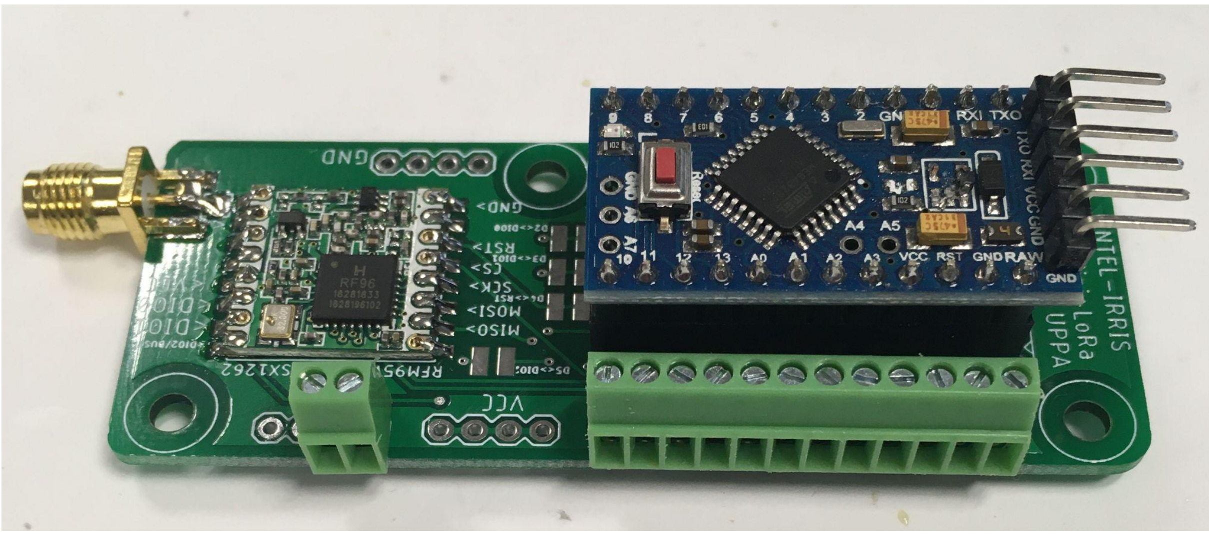


Figure 7 – The microcontroller platform with the INTEL-IRRIS PCBs

3.2. PCB with integrated antenna

WAZIUP provided a microcontroller PCB board with an integrated antenna in the 868MHz frequency band. We performed early tests of the integration of this board for the INTEL-IRRIS soil sensor device as illustrated in Figure 8 below. More tests will be performed in the next months in the deployment phase.

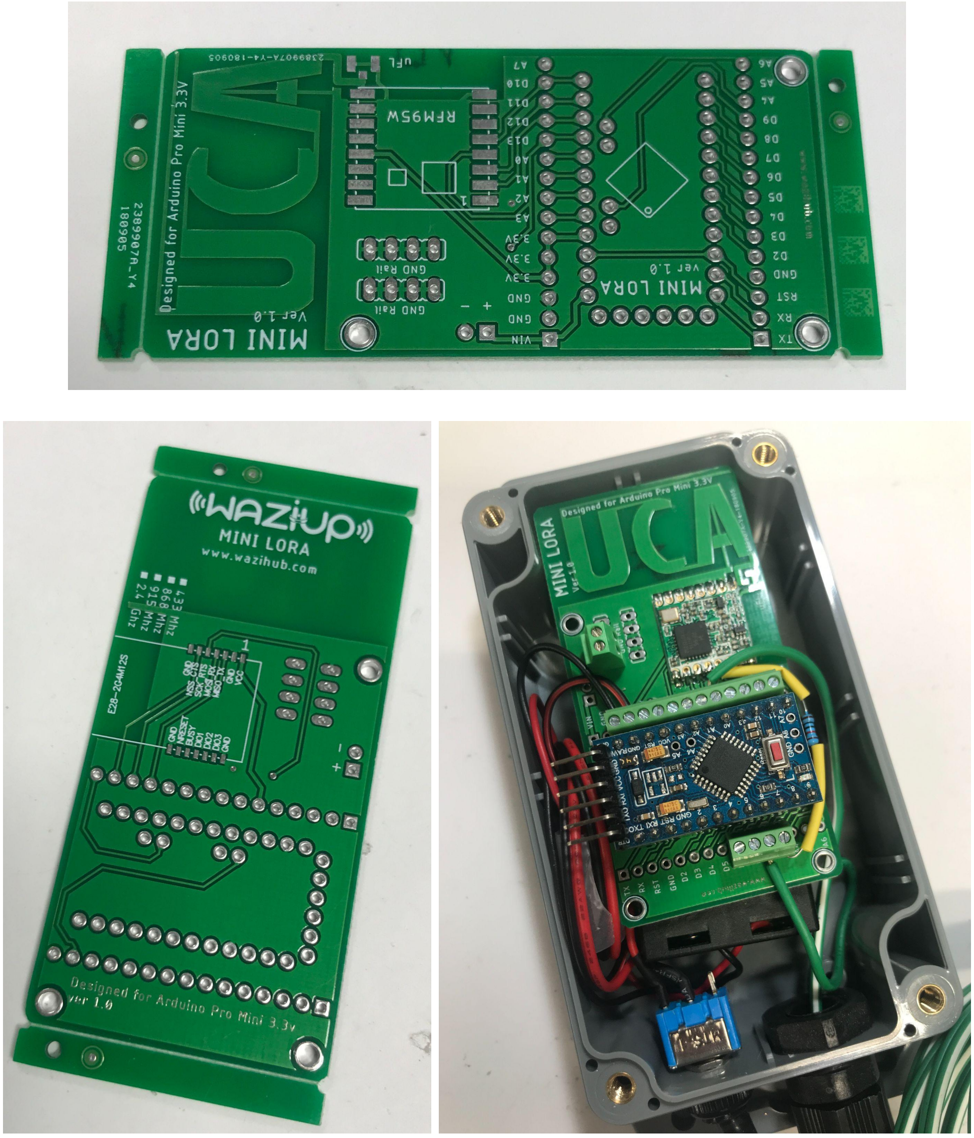


Figure 8 – The Arduino ProMini PCB break out with integrated antenna

4. Test of the generic hardware platform

4.1. Validating low power consumption

Low-power consumption in deep sleep mode is validated by UPPA to be under 5uA. The expected autonomy of the soil sensor device, assuming 1 measure every hour with transmission to the IoT gateway, is beyond 2 years with 2 heavy-duty AA batteries.

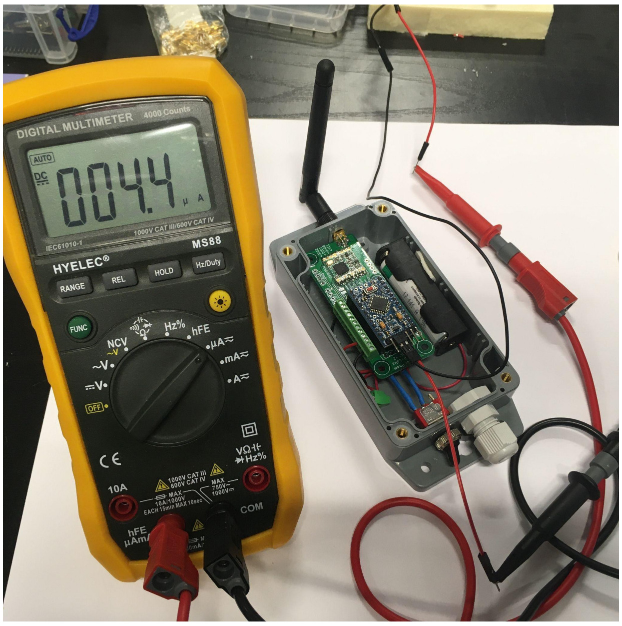


Figure 9 – Low power consumption in deep sleep mode

4.2. Testing outdoor deployment

Outdoor deployment has been tested by both UPPA and IRD to validate the enclosure resistance to water & humidity, especially at the junction with the external antenna.

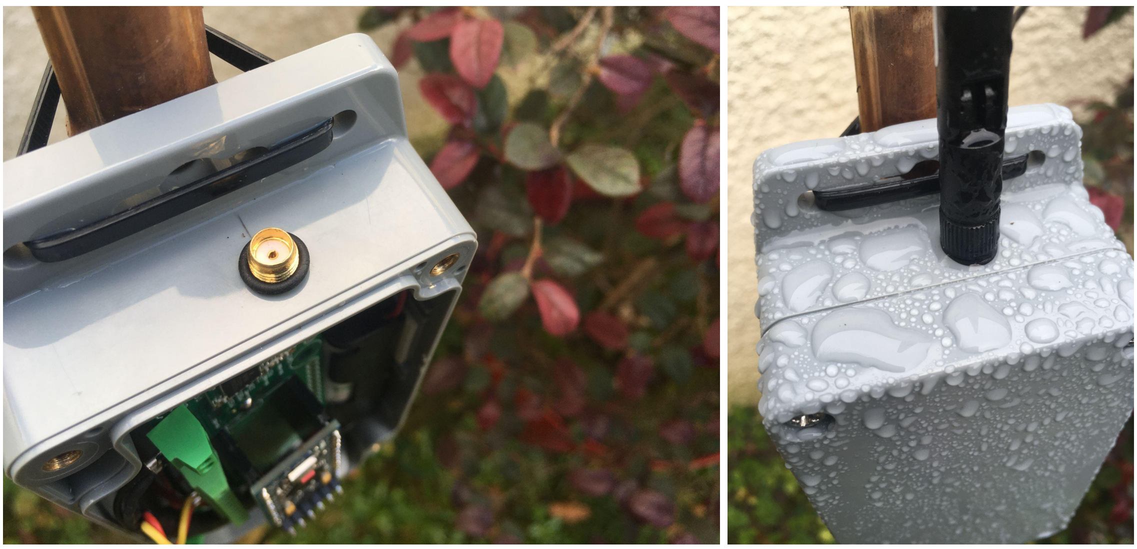


Figure 10 – O-ring for the antenna junction

O-ring must be placed on the antenna SMA connector, but it is also advised to add silicon to make the device more robust to deployment by smallholders.

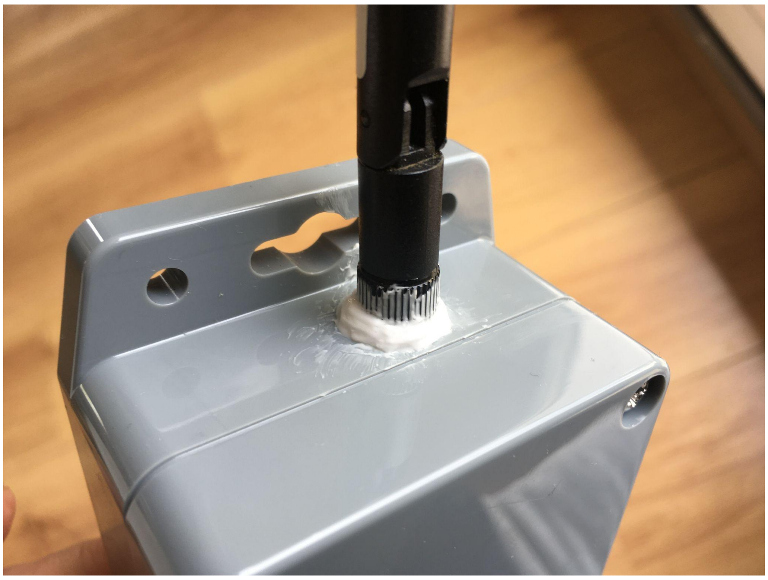


Figure 11 –Adding silicon to make it more waterproof

Figure 12 – Testing outdoor deployment & protecting enclosure from direct sun

Outdoor deployment tests were successful and deployed devices are able to run for several weeks in outdoor conditions without any issue. Note that, it is also advisable to protect the device from direct sun by a plastic shade.

4.3. Testing capacitive sensor stability

IRD also conducted extensive tests on SEN0308's stability.

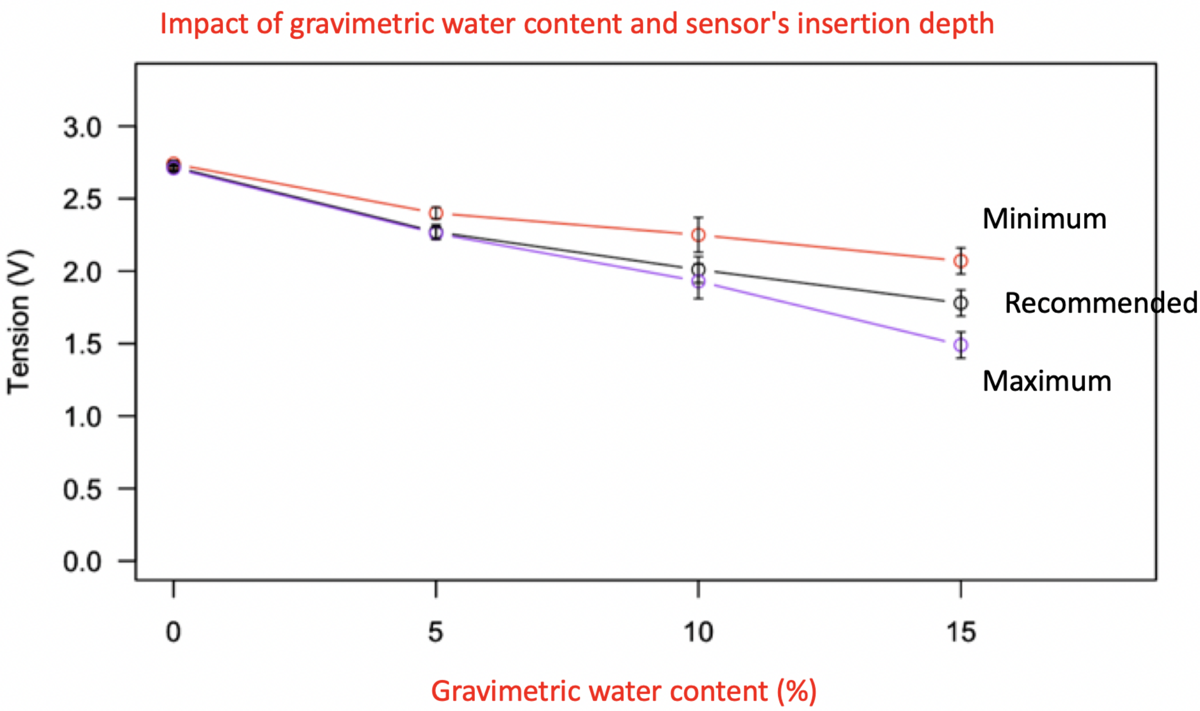


Figure 13 – Lab test at IRD: impact of SEN0308 insertion depth

We can observe in Figure 13 that measured values can vary significantly with insertion depth, especially when the amount of water is large. It is therefore important to maintain the recommended insertion depth mentioned on the sensor – Figure 14 – and also to keep this insertion depth as identical as possible from one area to another.

Figure 14 – Lab test at IRD: SEN0308 insertion depth marked on sensor

The impact of sunlight on the sensor casing itself has also been measured as the electronic part of the SEN0308 is protected from water and dust with a black plastic case – Figure 15 – compared to the lower cost SEN0193 sensor.

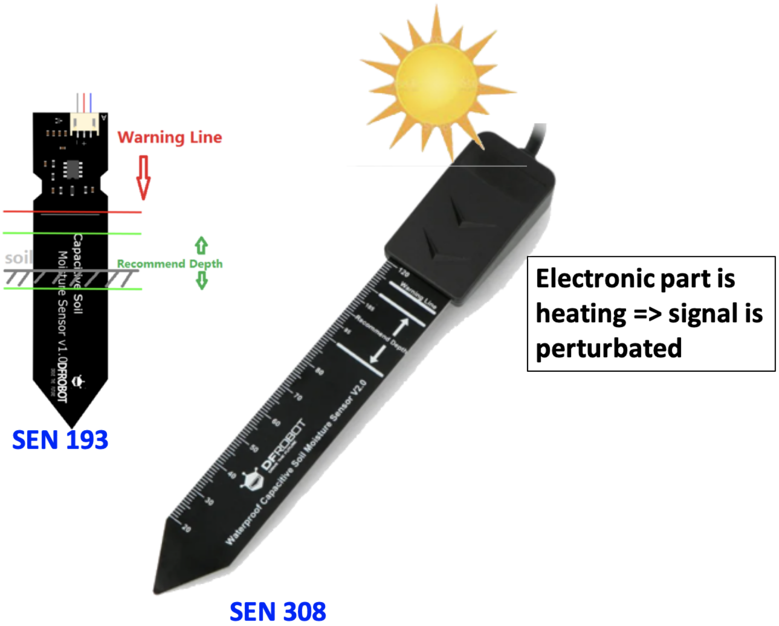


Figure 15 – Lab test at IRD: SEN0193 vs SEN0308

Figure 16 shows peaks in measured values when the sensor's casing is heated with sunlight, demonstrating that heat on the top casing part can actually have some impact. The lower cost SEN0193 does not have this issue as there is no such protective plastic case (that actually makes it unsuitable for outdoor deployment) – Figure 17.

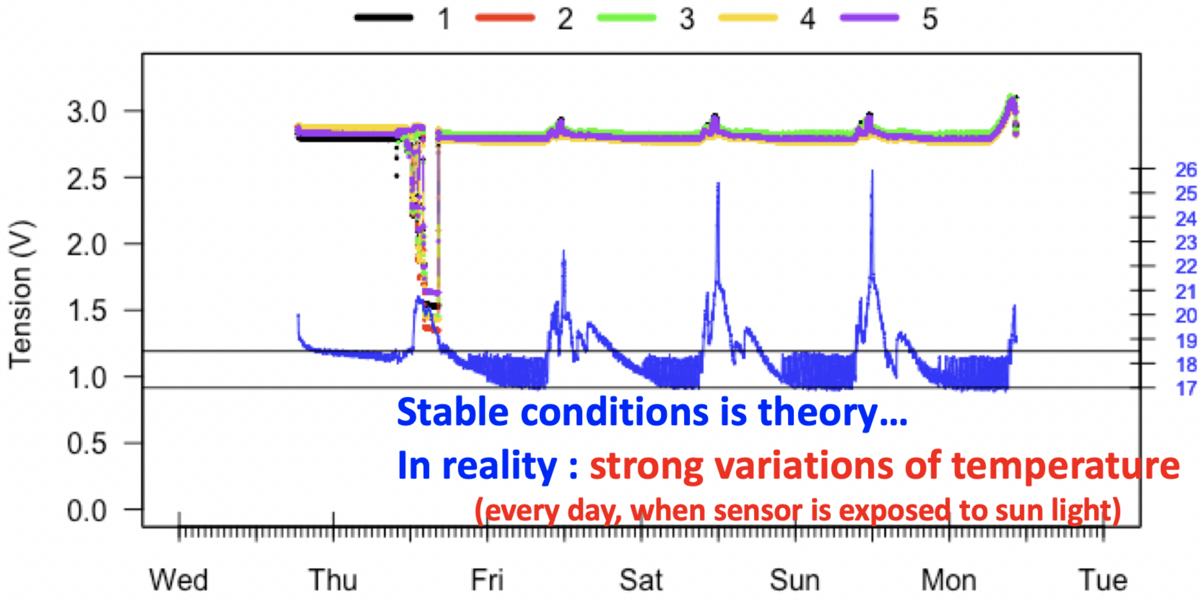
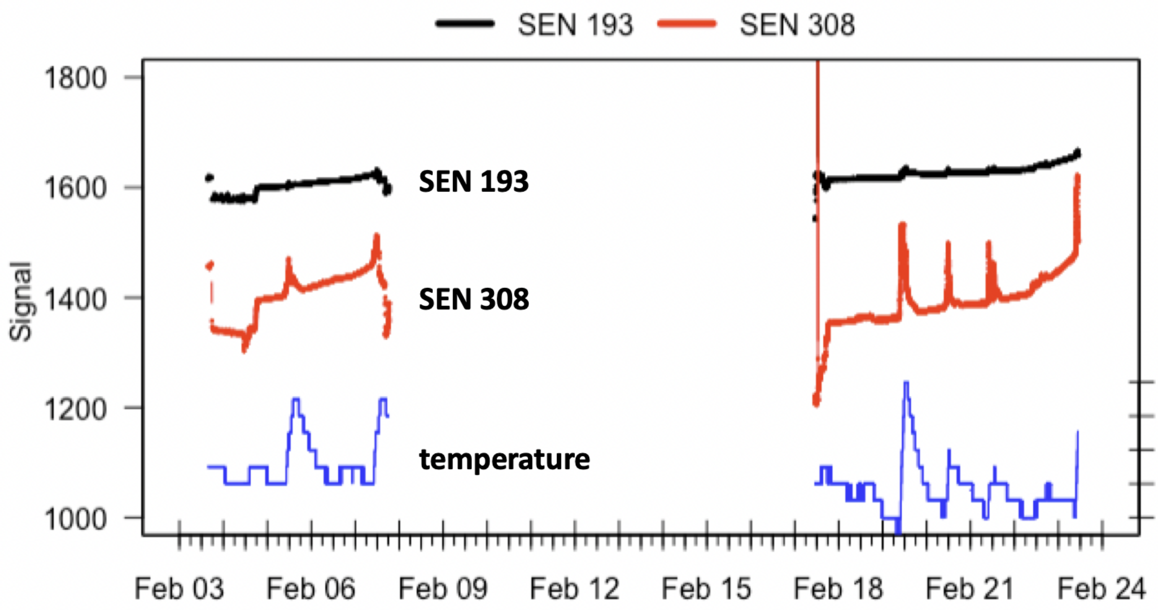


Figure 16 – Lab test at IRD: impact of sun on SEN0308 sensor



SEN 193 (smaller size) is not impacted by solar rays and its signal is not perturbated by the increased temperature

Figure 17 – Lab test at IRD: impact of sun on SEN0193 & SEN0308

Figure 18 – Lab test at IRD: protecting SEN0308

One solution would be to protect the soil sensor itself from direct sunlight as illustrated in Figure 18. It is expected that real deployment in fields with vegetation coverage would limit the impact of sunlight even if the sensor is not protected.

The impact of ambient air temperature is also tested. Figure 19 shows the setting with several sensors put in a heat chamber. Figure 20 then shows that the impact of ambient air temperature is low but the test also reveals that radiation when the heating lamps of the heat chamber are switched on can have some impact – Figure 21. However, we expect this phenomenon to be quite neglectable in real deployment scenarios.

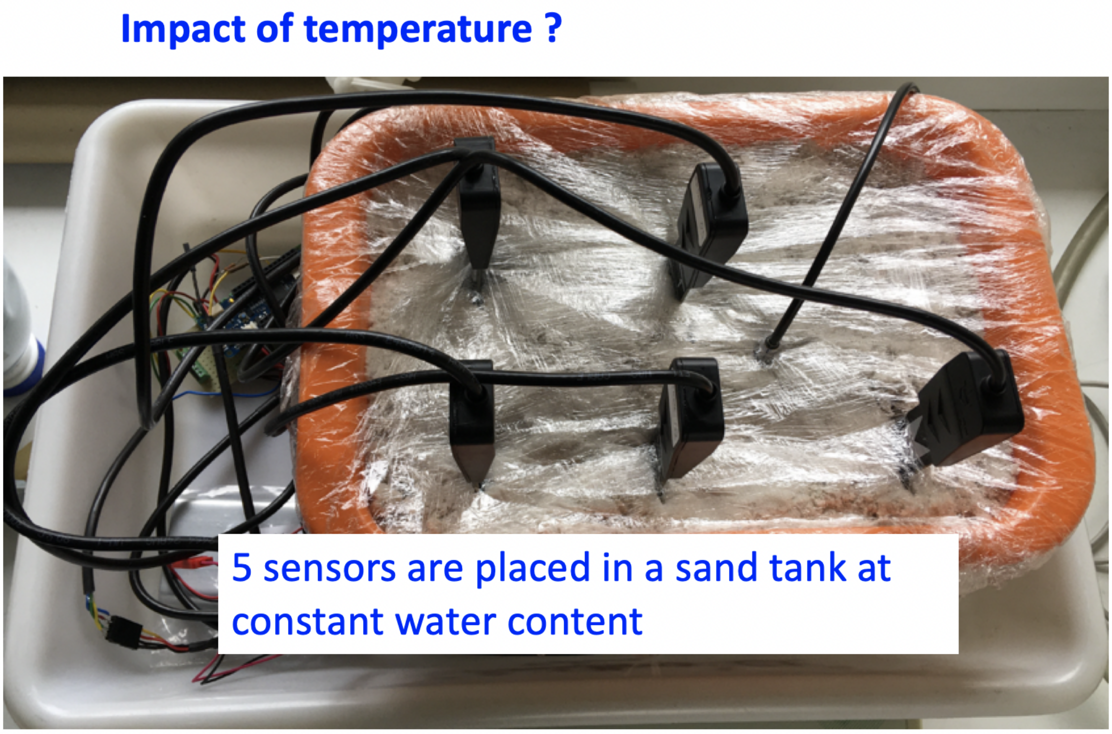


Figure 19 – Lab test at IRD: impact of ambient temperature

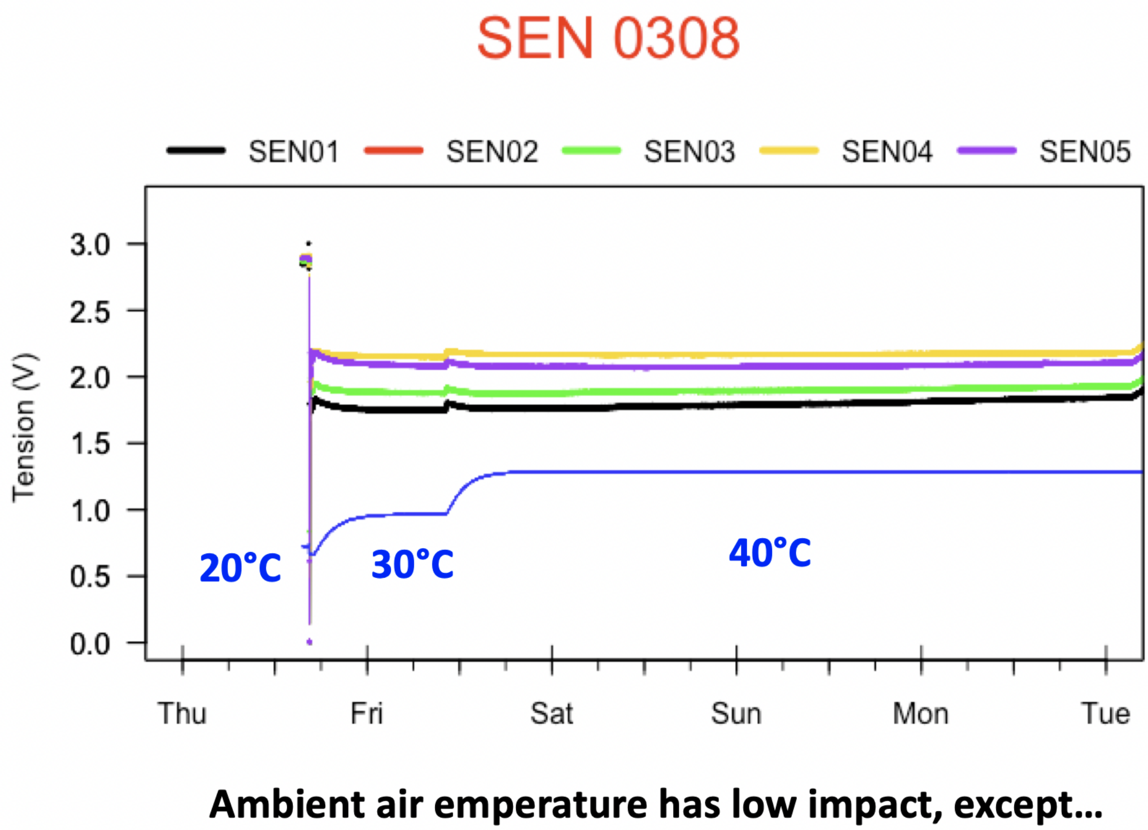


Figure 20 – Lab test at IRD: low impact of ambient temperature

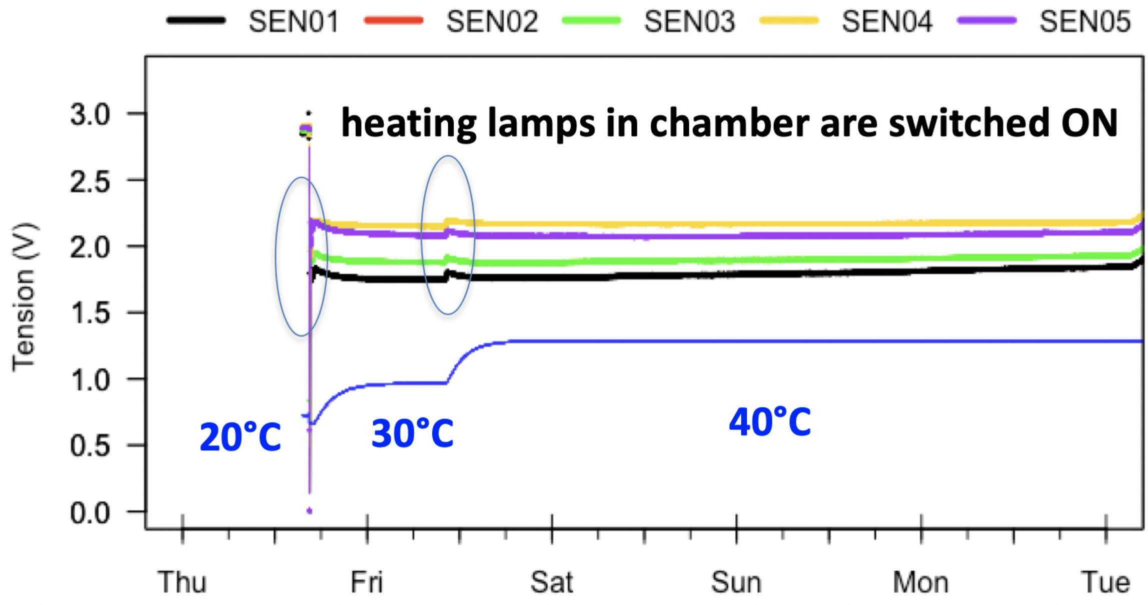


Figure 21 – Lab test at IRD: impact of radiation/electromagnetic

The impact of low voltage on SEN0308's response has also been tested. Figure 22 shows the digital value read at 2 pre-determined humidity levels (very dry and very humid) when the operating voltage is varied. Normally, for very dry conditions, the value should be very close to 800. And close to 100 for very humid conditions.

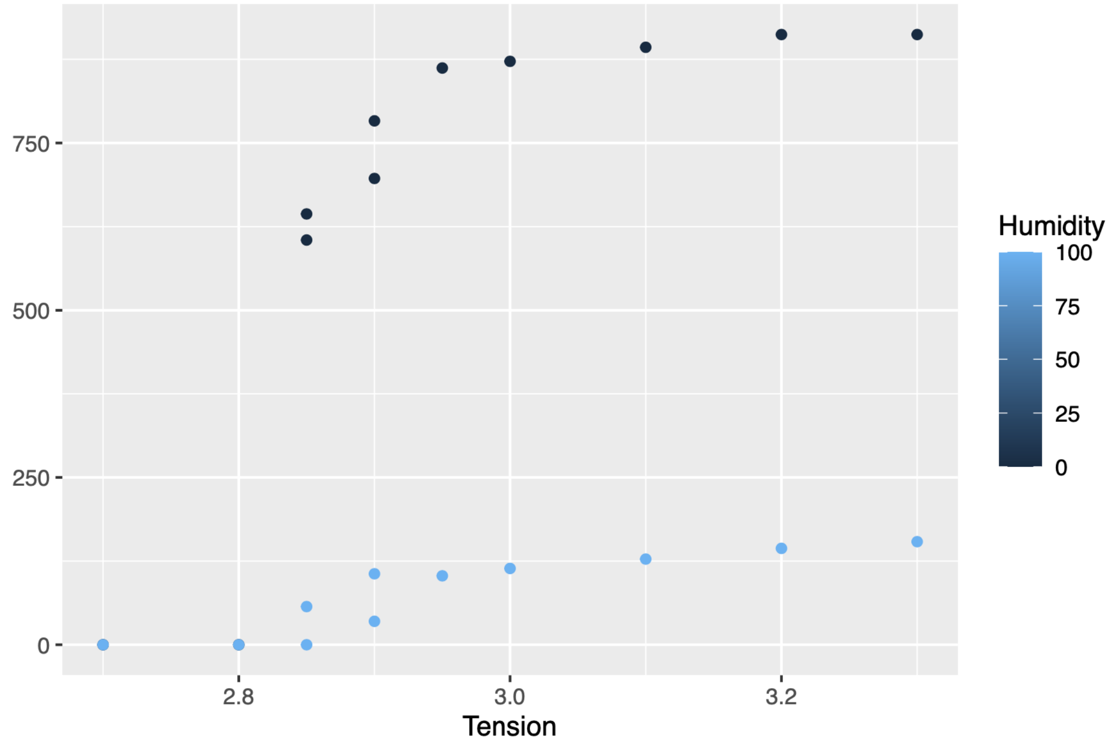


Figure 22 – Lab test at IRD: SEN0308

We can see that when the operating voltage is below 2.95V, the error can be significant for very dry conditions, leading to misinterpretations.

With 2 AA alkaline batteries, this threshold can be reached in some months while the microcontroller board is still operational.

For the next version, it may be better to use a single 3.6V lithium battery such as the one illustrated below. The cost of the battery is about 3€/unit so this would add an extra cost of 2€ compared to the 2 alkaline AA batteries version.

Figure 23 – SAFT 3.67V lithium battery LS14500

All these results are presented in more detail in [6].

5. Developing the soil sensor device with Watermark

In parallel to the extensive tests of the capacitive version and its preparation for the first phase of deployment, we also develop the methodology to integrate the Watermark sensor. Several technical meetings took place with INRA, IRD and UMAB to identify the needs, the technical issues and the future test campaigns.

5.1. The Watermark water tension sensor

The Watermark can be connected to a microcontroller. There is a recommended procedure (https://www.irrometer.com/200ss.html) [4] for reading from the sensor from Irrometer, the manufacturer of the Watermark.

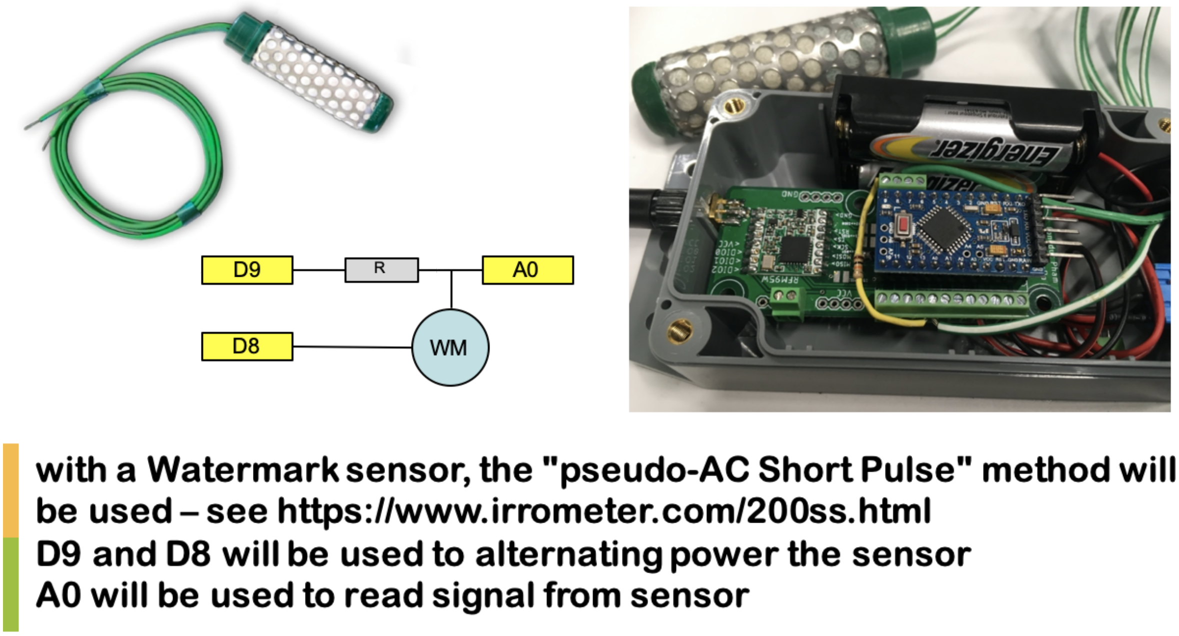


Figure 24 – Wiring diagram for the Watermark sensor

Figure 24 from [2] shows how the Watermark can be wired through a resistor R to be powered with the pseudo-AC short pulse method also recommended by the manufacturer..

5.2. Test of Watermark+microcontroller

IRD conducted a number of tests to validate the pseudo-AC short pulse powering method for the Watermark sensor.

Several Watermark sensors are connected to a microcontroller board as illustrated in Figure 25 and tested with several settings. One of the settings where the water succion can be varied is illustrated in Figure 26. The powering method viewed from an oscilloscope is shown in Figure 27.

More results are presented in [6].

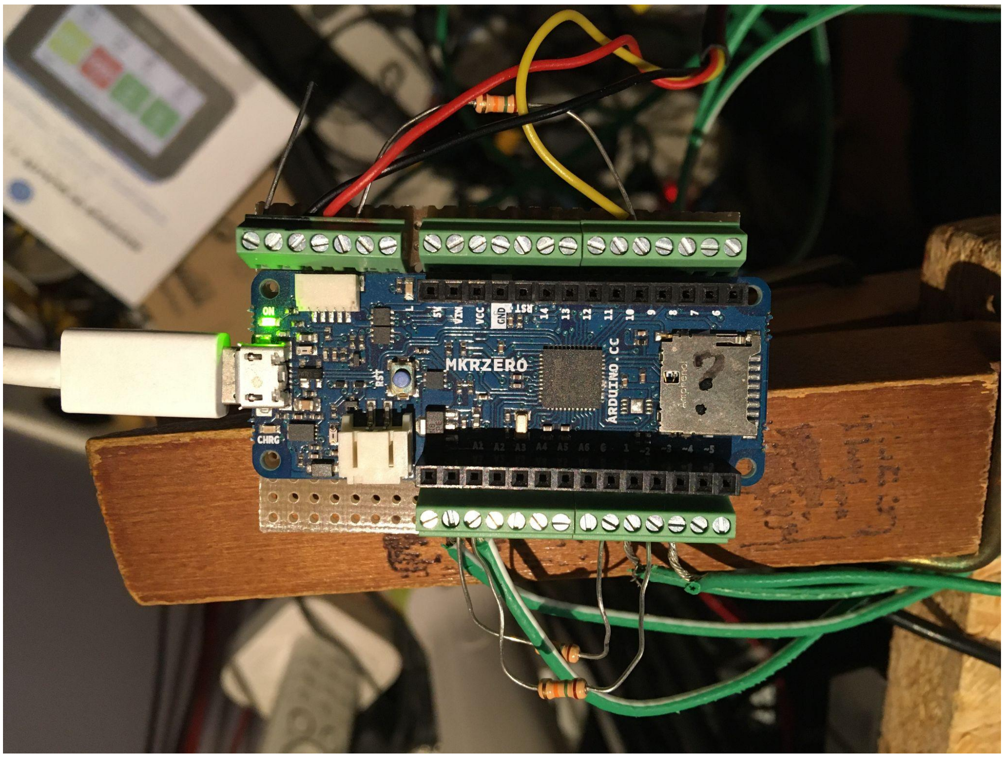


Figure 25 – The microcontroller board used by IRD for the tests

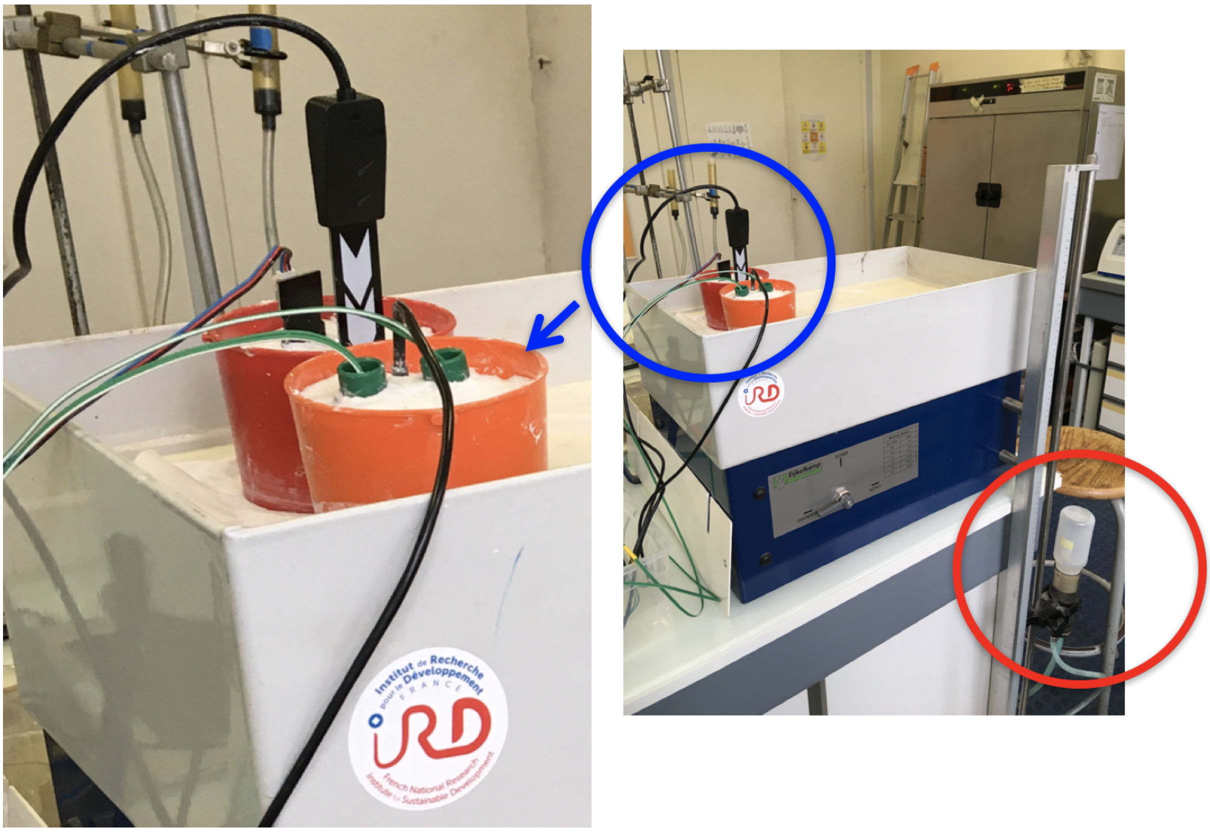


Figure 26 – One of the test setting for the Watermark sensor

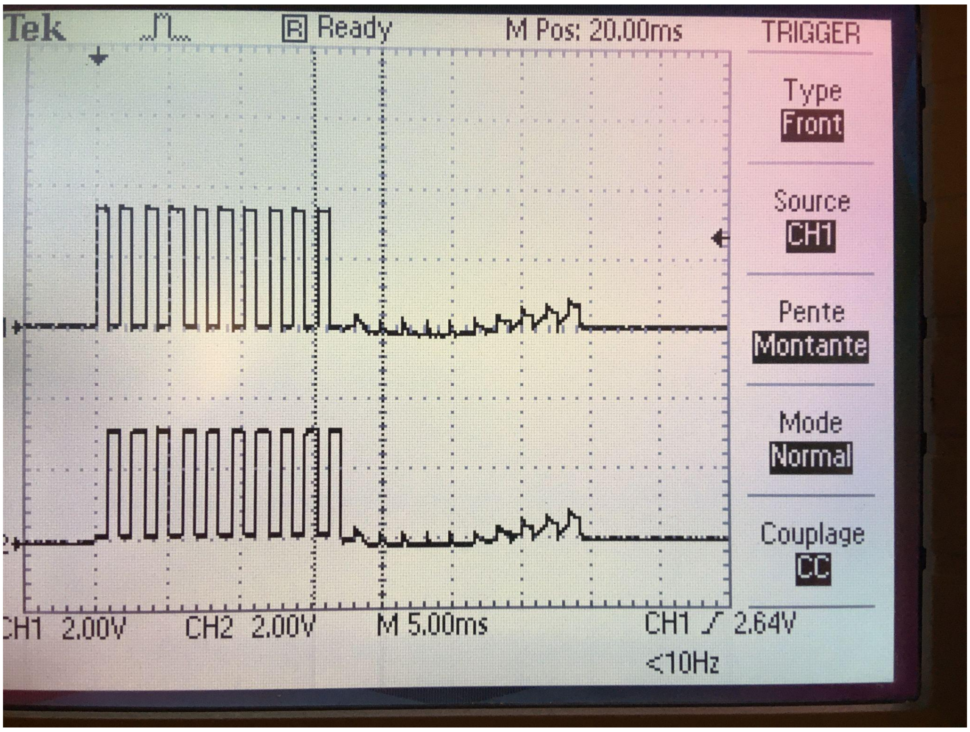


Figure 27 – The powering method viewed on an oscilloscope

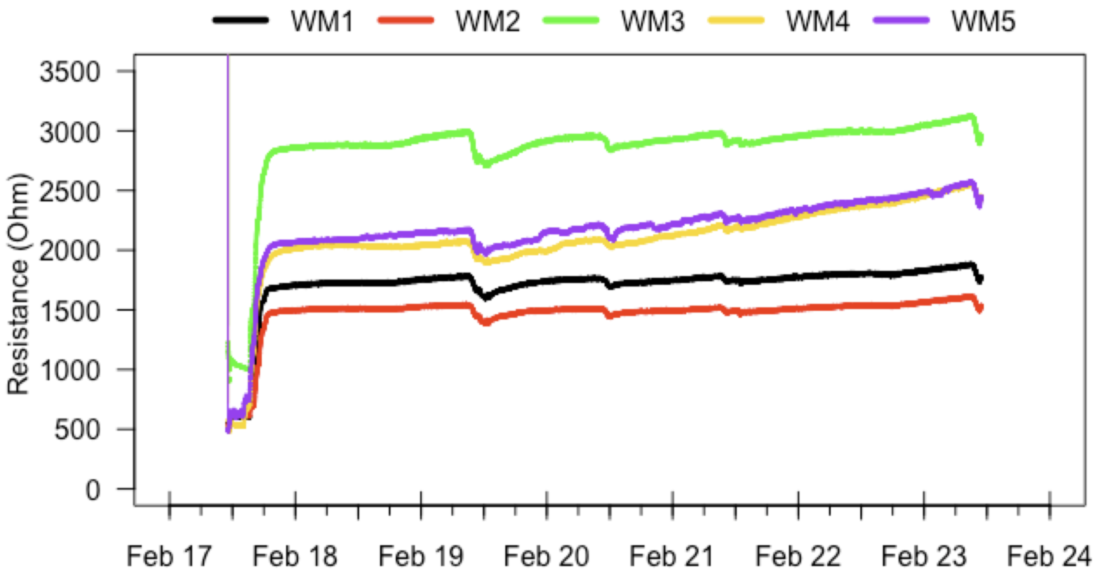


Figure 28 – Examples of reading from Watermark sensors

5.3. Extending the INTEL-IRRIS soil device software

The control software developed by UPPA that runs on the soil sensor platform has been extended to support the Irrometer Watermark water tension sensor.

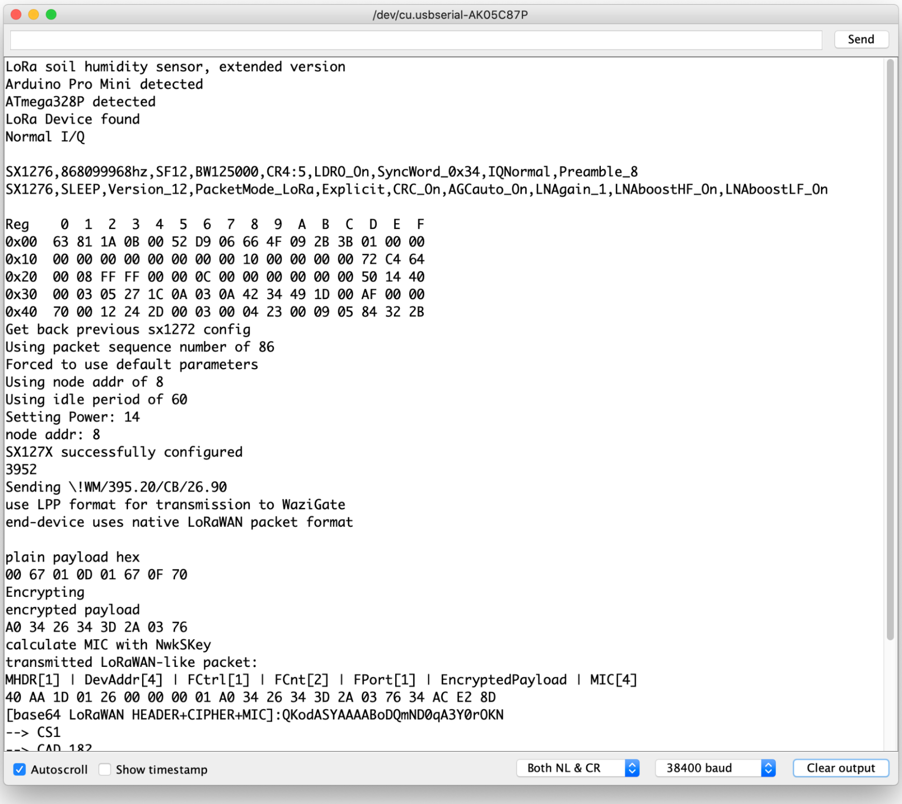


Figure 29 - Output from the soil device when connected to a computer

Here, in Figure 29, the clear ASCII message that is built is "\!WM/395.20/CB/26.90", , where 395.20 should be scaled to 3952 to represent the resistance value (in Ohms) read from the Watermark. 26.9 is then the translated water tension value in centibars. The formula used for this translation is the one proposed by the Watermark manufacturer [4]. The real transmissions to the WaziGate IoT gateway use a more compact data format (Cayenne LPP format). Figure 30 shows the pre-configured Wazigate dashboard for the soil sensor device using the Watermark sensor. The code is available on the INTEL-IRRIS github repository [5].

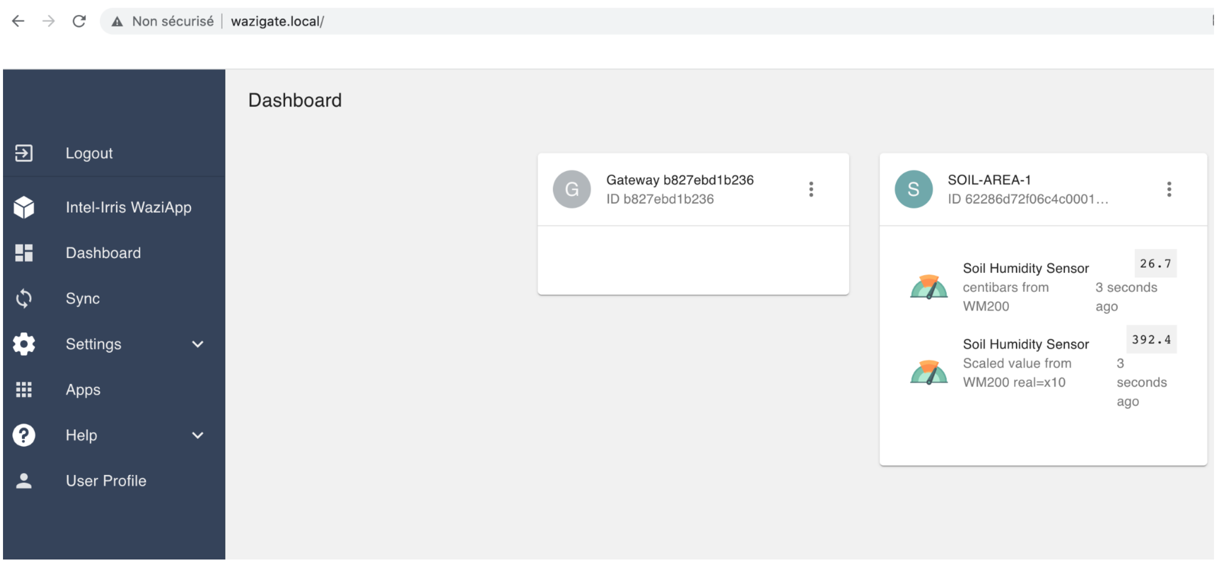
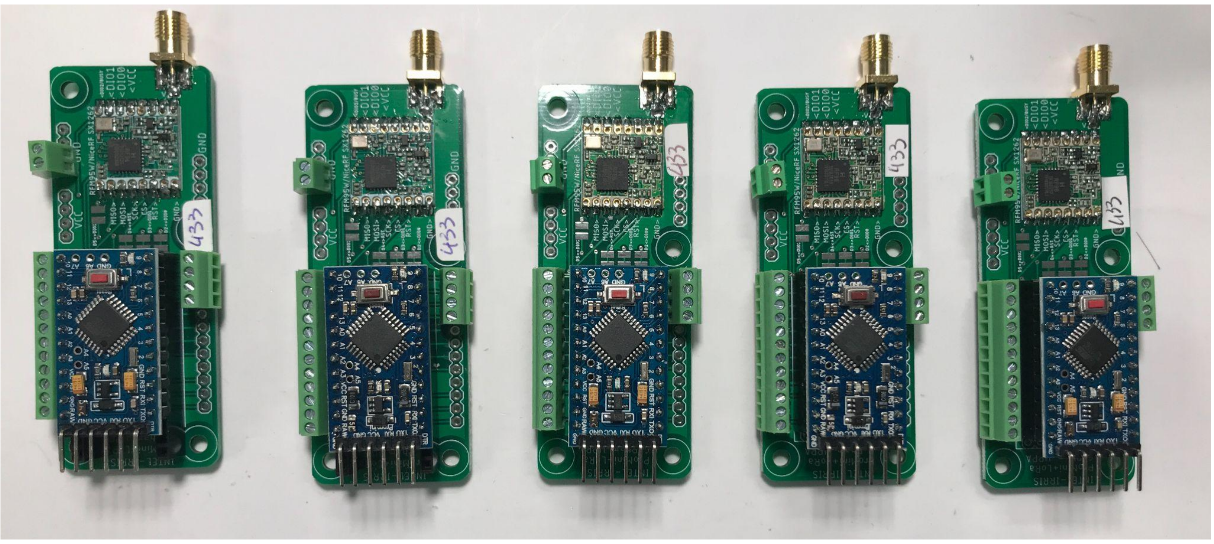


Figure 30 - Messages received on the WaziGate's dashboard

5.4. Test campaign in Algeria and Morocco

We are preparing a test campaign in Algeria and Morocco for the version 2 of the soil sensor device. A number of soil sensor platforms to host the Watermark sensor have been assembled to be deployed. These devices for the Watermark can easily be recognized with the additional resistor (the yellow part in Figure 31b).



(a)

(b)

(c)

Figure 31 - (a), (b) & (c). Preparation of version 2 of soil sensor device

Figure 32 - The two versions of the soil sensor device

6. Conclusions

D1.2b presented the updates on the low-cost sensor generic platforms for connected irrigation systems. The main two contributions added from D1.2a are the extensive test campaign for the capacitive soil moisture version and the development of the Watermark tensiometer version.

The low-cost sensor generic platform will be integrated into the INTEL-IRRIS starter-kit which is described in D2.2a “Starter-kit for smart irrigation system – v1”.

Related resources/documents

[1] C. Pham. INTEL-IRRIS List of parts to build the soil sensor device https://github.com/CongducPham/PRIMA-Intel-IrriS/blob/main/Tutorials/Intel-IrriS-low-cost-sensor-hardware-parts.pdf

[2] C. Pham. INTEL-IRRIS Tutorial slides on Building the INTEL-IRRIS LoRa IoT platform. Part 1: soil sensor device https://github.com/CongducPham/PRIMA-Intel-IrriS/blob/main/Tutorials/Intel-Irris-IOT-platform.pdf

[3] C. Pham. INTEL-IRRIS PCBs for the soil device https://github.com/CongducPham/PRIMA-Intel-IrriS/tree/main/PCBs

[4] Irrometer. Reading WATERMARK Soil Moisture Sensors. https://www.irrometer.com/200ss.html

[5] INTEL-IRRIS GitHub https://github.com/CongducPham/PRIMA-Intel-IrriS

[6] C. Hartmann. Capteurs à bas coût pour la mesure de l’eau dans le sol : opérations préliminaires de calibration au laboratoire. http://intel-irris.eu/wp-content/uploads/2022/04/Talk-Christian-Hartmann-April-01-22.pdf
Video at time t=4934s: https://youtu.be/npDGI-9Y-DA?t=4934.
Presentation at the Webinar sur l’irrigation 4.0. April 1st, 2022. Organized by INRA with ENSA Safi, UORAN1 and UMAB. Animated by Pr Tarik Benabdelouahab (INRA).

Acronyms List

Acronym	Explanation
PCB	Printed Circuit Board

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