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

Deliverable D1.2c

Low-cost sensor generic platforms for connected irrigation system – v3

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Document revision history

Version	Date	Changes
V1.1	June 28th, 2023	Public release
V1.0	June 23th, 2023	First draft version for internal approval
V0.1	June 19th, 2023	First release for review

Executive Summary

Deliverable D1.2c updates D1.2b and describes the "INTEL-IRRIS low-cost soil humidity sensor platform – v3". The deliverable will present the new features of the soil device firmware and the 2 new PCBs solutions to improve the INTEL-IRRIS starter-kit and the capacity to scale up deployment.

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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 [1] [2]. It is part of the INTEL-IRRIS starter-kit that has been presented in D2.2a "Starter-kit for smart irrigation system – v1".

Here, D1.2c "INTEL-IRRIS low-cost soil humidity sensor platform – v3" will present the improvement on the low-cost sensor generic platform that have been made since D1.2b "INTEL-IRRIS low-cost soil humidity sensor platform – v2". We will first review the hardware components then present the 2-watermark platform version, the improvements to the soil sensor firmware, the new PCB with solar charging capabilities and the WaziSense v2 hardware platform that can be used to scale up the deployment of the starter-kit.

2. The low-cost sensor generic platform

2.1. Review of hardware components

The component list to build the low-cost soil sensor generic platform are shown below [1].

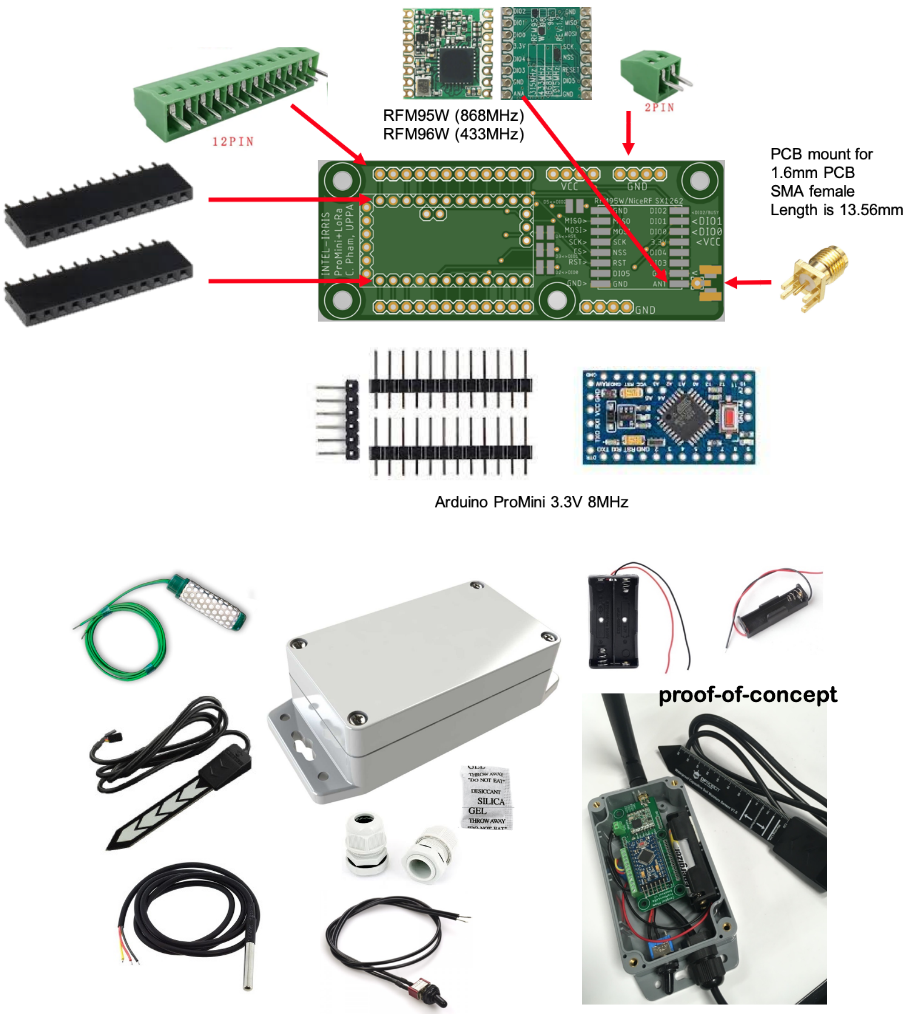


Figure 1 – All the parts of the soil sensor device

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

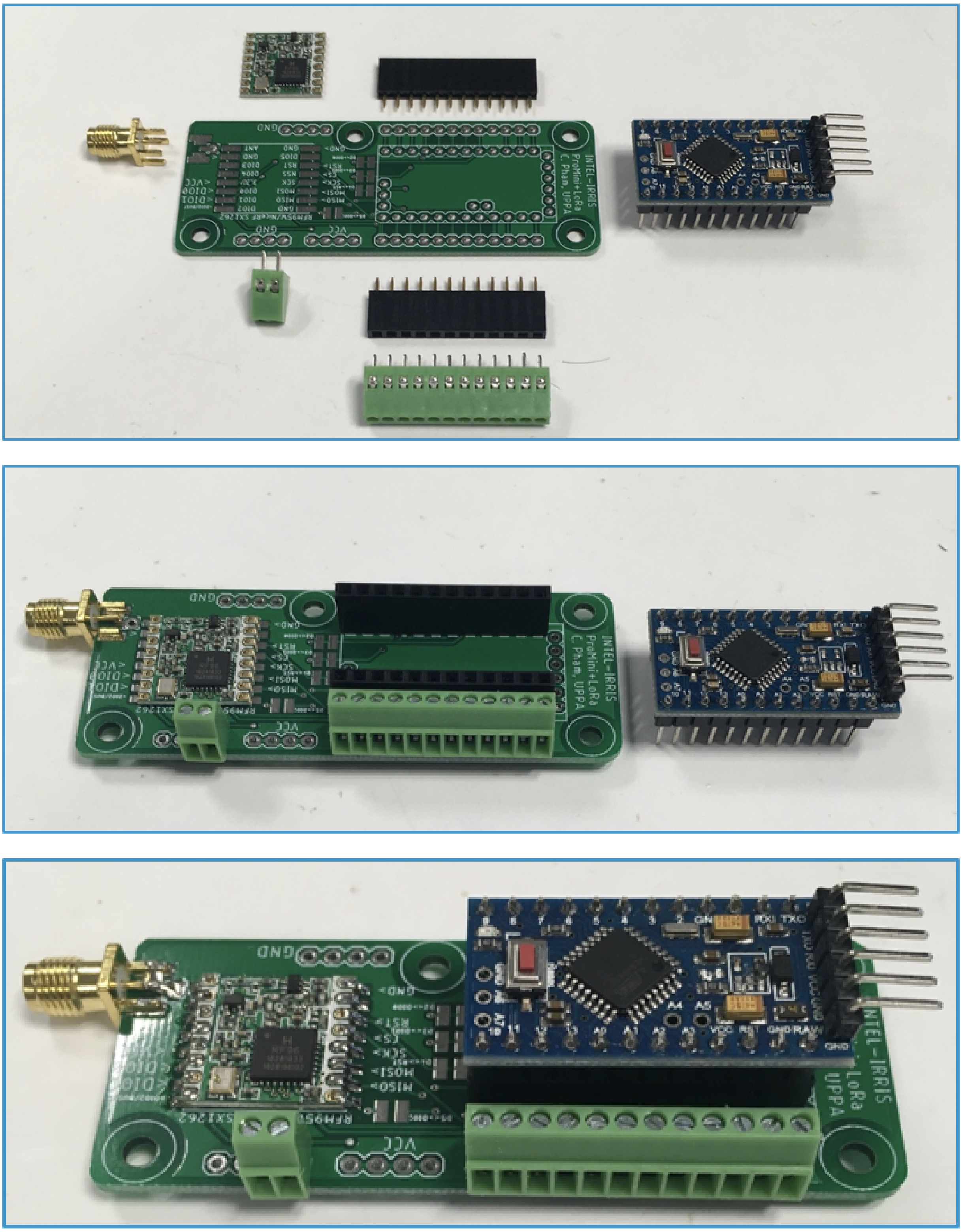


Figure 2 – The microcontroller platform

2.2. Review of 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 several 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 [3].

Figure 3b – Watermark water tension sensor

Figure 4 - The 2 current versions of the soil sensor device

2.3. Adding the 2-watermark version

Discussions with our agriculture partners highlighted the benefit of a 2-Watermark device version that would enable accurate detection of water movement between the 2 soil humidity sensors that would be buried at different depths. The visit of a citrus farm in the Mostaganem area in March 2023 confirmed the need for such a version, despite the increased cost of the device which would be around 100€. However, discussions with farmers showed that even a small number of these devices could advantageously replace the traditional "analog" vacuum-based water tension system, especially as the lifetime of the watermark sensors can span several years which is not the case for the vacuum-based water tension system.

Figure 5 - Traditional water tension sensors at 2 depths (30cm & 60cm)

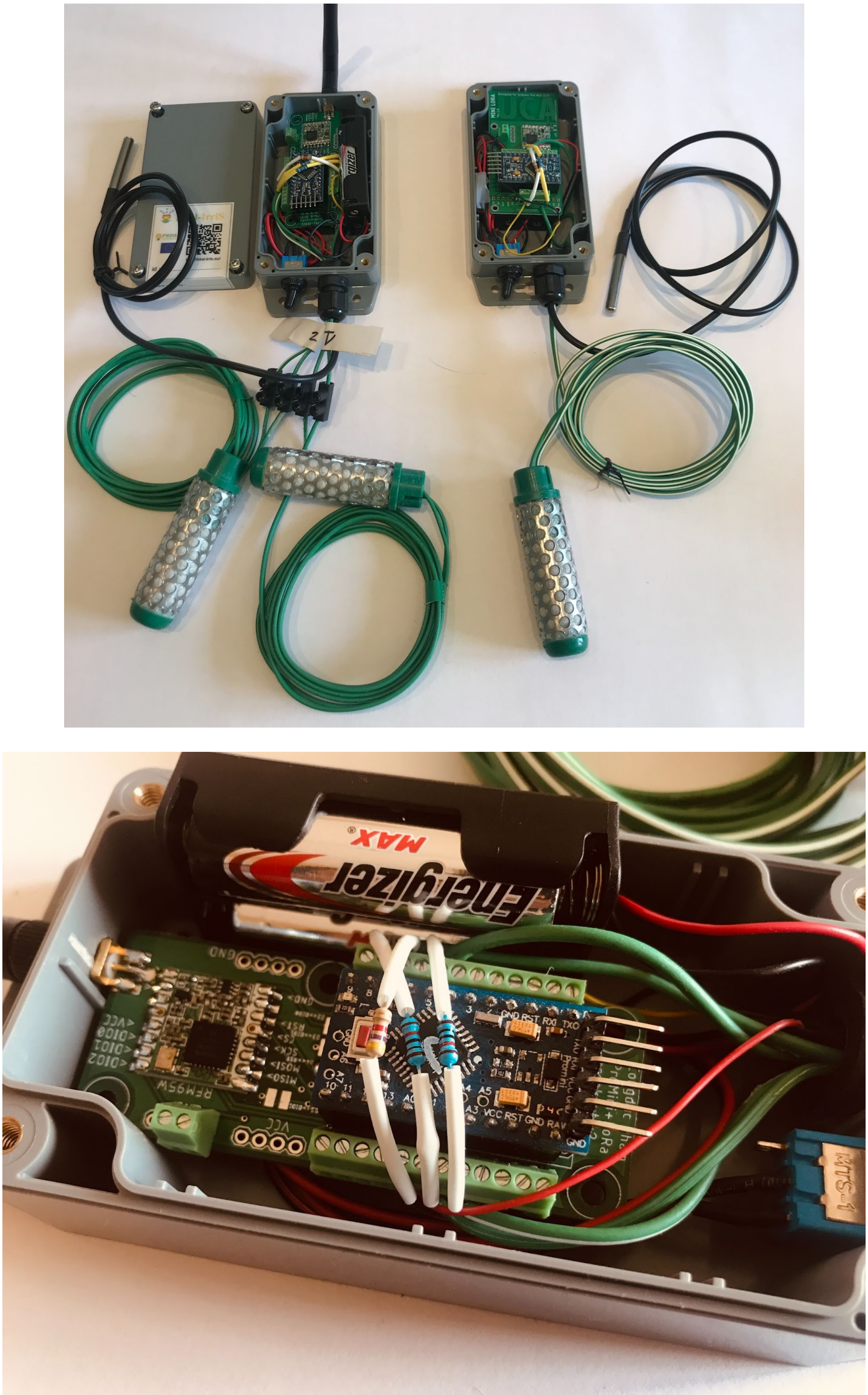


Figure 6 – the 2-Watermark version compared to the 1-Watermark version

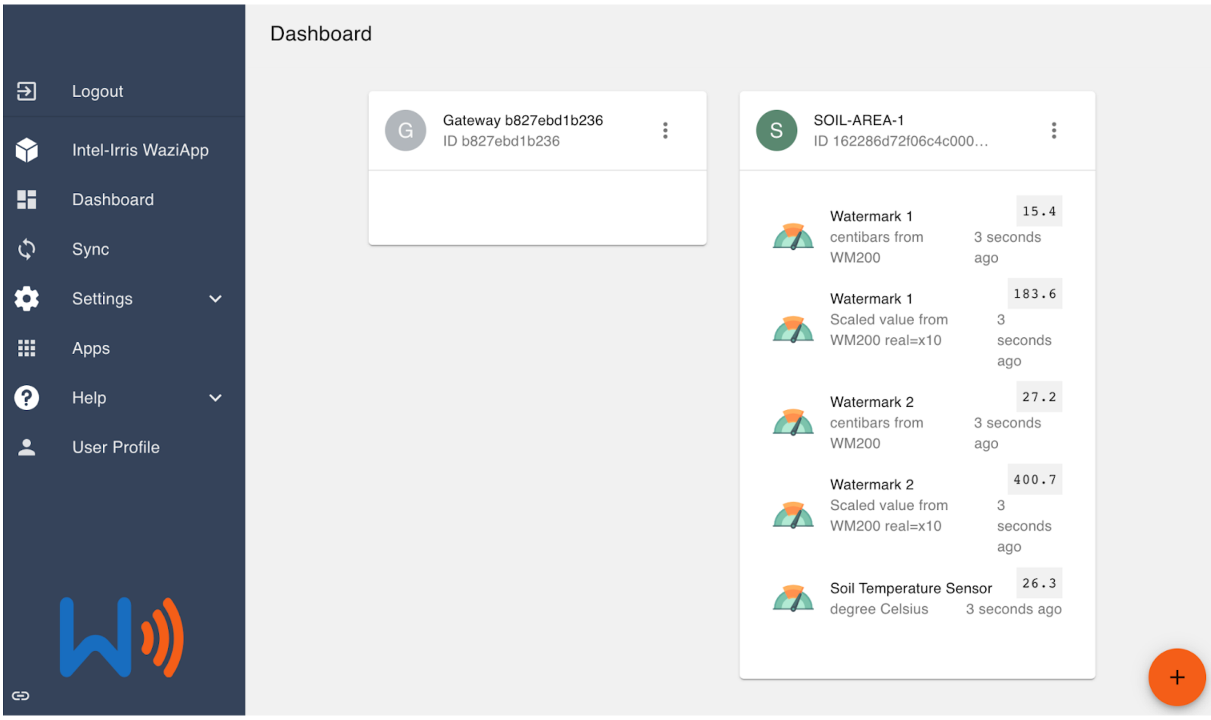


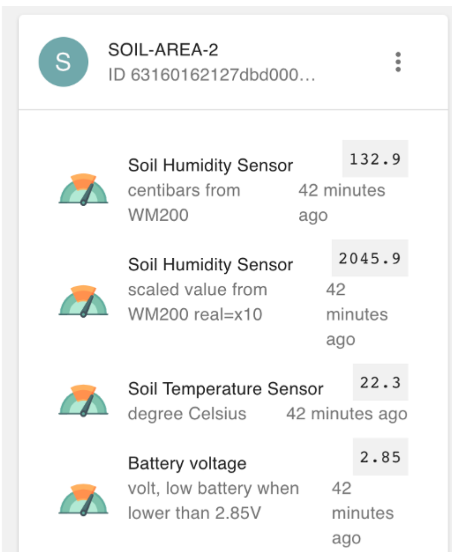
Figure 7 – The updated 2-Watermark device in WaziGate dashboard

2.4. Improvements to the soil device firmware

The soil device firmware is available on the INTEL-IRRIS GitHub [4].

2.4.1. Monitor & transmission of battery voltage

In order to better know the battery status, the soil device always transmits the battery voltage. This battery voltage is measured without any additional hardware by using a dedicated library: https://github.com/Yveaux/arduino_vcc. This battery voltage is visualized on the WaziGate dashboard as illustrated below.



2.4.2. Low battery safe mode

The ATMega328P microcontroller used in the Arduino Pro Mini board reboots at about 2.65V - 2.75V. Therefore, we define a VCC_LOW threshold at 2.85V. If supplied voltage from the batteries falls below VCC_LOW, then the soil device will enter into "Low battery safe mode".

The "Low battery safe mode" consists in the following additional mechanisms:

- low voltage mode is applied when the battery voltage falls below VCC_LOW
- once detected, the device will keep MAX_LOW_VOLTAGE_INDICATION=3 normal operation cycle
- then, it will increase the measure & transmission time interval to LOW_VOLTAGE_IDLE_PERIOD_HOUR=4 hours
- the mechanism prevents the ATMega328P microcontroller to reboot constantly

Note that as described above, the battery voltage is transmitted to the gateway and appears on the dashboard so that end-user can be warned of low voltage on the deployed device. Batteries should be changed as soon as possible when the indicated voltage falls below 2.85V. The "Low battery safe mode" is only a safe-guard and cannot fully guarantee smooth operation of the device.

2.4.3. Include capacitive SEN0308 calibration when low voltage

Based on previous tests described in D3.6a "First report on evaluation and KPI assessment in pilots", we integrated calibration when low voltage for the capacitive SEN0308 sensor. The SEN0308 has an internal regulator at 3V so maximum output is 3V (very dry – value would be 930 taking 1023 as a maximum when voltage is 3.3V). if Vcc is above 3V, the output at any given humidity condition is stable. If not, as the sensor is powered by the Arduino GPIO pin, which depends on the supplied voltage, the reference voltage can be lower than 3V and there is a drift in the output.

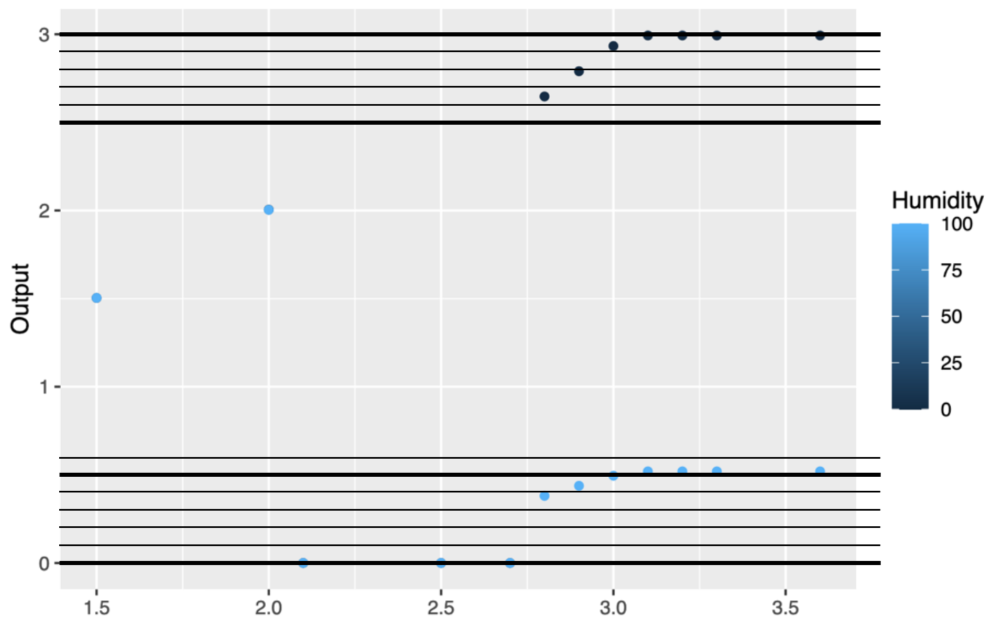


Figure 8 – SEN0308 output voltage

2.4.4. Transmit millivolt value with capacitive SEN0308

Normally, the transmitted value from the capacitive SEN0308 sensor is a converted digital value between 0 and 930, 0 meaning saturated soil and 930 being the maximum for dry soil which could depend on the type of soil. 930 is derived from the maximum output voltage which is 3000mV (the SEN0308 has an internal regulator at 3V so maximum output is 3V).

To enable more direct reading when debugging it is possible to transmit the original millivolt value instead of the digital conversion. This option can be enabled in the soil device firmware code.

3. New DIY IRD PCB

3.1. Motivation

This new DIY IRD PCB developed by IRD can be used either with a solar charging circuit, or simply as a replacement of the current INTEL-IRRIS PCB (without solar panel) to benefit from the easier wiring possibilities.

When we use 2 alkaline batteries, the voltage to power SEN0308 is a little lower than 3.0 V, but SEN0308 needs more than 3.0 V to work accurately.

When we use no-rechargeable lithium battery (3.6 V) at low temperature (< 5 degrees), radio consumption (130 mA) is too much to have enough voltage with the internal resistance of the battery and a reboot occurs.

For these 2 issues, we think rechargeable batteries and solar could be a good solution.

The new IRD PCB must also provide a simplified connection of the 3 resistors needed for the temperature and the 2 Watermark sensors.

3.2. Design

The following connectors are added to ease wiring of a number of selected sensors:

- One connector is added for direct SEN0308 connection (soil capacitive sensor)
- One connector is added for the DS18B20 temperature sensor (with pull up)
- Two connectors are added for 2 Watermark sensors
- One connector is added for I2C sensors such as the CO2 SCD30

In the first version, sensors were powered as desired with GPIO. We now add a mosfet to increase sensor power voltage (Vccm) if an alkaline battery is still used and also increase available current for other sensor types like CO2 sensors.

Because the mosfet is near a perfect switch, we need to add a soft start mechanism to avoid the microcontroller to reboot. The RC circuit can be increased by PWM software.

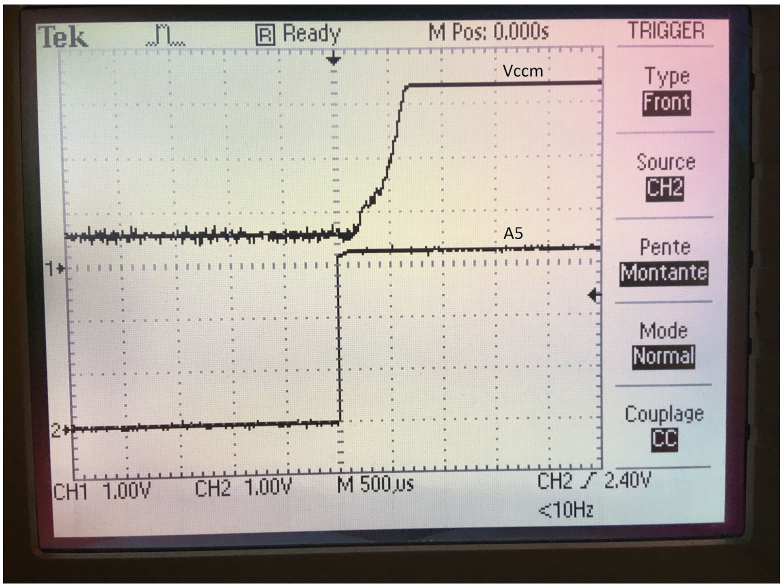


Figure 9 – PWM soft start for the sensor power line (Vccm)

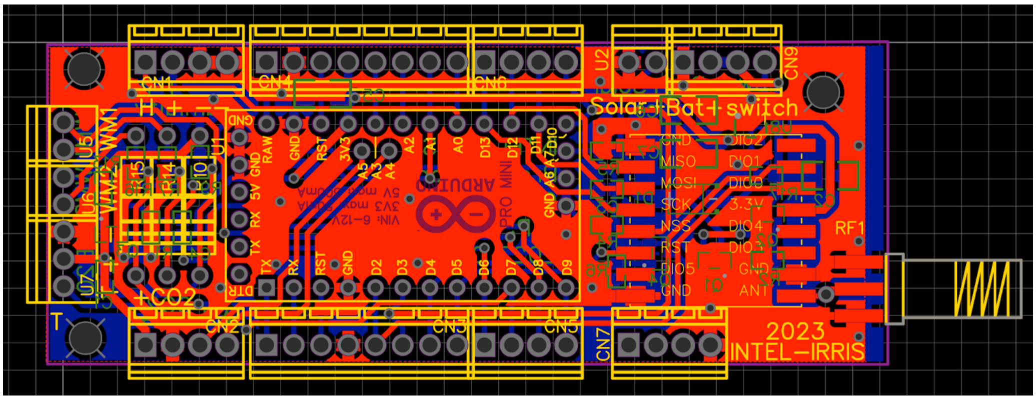


Figure 10 – PCB top

2639923A_Y22_SMT02305101235296 [BOTTOM] - Corrected Part Placement
[20230511093511286]

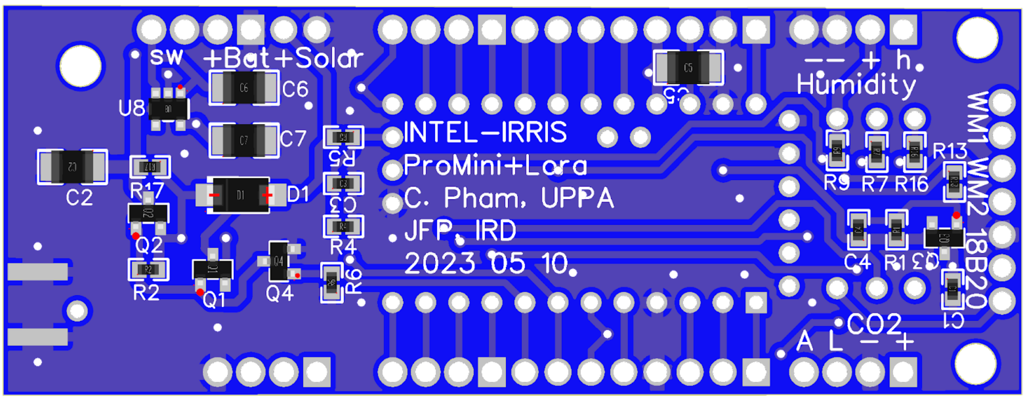


Figure 11 – PCB bottom with SMT

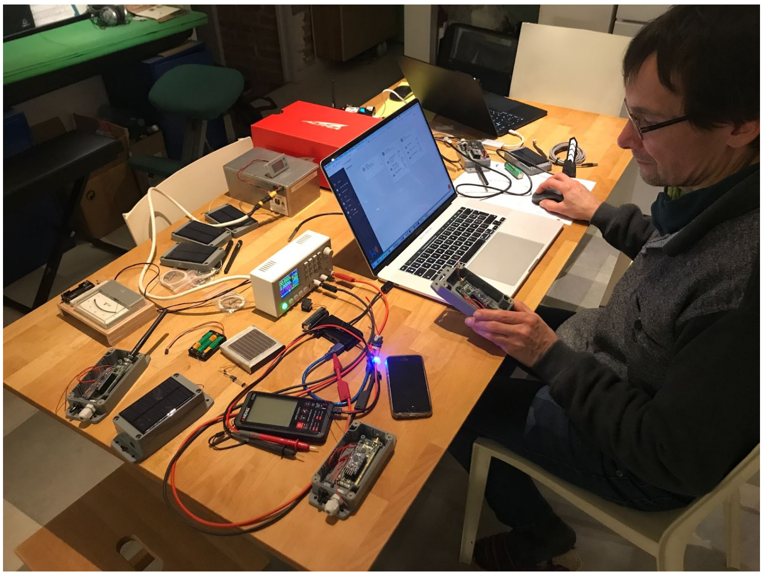


Figure 12 – Designing the new DIY PCB

3.3. Solar charging management in firmware

One main design choice is to avoid a complex and costly specialised electronic chip/circuit for solar charge management.

If the low battery condition occurs, NiMH may have a low charge in shutdown mode (switch off) for recovery.

The lithium-ion battery has no shutdown mode recovery and no charging by software if the temperature is below 0 degrees.

The solar panel is designed to work also without direct sunlight, in very cloudy conditions or in shade from the sun.

We recommend NiMH battery: a pack of 3 elements can be used (3.6 V 800 mAh).
https://fr.aliexpress.com/item/4000208396115.html

A Lithium-ion battery (3.7 V - one cell) with a Battery Management System (BMS) can be used. You can find such a cell in an old laptop, but it is mandatory to add a BMS for safety reasons. https://fr.aliexpress.com/item/1005003188455245.html

3.4. DIY integration pictures

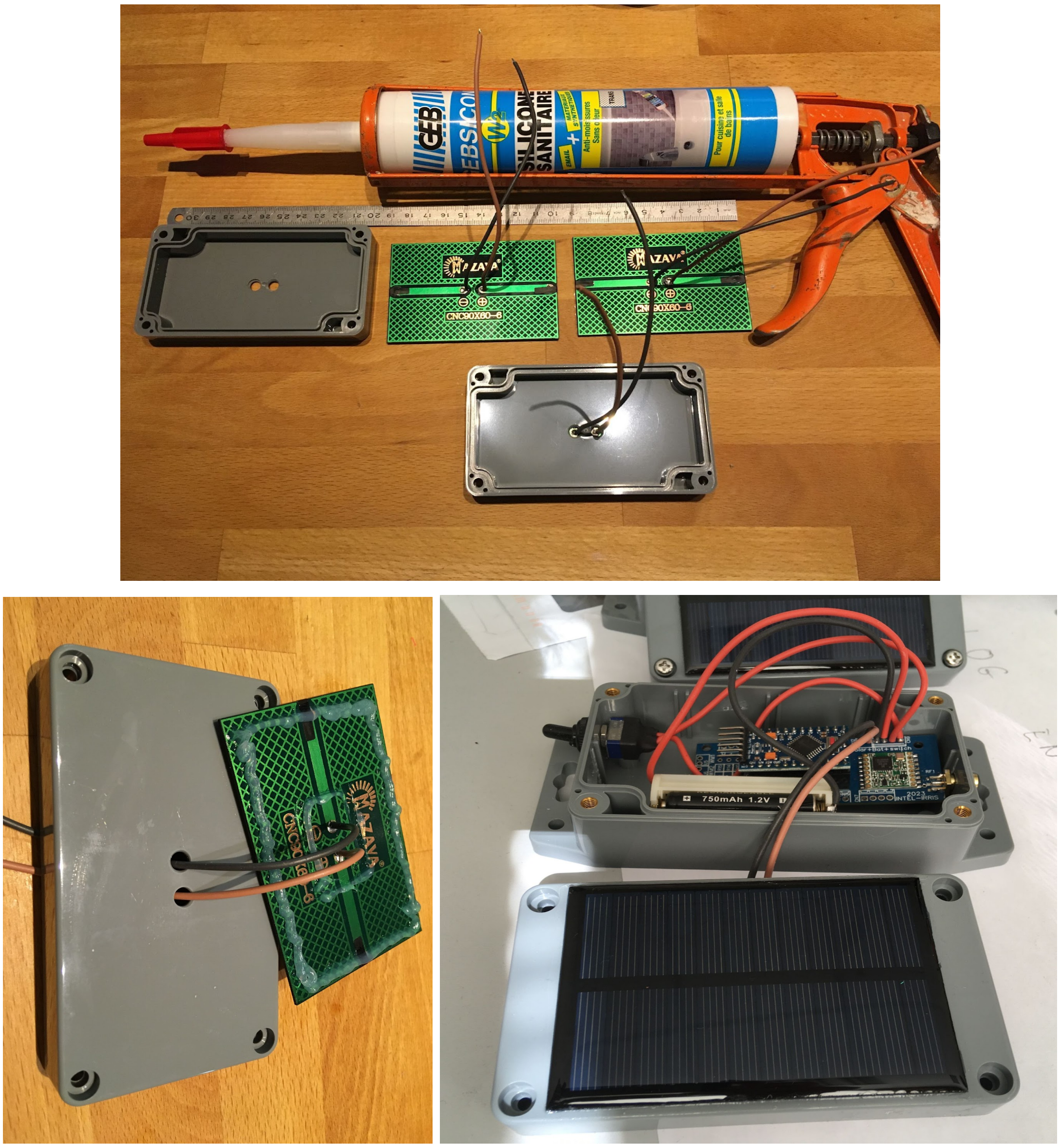


Figure 13 – Fixing the solar panel on the top of the box.

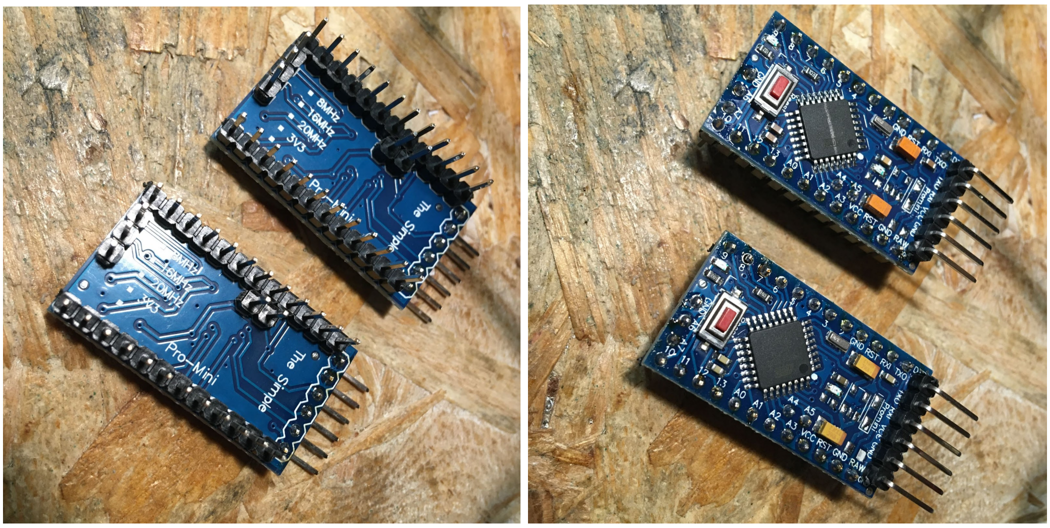


Figure 14 – On the Promini board : 1) add 1x2P and 1x3P 2.54 connector. 2) same as the first pcb : remove led resistor and LDO regulator (and also diode to be more easy to remove LDO).

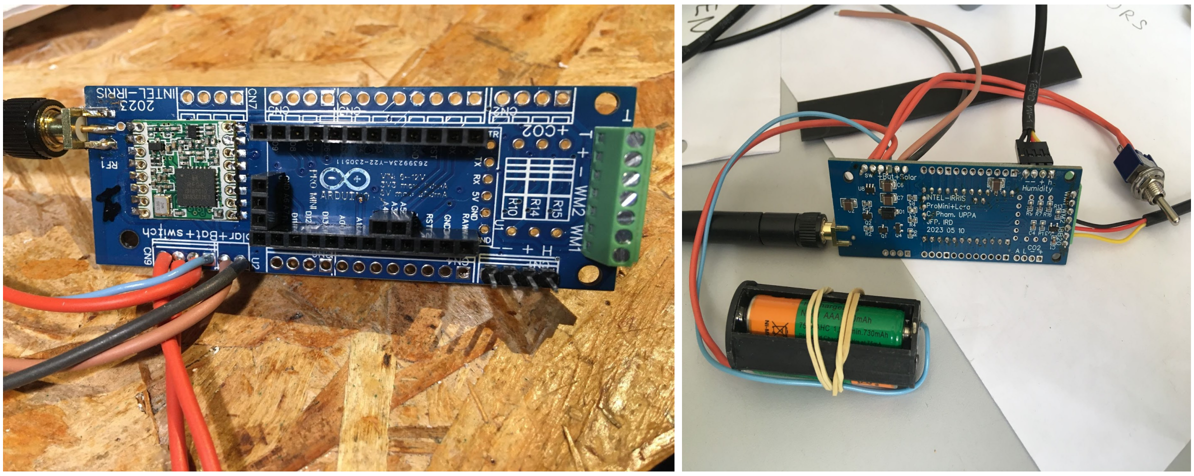


Figure 15 – Integration test of the new DIY IRD PCB

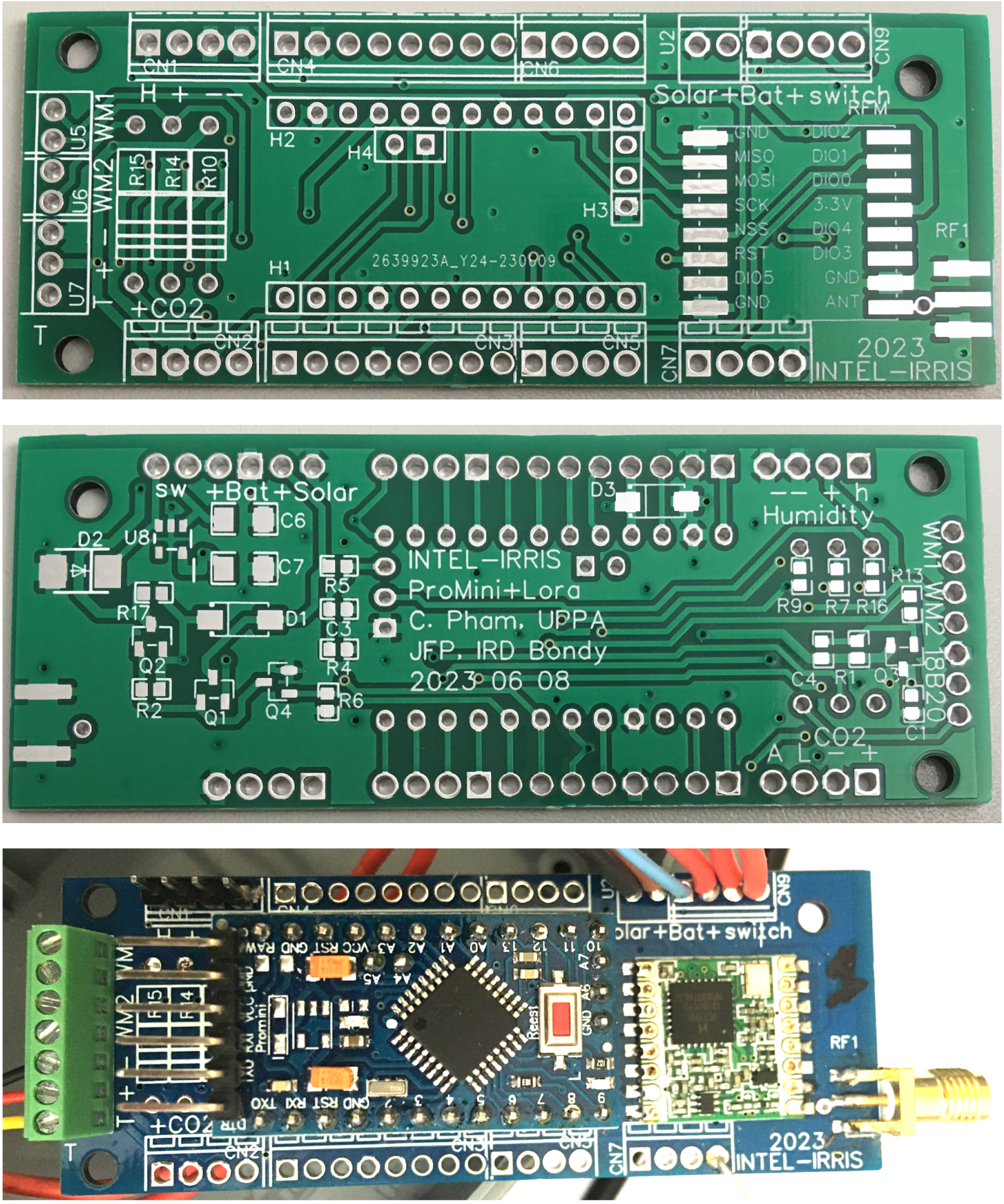


Figure 16 – manufactured PCB

3.5. Using simple version without solar panel support

The new IRD PCB can be a replacement for the first INTEL-IRRIS PCB, to only facilitate the wiring of sensors. In this case, the PCB can simply be ordered without any components pre-soldered. Then, the integration of the new IRD PCB can be realized as follows:

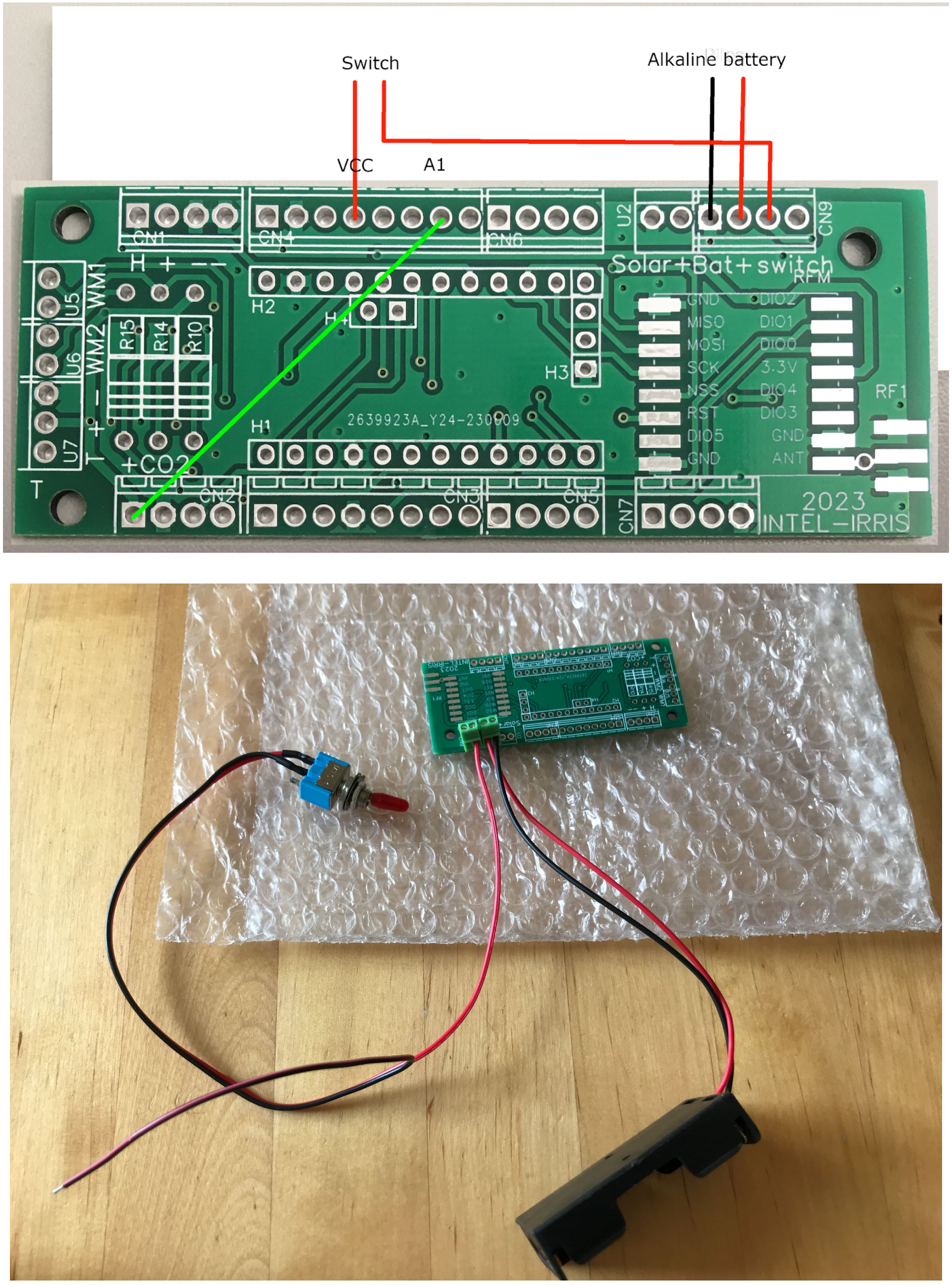


Figure 17 – PCB simplified version without any mounted component

A wire should connect A1 and Vccm which can be found on the '+' of the CO2 connector. The free wire from the switch should be connected to the VCC pin of the Arduino ProMini, as illustrated in the complete integration picture below. This picture also show that wiring of sensors can be realized in a much easier way.

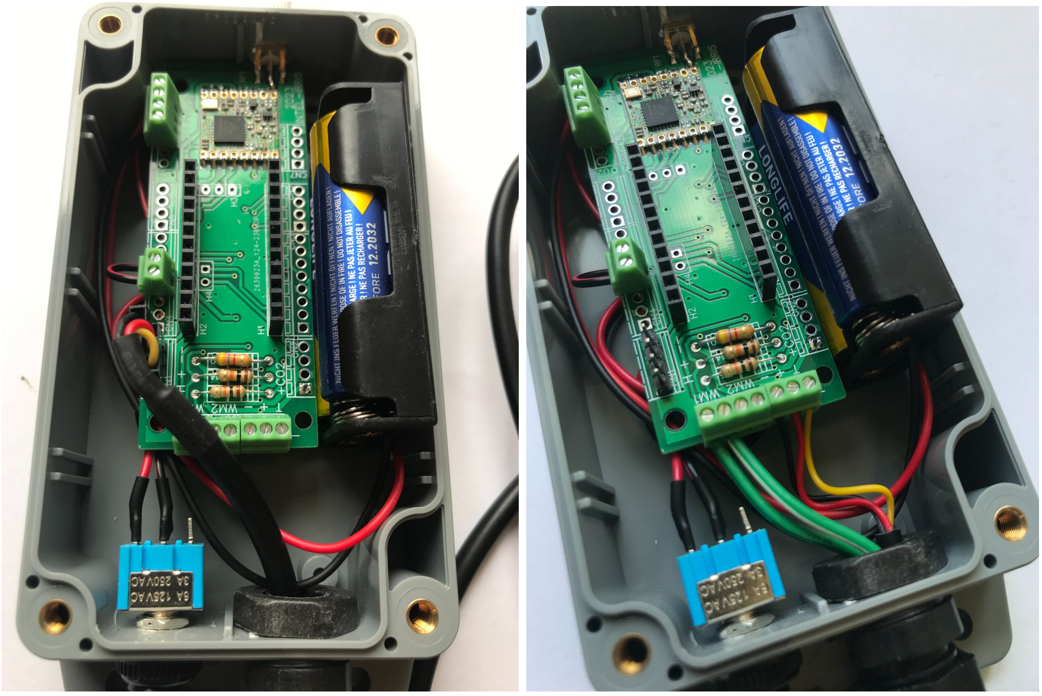


Figure 18 – Example of complete integration with the PCB simplified version. Left: capacitive sensor. Right: tensiometer + temperature sensor

The "INTEL-IRRIS Tutorial on building & assembling the soil sensor device" (https://github.com/CongducPham/PRIMA-Intel-IrriS/blob/main/Tutorials/Intel-Irris-IOT-platform.pdf) [1] as been updated to show how the integration using the new IRD PCB can be realized. The Arduino code on INTEL-IRRIS GitHub [2] as also been updated.

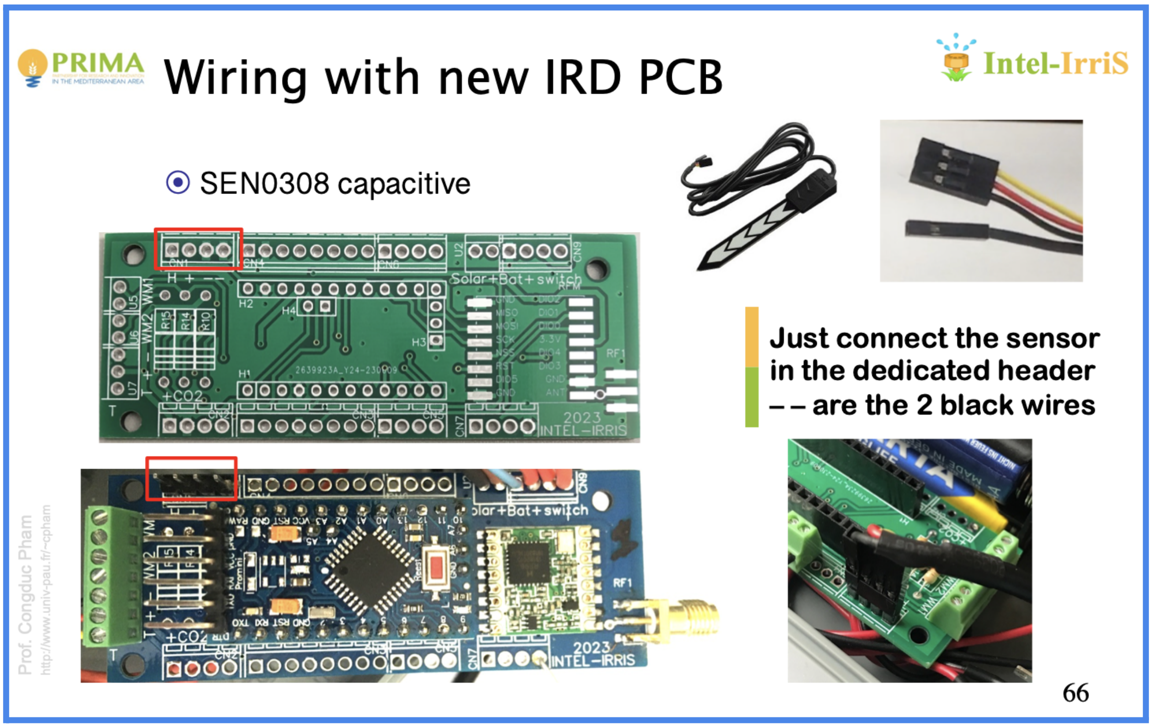


Figure 19 – Example of additional slide describing the integration procedure with the new IRD PCB simplified version

4. WaziSense v2 for large-scale deployment

4.1. Motivation

The WaziSense v2 is the successor to the WaziSense v1. This new version is designed to facilitate the development of Minimum Viable Products, proof of concept prototypes and use for field deployment purposes. It is focused on use cases or conditions where resources like **power and internet access is limited.**

The users include:

- **AgriTech startups** looking at developing a new product.
- **Small agri-businesses** looking to add IoT functionality to **existing products o**r test new IoT product ideas.
- **Researchers** looking to collect data in urban or remote areas to reveal useful insights.
- **Hobbyists, students** or people with some engineering/technical background looking to develop and deploy IoT solutions

As an example, the board supports the following use cases:

- Fish pond monitoring
- Soil moisture monitoring
- Cattle monitoring (geotracking & health)
- Weather station
- Hydroponics

It would be good to note that the new Wazisense v2 board will support general deployment use cases where all peripherals and sensors are powered OFF until there is a need to read sensor data.

4.2. New Features and Capabilities

With respect to the WaziSense v1, the new v2 board will have the following features and capabilities:

- approximately 10% smaller in size
- Solar maximum power point tracking and charging for Li-ion/Li-polymer batteries
- Programmable power rails for sensors and peripherals
- Ultra low power consumption in idle/sleep mode

4.3. Pictures

Below are some images of the WaziSense v2 board during its design and development phase.

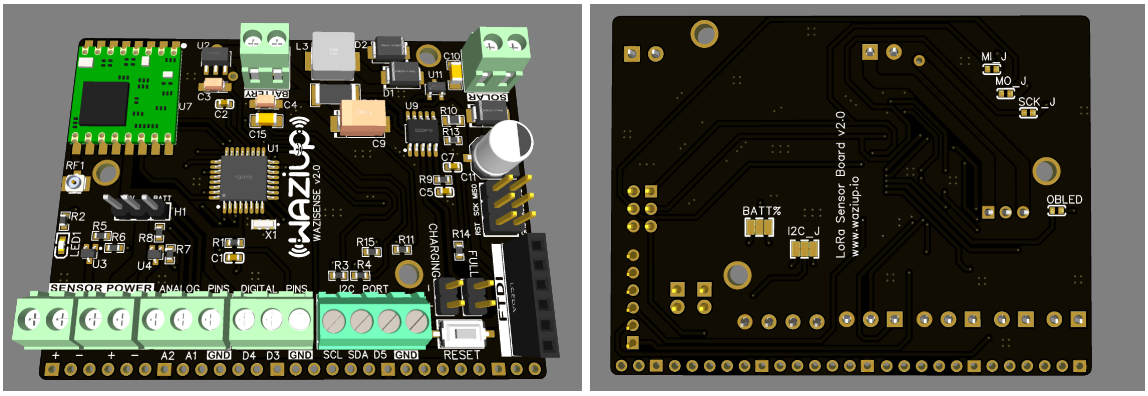


Figure 20 – Top (left) & Bottom (right) view of the WaziSense v2

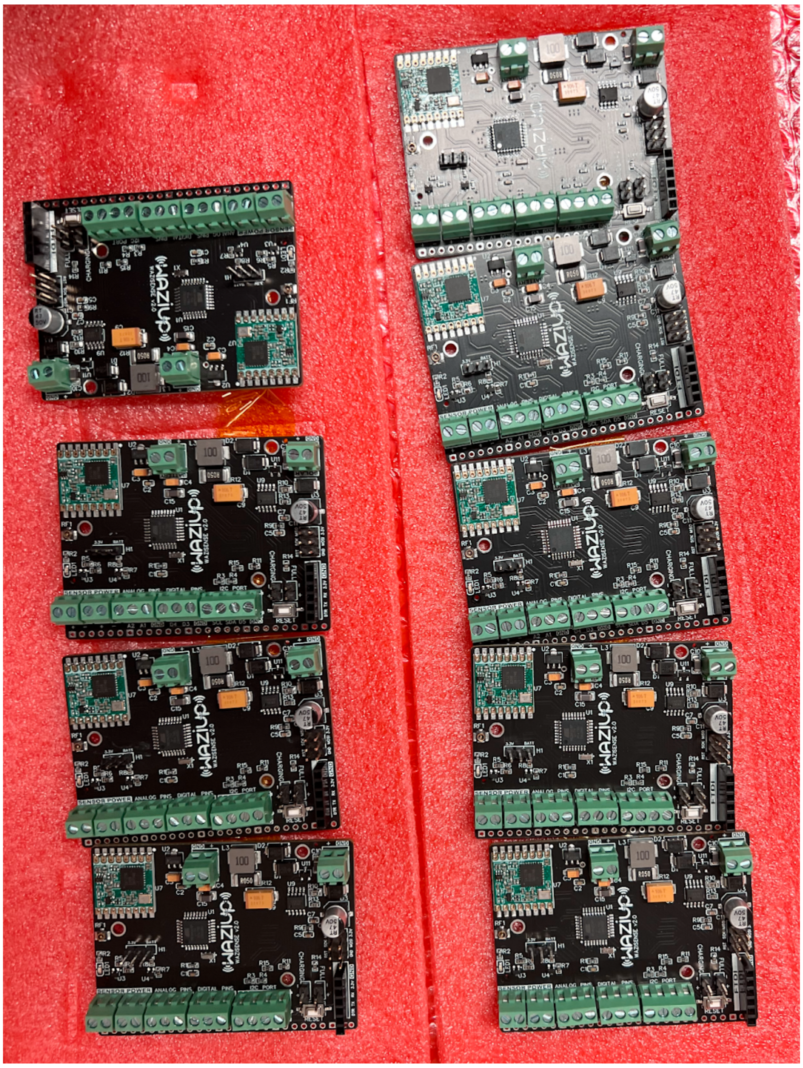


Figure 21 – 10 pieces of WaziSense v2 boards manufactured for testing

4.4. Testing and Deployment

Two WaziSense v2 boards were placed inside a waterproof case with one digital humidity and temperature sensor on the board). One board had its solar circuit isolated (cut) and the other board was intact as received from the manufacturer.

Both boards wake from sleep after 10mins, post sensor data and go back to sleep.

From here on, we will refer to the board with everything intact as "**solar board**" and to the board with the solar circuit isolated as "**no solar board**"

The reason for the solar and no solar board is to examine the characteristics and behaviour of the wazisense v2 board when its solar circuit is active and when it is not. Also this will help to paint a clear picture of what effect the solar circuit has on boards' operation with regards to the battery attached.

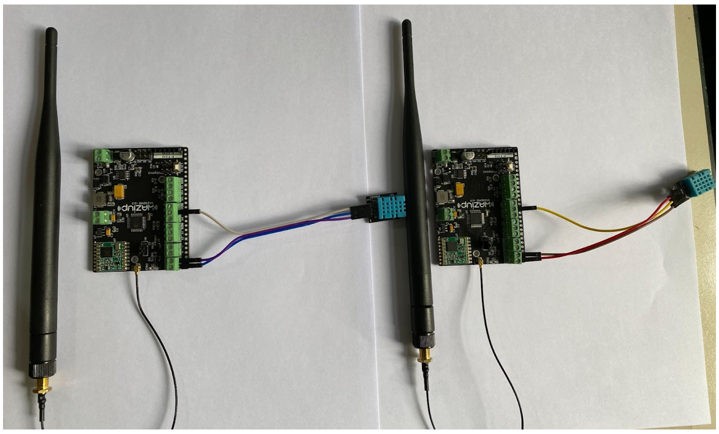


Figure 22 – 2 pieces of WaziSense v2 boards with DHT11 sensor

A waterproof case was used to keep water out of the box in the event of rain.

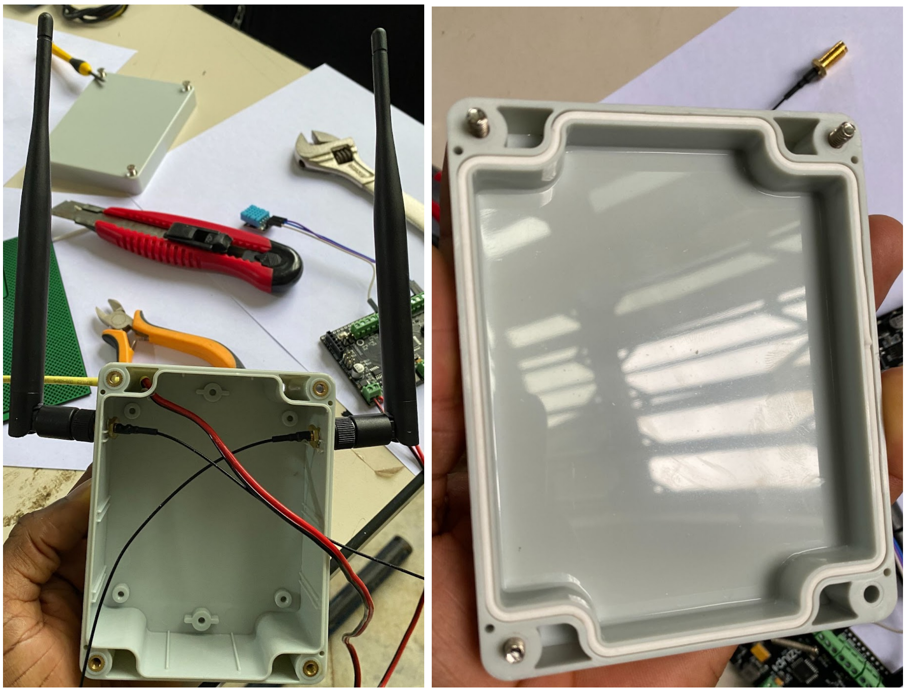


Figure 19 – water proof casing for outdoor deployment

Both boards were connected to one 2200mAH Lithium ion 18650 battery each. The solar board was connected to a 6v, 3W (145mm x 145mm) solar panel. This will allow the battery attached to charge during the day.

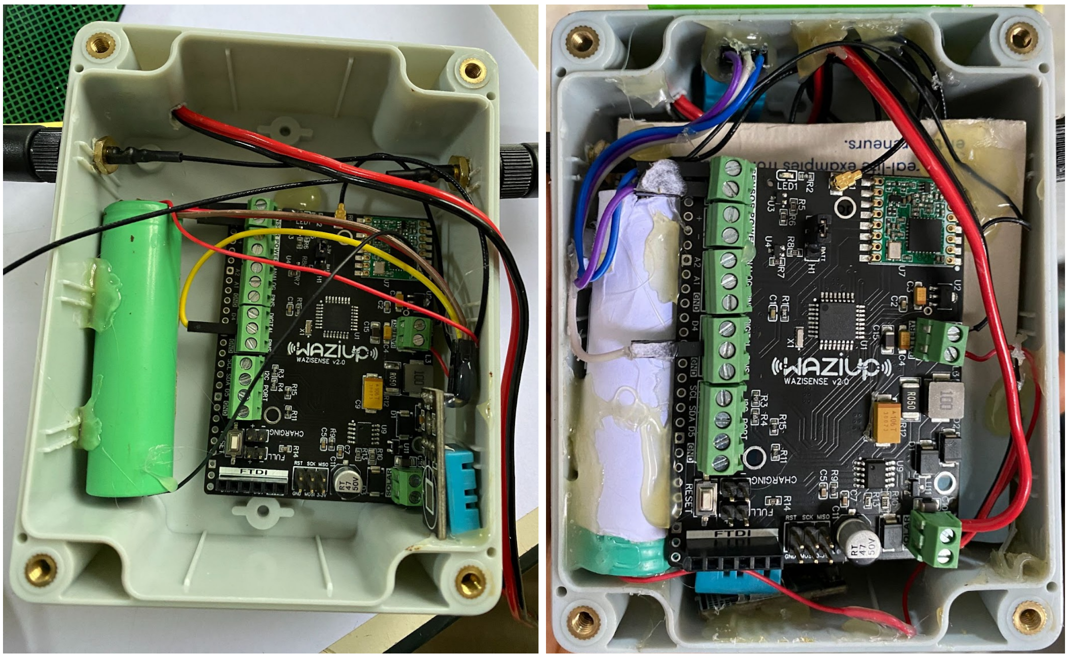


Figure 23 – 2 WaziSense v2 with DHT11 sensor and battery in waterproof case

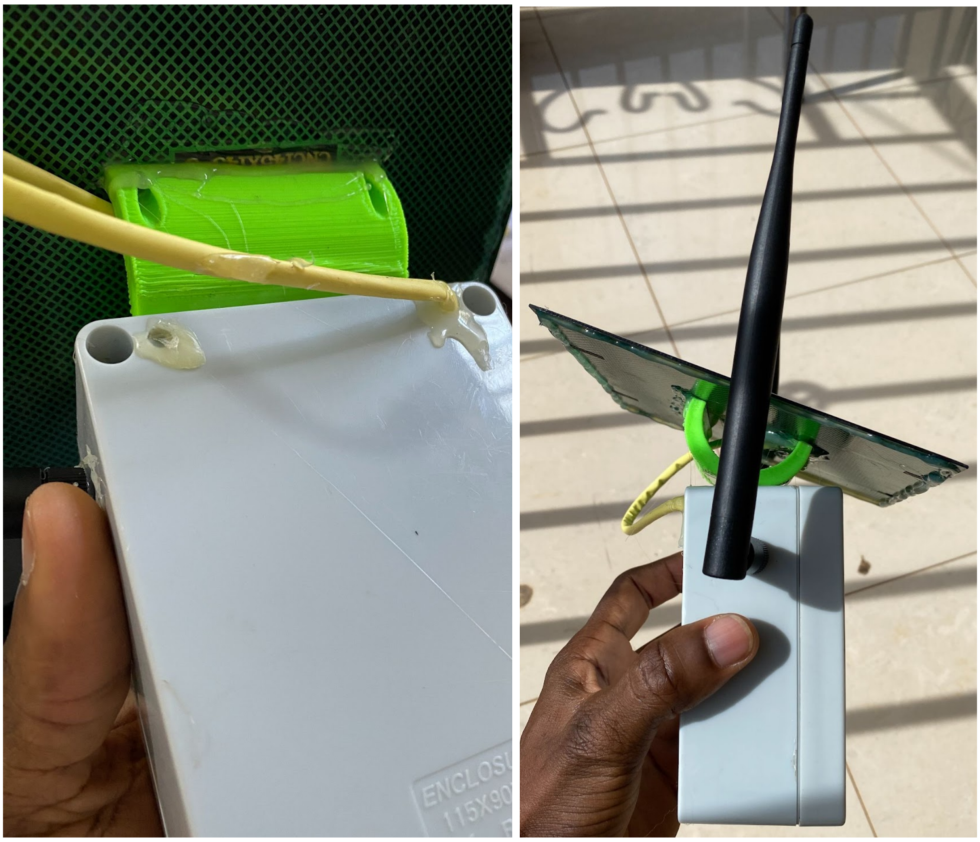


Figure 24 – solar panel inclined at 25-38 degrees with cable protected by heat shrink tube

A hard paper card was placed between the solar and no solar board as seen in the images above. The DHT11 sensor was placed at opposite ends of the box. Wires and all parts in the box were held in place with hot glue.

The solar panel cable was passed through a heat shrink tube to serve as an extra layer of protection from the sun, water and other outdoor harsh elements. The solar panel was also mounted on a 3D printed semi-circle structure, to angle the solar panel between 25 to 38 degrees.

Any remaining holes were sealed with hot glue, to prevent moisture or insects from getting into the case. This includes the drilled holes for the antenna and breathing hole at the back of the case.

Figure 25 – waterproof casing breathing holes sealed with hot glue

The case was then deployed outdoor on the 8th June 2023 at 11:20 AM

Figure 26 – Complete unit is deployed outdoor

4.5. Deployment results

A WaziGate was installed to receive data from the 2 WaziSense.

After approximately 5 days of deployment on 13th June 2023, the no solar board and no solar board had made 709 and 135 posts respectively to the WaziGate dashboard.

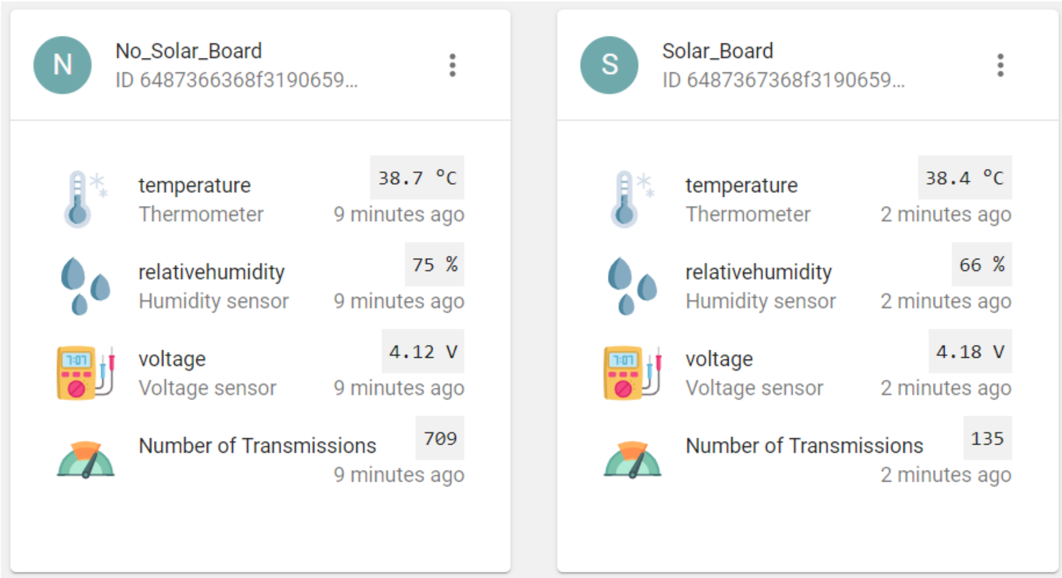


Figure 27 – Sensor data received and displayed on gateway dashboard

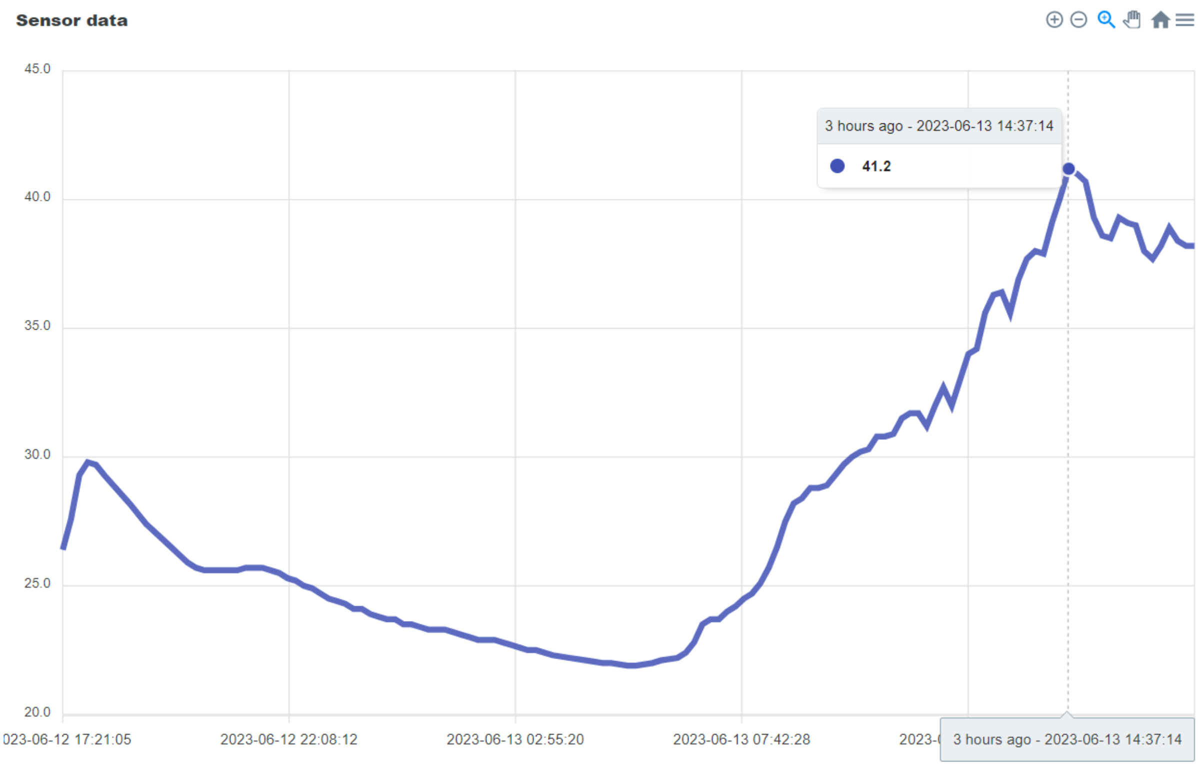


Figure 28 – temperature reading in the case. Maximum was 41.2 ° Celsius

The solar battery for the solar board was replaced on 12th June 2023 due to inconsistencies with its operation. This led to a reset of the solar boards "number of transmissions" counter, hence the huge difference between the number of transmissions between the boards.

The deployment also revealed some useful information such as: temperature inside the sealed case during the day and at night, how fast the battery charges etc...

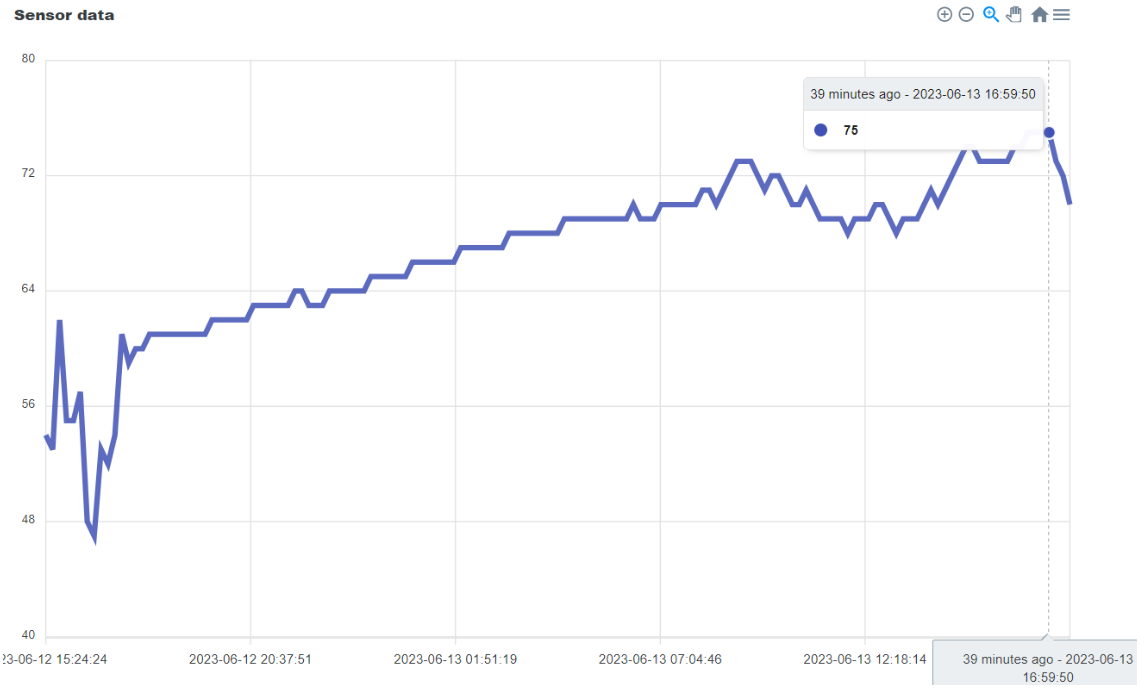


Figure 29 – relative humidity within the case during the day was 69%

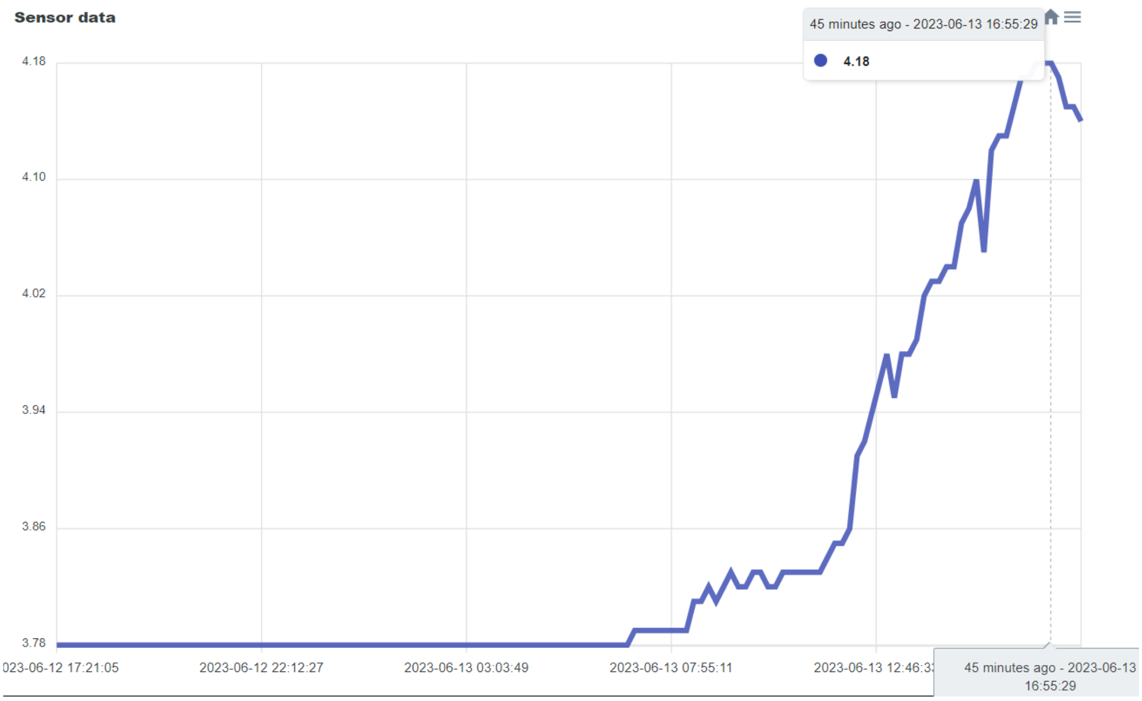


Figure 30 shows that it takes approximately just one day (that is 8 hrs) for the battery to be fully charged.

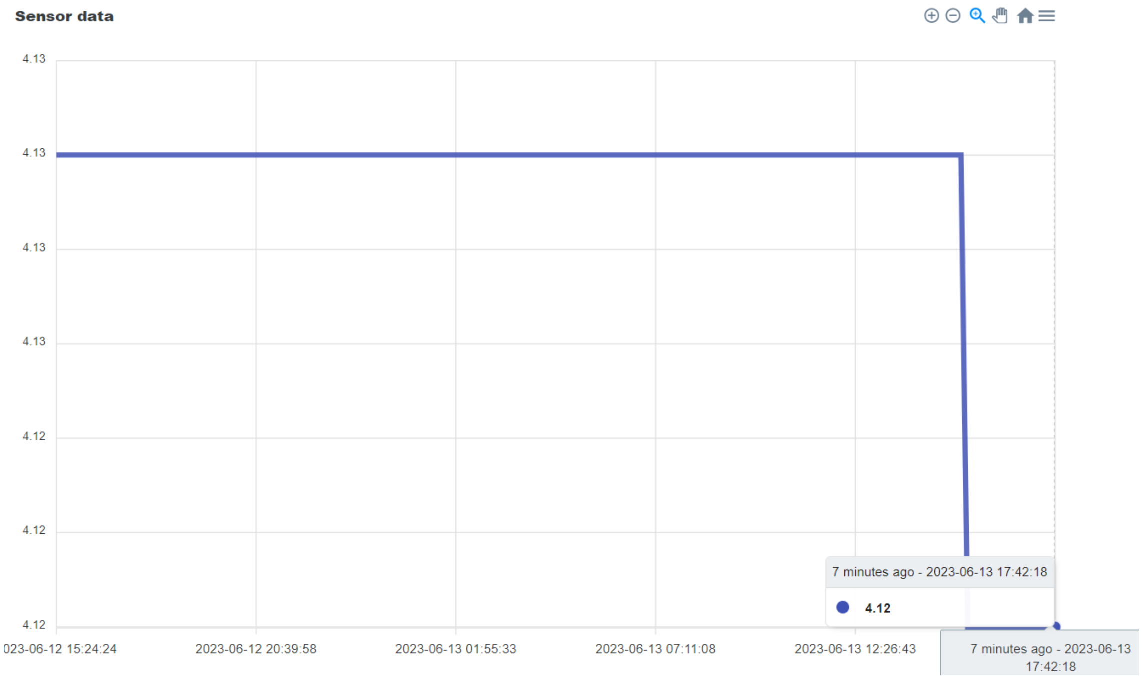


Figure 31 – the no solar boards battery voltage over time.

The solar board's battery was at 4.15v when the test initially started on the 8th June. By 13th of the same month, it was now 4.12v.

Taking into consideration the battery is rated to be completely discharged at 2.9v. The recorded 4.12v will mean 2.4% of the available battery charge has been used.

From the above consumption rate, we can calculate how long it will take for the solar boards' battery to be completely discharged. See figure below

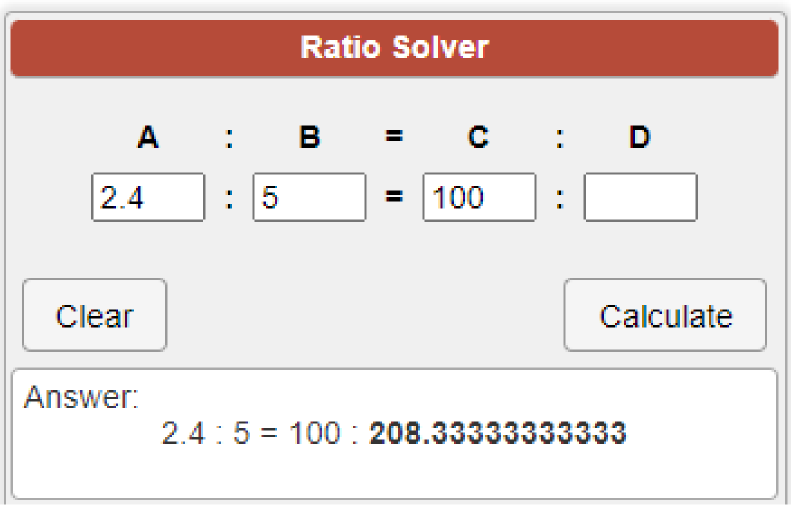


Figure 32 – number of days for the no solar board to completely drain its battery

That is, if it took **5 days** to consume **2.4%**, how long will it take to consume **100%**. From the results in the figure above, it will take 208 Days or 6.7 Months approximately.

The WaziSense v2 was found to operate with the following current draw characteristics:

Solar Board	No Solar Board
Sleep: 29uA Lora RX: 15.44mA Lora TX: 80.3mA Idle: 5.8mA	Sleep: 6.5uA Lora RX: 15.36mA Lora TX: 92.3.5mA Idle: 5.8mA

NOTE: The battery charge depletion rate is also affected by the temperature and humidity changes within the case, mAH capacity, battery age etc…so for instance, given a newer battery with higher mAH capacity, the setup could last longer than the estimated 208 days**.**

4.6. WaziSense v2 for INTEL-IRRIS

The WaziSense v2 board is currently under test for integration into the INTEL-IRRIS starter-kit. With this line of production, INTEL-IRRIS will be able to sustain a large number of deployments.

Figure 33 – WaziSense v2 under test for INTEL-IRRIS starter-kit

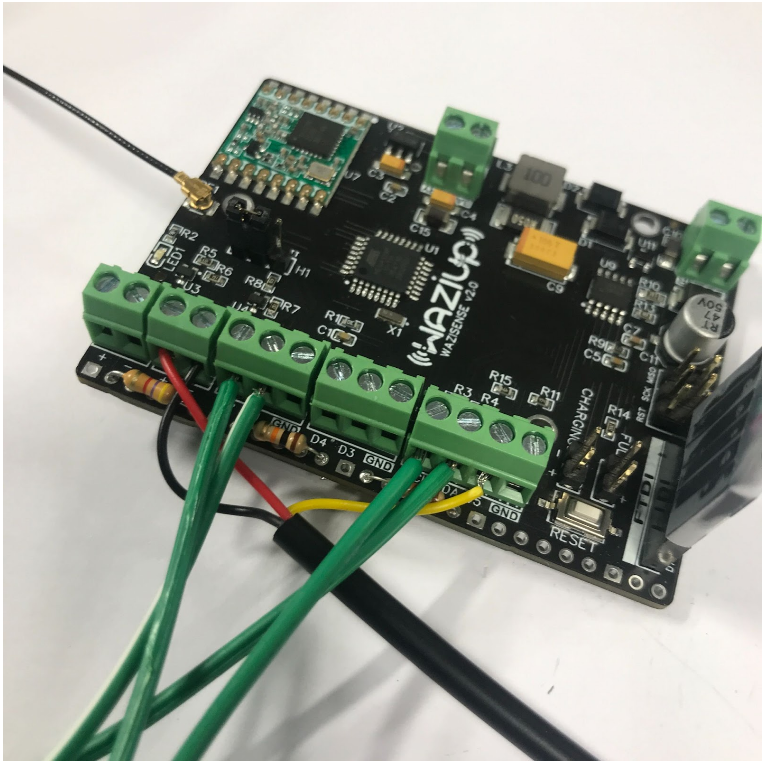


Figure 34 – Testing the WaziSense v2 with the INTEL-IRRIS's sensors

The "INTEL-IRRIS Tutorial on building & assembling the soil sensor device" (https://github.com/CongducPham/PRIMA-Intel-IrriS/blob/main/Tutorials/Intel-Irris-IOT-platform.pdf) [1] as been updated to show how the integration using the new WaziSense v2 can be realized. The Arduino code on INTEL-IRRIS GitHub [2] as also been updated.

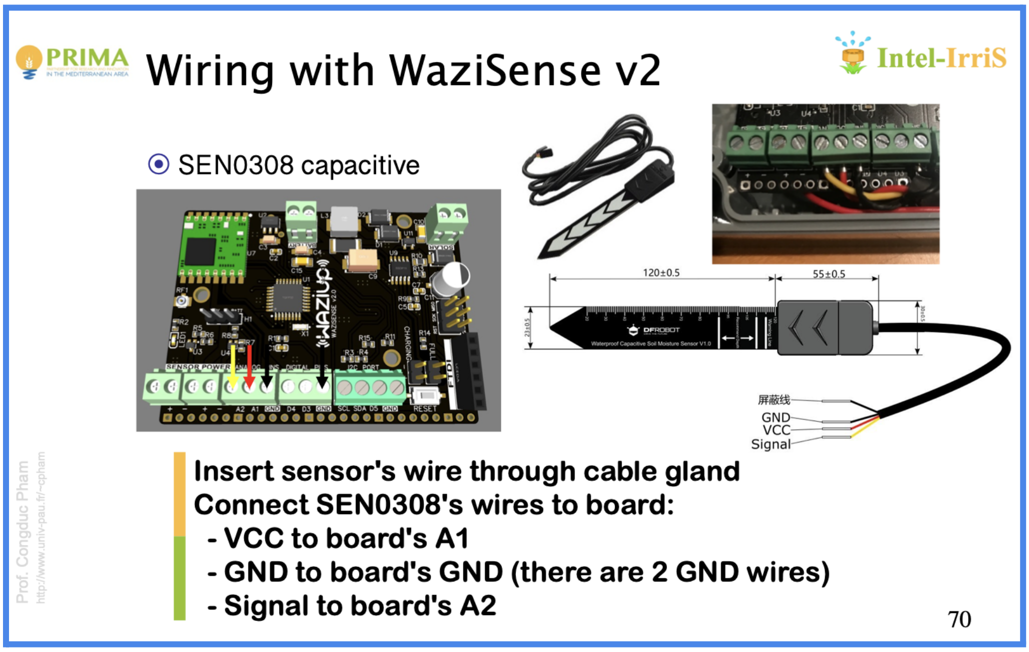


Figure 35 – Example of additional slide describing the integration procedure with the new WaziSense v2

5. Conclusions

D1.2c presented the updates on the low-cost sensor generic platforms for connected irrigation systems. The main contributions added from D1.2b are the new features of the soil device firmware and the 2 new PCBs solutions to improve the INTEL-IRRIS starter-kit and the capacity to scale up deployment.

The low-cost sensor generic platform will be integrated into the INTEL-IRRIS starter-kit which is described in D2.2b "Starter-kit for smart irrigation system – v2".

Related resources/documents

[1] 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

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

Acronyms List

Acronym	Explanation
BMS	Battery Management System
DIY	Do It Yourself
GPIO	General Purpose Input/Output
LDO	Low-dropout regulator
LED	Light Emitting Diode
NiMH	Nickel-Metal Hybrid
PCB	Printed Circuit Board
SMT	Surface Mount Technology

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