Ref. Ares(2023)8898548 - 29/12/2023

PHENET

PHENOTYPING & ENVIROTYPING SOLUTIONS FOR AGROECOLOGY

TOOLS AND METHODS FOR EXTENDED PLANT PHENOTYPING AND ENVIROTYPING SERVICES OF EUROPEAN RESEARCH INFRASTRUCTURES

Deliverable 2.1

Deliverable: Draft of specification for phenotyping devices

Due date (as in DoA):	Dec. 2023
Actual achievement date:	Dec. 2023
Work package:	Work package 2
Work package leader:	University of Angers, David Rousseau
Deliverable leader:	University of Angers, David Rousseau
Version:	V1.0

Dissemination Level	
PU Public	X
CI Classified, as referred to Commission Decision 2001/844/E	
CO Confidential, only members of the consortium (including the Commission Services)	

Research and Innovation action: GA no. 101094587
Start of the project: 1 January 2023

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1 Summary

1.1 Objectives

WP2 develops phenotyping methods for all the UC involved in PHENET to measure the traits listed in Milestone 4. For some UC, the sensors already exist and the need of support from WP2 lay on the data processing either by training the UC members or through technological research and development by WP2 members. For some UC, the sensor may not already exist and WP2 will develop these sensors during PHENET. This deliverable lists the specification for the phenotyping devices that will be developed during the PHENET project.

1.2 Rationale

Among all the UC, three need specific device development in the PHENET project. This includes UC orchards which needs a rover equipped with sensors (phenomobile). This also includes UC F2P and UC GxE with connected sticks equipped with sensors. As a disclaimer, it is important to mention that orchard phenotyping rovers exist in the literature and as commercial study (GreenAtlas company for instance). However, after careful bibliographic reading and test of existing available commercial services, these solutions appear either not described sufficiently in detail to be reproduced from the literature or not open enough to allow adaptation to the specific traits selected in Milestone 4 when coming from a private company. Same situation was found for the connected stick. We therefore decided to develop our own devices for these three UC.

1.3 Teams involved

This deliverable involved mainly UA, HiPhen, INRAe (Clermont-Ferrand, Montpellier), Univ. Louvain and the partners of UC Orchard.

2 Introduction

An analysis of the existing large-scale experiment on connected sticks has been organized during the IPPN workshop on affordable phenotyping (Angers, France) with contributions from Canada, USA, Australia, France, Belgium. The talks are visible on the youtube channel of UA https://www.youtube.com/channel/UCsd9Dt6N7O-fydynsWEfkww

Based on this analysis, two distinct connected sticks have been proposed to meet the requirements of UC GXE and UC F2P. For the UC GxE, few sites are to be observed as planned in the project the price is following a predefined limitation. For the UC F2P, the system has to be much cheaper to allow a larger scale dissemination and possible use on a farm. Concerning the phenomobile, the consortium of UC Orchard has listed the traits to be measured (as visible in Milestone 4). These choices have enabled the specification of the sensors to be embedded on the rover.

3 Results

We reach a technical description of how to produce the two connected sticks as described in the annexe and we provide a video demo of this production. We also produce a technical document detailing the specification for the phenomobile which will be built by HiPhen in 2024 as detailed in annexes. The cost of the GxE connected stick is estimated around 1355 euros which is half the price of similar systems commercially available but again not open to research and innovation.

The cost of the F2P connected stick is estimated around 100 euros which is compatible with a large scale replication.

4 CONCLUSIONS

The phenomobile is now ready to be ordered by the UC Orchard partners thanks to the specification provided in this deliverable. Concerning the connected sticks, it is to be underlined that we not only provide the specification but we also include the description of the first prototype, how to make them based on an assembly protocol and a shopping list. Video tutorial on the assembly protocol are provided on the the youtube channel : https://www.youtube.com/channel/UCsd9Dt6N7O-fydynsWEfkww

The two connected sticks are ready to be replicated for the UC F2P and UC GxE and tested at larger scale in PHENET.

5 ANNEXES

We provide three detailed annexes including the description of the specification for:

Annexe 1 Phenomobile developed for UC Orchard,

Annexe 2 Connected stick developed for UC GxE

Annexe 3 Connected stick developed for UC F2P.

Annexe 1 Deliverable D2.1 PHENET
Specification of the phenomobile UC Orchard

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Technical description

David Rousseau

Research and Innovation action: GA no. 101094587
Start of the project: 1 January 2023

1. CONTEXT

The development of horticultural cropping systems based on the principles of agroecology, which are low in inputs (pesticides, fertilizers, irrigation water, etc.), and which guarantee quality fruit and vegetable production and the economic viability of farms in the context of climate change, requires a detailed understanding of the processes and, above all, of the multiple interactions within these complex systems, which are increasingly associating different plant species (fruit or vegetable cash crops and companion plants, market garden orchards, etc.)

This requires the acquisition of a large amount of data on the different components of agro-ecosystems (soil-plant-microclimate continuum; fruit trees and associated crops and their pest and disease communities; root, leaf and fruit systems; water and nutrient status; technical management operations, etc.) at temporal and spatial scales that are more or less fine or integrative, depending on the mechanisms analyzed.

Current technical innovations based on different sensors and imaging methods should allow monitoring at different scales, from the organ to the plot scale. However, this requires an important methodological development to adapt them to horticultural systems (fruit trees in particular) which are often multispecific.

2. PURPOSE

The aim is to acquire a digital phenotyping prototype, adapted to fruit orchards. These phenotyping tools promise to gain in throughput and frequency of characterization of orchards, but also in accuracy and diversity of information while being non-destructive. These tools are already efficient for annual plants in the field, but still under-exploited in fruit trees.

The object of the contract is a "Phenomobile Orchard" equipment. This device will be positioned on an electrical vehicle and must include:

- (1) a frame supporting measuring heads and fixed on the electrical vehicle,
- (2) sensors allowing the acquisition of data on the whole height of the scene and the depth of the row,
- (3) a supervision and control system.
- (4) an electrical vehicle capable of holding the items (1-2-3)

It will allow to evaluate the individual and/or combined effect of different agro-ecological levers that could be used as an alternative to pesticides (UVC treatment, SDP, introduction of companion plants, nitrogen fertilization) on the functioning of trees and their production.

This device will be a very useful tool to design orchards capable, in the global framework of climate change and in the objective of reducing the use of pesticides, of proposing combinations of practices adapted to different service profiles (production, climate regulation, regulation of the water cycle and quality).
The consultation concerns the supply and the installation of a system allowing the acquisition and the

automatic storage in orchard of data resulting from sensors of various natures on experimental devices in place or to come.

The acquisition includes supplies, delivery, installation, training in the use, data transfer to the existing local server by Ethernet link.

3. Definition of the need

3.1 Existing and future experimental orchards to be phenotyped

Several experimental plot could be used to collect phenotyping data, but the first step will be to phenotype an experimental orchard of apple trees.

- Apple collection orchard (one to 3 replicates randomly planted).
- One axis minimum high in winter: 3.5m. Inter row: 4m. between two trees: 1.05m.
- Manual thinning, one plot with conventional management. One plot with low fungicide management.
- Inter-row with ray grass,

3.2. Traits to be evaluated

More precisely, this phenotyping device will have to allow the acquisition of information allowing to measure the following parameters with the specified accuracy:

Parameter	**Expected accuracy/classes**
Flowering intensity	Class 1 to 9
Tree architecture	maximum height, maximum width, tree volume, total length of branches, total length of trunk (during winter time), if possible tree architecture reconstruction
Number of fruits	maximum acceptable error 10% accuracy on absolute number
Fruit size	5 mm diameter classes at harvest

Fruit size (dynamics)	track 5 single fruits per individual starting from 35 mm size
Color	maximum acceptable error 10% accuracy on percentage of red overcolour

Health status of the trees (general index)	3 classes based on the detection of the sensitivity / resistance of trees to pests on leaves
Health status of fruits (general index)	3 classes based on the damage on fruits caused by the main pests and pathogens

In the perspective of orchard diversification, measurements of biomass of companion plants and market garden plants on the row and inter-row are also envisaged.

4. DESCRIPTION OF THE SPECIFICATIONS

4.1. FRAME

The frame will have to be adapted to an electrical vehicle. This Electrical vehicle will have sufficient power to move the entire data collection system and have characteristics (length, width) adapted to an orchard...

The frame must be able to support up to three measuring heads. The mechanical links between the frame and the electrical vehicle on the one hand, and between the frame and the measuring heads on the other hand, will allow disassembly.

The structure of the frame must allow a certain evolution. In particular, the position of the measuring heads must be easily modified, in terms of height and also to allow them to be switched from a horizontal view (towards the row) to a vertical view (towards the inter-row).
The frame (or the measuring heads) must be stabilized to avoid soil flatness problems (rolling, pitching, etc.).

The power supply must allow the acquisition of a plot of 1ha without stopping and power failure. An additional battery may therefore be required if the electrical power supplied by the electrical vehicle is not sufficient.

4.2. MEASURING HEADS

Each measuring head will be designed to accommodate different phenotyping sensors (Lidar, Camera, Flash). For each sensor, a specific support will be installed to fix them on the measuring head and keep the possibility to move them if needed.

The whole system will be covered, so that the sensors are protected from rain and sun. An electrical box will be integrated into the frame and the sensors will be connected to it. It will also integrate the computer components.

For the connection of the equipment, differentiated connectors will be used to separate the electrical part necessary for the power supply and the control of the equipment.

A complete measuring head should include 1 Lidar, 2 RGB cameras (stereovision) and 2 Xenon flashes.

The chosen Lidar reference will have to allow a precise description of the finest tree branches, for this purpose the following specifications are expected:

- Finest detail of order of cm,
- Minimum range of 4m to ensure acquisition of the entire width of the row (> 1m in full vegetation),

The RGB cameras must be industrial to ensure the longevity and robustness of the images taken for several years and respect:

- Genicam standards to allow a fine adjustment and control of the images taken,
- Electrical triggering of the image capture (not software),
- Synchronization of several cameras with their flashes within 200µs,
- Global shutter triggering,
- Resolution greater than or equal to 12 MP,
- Sensor size: greater than 14 x 10 mm,
- Focal length adapted to take pictures of the whole height of the tree.

Xenon flashes must:

- have an adjustable power to adapt to the different ranges of the measurement heads (horizontal aiming for trees or vertical aiming for ground vegetation),
- be powerful enough to allow a complete independence from the sun and limit the blur due to the movement and vibration of the machine (order of magnitude of image capture: 200 µs)

Depending on the size of the inter-row and the height of the trees, the number of measuring heads required to be able to cover the entire trees have to be proposed.
Different versions with specific configurations will have to be proposed and costed as optional but mandatory items:

- Version 1: A complete configuration allowing to visualize the whole height of the row (from the base of the trunk to the top of the foliage) and the inter-row,
- Version 2: a single complete measuring head which can switch from a horizontal view (towards the row) to a vertical view (towards the inter-row).

4.3. Supervision and control system

The quality of phenotyping data relies heavily on accurate control of data acquisition and a good data storage system. This is a requirement for an efficient data processing step. The acquisition control will need to rely on 3 main components:

- A man-machine interface to program the measurement scenario and monitor the data acquisition in real time,
- An embedded software solution to drive the phenotyping sensors and store the data,

The man-machine interface will be provided by:

- A ruggedized tablet PC, capable of exchanging data with the onboard computer,
- A software for planning and monitoring acquisitions,
- The interfaces must be user-friendly and relatively simple to use so that a tractor technician who is not a computer expert can implement a project in the field after a quick training.

All the data collected by the onboard acquisition system must be controlled and monitored in real time via a user-friendly interface:

- The operator must be able to create a project by importing geo-referenced objects, with identifiers and GPS coordinates, and then visualize it on a graphical interface allowing to plan a route,
- It must be possible to define "borders" for the experimental modalities, expressed in centimeters, i.e. a zone at the beginning and end of the plot in which data acquisition should not be done.
- Program definition:
  - o per sensor allowing to easily change the settings of each sensor on the fly:
  - o by experimental modality, the intervals between events must be configurable sensor by sensor and for each possible lighting source.
- Definition of acquisition sequences according to time or geo-position, in order to chain a series of programs within a plot,
- Manual or automatic start/stop of an acquisition sequence must be possible, even in the absence of GPS signal,
- The operator must be able to manually stop the acquisition process and resume it at his convenience,
- The operator must be able to visually follow the progress of the project:
  - o Real-time preview of the data being acquired,
  - o Real-time monitoring of the quality of the sensor data, with a set of alerts/alarms if the data does not correspond to a predefined set of quality criteria,
  - o In case of malfunction of the data acquisition (inappropriate speed of advance, problem on a sensor, ...) the system must propose to the operator either to restart the process, or its abandonment with saving of the information "acquisition impossible ».
  - o In case of the choice of the geopositionning option, the system must display his position in real time on a map of the experimental plot.

- The data recovery must be possible on a computer for saving and later exploitation.

The onboard computer and electronics will include:
- A ruggedized computer with a minimum of 1TB HDD to drive the sensors and record data, the storage capacity will be sized to record data for all onboard sensors simultaneously and for an entire mission,
- An Ethernet switch for communication with the phenotyping sensors and the tablet,
- A synchronization card to ensure the synchronization of the sensors (e.g. several cameras with their flashes) in an electrical way,
- Electrical power distribution and cables,
- A software that controls the sensors (preventive maintenance) and records the data:
  - o Health test of the sensors to program an intervention,
  - o Monitoring of the memory status,
  - o Integrity of the processing chain,
  - o A global alert system will directly inform your support team in case of a major problem without any action from your operators.
- The output data format must be of type monthHDF5

Concerning the raw phenotyping data, the HBF5 format is requested. Access, at no additional cost, to algorithms and analysis pipelines dedicated to these observations in the orchard to obtain a set of traits (see above, list of traits to be phenotyped) is desired. The description of the available algorithms and pipelines as well as their access conditions will be included in the evaluation criteria of the responses to the call for tender. This access may be limited in time to become paying beyond. The conditions of access (duration, price, access to future evolutions and developments) will then have to be specified.

4.4. Particular constraints

- The whole system must be insensitive to bad weather, dust, moderate shocks (e.g. branch or push on the path) and functional at temperatures between -5° and +40°C,
- The whole system must be compatible with traffic on uneven ground (vibrations, bumps). If necessary, the sensors must be stabilized,
- The system must be easy to handle so that it can be mounted/dismounted without difficulty, and transported remotely with a trailer or a utility vehicle,
- The sensors must acquire data over the entire height of the trees. The acquisition and storage frequency must be adapted to a tractor boarding, i.e. at a forward minimum speed between 2 and 4 km/h for all types of sensors considered (LIDAR, RGB camera or multispectral camera),
- Power supply on 12V electrical vehicle plug or on independent batteries, allowing the phenotyping of a 1ha plot,
- The system must be delivered ready to be installed on an electrical vehicle (power supply, triggering and measurement acquisition unit, optional GPS antenna, sensors and wiring),
- The system must be scalable and configurable to control the triggering and acquisition of images from infrared thermal cameras and multispectral cameras,
- In terms of safety, the system must comply with the standards and regulations in force, in particular concerning the electrical risk and the Machinery Directive (not exhaustive). The necessary supporting documents will be provided.

5. Warranties, after sales service and maintenance

The device will be delivered with a total guarantee of a minimum of 24 months (parts and labor, travel).

The warranty must cover computer malfunctions.

The greatest importance will be attached to the quality of the after-sales service and the speed of intervention in the event of breakdown. We expect a minimum service including the preventive and curative maintenance with hotline from 8H to 17H on office days. The service provider will specify in the offer the deadlines and the terms of intervention of the after-sales service (cost of travel and hourly cost of the intervention on site out of warranty). The maintenance conditions for a period of three years will be specified and costed separately, indicative price not included in the contract price

6. Delivery - installation

The delivery of all the equipment must be made by traced parcel.

The tracking number(s) will be provided by the contractor to the researcher in charge of the project will allow the tracking of the parcels in the shortest possible time.

The admission of the equipment will be pronounced after the installation, the commissioning, the training of the staff and the admission phase with tests in orchard.

A field testing phase will be carried out over a period of 1 month from commissioning. This phase should cover contrasting weather situations (overcast, sunny).
The equipment must be new and the period between the notification of the contract and the commissioning must not exceed 4 months.

The admission of the equipment will be pronounced after installation, commissioning, training of personnel and the admission phase with tests in the orchard.

7. TRAINING

A training on site, for between 3 and 6 persons, in the use, maintenance (routine maintenance, calibration) and management of the different cameras will have to be proposed and be concomitant to the commissioning.

The supply of a manual in ENGLISH (assembly, connectors, use of interfaces, malfunctions and solutions ...) is imperative.

All the technical documents of the sensors must be provided at the time of the offer as well as the data processing algorithms at the time of the installation.

The offer of the holder includes a support to the users during a minimum period of six (6) months following the admission of the material, in order to guarantee them an optimal use.

8. MANDATORY SUPPLEMENTARY OPTIONS

- As an option a geo-positioning system to trigger the measurements according to the position of the wearer and to geo-reference the data will be proposed.

The optional positioning system will consist of:

- An RTK reference base station (GPS receiver + antenna, UHF (Ultra High Frequency) modem for RTK corrections for communication with the mobile, battery with 8 hours of autonomy), allowing the obtaining of GPS coordinates to within 2 cm in x, y and in real time, at a minimum frequency of 50Hz,
- An RTK GPS receiver and an antenna positioned on the rover operating at a minimum frequency of 10Hz,
- A UHF modem to receive RTK corrections from the base station.
- Although great care will be taken to ensure the stability of the frame and the measurement heads, a mast attitude control unit should allow correction of pitch, roll and heading to correct the aim of the measurement heads.
- As additional option, thermal cameras and spectral cameras adapted to orchard monitoring will be proposed.

Annexe 2 Deliverable D2.1 PHENET Specification, assembly and installation of the connected stick

Model: Connected Stick GxE PHENET developed
@ INRae Clermont-Ferrand Boris Adam, Nathan Drogue

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Herearii Metuarea, Engineer Julien
Garnier, Engineer

Research and Innovation action: GA no. 101094587
Start of the project: 1 January 2023

1. Introduction

1.1. Context

This annex describes the connected stick that will be used for GxE UC of PHENET as designed by INRAe Clermont-Ferrand. The proposed solution involves designing a connected stick for plant phenotyping and envirotyping. It is an autonomous stick in terms of electrical power, data transmission, acquisition, and data processing. It allows data to be collected from a specific point in the field. This stick has two main features: firstly, the position of the sensors is adjustable, and secondly, the choice of environmental sensors is not limited. Easy to use and configure on-site, two user interfaces are provided: one for programming data acquisition, and the other for allowing the user to view and download the collected data onto their PC. These data are stored on a remote server via a web service.

1.2. List of material

Here's a summary of the specifications for a sensor system:

Sensors:

- RGB camera
- Radiation sensor (PAR - Photosynthetically Active radiation)
- Air temperature/humidity sensor
- Soil temperature sensor (approximatively 10cm depth)
- Soil moisture sensor (tensiometer type)
- Rain gauge
- Wind speed and direction sensor

Image acquisition: capable of acquiring 1 to 4 images per day

Power supply:

- Solar panel
- Battery

Data transmission: GSM (Global system for mobile communication)

Spatial coordinates: GPS (Global Positioning system)

Configuration: Local in wireless way

2. Technical Operation of the System

2.1. Electronic system

The motherboard remains a permanent and essential component of the stick. The image sensors are modular as long as they remain within the Raspberry range and their model remains the same. The environmental sensors do not have any specific model.

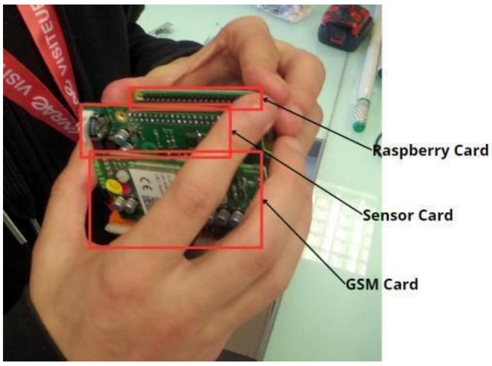
As for the electronic part, apart from possible breakdowns, there is no real wear and tear of components with use, the same applies to most of the sensors.

2.1.1. Motherboard

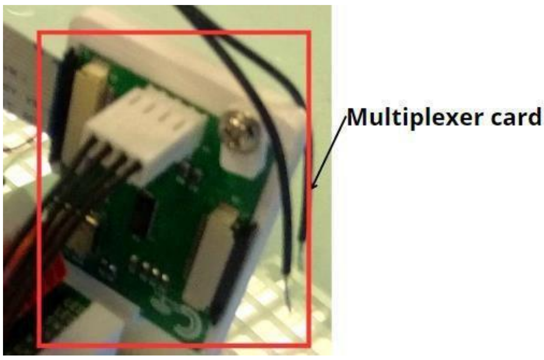
Sensor card: A board to collect data from six types of environmental sensors. On this board, a user can connect: three temperature probes, one humidity probe, one air temperature probe, a PAR sensor, four soil moisture probes, and an anemometer. This board includes a continuously active internal clock.

Raspberry Pi zero card: A Raspberry Pi board is used for data acquisition and transmission. It should have a port to connect an SD card. A Python code is used to control data acquisition and transmission. This code is embedded in the SD card and can be accessed in a FORGEMIA directory. On this Raspberry Pi board, a user can directly connect an 8 Mega Pixel camera. Equipped with Wi-Fi, it can receive data from acquisition parameters to be sent to the sensor board. The Raspberry Pi Zero can be replaced by another Raspberry Pi model. For example, it can be replaced with the Raspberry Pi 4, which has more powerful computing capabilities.

GSM card: A board to ensure data transmission, which must include a port for connecting a SIM card. The SIM card used is a commercially available one. In this case, it is an SFR SIM card costing 3.30€. It enables the transmission of data acquired from the sensor boards and Raspberry Pi to the server. The manufacturer SIMCom offers two models of GSM cards: one with GSM only, and another with GSM+GPS.



(a)



(b)

Figure 1. Photo of the motherboard (a) and of the multiplexer card (b).

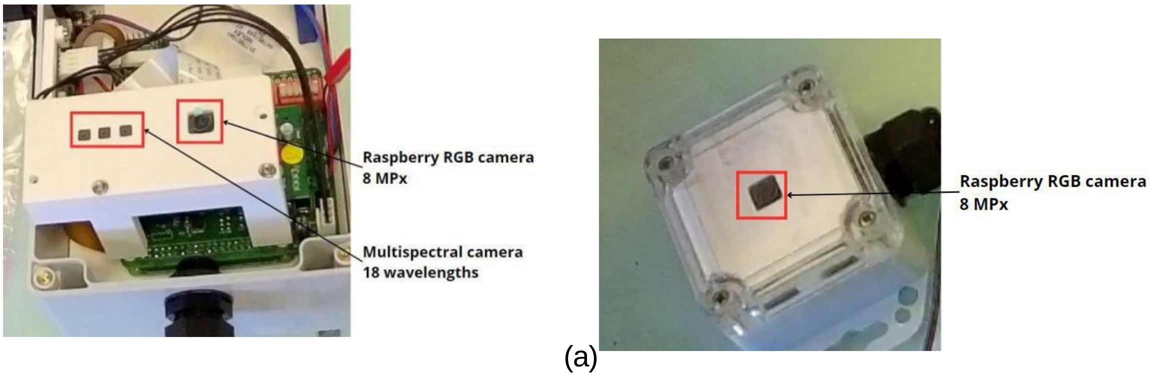
2.1.2. Multiplexer card

A card for controlling two 8 Mega Pixel RGB cameras. This multiplexer card is connected to the Raspberry Pi board. The computer and electronics group also includes: electrical distribution and cables. The format of the output data is in .csv for environmental data and .jpg for images.

2.1.3. Image sensor

Three image sensors to obtain images in RGB and in 18 wavelengths of the canopy from two perspectives: overhead and oblique.

Two RGB camera : Two 8 megapixel Raspberry RGB cameras connected by a multiplexer card. One RGB camera is mounted on the casing for a lateral view of the canopy. Another Raspberry RGB camera is placed at the end of a pole to obtain a zenithal view of the canopy. The camera model may change, but must remain within the Raspberry range, and the two cameras should be of the same model.



(a) (b)

Figure 2. Photo of an RGB camera with a multispectral camera on the electronic box (a); and an RGB camera for the lateral view (b).

2.1.4. Environmental sensor

Six types of environmental sensor for environmental measurements.

Radiation Sensor (PAR): A sensor to measure (in millivolts) the radiation from the sun.
Air Thermo-Hygrometric Sensor : A sensor to measure (in degrees Celsius) the temperature and humidity of the air. A protective plastic cover shields the sensor from rain, snow, and direct contact with the sun.
Soil Temperature Sensor (~10cm): A sensor to measure (in degrees Celsius) the soil temperature. This sensor is to be inserted approximately 10 cm into the soil. \paragraph{Soil
Moisture Sensor (Tensiometer Type): A sensor to measure (in centibar) the soil moisture.
Rain Gauge A rain gauge to measure the amount of water (in mm) that falls at the stick's location.
Anemometer: An anemometer with propellers topped with a weather vane to measure the wind speed (in m/s) and direction (in degrees). At the beginning of each data acquisition project, a user must orient the anemometer's arm toward geographic north.

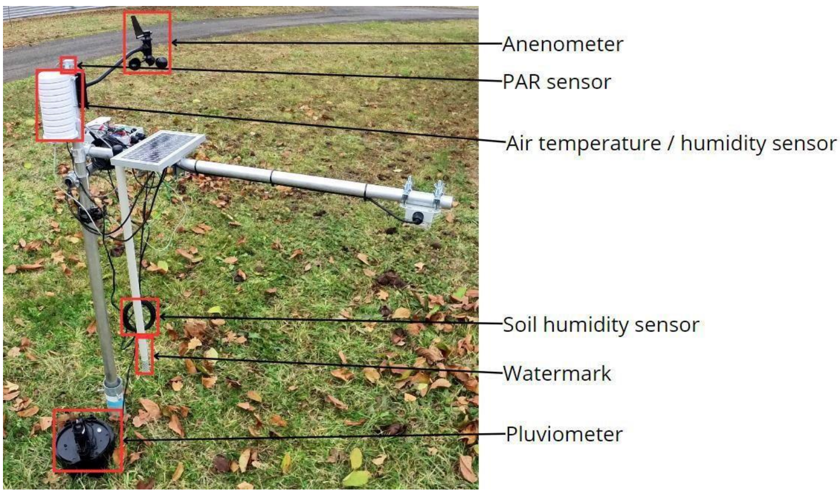


Figure 3. Arrangement of the Six Environmental Sensors.

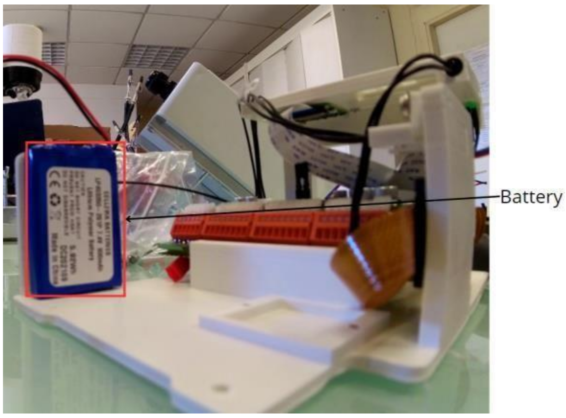
2.1.5. Communication

The GSM card provides a wireless connection to transmit data to a remote FTPS server. It is capable of sending a certain volume of data (quantitative + image). Connected to an antenna, the stick covers a sufficiently wide transmission radius. Data transmission is based on the Authenticated Transfer Protocol (AT). Data storage relies on a remote FTPS server. This server must already be part of a user's equipment before using the stick.

2.1.6. Alimentation

The stick is powered by a lithium battery. It provides a voltage of around 7.4 volts. This battery supplies electricity to the three electrical components of the stick (GSM Card, Sensor Card, and Raspberry Pi). A solar panel generates electricity for the battery with a maximum power of 3 watts. The solar panel is adjustable. The model of solar panel used must generate maximum power at the limit of the installed battery's capacity.

(a)



(b)

Figure 4. Two components that provide electricity to the stick: the solar panel (a) and the battery (b)

2.2. Operation of the System

Stored on the Raspberry Pi card, an initialization file for data acquisition and transmission is modifiable on site. The control code for data acquisition and transmission is structured by a Python script. This file sets the time interval for acquiring environmental data and an hour for taking photos. The sensor card receives environmental data at the time interval set by the user. An internal clock is integrated into this sensor card. At a time set by a user, the sensor card triggers the Raspberry Pi card. This Raspberry Pi takes an image and is then turned off by the sensor card. Before and after taking images, the Raspberry Pi is off. As soon as the last image of the day is taken, all data (environmental and images) are transferred to the Raspberry Pi so that they can be transmitted to the FTPS server. The transmission is carried out via a cellular network provided by the GSM card. After the data is transmitted, the sensor card turns off the Raspberry.

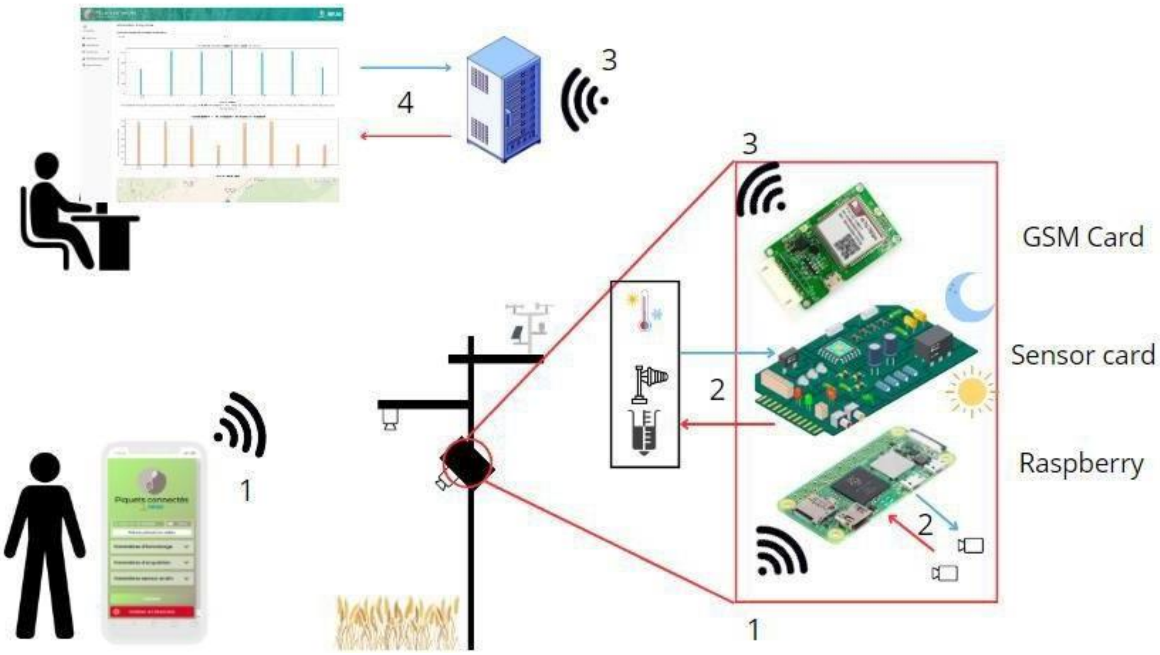


Figure 5. Summary of the System Operation. Instructions for acquisition are sent to the Raspberry Pi card in the stick (1). Environmental data and images are acquired using a Python script located on the Raspberry's SD card (2). The sensor card turns off and wakes up if there are data to be acquired. It is the one that wakes and turns off the Raspberry if images need to be acquired. From the last image taken in the day, all environmental data and images are sent to the FTPS server (3). The data can be viewed with a user interface (4).

2.3. Flexibility of the Stick

Designed for experimental units, the stick is designed to be easily usable and configurable. Being easy to use, the stick is lightweight and portable. The stick can be placed either on soft soil on a screw-in post (suggested soil depth: 65 cm) or on hard ground on a base. The body of the stick is detachable and adjustable. There is a wide choice of environmental sensors that can be installed. As for image sensors, they must remain within the Raspberry range, and the two cameras must be of the same model. This adjustment may require some DIY work for the user.

3. Design of Our Connected Stick

3.1. Overall Vision

3.1.1. Original design

The GxE stick consists of an aluminum mast, six environmental sensors, three image sensors, and a housing containing the electronic assembly. The figure 6 shows a stick installed in the field. The mast is adjustable up to two meters. The body of the mast is made of two aluminum tubes. A 1m aluminum perch is attached 33 cm from the top. Aluminum is a light metal, easy to work with, sufficiently durable over time, and less expensive. Figure 6 shows a stick installed in the field.

Figure 6. GxE Stick

More specifically, you can find information about the materials used for manufacturing in the document attached to this report: list_composants_Piquet.xlsx.

3.1.2. Principle of Assembly and Replicability

The principle is to maintain the ability to move the environmental sensors and the zenithal camera. The cables for connection to the main box will require soldering.

Permanent Assembly: This assembly concerns the connection of the sensors. Regarding the anemometer and the rain gauge, two wires are needed for the rain gauge and four wires for the anemometer in Dupont female connectors. Connecting these wires to a Dupont female connector requires soldering after threading the cables through the cable gland. The other wires are to be fixed on the spring terminal block of the sensor card, which are part of a so- called detachable assembly. Instructions for connecting the wires are necessary to precisely identify the blocks.

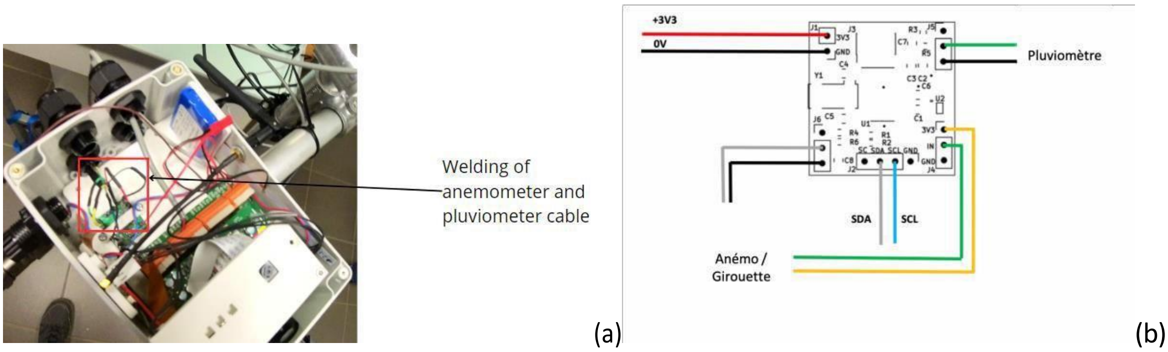
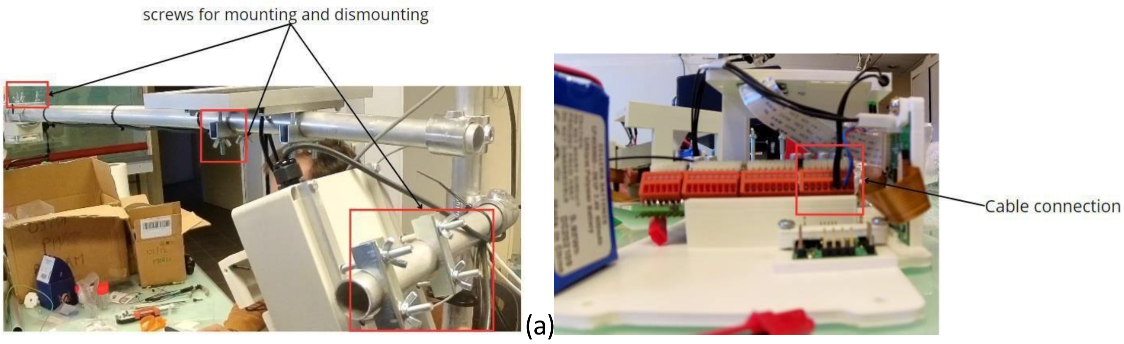


Figure 7. Connection of anemometer and rain gauge sensor cables after soldering (seen with black protective cover) (a) with its connection diagram (b)

Detachable Assembly (Replicability): The choice of environmental sensor models and power supply is flexible, as is the choice of their position on the mast. The position of the electronic box on the mast is adjustable. The Thunderbolt cable connecting the RGB camera for zenithal view is detachable.



(a) (b)

Figure 8. The parts for disassembling the components: the screws on the mast (a) and the cable connection on the spring terminal block (b)

3.2. Assembly of the Parts

Solar panel : First, you connect the solar panel to the coaxial cable. Then, you connect the coaxial cable to a BNC (Bayonet Neill-Concelman) connector by soldering the wires into the connector.

Figure 9. Mounted solar panel

Mother box : First, a base needs to be designed using a 3D printer. We already have a pre- made plastic casing. The base will serve to attach the computer and electrical components, while the casing will protect these components from weather conditions or impacts. On the casing, seven holes are drilled on the sides to allow the sensor cables to pass through. The mounting device consists of an aluminum bar fixed to the casing with two screws, and a half- circle mounting piece held in place by a U-shaped mounting handle secured by the bar and two wing nuts. In one of the casing holes, a BNC-type cable gland connector is integrated for the solar panel.

Next, the three electronic boards (Raspberry Pi, sensor, GSM) are assembled together. This assembly, along with the multiplexer, Raspberry Pi camera, LED light, and battery, is attached to the base. The Raspberry Pi camera and the multiplexer are connected with the white ribbon cable. The multiplexer and the Raspberry Pi are connected with the motherboard ribbon cable (orange). On the multiplexer, the acquisition board and the sensor board are connected with a Dupont-type connector. The wires from the LED are connected to the spring terminal block on the sensor board. The wires intended for the solar panel and the battery are connected to the screw terminal block on the sensor board. The battery and the sensor board are connected with a Dupont-type connector. Finally, the base is integrated into the casing. Five cable glands with sensor cables are fixed into the five holes of the casing.

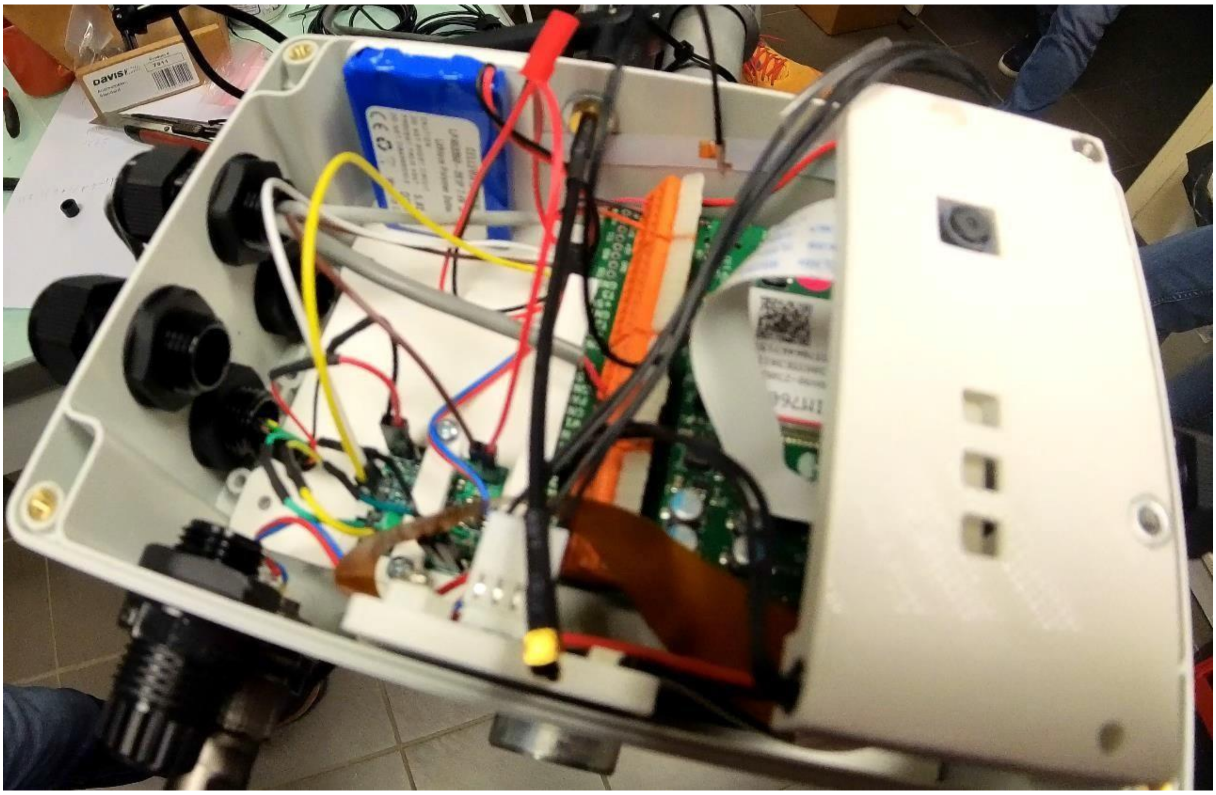


Figure 10. Final assembly of the mother box

RGB camera housing for a zenithal view : Firstly, a base needs to be designed using a 3D printer. We already have a plastic casing in place. The base is used to secure the RGB camera. The casing provides protection for the circuit and camera against weather conditions and impacts. On this casing, a hole is drilled to thread the sensor cable through, and four holes are used to attach a mounting device to the stick's pole. This mounting device is identical to the one on the casing but smaller in size.

Next, the camera and circuit are connected via a white ribbon cable. The camera is attached to the base, and the circuit will be connected to the casing with a Thunderbolt-type cable. A cable gland is fixed into the hole on the casing. Using a tube placed in the cable gland, the cable is routed into the casing.

Figure 11. Final assembly of the RGB camera box for a zenithal view

3.3. Installation on site

The stick can be installed inside or outside a building.

Indoor : In a studio, the stick can be used if it rests on a stable base. The developing team made a base by welding the base of a scaffold to a tripod.

Outdoor : On soft ground with a flat surface, the stick can be placed on a screw-in post. It is necessary to dig 65 cm into the ground to stabilize the stick against the weather for a few weeks. The RGB camera on the pole captures images of the cover. It is essential for the stick to be as perpendicular to the ground as possible. If the diameter of the pole is smaller than the screw, three screws on the screw-in post will correct the angle of the stick to make it straight. As for the environmental sensors:

- The soil temperature sensor is submerged at a depth of 10 cm in the ground.
- The soil moisture sensor is submerged in the soil so that the earth covers the entire sensor. With the Watermark sensor, it is advisable to wet the sensor before submerging it to equalize the pressure and prevent erroneous data.
- The arm of the anemometer requires orientation to the geographic north.
- The rain gauge must be placed at a certain distance from the stick to prevent water accumulation from disturbing the soil measurements and to avoid the stick and its sensors from blocking some of the rainfall. Placing this sensor at a certain height is more critical than the horizontal distance.

(a) (b)

Figure 12. Major Step in Field Installation: Insertion of the screw-in stick that will secure the post in the ground (a) and fastening the post to the screw-in stick (b).

4. HUMAN-MACHINE INTERFACE (HMI)

4.1. STICK CONFIGURATION

The stick configuration refers to the programming of a data acquisition campaign for the stick. This programming is done through an interface called the "Connected Stick" (URL link: 172.16.0.1/piquetPhacc), which is accessible on the Piquet Phacc WiFi network emitted by the stick. A user can access this interface using their mobile phone or computer. Before configuring, a user must be in proximity of the stick to turn it on using a magnet. This magnet is placed near the LED. Then, the user proceeds to configure the stick. Wireless configuration of the stick allows users to avoid moving the stick from their workshop. It consumes minimal electricity. Configuration involves entering a set of timestamp, acquisition, and SIM server parameters.

The interface is a web service displaying the time, date, and battery level of the stick. It is available on a wireless network (WiFi, 4G). However, it's essential to connect to the Piquet Phacc network emitted by the stick for the defined configurations to take effect. On any other network, the interface is inaccessible.

The interface is divided into three parts:

- **Live camera preview:** In this section, users can view live two cameras outputs.
- **Project parameter:** Users input various information to configure the stick. They update the stick's internal clock in timestamp settings (manual time setting, automatic time update based on the time zone). Users define which sensors to use for data acquisition and specify the GPS location of the stick in acquisition settings (number of photos

taken per day, active camera, active sensors). Users also set server identifiers to specify the data storage location in server-sim settings (stick and user identity, server information, data management). It's worth noting that the sticks are not technically identified by a unique name; the unique name is defined by the user in acquisition settings. According to the designer, the stick's name defines the name of the data acquisition campaign.

- **Parameter validation:** In this part, two buttons are presented to the user. The "Valider" button saves the entered parameters and keeps the Raspberry Pi powered on. The powered-on Raspberry Pi keeps the web page accessible, allowing the user to verify whether the defined parameters have been saved. For example, if a user updates the time, they can check if the updated time has been applied. The "Valider et éteindre" button saves the defined parameters and then shuts down the Raspberry Pi. The web page becomes inaccessible, saving electricity in the stick.

Users can change acquisition parameters at any time during the acquisition phase. Changing the parameters simply involves updating the acquisition program.

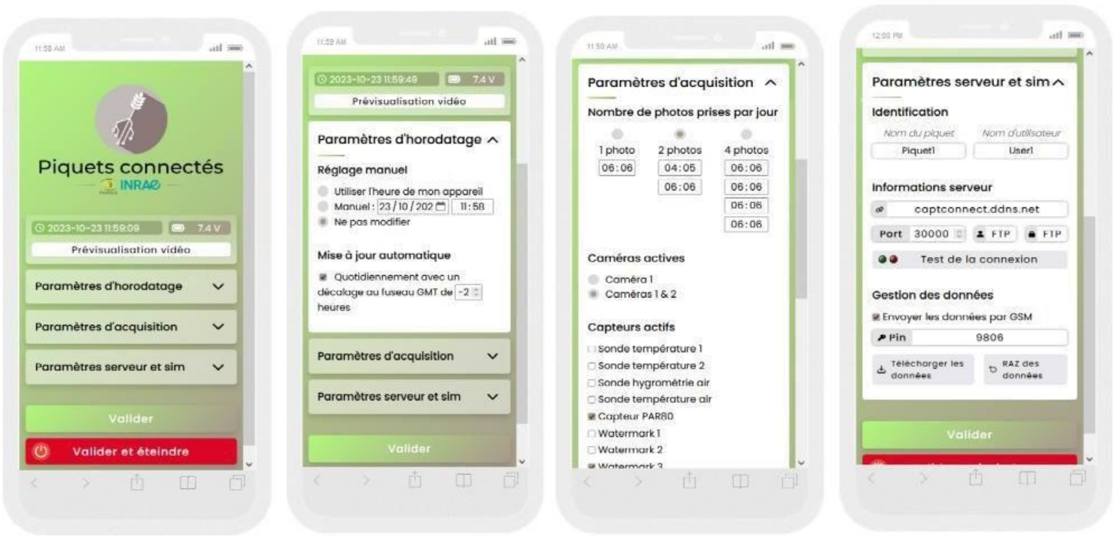


Figure 13. Four screenshots of "Piquet Phacc": home screen (a), timestamp settings (b), acquisition settings (c), and server settings (d).

Two solvable problems encountered in the difficulty of connecting to the website are:

- Some web browsers may have difficulty connecting. Simply trying different web browsers can resolve this issue. In our test, one mobile device worked with Firefox but not with Google Chrome, while another mobile device worked with Google Chrome but not with Firefox. Regarding iPhone users, Safari worked very well.
- For mobile phones equipped with two SIM cards or an eSIM, you simply need to disable data sharing in the settings.

4.2. Data Visualization: "Connected Stick GxE"

The interface is a web page linked to an R package from the SK8 project. It has been designed for visualizing and monitoring acquisitions. This page allows you to:

- View the evolution of environmental measurements over time in a single chart with a curve.
- Visualize the evolution of environmental measurements for multiple sticks separately, where one chart represents one stick.
- Visualize the weight and the number of images per day in a bar chart.
- Visualize the acquired images over time using a slider bar indicating the time.
- Visualize the evolution of environmental measurements over time in a chart with a curve in the upper section, and below it, represent the time-based position of acquired images using a 1D scatter plot.

Figure 14. User Interface of "Connected Stick GxE"

A page widget should allow users to identify the sticks on a map accompanied by information (environmental data, images, download, and sending to PHIS). Regarding data export, a user has the option to export data for a user-defined time period. They can export either environmental data (CSV table), images (JPG), or both environmental data and images (compressed file containing CSV tables and JPG images).

The website was created using R with R-Shiny. The diagrams use the Plotly library. The website can be accessed either by running an R code locally on a PC or through a web link (www.piquet-phacc.sk8.inrae.fr) connected to FORGEMIA. The source code is accessible on FORGEMIA

5. Particular constraint

Stick configuration : If a user has many sticks, the configuration of the sticks is done stick by stick.

User Equipment : A user must have a SIM card and access to an available FTPS server.

Problem in Data: The interfaces do not send an error message to the user if there was an issue in data acquisition or transmission. A user does not receive any error message if a sensor or camera encounters a problem. A user only becomes aware of an issue after exporting the data to the server. They realize the problem when reading the data presented by the "Connected Stick GxE" interface.

Stick Activation : When the stick is powered on, a preview of the cameras is possible on the "Connected Stick" interface. When the stick powers on, the interface checks if the main camera is functioning. However, there is an issue with the design of the Python code as the main camera is supposed to be an option. The main camera is intended to be the one attached to the main casing. The developing team is currently working to resolve this problem.
Transmission : There is no existing security during the acquisition phase. Nothing protects the stick's data from being stolen before being sent to the server. There are no safeguards against the introduction of malicious elements into the computer and electronics.

Connected Stick GxE Currently, there is no user guide available. Additionally, the interface is accessible only to INRAe agents, as per the initial concept. The interface is connected to the FORGEMIA directory of the R package in the SK8 project. FORGEMIA is accessible only to INRAe agents. Therefore, access to the interface via the web requires INRAe credentials. Finally, the interface has been designed for data visualization only. It is not possible to conduct conventional statistical studies, create dynamic tables, or cross variables.

6. Perspective

Adding Time Of Flight Sensor: A Time Of Flight camera (coming soon) will enable distance measurements to be taken.

Adding Multispectral Camera Sensor: An 18-wavelength multispectral camera is attached to the casing. Multispectral images provide a top-down view of the cover under 18 wavelengths.

Development of the Connected Stick GxE Interface: Writing an article about the stick and its interfaces. The "Connected Stick GxE" interface is still under development to enhance its appearance. To improve both the stick and the interfaces, the experimental units of the PHENET projects will provide valuable experiential feedback (including new errors) to refine the stick and the interfaces.

7. Contact for Additional Information

The stick was designed by Boris Adam (boris.adam@inrae.fr) and the P3C team at INRAe Clermont Ferrand, including Nathan Drogue (nathan.drogue@inrae.fr) for the user interface. Document written by Herearii Metuarea (herearii.metuarea@univ-angers.fr), Julien Garnier and David Rousseau for Univ. Angers;

8. CONCLUSION

The stick allows for environmental and phenotypic experimentation. It has been designed to be modular and can be used outdoors or indoor. Users have the option to install a set of environmental sensors and must go through a cable soldering step for connection with the main casing. Users can also choose the position of these sensors. The wireless aspect in stick configuration and data export simplifies its use.This is a prototype. The use of sticks in the PHENET projects will help us better understand this tool. For example, weather conditions could pose a problem for the mechanical part (support casing, etc.). The designers do not have precise knowledge of the effects of weather and UV on the casings, cable glands, and cables.

DESIGNATION	DESTINATION	PUHT	QTE	PRIX TOTAL	FourniFOURNISSEURsseur
Boitier camera 2	Boitier Camera 2	3,6	1	3,6	TME
Camera Raspberry 12Mp	Boitier Camera 2	22,7	1	22,7	Envytech
Presse-etoupe M16	Boitier Camera 2	0,95	1	0,95	TME
Nappe camera Rasberry Pi 5 cm	Boitier Camera 2	2,5	1	2,5	
Carte capteurs	Boitier principal	260	1	260	CaptConnect
Carte GSM	Boitier principal	170	1	170	CaptConnect
Cartes multiplex camera	Boitier principal	40	1	40	CaptConnect
Carte anemometre	Boitier principal	35	1	35	CaptConnect
Carte mesures multispectrale	Boitier principal	60	1	60	CaptConnect
Cable Thunderbolt	Boitier principal	11	1	11	Amazon
Insert de presse etoupe double	Boitier principal	0,65	5	3,25	TME
Antenne gsm	Boitier principal	2,73	1	2,73	TME
Boitier 120x180x90	Boitier principal	11	1	11	TME
Batterie 7.4 V	Boitier principal	7,8	1	7,8	TME
Presse-etoupe M16	Boitier principal	0,95	5	4,75	TME
Interupteur reed	Boitier principal	2,4	1	2,4	TME
Led verte	Boitier principal	0,16	1	0,16	TME
Embase panneau solaire	Boitier principal	4,4	1	4,4	TME
Raspberry Pi zero WH	Boitier principal	19,5	1	19,5	Envytech
Camera Raspberry 8Mp	Boitier principal	22,7	1	22,7	Envytech
Nappe cameras Rasberry Pi zero 15 cm	Boitier principal	3	1	3	
Capteur thermo-hygro	Capteurs	20	1	20	CaptConnect
Abris thermo-hygro	Capteurs	15	1	15	Amazon
Capteur Temp DS18B20	Capteurs	3	3	9	Amazon
Capteur PAR 80	Capteurs	66	1	66	Solems
Watermark (tensiometre)	Capteurs	42	3	126	Agroressources
Pluviometre	Capteurs	141	1	141	MeteoShopping
Anemometre girouette	Capteurs	191	1	191	MeteoShopping
Panneau solaire 3W	Panneau solaire	5,6	1	5,6	TME
Connecteur panneau solaire	Panneau solaire	5,5	1	5,5	TME
Collier serrage tube 35 mm	Support	8	1	8	Amazon
Collier serrage tube 40 mm	Support	8	1	8	Amazon
Piece de liaison tube	Support	1	6	6	TME
Cavalier liaison tube	Support	1,35	6	8,1	TME
Raccord 90 tube 30	Support	6,71	2	13,42	Centurion
tube alu 30 (2 m)	Support	9,5	2	19	
tube alu 35 (1 m)	Support	10,5	1	10,5	
tube alu 40 (1 m)	Support	13	1	13	
tube alu 30 (0.3 m)	Support	9,5	0,3	2,85	
				1355,41	

Annexe 3 Deliverable D2.1 PHENET Specification, assembly and installation of the connected stick

Model: Connected Stick F2P PHENET developed
@ UC Louvain by Xavier Draye

–

Technical description Herearii Metuarea, Julien Garnier

Research and Innovation action: GA no. 101094587
Start of the project: 1 January 2023

1. Introduction

This report was written following a 3-day visit (December 10-12, 2023) to the PEPA team at Université Catholique de Louvain (UC Louvain). The two authors were warmly welcomed by Mr. Xavier Draye (Full professor UC Louvain) and the PEPA team.

1.1. Context and problematic

The agricultural transition requires the mobilization of all these players (private companies and scientists). The goal is to achieve intelligent crop management. Reaching this goal requires defining this management by collectively studying various scientific questions. This collective is composed of private actors (SC and farmers) and public infrastructures (UC Louvain and EMPHASIS). The study of scientific questions involves applying phenotyping and envirotyping experiments. These experiments are applied separately and in parallel by two actors: on one hand, an experiment by UCLouvain with EMPHASIS, and on the other hand, an experiment by SC with a network of over 100 farmers. Undertaking an experiment requires equipment for phenotyping and envirotyping. However, acquiring equipment, especially for over 100 farmers, becomes very costly. The solution proposed by the team in Louvain is the creation of a connected stick for envirotyping and phenotyping. Most of these components are easy to find and affordably priced. Modular and simple to use, this stick gives users the choice to attach any sensor anywhere on the stick. Data transmission to a server is done centrally. In a network of sticks, data is sent to a stick capable of transmitting to a server. It is self-sufficient in electrical power and data acquisition. This solution has already been implemented in a first indoor stick. However, this first version needs to be revised for outdoor suitability.

1.2. Bill of material

Sensors: pure analogic, analogic with built-in ADC, pure digital, point or camera

Data transmission: Locally or GSM (Global System for Mobile Communication)

Power supply:

- Solar panel
- Battery

Configuration: Local and wireless

2. Technical operation of the system

We define two types of stick: stick with datalogger in mother box, stick with gateway in mother box. A datalogger is an electronic card for acquiring data with MCU and send data with LoRa module. A gateway is an electronic card including MCU for acquiring data, LoRa module for sending data and GSM/GPRS card for uploading data to the server. In a network of stick, dataloggers acquire measure and send them to a gateway with LoRa module. The gateway takes all data from LoRa module and send them to GSM/GPRS card. The GSM/GRPS card upload data in HTTPS server.

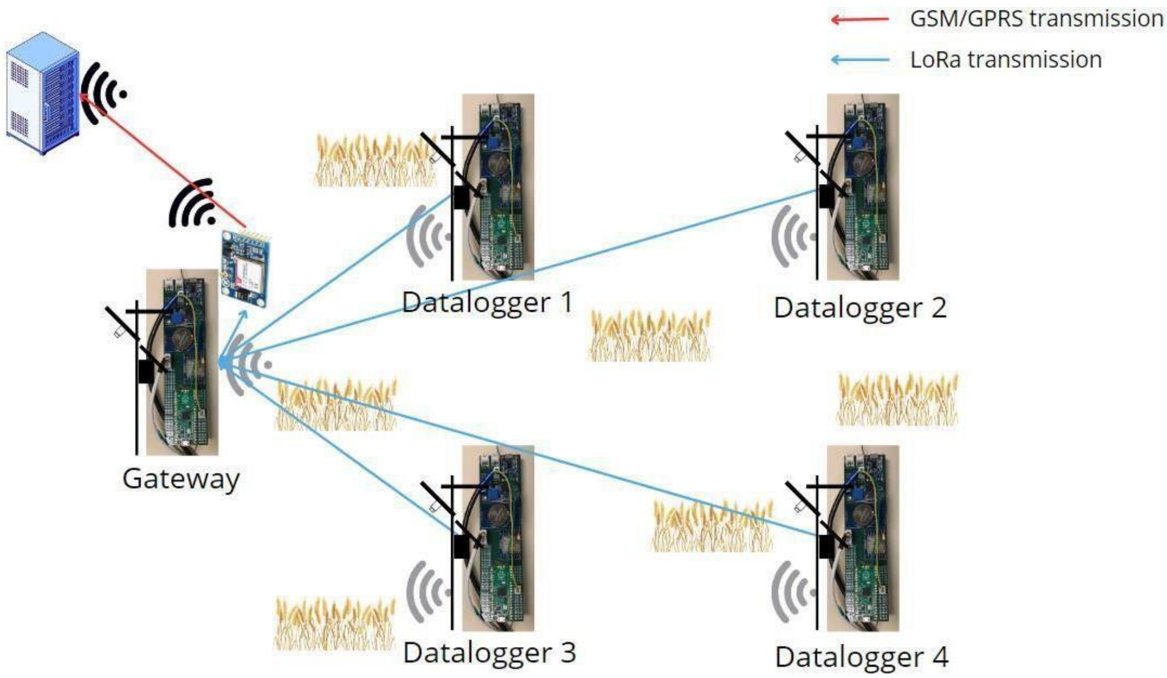


Figure 1. Data transmission figure for a network of stick with datalogger and gateway. One gateway is sufficient in a network because one gateway can gather a set of data and the transmission of data with wireless is heavy in energy consumption.

This section talks about the technical operation of the system.

2.1. Electronic system

2.1.1. Datalogger

The Datalogger is a PCB designed by Xavier Draye which hosts various modules. This PCB is streamlined to accommodate the most essential components: MCU, communication and power supply, and sensors.

1. Microcontroller unit (MCU)

The Microcontroller is an electronic board that integrates code to control data acquisition and transmission. Here, two choices of microcontroller are possible: ESP32 and Raspberry Pico. However, this choice should be based on the card's power to process and store, and on the types of data to be acquired (image, quantitative data). With the chosen microcontroller, the number of sensors to connect is only limited by the number of input/output options offered by the board and the type of port (I2C, UART, etc.). Additionally, the choice of communication principle (I2C, SPI, UART, 1Wire, etc.) between the microcontroller and a sensor is flexible. For example, two elements can communicate in a hierarchical (I2C) or asynchronous (UART) manner. Two interesting microcontrollers that are cost-effective can be mentioned: ESP32 and Raspberry Pico. Finally, the microcontroller has an internal clock that is always active, useful for timing acquisitions, but it is easily subject to drift.

2. Clock (RTC)

A constantly active clock is used to wake the microcontroller at a regular schedule. It is very useful for solving the problem of the microcontroller's clock.

3. Communication

LoRa : An electronic board is used to prepare and transmit data. Low in power consumption, it can cover an optimal radius of over 10km. It can be useful for connecting to a gateway. A gateway is a datalogger equipped with a GSM/GPRS card. It is capable of sending small volumes of data in the form of character strings. Sending images is very challenging.

GSM/GPRS card: The GSM card provides a wireless GSM/GPRS connection to send data (character strings or images) to an HTTPS server. It has a port for a standard SIM card with an active account, available commercially, allowing access to the cellular network.
Connected to an antenna, the stick can cover a wide radius and access the cellular network. However, among the stick's components, the GSM/GPRS card is the most power-hungry.
Equipping it on every stick in the network is not mandatory; it can be installed on at least one stick. By attaching the GSM/GPRS card to the datalogger of the stick, a gateway is created. The stick with the gateway facilitates connection to the cellular network and can be placed closer to buildings for mains power or on a battery with a more powerful solar panel.

SD card slot : Depending on the model of the MCU (Microcontroller Unit), the Datalogger can include an SD card slot for integrating code, storing data, and manually retrieving data. Local communication is also possible, depending on the MCU model used.

4. Power supply

Battery : The stick is powered by a lithium battery, providing a voltage of approximately 3.7 to 4.2 volts. This battery supplies electricity to the microcontroller unit, sensors, and communication components of the Datalogger board. It is connected to the Datalogger using a JST-PHR-02 connector

Solar panel : A solar panel generates electricity for the battery with a maximum power of about 5V. The solar panel is modular, and the chosen model should generate power up to the limit of the installed battery's capacity. It is connected to the Datalogger using a JST- PHR-02 connector.

Power regulator : A power regulator is used to stabilize the incoming electrical power before distributing it throughout the PCB. It can also manage the battery's recharge.

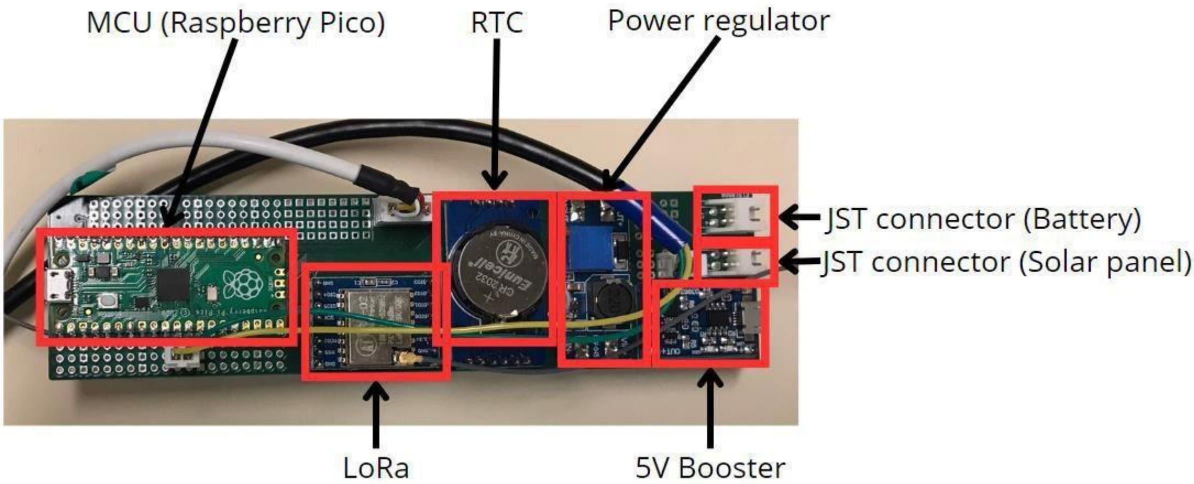


Figure 2. Datalogger with MCU Raspberry Pico

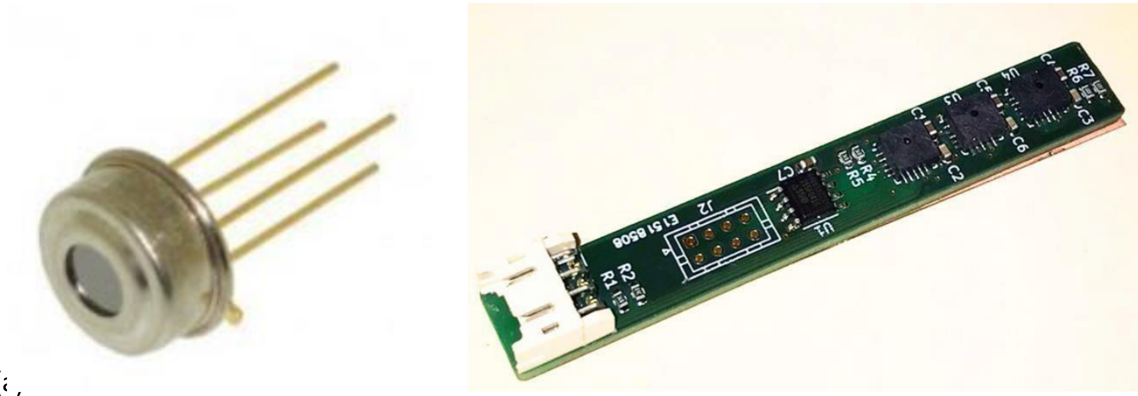
2.1.2. Phenotyping and envirotyping sensor

The sensor selection is flexible in terms of energy capacity, consumption, and sensor type (physical or electronic). Below are the possible types of sensors that can be integrated into the Datalogger:
Pure analogic : The sensor must be paired with an ADC (Analog-to-Digital Converter) to make the data usable in Python or C programs in the datalogger. The ADC converts continuous signals captured by the sensor into digital data. However, the limitation of this sensor is its temperature sensitivity, which affects the accuracy of measurements. For example, a thermistor can be used to measure voltage on a continuous scale. Noise on this signal translates into noise in the data.

Analogic with built-in ADC : The integration of the sensor is straightforward. The main limitation is the cost of the sensor, which is determined by the prices listed on sales platforms and by the manufacturer.

Pure digital : This type of sensor is low in energy consumption. However, it requires the activation of the microcontroller to process the sensor's measurements. For example, a sensor that detects an event or counts pulses (like a wind sensor counting the number of rotations per second) would fall into this category.

Point (a datum = a pixel) ou camera (a data = an image)



(a) (b)

Figure 3. IR Thermal Sensor (for envirotyping) (a) and Spectrometer (for phenotyping) (b)

Sensor supply voltage : To have a power port that provides the same supply voltage for the sensor

Sensor consumption : Choose sensors considering their activation time and power consumption. It is crucial to ensure that the activation time and consumption are limited to what is strictly necessary. For instance, a sensor with high power consumption and low activity level is more energy-demanding than a sensor with low consumption and high activity.

2.2. Operation of the System

The solar panel powers the battery. The code for controlling data acquisition and transmission is embedded in the MCU. The stick's configuration is done manually by directly interacting with the code in the MCU. If the code is not stored on an SD card, the Datalogger/gateway needs to be extracted from its stick to interact with the code. The RTC clock wakes up the sensors and the MCU. Based on a time set by a user in the code, the internal clock activates the MCU. Sensors connected to the MCU are then powered to perform measurement acquisition. In dataloggers, their data are sent to the gateway via LORA. In gateway, its data are sent to the SIM800 card. The gateway receives the datalogger’s data via its LoRa module. The gateway sends it over the cellular network with the SIM800 card to an HTTPS server. After acquisition and transmission, the MCU stops powering external components and goes into standby mode, cutting off power to the sensors.

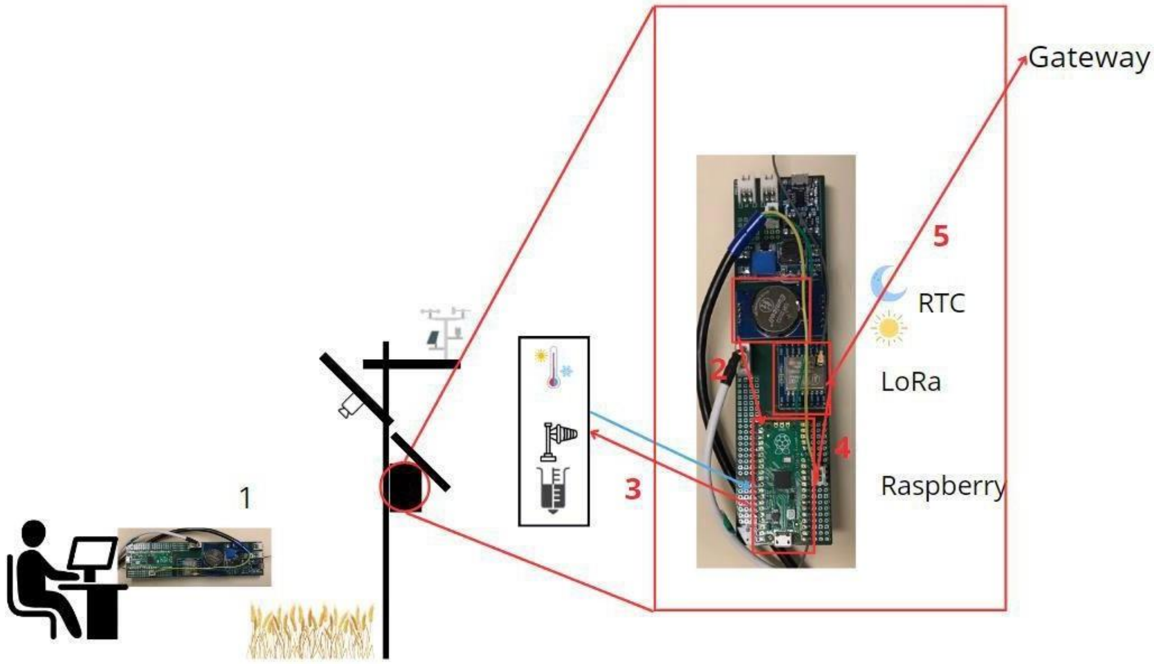


Figure 4. Operating system for datalogger. The configuration is done directly on the MCU of the Datalogger (1). After configuration, the Datalogger is placed in its mother box. During the acquisition campaign, the RTC clock wakes up the Raspberry. The acquisition code is launched. Sensor measurements are acquired and stored in the Raspberry (3). They are transmitted to LoRa (4) so that the data can be sent to the Gateway (5).

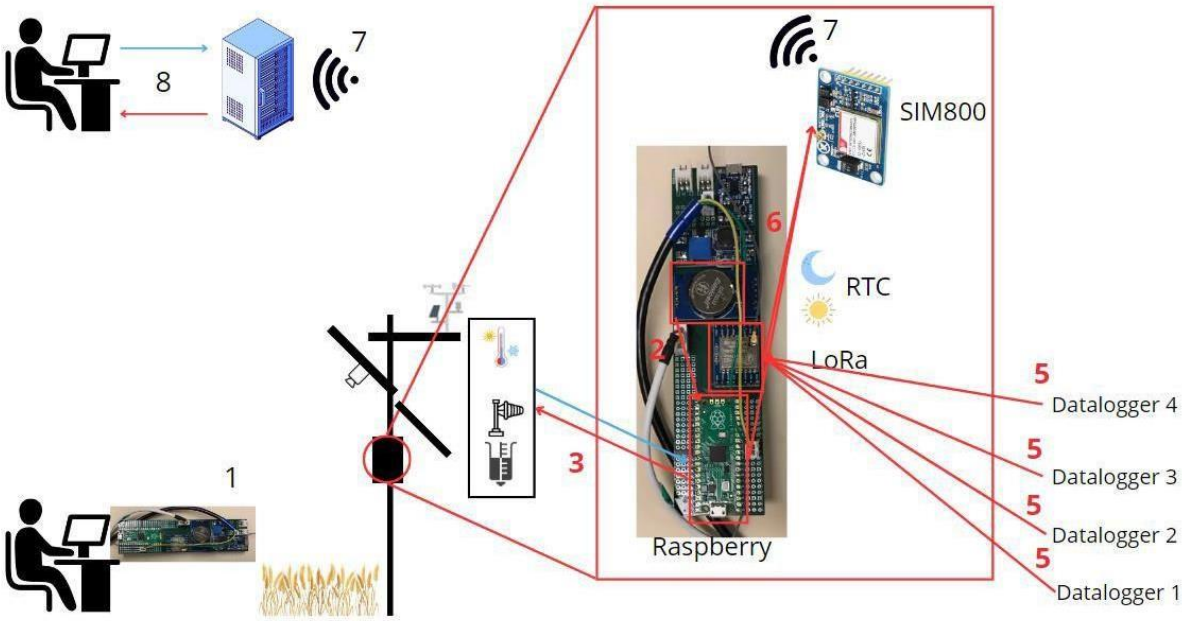


Figure 5. Operating system for gateway. The configuration is done directly on the MCU of the Gateway (1). After configuration, the Datalogger is placed in its mother box. During the acquisition campaign, the RTC clock wakes up the Raspberry. The acquisition code is launched. Sensor measurements are acquired and stored in the Raspberry (3). The gateway get its own data and datalogger's data (5). It sent the data to the GSM card (6) to be uploaded to a wireless cellular network on an HTTPS server (7). From this server, the data can be accessed by a user (8).

2.3. Flexibility of the Stick

The stick is designed for experimental units and has two main advantages. Firstly, the cost of its components is low. Secondly, the body of the stick is modular. On this body, a user can easily fix the position of electronic components (Datalogger and sensors) and poles using simple tools. The choice of sensors is flexible within the limits of the Datalogger's power and memory capacity and the available connections on the MCU.

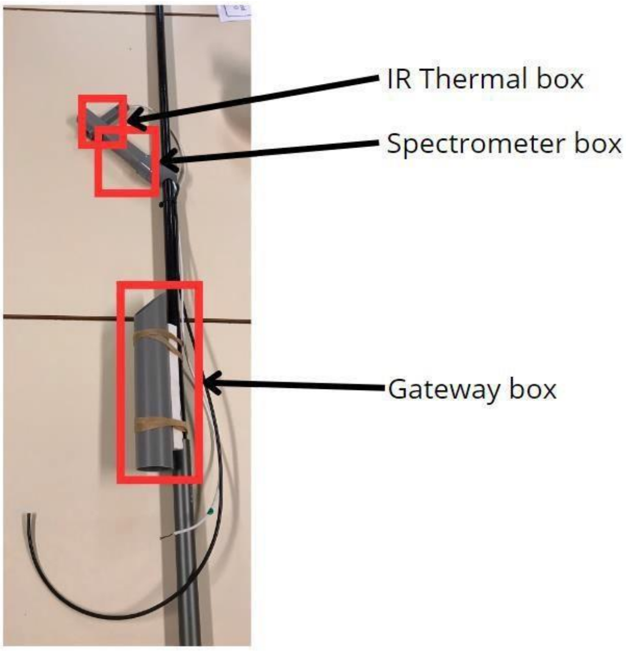


Figure 6. The boxes (sensor and Datalogger/Gateway) are modular on the mast.

3. Design of Our Connected Stick

3.1. Overall Vision

The stick is composed of a fiberglass pole, an environmental sensor, a sensor for phenotyping, a casing containing the Datalogger, and a solar panel for power supply. The pole is an adjustable fishing rod that can extend up to 5 meters. The parts containing the sensors are PVC tubes. One part is open for the phenotyping sensor through a hole closed with a glass microscope slide. The parts that make up the body of the stick were obtained in a workshop.

Figure 7. UC Louvain stick

More specifically, you can find information about the materials used for manufacturing in the document attached to this report: Bill of material IoT UCLouvain - 20231214.xlsx.

3.2. Principle of Assembly and Replicability

The principle of keeping the sensors and the housing detachable. Only the parts of the Datalogger remain permanent.

Permanent Assembly: This assembly involves the Datalogger housing and the connection of the cards and ports on the PCB. The Datalogger housing is a PVC tube open at both ends. It is fixed vertically on the mast. A solar panel closes the upper part of the tube with adhesive, for example. Regarding the connection of the cards and ports on the PCB, connecting these components requires soldering. Once the number of ports (determined by the number of sensors to be connected) is determined, the ports are soldered to the PCB next to the Raspberry Pi. These ports remain fixed. However, these ports can be removed, but it requires desoldering work.

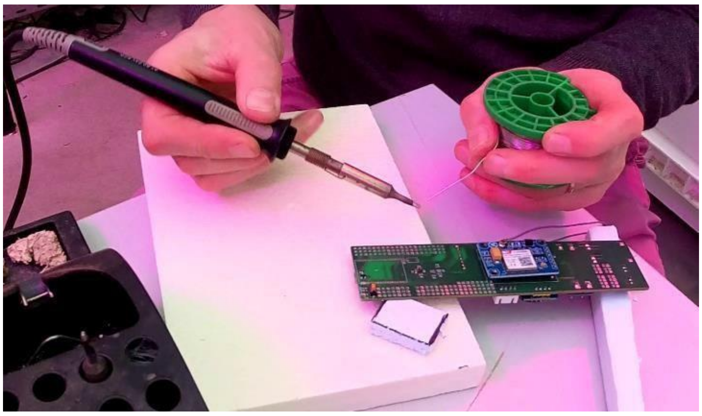


Figure 8. Soldering a port onto the PCB.

Detachable Assembly (Replicability): This assembly concerns the sensors, the enclosures (Datalogger and sensor), and the attachment of the components to the mast. The sensors and the Datalogger are connected by a detachable connector. The Datalogger enclosure is secured by two elastics, making it mobile. The mounting hardware can be replaced with a steel hose clamp for permanent outdoor attachment. Inside the enclosure, the Datalogger is suspended under the solar panel. A user can remove the Datalogger from the enclosure by disconnecting it from the solar panel.

The sensor enclosures are made from assembled PVC tubes. Inside the enclosures, the sensors are attached to insulating foam. With a PVC support, the enclosures are easily attached and removed.


(a)

(b)

Figure 9. Assembly of the sensor enclosure (a) and the Datalogger enclosure (b)

3.3. Assembly of the Parts

This section presents the implementation protocol. We have:

- PCB designed by Xavier Draye
- MCU : Raspberry Pico
- Environmental sensor : Temperature sensor
- Phenotyping sensor : Spectrometer
- Power supply : Solar panel
- Sensor box : pvc tube
- Sensor box support: pvc tube
- Mast : Fishing rob

The datalogger consists of :

- MCU : Raspberry Pico
- Communication : LORA
- Clock : RTC
- Power supply : 3.3V battery

The Gateway consists of :

- MCU : Raspberry Pico
- Communication : LORA
- Clock : RTC
- Power supply : 3.3V battery
- 5V Booster : MT3608
- Transmission : SimCom GSM/GPRS card

Mother box : The main enclosure contains the Datalogger and the solar panel. It is a PVC tube. The solar panel is connected to the Datalogger and then slid into the tube from below. Then, the tube is closed by the solar panel. The main enclosure is attached to the mast with two elastics. Stability is ensured by insulating foam. The enclosure is closed from below with a small plastic hatch.

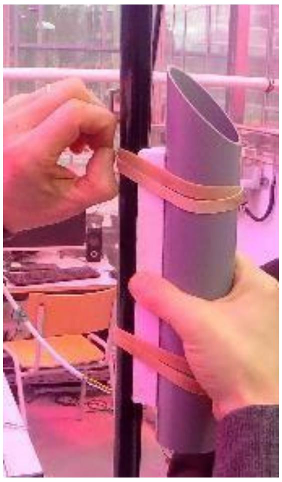


Figure 10. Attachment of the main enclosure to the mast

Sensor box : The enclosures are assembled from PVC tubes. Regarding the temperature sensor, a simple tube is sufficient. The insulating foam is used to secure this sensor inside the tube. Its position is set not too far from the opening to prevent the tube walls from interfering with the measurements, nor too close to avoid overexposure to light. As for the spectrometer, a custom PVC tube assembly has been created. The spectrometer collects its measurements through an opening covered by a glass microscope slide. The spectrometer is attached to an insulating foam. The enclosures are closed with a small plastic hatch. The enclosures can be assembled to form a single piece. The sensors are connected to the Datalogger from beneath the main enclosure.

Figure 11. Assembly of the sensor enclosure on the pole.

Sensor support: The support is a simple PVC tube with a transversal hole to be installed from the top of the mast. The sensor enclosure is inserted into the hole of the support.

Figure 12. Mounting the sensor support on the mast

3.4. INSTALLATION

The post can be installed both indoors and outdoors. Indoors, the PEPA team used a concrete base with a PVC plinth to secure the post.

4. HUMAN-MACHINE INTERFACE (HMI)

Human-machine interaction takes place when the post is configured and the data is received.

4.1. STICK CONFIGURATION

Stick configuration is the programming of a stick acquisition campaign. This programming takes place in the MCU's source code. For the Raspberry, programming is carried out using Thonny software in micropython. For the ESP32, programming is carried out on the Arduino software in C language or in micropython on Thonny. To write the programme, you need to be familiar with the MCU and the programming language.

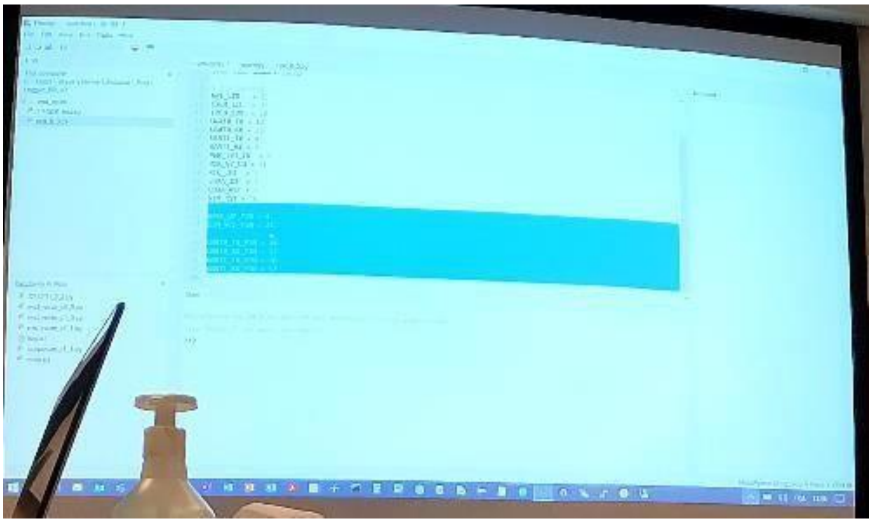


Figure 13. Stick configuration on Raspberry MCU using Thonny software

4.2. DATA RECEPTION

Data can be received in two way : directly with SD card or with wireless connexion with HTTPS server.

In this section, we discuss about the reception by data with HTTPS server. Data are sent by GSM/GPRS card to HTTPS server connected to PHIS interface.

5. Particular constraint

Datalogger selection: Our Datalogger does not allow the acquisition of images. Indeed, the LoRa card only returns a string of characters. And, its transmission speed is slow.

Vibration effect : The size and flexibility of our rod make it very sensitive to vibrations caused by wind and rain.

Transmission : The GSM/GPRS card has difficulty transmitting data. The transmission is under development.

Port size on PCB: The size of the female ports restricts the space for connecting other female ports. By transitivity, this limits the number of sensors that can be connected to the Datalogger.

6. Perspective and Development

PCB : The Datalogger's PCB will be streamlined to simplify the board's structure.
Vibration effect : Search for another financially accessible mast.
Transmission : Make wireless transmission possible.

7. Contact for Additional Information

The stick was designed by Xavier Draye (xavier.draye@uclouvain.be). This document was written by Herearii Metuarea (herearii.metuarea@univ-angers.fr), Julien Garnier and David Rousseau from Université d'Angers.

8. Conclusion

The stick allows for envirotyping and phenotyping experiments. Apart from the Datalogger, it has been designed to be Do-it-yourself, modular, and usable both outdoors and indoors in a building. A user has the option to install a set of sensors without going through a soldering step on the Datalogger. They also have the choice to fix their sensors anywhere and think about the shape of the stick's body. It is yet a prototype. The practical use of the stick in PHENET projects will allow the assessment of its limitations and advantages.

PHENET – Deliverable D2.1

Designation	Destination	Unit cost	Qty	Cost	Part number	Manufacturer	Web info	Supplier
PCB-Datalogger	Datalogger	7	1	7	-	Eurocircuit	Kicad PCB design - Github XD	Eurocircuit
MCU Option 1	Datalogger	6	1	6	Raspberry Pi Pico	Raspberry	www.raspberry.com	Electronic supplier (Farnell...)
MCU Option 2	Datalogger	6	1	4	ESP32 WROVER IE			
								
RTC module	Datalogger	2,08	1	2,08	DS3231 Module			AliExpress
LoRa module	Datalogger	4,31	1	4,31	Ra-02	Ai-Thinker		AliExpress
5V Booster	Datalogger	2	1	2	MT3608			AliExpress
Battery charger	Datalogger	0,7882	1	0,7882	TP4056			AliExpress
SIM module	Datalogger	3,77	1	3,77	SIM800L EVB			AliExpress
SMT components	Datalogger	6	1	6	-	-	Kicad BOM - Github XD	Electronic supplier (Farnell...)
				0				
Thermal sensor	Sensor box 45°	17	1	17	MLX90614	Melexis		Electronic supplier (Farnell...)
				0				
Spectrometer PCB	Spectrometer	5	1	5	-	Eurocircuit	Kicad PCB design - Github XD	Eurocircuit
Spectrometer SMT	Spectrometer	28	1	28	-	-	Kicad BOM - Github XD	Electronic supplier (Farnell...)
				0				
Stick	Stick	12	1	12		Decathlon		Decathlon (or AliExpress)
				0				
Solar panel	Datalogger	4,97	1	4,97	CNC120x180-5	iSNK	5V 3W	AliExpress
Battery	Datalogger	3,17	1	3,17			Lithium 104050 3.7v 2500 mAh	AliExpress
				101,0882				