Interreg North-West Europe

REAMIT

European Regional Development Fund

WP T1 - Deliverable 3.2

User Manual for REAMIT pilot tests

Improving Resources Efficiency of Agribusiness supply chains by Minimizing waste using Internet of Things sensors (REAMIT)

REAMIT

User manual for each pilot test

Table of content

1 Introduction

The aim of this document is to guide step-by-step any users willing to test the REAMIT technologies. Each pilot will present and detail the manner to install and configure the sensors and additional equipment deployed on site. The objective is to make any users autonomous in deploying any component of one pilot for test purpose.

2 Base configuration of technologies

While the system architecture of each pilot is designed on a case-by-case basis, the REAMIT deployed technologies were built upon one of two network / communication stacks. These were either LoRa-based solutions or cellular-based solutions. The communication stack was generally chosen on the convenience and feasibility of installing a LoRa gateway, except for the pilots based in the Netherlands since they have nationwide LoRa coverage from provider KPN thus do not need additional hardware to use the LoRa network. LoRa-based solutions followed the same registration procedure, while the cellular-based solutions implemented in this project were all based upon the Digital Matter Eagle datalogger. This section therefore reviews the common configuration and components of each of these two network stacks which the pilot-specific solutions were built upon.

2.1 Configuration template for LoRaWAN-based pilots

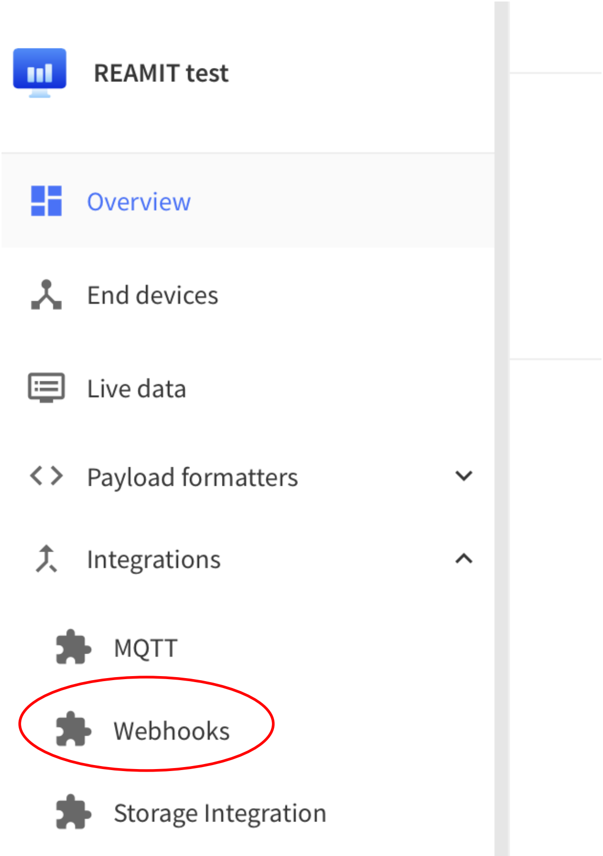
All pilots which used the LoRaWAN network architecture used TheThingsNetwork(TTN), a global collaborative Internet of Things ecosystem that creates networks, devices and solutions using LoRaWAN. It contains a LoRaWAN network server, built on an open source core, allowing a user to build and manage LoRaWAN networks on their own hardware or in the cloud. TheThingsNetwork service acts as a 'middleman' between the pilot company's sensors and the REAMIT server, translating the packets sent by the devices into meaningful data that can then be displayed and stored on the REAMIT dashboard / server. This service is the de-facto way to connect LoRaWAN sensors to the cloud. Once data is recorded in TheThingsNetwork, it can be retrieved, transferred, and displayed to REAMIT applications using the API / webhook functionality. Each LoRaWAN based pilot followed the following steps for sensor configuration.

Configuring sensors to TheThingsNetwork

1. Create a user account for TheThingsNetwork
2. Login to the TheThingsNetwork, click "Console" then "Applications"
3. Click "Create application", and fill out the details (Application ID can be REAMIT-***-app where *** is the pilot name, for example) and finally click "Create Application"
4. On the main screen you will now see your TTN application, now we can add devices to the application.
5. Click "Register end Device" and on the menu that appears inset the following information.
    - Device ID – a unique identifier for this device
    - Device EUI – this is obtained from the sensor
6. Click "register"
7. Click "Manage devices" and then click your newly created device
8. Copy the "Application EUI" from TTN and copy it into the field within LoRaWAN settings on your device.
9. Copy "App key" and paste into "Application key" on your device
10. Click "Data" within your device in TTN and you should see packets start to appear after a few minutes.
11. This means the sensor is now successfully connected to a TTN application.

Connecting TTN to the Whysor cloud

1. On the left-hand menu of applications, expand the 'Integrations' dropdown and select 'Webhooks'

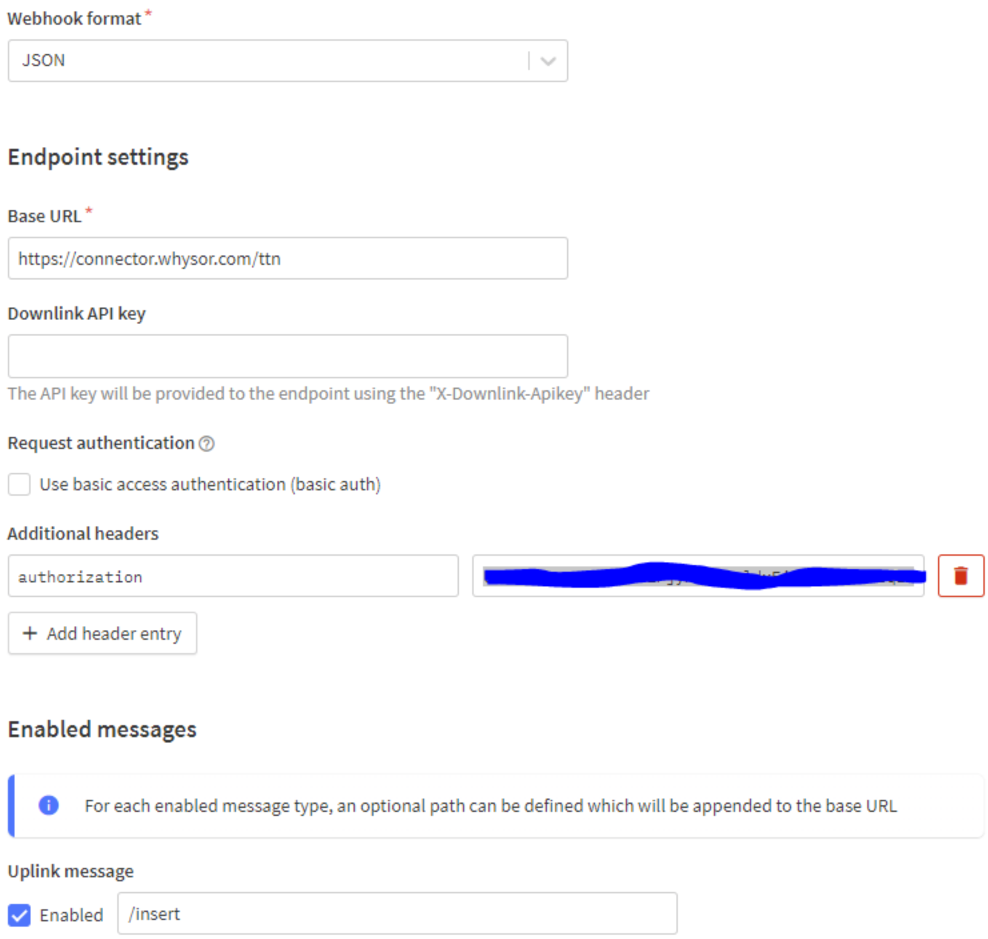


2. Select add webhook, then on the next screen select Custom webhook.
3. Give the webhook a custom ID (for example REAMIT-*** where *** is the pilot name)
4. The following is Whysor platform specific information:

Webhook format: JSON
URL: https://connector.whysor.com/ttn
Additional Header: authorization : xxxxxxx

Where xxx is the authorisation token provided by Whysor.

5. Check Uplink message enabled and add : "/insert"
6. Save changes



2.2 Configuration template for Cat-M1 / 4G based pilots

All pilots which used the cellular CAT-M1 / NB-IoT 4G based network architecture deployed the Digital Matter Eagle (Digital Matter, South Africa) cellular datalogger. The logger is an IP67 rated rugged cellular IoT device, supporting a range of inputs for various IoT applications. The Eagle runs on either 4 x C Alkaline or Lithium Thionyl Chloride (LTC) batteries, or can be wired to permanent power (6-16 V DC). It contains I2C, SDI-12 and RS-485 interfaces as well as 2 x analogue inputs, 3 x digital inputs, 2 x switched ground inputs, and 2 x 4-20 mA inputs, thus supporting a vast array of sensors to connect to the device. Additionally, it has an onboard GPS module and an accelerometer for geofencing and movement detection, and is equipped with a SIM card allowing the device to run on the IoT low power LTE-M (CAT-M1) network. The Eagle offers third party cloud integration via HTTPS webhook allowing for the convenient retrieval of recorded data for visualisation and analytics.
Each pilot test which utilised this logger was equipped as standard with a temperature / humidity probe. For this, the highly accurate and robust T9602 Temperature / Relative Humidity (T/RH; +-2% RH, +-0.5 oC, 0.01 oC resolution) I2C sensor (Amphenol, USA) was chosen.

List of base equipment deployed for 4G based pilots:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Digital Matter (South Africa)	Eagle logger	Upload real-time data, Trip detection
Amphenol (USA)	T9602 T/RH sensor	Measurements of Temperature and Relative Humidity

Step-by-step installation and configuration guide:

1. **Software set-up**

The Digital Matter loggers are configured through a vendor-specific platform, called OEM-server. The following steps and images show the configuration applied there in detail.

Step 1: Configuration of the T/RH sensor

Configuration of the T9602 T/RH sensor was set for inputs 8 and 9 in this example. For the Whysor platform input 8 is always chosen for Temperature and input 9 is always chosen for Humidity. As this is a Whysor platform specific convention, other platforms may use different inputs.

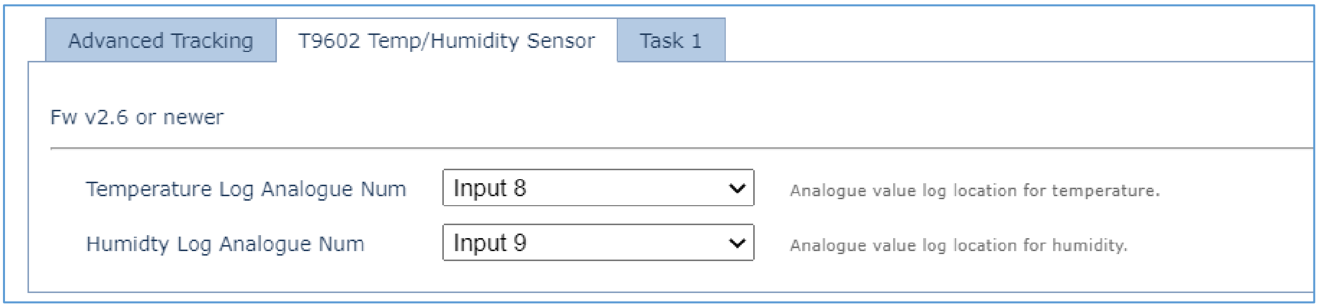


Figure 1 Sensor configuration

Step 2: Configuration of the task

The configuration of the task defined for the pilot test defines the measurements and sending frequency of data (temperature, humidity, in/out of a trip, GPS, battery voltage). Those frequencies are defined for either a sensor is in a trip or out of a trip.

For the sensors inside the trucks a trip detection algorithm was developed based on accelerometer measurements and GPS data reported by the Eagle logger. A trip is reported if motion is detected by the accelerometer and if the GPS coordinate has changed from the previous reading. After a trip is detected, the sensors will start measuring temperature and humidity every 5 minutes and send the data every hour. Out of a trip the sensors measure every 2 hours and send data every 4 hours. Alerts are not sent when the truck is out of a trip. This algorithm allows the system to sleep when trips are not being performed to conserve battery life, as well as avoiding sending false alerts while trucks are parked overnight.

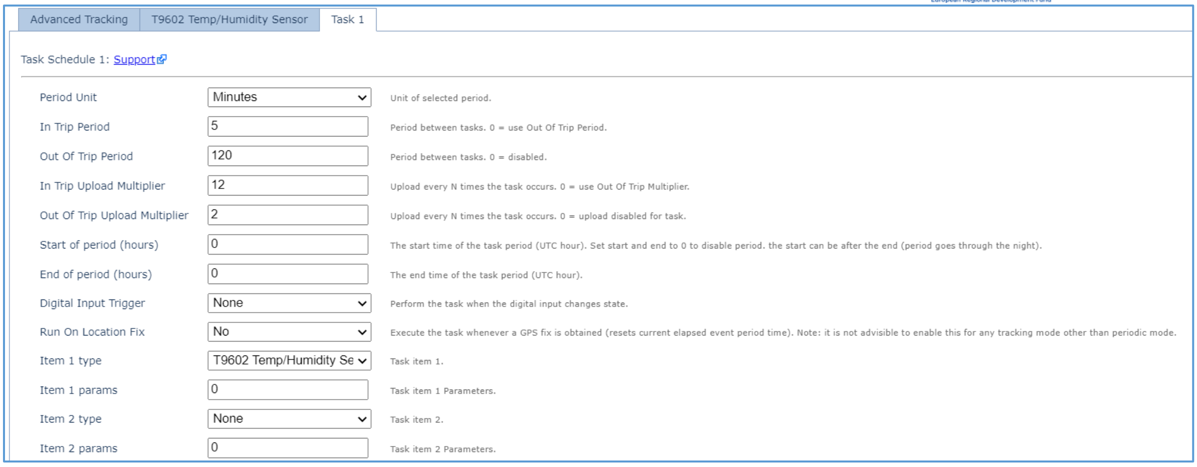


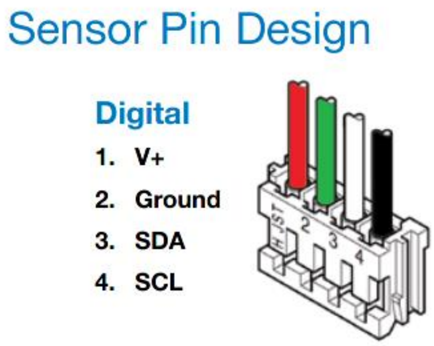
Figure 2 Task configuration

Hardware set-up

Step 1: Connecting sensor to logger

Firstly, the T9602 T/RH sensor needs to be prepared for installation in the logger. In order to connect the temperature probe to the Eagle's screw terminal, the connector the probe comes with needs to be removed by cutting it off. When the logger is opened, on the top left side of the printed circuit board (PCB) the following inputs are observed: 3.3v, i2cSCL, i2cSDA, and gnd. Figure bellow displays the corresponding wire colour of the T9602 for the inputs.

The Amphenol RV/T sensor is delivered with a connector having the following pin design:



When the connector has been removed, wire strippers should be used to remove each of the cables insulated coating and exposing the copper wire underneath. Approximately 1cm of insulation should be removed per cable. Note that some of the black cable insulation will also need removed to provide the required length on each cable to reach each screw terminal. Wire cutters and strippers are required for this job.

Given the colour of the cable and the logger terminals, the sensor should be wired from the top red, black, white, and green. Note there is an exposed wire with no insulation too. This should also be wired into gnd along with the green wire. Figure 3 shows the complete temperature probe wiring.

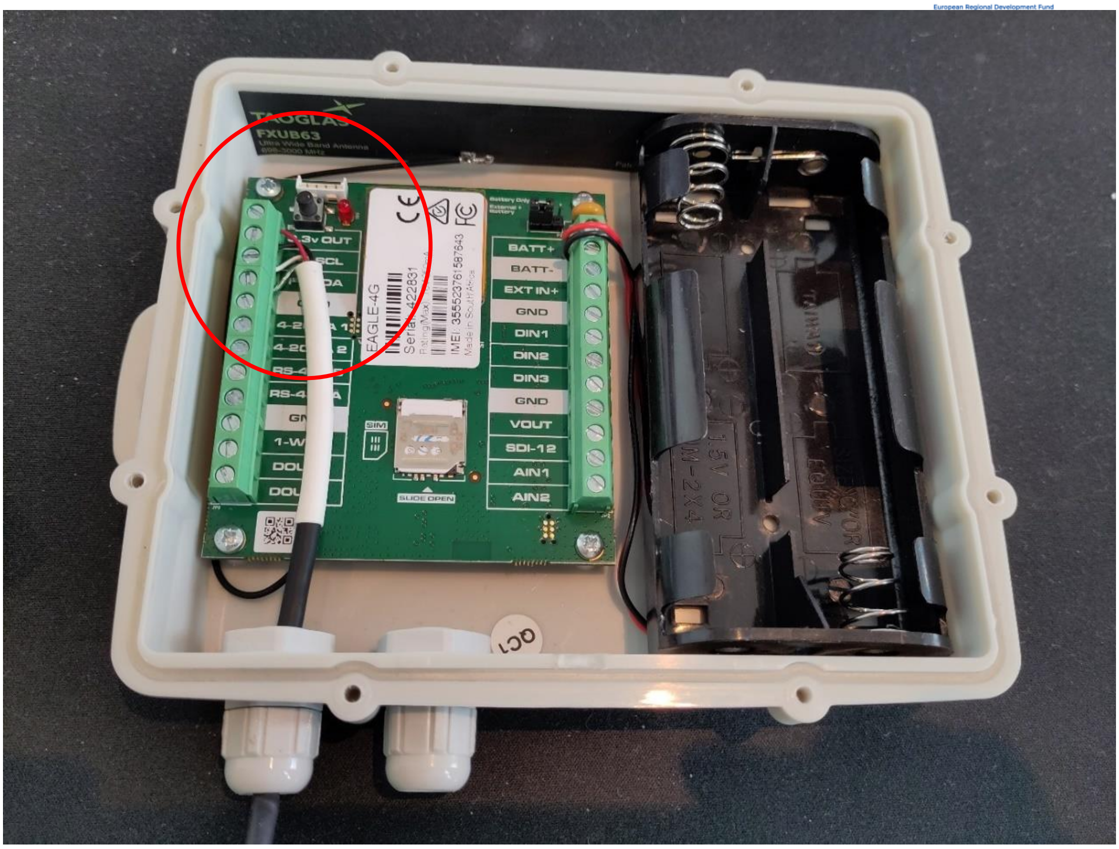


Figure 3 Connecting sensor to the logger

Step 2: Batteries

The Digital Matter Eagle logger runs on 4 x C Alkaline batteries that are normally installed before configuration. After configuration the batteries are removed again and reinstalled before installation at the customer's site.

Figure 4 Total hardware set-up

Step 3: Connectivity configuration

The Digital Matter Eagle logger is using a cellular connection to report data. Its modem supports two radio access technologies (RAT): Cat-M1 and NB-IoT. In order to make a

successful connection the device has to be set with the correct RAT, as well as the cellular band to be scanned.
This is done via a special USB-dongle and software, provided by Digital Matter (see Figure 5).

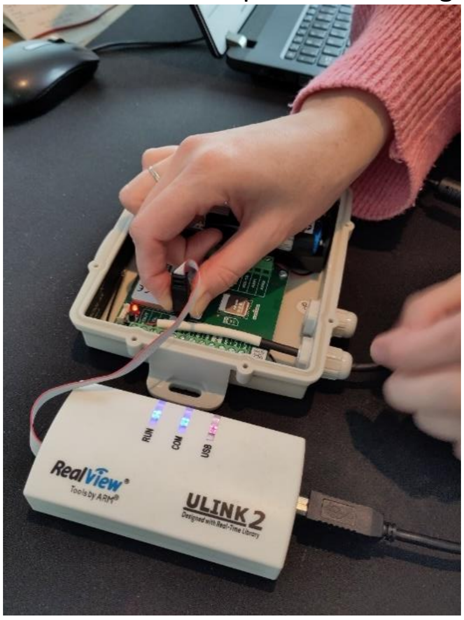


Figure 5 Connectivity configuration

Based upon the provided infrastructure of the pilot company country’s and the connectivity tests Whysor conducted, Cat-M1 was selected as RAT on band 8 and 20 (see figure 7). This worked in both the UK and Luxemburg, where the Eagles were deployed.

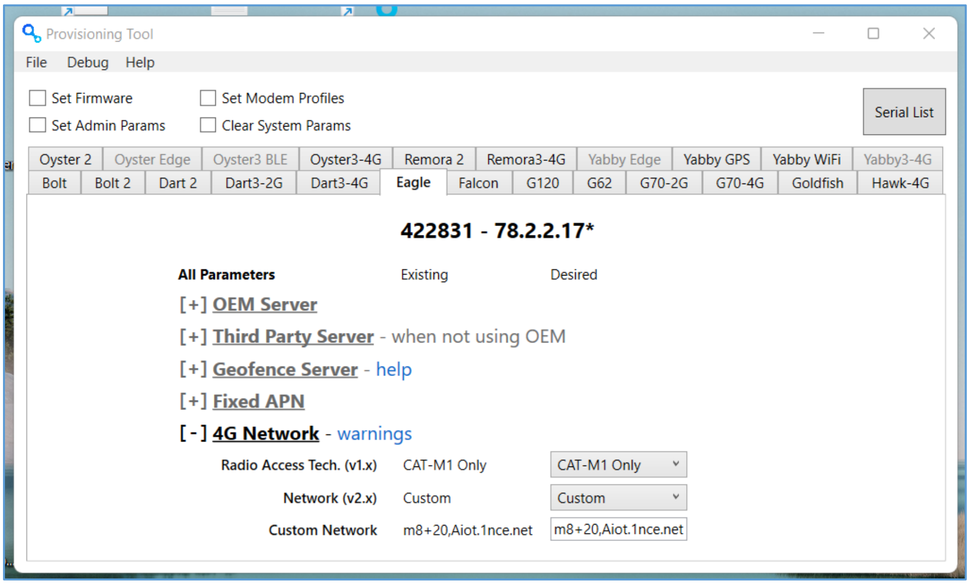
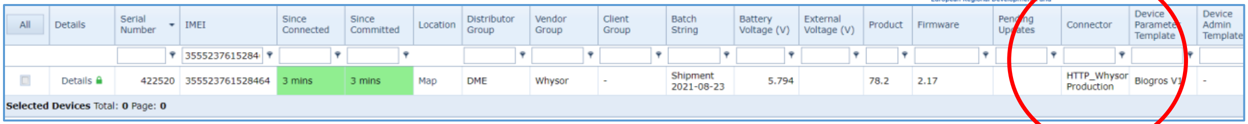


Figure 6 RAT and Band

Step 4: Platform integration
In the OEM-server the user can set an endpoint via the connector option of the server. This determines where the data of the logger is forwarded to.



All	Details	Serial Number	IMEI	Since Connected	Since Committed	Location	Distributor Group	Vendor Group	Client Group	Batch String	Battery Voltage (V)	External Voltage (V)	Product	Firmware	Pending Updates	Connector	Device Parameter Template	Device Admin Template
			3555237615284															
	Details	422520	355523761528464	3 mins	3 mins	Map	DME	Whysor	-	Shipment 2021-08-23	5.794		78.2	2.17		HTTP_Whysor Production	Biogros V1	-

Selected Devices Total: **0** Page: **0**

Figure 7 Connector option OEM-server

For the purposes of the REAMIT-project, the data was forwarded to the Whysor platform. For this, Whysor developed a specific endpoint for Digital Matter devices to connect to. As this development is Whysor-specific, it is out of the scope of this document to describe this process.

3 Dutch Pilot

3.1 REAMIT technologies for last mile supply chain with Picnic

Short pilot description:
Based on the Picnic data driven weather regime, online supermarket Picnic decides daily how many icepacks are added to every box that contains refrigerated items and how much dry ice is added to every box that contains frozen items. Picnic wants REAMIT to prepare a personalized cooling profile per box, using data from a.o. the Picnic weather regime, the duration of travel, such as shipment from Picnic regional fulfilment centre to Picnic local hub and the duration of the last mile delivery of every box.

Architecture of the pilot:

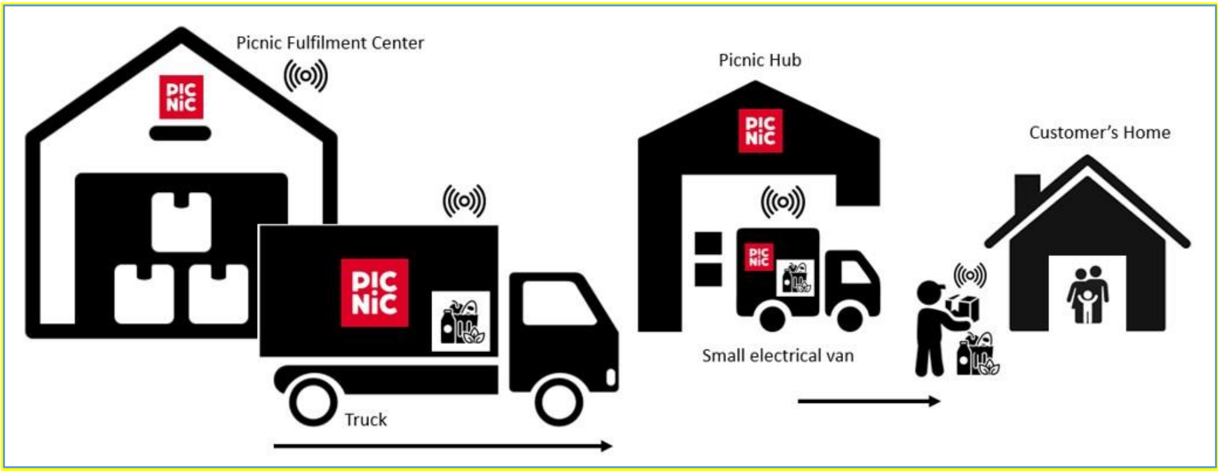


Figure 8 Picnic Supply chain

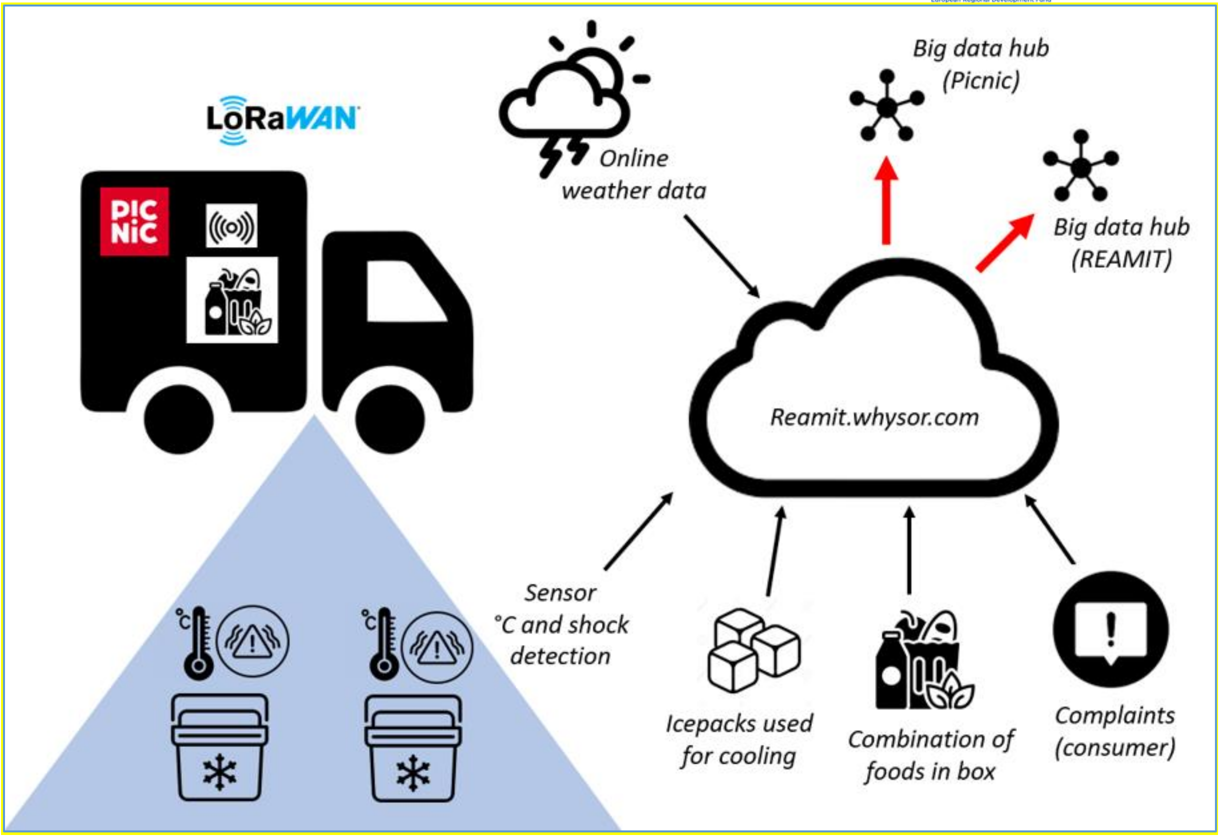


Figure 9 Proposed IoT solution

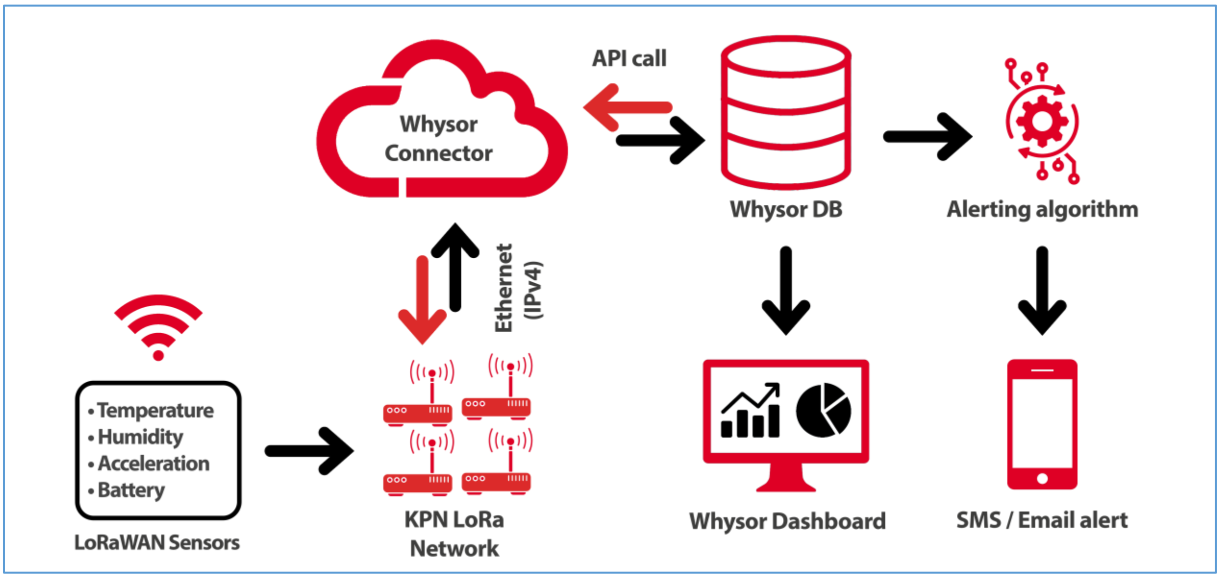


Figure 10 System Architecture

The REAMIT cloud is used to store the recorded values of the sensors. The sensors send values to the cloud periodically.

To ensure an optimal battery lifetime the sensors in this pilot are configured to send data every 10 minutes. Also, a lower transmission speed has been chosen. With this configuration, battery life is expected to be 1-2 years.

The data collected from the sensors is sent to the LoRaWAN gateway by the loggers. In turn the gateway sends the data to the Whysor database directly. From the Whysor database the data can be sent to various systems (see Figure 10).

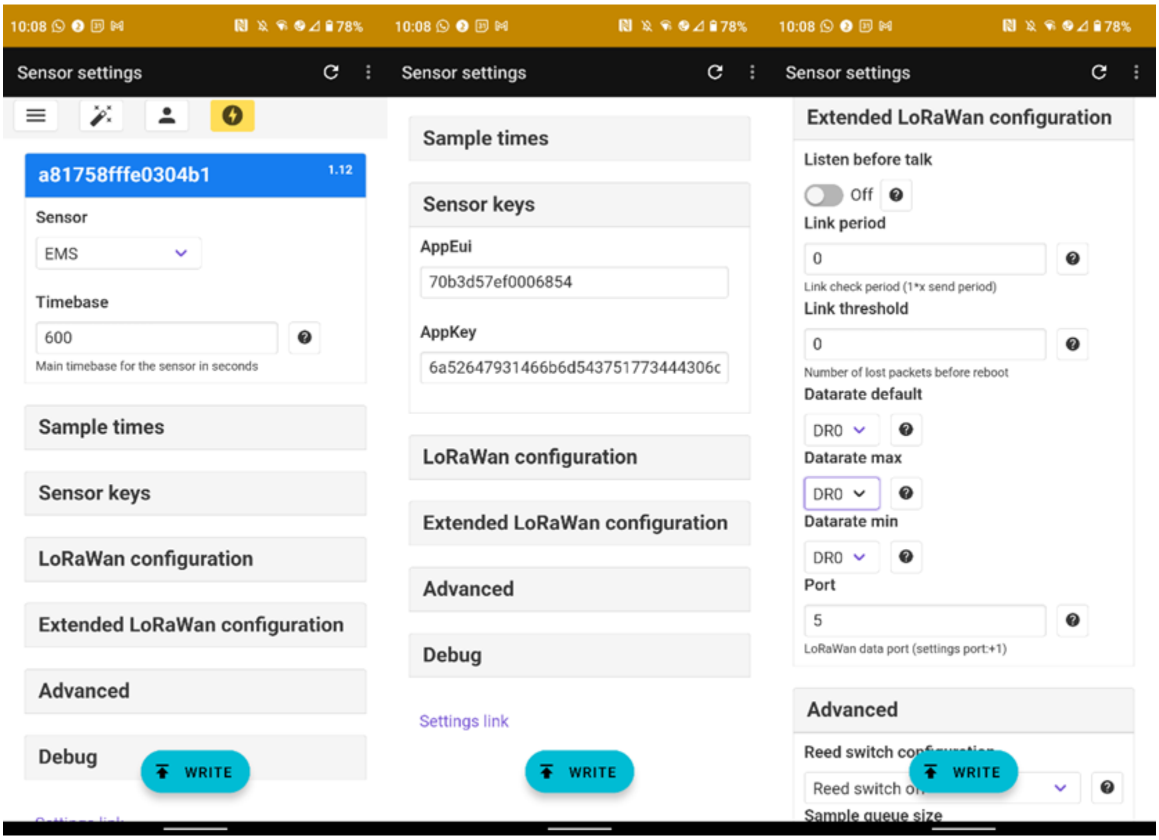
- Data can be analysed using the Whysor Dashboard which provides an overview of the collected data.
- Data can be used to trigger SMS/Email alerts when rule conditions are triggered.
- Data can be forwarded to the REAMIT big data hub to ensure all pilot partners have access to the data.

List of equipment deployed for this pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Elsys (Sweden)	EMS	Measurements of Temperature, Relative Humidity and shock detection

Step-by-step installation and configuration guide:

1. **Software set-up**



From the Elsys settings app perform the following actions :

1. Put a 3.6 V lithium battery into the EMS device.
2. Open the Elsys settings app and select advanced settings (the button highlighted yellow in the left most screenshot).
3. While having the Elsys settings app open, tap the sensor with your phone to read the NFC tag of the EMS sensor. The active settings will be displayed.
4. Set the timebase to 600 seconds (10 minutes).
5. Open the sensor keys tab.
6. Copy the AppEui, DevEui (in the blue bar at the top of the app) and AppKey and note them down.
7. Open the Extended LoRaWan configuration.
8. Set the datarate default, max and min to 'DR0'. This locks the spreading factor to 12 to insure the most consistent data delivery.
9. Click the blue write button at the bottom of the screen.
10. After you press the bottom tap the NFC tag of the sensor and the app will display settings written.
11. Use the noted down keys from step 6 to register your device at your gateway (depends on network configuration).

2. Hardware set-up

Mount the sensor with the provided protected rings, put the battery in and that's it! There are no external sensors.

Good practice and recommendations:

<u>Recommendations</u>

Protecting the sensor when the boxes are filled with groceries, has appeared to be challenging, due to the frequency of handling and the impact of heavy groceries.

The tracing of sensors that are not working needs more research because of the complexity of the Picnic box routing method.

<u>Good practice</u>

The technical specifications of the sensors meet the expectations of Picnic. The sensor responds well to changes in temperature and has a stable signal during all phases of the transport.

4 Luxembourg Pilot

4.1 REAMIT technologies for farm to retailing with pilot partner company Biogros

Short pilot description:
Biogros is a wholesaler for high quality organic and biodynamic foods (3.500 items in fruit, vegetables, dry goods and dairy produce) in Luxembourg. For more than 25 years, Biogros has been supplying high quality organic food six days a week to their Luxembourg customers.
Biogros stocks products from well-known organic brands like Naturata, Rapunzel and Lebensbaum, as well as organic products from lesser known or smaller producers. Thanks to their close collaboration with organic farmers from the cooperative Bio-Bauern-Genossenschaft Lëtzebuerg (BIOG), they also offer a whole range of regional organic products.
While receiving deliveries from BIOG organic growers in Luxembourg, Biogros noticed that the quality of fragile produce, such as mushrooms, unions, potatoes and celery roots, would occasionally not be up to standard. Biogros wants to gain insight in the climatic conditions (temperature and humidity) in the full supply chain, from grower to supermarket.

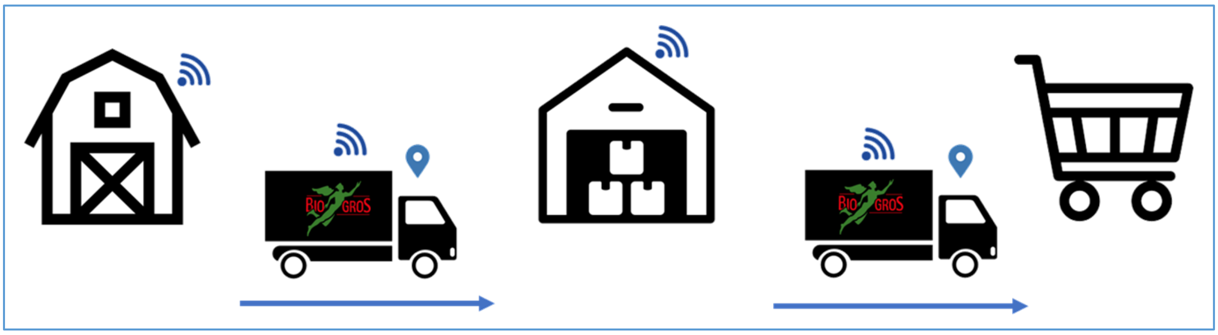


Figure 11 Biogros' supply chain

Architecture of the pilot:
Biogros sought a system which would perform the following:

1. The trucks should be connected to the cloud to allow for real-time data reporting / monitoring while the trucks perform deliveries
2. The warehouses of both the farmer and Biogros should be connected to the cloud, measuring temperature and humidity to allow for real-time data reporting/ monitoring
3. An alerting system should send SMS messages to drivers and warehouse logistics staff notifying if any anomalies occur
4. Alerts should not be sent when the trucks are stationary e.g., parked overnight, performing a delivery, etc.
5. The power consumption of the proposed system should be such that maintaining the equipment does not become a laborious task

The REAMIT team at Whysor (the Netherlands) examined Biogros' system requirements and proposed a real-time monitoring and alerting system for anomaly detection during the full supply chain.

The system needed to allow real time data upload while the sensors were moving in trucks. Loggers with cellular connectivity were selected because these loggers also include the feature of detecting whether a truck is moving or stationary, this is also known as trip-detection.
For the Biogros pilot, the logger was fitted with a Temperature/ Relative Humidity sensor, to allow monitoring in ambient and chilled zones of trucks and warehouses.

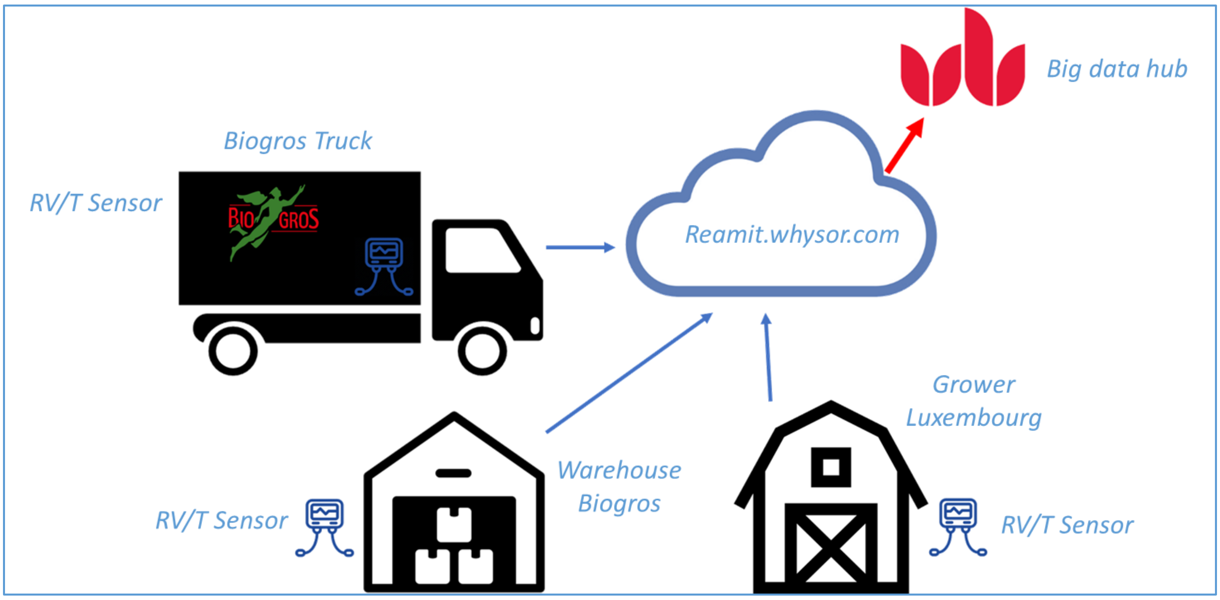


Figure 12 Proposed IoT solution

The REAMIT cloud is used to store the recorded values of the Amphenol RV/T sensors. The Digital Matter Eagle loggers send values to the cloud periodically.
The Digital Matter Eagle loggers are equipped with intelligent firmware which is able to detect whether a logger is moving (in a trip) or not. The sending and measuring frequency is increased when the loggers are moving.
This ensures maximum data accuracy while also making sure the battery life stays optimal. The Digital Matter Eagle loggers' intelligent firmware is able to store measurements locally, and transmit the data periodically e.g.: Measure every 20 minutes and transmit every 6 hours. Also, when the signal quality is poor and a transmission cannot be completed successfully, the Digital Matter Eagle loggers will try again the next transmission. The loggers are also configurable over the air, so changes to measuring and sending interval can be made on the fly.

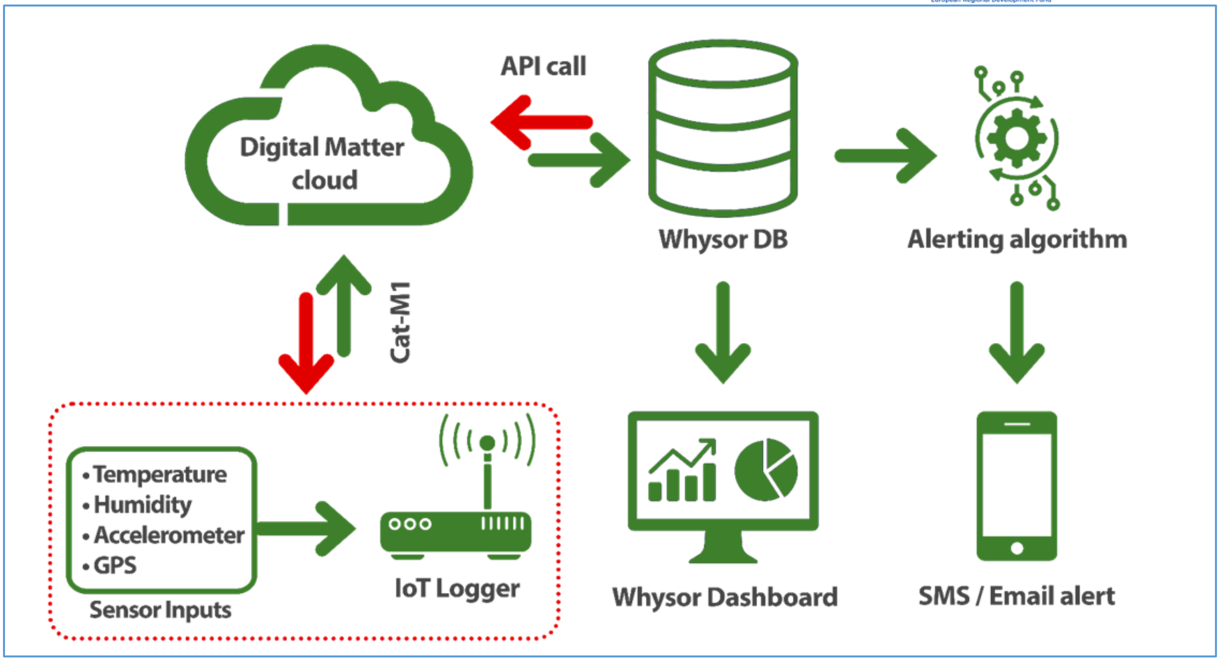


Figure 13 System architecture

The data collected from the Amphenol RV/T sensors is sent to the Digital Matter cloud by the Digital Matter Eagle loggers, using Cat-M1 radio access technologies (RAT). In turn the Digital Matter cloud sends the data to the Whysor database directly. From the Whysor database the data can be sent to various systems. (see Figure 13)

- Data can be analysed using the Whysor Dashboard which provides an overview of the collected data.
- Data can be used to trigger SMS/Email alerts when rule conditions are triggered.
- Data can be forwarded to the REAMIT big data hub to ensure all pilot partners have access to the data.

For the pilot test at Biogros data was visualised using the Whysor Dashboard via reamit.whysor.com (see figure 14).

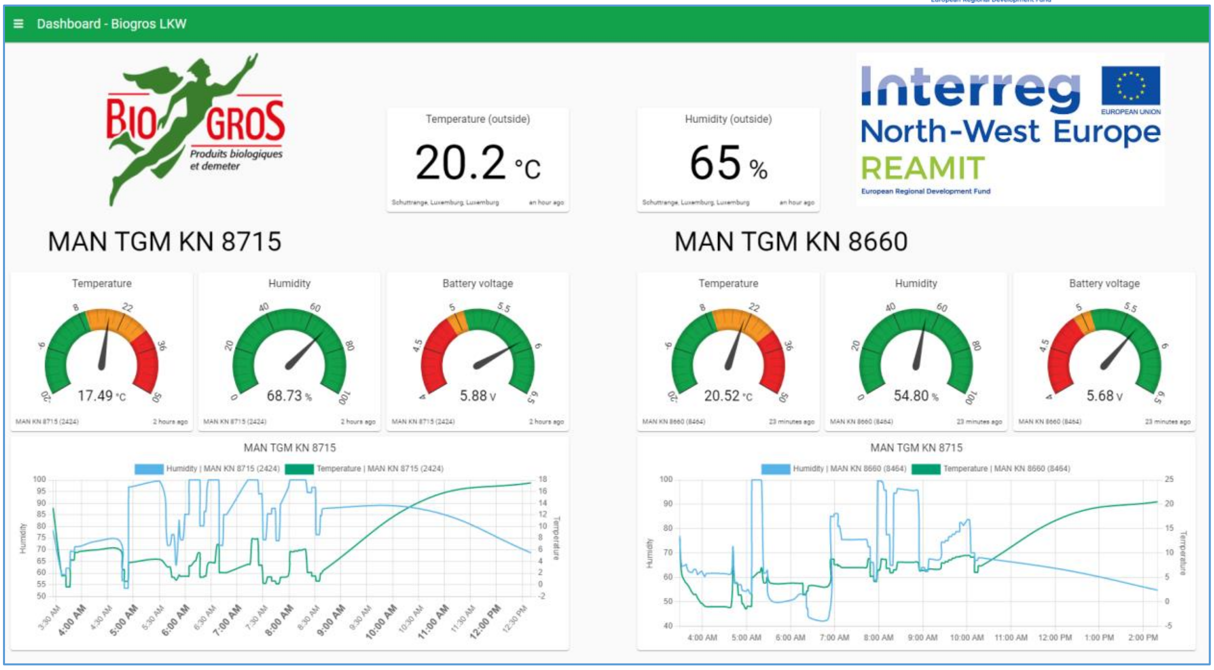
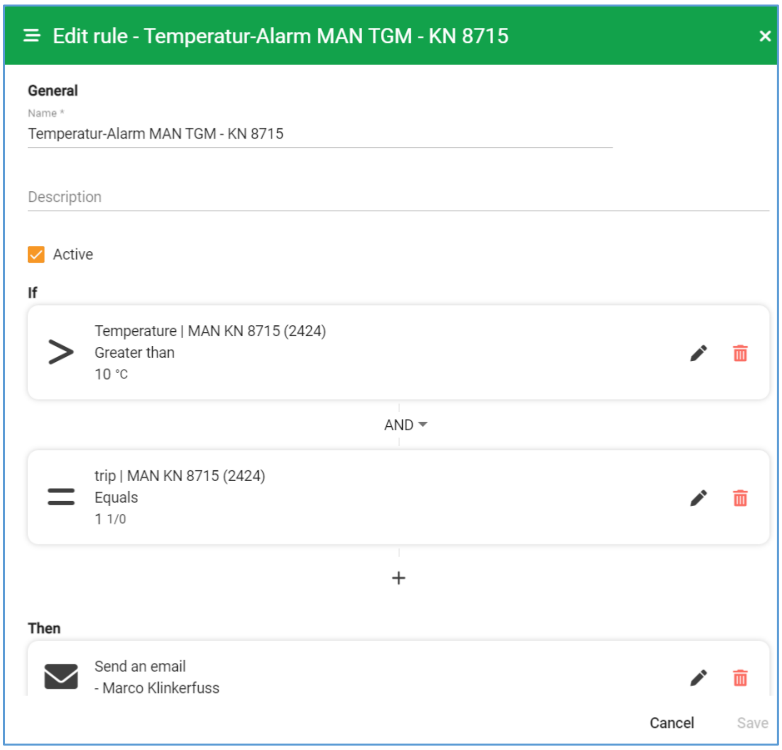


Figure 14 Screenshot of a part of the Biogros REAMIT dashboard

Temperature alerts were defined using the thresholds defined by Biogros, for both the sensors inside the Biogros warehouse and inside the trucks. For example for Truck MAN TGM KN 8715 the Temperature alert is set if temperature is greater than 10°C is measured for 6 executive measurements in a row AND the truck is in a trip for 6 executive measurements in a row. The alert is sent via an e-mail to the Biogros technician.



List of equipment deployed for this pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Digital Matter (South Africa)	[Eagle logger]()	Upload real-time data, Trip detection
Amphenol (USA)	[T9602 T/RH sensor]()	Measurements of Temperature and Relative Humidity

Step-by-step installation and configuration guide:
The Biogros pilot test expands on the Eagle logger base configuration (documented in Section 2.2) by adding trip detection.

1. **Software set-up**

Trip detection on the Digital Matter loggers is configured through OEM-server.

Trip detection:
The configuration of the trip detection has to be set. The default settings are optimized for asset tracking in trucks.

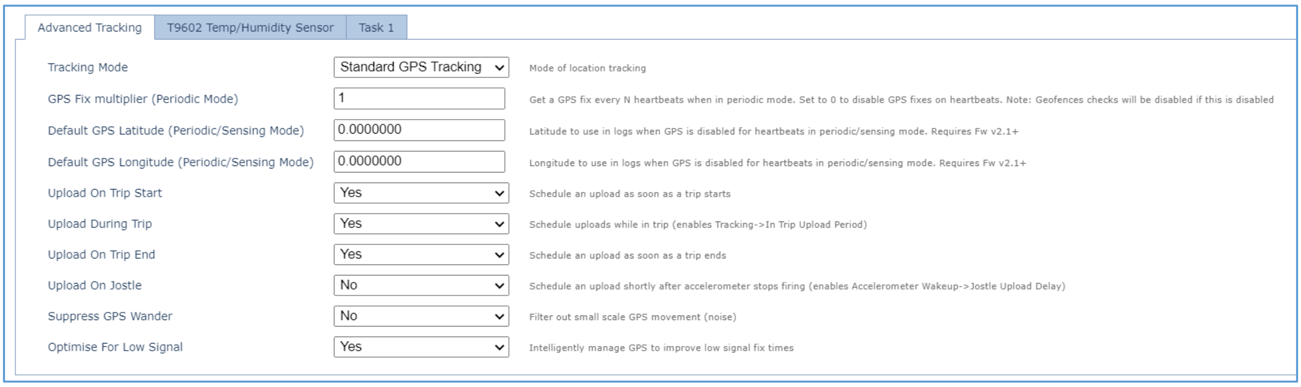


Figure 15 Trip detection configuration

Configuration of the task:
The configuration of the task defined for the Biogros pilot test defines the measurements and sending frequency of data (temperature, humidity, in/out of a trip, GPS, battery voltage). Those frequencies are defined for either a sensor is in a trip or out of a trip.

For the sensors inside the trucks a trip detection algorithm was developed based on accelerometer measurements and GPS data reported by the Eagle logger. A trip is reported if motion is detected by the accelerometer and if the GPS coordinate has changed from the previous reading. After a trip is detected, the sensors will start measuring temperature and humidity every 5 minutes and send the data every hour. Out of a trip the sensors measure every 2 hours and send data every 4 hours. Alerts are not sent when the truck is out of a trip. This algorithm allows the system to sleep when trips are not being performed to conserve battery life, as well as avoiding sending false alerts while trucks are parked overnight.

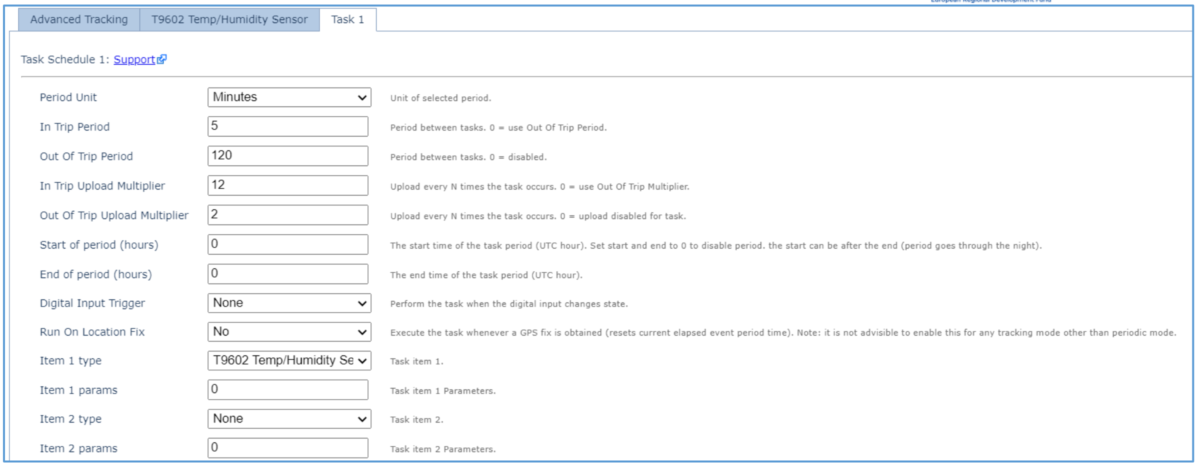


Figure 16 Task configuration

2. Hardware set-up

See chapter 2: Base configuration of technologies

Good practice and recommendations:

<u>Recommendations:</u>

After installation the batteries went empty really quickly. Because default settings of the sensors were set to measure and send data every 5 minutes, the batteries of the sensors had gone empty in a short time. Default settings of sensors are set to send data every 5 minutes, to be able to test whether the sensors are reporting to the connected dashboard, directly after installation, without the installer having to wait for a long waiting time for the first data to be send and received. When Biogros defined how often they wanted to measure and receive data, we altered the settings for the sensors inside the warehouse to measuring every 2 hours and sending data every 4 hours. This extended the lifetime of the batteries from 2 months to approximately 8 months.

We recommend that sensor settings are adjusted soon after installation, to save battery lifetime.

<u>Good practice</u>:

On a Sunday in the beginning of 2023 Biogros received a notification of their own operating system that their cooling system was failing. Normally, in weekends, the operating system would also send a notification to an external service company, hired to resolve malfunctions outside the working hours of the Biogros employees.

In the evening the technician of Biogros received an alert notification of the REAMIT system in his e-mail, telling him there was an anomaly detected in the temperature of the warehouse. Because of the alert, the technician drove to the Biogros' warehouse on Sunday evening and discovered the system failed to send the notification to the external service company and the problem of the cooling system had not been resolved during the day. Due to the alert sent by the REAMIT system, there was no loss of fresh food products and the problem of the failing cooling system was resolved in time.

5 Northern Irish Pilot

5.1 Last mile food delivery with Musgrave NI

Musgrave Group Ltd. Is an Irish food wholesaler, founded in Cork by the Musgrave brothers, Picnic Thomas and Stuart in 1876. It is currently Ireland's largest grocery distributor, with operations in Ireland and Spain, and estimated annual sales of over €4 billion. They estimate that they are responsible for feeding 1 in 3 people in Ireland through 11 leading food and beverage brands whom they supply groceries to. They employ approximately 250 employees and operate from 10 warehouse locations in Ireland. The company is still largely owned by the Musgrave family. Musgrave Northern Ireland, a subsidiary of Musgrave Group, has warehouses in Belfast, Lurgan, and Derry and is headquartered in Belfast, Northern Ireland. Robert Gallagher, Warehouse & Transport Operations Manager at Musgrave recognised that on occasion, the refrigeration units in the delivery vans operating in the greater Belfast area would break down, without any indication to either the driver or the logistics staff at the warehouse. The temperature in van carrying chill and frozen products would rise, resulting in a van load of spoiled stock.

Musgrave sought a system which would connect to the cloud to allow for real-time data reporting / monitoring while the vans perform deliveries. The vans have both a chill and a freeze zone, both of which should be monitored throughout a journey. They wanted an alerting system which would send SMS messages to drivers and warehouse logistics staff notifying if any anomalies occur. However, these alerts should not be sent when the van is stationary e.g., parked overnight, performing a delivery, etc. Finally, the power consumption of the proposed system should be such that maintaining the equipment does not become an arduous task.

Architecture of the pilot:

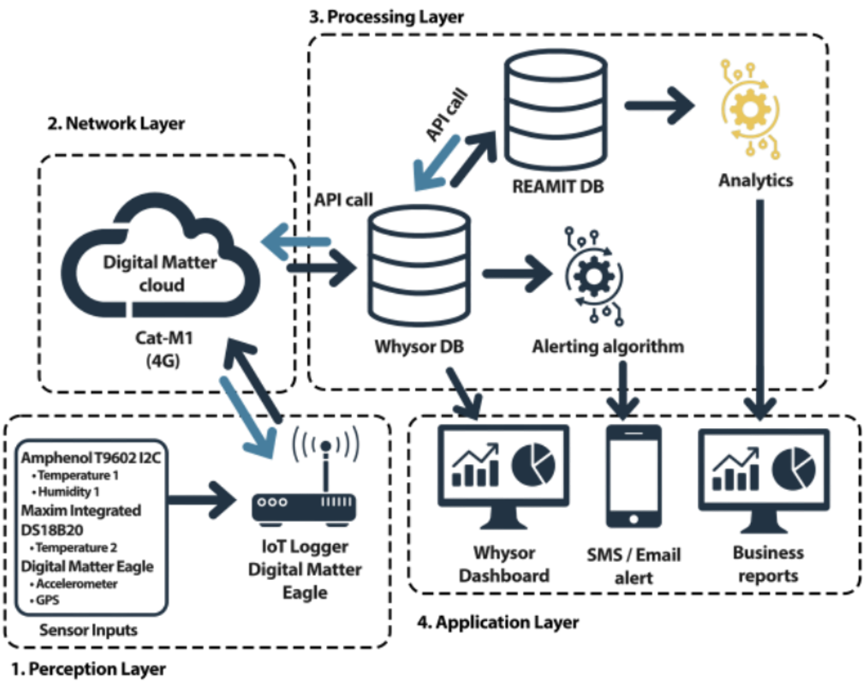


Figure 17 Musgrave architecture

List of equipment deployed for this pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Amphenol	T9602 I2C T/RH	To measure temperature and humidity
Maxim Integrated	DS18B20	To measure second temperature (different zone in van)
Pololu	2119 voltage regulator	Boost Eagle supply voltage from 3.3V to 5V to power DS18B20
Digital Matter	Eagle	LTE-M cellular gateway to connect to the cloud. Also internally logs GPS and accelerometer parameters for trip detection.

Step-by-step installation and configuration guide:
The Musgrave pilot test expands on the Eagle logger base configuration (documented in Section 2.2) by adding a second temperature probe so that both the chill and freeze zones of the van could be monitored at the same time. Additionally, trip detection is enabled for this pilot test.

Step 1: Adding the second temperature probe
Hardware
For the second temperature probe, the popular one-wire DS18B20 was selected. The DS18B20 sensor needs to be prepared for installation in the logger. One caveat of selecting the DS18B20 on a cable run >2m is that it needed a 5v supply due to voltage drop on the longer cable. Unfortunately, the Eagle logger only had a 3.3V supply so a voltage regulator had to be added to the circuit, which would step up the 3.3V to 5V. The Pololu 2119 was selected and added to each of the DS18B20 probes.

Using a soldering iron and 26AWG hook up wire, the DS18B20 was connected following the depiction in Figure 18.

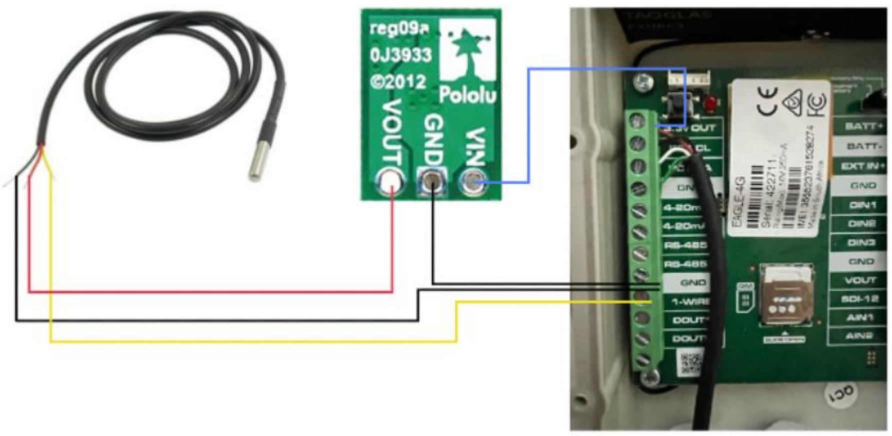


Figure 18 Wiring diagram to add the Pololu 2119 and DS18B20 to the Eagle logger.

Firstly, a hook up wire is soldered to VIN of the 2119 and connected using the screw terminal of 3.3V out. Another wire is soldered from GND of the 2119 and added to the GND screw terminal. The VIN of the DS18B20 (red wire) is soldered into VOUT of the 2119. The black GND of the DS18B20 is added to the GND screw terminal of the logger. The yellow wire from the DS18B20 is added to the 1-wire screw terminal of the logger.

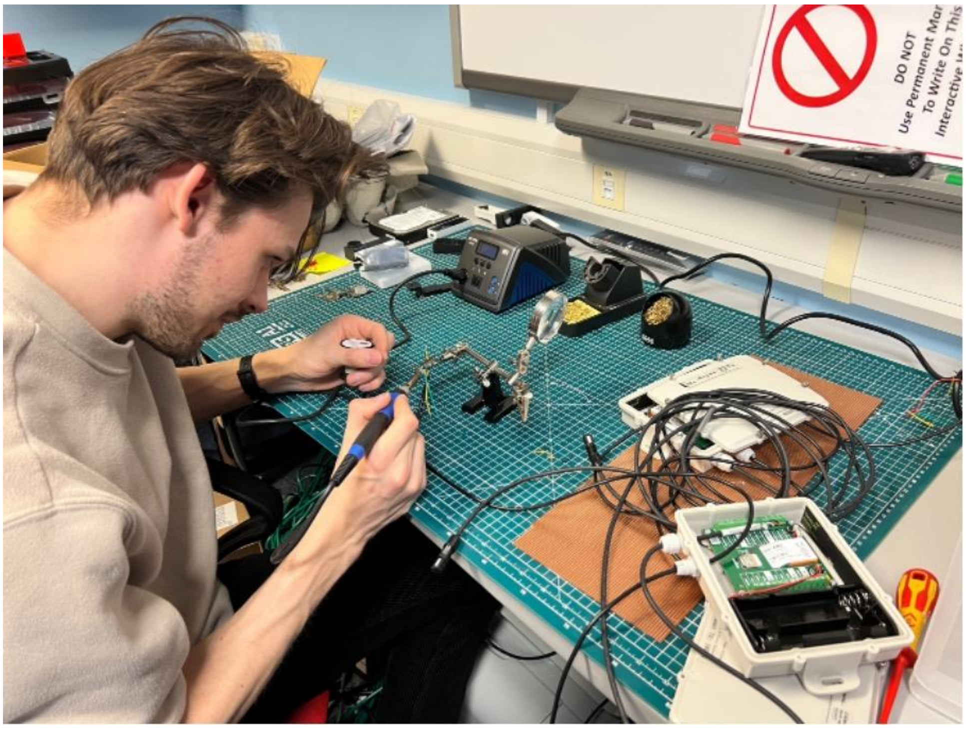


Figure 19 adding the hook up wires to the 2119 using a soldering iron.

Configuration in OEM server

Configuration of the DS18B20 sensor was set for input 12 for the Musgrave pilot. For the Whysor platform input 12 is chosen for a second Temperature. As this is a Whysor platform specific convention, other platforms may use different inputs.

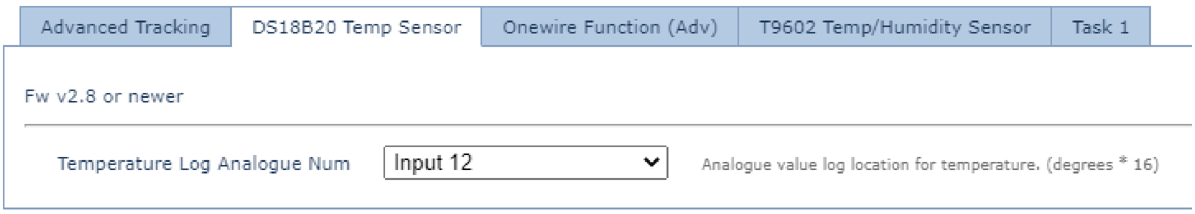


Figure 20 DS18B20 sensor configuration

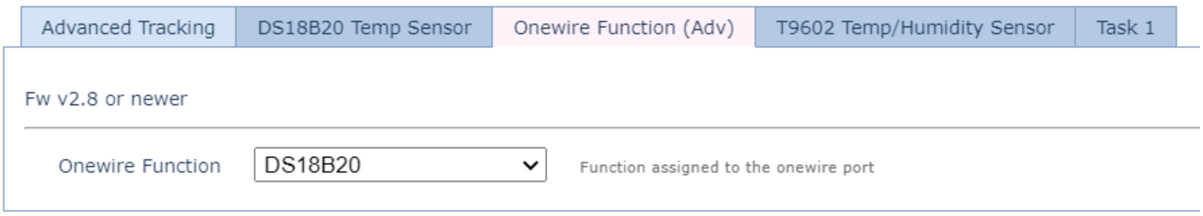


Figure 21 DS18B20 sensor configuration

Step 2 : Adding trip detection
Trip detection was enabled on each of the loggers. The parameters were configured on Digital Matter OEM server as documented in Figure 22.

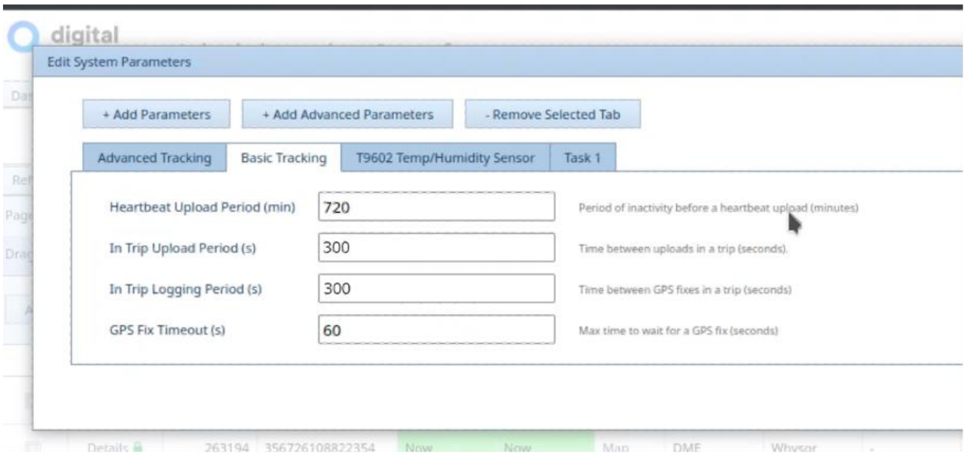


Figure 22 trip detection parameters

When in a trip, the environmental parameters were measured and uploaded to the cloud every 5 minutes. When out of a trip, the parameters were measured and uploaded every 12 hours. To ensure the device did not draw too much power when attempting to detect the trip, a GPS timeout of 60 seconds was applied. If no GPS fix could be achieved within this timeframe, the device would wait 5 minutes before trying again.

Data is uploaded from the device to the Digital Matter cloud. The data is accessible using a HTTPS webhook in real time. The Whysor platform retrieves the data and parses it using their own bespoke database connector, again in real time. At this stage, the data is visualized on the dashboard and the alerting algorithm can be configured.

Configuring alerting
For the alerting algorithm, trip detection status is used as the first condition to ensure the vehicle is in motion. Musgrave knew vans had a cool down period of approximately half an hour and so did not want to receive an alert until this time period had elapsed. Since recordings are uploaded every 5 minutes, the trip condition should therefore be true 6 times before progressing to the next stage of the alerting. Next, temperature threshold abuse is checked. To ensure detection anomalies are avoided, the temperature threshold should be passed twice before sending an alert. Figure 23 shows the alerting criteria configured on the Whysor dashboard.

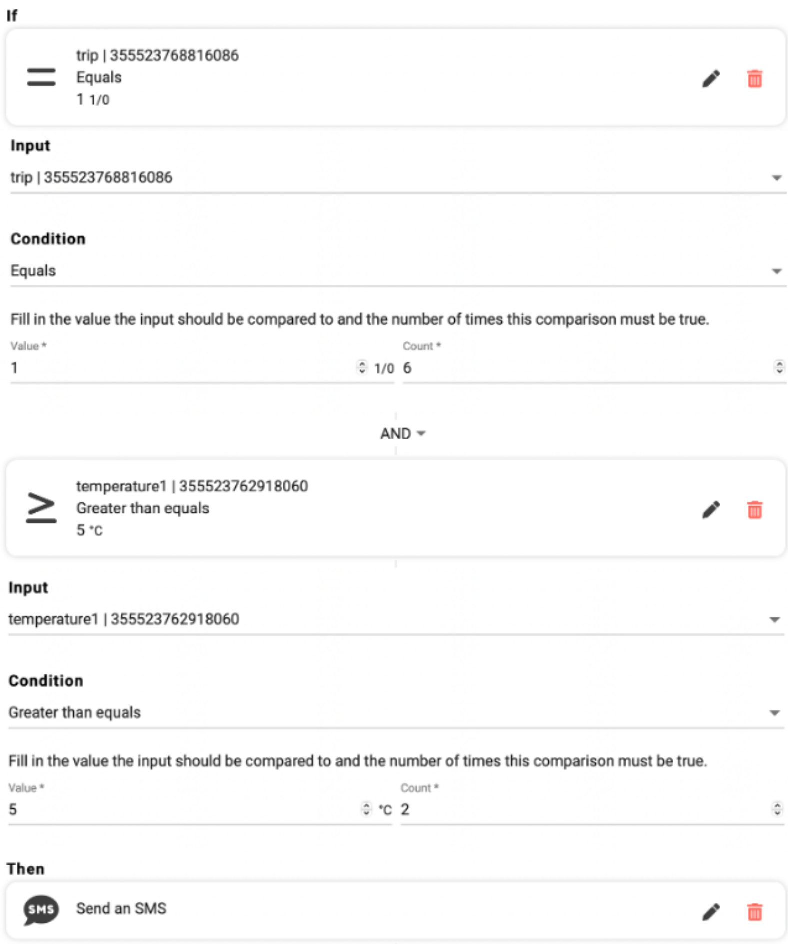


Figure 23 alerting criteria configured on Whysor dashboard.

Installation

The Eagle was affixed to the dividing insulted wall of the van which separates the frozen area maintained at -18oC and the chill area maintained at ~5oC. To mount the Eagle, large cable ties were used and passed through a mounting point which already existed on the wall. Small adhesive cable tie anchors were affixed along the wall and roof of the van before cable ties were used to secure the cables of the sensors. The 3m DS18B20 was used in the freezer compartment of the van and mounted at the 'air on' location of the refrigeration unit (see right hand image). This is where the air gets drawn back into the refrigeration unit after circulating the entire freeze area and is meant to produce the true ambient temperature of the freezer. The sensor was mounted directly below the fan by passing a cable tie around the fan grill. The T9602 was used to monitor the chill area of the van. This was because it also had the capability of monitoring humidity which is more relevant for chilled products (for example vegetables). The T9602 passes through the dividing wall and is affixed to the roof approximately half-way down the chill area. Figure 24 depicts the final sensor setup.

Figure 24 Left: Eagle affixed to dividing wall. DS18B20 affixed to the air-on fan grill for accurate ambient temperature monitoring of the freezer. Right: T9602 used to monitor the ambient temperature of the chill area;

Data Dictionary

Column	Data Type	Description
device_id	Int	Numeric device ID, unique to the sensor
datetime_measure	ISO8601 date-time format, "yyyy-MM-dd'T'HH:mm:ss.SSS'Z'"	Datetime stamp of sensor recording
battery	Float	Battery level during sensor recording
temperature1	Float	Temperature 1 recording, in freezer of van
temperature2	Float	Temperature 2 recording, in fridge of van
humidity	Float	Humidity recording, in freezer of van
device_name	nvarchar(50)	Descriptive name of device. Should help identify where device is installed, but often left as device_id.
trip	char(1)	Indication if the van is being driven (1) or is stationary (0) when the recording was made.

Good practice and recommendations:

Sensor location

Careful consideration should be given to the chosen sensor location to monitor ambient temperature within vans. Ambient temperature monitoring can fluctuate as much as 10oC+ depending on the chosen installation location of the temperature probe. We believe, after experimentation, that the true reflection of ambient temperature within the van is located at the 'air on' site of the refrigerator, which is where the air is drawn back into the compressor after circulating the entire van.

External power

While enabling trip detection has increased battery performance significantly (~6 months), sensor maintenance is still an issue when working with a large logistics company. Therefore, we recommend that, if possible, external power should be added to the loggers so that the maintenance window is reduced much further.

Trip detection sensitivity

The sensitivity of the trip detection algorithm is configurable by adjusting the time out between GPS readings. For Musgrave NI, the detection window was every 5 minutes, meaning this was the time between GPS location checks to detect if the van was in motion. However, if the system was deployed in a traffic dense city, the users of the system could increase this parameter accordingly. Extending the window between trip checking could help ensure trip status remains valid in the case of a traffic jam.

Future work

Future work may wish to explore the use of a geofencing algorithm in the event of a breakdown. Through the establishment of the base location of the vans, the alerting system could be expanded to offer a breakdown monitoring mode if, for example, the van had been stationary for one hour and it was not located at the known home location of the van. Rather than not uploading data due to a lack of vehicle motion, breakdown monitoring mode could continue to upload data in 5-minute intervals, ensuring the integrity of the products.

The warning system currently deployed, which offers alerts via SMS or email, can also be a limitation. It is sometimes the case that logistics staff working in warehouses do not have GSM cell coverage, rendering alerts sent on the SMS system undeliverable. While the email system provides an alternative alerting mechanism to ensure that while out of cell coverage but within WiFi range the end user still receives alerts, many end users do not have push notifications enabled for email due to the quantity they receive on a daily basis. Future work will focus on expanding the alerting system to a smartphone application so that push notifications can be delivered while in range of WiFi.

Additionally, technologies such as the real time anomaly detection system presented could be deployed at each stage of the cold chain to allow for the uninterrupted monitoring of perishable goods. This would result in anomalies being detected not only during transportation, but also during storage, at the retailer, etc. Each of these efforts could further reduce potential food wastage in agri-food businesses.

5.2 Dry ageing optimisation with WD Meats

Located in Coleraine, Northern Ireland, WD Meats have been supplying quality assured beef and innovative beef products to retail customers throughout UK, Europe, Africa and Asia for over 35 years. WD Meats select only the best local beef that Northern Ireland has to offer. Then they process and deliver it with the utmost care and attention to the animals, and to the highest standards that their customers demand. Total traceability of the livestock, their

husbandry and welfare all form part of product specification at WD Meats. WD Meats has a modern, 100,000 sq ft plant, built on a 35-acre site, which incorporates every aspect of the company's processing operation under one roof. The Slaughtering, Boning, Packing and Despatch facilities are all provided in-house, which gives them complete control over all stages of production. This means customers can be assured that the highest standards are maintained throughout. WD Meats employs over 400 staff and have annual sales in excess of £62 million.
At WD Meats, there was an opportunity for optimising the dry-ageing process. This is a 28-day cycle used for premium cuts of beef to both improve the tenderness of the beef and enhance the flavour, achieved by maintaining temperature and humidity in a sealed, refrigerated room. The ideal parameters for this room are still being explored, so it was proposed the REAMIT team fit sensors to the room to help map the conditions during the current ageing process and thus help identify more "ideal" parameters to reduce the weight percentage lost during the process, while avoiding the dark-face phenomenon. "Dark facing" meat forms when too much moisture is drawn from the hindquarter, which must be cut off (or trimmed) prior to sale. This meat is classified as food waste.

Architecture of the pilot:

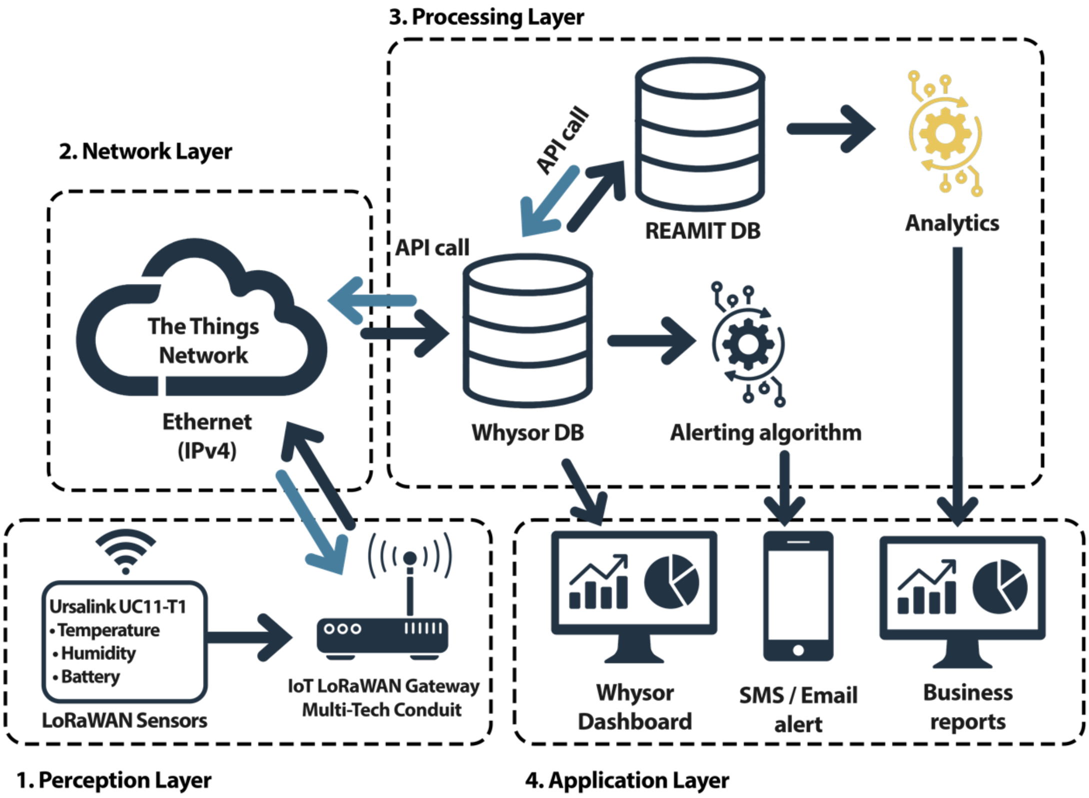


Figure 25 WD Meats architecture

List of equipment deployed for this pilot:

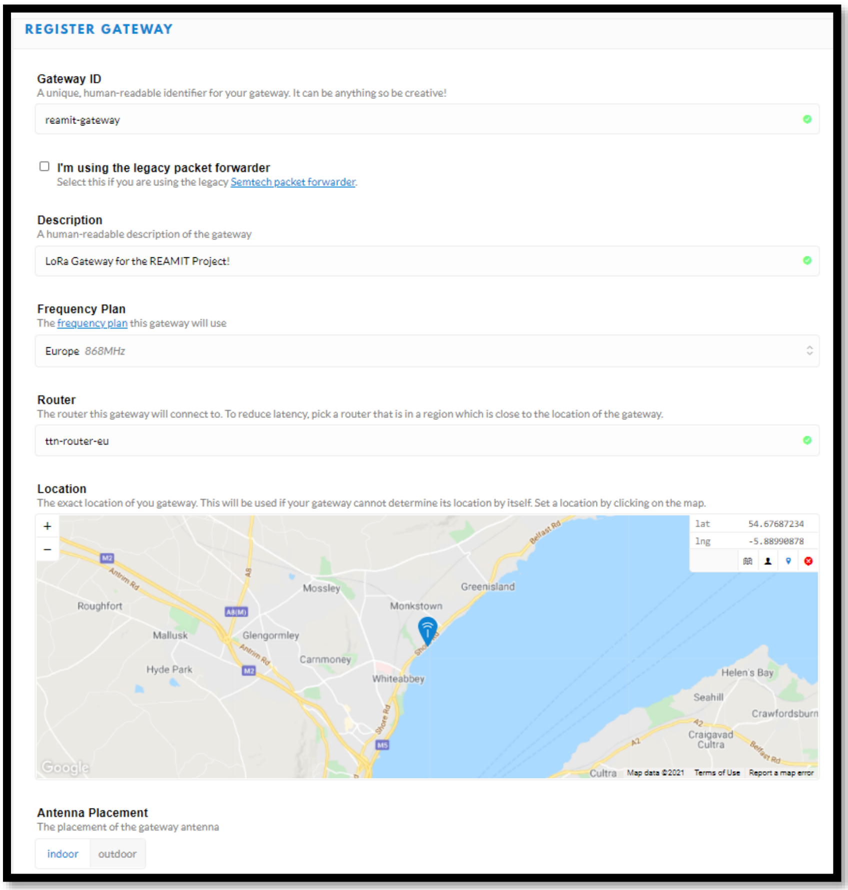
Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Ursalink	UC11-T1	To measure T° and humidity

Multi-Tech	Multi-Tech Conduit (MTCDT-AEP)	LoraWAN gateway to reach the cloud

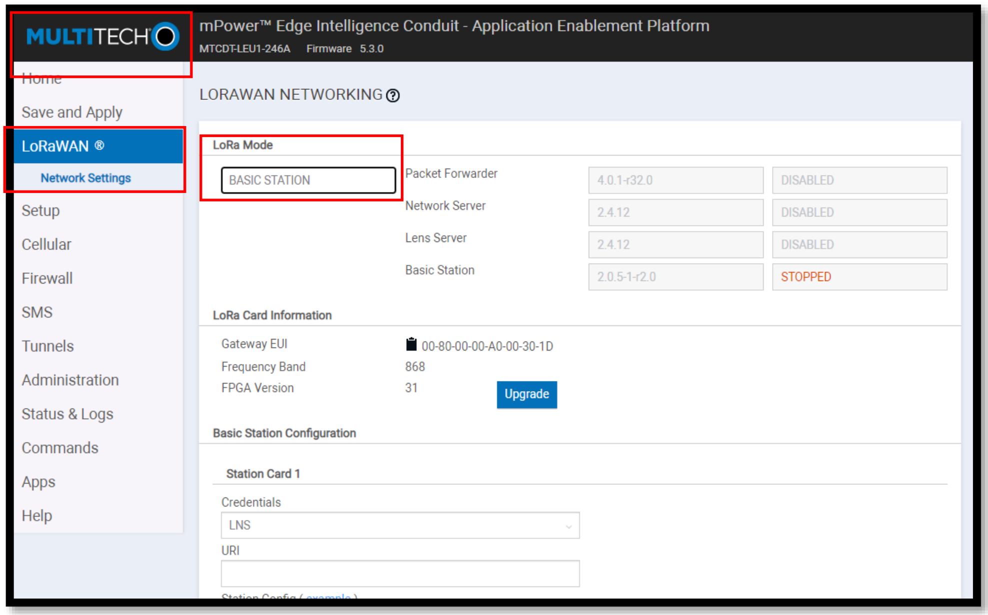
Step-by-step installation and configuration guide:

Multi-Tech Gateway configuration on TTN

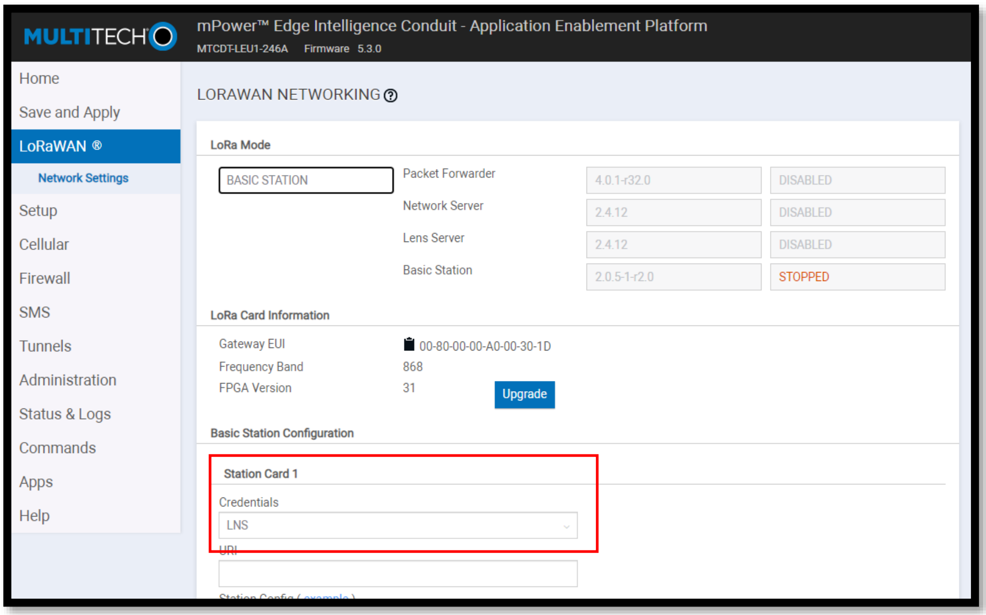
1. Browse to https://www.thethingsnetwork.org/
2. Click Signup and create an account for the things stack
3. Login to your newly created account
4. Click your account name in the top right of the browser, then click **console** in the menu that pops up
5. Click **Gateways**
6. Click **Register Gateway**
7. Enter a unique id for this gateway
8. Fill in the details
    a. Gateway-ID – Unique identifier for the gateway
    b. Description – Plain text description of what the gateway is
    c. Frequency plan – The frequency of the selected gateway. EU is 868MHz
    d. Router – The router your gateway will connect through
    e. Map – Find and select the exact location of the gateway
    f. Antenna placement – Select if it is indoor or outdoor



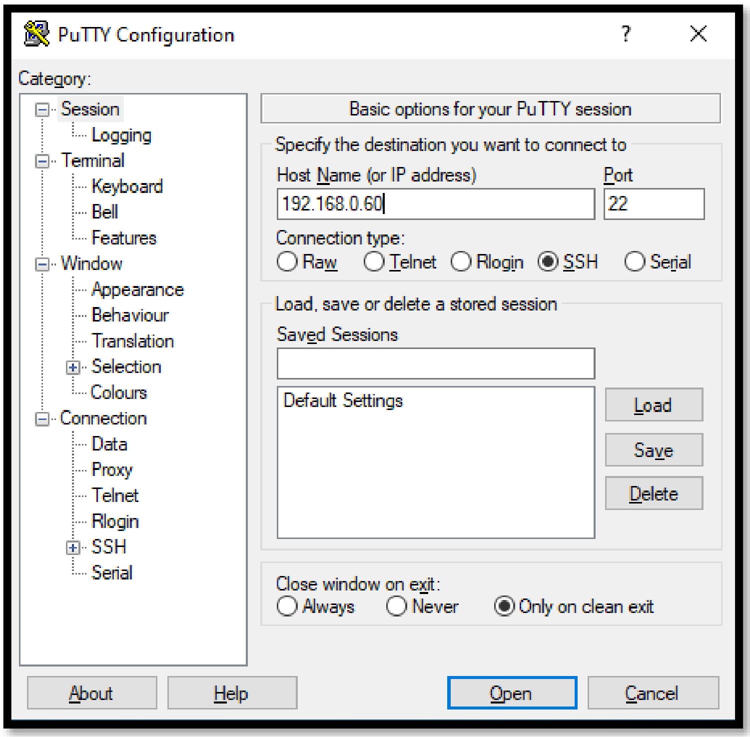
9. At this point it is advisable to ensure the gateway's firmware is up to date. Login to the gateway and along the top bar the current firmware is listed. Check here for most recent firmware https://www.multitech.net/developer/downloads/. For more information on updating the firmware, browse to the **Firmware Update** section of this guide.
10. Click **LoRaWAN** from left hand menu, then change the **LoRa mode** from **Disabled** to **Basic Server**.



11. Select **LNS** in **Credentials**

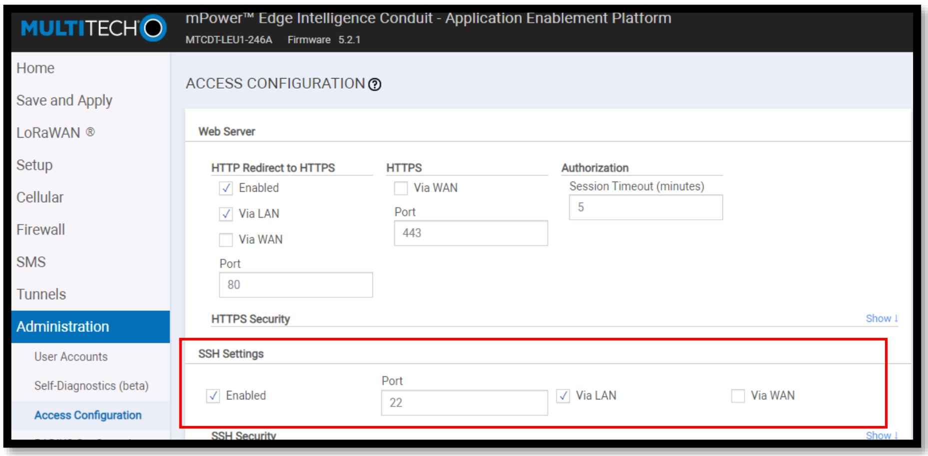


12. To configure the router beyond this point you will require terminal software capable of ssh. Mac OS/Linux can use the “Terminal” application. For windows “PuTTy” is recommended. Putty can be downloaded from https://www.chiark.greenend.org.uk/~sgtatham/putty/latest.html
13. Open PuTTY and in the **Host Name** put the local IP address of your gateway in. In our example, it is 192.168.1.60 and keep the **Port** at 22. If you don’t know your local IP address of the gateway, login to your network router and look through the connected devices for the mac address of your gateway and beside it should be your gateways local IP address. The mac address can be found on the label on the back of the gateway under “NODE-ID” and will be a series of alpha numeric characters in the format “XX-XX-XX-XX-XX-XX”



If you get a connection error then follow step 11, otherwise skip to step 15.

14. Login to your router by opening a web browser and browsing to the gateways local IP address we found in step 10. If you can't access your gateway via the web browser then you may have the wrong local IP address.
15. Click **Administration**, then click **Access configuration** from the left-hand menu.
16. Make sure **SSH Settings Enabled** is checked and **Via Lan** is checked and ensure you have the correct **Port.** Click **Submit,** then **Save and Apply**
17. Now re-try accessing the router via PuTTy as mentioned in step 10.

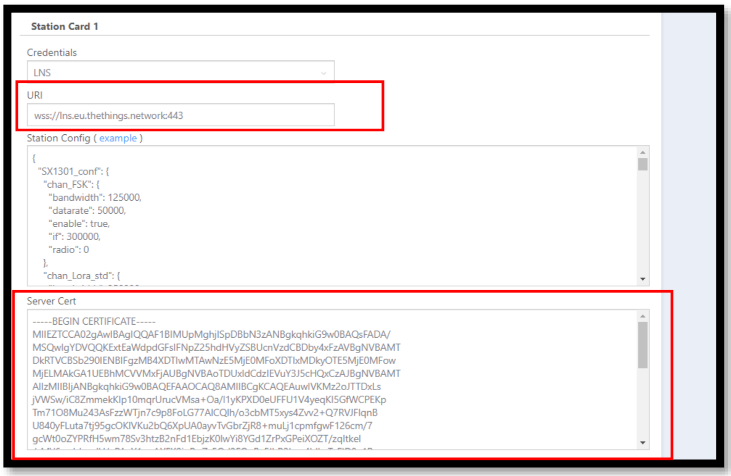


18. Login to the gateway via terminal using the login credentials you setup earlier.
19. Run the following command from the terminal

openssl s_client -showcerts -servername multitech.eu1.cloud.thethings.industries -connect multitech.eu1.cloud.thethings.industries:8887

20. The output will contain two SSL certificates, copy the second one.

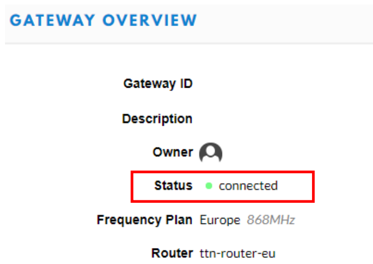
21. Login to the gateway via web browser and navigate to **LoRaWAN** -> **Network Settings**
22. Paste the certificate you copied into **Server Cert**
23. Enter the following into the URI field *wss://lns.eu.thethings.network:443*



24. Enter the following into **Gateway Key**

Authorization:
NNSXS.XXXXXXXXXXXXXXXXXXXXXXX.XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

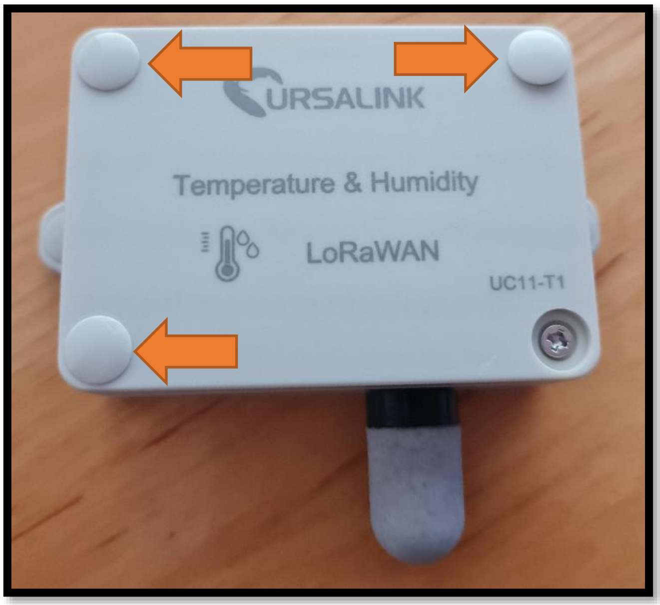
25. Click **Submit** then **Save & Apply**
26. Check the gateway on the things network and it should now say **connected**.



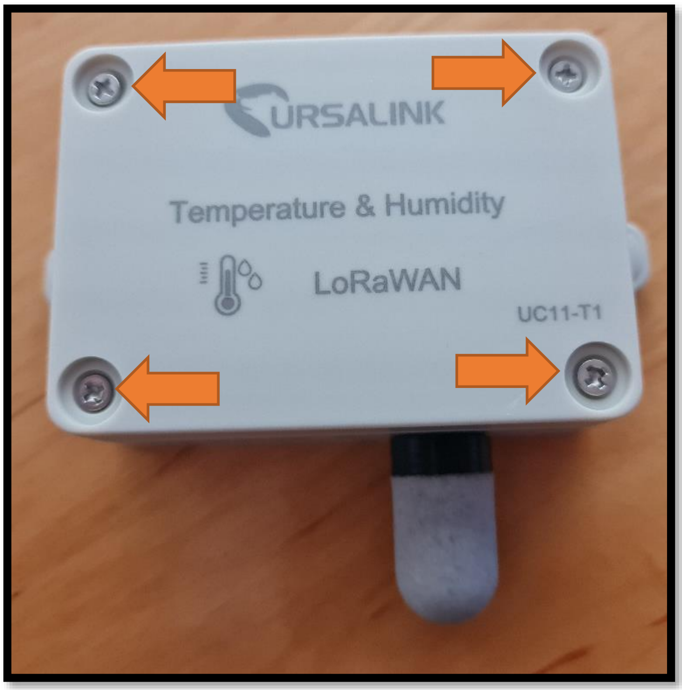
Ursalink UC-11 Temperature and Humidity sensor configuration
Note: Configuration software must be downloaded, Toolbox_v6.25 available from Ursalink website here.

Connecting to a computer for configuration

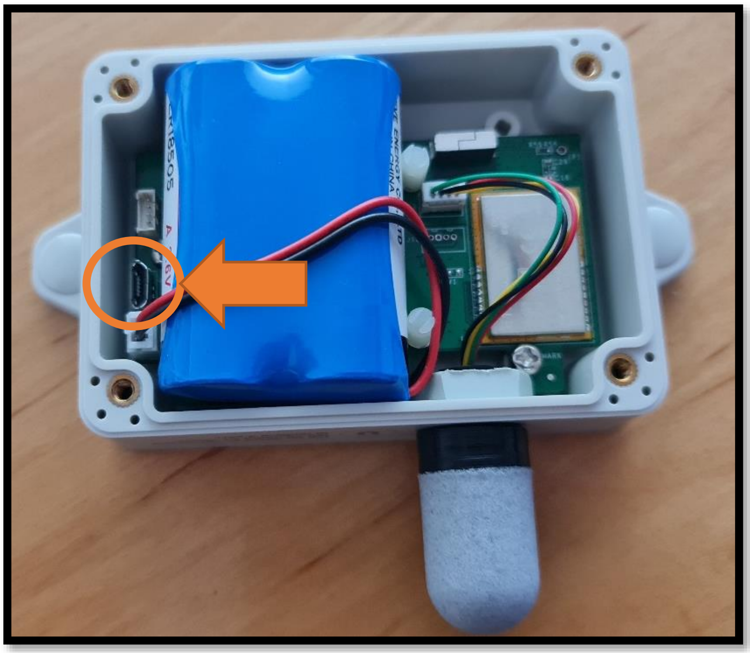
1. Remove the four plastic caps over the screw holes using a screwdriver and prying them off to expose the screws inside. The bottom right plastic cover has already been removed in the image below, do not lose these covers as they will be reattached on reassembly.



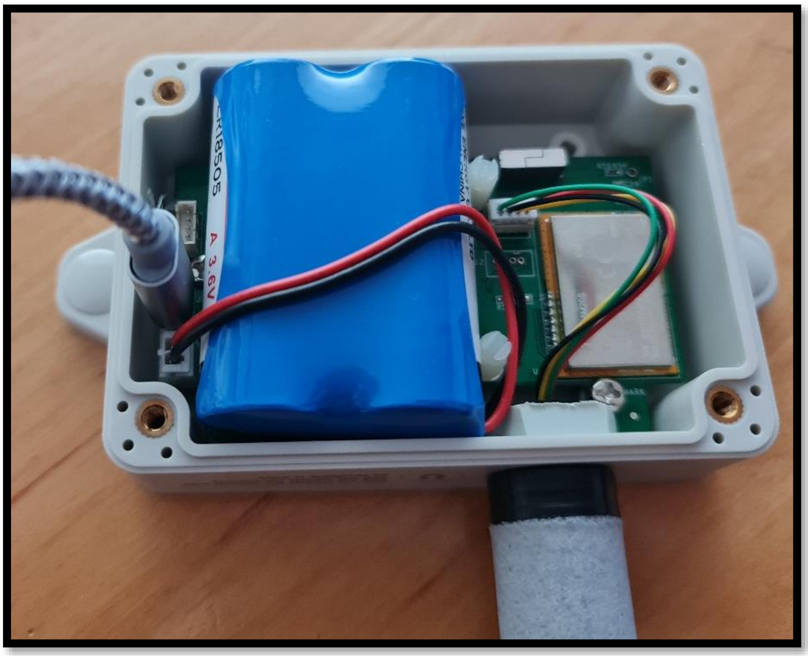
2. Now that the plastic caps have revealed the four screws holding the top cover onto the device, remove the four screws.



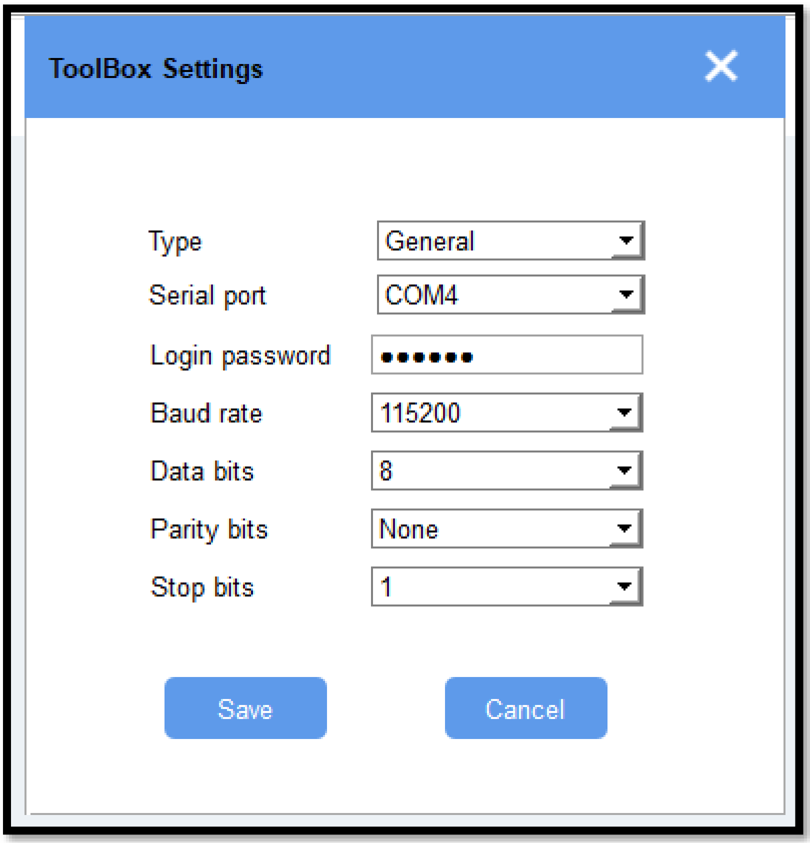
3. Once the screws have been removed, the top cover can be lifted to reveal the circuitry. If the rubber gasket falls out of the top cover, then push it back into the recess in the cover.



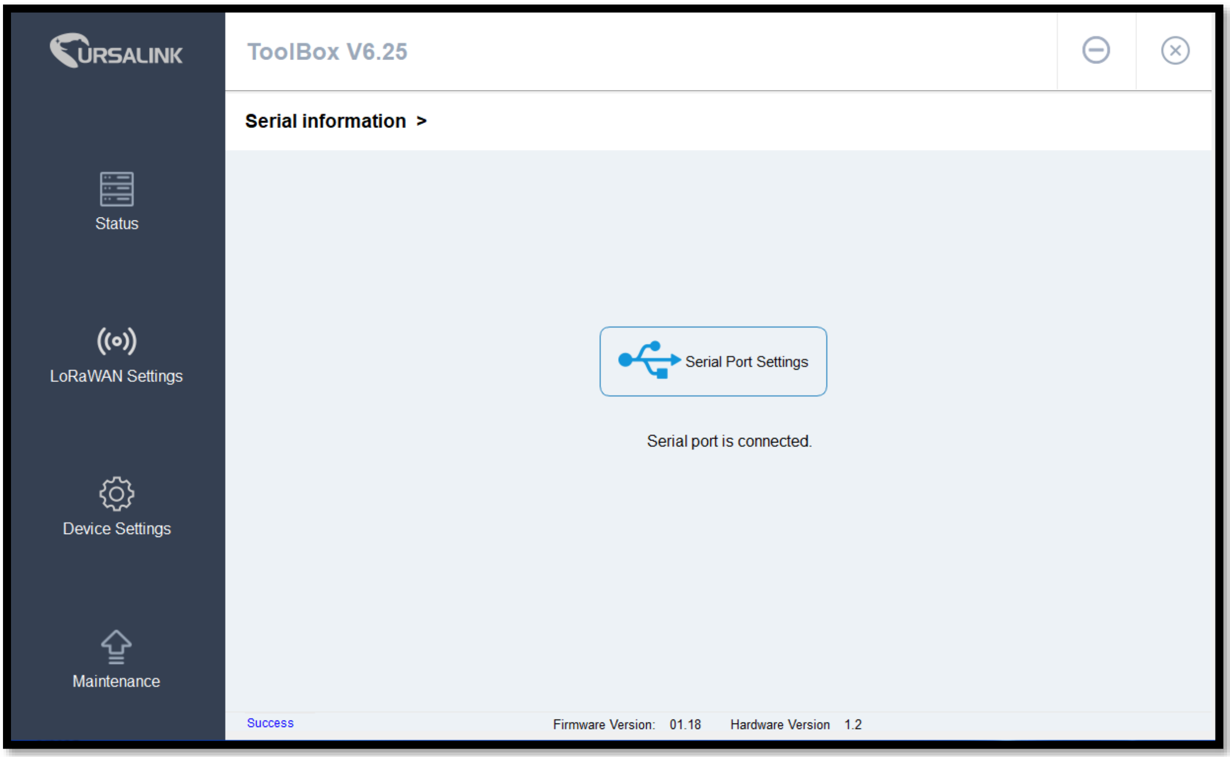
4. Attach a micro-USB cable to the provided slot on the circuit board. It is circled in the image above. Make sure to insert the cable in the correct orientation.



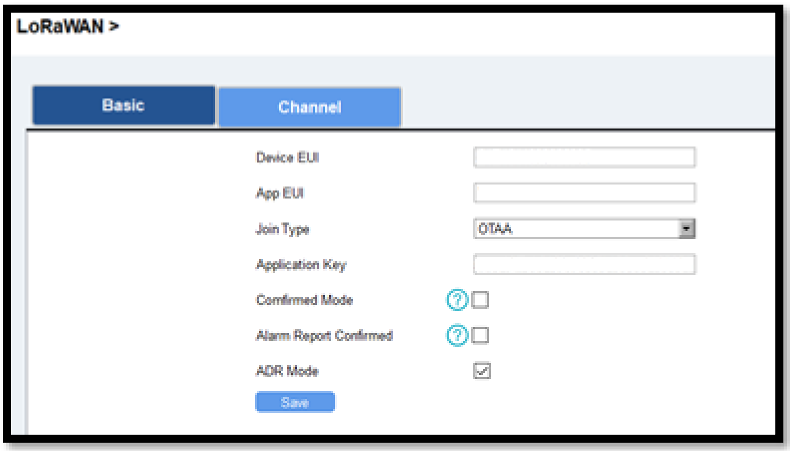
5. Connect the other end of the USB cable to your PC and open the toolbox software (download link on first page of this document).
6. When the software opens you will be presented with settings box as shown below. The COM port may be different on your computer depending on the USB port selected. The “Login Password” is **123456**



7. Click “Save” and if the computer successfully connects to the device you will see the following screen. Click “LoRaWAN Settings”.



8. On the LoRaWAN Settings screen, you will see the Device EUI, APP EUI and APP Key.



9. To finish configuring the sensor, follow the generic steps presented in section 2.1 (LoRaWAN configuration template)

Installation

Due to the amount of signal attenuation expected from placing the sensors inside a heavily insulated container with large quantities of meat, which would undoubtedly absorb much of the signal, we wanted to place the LoRa gateway as close to the dry-age chamber as possible. Because the dry-age chamber was a 40ft refrigerated trailer located in the parking lot of WD Meats however, the gateway would have to be mounted outside and be placed in waterproof housing. A waterproof box was mounted to the palisade fencing in the parking lot in close proximity to the trailer, and the gateway was placed inside. Holes were drilled in the bottom of the casing for cable entry and for the antenna to protrude. A cover was then placed on the box to ensure it remained waterproof. Figure 26 shows the gateway location setup.

Figure 26 Gateway installation at WD Meats. Waterproof box mounted to palisade fencing, with gateway located inside. Holes drilled at the bottom of the casing for cable entry and for the antenna to protrude.

The Ursalink UC11 sensors were placed in the 4 corners of the dry age chamber. The sensors were mounted to the hooks which hold the hindquarters using cable ties so that they could be removed after the 21-day ageing period. 2 sensors were located at the front of the chamber closest to the refrigeration unit, and 2 at the rear, closest to the door. Figure 27 shows the sensor location setup.

Figure 27 Sensor installation location inside the dry-age chamber. Sensors are mounted to the hooks which hold the hindquarters using cable ties so that they can be removed after the 21-day ageing period. 2 sensors are located at the front of the chamber, and 2 at the rear.

Data Dictionary

Column	Data Type	Description
device_id	Int	Numeric device ID, unique to the sensor
datetime_measure	ISO8601 date-time format, "yyyy-MM-dd'T'HH:mm:ss.SSS'Z'"	Datetime stamp of sensor recording
Battery	Float	Battery level during sensor recording
temperature	Float	Temperature recording inside chamber
Humidity	Float	Humidity recording inside chamber
device_name	nvarchar(50)	Descriptive name of device. Should help identify where device is installed, but often left as device_id.

Good practice and recommendations:
During the first iteration of monitoring the dry-age process, the sensors were mounted to the side of the chamber using double-sided Velcro. However, due to the humidity build-up over the 21-day period of dry-ageing beef, the Velcro failed, and the sensors fell to the ground. Therefore, it is recommended that a more robust mounting solution is used to ensure sensors stay affixed in the correct position and so damage does not occur. We chose cable ties and hung the sensors from the hooks that the hindquarters go on for the next iterations.

Monitoring other dry-ageing chambers emphasised the importance of selecting a sensor with an external / protected humidity probe. Probes with a foam exterior allow for the most accurate monitoring of humidity in a closed, humid environment.

5.3 Cold store anomaly detection with Andy Keery Refrigeration

Andy Keery, owner of rent-a-fridge, has over 25 years' experience in the refrigeration industry and has designed bespoke portable cold storage systems that he rents and delivers to anywhere in Northern Ireland & Ireland. Andy's portable cold stores appeal to a wide variety of clients, from fast food outlets based at festivals and supermarkets who are performing maintenance on their main fridges to florists, wineries, and more.

For Andy, it is vital that his portable cold stores are reliable. In the unlikely occurrence that a breakdown is detected, Andy offers 24-hour support and call-out ensuring that the customer's chilled products are not at risk of spoilage. Andy wanted a remote monitoring solution with visualisation to let him view current and historical data, and text alerting if any breakdowns were detected during a hire of one of his cold stores.

Architecture of the pilot:

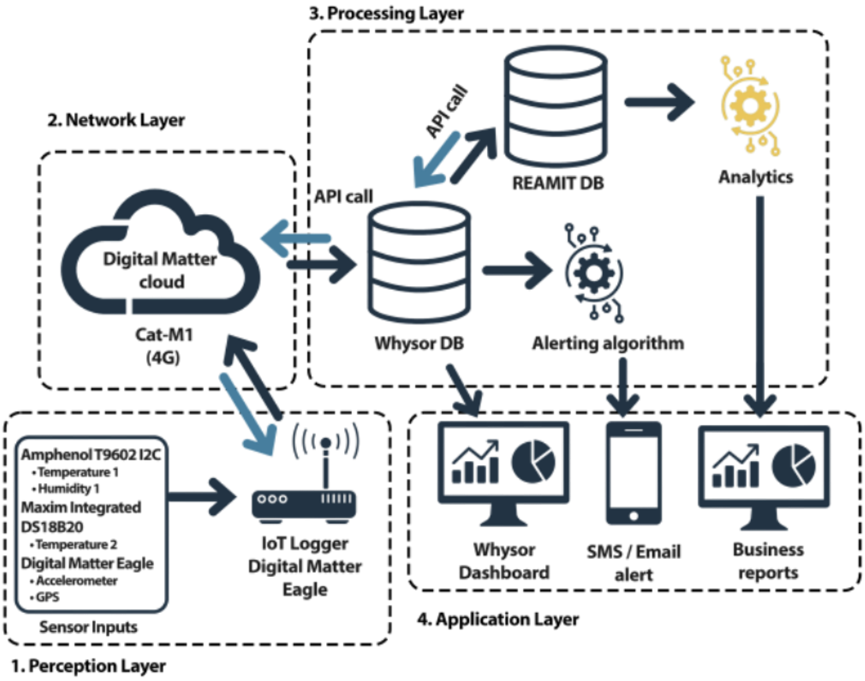


Figure 28 Andy Keery architecture

List of equipment deployed for this pilot:

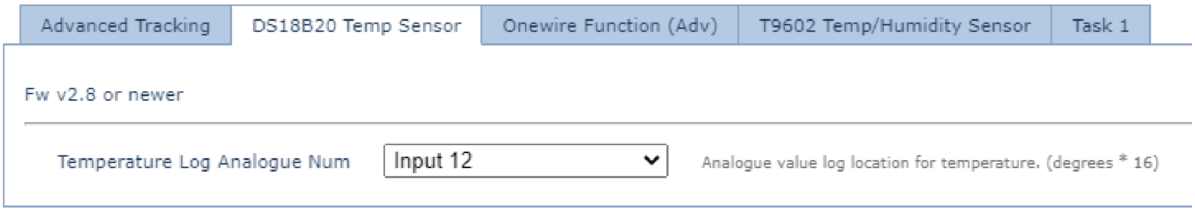
Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Amphenol	T9602 I2C T/RH	To measure temperature and humidity
Maxim Integrated	DS18B20	To measure second temperature (different zone in van)
Pololu	2119 voltage regulator	Boost Eagle supply voltage from 3.3V to 5V to power DS18B20
Digital Matter	Eagle	LTE-M cellular gateway to connect to the cloud.

Step-by-step installation and configuration guide:

The Digital Matter Eagle with 2 temperature probes was deployed with Andy Keery. It uses the same hardware stack as was prepared for Musgrave NI (see Section 5.1). However, for this pilot, since the cold stores are stationary, the trip detection system was disabled. This meant that recordings were made and uploaded every 5 minutes while stationary so that accurate monitoring could be performed. Since this would result in significantly more power draw, an external 12v power feed was added to the Eagle from the refrigeration unit which was powered by a generator.

Configuration in OEM server

Configuration of the DS18B20 sensor was set for input 12 for the Andy Keery pilot. For the Whysor platform input 12 is chosen for a second Temperature. As this is a Whysor platform specific convention, other platforms may use different inputs.



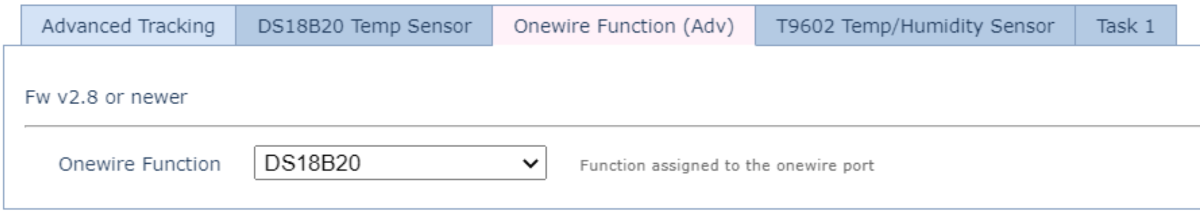


Figure 29: DS18B20 sensor configuration

Installation

The Eagle was deployed with both external power and 4 x C cell batteries installed in the logger. The logger was configured to prioritize external power as the power source when available. However, it automatically switches to battery power to continue real-time monitoring if the external power source is removed. In this way, data is captured and uploaded even if a breakdown in the refrigeration unit / power supply occurs.

To allow the logger to be equipped with two temperature probes and an external power feed, a third cable gland was added to the logger. This ensured the external power connection could be added while retaining the IP67 rating of the device. The external power was taken from the refrigeration unit and the logger was secured in place beside the gas for the compressor using cable ties. The sensor cables were run from the exterior refrigeration compressor to the inside of the cold store through a cable entry hole which already existed.

Figure 30: Installation of the Eagle at Belfast's Continental Market.

To make the installation less invasive, cable ties were employed to mount the temperature probes inside the cold store, as depicted in Figure 31. Two temperature sensors were utilized during the pilot test. One of them was used for monitoring the 'air-on' of the fridge unit, which is where the air is drawn back into the compressor after circulating the entire store. This is where the true ambient temperature is monitored, and can be seen at the rear of the left hand photo in Figure 31. In addition, a second probe was added to the 'air-off' of the fridge unit. Air-off is where the air exists the compressor for the first time before it circulates the rest of the fridge and should produce a significantly colder reading.

Figure 31: Temperature sensors located in the cold store at the continental market. Front: Air off; Rear: Air on. Right: stock loaded in the cold store.

Data Dictionary

Column	Data Type	Description
device_id	Int	Numeric device ID, unique to the sensor
datetime_measure	ISO8601 date-time format, "yyyy-MM-dd'T'HH:mm:ss.SSS'Z'"	Datetime stamp of sensor recording
battery	Float	Battery level during sensor recording
temperature1	Float	Temperature 1 recording, in freezer of van
temperature2	Float	Temperature 2 recording, in fridge of van
humidity	Float	Humidity recording, in freezer of van
device_name	nvarchar(50)	Descriptive name of device. Should help identify where device is installed, but often left as device_id.

Good practice and recommendations:

Sensor location

Careful consideration should be given to the chosen sensor location to monitor ambient temperature within cold stores. Ambient temperature monitoring can fluctuate as much as 10oC+ depending on the chosen installation location of the temperature probe. We believe, after experimentation, that the true reflection of ambient temperature within the cold store is located at the ‘air on’ site of the refrigerator, which is where the air is drawn back into the compressor after circulating the entire store.

Future work

In the future, Andy would like to see an option to toggle alerting on and off from the main dashboard screen. This functionality would be particularly relevant for Andy who will have his cold stores in his yard unused during particular weeks of the year; therefore while not in rent he could quickly turn alerts off rather than having to enter the management menu.

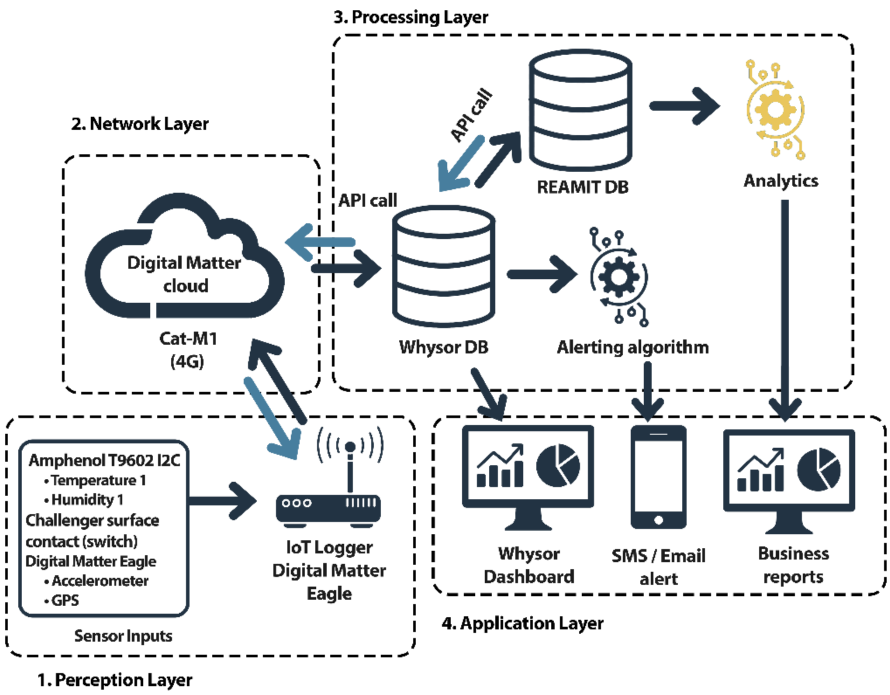
Andy would also like to see the functionality of the Eagle expanded to allow him to use the outputs of the device to trigger a remote defrost cycle from the dashboard. Whysor are currently investigating how this could be implemented.

6 Other UK pilot tests in England

6.1 Human Milk Foundation

The Human Milk Foundation (HMF) plays a critical role in providing rapid delivery of breast milk to neonatal wards in South England using motorcycles and cars. However, due to a lack of means of temperature monitoring, there is presently a risk of spoilage if their cold storage fails without their knowledge until the milk is delivered to the hospital. To help reduce the chances of undetected cold storage failures during transportation, the REAMIT team proposed deploying temperature and humidity IoT sensors with HMF allowing them to monitor the parameters of the storage conditions and receive alerts if problems arose during milk delivery.

Architecture of the pilot:



List of equipment deployed for this pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Amphenol	T9602 I2C T/RH	To measure temperature and humidity
Digital Matter	Eagle	LTE-M cellular gateway to connect to the cloud. Also internally logs GPS and accelerometer parameters for trip detection.
RS	RS PRO Door and Window Switch 9182671	To measure if the bag status is open or closed

Step-by-step installation and configuration guide:
The HMF pilot test expands on the Eagle logger base configuration (documented in Section 2.2) by adding a magnetic door sensor (a binary switch) so that the status of the bag

transporting the milk could be monitored (i.e., open or closed). Additionally, trip detection is enabled for this pilot test.

Step 1: Adding the binary switch

The binary sensors contain a positive and ground (gnd) line, as well as a two-wire tamper loop which we will not use. Using a multimeter, a continuity test should be performed to identify what wires are the positive and ground and which belong to the tamper loop. Through an iterative process, place one probe on one cable and the second multimeter probe on a second wire. The multimeter should read 0 when the switch is open. Then move the magnet close to the switch (touching) and it should change to 1. If it remains at 0, change the second probe to another cable and try again. A trial-and-error process is required to identify the appropriate cables. In this instance, the wires for the sensor are identified as the black and red ones, while the tamper circuit uses the green and white wires.

Wire the black cable of the binary sensor into gnd on the right-hand side of the eagle logger, and the red cable into DIN1. The tamper circuit wires can be trimmed to leave only the insulated sleeve. It should look something like this:

Figure X: Binary sensor wiring.

Both cable entries at the bottom of each logger should be used; one for the temperature probe and one for the binary sensor. This will ensure the logger remains IP67 rated. Note the second cable entry will need opened as by default it comes plugged. This plug can be removed with a screwdriver.

Configuration in OEM server

Configuration of the binary sensor was set for input 1 for the HMF pilot. For the Whysor platform input 1 is chosen for a digital switch input. As this is a Whysor platform specific convention, other platforms may use different inputs.

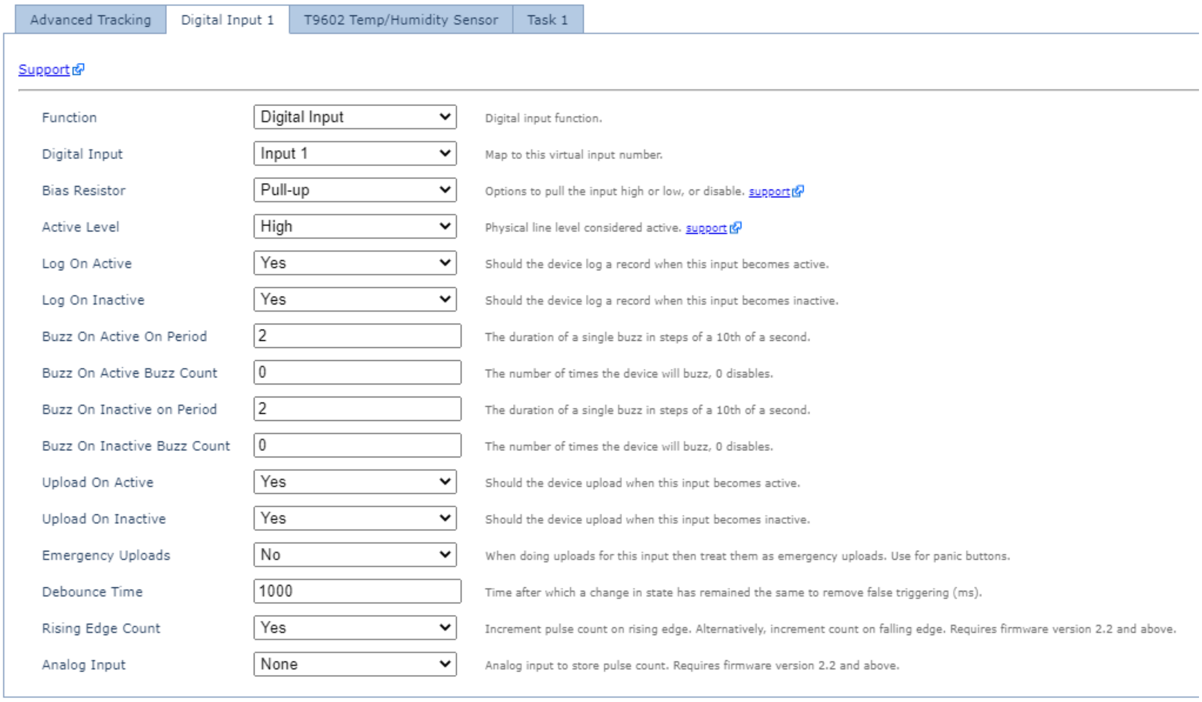
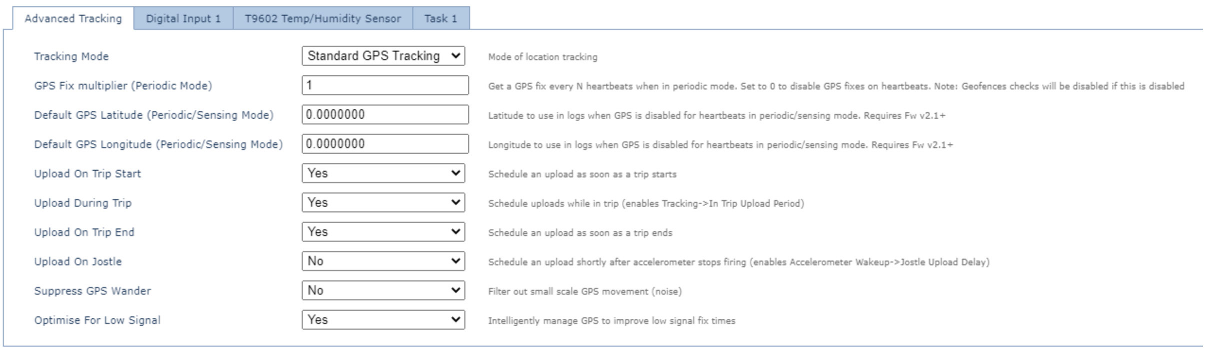
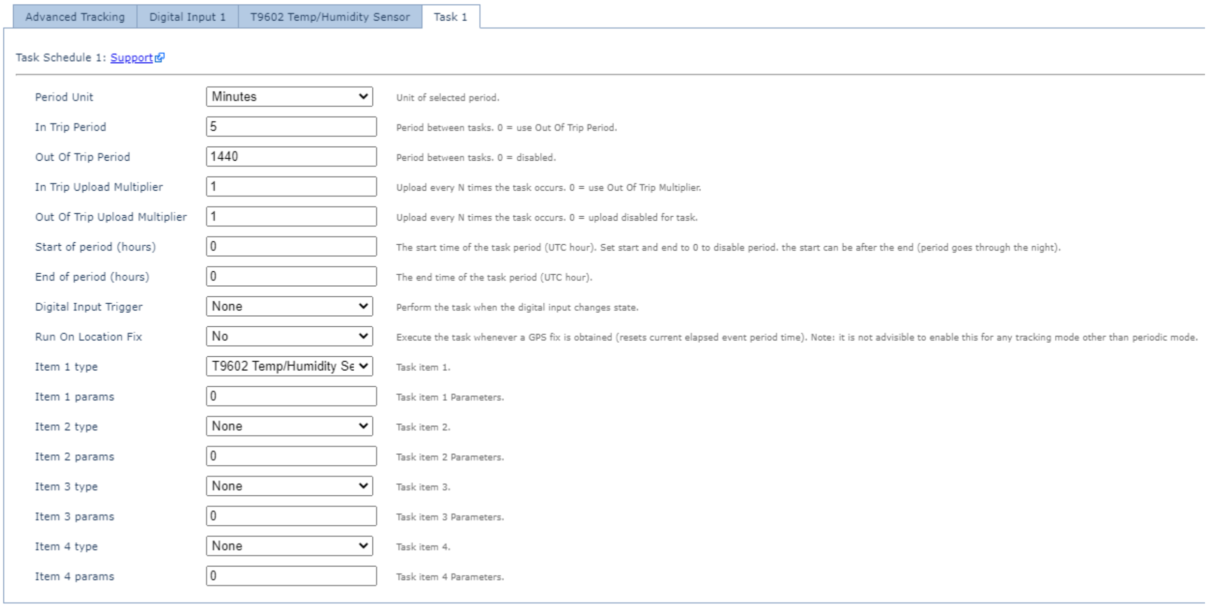


Figure X: Binary sensor configuration in OEM server.

Step 2 : Adding trip detection

Trip detection was enabled on each of the loggers. The parameters were configured on Digital Matter OEM server as documented in Figure X.



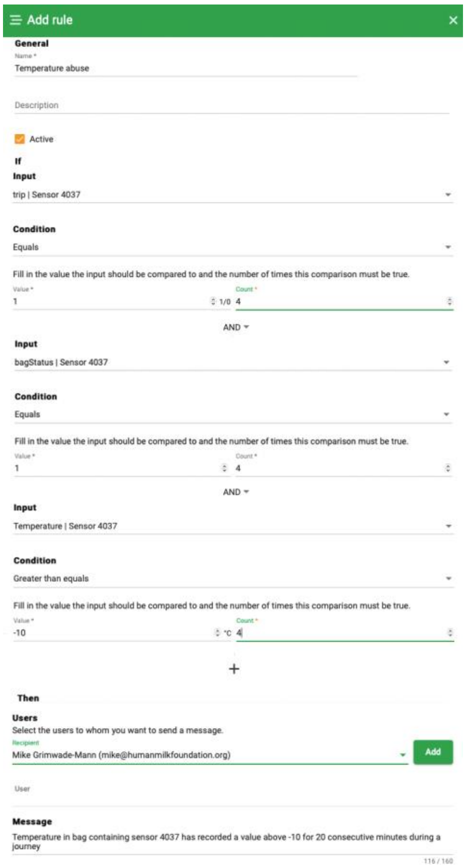


When in a trip, the environmental parameters were measured and uploaded to the cloud every 5 minutes. When out of a trip, the parameters were measured and uploaded every 12 hours. To ensure the device did not draw too much power when attempting to detect the trip, a GPS timeout of 60 seconds was applied. If no GPS fix could be achieved within this timeframe, the device would wait 5 minutes before trying again.

Data is uploaded from the device to the Digital Matter cloud. The data is accessible using a HTTPS webhook in real time. The Whysor platform retrieves the data and parses it using their own bespoke database connector, again in real time. At this stage, the data is visualized on the dashboard and the alerting algorithm can be configured.

Configuring alerting

In the alerting algorithm, the first condition involves checking the trip detection status to ensure that the vehicle has been in motion for a minimum of 20 minutes. Next, the algorithm verifies that the bag has remained closed for the last 20 minutes before proceeding. Finally, the temperature condition is examined to confirm that temperature abuse has consistently occurred for a duration of 20 minutes, indicated by four consecutive readings. Only when all of these conditions are met, a notification is sent to Mike at HMF, alerting him of the temperature abuse that occurred during one of the deliveries.



Installation:

In order to ensure a non-invasive installation process during the trial period of IoT monitoring, Velcro was employed to attach the Eagle logger securely inside the bag. This Velcro attachment method allowed the staff at HMF to easily remove the loggers as needed, particularly for battery replacement. To ensure stability, the sensor and Velcro mounting points were positioned at the bottom of the bag, utilising the bag's base to provide support for the majority of the sensor's weight.

Similarly, the binary sensor used to monitor the bag lid status was affixed using Velcro. This sensor consisted of two parts: the main sensor and a magnet responsible for triggering the status. The magnet was placed within a netted area on the lid and secured in position using Velcro. The main sensor, on the other hand, was attached to the side of the bag using Velcro. When the lid was closed, the magnet aligned with the main binary sensor unit, enabling reporting of the bag's status.

It is worth noting that the same mounting protocol was applied to all ten bags, ensuring consistency across the setup. This meant that any sensor could be picked up and placed in any bag and the mounting points would align.

Data Dictionary

Column	Data Type	Description
device_id	Int	Numeric device ID, unique to the sensor
datetime_measure	ISO8601 date-time format, "yyyy-MM-dd'T'HH:mm:ss.SSS'Z'"	Datetime stamp of sensor recording
battery	Float	Battery level during sensor recording
temperature1	Float	Temperature recording inside bag
humidity	Float	Humidity recording inside bag
bag_status	char(1)	Indication if the bag is open (0) or closed (1)
device_name	nvarchar(50)	Descriptive name of device. Should help identify where device is installed, but often left as device_id.
Trip	char(1)	Indication if the bike is being driven (1) or is stationary (0) when the recording was made.

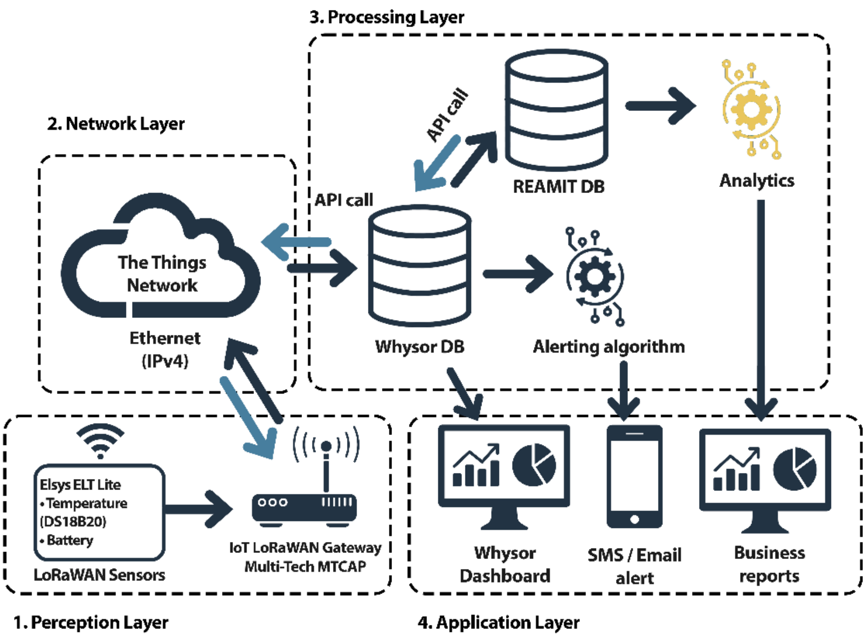
Good practice and recommendations :

During the testing phase, binary switch sensors were employed to monitor the status of the bag. To attach these sensors to the bag, double-sided Velcro was used to mount them on the side. However, this mounting method proved inadequate as humidity built up inside the bag due to melting ice, causing the Velcro to fail and the sensors to fall to the bottom of the bag. As a result, incorrect bag status was reported. To address this issue, it is recommended to employ a more robust mounting solution that ensures the sensors remain securely affixed in the correct position. Alternatively, a different type of sensor, such as a light-dependent resistor (LDR), could be used to monitor the bag status. By detecting the difference in light levels when the bag is closed versus open, an LDR can effectively determine the bag's status without requiring Velcro attachment at the top of the bag. This alternative approach offers a potential solution to improve the reliability and accuracy of bag status monitoring.

6.2 Yumchop

Yumchop specialises in producing African flavoured frozen ready meals. They provide flavoursome and authentic food from around the world with an African twist that is frozen to retain its goodness and freshness and minimise waste. Their tasty meals are distributed at institutions such as universities or hospitals through self-service automated vending machines. These unattended retailing kiosks have been fitted with an integrated microwave oven which enables them to warm the food upon purchase. Yumchop also delivers food to customers' homes through direct purchase at their website, enabling one-off purchases and monthly subscriptions that customers can customise to receive food at their preferred intervals. At Yumchop, there was identified potential for food waste through the failure of one of their cold stores. Therefore, Yumchop sought a system which would monitor the temperature parameter of cold stores throughout their production facility and alert them if any anomalies were detected during the storage of chilled and frozen products. These alerts would allow Yumchop to take the necessary corrective action and prevent food from becoming waste.

Architecture of the pilot:



List of equipment deployed for this pilot:

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment

Elsys	ELT Lite	Sensor to handle LoRa communication to gateway. Sensor supports variety of inputs, like temperature probes.
Maxim integrated	DS18B20	Sensor probe measure T°. Connected to Elsys ELT.
Multi-Tech	Multi-Tech MTCAP-L4E1	LoraWAN gateway to reach the cloud

The Yumchop pilot consisted of a LoRa-based IoT system and as such followed a configuration approach akin to the other previously described LoRa solutions. As a summary, prior to the placement and installation of the sensors at the company's premises, sensors were registered and configured in the TTN (The Things Network) server, a service that acts as an intermediary communication point between the pilot company's sensors and the REAMIT server, translating the packets sent by the devices into meaningful information. For a complete step-by-step sensor configuration guide to TTN, the reader is referred to section 2.1.

Sensor settings

For this pilot, the default 10-min data recording rate was left unchanged. However, the manufacturer, Elsys, has an application available on Google PlayStore (Sensor settings) which allows communication with the sensors using a smartphone and via Near-Field Communication (NFC) if a change is desired – it allows for a change in the recording rate, as well as other parameters and the configuration of external probes.

Installation

10 Elsys ELT Lite sensors were installed in the following zones at Yumchop Foods factory. For the large cold room Fridge and Freezer, the sensors were affixed to the wall of the chill rooms using screws. For the other fridges and freezers, sensors were either placed inside or cable tied to a suitable mounting point. Figure x presents the 10 installation locations of sensors in Yumchops factory.

1. Zone B – Freezer 1
2. Zone B – Freezer 2
3. Zone E – Freezer
4. Zone E – Fridge
5. Zone D – Cold room freezer
6. Zone D – Cold room fridge
7. Zone D – Fridge
8. Container cold room (= freezer)
9. Green Kitchen Fridge

10. Vending Machine (= freezer)

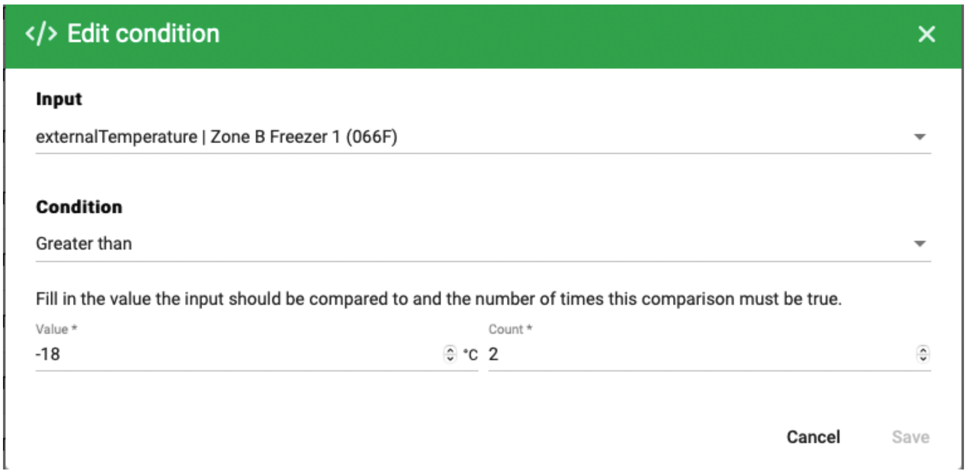
Figure x. Yumchop's factory zonal layout

Data Dictionary

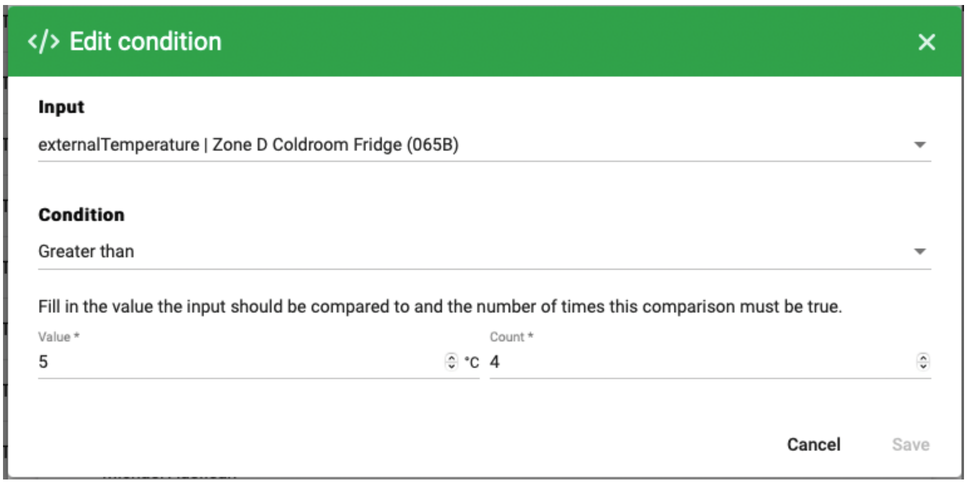
Column	Data Type	Description
device_id	int	Numeric device ID, unique to the sensor
datetime_measure	ISO8601 date-time format, "yyyy-MM-dd'T'HH:mm:ss.SSS'Z'"	Datetime stamp of sensor recording
battery	float	Battery level during sensor recording
temperature	float	Temperature recording inside chamber
device_name	nvarchar(50)	Descriptive name of device. Should help identify where device is installed, but often left as device_id.

Configuring alerting

The alerting criteria for Yumchop was defined as follows. For any sensors installed in freezers, alerts would be sent to the owners of Yumchop if the threshold value (-18oC) was broached two consecutive times.



Alternatively, for any sensors installed in fridges, alerts would be sent to the owners of Yumchop if the threshold value (5oC) was broached four consecutive times.



Good practice and recommendations:

7 Irish Pilot

7.1 Dry-ageing process of beef with Burns Farm Meats

The Irish pilot at Burns Farm Meats mainly consisted in the monitoring of environmental parameters - temperature and humidity - in the two refrigeration chambers that they use to carry out dry ageing of beef.

To provide some context, Burns Farm Meat Ltd. is a small-sized, family-owned company in north Sligo, Ireland, the main activities of which include farming, operation of an abattoir, and processing of organic meats, among others. As part of these activities, being firmly committed to animal welfare and providing meat of the highest quality, they run a dry-ageing process to deliver tender cut meat of their own locally raised, fed and cared for animals. The dry ageing of beef is a process aimed at improving the quality and tenderness of the meat and enhancing overall customer appreciation. It is achieved by hanging meat carcasses (or hindquarters) in refrigeration chambers under controlled conditions for a period that normally takes from 2 to 3 weeks.

To this company, it was important to obtain a system capable of monitoring environmental parameters in their refrigeration chambers that would ultimately provide them with a higher understanding and the means to enhance the quality of meat and reduce its loss. As a matter of fact, the dry-ageing process, despite increasing the flavour and tenderness of the meat, is regarded as a costly process for abattoirs because of shrinkage of the meat, trim loss, and risk of contamination; therefore, they were especially interested in the real-time monitoring of their chambers with the goal of tuning and optimising the refrigeration parameters for greater quality and efficiency.

Architecture of the pilot:

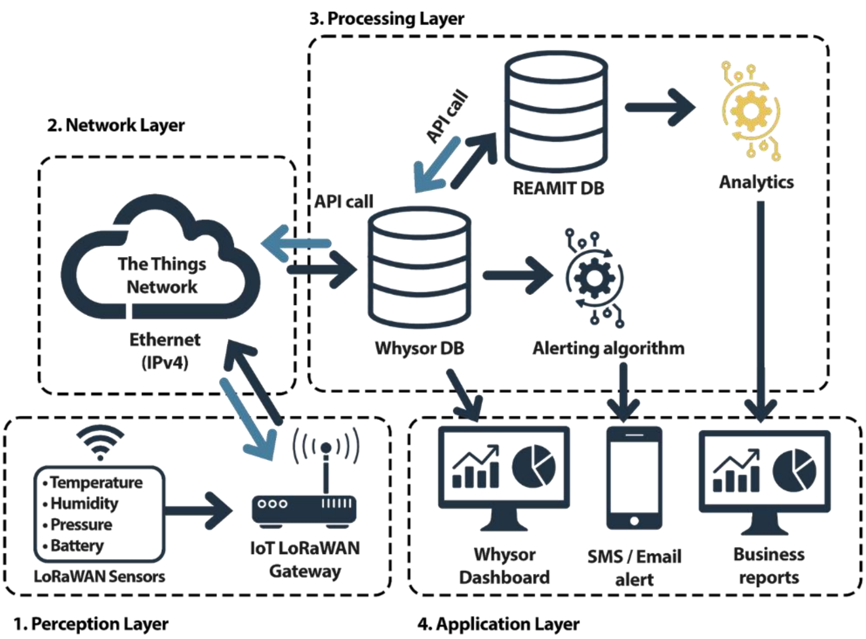


Figure 32 Burns Farm Meats IoT architecture

As seen in Figure 32, the perception layer for this pilot consisted of the chosen sensors (ELT-2 Internal Antenna, Elsys) for environmental parameter monitoring, which transmitted the data to a gateway device (Kona Micro IoT Gateway, Tektelic) via LoRa signal. Together with 10 ELT-2 Internal Antenna sensors, a Kona Micro IoT Gateway was installed in the premises of Burns Farm Meats, in an office space not far away from the refrigeration chambers where the sensors were located for monitoring of the dry-ageing process. This gateway communicated in real-time with the network layer of the architecture via an internet connection. The network layer, in turn, provided our databases in the processing layer with sensor data via API calls in an organised and meaningful manner. Alerting and analytics would then take place as part of the processing IoT layer by allowing REAMIT data analytics members to safely retrieve the data for subsequent analysis. Lastly, the last layer of the architecture consisted of the development of a user-friendly application layer from which company representatives could access real-time data at any given time in an easy manner, receive alerts via SMS or email and obtain reports arising from the data analytics work.

List of equipment deployed for this pilot (available in DEL 3.1):

Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
Elsys (Sweden)	ELT-2 Internal Antenna	1. Measurements of temperature and relative humidity (integrated internal sensors enclosed in an IP67 box) 2. Transmit (Lora) real-time sensor data to a nearby gateway device
Tektelic (Canada)	Kona Micro IoT Gateway	LoraWAN enabled device used to upload real-time data to the cloud (connected via ethernet cable)
Challenger (UK)	AC03 - Surface Aluminium Contact Normally Closed	Contact sensor for the doors of the refrigeration chambers to detect when these are open

Step-by-step installation and configuration guide:

The Burns Farm Meats pilot consisted of a LoRa-based IoT system and as such followed a configuration approach akin to the other previously described LoRa solutions. As a summary, prior to the placement and installation of the sensors in the company's premises, sensors were registered and configured in the TTN (The Things Network) server, a service that acts as an intermediary communication point between the pilot company's sensors and the REAMIT server, translating the packets sent by the devices into meaningful information. For a complete step-by-step sensor configuration guide to TTN, the reader is referred to section 2.1.

Sensor settings

For this pilot, the default 10-min data recording rate was left unchanged. However, the manufacturer, Elsys, has an application available on Google PlayStore (Sensor settings) which allows communication with the sensors using a smartphone and via Near-Field Communication (NFC) if a change is desired – it allows for a change in the recording rate, as well as other parameters and the configuration of external probes.

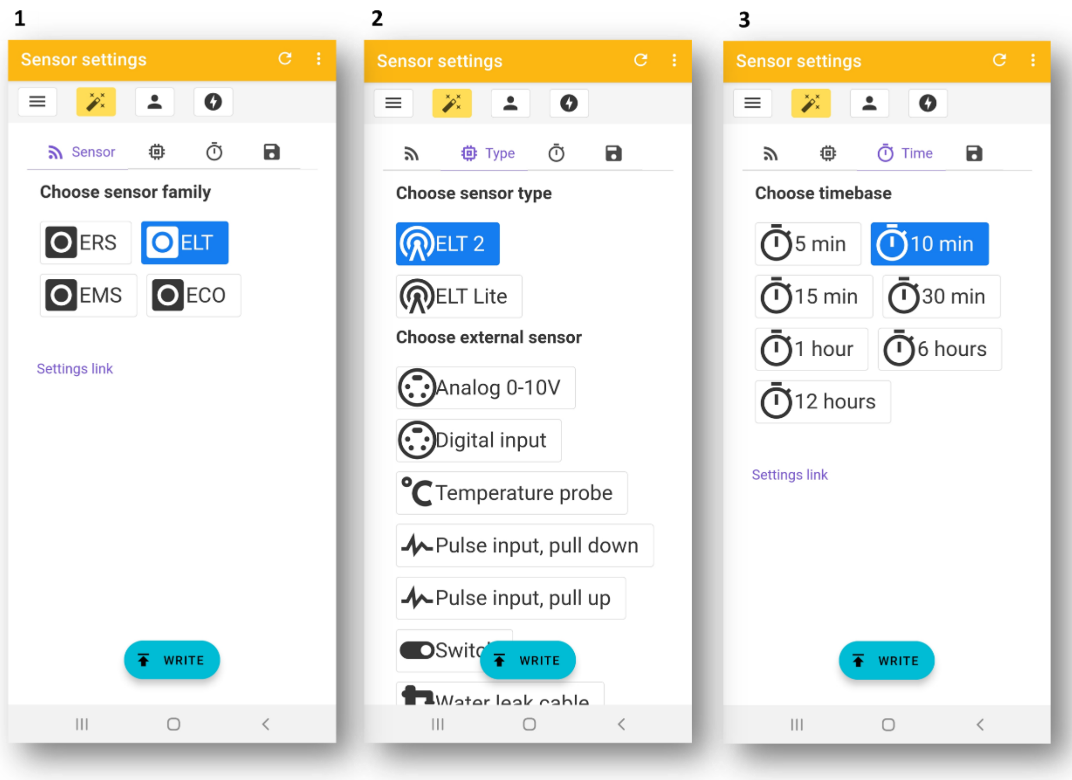


Figure 33 Smartphone screenshots, in sequential order, showing how to change the data recording rate on the Elsys app.

The app has an option called "wizard mode" (notice the highlighted icon with an image resembling a magic wand in the upper part of each Figure 33 screenshots) which allows to configure the sensors in an intuitive and easy manner. A configuration "normal mode" and an "advanced mode" are also available, but for the purpose of this pilot test, these were not required.

Using the wizard mode, a new menu/tab is prompted once an option is selected. In this particular case, ELT would be chosen as sensor family and ELT2 as type, followed by the desired time frequency. Once all the appropriate and desired options have been selected, changes need to be written and recorded in each sensor - the app will display sensors in range, so it is necessary to have the sensor in close proximity to the smartphone.

Addition of a binary/switch external sensor

With the goal of upgrading the alerting system at Burns Farm Meat, an additional external switch probe (Surface Aluminium Contact Normally Closed, Challenger) was installed to obtain binary readings on the chamber door status. This door switch consisted of two separate magnets that when not in contact would output an "open" (1 as opposed to 0) signal, and when in contact a "closed" one (0, in binary terms). The reason for this was, there were times that staff needed to open the doors for a certain amount of time to load/unload meat or for cleaning procedures, and the implementation of an alerting system warning of environmental anomalies would notify staff repeatedly at times when they were fully aware of the door being open. Thus, to refine the alerting system and account for the door being open for a given amount time before sending alerts, the switch probe was added to the monitoring system.

To install the door switch and set it up in such a way that the signal would be transmitted to the cloud, it was wired to one of the installed ELT-2 sensors. In order to do that, the 4 screws that lock the front lid of the ELT-2 sensor need to be removed as shown in Figure 34.

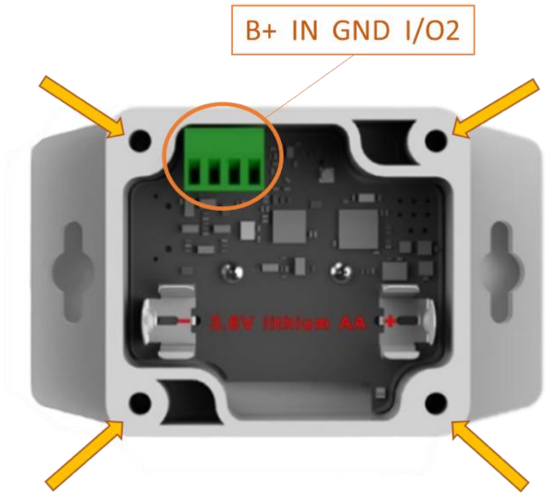


Figure 34 Image showing the location of the screws on the front lid and the pins inside the ELT-2 Internal Antenna sensor.

The binary/door switch sensor contains a positive and ground (GND) line. With the use of a multimeter, a continuity test should be performed to identify what wires are the positive and ground. To do so, place one multimeter probe on one of the cables and the second probe on the second wire. The multimeter should read 0 when the switch is open. Then move the magnet close to the switch (touching) and it should change to 1. If it remains at 0, change the second probe to the other cable and try again.

Wire the black cable of the binary sensor into GND on the upper part of ELT-2 sensor, and the blue cable into IN.

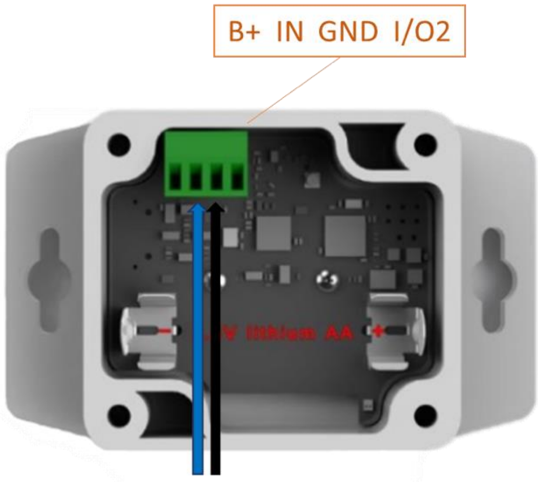


Figure 35 Image showing the wiring of the binary/door switch.

The last step of the installation is to configure the newly added probe on the app. For this, as shown for changing the recording rate, the wizard mode on the app can be used to write or record the change in an external sensor menu.

With the sensor in range, the appropriate sensor family and type are selected on the app. After this, a Switch external sensor is chosen as shown in Figure 36.

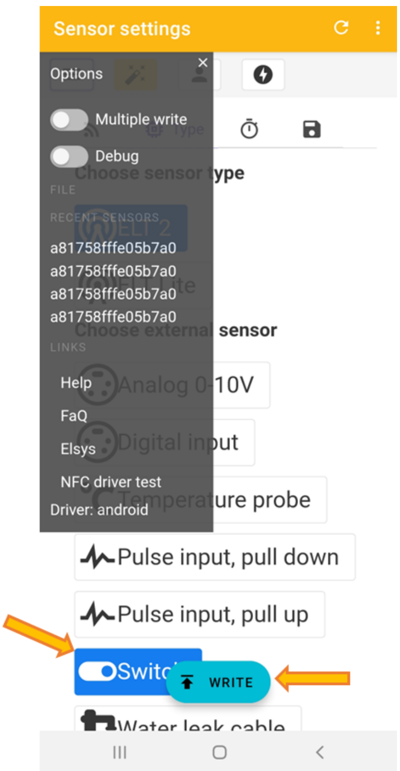


Figure 36 Screenshot showing the external sensor configuration on Elsys app.

Data dictionary

Column	Data Type	Description
device_id	int	Numeric device ID, unique to the sensor
datetime_measure	ISO8601 date-time format, "yyyy-MM-dd'T'HH:mm:ss.SSS'Z'"	Datetime stamp of sensor recording
battery	float	Battery level during sensor recording
temperature	float	Temperature recording inside chamber
humidity	float	Humidity recording inside chamber
pressure	float	Air pressure recording inside chamber
device_name	nvarchar(50)	Descriptive name of device. Should help identify where device is installed, but often left as device_id

Good practice and recommendations:

While confirmation is, at present (March 2023) still being sought to determine this, the sensor solution that was chosen for this pilot test may not have been the best fitted for humidity monitoring. Although with features that were considered advantageous, the ELT-2 consisted of internal probes (enclosed within the ELT-2 outer box) for measuring temperature and humidity which were utilised for the environmental monitoring. It is worth noting that the ELT-2 sensors can be coupled with external probes; however, when screening for sensor solutions for the pilot test, the fact that the ELT-2 had internal ones was considered especially convenient as it would minimise the amount of wiring, as well as limiting the deployment of equipment within the refrigeration chambers to the (compact) size of the ELT-2. Future work is expected to be completed before the end of the project, July 2023, to validate the recordings of humidity as these were consistently higher than expected. It was suggested that perhaps internal probes were not the best suited for measuring humidity as the air flow might be restricted and moisture getting trapped inside. This validation will be aimed at determining whether the humidity readings coming from the ELT-2 sensors are correct or other sensors/external probes would have been a better fit.

8 French Pilot

8.1 Introduction

The aim of this document is to guide step-by-step any users willing to test the portable Raman system. This manual provides detailed installation information to get the Raman portable system up and running. It also includes safety guidelines as the laser used in this system is classified as a class 4 laser.

8.2 Pilot test: UoN – Routhiau

The portable Raman system is a promising solution for helping food industries (Routhiau) in monitoring their product quality and reducing food waste during transportation. This portable system will be incorporated into a refrigerated truck and function as an alert mechanism that can notify the driver of any changes in food quality. In the event of potential food spoilage, the system can prompt the driver to deliver the products to the nearest food outlet or distribution center to prevent any loss of food.

8.3 Caution

The laser in use is classified as class 4 laser (severe hazard to eyes and skin). The use of eye protection is strongly recommended when operating lasers of any class beyond class 1.

8.3.1 Safety guidelines

Anyone who uses a laser source should be aware of the risks involved. This awareness is not solely dependent on the amount of time spent with lasers; in fact, prolonged exposure to invisible risks, such as those associated with infrared sources, can often lead to a diminished awareness of the risks involved.

Here are some guidelines to follow when dealing with laser sources:

- Only use the laser in a controlled access room with door interlocks and prominently displayed warning signs. Limit access to individuals who have been trained in laser safety.
- The laser operator must be responsible for controlling access to the laser area and notifying others of laser usage.
- All personnel present in the area, including operators who are not directly using the laser system, must wear appropriate personal protective equipment, particularly eyewear, before the laser is activated.
- Remove watches and jewelry before using the laser.
- Never look directly into the laser output port when the laser is active.
- When possible, perform beam and optical component alignments at reduced power levels.
- Do not install or terminate fibers while the laser is active.
- Ensure that the work surface is properly vented to prevent the generation of gases, sparks, or debris that could pose additional safety hazards.

8.4 List of equipment deployed for this pilot

- Raman spectrometer (QE Pro, Ocean Optics). *See Appendix I for more information.*
- Fiber-optic probe (InPhotonics, RPB78)
- Laser 785 nm (Oxxius, LBX-785-HPE)
- Laser controller (Oxxius, LaserBoxx series, ControlBoxx for LBX models)
- 3-axis motorized platform (Standa, 8-0026)
- 3-axis controller (Standa, 8SMC4-USB-B8-B9)
- A lockable box (QUIPO Locker - dimensions: height 450 mm x width 450 mm x depth 450 mm) covered on the inside with black opaque adhesive film (Adhesive vinyl, ME310-61). The box is equipped with four adjustable legs.
- Pilot computer that contains the following programs:
    - An API to automatically control the spectrometer and the 3-axis motorized platform allowing multiple sample measurements: Raman Automatization (IUT de Nantes)
    - Laser operating software (Oxxius, LaserBoxx HPE series)
    - Spectrometer operating software: OceanView (Ocean Optics)
    - 3-axis motorized platform operating software: XILab (Standa).

8.5 Step-by-step installation and configuration guide

8.5.1 Hardware set-up

8.5.1.1 3-axis motorized platform

- Place the 3-axis motorized platform in lockable box.
- Secure the platform with four M6 screws.

8.5.1.2 Fiber optic probe holder

- The fiber optic probe holder consists of four principal parts: "Upper fix holder", "Lower fix", "Back cage", "Front cage".
- Use five screws with 3 mm diameter to fix all above mentioned parts.
- Fix the fiber optic probe holder with four screws of 6 mm diameter to the "ceiling" of the lockable box.
- The fiber optic probe holder has a height change function: with a U-bolt (diameter of 34 mm and screw thread M6), adjust the "Upper fix holder" and the "Lower fix" on the desirable level.

8.5.1.3 Connecting the developed biosensor (see Figure 37 37)

- Connect the integrated cables of motorized XY stage to two-axis controller (8SMC5-USB-B9-2) via HDB15(M) cable. Secure the connectors using the locking screws.
- Connect the motorized Z-axis using (male/female 8CA15F-15MR12) cable to one-axis controller (8SMC5-USB-B8-1). Secure both connectors using the locking screws.
- Connect the two-axis controller with the one-axis controller using a USB cable 0.2 m (USB/A-B).

- Connect the power distribution cable (8A-KPPX-KPJX) to the two-axis controller and one-axis controller.
- Connect the two-axis controller using USB cable to PC, 1.8 m (USB/A-USB/B).
- Connect the DE-9 cable (male/female, commercial RS-232 cable) to the socket located on the rear panel of the laser controller. Connect the opposite side of the cable to the rear panel of the laser probe. Secure both connectors using the locking screws.
- Connect the interlock safety circuit to the “Interlock” pins on the front panel of the controller. If you are not using any interlock circuit, use the interlock wire to short-circuit these pins.
- Plug the 2.1mm power supply connector into the rear panel of the controller.
- Communication with the laser can be achieved by connecting a computer to the laser directly using a “USB A to micro-B” standard cable.
- Using a fiber optic connector, connect the fiber optic coming from the probe to that coming from the laser box.
- On the front panel of the spectrometer, take off the protective cap and connect the second channel of the fiber coming from the probe to the spectrometer. Secure the screw.
- Plug the power supply connector into the rear panel of the spectrometer.
- Connect spectrometer using a USB cable to PC (USB/A-USB/B).

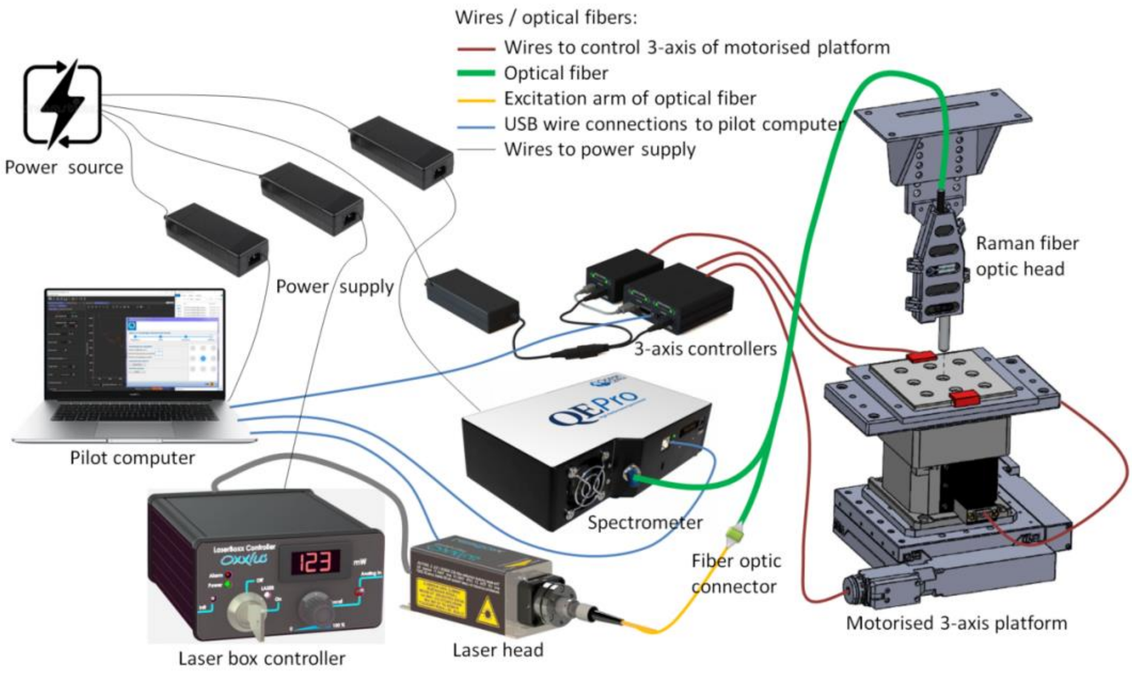
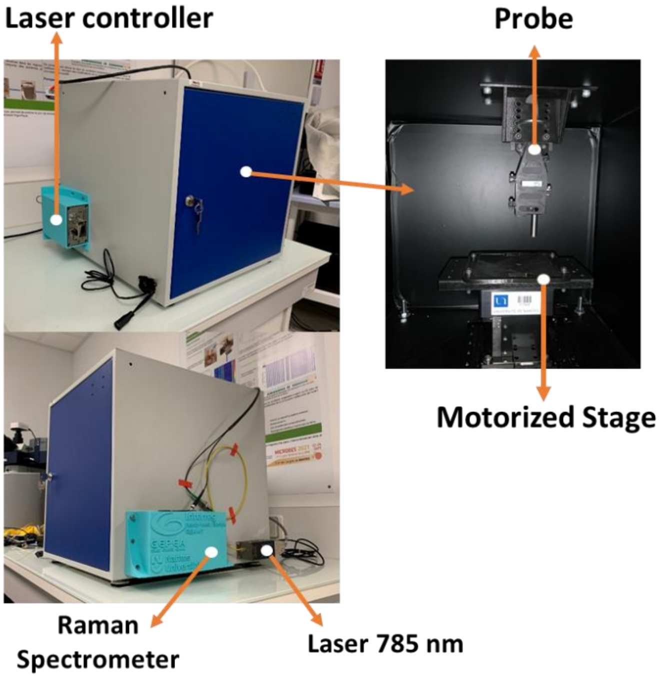


Figure 37 A guide to connect the wires included in the portable system

8.5.1.4 Transferring to the box

All above components (except the laptop) were transferred to the lockable box (QUIPO Locker - dimensions: height 450 mm x width 450 mm x depth 450 mm) as shown in the Figure below.



8.5.2 Software set-up

1. Turn on the computer and plug in the spectrometer, the laser box controller and the 3-axis platform controllers to a power source.
2. Turn the laser safety key to the position "ON". Flick the switch of the spectrometer in the position "ON".

8.5.2.1 Laser operating software (Oxxius Lasers)

3. Open laser operating software (Oxxius Lasers) on the computer. The laser should appear automatically on the laser list
4. Select the detected laser device on the list and click on the "Connect" button.
5. Set up the necessary parameters like laser power and current level (*Figure 38*).

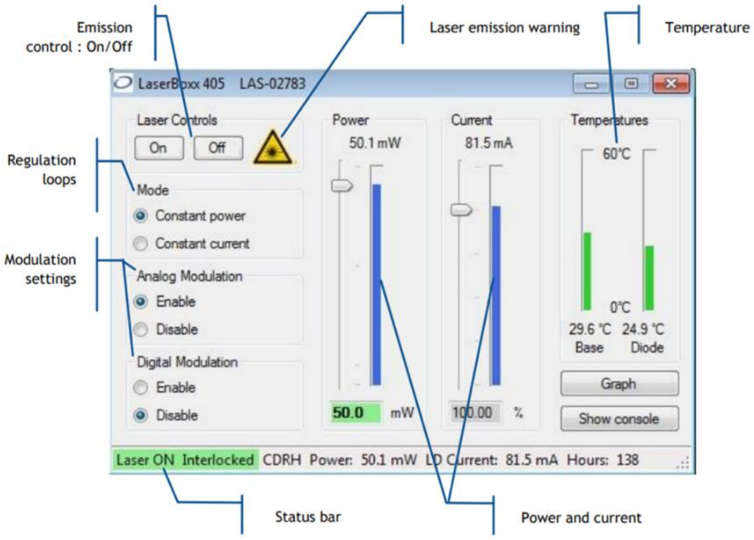


Figure 38. Laser box interface

8.5.2.2 Three-axis platform software (XiLab)

6. Open the 3-axis platform software (XiLab). In the start window choose the 3 detected controllers and open them using the "Open selected" button.

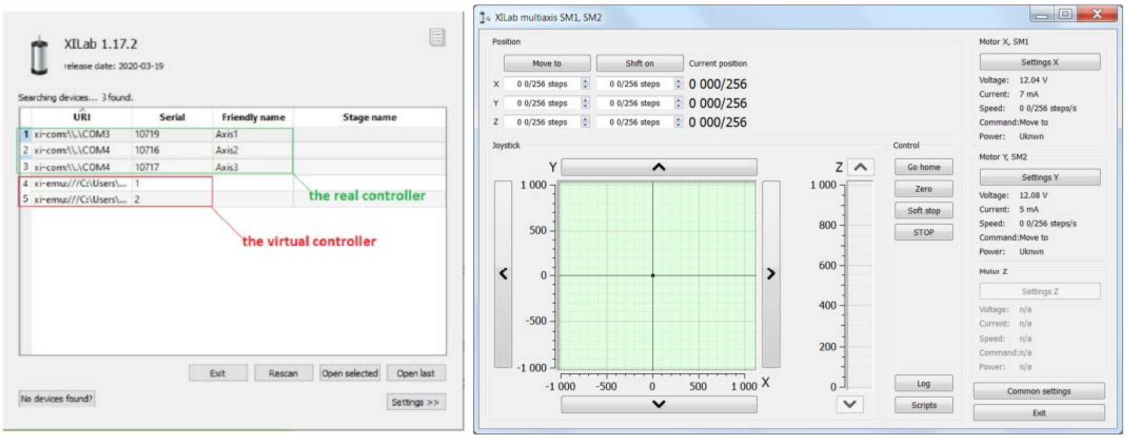


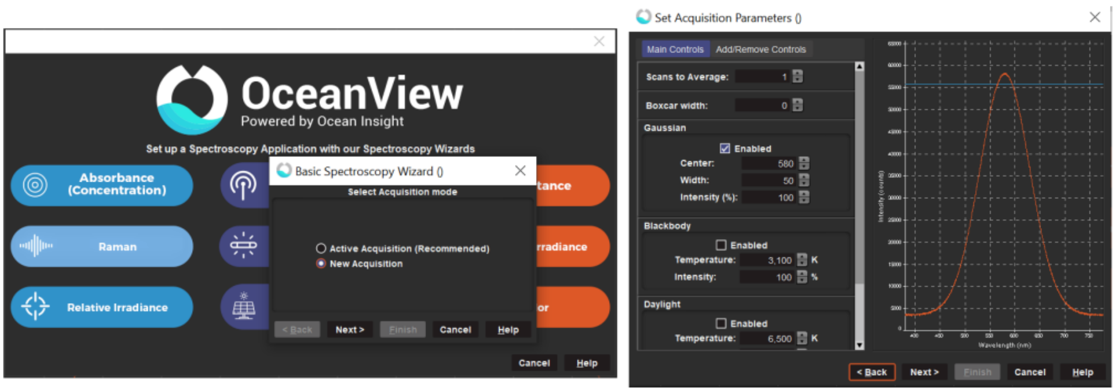
Figure 39. Motorized table interface

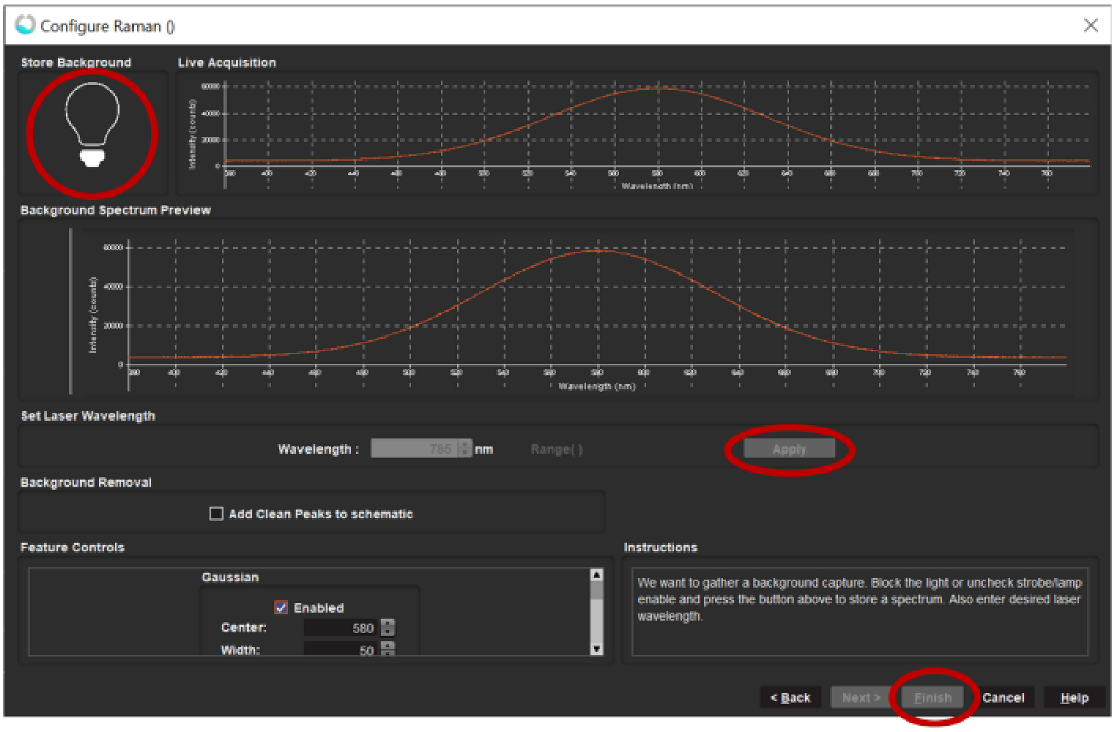
7. When the 3 controllers are assigned to the correct axis, you can use the X, Y and Z axis to move the sample under study in the desired location (*Figure 39*).

8.5.2.3 Spectrometer operating software (OceanView)

8. Open spectroscope software (OceanView). The program will automatically detect the connected spectrometer. The First window "Spectroscopy Application Wizards" shown in Figure 4 proposes to choose the type of measurements to perform, select "Raman".

9. In the next window "Basic Spectroscopy Wizard" select "New Acquisition" and press "Next".
10. In the next window "Set Acquisition Parameters" (Figure 40) all parameters are already set to measure the background noise of the spectrometer and optical fiber, click "Next".
11. Close the exit of the laser by sliding the button on the fiber optic probe to prepare for background measurement. Make sure in this step that the background measurement is done completely in dark conditions.
12. In the next window "Configure Raman" (*Figure 40*) as you close the slit on the exit of the laser, the signal change and it will be noticed during "Live acquisition" in the top right graph. Click "Store Background" and the spectra of the background noise will appear in the lower graph "Background Spectrum Preview". Click "Apply" and then "Finish".
13. To prepare for the focusing step, set the integration time to 700 ms in the Main Controls window





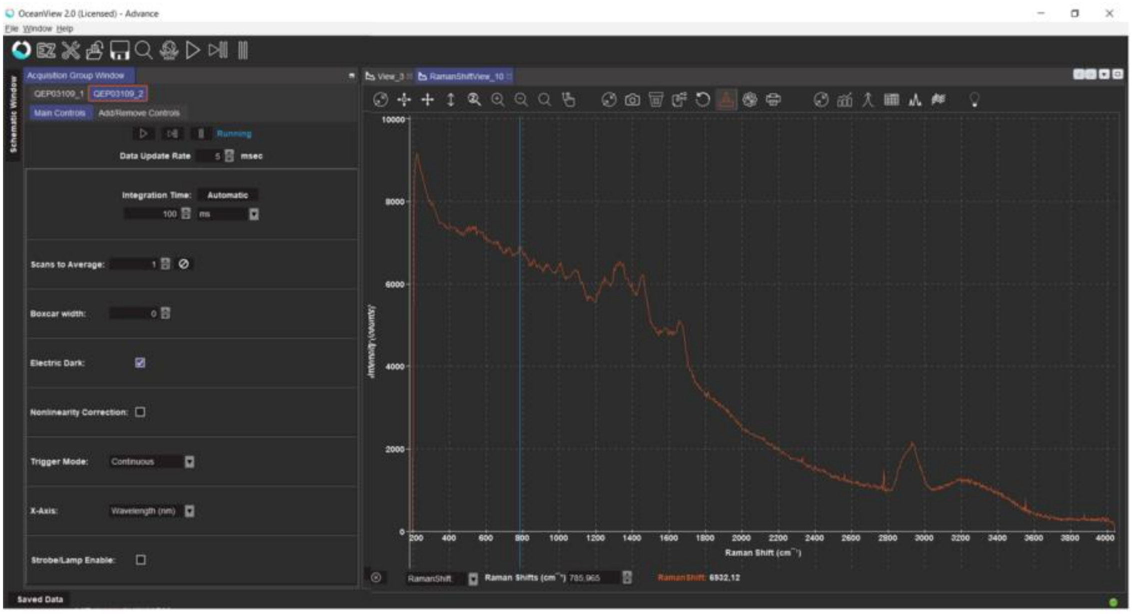


Figure 40. Interface of Oceanview Software

8.5.2.4 Focusing the fiber optic head in z-direction using 3-axis motorised platform

14. In the main window of 3-axis platform software XiLab (Figure 39), press on “Shift on” located at the top left corner of the window, second column. Under "Shift on», in the third row "Z axis" type "-100" instead of the first zero.

15. Press "Shift on" and the motorized platform should go down for about 1 mm as you observe the spectrum intensity.
16. If it decreased, it means that focus point is situated in the other direction. Type "100" instead of "-100" and press "Shift on".
17. Continue to press "Shift on" as intensity of the spectra in "live" mode increases and stop when it will start to decrease. Record the number and use it for taking acquisitions of Raman from the same spot. For the chicken sample, the estimated Z was about 12588 or other words, the distance between the sample and the laser was about 2 mm.
18. For finer focusing, type "50" or "-50" in respect of the focus placement and find the position in z-axis where the intensity of the displayed spectra is the highest.

8.5.2.5 4.2.5. Launch of the automated spectroscopic measurements

19. Close the spectrometer software (OceanView) and the 3-axis platform software (XiLab).

20. Open the API (Automatization Raman), the API will automatically detect both the connected 3-axis platform and the spectrometer.
21. When the position of the table is set, especially the Z-distance (identified in step 17) click on "Calibration" in the upper box of the window (Figure 41) to proceed to the next window (*Figure 41*).

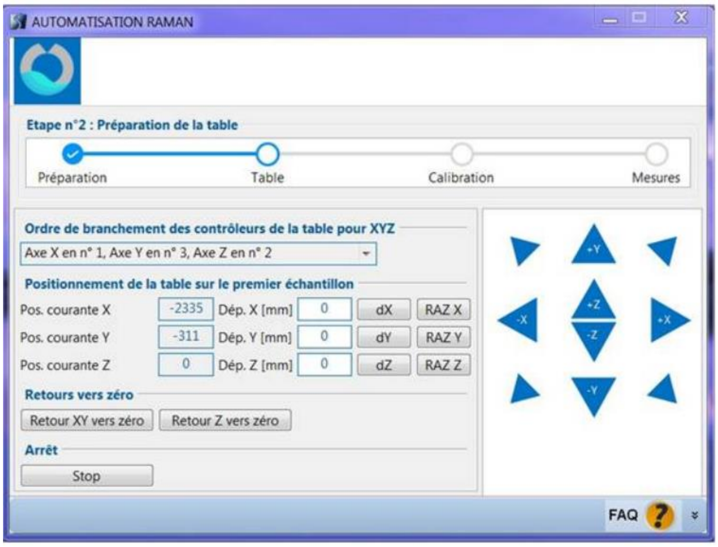


Figure 41. API software. Preparation of the Motorized table

22. Set the power of the laser to a desirable level for measurements using laser operation software Oxxius Lasers (Figure 38). Then click on the box next to "Confirm the setting of the laser intensity" (Validez le réglage de l’intensité du laser). The laser power in our testing (chicken samples) was set to 250 mW.
23. Close the exit of the laser by sliding the button on the fiber optic probe to prepare the measurements of the background. Then, click on the box next to "Confirm the closure of the probe shutter" (Validez la fermeture du clapet de la sonde) (*Figure 42*).

Figure 42. API software. Calibration

24. Press on the button "Launch" (Lanecement) to launch the measurement of the background to calibrate the spectrometer. At the end of the procedure, a message will appear which confirms that the spectrometer calibration has been successfully completed (Figure 42).
25. Type in desirable acquisition parameters in the boxes such as "Integration time" (Temps d'intégration), "Number of spectra to average" (Nombre d'acquisition moyennées) and "Number of runs per well" (Nombre de passages par puits). The integration time, Number of spectra to average and number of runs were set to 5 seconds, 10 and 1 respectively (Figure7). Kindly note that " Number runs per well" is the location of the sample in the software. In our case, we specified only one location and carried all measurements (or runs) based on this location.
26. Press "Launch" (Lanecement) to start the automated spectroscopic measurements of the chosen samples (*Figure 43*).

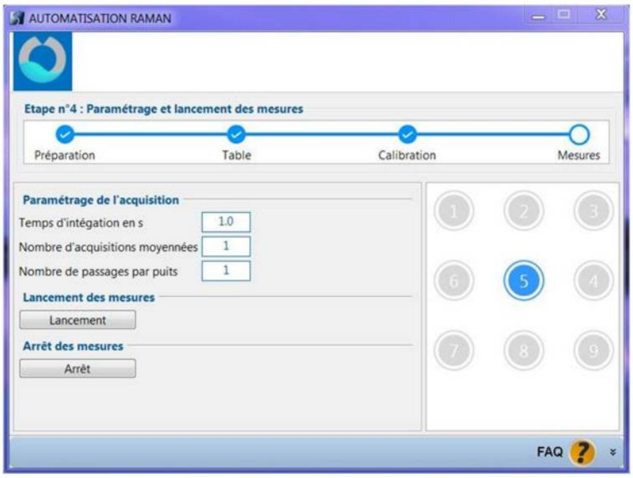


Figure 43. API software. Measure

27. Wait till the end of the programmed cycle or press "Stop" (Arrêt) to stop the cycle of automated spectroscopic measurements.
28. Close specially created API (Automatization Raman) and laser operation software (Oxxius Lasers). 36. Turn the laser safety key to the position "OFF". Flick the switch of the spectrometer in the position "OFF"

29. Unplug spectrometer, laser box controller and 3-axis platform controllers from the power source.

8.6 Good practice and recommendations

The tested portable system was capable to monitor the quality of packaged chicken meat in function of storage time. This system was able to detect the shift in the product's quality, the chemical components impacted during the course of quality deterioration, and the day when the food quality started changing.

Recommendations

- Make sure to always follow the safety guidelines when using this apparatus.
- Make sure that the temperature for the laser source is between 10 °C and 18 °C.
- Several types of food samples can be used with system. It can be solid or liquid.
- To have the best spectrum, make sure to adjust the Z-axis till you have the highest intensity spectrum with optimum number of peaks.
- Always close the door of the lockable box when using the system. Light can weaken the emitted signal by the Raman spectrometer.

Example of Raman spectrum obtained by the Portable Raman system

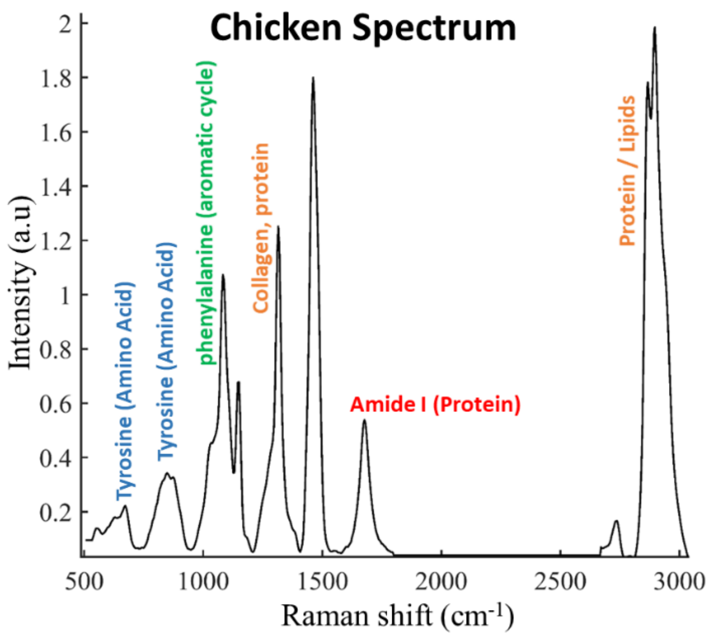


Figure 44. This Raman spectrum is considered as a structural fingerprint where this spectrum shows all chemical components in a sample including nucleic acids, carbohydrates, lipids, and proteins.

8.7 Appendix.

QE PRO Scientific-grade Spectrometer Product Overview

The Ocean Optics QE Pro Spectrometer is a scientific-grade spectrometer that is ideal for researchers and industrial customers. Its broadband sensitivity, from UV to NIR, makes it suitable for a wide range of applications, while its high sensitivity and thermo electric cooler enable effective measurements at very low light levels. The QE Pro also has the highest dynamic range of any fiber optic CCD spectrometer in its class.

Figure 45. QE Pro Spectrometer

Two LEDs are provided to monitor spectrometer and TEC operation. The QE Pro operates from power provided from a separate +5VDC power supply.
The QE Pro features a Hamamatsu low-etaloning, back-thinned FFT-CCD detector with a 2-D arrangement of pixels (1044 horizontal x 64 vertical) that is responsive from 200-1100 nm and has a peak quantum efficiency of ~90% (with a QE of 65% at 250 nm). The detector's columns are binned, or summed, inside the detector prior to the readout process, thereby minimizing readout noise. Additionally, the detector can be cooled from 40°C below ambient up to 50°C with the onboard TE-Cooler to reduce dark noise. The reduction of noise and dark signal allows integration times of the spectrometer (analogous to the shutter speed of a camera) of up to 60 minutes, which greatly enhances the detection limit in lowlight level applications. The back-illuminated detector has enhanced response in the UV. The inherent UV response eliminates the need for UV-sensitive detector coatings that can be difficult to apply consistently from batch to batch.
The combination of the spectrometer's low-noise detector and 18-bit A/D Converter delivers a dynamic typical range of ~85,000:1 and a signal-to-noise ratio of 1000:1 (at full signal).
The QE Pro's onboard module has 10 user-programmable digital I/O lines for interfacing to other equipment; and a pulse generator for triggering other devices. You can use the I/Os to flash a lamp, stop/start a process, and send a message/alarm during the spectrometer's integration period. The spectrometer's operating parameters can be controlled through software. In fact, wavelength calibration coefficients unique to each spectrometer are programmed into a memory chip right on the spectrometer. The QE Pro's high-speed electronics have been designed for considerable flexibility in connecting to various modules and external interfaces, including PCs, PLCs and other embedded controllers, through USB 2.0

or RS-232 communications. A +5 VDC external power supply is required to operate the spectrometer. This power supply is included with your spectrometer. An optional internal shutter is available on custom-configured spectrometers (INTERNAL-SHUTTERLRG-BENCH). This makes it easier to take dark measurements and when you need fast integration times with the best possible signal. This optional feature is also recommended for probe-based or emissive measurements where it is difficult to introduce a shutter into the optical path. The shutter can be added to an existing QE Pro for an extra charge.

Features

Hamamatsu S7031-1006S Detector:

- Typical dynamic range ~85,000:1
- Peak QE: 90%
- Back-thinned for enhanced UV sensitivity
- Integration times from 8 ms to 60 minutes
- TE Cooled

Scientific-grade Optical Bench:

- Symmetrical Crossed Czerny Turner
- 101mm focal length
- F number: f/4
- Interchangeable slits
- 14 gratings (H1 – H14); HC1
- 6 slit widths, plus no slit in SMA or FC bulkhead

Communications

- USB 2.0 Full Speed
- RS232 up to 460K Baud

Thermo Electric Cooler (TEC)

- Software-controlled set-point
- LED indicator to show when the TEC is stable and accurate
- Temperature stability: <0.1ºC
- Continuous TEC setpoint control 15 to 40ºC below ambient

GPIO

- Single strobe
- Continuous strobe
- 10 user-programmable digital I/O pins
- SPI/I2C for controlling peripherals

Nonvolatile storage

- Wavelength calibration coefficients
- Linearity correction coefficients
- Absolute irradiance calibration

Buffering

Triggering (4 modes)

Resets

- Watchdog timer for reliability
- Hardware power recycle via reset pin or software command

Kensington security slot
LEDs for feedback on TEC readiness and general spectrometer health
Software support:

- OceanView

CE certification

System requirements
You can use the QE Pro's USB connectivity with any computer that meets the requirements for the spectrometer operating software being used (Windows XP/Vista/Windows 7, Mac OS X and Linux). See About Ocean Optics Software. Alternately, the QE Pro has a serial port for connecting to PCs and PLCs. However, this connection method requires an external power supply to power the QE Pro, the Breakout Box, and a serial cable.
About Ocean Optics Software
OceanView is the latest generation of operating software for all Ocean Optics spectrometers. It is a completely modular, Java-based spectroscopy software platform that operates on Windows, Macintosh and Linux operating systems. The software can control any Ocean Optics USB spectrometer and device. OceanView is a user-customizable, advanced acquisition and display program that provides a real-time interface to a variety of signal-processing functions. With OceanView, you have the ability to perform spectroscopic measurements (such as absorbance, reflectance, and emission), control all system parameters, collect and display data in real time, and perform reference monitoring and time acquisition experiments.
Sampling System Overview
How Sampling Works
Ocean Optics components function in a sampling system as follows in this example:

1. The user stores reference and dark measurements to correct for instrument response variables.
2. The light transmits through an optical fiber to the sample.
3. The light interacts with the sample.
4. Another optical fiber collects and transmits the result of the interaction to the spectrometer.
5. The spectrometer measures the amount of light and transforms the data collected by the spectrometer into digital information.
6. The spectrometer passes the sample information to Ocean Optics software.
7. Ocean Optics software compares the sample to the reference measurement and displays processed spectral information

Interface Options
The QE Pro has both USB and serial port connectors (with the use of an adapter), enabling you to connect the spectrometer to a desktop or notebook computer via a USB port or serial port.
Installing the QE Pro
Overview

You must install the operating software application prior to connecting the QE Pro Spectrometer to the computer. The Ocean Optics spectrometer operating software installs the drivers required for the QE Pro spectrometer installation. If you do not install the software first, the system will not properly recognize the QE Pro.

QE Pro Installation

This section contains instructions for connecting the QE Pro via both USB and serial modes.

USB Mode

This section contains instructions for connecting the QE Pro in USB mode. To connect the QE Pro to a computer via the USB port, the computer must be running a Windows XP/7/8/10 or Vista (32-bit only), Mac OS X (10.5 or later), or Linux (x86 or amd64 platform since 2010) operating system.

Procedure

Follow the steps below to connect the QE Pro to a computer via the USB port:

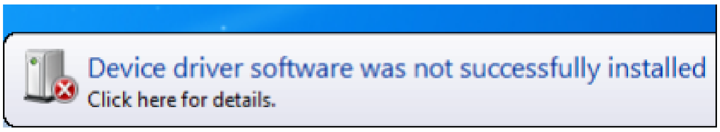
1. Install the spectrometer operating software on the destination computer.

   Caution Do NOT connect the spectrometer to the computer until you install the spectrometer operating software. Follow the instructions below to properly connect and configure your system.
2. Plug the +5 VDC power supply into the QE Pro.
3. Locate the USB cable (USB-CBL-1) provided with the QE Pro.
4. Insert the square end of the cable into the side of the QE Pro.
5. Insert the rectangular end of the cable into the USB port of the PC.

The QE Pro spectrometer requires special device driver installation instructions. Choose the appropriate instructions listed below depending on the type of Windows system your computer is running.

Installing the Driver Software for QE Pro Spectrometers on Windows 7 (32 and 64-bit)

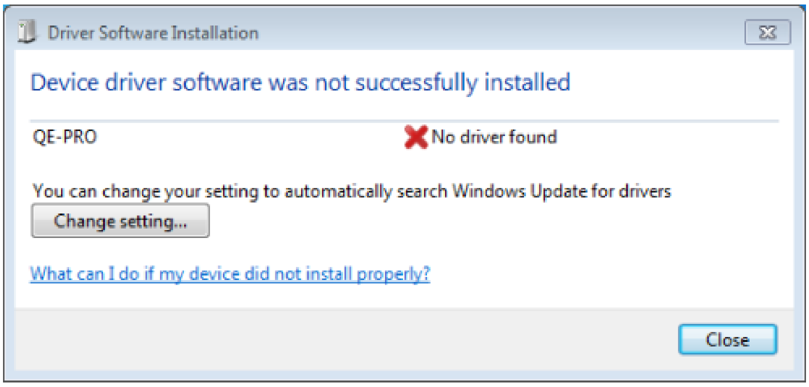
When you first plug in your spectrometer, Windows 7 will attempt (unsuccessfully) to automatically install the driver for your spectrometer. Click close to close the warning message:



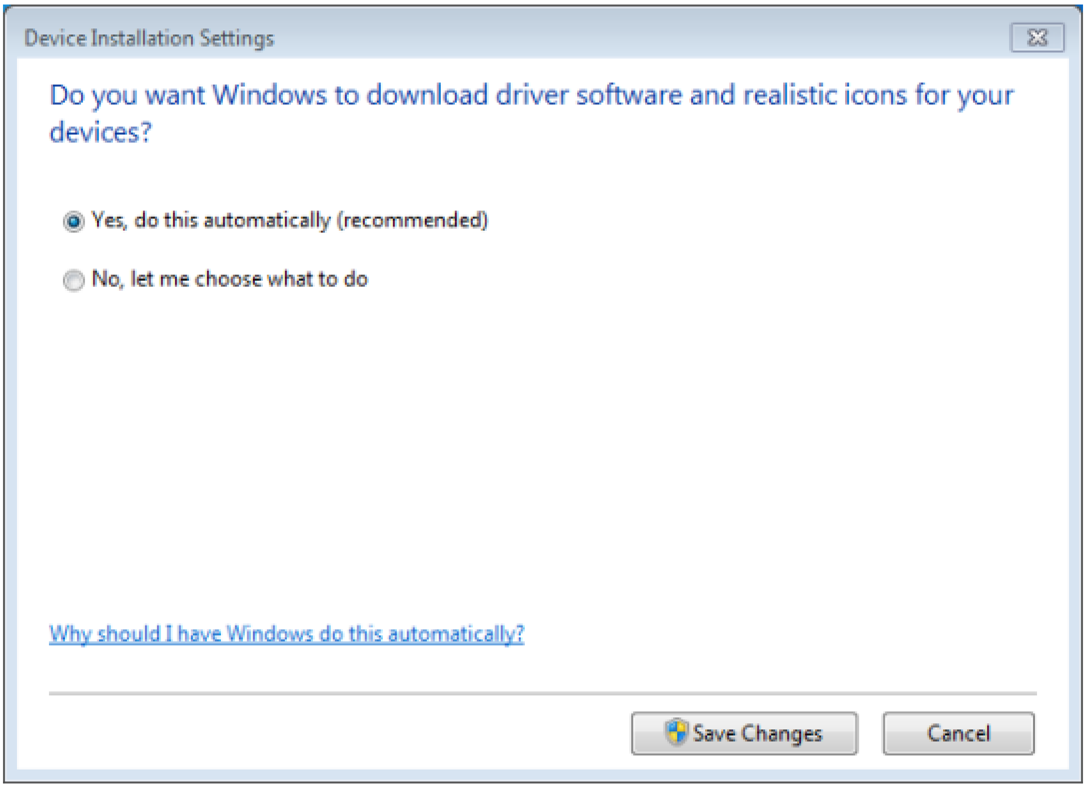
Procedure

To manually install the new 64-bit driver for your spectrometer:

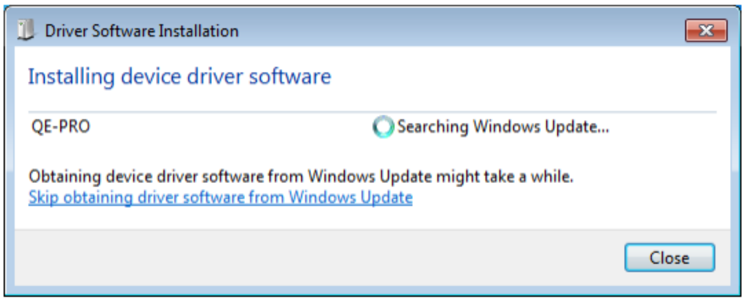
1. Click Change setting.



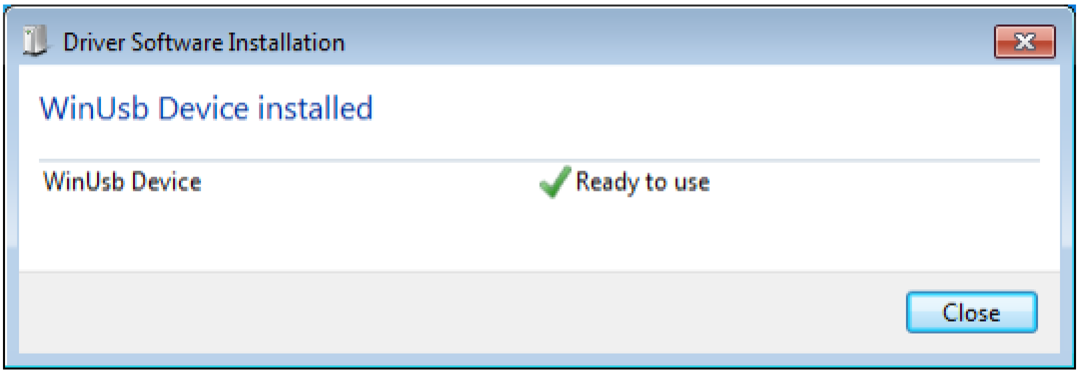
2. Select *Yes, do this automatically*



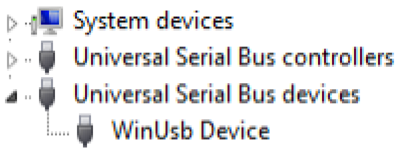
The system installs the device driver software.



When the installation process has finished successfully, the following screen displays:



The Device Manager reports the following information:

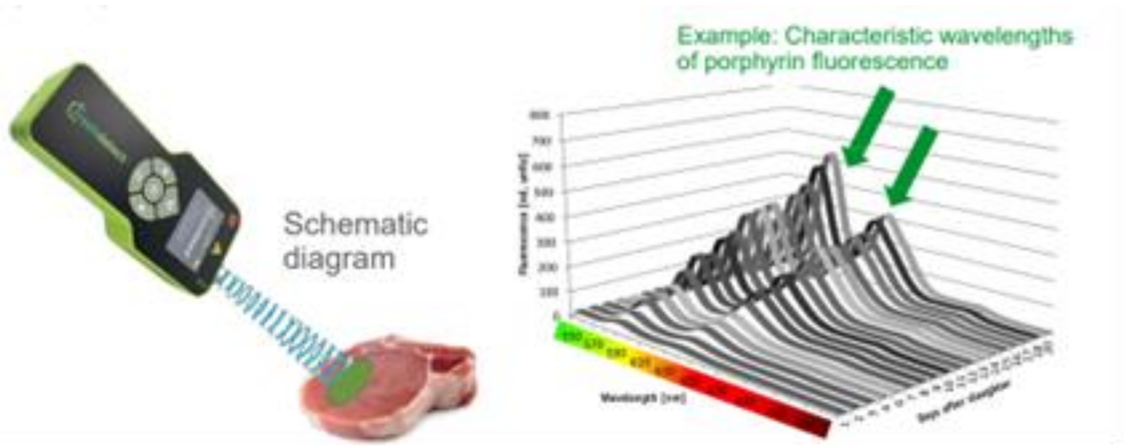


LED Operation

LED Position	LED Position
Top LED	Monitors Spectrometer status: • Off – spectrometer does not have power • Flashing orange – spectrometer is booting • Steady green – spectrometer is ready
Bottom LED	Monitors TEC status: • Off: The TEC system is off. • Orange: The TEC has not yet stabilized at its given setpoint. • Green: The TEC is stable (has been within 1°C of the setpoint for at least 15 seconds).

9 Northern Ireland laboratory testing pilot: Ulster University in collaboration with FreshDetect GmbH

FreshDetect GmhH manufacture the FreshDetect BFD-100, a handheld non-invasive fluorescence spectrometer device that operates at an emission wavelength of 405nm. The FreshDetect device was initially designed for monitoring the quality of meat products by determining bacterial contamination through the estimation of the total viable count, which refers to the number of viable microorganisms present in a sample. However, in the REAMIT project the FreshDetect device has been the subject of exploration to determine its applicability in assessing the freshness of other household food items that are prone to spoilage.



In this pilot, the goal was to expand the application of FreshDetect beyond meat products and evaluate its effectiveness in determining the freshness of whole milk (2%). The motivation behind this was fuelled by the removal of use-by dates on milk by some UK supermarkets, promoting alternative methods like the "sniff test" for determining milk spoilage. This pilot sought to explore the potential of utilising the portable handheld spectroscopy device as a quantitative tool for measuring milk quality. By doing so, it aimed to reduce the reliance on subjective olfaction techniques and potentially pave the way for the introduction of handheld spectrometers as a commonplace tool in households, in turn offering consumers a more reliable and convenient method for assessing the freshness of their milk.

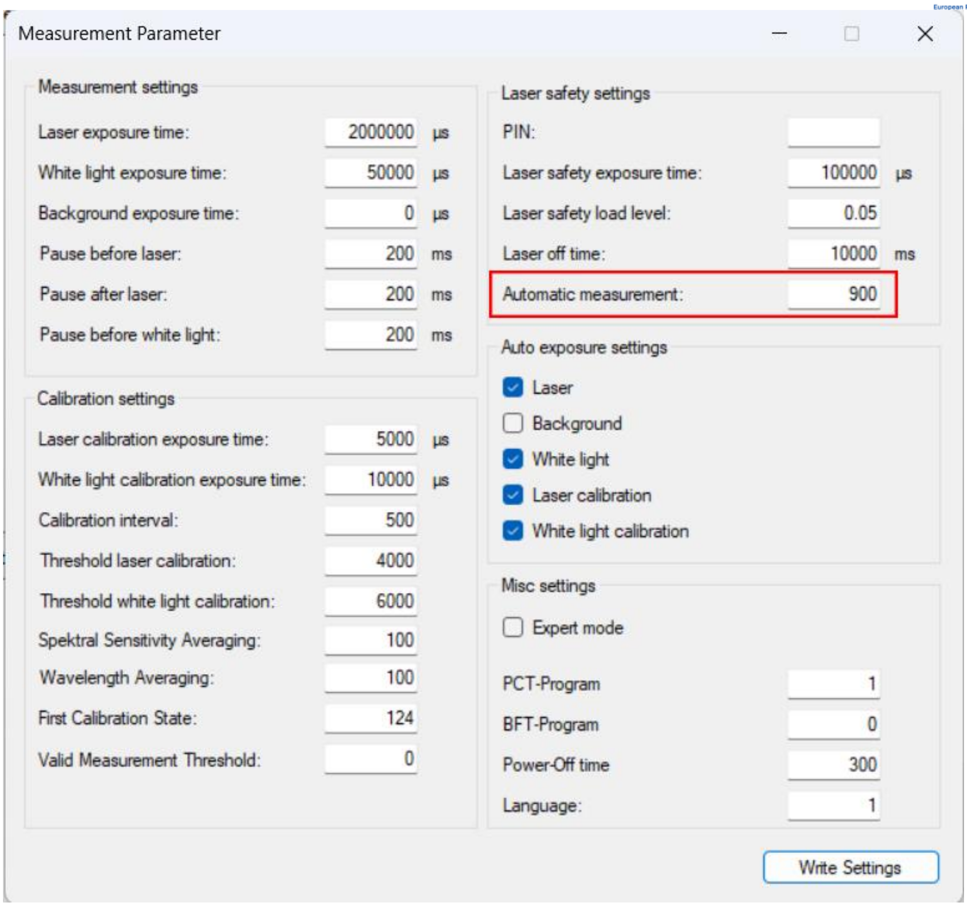
The objective was to examine the relationship between the fluorescence signals emitted by milk and attempt to correlate it to its freshness status by comparing it to obtained pH measurements from the same milk sample. The decrease in pH is one of the indicators of milk spoilage. Fresh milk typically has a pH of around 6.6 to 6.8, which is slightly acidic. As spoilage progresses, the pH can drop significantly below this range, indicating that the milk has become more acidic.

List of equipment deployed for this pilot:

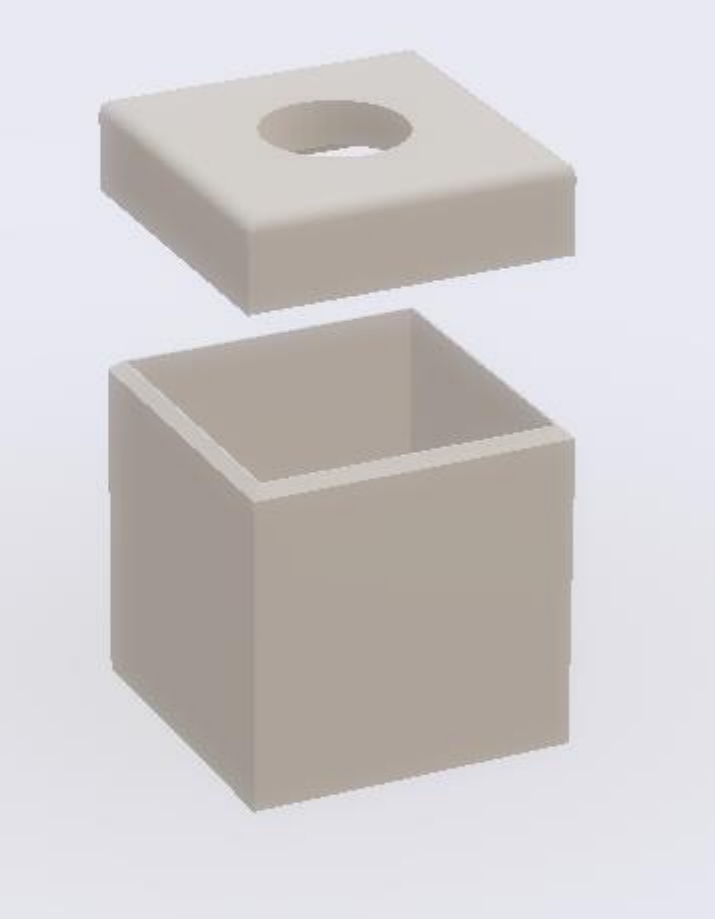
Manufacturer	Equipment reference (Sensor, GW, Other…)	Use of the equipment
FreshDetect	BFD-100	Handheld spectrometer used to excite food sample and measure spectra
Thermo Scientific	Orion Star A215	To measure pH

Step-by-step installation and configuration guide:

The FreshDetect was designed to take measurement upon button push. However, to collect enough data to build a useable model to detect milk freshness, an automated way of recording scans was required. Using the *Expert Software Tool* computer software provided by FreshDetect, it was possible to enable automatic scans on the FreshDetect with a user-defined time period between scans. By enabling this mode, it was possible to press the begin scan button once to start the experiment and once again to finish the experiment, allowing researchers to collect a large dataset of spectra samples without needing to tediously press the button each time or supervise the data collection. To enable automatic scanning from the expert software tool, plug the FreshDetect device into your computer and navigate to settings > measurement parameter. From here, replace the Automatic measurement value, which is defaulted to 0, to the time required between automatic scans in seconds. In our case, we use 900 seconds, representing 15 minutes.



To ensure that the FreshDetect took samples from the same distance and under the same lighting conditions during each scan, a custom 3D printed case was designed in FreeCAD which held the sampling container (a glass beaker) inside. The case consisted of a lid which contained the cutout for the FreshDetect's laser and spectrometer, and a base which held the beaker.



Once the lid was placed on the base, the FreshDetect would be positioned at the required distance from the top of the liquid for data collection. Presented in Figure is a depiction of the experimental setup with the 3D printed sample holder.

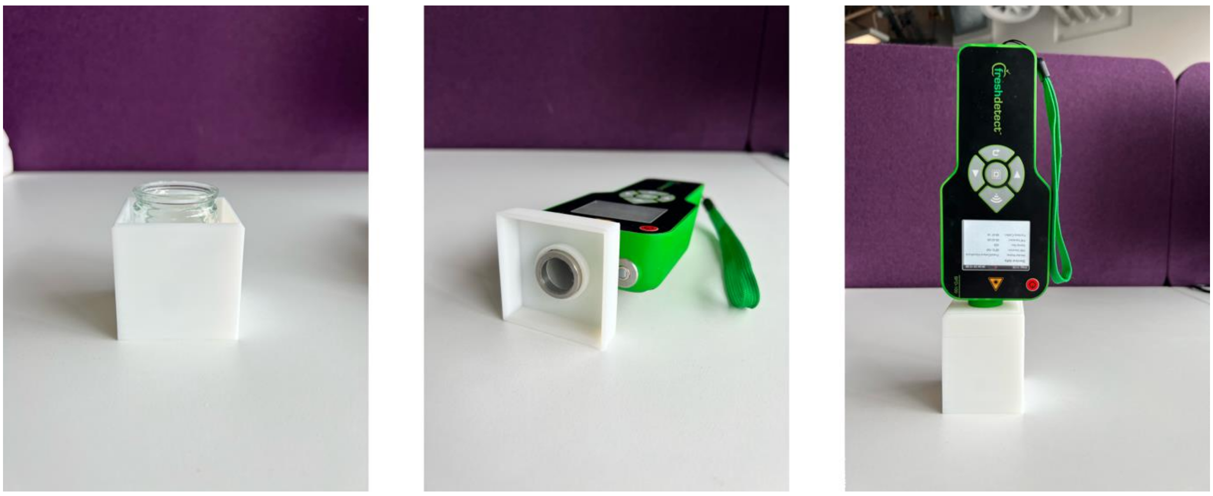


Figure: Milk sampling procedure using custom designed and printed 3D housing to ensure the same light level and distance was used between recordings.

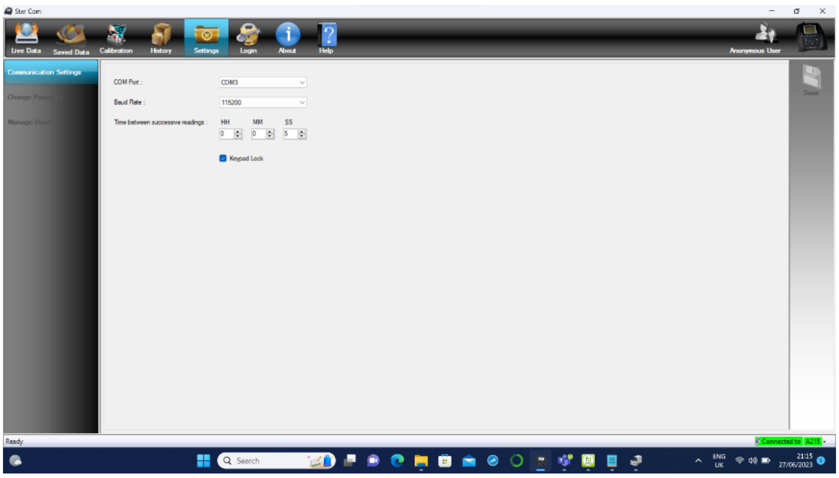
In order to obtain accurate and consistent pH measurements, the Thermo scientific Orion Star A215 pH meter was chosen. This laboratory grade pH meter offered the ability to log pH measurements automatically using a provided user specified time increment, ensuring that the milk quality degradation could accurately be monitored without constant supervision. The device offered USB communication allowing the measurements to easily be exported and transferred to a computer, enabling the researchers to map the pH data to spectra obtained by the FreshDetect at the same timestamp.

Figure 56: Thermo Scientific Orion Star A215

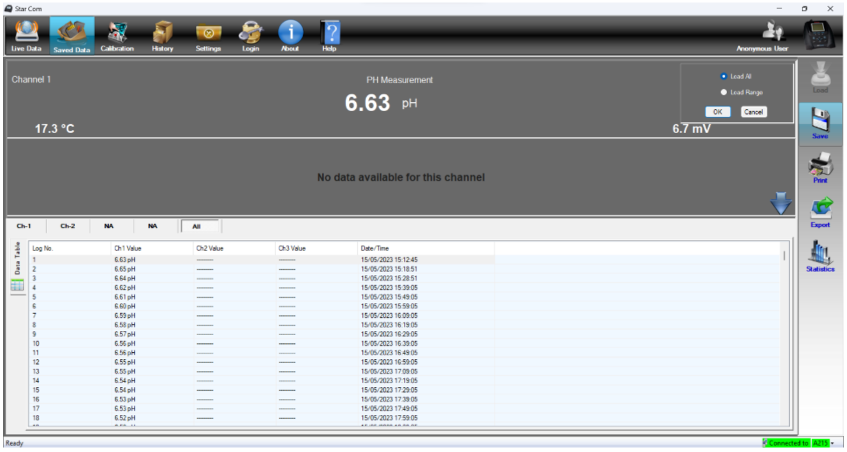
To enable automatic scanning on the Orion Star A215, turn the device on and first press the Setup key (up arrow on the meter). Select pH channel (1) using the F3 key, then select Mode and settings, read type, and choose timed read. On this screen, you can configure the interval between scans.

Once you have selected the desired interval, click Select using the F3 key to confirm your selected parameters and begin automated timed readings.

To download the recorded pH data, you need to install the Star Com application on your computer from Thermo Scientific. Using a mini-USB cable, connect the meter to your computer. Start the Star Com application and choose settings. Choose the COM port the pH meter has registered itself to (in this example COM3) and the status bar in the bottom right-hand corner will change from not connected with red background to connected in green.



Once connected, choose the Saved Data tab and click load from the right-hand menu bar. An options box appears allowing you to choose between loading all data recorded on the pH meter or loading a specific range of data.



Once the relevant range of pH data is selected and Ok is clicked, the data recorded during the experiment will appear in the window, displaying the log number, pH value, and datetime stamp. To export the data for later use, choose export on the right-hand menu. The data can either be saved as excel format (.xls) or CSV.

Good practice and recommendations:

To ensure accuracy and reliability in obtaining a spectra training set, it is important to maintain consistent lighting conditions and a fixed distance between the FreshDetect device and the sample during each scan. A custom 3D printed casing was specifically designed to address these requirements. This casing serves two purposes: firstly, it ensures a consistent scan distance, guaranteeing that the device is held at the same distance from the sample for each scan. Secondly, it helps maintain consistent lighting conditions by ensuring that the sample is exposed to the same quantity of light during each scan. By utilising the custom casing, researchers can adhere to a standardised scanning procedure, leading to improved precision and reliability of the obtained spectra for subsequent training and analysis.

One should ensure that the pH meter they have selected for their data collection is rated for food sampling. When collecting pH data for milk, it is crucial to use a pH meter and probe specifically designed for food measurements due to the presence of proteins, fats, and other components in the liquid. Standard probes that come with many pH meters are typically intended for measuring liquids that are not dense or contain particulates. Using such a probe for tracking the pH in milk may lead to inaccurate pH readings.

10 Contact

Website: www.reamit.eu

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