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AquaVitae

Project title:

New species, processes and products contributing to increased production and improved sustainability in emerging low trophic, and existing low and high trophic aquaculture value chains in the Atlantic

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[1] Document will be a draft until it is approved by the coordinator
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Deliverable D4.3

Report on first development phase for IoT-enabled sensor

21/04/2021

Contents

Executive summary

In WP4 of the AquaVitae project, "Sensors, data integration and Internet of Things", three different sensors will be developed by DTU, Biolan and Norce. The physical sensors are already created, but in this WP the purpose is to develop them further in order to meet the practical needs and requirements of the aquaculture sector, in particular the low trophic aquaculture producers. To accomplish this task, stakeholders have been interviewed to ascertain their needs regarding the use of the sensors developed in the project. Based on this feedback, the scope and a plan of development for each sensor has been created.

The first sensor prototypes will be delivered by month 12, and they will then be tested and evaluated by the stakeholders, both internal ones among AquaVitae's partners and external ones. A second prototype, incorporating the feedback from stakeholder evaluation of the first prototype, will be delivered by month 36.

During the lifetime of the project, WP4 delivers four reports documenting the work on the sensor development:

- D4.1: Scope, plans and initial stakeholder feedback, M5
- **D4.3: Report on first development phase, M12**
- D4.4: Report on second development phase, M30
- D4.5: Report on final development phase, M46

The current deliverable follows on from Deliverable 4.1 "Scope, plans and initial stakeholder feedback", that gave a detailed overview of the feedback obtained. It also contains the development plan for first and second iteration of each of the different sensor prototype development processes. In summary, the stakeholder's main requirements regarding use of the sensors are (from D4.1) better process control, better yield, and lower costs. The main requirements for the sensors themselves are accuracy, affordability, and robustness.

This deliverable reports the status of the three sensors at month 12, at the end of the first 12 months development phase. For Biolan and Norce, the progress is mainly according to plan. Both will begin phase two: extensive stakeholder consultation and prototype testing which is due to be completed by M18. Restrictions on travel, availability of equipment, and access to facilities due to COVID-19 may have an impact on prototype testing for NORCE in phase 2, but they expect to be able to mitigate these challenges and be able to give a preliminary prototype evaluation by M18. DTU was more impacted by COVID-19 and announced delays in the accomplishment of phase one due to limited access to their facilities. They plan to generate data in the lab to compensate for in situ data collection to make up for lost time and reschedule the work at sea as soon as possible. This should not have major impacts on other parts of the project. At worst, the software development will have a one-two month delay because of lack of in situ data.

1. Introduction

i. Scope of AquaVitae

AquaVitae is a research and innovation project funded by the EU's Horizon 2020 programme, BG-08-2018. The project consortium consists of 35 partners, from 16 different countries, spread across four continents. In addition to Europe, partners are situated in countries bordering the Atlantic Ocean, including Brazil, South Africa, Namibia, as well as in North America. Its broad objective is to introduce new low trophic species, products and processes in marine aquaculture value chains (VCs) across the Atlantic.

ii. Scope of WP4 Sensors, data integration and Internet of Things

The objective of WP4 is to develop or improve and test new or existing sensors for use in the aquaculture industry using an Internet of Things (IoT) approach; this includes biochemical sensors, biomass sensors, and the integration and visualisation of data from environmental sensors (SO5). Specific objectives are:

- To develop new methods for biomass monitoring in offshore aquaculture sites by combining underwater laser cameras with computer vision and machine learning algorithms
- To design and develop a smart sulphite biosensing device for use in aquaculture production
- To develop an IoT platform for integration and analysis of sensor data related to aquaculture production
- To develop a Data Management Plan (DMP) for the data generated in AquaVitae, and to update the DMP at the end of every reporting period

iii. T4.1 Scoping, planning, and eliciting stakeholder feedback for sensor development.

In WP9 the AquaVitae multi-actor platform will be created and put into operation, and this involves numerous stakeholder meetings on CS level. AV will employ a multi-actor approach to ensure that project outcomes are co-created with extensive involvement of users and other stakeholders, to ensure relevance and acceptability. In this task, the scope and a detailed multi-actor plan for the sensor development work that is linked to WP4 will be defined, based on the overall AV / WP project description, the priorities of the industry participants and the scientists, and the feedback from the stakeholders. The plan for the sensor development will contain descriptions of who will do what when and where, and it will need to be synchronised with the plans made for the CSs in WP1-3.

2. Company case examples

i. DTU – 3D camera for mussel biomass monitoring

Develop new methods for biomass monitoring in offshore aquaculture sites (DTU, Norut)

This task use and adapt next generation range-gated camera technology based on state-of-the art "time of flight" image sensors and innovative pulsed laser illumination (LiDAR). This is referred to as an Underwater Time Of Flight Image Acquisition (UTOFIA) camera, and it was an output from the H2020 UTOFIA project which ended in 2018. DTU is developing optimized range gating for mussel production, and specific software for volumetric reconstruction of the mussel lines with machine learning functionality. In AquaVitae, we develop and test the system in CS8 and CS9, but it is also applicable in other CSs where biomass monitoring is relevant, e.g IMTA (Integrated multi-trophic aquaculture) production and finfish production. The monitoring device is in phase of being integrated with the IoT platform to enable data storage, visualisation, and data analysis (machine learning). The encoding and exchange format for all data to be transferred to the IoT platform will be defined. Application program interface (APIs) will be developed to enable the collection of data from the biosensor.

ii. Biolan – sulphite sensor for shrimps

Design and develop a smart sulphite biosensing device for use in aquaculture production (Biolan, Norut)

This task delivers a prototype of a high-performance, battery-operated, portable and connected biosensor for sulphite monitoring, aimed to be used in shrimp production. The electronics are designed to achieve technical specifications by first running simulations, and then testing different circuit architectures. The layout of the printed circuit boards are defined and created for mounting the prototypes. For software development, the tool-chain is selected and configured, and signal processing and calibration processes coding are ongoing. The mechanical structure design consists of the design of the mechanical frame of the portable device based on 3D printing and/or other technologies for first prototypes and design of the final casts. The biosensing device is starting to be integrated with the IoT platform to enable data storage, visualization, and analysis (machine learning). The encoding and exchange format for all data to be transferred to the IoT platform are under analysis. APIs is developed to enable the collection of data from the biosensor.

iii. Norce – integrated sensor data platform

IoT platform for integration and analysis of sensor data (Norut, Nofima)

Data gathering is based on local infrastructure for power efficient and resilient communication between low power IoT devices without fixed infrastructure and to enable integration with existing IoT devices and platforms at the test sites. Machine learning functionality are developing for sensor data fusion, sensor calibration, sensor monitoring and prognosis. A flexible and simple visual tool (dashboard) to create AI training sets with automated training, validation and deployment of AI based monitors / virtual sensors is developing. Edge computing support for sensors and AI trained monitors/virtual sensors will be provided for sites with no or unstable Internet access. The IoT platform will be tested in IMTA, shellfish, and finfish production cases.

3. Method

The method applied is the spiral method (see D4.1 for more detail). At month 12, we are at the end of the first 12-month iteration loop. According to the development process, this is the end of the initial development phase when a prototype is planned to be available for user testing.

The next 24-month development phase (M13-M18) will consist of extensive stakeholder consultation and prototype testing.

To create the prototypes, the three partners have interviewed many stakeholders to gather their needs and priorities regarding the sensors. The outcomes were (see D4.1 for more detail):

- The stakeholder's main purposes by using the sensors were: better control, better yield and lower cost
- The most important sensor attributes were: accuracy, affordability and robustness.

Based on the feedback, the first prototype delivered by M12 was planned to have the following attributes:

DTU:

- Ability to **collect 3D images** of object of interests (e.g. mussels)

Biolan:

- **Bluetooth** enabled biosensing device
- First prototype of an **App** on a mobile device as connection to BIOLAN cloud

Norce:

- A **preliminary** prototype version of the IoT platform, with support for **automatic** transfer and storage of data and **simple** visualization.
- Sensors of interest for the use-cases **identified** and **integrated** with the IoT platform.
- **Machine learning** functionality for sensor fusion, sensor calibration, sensor monitoring and prognosis.
- **Integration** with sensors and platforms at the selected test sites, were possible, for data import and export.
- **Preliminary** integration of the UTOFIA camera into the AquaVitae IoT platform, enabling automatic transfer and storage of data, and **simple** visualization. (with DTU)
- **Preliminary** integration of the BIOFISH biosensor into the AquaVitae IoT platform, enabling automatic transfer and storage of data, and **simple** visualization. (with Biolan)

4. Results

The progression of each partner is presented separately: DTU's status after 12 months, then Biolan and finally Norce.

i. DTU

Objectives Planned to be achieved M12	M12 achievements
Design a protocol for volume reconstruction based on UTOFIA data	Achieved
Plan and execute experiments in laboratory conditions	Started

Organize shipping of equipment (two UTOFIA prototypes exist so far and they need to be booked in advance)	Organized delivery of the UTOFIA camera and prepared first algorithm for data collection
Workout data and design algorithms for autonomous data processing	In preparation

DTU encountered issues as a result of the COVID-19 crisis. They announced delays to be expected for phase one (Data collection in tanks), due to limited access to DTU facilities. This might also impact phase two (Software development) phase three (data collection in real conditions) and phase four (Refining software end user test).
They have postponed the delivery of the camera, rearranged laboratory time and rescheduled the experiments to run in weeks 22 – 23 and notified the project management. The activities at sea have to be discussed based on the new schedule. This should not have major impacts on other parts of the project. At worst, the software development will a have one-two month delay because of lack of in situ data. To make up for lost time, the plan is to expand the data collection in the lab to compensate for in situ data collection; to use targets in the lab mimicking real conditions (e.g. color, shape, visibility,…) and start developing software based on these data; and to reschedule the work at sea and introduce the additional data in the machine learning software.

UTOFIA Data collection in the Autonomous Test Arena

The protocol for data collection with the UTOFIA camera in laboratory conditions will include recordings of given targets with different geometrical and optical (e.g. colour) properties). Those data will provide the reference for algorithm development.
The test arena (Figure 1) includes a pool of dimensions 3.5 m wide x 6 m long x 3. m depth.

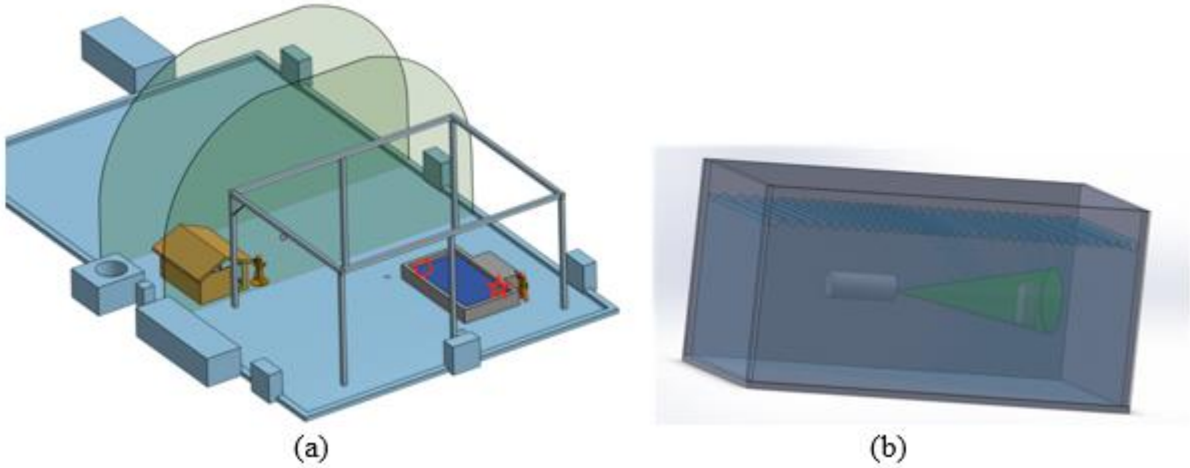

Figure 1:. (a) Autonomous systems test arena (ASTA) with indication of the experimental pool and the approximate location of the UTOFIA camera (red circle) and given targets (red star); (b) schematic of the data collection with location of the camera and its field of view with the position of the target.

Laboratory experiment

The first experiment was performed the 20th of May 2021 with data collection in ASTA pool (Figure 2). The UTOFIA system has been used to collect images from known targets at different level of complexity (from a simple box to mussels). Data (ca. 450 Mb) have been stored in binary format for further analyses and software development. The protocol included:

- Collection of data and images for different targets
- Determine optimal parameters for data collection
- Start processing data for measuring size and volume of the objects

Figure 2: Underwater position of the UTOFIA camera and targets in the testing pool

Two targets of equal material but different colors (black and white) have been used and recorded at a distance of approximately 5.5 m (Figure 3). As expected, the white target provides a large single to noise ratio while the black absorbs more photons. The resolution of the camera allows to track a small objects including a white tag on the black target (Figure 4).

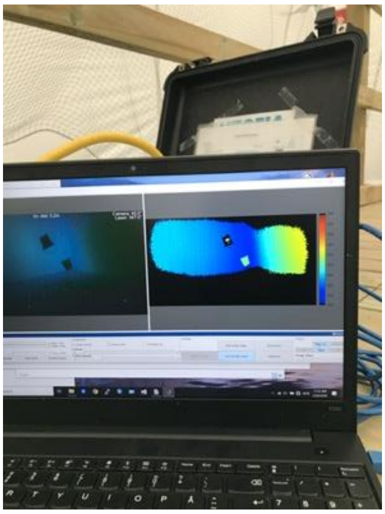

Figure 3:Top side controller for UTOFIA with the software for data collection and tuning of the parameters

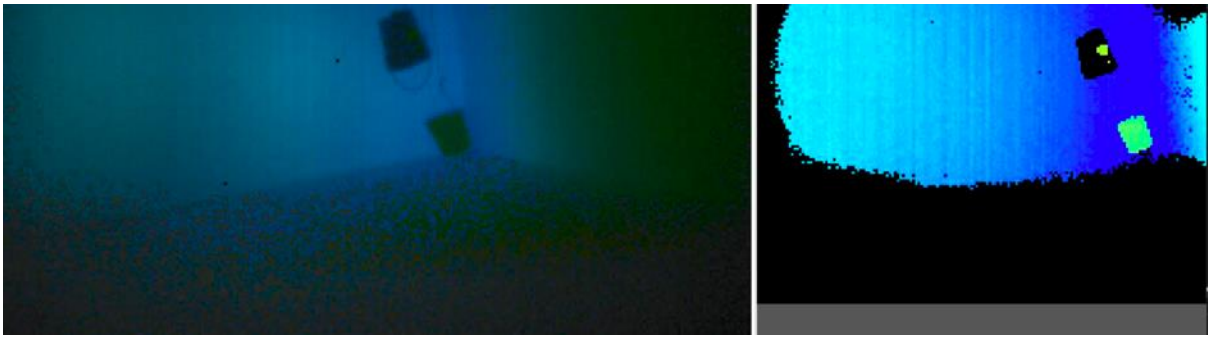

Figure 4:Examples of image collection: Intensity of the two targets (left panel) and estimated distances (right targets)

Questions remains on identifying the reflectance of mussels shells in the lab (before to test the system in the field). Collected raw data will be used to process volumetric estimates for the black and white targets (assuming symmetry and/or for the entire rotation of the object).

ii. Biolan

Objectives Planned to be achieved M12	M12 achievements
Improvement of biosensing device by implementation of Generic Attribute Profile (GATT) Bluetooth (BT) module, integration of the BT communication solution.	Electronic Hardware modification to implement a GATT based BT
Development of an App that will be implemented on a mobile device acting as a data Gateway and user interface.	First version of BIOFISH App developed. First version of BIOFISH and mobile device pairing developed through GATT BT.
	Stakeholder engagement, PESCANOVA

The work done was focused on the implementation of a BT connectivity system. The system of the device has 3 different parts: i) Central processing unit (CPU), that is in charge of communication with the BT module and of performing the analysis, managing communication with other platforms for internet content selection (PICS), ii) BT-module, that is responsible for managing BT communication and communication with the CPU, iii) Android App: Application that perform part of the measurement and data collection through bluetooth low energy (BLE) communication.

At the device boot time, the bluetooth module configures the required pairing security (Just Works) and starts the advertisement process for a mobile device to link to it. The name of the advertising that the bluetooth module issues is BIO700_XXXXX, where XXXXX is the serial number of the device. In case no device ID has been configured and/or the CPU does not respond with this information, the module starts the advertising with the generic name BIO700_00000. The bluetooth module remains in advertising indefinitely until a device is paired to it. When a device is already paired to the bluetooth module, it can connect to it to write and read the services/features it publishes. Once the device disconnects, the bluetooth module returns to the advertising state. After the BT modules implementation on the printed circuit board (PCB) and software (SW) codification, linkage tests were performed with the corresponding Android App.

Figure 5: Detail of the device, the PCB and the developed App

Validation tests of the prototype were performed at the lab with water containing sulphite. Analyses were performed on the strips containing the specific enzyme for sulphite. After the analyses, the results were sent to a mobile device through BLE connection and the developed

App. Different batches of strips were assayed in different concentration ranges. The measuring conditions were pH 10,2, 225 mV, 50 s of analysis tie and 0,3 ml of sample.

Table 1: Sulphite analyses with the developed biosensor. T (target value), If (final intensity),SMBS (metabisulphite), Desvest (statistical function), Rsd (relative standard deviation).

T value	If (nA)	SMBS	value	Desvest	Rsd	% Recovery
8 g/L	11987,9	9,21	8,41	0,70	8,3	105
	11565,7	8,72				
	11013,5	8,08				
	10623,7	7,63				
24 g/L	29589,7	29,59	28,0	2,82	10,1	117
	25042,3	24,33				
	27640,7	27,34				
	30563,7	30,72				
40 g/L	39658,1	41,25	40,05	2,75	6,9	100
	36734,9	37,44				
	39982,3	40,96				
	41931,6	43,07				
	37709,4	38,49				
	38034	38,85				
	37059,6	37,79				
	43879,8	45,18				
	36735,2	37,44				
50 g/L	26341,4	55,81	54,4	2,16	4,0	109
	26666,6	56,60				
	25367,4	53,46				
	24717,8	51,90				
75 g/L	39008,4	81,00	80,8	1,9	2,3	108
	38034,4	78,75				
	39658	82,51				
100 g/l	57520,5	123,88	122,0	2,7	2,2	122
	55897,2	120,12				

T value	If (nA)	SMBS	value	Desvest	Rsd	% Recovery
8 g/L	11045,9	8,12	8,54	0,35	4,2	107
	11306,1	8,42				
	11760,5	8,95				
	11533,1	8,68				
24 g/L	28615	28,47	29,3	1,52	5,2	122
	27965,4	27,71				
	30888,4	31,10				
	29914,2	29,97				
40 g/L	40307,5	42,01	40,1	2,64	6,6	100
	35111	35,68				
	41282	42,37				
	38033,4	38,85				
	39657,6	40,61				
	41282,2	42,37				
	40307,3	41,31				
	40633	41,66				
	35435,5	36,03				
50 g/L	29914,3	64,44	60,3	5,91	9,8	121
	28290,3	60,52				
	29914,8	64,44				
	24718,1	51,90				
75 g/L	37384,7	77,24	77,1	5,2	6,8	103
	38358,7	79,50				
	39331,9	81,75				
	34135,4	69,72				
100 g/L	51349,8	109,59	114,8	6,7	5,8	115
	52649,5	112,60				
	56845,9	122,32				

The accepted recovery value is 85-115%. At the moment the recovery is always above the theoretical value. To overcome that issue BIOLAN is currently designing a new electrode with an optimized electrode surface.

In addition to having completed their objectives, Biolan also recruited PESCANOVA as an AV stakeholder in October 2019. This was an important step as the sensor developed by Biolan is a very specific sensor and there was not a suitable AquaVitae partner for testing the sensor. Pescanova is a large organization that owns several different shrimp producers and so they are an ideal stakeholder. Biolan will continue looking for other stakeholders through the course of the project.

Biolan's M12 prototype is ready to be tested during the next phase. The tests were initially intended to be performed during April, but due to COVID-19 Pescanova have had to postpone it. Biolan is waiting for new dates from them and meanwhile reported the delay in the AV questionnaire regarding COVID-19.

iii. Norce

Objectives Planned to be achieved M12	M12 achievements
A preliminary prototype version of the IoT platform, with support for automatic transfer and storage of data and simple visualization.	Achieved
Sensors of interest for the use-cases identified and integrated with the IoT platform.	Some sensors of interest for the use-cases identified and some are integrated with the IoT platform.
Machine learning functionality for sensor fusion, sensor calibration, sensor monitoring and prognosis.	Started working on Machine learning functionality for sensor fusion, sensor calibration, sensor monitoring and prognosis.
Integration with sensors and platforms at the selected test sites, where possible, for data import and export.	Integration with sensors and platforms at the selected test sites is slightly delayed due to among other COVID-19 and travel restrictions.
T4.2 & T4.3: preliminary integration with UTOFI-camera and BIOFISH biosensor.	Preliminary integration with UTOFI-camera slightly delayed. Expect to have a preliminary integration of the upgraded BIOFISH biosensor in M12.

The AquaVitae sensor nodes are built on PyCom development boards, using MicroPython. This microcontroller supports communication over both WiFi, Bluetooth, LoRa, Sigfox and dual LTE-M (CAT M1 and NBIoT) and is able to integrate with a multitude of sensors. For testing purposes, a water tight box with an extra battery pack was used, allowing for several days of runtime on a single charge.

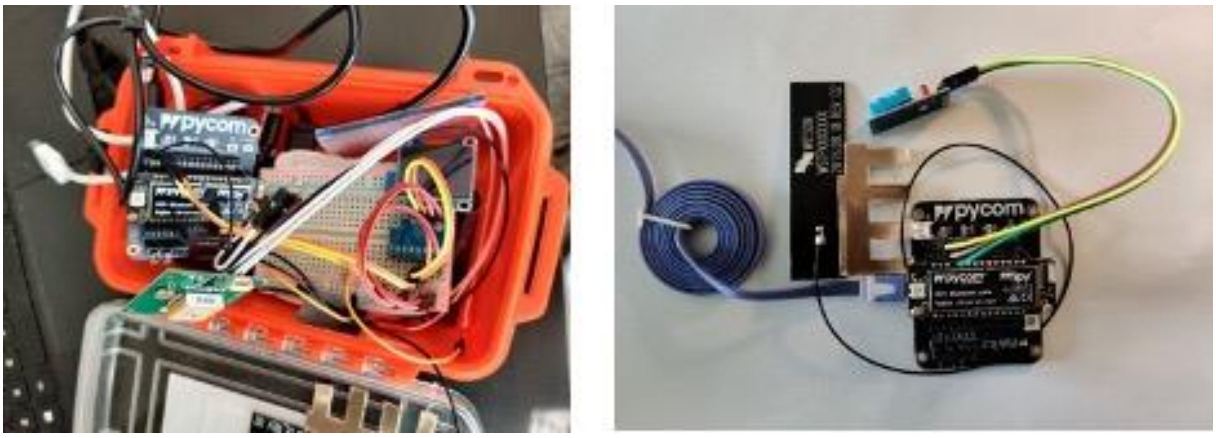

Figure 6: Casing and electronic system of the sensor integrating platform.

The sensor nodes are running the CryoSense software, while the backend server is running the CryoCore software, all developed by NORCE. The CryoCore platform provides Web APIs, databases and a number of visual components.

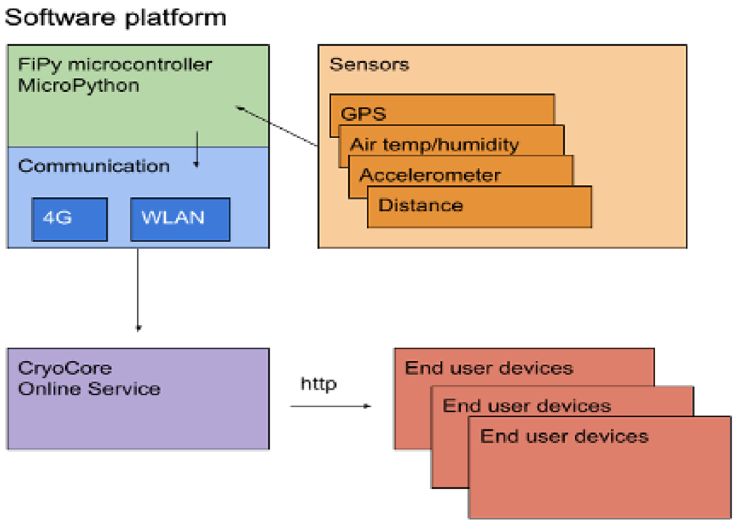

Figure 7: Visualization of the Software platform.

Validation tests

There was performed a number of tests to validate the IoT platform.

(1) In one test, a CryoSense box was equipped with an IMU (accelerometer, gyroscope) and driven in a rural area in Northern Norway. The main point of this test was to **validate the stability of the platform**, including 4G dropouts, reconnects and general stability.

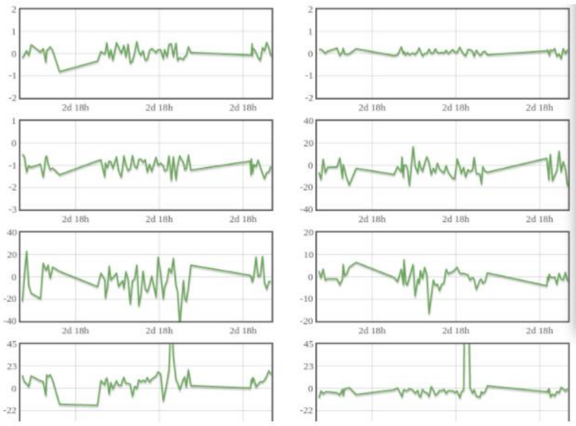

Figure 8: Screenshot from a visualization of the sensor data - here with two dropouts. X=time, Y= individual movement along a given axis.

The system will buffer just a few seconds of data, so the straight lines represent slightly longer dropouts where data was lost due to missing connectivity and lack of local storage on the microcontroller.

For this test, video was also recorded to verify that timestamps were correctly captured, and that playback is able to synchronize back to an actual event. Ensuring correct timestamps is important to ensure high data quality, and the microcontroller does not have an internal real time clock but needs to be synchronized every time it starts. An online resource was used for this if no GPS is available.

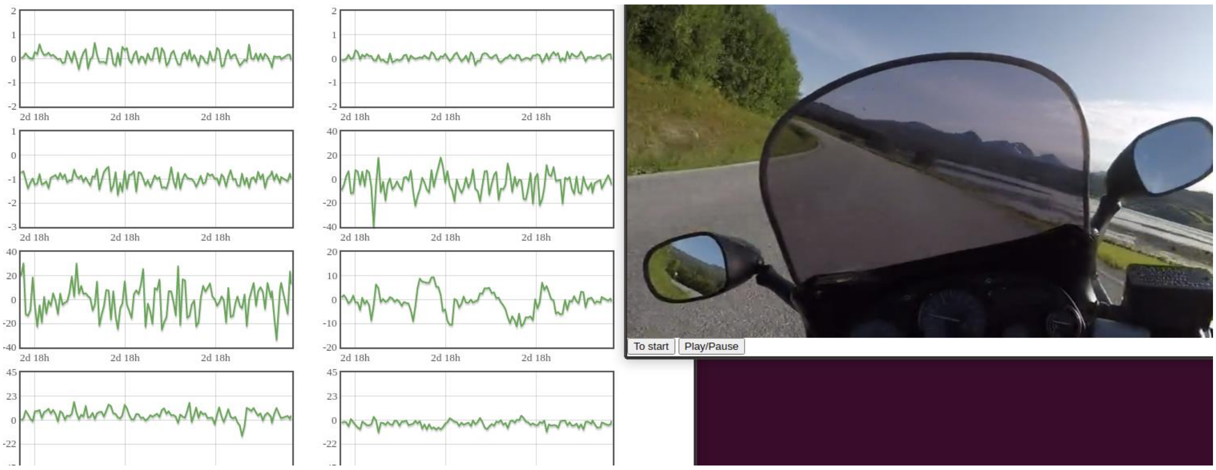

Figure 9: Screenshot from data capture. X=time, Y= individual movement along a given axis.

The graphs are quite noisy (due to vibrations), but the lower right one visualizes large bumps in the road, the one above it shows curves in the road (the angle of the motorbike).

(2) A sensor box was also equipped with a **GPS** and used in another test, where it provided a GPS trace, also in a rural area. A second GPS was also onboard, giving us a comparative data source to **validate the correctness of the platform**. At this stage, the IoT platform performed satisfactorily, with consistent timestamps and data, and live streaming of sensor data was also working.

(3) The platform was also set up to measure temperature and humidity in an office for a duration of 5 weeks, collecting over 250.000 samples, using WIFI for communication. Running the system for an extended period ensures that there are no resource leaks. This test also passed.

Conclusion
The IOT platform appears stable and data recall for graphical representations is sufficiently fast for replays and data analysis. A number of graphical elements are available, like plots, maps, bars etc. The system is built with timestamps on all data points, and data retrieval can be done for limited time spans and for a subset of sensors.

In addition to the objectives solely involving NORCE, they have also started collaborative objectives with Biolan and DTU, on the BIOFISH biosensor and the UTOFI camera respectively.

They will design initial prototype test-cases based on previous stakeholder feedback, and will consult with some partners in early June, following up with EMBRAPA (AquaVitae partner) and Bohus first. Having a prototype evaluation totally finished by M15 is optimistic but a "preliminary" prototype evaluation will be ready.

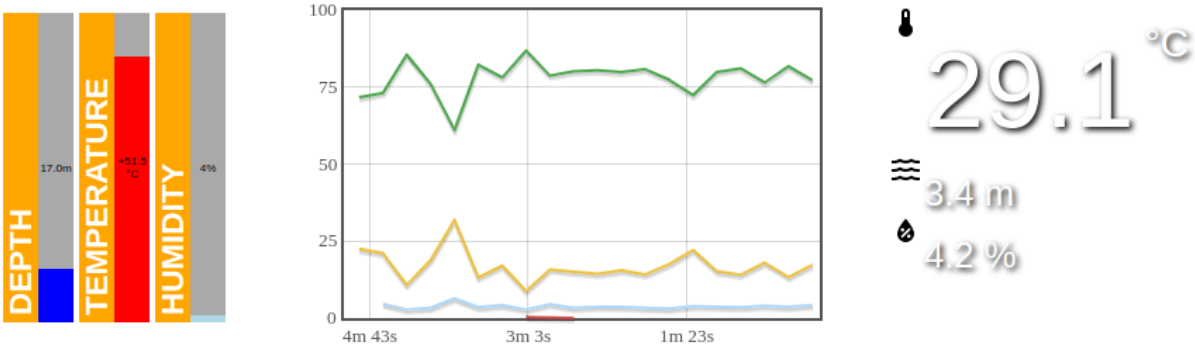

Figure 11: Example of a task-oriented GUI for one of the use-cases (can be accessed on a phone)

5. Conclusion

In conclusion, Biolan and Norce have almost completed their objectives for the first 12 months. Both can enter into phase two: extensive stakeholder consultation and prototype testing due by M18. Restrictions on travel, availability of equipment, and access to facilities due to COVID-19 may have an impact on prototype testing for NORCE in phase 2, but they expect to be able to mitigate these challenges and be able to give a preliminary prototype evaluation. DTU on the other hand, is ready in terms of design and planning, but was delayed in terms of experiments due to the restrictive access to their facilities and thus encountered some delay in the phase one achievement. They plan to generate data in the lab to compensate for in situ data collection to make up for lost time and reschedule the work at sea as soon as possible.