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NAUTILOS

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Data sheet of final animal towed tagging system with O2 sensor

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NAUTILOS - New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation is an H2020 project funded under the Future of Seas and Oceans Flagship Initiative, coordinated by the National Research Council of Italy (CNR, Consiglio Nazionale delle Ricerche). It brings together a group of 21 entities from 11 European countries with multidisciplinary expertise ranging from ocean instrumentation development and integration, ocean sensing and sampling instrumentation, data processing, modelling and control, operational oceanography and biology and ecosystems and biogeochemistry such, water and climate change science, technological marine applications and research infrastructures.

NAUTILOS will fill-in marine observation and modelling gaps for chemical, biological and deep ocean physics variables through the development of a new generation of cost-effective sensors and samplers, the integration of the aforementioned technologies within observing platforms and their deployment in large-scale demonstrations in European seas. The fundamental aim of the project will be to complement and expand current European observation tools and services, to obtain a collection of data at a much higher spatial resolution, temporal regularity and length than currently available at the European scale, and to further enable and democratise the monitoring of the marine environment to both traditional and non-traditional data users.

NAUTILOS is one of two projects included in the EU´s efforts to support of the European Strategy for Plastics in a Circular Economy by supporting the demonstration of new and innovative technologies to measure the Essential Ocean Variables (EOV).

More information on the project can be found at: https://www.nautilos-h2020.eu/.

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EXECUTIVE SUMMARY

This deliverable is the outcome of the work performed in Task 5.8 (sensor integration for animal tagging) stating the data sheet of final animal towed tagging system with O_2 sensor, where the main objective was to collaborate and integrate new sensors into animal borne tagging systems to augment the dataset that can be retrieved from seafaring animals and simultaneously better inform about the animals' behaviour and the surrounding habitat with a view to data sharing with the wider community.

This document details the requirements of an animal towed tagging system, ethical considerations of when using such components, an explanation of the whole mechanical development process and a market survey and review of the dissolved oxygen sensor to use within NAUTILOS.

Therefore, it is organized in six main sections:

Chapter I: Introduction provides a description of what is an animal towed tagging system and the need for a dissolved oxygen sensor in the context of NAUTILOS project. It also includes a general description of system requirements both operational and electronics requirements of an animal towed tag.

Chapter II: Ethical Considerations contains an analysis of the acquired data regarding personal or special protection, as well understanding environmental protection related to the batteries, losses or disposal equipment. In this chapter includes also considerations of health and safety and protection of marine life related to the as batteries, dangerous goods, pressure housing and RoHs.

Chapter III: Tag Development Process introduces an overview of the development process of an animal tag from conceptual design to manufacturing and assembly.

Chapter IV: Dissolved Oxygen Sensor Market Survey presents an overview of considerations to be taken into account when procuring a new sensor as the revision of the different options available on the market and decision process for the selected sensor.

Chapter V: Animal Tags Specifications forward analyses into the systems specifications to be developed though this project.

Chapter VI: Summary closes the report highlighting the data sheet of final animal towed tagging system with O_2 sensor to be developed and tested for further monitoring and study of the marine animals and their deep-sea habitats.

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
2D	2 Dimensions
3D	3 Dimensions
ATS	Advance Telemetry Systems
BoM	Bill-of-Materials
C.B.	Centre-of-Buoyancy
C.G.	Centre-of-Gravity
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
CNC	Computer Numerical Control
COTS	Commercial off-the-shelf
EU	European Commission
FoV	Field-of-View
GM	Metacentric Height
GZ	Righting Arm
LED	Light-emitting diode
Micro-SD	Micro-Secure Digital
O_2	Oxygen
OBC	On-board Controller
PC	Personal computer
RoHS	Restriction of Hazardous Substances Directive
UN	United Nations
USB	Universal Serial Bus
VHF	Very High Frequency
WEEE	Waste from Electrical and Electronic Equipment

I. Introduction

The implementation of animal towed tagging systems capable of in-situ monitoring of marine animals and their deep-sea habitats enables not only for scientific and academic communities to more accurately know these species' habitats and better understand the impacts of the human activities, but as also to assist on the dissemination of the environmental challenges that these habitats suffer through superior data quality acquisition. These tagging systems are developed to be significantly smaller than the species to be tagged and can integrate any available kind of sensors. The information collected from the instruments is relevant for comprehending migration routes, interaction of the animals with their environment, occupational habits, interactions between different species together with other important parameters in the comprehension of the marine environment. The acquired knowledge serves as a foundation for developing measures aiming to guarantee the conservation of species as well as assuring an appropriate co-habitation with human beings and their activities.

To augment the dataset that can be retrieved from seafaring animals, and simultaneously better inform about the animals' behavior and the surrounding habitat with a view to data sharing with the wider community, the animal borne tagging systems integrate sensors that provide geo referenced data, temperature, depth, salinity, fluorescence, light, acceleration and optical cameras. Besides, an essential sensor to be incorporated into the animal tag system is the oxygen sensor, to ensure ease of integration and deployment for further enhanced data on the sea, such as deoxygenation, as well as the animals themselves.

Therefore, an oxygen sensor of significant maturity will be integrated into a field tested and proven non-invasive animal towed tagging system developed by CEiiA and IMAR and used with animals such as manta rays and sharks in preparation for deployment in field trials in WP7.5. The oxygen sensor in animal tagging systems can help better understand the biological aspects of the animal, such as breathing rate, but also indicate the level of oxygen in the water where the animal passes and so inform on the possible deoxygenation of the seas. These measurements will contribute in better understanding the distribution and density of the mesopelagic organisms within the water column. All these parameters will be sampled simultaneously with the in-situ oceanographic conditions to assess their influence on the vertical distribution of mesopelagic organisms.

1. System Requirements – Animal Tag Mechanical Requirements

The mechanical requirements derive from the expected operation and objectives defined along with the ocean observing community These mechanical requirements are commonly divided into two categories, the operational requirements and payload requirements. The typical operational requirements required for the development of an animal tagging platform are detailed in Table 1.

Table 1 - Operational Requirements of a tagging platform.

Type	Requirements
Tagged animals	Manta Rays / Sharks
Type of Attachment	Non-invasive, body harness
Platform Dimensions	Minimized size
Platform Colour	Red / Yellow (must be visible for recovery)
External Shape	Minimized drag (up to 25%, 8% optimum, increase of tagged animal drag)
Weight	Minimized weight (up to 5% increase of tagged animal weight)
Animal's length	Up to 4 m
Buoyancy	Slightly positive

Type	Requirements
Static Stability	Stable & Antennas above water
Dynamics	The platform shall follow the animal motion with minimum interference
Maximum Depth	2000 meters
Average swimming speed	From 1 to 2 m/s
Maximum swimming speed	Up to 5 m/s
Nominal Surface Velocity (for VHF and SAT Operation)	Up to 1 kts
Nominal Depth close to surface (for VHF and SAT Operation)	Up to 1 m
Mission duration	Up to 48 Hours

The payload, or scientific, requirements can include several instruments that can be integrated on the tag system. Their operation shall be independent, i.e. each instrument has its own power source, sensors, and communication systems (when applicable). The typical payload requirements needed for the development of an animal tagging platform are demonstrated in Table 2.

Table 2 - Payload Requirements of a tagging platform.

Instrument	Model	Requirements
Waterproof Recording Camera (without Lighting Equipment)	Custom-made or COTS	- Adjustable horizontal to slight negative pitch (preferably). - Placed above tow line attachment point (preferably).
Waterproof Recording Camera (with Lighting Equipment)	Custom-made or COTS	- Adjustable horizontal to slight negative pitch (preferably). - Placed above tow line attachment point (preferably).
VHF Transmitter	ATS family	- VHF Antenna vertical and out of water when emerged.
ARGOS Transmitter	Wildlife Computers family	- ARGOS Antenna out of water for recovery.
Data logger (with temperature & pressure sensors, and others)	Custom-made or COTS	- Interferences with foam or other components shall be avoided and needs to be integrated in a specific orientation, as per data sheet specification.

2. System Requirements – Animal Tag Electronics Requirements

The diagram presented in Figure 1 shows the current architecture of the tagging system.

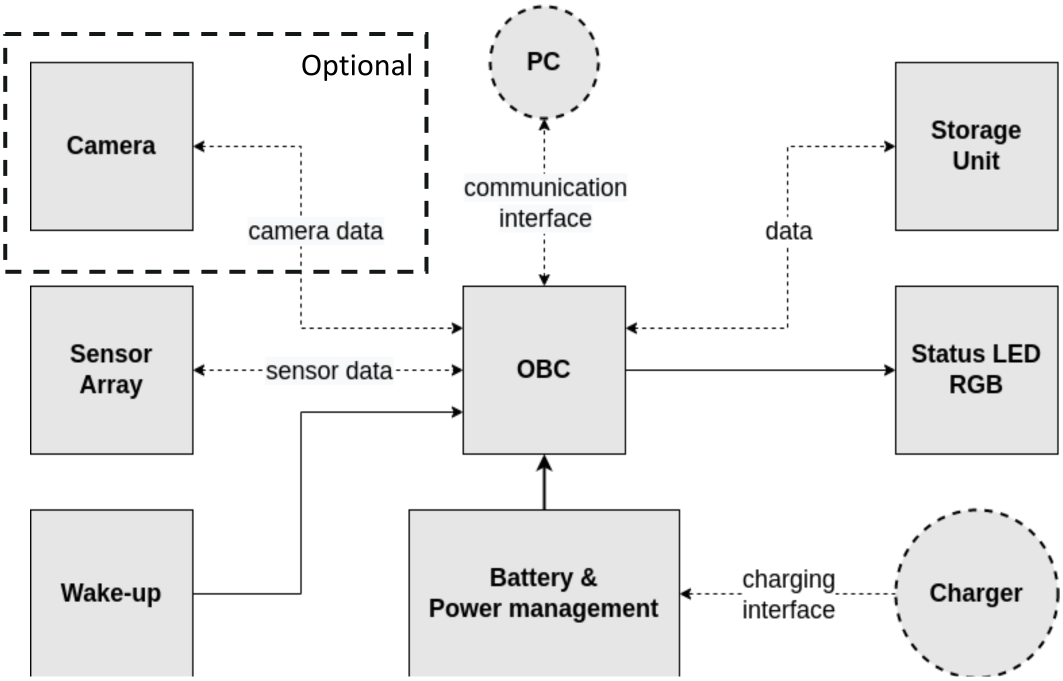

Figure 1 - Animal tagging system architecture

2.1. Sensors

The sensors can be divided in two main categories:

Animal movement and behaviour - The movement and behaviour sensors (Acceleration, Orientation, Magnetic field and Velocity sensors) are responsible for measuring the animal movements such as: acceleration, heading, pitch, roll and speed.

Environmental conditions - The environmental sensors (Pressure, Temperature, Light intensity and Dissolved O_2) can help describe the conditions in which the animal is, such as depth, water temperature, environment luminosity, and level of Oxygen dissolved in the water.

2.2. OBC

The On-Board Controller is the main unit which connects all the peripherals. It is responsible for: preparing, starting and stopping the mission accordingly to the configuration, control the Status LED, receive sensor measurements and log them in the storage unit and keep track of battery remaining charge.

2.3. Status LED

Visual representation, via colours (Red, Green, Blue), of Tag system state such as: Battery status, Error States, Starting/Preparing mission, Connected to PC and others. Note: The LED remains off during mission.

2.4. Storage Unit

All data from sensor measurements and system logs are saved on the devices memory (micro-SD card).

2.5. Battery & Power Management

Power is provided by a lithium-ion battery pack which is then rectified by the power management system and distributed to the remaining peripherals. The power management is also responsible for protecting the battery pack from under voltage drops and ensure the discharge is minimum when the device is shut down.

2.6. Communication and Charging Interface

Both communications and charging can be achieved by using the custom-made USB cable. It can be used to charge, add/delete mission configurations, calibrate sensors and view in real-time the data measured by the sensors.

2.7. Wake-up

This component has the function of turning ON the device through the passage of a magnet in the designated area. This trigger is also used to start a mission (when selected).

2.8. Camera (optional)

With the use of a camera it is possible to acquire footage of the animal behaviour. The camera can be used in low-light environments with the help of a set of external LEDs.

II. Ethical Considerations

1. Data Protection

The ethical questions related to data protection when using several sensors in a tag system may arise. In this sense and having in mind that more information lead to a more valuable understanding of the animal life and their habitats is important to have a process of safeguarding information from corruption, compromise or loss.

The Tag system besides the sensor data could also record images of marine animals in their natural habitat. The images and data acquired in the scope of the project doesn't follow the applicable procedures of data protection and it will be used only in the scope of this project. Therefore, in the tag system personal data is not record and stored and therefore don't need to follow applicable laws of the EU.

2. Environmental Protection

2.1. Batteries

The TAG system has an internal battery, however in case of loss there would be no danger for the environment since its installed in a metallic container. Besides, as per the battery specifications, the battery cells contain no environmentally hazardous component, such as lead or cadmium. The cells should be disposed with a discharged state to avoid heat generation by an inadvertent short-circuit.

2.2. WEEE considerations

The TAG system disposal must follow the Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) since this equipment could contains any complex mixture of materials, some of which could be hazardous for the environment. The equipment was designed to facilitate the re-use and treatment of WEEE.

In accordance with local laws and regulations, the equipment and/or its battery must be disposed separately from the household waste. When this device reaches the end of its life, take it to a collection point designated by the local authorities. The separate collection and recycling of the device and/or its battery at the time of disposal will help conserve natural resources and ensure that it is recycled in a way that protects human health and the environment.

3. Health and Safety

3.1. Batteries

The Tag system which includes a battery pack of 3 x INR18650 cells. The cells safety is fully tested by the manufacturer.

The battery pack is deployed inside a metallic container capable to resist 200 bar pressures. Besides all the electronics protections designed to avoid any malfunction of the batteries, in case any problem occurs with the batteries (e.g.: explosion), the container prevents any possible leak to the environment.

The TAG system batteries must handle with care and should not be in contact with water/ sea water.

3.2. Dangerous goods (if Lithium is used)

Since the TAG system has its own lithium-ion batteries, accordingly with the UN model regulations (Recommendations on the Transport of Dangerous Goods), the system is classified as Class 9 — miscellaneous dangerous substances and articles. Since the battery pack is rechargeable and contained in our Tag system is classified as UN3481 and shipping of the system should follow the applicable legislation depending on the type of transportation.

The following symbols should be on the package of the system to identify the presence of Li-Ion batteries inside.

Figure 2 - Symbols to identify the presence of Li-Ion batteries on the system

3.3. RoHS

The Tag System components are carefully chosen to avoid hazardous substances on its composition. The electronics and batteries are lead and cadmium free. The system can be considered RoHS compliant.

4. Protection of Marine Life

Despite of biologging technologies have produced new insights into the ecology and behaviour of marine animals, most studies still involve invasive methods or capturing and restraining animals to deploy the tags. These methods have proven to be of lesser quality or even ineffective, since typically result in a period of unusual and undesired behaviour not representing the common daily routine of the captured animal. Furthermore, capturing some large and vulnerable species is neither practicable nor desirable option.

This way, animal welfare is the central factor for any biologist, scientist and engineers responsible for the development of the technology. Depending on study location and species involved, is critical to have in consideration the impact of the tag system on the animal behaviour, health or welfare of the animal. Therefore, the main goal of the Tag system is to be deployed in a way to avoid any harm to the marine life. The Tag is non-invasive since it is towed by the animal, causing no harm to the animals and when is released is collected from the water.

III. Tag Development Process

1. Introduction

An animal tagging platform deployed through non-invasive harnesses provides an effective low-impact solution for acquiring high resolution behaviour and environmental data without capturing and handling animals. The general characteristics of each marine animal tag are fully dependent on the required instrumentation, and the purpose of the study. This way, and to assure the animal tags will have the least impact on the target species, there are several technical considerations and trade-offs that must be considered when developing these subsea data gathering platforms.

This chapter aims to briefly go through the methodology adopted for the development of the marine animal tags by explaining the relevant disciplines involved during the engineering loop and manufacturing of these devices. An overview of the different interlinked aspects of designing and manufacturing a towed animal tag to give an appreciation of the work involved.

2. Mechanical Design

Several different aspects are required to be considered when designing the animal tag that are not always evident and even minor adjustments can imply a redesign of current tag designs. Being a non-invasive (as much as possible) towed tag means ensuring the tag has minimal drag and the least impact on the natural behaviour of the animal. Thereby, a stabilized design passively ensuring adequate attitude is essential to comply with these operational requirements and thus achieving superior data quality. Thus, the approach for the mechanical development of an animal tagging platform, demonstrated in Figure 3, consists on a spiral model where interactions between several disciplines must be executed such as the operational and payload requirements defined by the instrumentation and the biology of the target species, as well as the optimal instruments' configuration taking into account the outcomes of the structures and materials endurance, weight and buoyancy studies, and hydrostatics and hydrodynamics disciplines. Following this methodology, whenever major changes occur to the external shape of the animal tagging platform, a new and more detailed iteration of the engineering loop development must be performed.

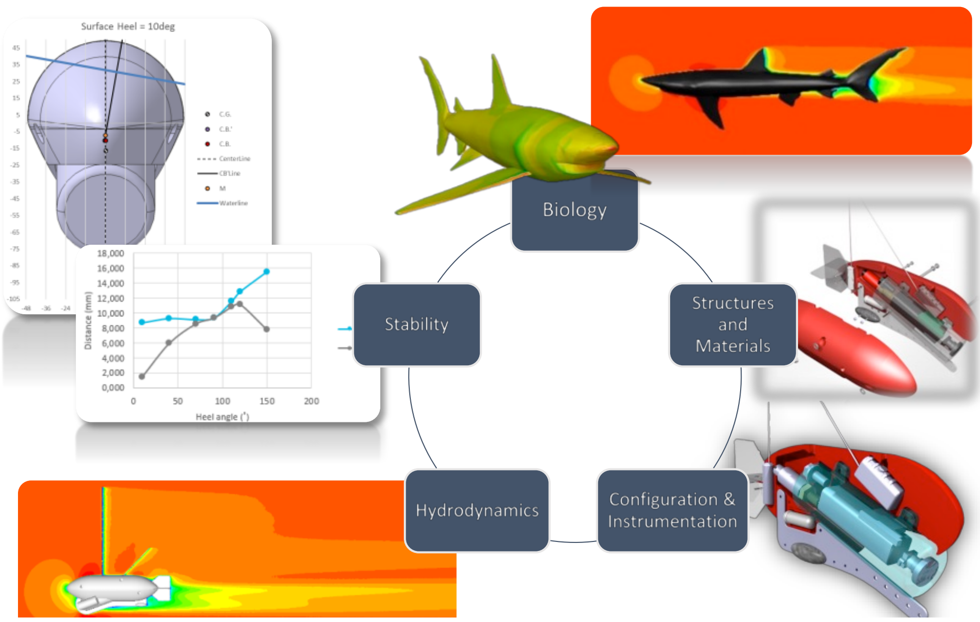

Figure 3 – Animal tagging platform engineering loop development.

2.1. Mechanical Design: Concept and Detailed Phases

This discipline is concerned with the definition of the mechanical solutions concepts for the main body, the supports for every equipment, mechanisms, detail design for manufacture, production of manufacturing drawings and general assembly in articulation with the constraints provided by the other disciplines using Computer Aided Design (CAD) tools.

During the Conceptual Phase several configurations are assessed, based on the constraints imposed by all involved disciplines and requirements. The chosen design to be further detailed must assure the proper functioning of the instrumentation for a most reliable data acquisition, and especially to guarantee the tag can be recovered by starting to communicate with the receiver sources once it reaches the surface. Therefore, the designs' evaluation should account for not only the submerged mode when the tag is deployed on the species, but also for the surfaced mode when the tag is released from the animal waiting for recovery.

Since the external shape of the tag is mostly defined by the buoyant parts encasing the instruments, a preliminary dimensioning of the required buoyancy, and consequently tag volume, is also estimated at this stage. Once the instruments' configuration is complying with all requirements, the design can then be enhanced for the further technical assessments.

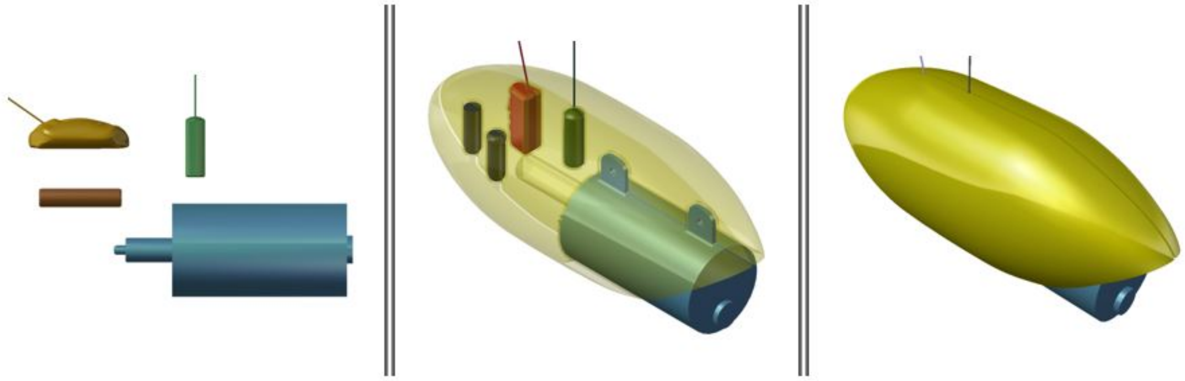

Figure 4 - Conceptual phase of tagging platform development.

From the final concept and the technical requirements, the design transitioned to a detail phase. At this stage, all components are integrated to assess the implications of their assembly, and the tailor-made components are designed to accommodate the design. This 3D model representation not only helps in defining and validating the interaction between the geometries, but also provides the required inputs for weight and buoyancy control and the hydrodynamic assessment, as well as the preparation for manufacturing.

Aside from the instruments, payloads and electronics, the animal tagging platform's components can be classified and divided into groups according to their function as demonstrated in Figure 5, a representative image of a tagging platform.

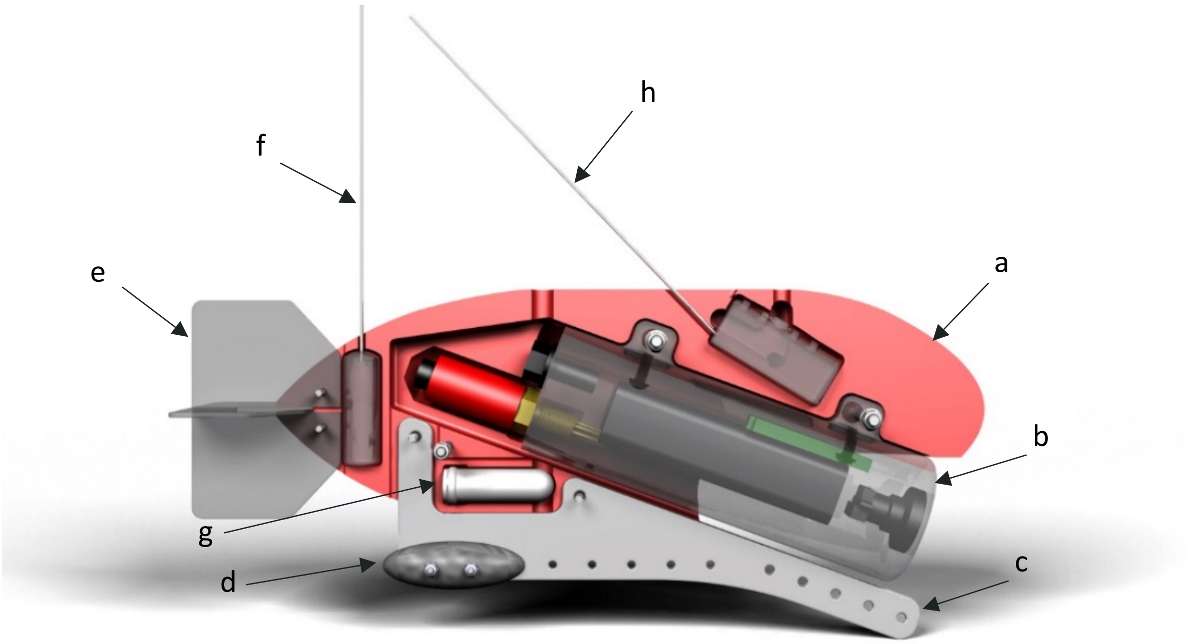

Figure 5 - Sectional view of a tagging platform: a) Syntactic foam half; b) Main sensor: Camera or Dissolved Oxygen; c) Attachment bracket; d) Trim weights; e) Stabilizers; f) VHF Transmitter; g) Data logger; h) Satellite Transmitter.

This discipline concerns the sizing, analysis, and validation of the components, assessing the operation conditions and safety margins to avoid the failure of components, and design optimization, both at operational depth and during handling. Furthermore, this discipline also involves the materials decision to be used in each component, ensuring that the choice is appropriate for the mechanical solicitations and surrounding environment, as well as manufacturability of the designed parts.

Depending on the species, marine animals such as manta rays and sharks can reach as far as 2000 metres depth, which can expose tags to the harsh and corrosion prone subsea environment, as well as high-pressure conditions that demands the usage of high strength material and requires the application of appropriate surface treatments to avoid deterioration over continued use. Therefore, it is of utmost importance that the tag components shall be dimensioned, or rated, to withstand not only these harsh environments, where the ambient pressure these species dwell is huge, but also have a satisfactory performance when subjected to sudden external forces during deployments. Furthermore, the chosen materials should also be corrosion-resistant to allow for long-lasting deployments, and consequently reduce the risk of loss of the marine tagging system.

2.2. Weight and Buoyancy

This discipline is concerned with the control of the vehicle weight and buoyancy budget. The weight, associated to Centre-of-Gravity (C.G.) of the vehicle and its buoyancy, associated to Centre-of-Buoyancy (C.B.), both demonstrated in Figure 6, are very important parameters not only for the animal tagging platform stability, but also to ensure the desired characteristics during each phase of the deployments. On one hand, the animal tagging platform should present neutrally buoyant characteristics (considered weightless when it is submerged) to minimize as much as possible the impact on a tagged species. On the other hand, the tagging platform must be developed to present slightly positive buoyant characteristics to assure the tag will reach the surface safely after detaching from the animal. To achieve this goal, the tagging platform must displace an amount of water slightly higher to its weight. Therefore, adequate buoyancy for each specific tagging platform is fundamental not only for the tag’s performance, but also for the welfare of the species. During this process, parameters such as Weight (dry/wet), Volume, Density, C.G. coordinates (x, y and z), C.B. coordinates (x, y and z) and Net Buoyancy are controlled.

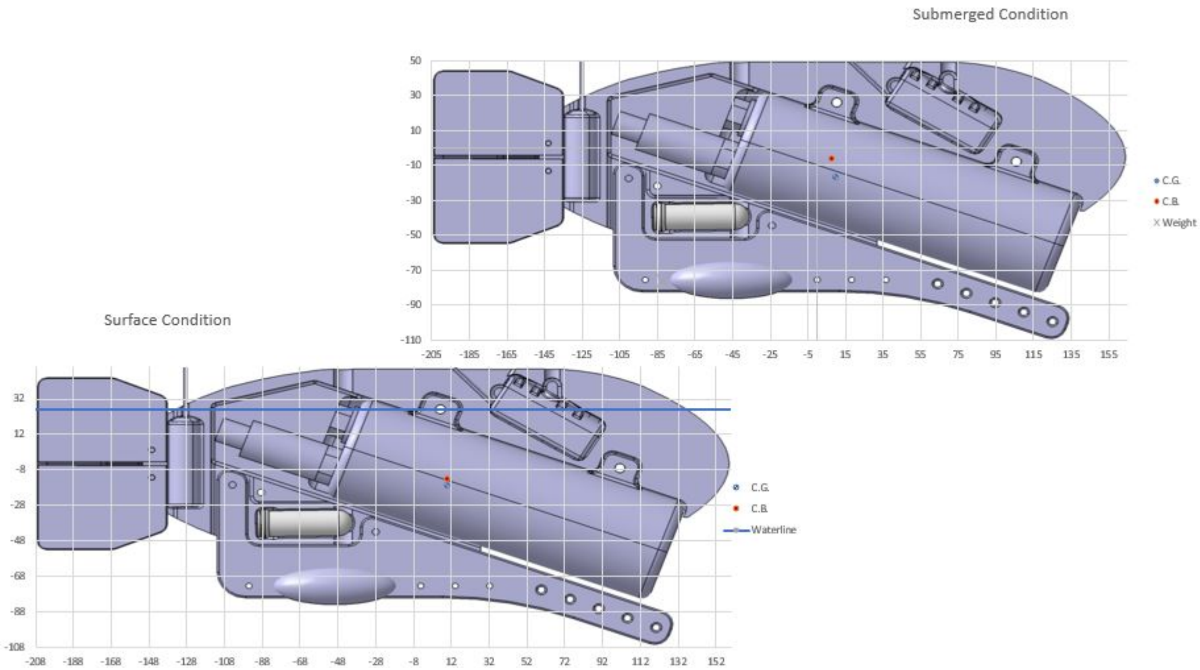

Figure 6 - Weight & Buoyancy representations for the submerged and surface conditions.

2.3. Hydrostatics

This discipline concerns the hydrostatics and heeled stability of the tagging platform when submerged and at surface during the recovery phase. The requirements regarding the attitude of the platform, mainly the antennas and sensors' orientation, either during operation or after detaching from the animal waiting for recovery, can be assessed and complied with by design. As a first step, a completely submerged state is considered to assure the tagging platform will present a correct attitude/orientation (antennas upward) during the deployments (underwater). When emerged (at surface), either attached to the animal or waiting for recovery after detachment, a correct attitude/orientation is of utmost important, since it is the only way of ensuring the transmitters (antennas) are above water to start communicating its geolocation. Furthermore, the tagging platform must be passively stable to assure that it will return to its equilibrium position when subjected to any potential external force, i.e. regardless the external forces exerted on the tagging platform, it must return to its equilibrium position maintaining the antennas facing upwards. To fulfil these conditions, a trade-off between stability results and other parameters such as total weight and buoyancy are required. During this step, several equations are taken into account to assess and validate the static attitude during the different phases of the deployments (submerged/emerged and attached/detached), such as the Metacentric Height (GM) or Righting Arm (GZ).

2.4. Hydrodynamics

This discipline is concerned with the external shape evaluation and optimization, by assessing the interaction of the animal tagging platform with the surroundings. The hydrodynamic qualities of the external shape of each iteration of the tagging platform is evaluated at the significant operating condition through Computational Fluid Dynamics (CFD) models, as illustrated in Figure 7. Parameters such as water properties or swimming speed, are crucial inputs for the numerical simulations, derive from the target species habits. In addition, the animal drag estimation is also performed to calculate the tag to animal drag ratio (percentage of added drag by the tag). Throughout the several design stages and iterations, tagging platform hydrodynamics should be considered for several purposes. Trade-offs for conceptual design, optimization of detail design and instruments positioning, as well as forces and moments assessment for dynamic stability prediction when the tag is being towed by the animal should be conducted, resulting in several implemented design solutions. Considering the constraints imposed by the operational and payload requirements, a streamlined torpedo-shaped geometry should be achieved to reduce the drag, and thus avoid the occurrence of unsteady oscillatory phenomena that may lead to unstable behaviours. Modifications to the design are guided by the obtained hydrodynamic results in respect to the desired hydrodynamic qualities. The outcome of this study allows designing a dynamically stable tagging platform optimized for lower hydrodynamic drag, resulting in a low percentage of added drag by the tag on the animal (which represents a low energy expenditure for towing these platforms). Furthermore, the results of this study are also used to understand the attitude of the platform when being towed through a tether by an animal. This will ensure the correct orientation of the video camera to capture the desired Field-of-View (FoV), as well as a superior data quality acquisition from the remaining instruments. During this procedure, parameters such as forces (x, y and z axis), drag and lift, hydrodynamic moments (x, y and z axis), static stability and buoyant force are controlled.

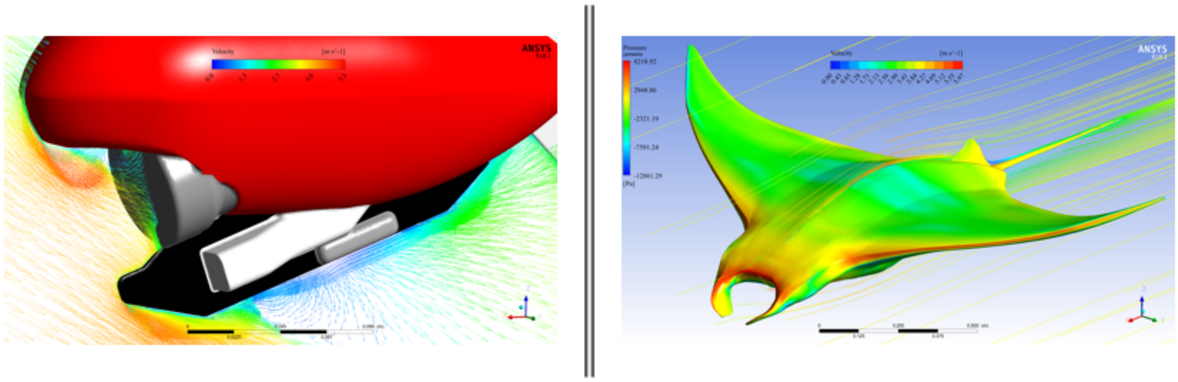

Figure 7 - Computational Fluid Dynamics models of a tagging platform and a Manta Ray.

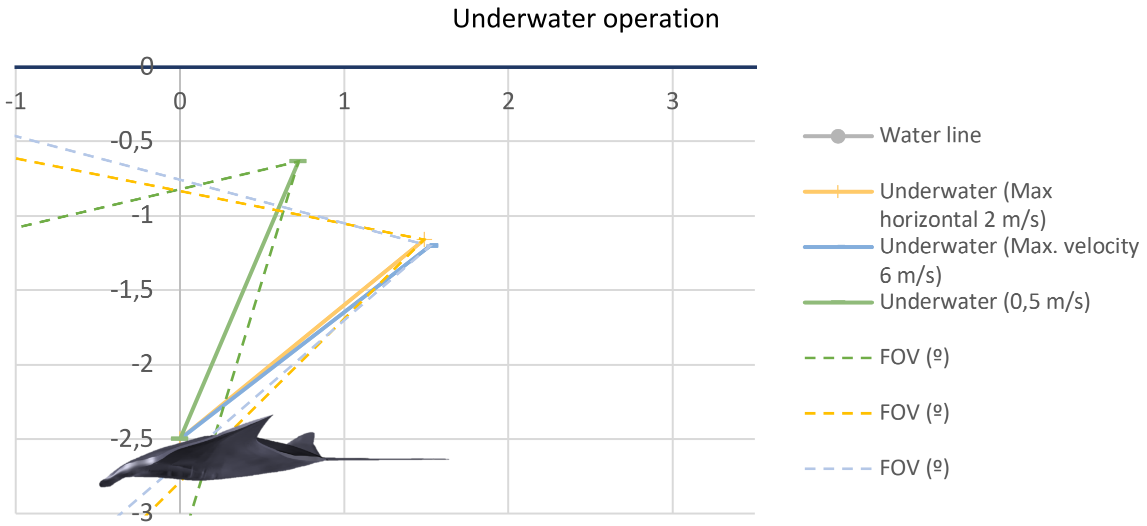

Figure 8 - Tagging platform attitude during deployment, and the expected FoV for each swimming speed.

2.5. Manufacturing and assembly

Once the design is closed activities for the release to manufacturing include adjustments to the components' design considering the applicable fabrication methods, as well as the materials and hardware available on the market according to the project's deadline. Bearing this in mind, the preparation of the following documents shall be prepared: Manufacturing Specifications document, 3D CAD final model of each component to be manufactured, 2D drawing of each components to be manufactured, and a bill-of-materials (BoM) including all the raw materials and hardware needed. The manufacturing processes commonly used for the tagging platform are CNC machining, 2D waterjet cut (polymer and metallic materials), casting and moulding, and 3D printing.

Since the tagging platforms are usually assembled on board the deployment vessel the design already requires several considerations in how all components should attach to each other to simplify as much as possiblethe hand-made assembly process. The assembly approach (demonstrated in Figure 9) consists of using two custom machined buoyant halves made of syntactic foam blocks rated for the desired depth to enclose the components and hold them in their very specific position. Assembly hardware is also used to fix these buoyant halves to each other, mainly consisting of bolts, nuts, washers, pins and eyelets. These components are all then placed in a custom briefcase especially designed for the delivery of the tagging platform.

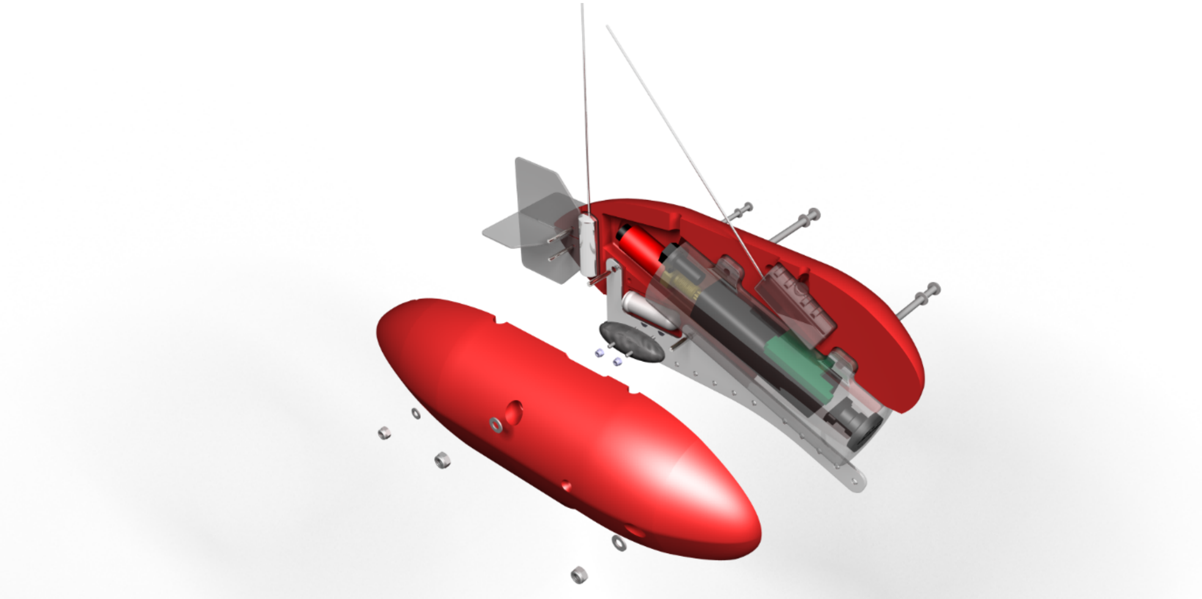

Figure 9 - Assembly of a tagging platform.

IV. Dissolved Oxygen Sensor Market Survey

1. Market Survey Considerations

The dissolved oxygen data is one of the most important indicators of water quality. The dissolved oxygen concentration in seawater is essential for the survival of fish and other aquatic organisms. The acquisition of this parameter can be used for example to study the impact of the climate change in the animal life in oceans and seas.

The integration of a sensor to measure the dissolved oxygen is one of the main requirements of the tagging system project in WP5. A market survey was performed to choose the most suitable sensor for the project.

The state of art and research had the following topics as requirements:

- Physical characteristics
- Dimensions
- Weight
- Depth range
- High sensitivity and accuracy
- Acquisition technology
- Calibration method and frequency
- Integration with TAG
- Power consumption
- Communication protocol
- Stock and Lead time

The weight and size of the sensor are important requirements since the animal needs to support the weight of sensor and the Tag system.

The sensor acquisition technology, all its individual characteristics (sensitivity, accuracy, range), calibration method and the frequency that the sensor needs to be calibrated will help to decide which sensor on the market will have the best performance and is ready for long-term use.

Having the requirements above in mind the sensor and the Tag need to have the same communication protocol and the same power level to facilitate the integration.

2. Review of Market Options

The market survey resulted in a set of sensors to be considered, shown in Table 3. Due to the constraints of the system, the sensors were evaluated regarding their dimensions, weight, maximum depth rate and if it needs a container or not.

Table 3 - Dissolved Oxygen Sensors Comparison

Manufacturer	Model	Dimensions (mm)	Weight (g)	Depth (bar)	Accuracy (mg/L)	Measuring Range (mg/L)	Sensibility (mg/L)	Container	Technology	Sample Rate (s)
PyroScience	AquapHOx®-LX	63 x 63 x 375	1350	400	No Info	0 - 23	0,01	Yes	NIR	1
PyroScience	AquapHOx®-TX	63 x 63 x 300	1310	400	No Info	0 - 23	0,01	Yes	NIR	0,025
PyroScience	PICO-O2-SUB	59 x 17 x 17	20	None (needs container)	±0,1	0 - 23	0,005	No	NIR with Oxygen sensor caps	0,05
PyroScience	FSO2-SUBPORT	30 x 30 x 127,4	115	None (needs container)	±1	0 - 23	0,005	No	NIR with Oxygen sensor caps	0,05
PyroScience	FD-OEM-O2	26,3 x 26,3 x 19	5	20	±0.5	0 - 23	0,005	No	NIR	15
Hach	Orbisphere Oxygen EC	42 x 42 x 220	700	200	±1	0 - 80	No Info	No	Electrochemical sensor	90
Mettler Toledo	InPro6970i/12/220	25 x 25 x 350	No Info	12	±1	0 - 2	0,002	No	Optical fluorescence quenching	No Info
IDRONAUT	Optical Oxygen Sensor	11,7 x 11,7 x 44	No Info	700	±1	0 - 2	No Info	No	NIR	20
IDRONAUT	OCEAN SEVEN 310 CTD	75 x 75 x 660	5,600	200	±0,1	0 - 45	0,025	Yes	Optical	3
IDRONAUT	OCEAN SEVEN 310 CTD	75 x 75 x 630	8,000	700	±0,1	0 - 45	0,025	Yes	Optical	3
Endress+Hauser	Oxymax COS51	40 x 40 x 220	300	10	±1	0 - 100	0,01	No	Memosens technology	180
Aanderaa/Xylem	EXO1 Sonde	47 x 47 x 647	1,420	250	±5	0 - 50	0,01	Yes	Optical	0,25
Aanderaa/Xylem	Oxygen Optode 4831/4831F	36 x 36 x 111	217	1200	±1,5	0 - 250	0,05	No	Optical	2
Aanderaa/Xylem	Oxygen Optode 4330/4330F	36 x 36 x 86	175	1200	±1,5	0 - 250	0,05	No	Optical	No Info
Aanderaa/Xylem	Oxygen Optode 4835	36 x 36 x 86	118	30	±5	0 - 250	0,05	No	Optical	30

3. Review and Final Choice

As shown in the Table 3, it was collected the main information related to the most commonly used sensors on the market used for monitoring dissolved oxygen in water, specifically in marine applications.

In order to have a more accurate idea of how to integrate the sensor into the TAG, the sensors evaluation focused essentially on dimensions, accuracy and maximum depth. Despite not being shown in the table, energy consumption and communication protocols were also considered, but they were all very similar, so they were not a decisive factor.

The ability to integrate with existing electronics was a key element and so, regarding the considerations described in the table above, the sensor chosen was the PICO-O2-SUB. The sensor is not the smallest, but the dimensions are acceptable and is one of the lightest. It is also very accurate, has high measuring sensibility and provides UART communication, very useful for this integration.

Figure 10 - PICO-O2-SUB Optical Oxygen Sensor from PyroScience

The PICO-O2-SUB is a fiber-optic oxygen sensor which uses a manufacturer proprietary technology, the sensor materials are excitable with red light and show an analyte-dependent luminescence in the near infrared (NIR). This provides high precision, high reliability, low power consumption, low cross-sensitivity and fast response times. The NIR detection technology significantly reduces interference with ambient light.

The sensor must be installed inside a container, and for this application this provides much more integration flexibility. It can be installed inside a dedicated container, or it can be installed inside the TAG datalogger container. Also, the PICO-O2-SUB optical fiber sensing probe can be replaced when damaged and other types of probes can be used (eg. contactless probes).

Figure 11 - Oxygen optical fibre sensing probes to be fitted into the PICO-O2-SUB

The manufacturer of the sensor also provides a developer tool which allows to calibrate the sensor or configure the logging, providing an easier software integration with the datalogger system.

The PICO-O2-SUB from PyroScience, has the following main specifications:

- Power consumption: 3.3V @ 10mA
- Protocol: UART
- Measuring Range: 0-23 mg/L
- Accuracy: +/- 0.01 mg/L
- Resolution: 0.005 mg/L
- Detection Limit: 0.01 mg/L

The PICO-O2-SUB is mounted inside a container and the sensing probe, supported by the OXCAP-SUB, is installed on the outside the container in contact with the water.

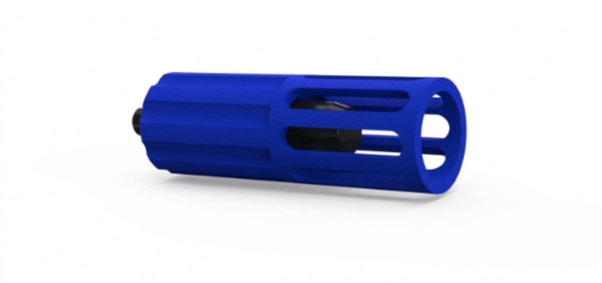

Figure 12 - OXCAP-SUB with oxygen probe

The following image shows an example of the installation of the sensor and its components on the tagging platform.

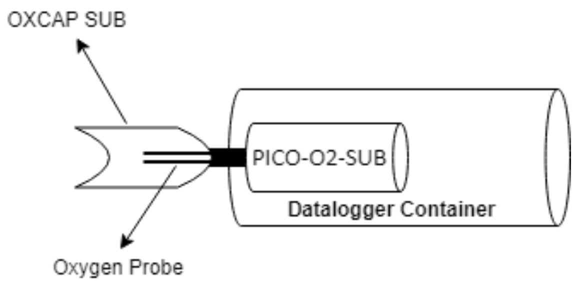

Figure 13 - Oxygen Sensor integration

V. Animal Tag System Specification

1. Animal Tag System Specification Description

To meet all the expected requirements and increase the capability of collecting various types of data two different versions of the tag system are being developed: Tag Cam and Tag Lite. Below a description of each configuration chosen, one only with a multi-sensor datalogger and another version with an additional camera module capable of collecting video. Although the system versions have different characteristics that are described below, both will have the dissolved oxygen sensor integrated to acquire this parameter.

Tag Cam

The Tag Cam version is composed by a data logger, with environmental and motion sensors, and by a camera module. The Tag Cam can execute missions where sensor and camera data are acquired and stored in memory. The missions can be configurable by choosing how to start: manual trigger (through the passage of a magnet) or scheduling an alarm, by choosing the mission duration and which sensors are enabled:

- Environmental Sensors
    - Pressure (Depth)
    - Temperature (Water Temperature)
    - Luminosity (Ambient light)
- Motion Sensors
    - Hall (Velocity)
    - Accelerometer (Acceleration)
    - Magnetometer and Gyroscope (Orientation)

This version is already in testing phase, so the photos presented in Figure 14 and Figure 15 are from the first prototype. In the first image is shown the assembled electronics block and on the second is shown the electronics assembled inside the container.

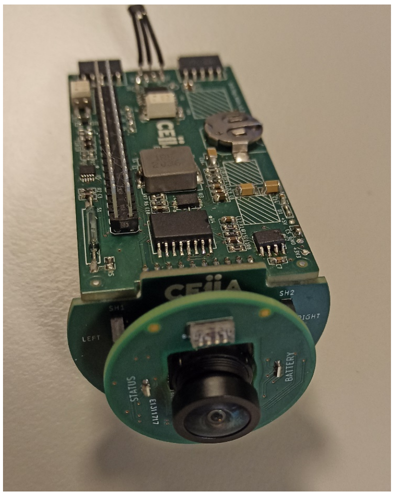

Figure 14 - First prototype of the TAG CAM version

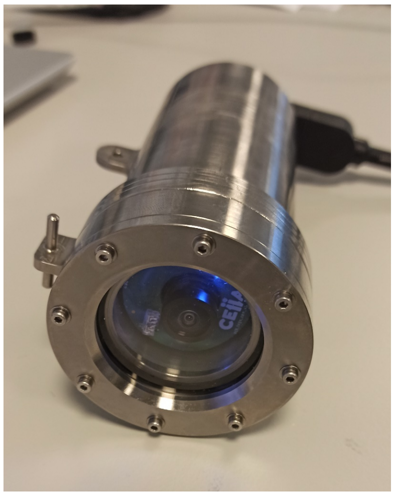

Figure 15 - TAG CAM mounted on the pressure container

In this version, there are two recording types: video and time-lapse. Both can be configured how to start: by scheduling an alarm, by selecting a date/time interval or by selecting a depth range. It is also possible to stop the recordings by setting the battery percentage level.

Since the camera can be used in low-light environments there is a set of external LEDs to light the environment. The LED brightness is configurable, and it is possible to set a luminosity and depth range to trigger the LEDs. The camera has the following configurable parameters: brightness, contrast, video stabilization, frame rate, horizontal flip, video resolution, text stamp with multiple text size and selectable values (date and time, pressure, luminosity, temperature, velocity).

The batteries are rechargeable using a custom-made USB cable and an external charger.

This device is complemented by a graphical user interface where the user can configure all the settings described above, can calibrate the sensors, access the data and see the sensor measurements and camera feed in real-time.

The connection between the device and the PC is made by a custom USB cable.

Table 4 summarises the Tag Cam version specifications.

Table 4 - Tag Cam specifications

Parameter	**Specification**			
Depth Rating	2000 m (200 bar)			
Housing Material	Titanium			
Dimensions	100 x 48 mm			
Weight	220g			
Camera Resolution	Full HD @ 30fps			
Sensor	**Sampling (Hz)**	**Range**	**Accuracy**	**Resolution (bit)**
Pressure	20	0 to 200 bar	0.3 bar	16
Temperature	20	-10 to 80 ºC	2 ºC	16

Luminosity	20	0 to 120000 lx	0.0036 lx	16
Velocity	1000	0 to 20 m/s	0.1 m/s	-
Accelerometer	20	±2g to ±16g	16.4 LSB/g	16
Gyroscope	20	±250 to ±2000 dps	16.4 LSB/dps	16
Magnetometer	20	4900 µT	0.6 µT/LSB	16
Sensor Log type	.csv			
Storage Unit	256 GB			
Battery Pack	Li-Ion battery pack			
Battery Autonomy	Camera	Camera + White LEDs	Camera + Red LEDs	
	18h	12h	8h	
Battery Charging	3 hours			

Tag Lite

The Tag Lite version is composed by a data logger, with environmental and motion sensors. The Tag can execute missions where sensor data are acquired and stored in memory. The missions can be configured by choosing how to start: manual trigger (through the passage of a magnet) or scheduling an alarm, by choosing the mission duration and which sensors are enabled:

- Environmental Sensors
    - Pressure (Depth)
    - Temperature (Water Temperature)
    - Luminosity (Ambient light)
- Motion Sensors
    - Hall (Velocity)
    - Accelerometer (Acceleration)
    - Magnetometer and Gyroscope (Orientation)

The batteries are rechargeable using a custom-made USB cable and an external charger. Figure 16 shows the main electronics block design of the Tag Lite electronics.

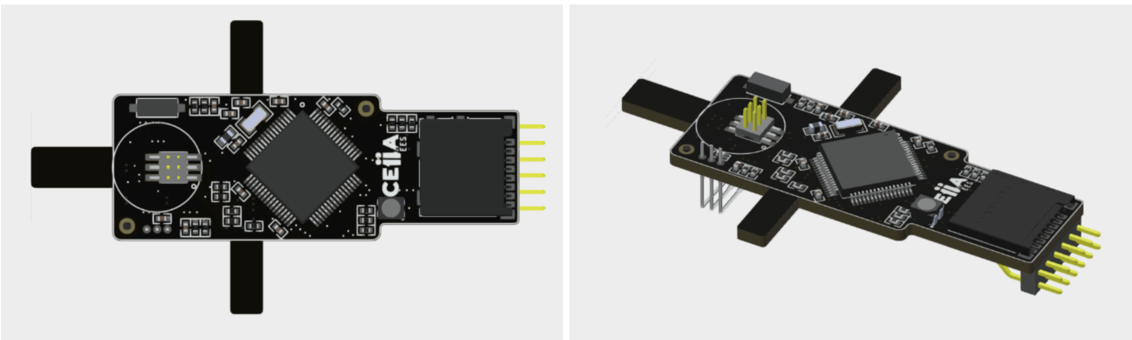

Figure 16 - TAG Lite electronics

This device is also complemented by a graphical user interface where the user can configure all the settings described above, can calibrate the sensors, access the data, see the sensor measurements in real-time and to update the devices firmware.

There are two strategies of connection:

1. Remove the micro-SD card from the device and insert it on the PC
    - To configure missions and access data
2. Connect the custom-made USB cable
    - To calibrate the sensors, to get the sensor measurements in real-time and to update the devices firmware.

Table 5Table 5 - Tag Lite Specifications resumes the Tag Lite version specifications each is still under test and development, that may lead to some iterations to improve the system.

Table 5 - Tag Lite Specifications

Parameter	**Specification**			
Depth Rating	2000 m (200 bar)			
Housing Material	Resin			
Dimensions	Main Module	Standard Battery		Long Life Battery
	18 x 55 mm	18 x 35 mm		18 x 65 mm
Weight	TBD			
Logging rate	Testing			
Sensor	**Sampling (Hz)**	**Range**	**Accuracy**	**Resolution (bit)**
Pressure	Testing	0 to 200 bar	0.3 bar	16
Temperature	Testing	-10 to 80 ºC	2 ºC	16
Luminosity	Testing	0 to 120000 lx	0.0036 lx	16
Velocity	Testing	Testing	0.1 m/s	-
Accelerometer	Testing	±2 to ±16 g	16.4 LSB/g	16
Gyroscope	Testing	±250 to ±2000 dps	16.4 LSB/dps	16
Magnetometer	Testing	4900 µT	0.6 µT/LSB	16
Data log type	.csv			
Storage Unit	8 GB			
Battery Pack	Li-Ion battery pack			
Battery Autonomy	Standard		Long Life	
	72h (3 days)		240h (10 days)	
Battery Charging	2h		4h	

VI. Summary

As part of task 5.5, several dissolved oxygen sensors on the market were analysed in order to be integrated on a non-invasive animal tag system. The sensors were studied according to their characteristics, considering mainly their measurement accuracy and their interface capabilities for integration with tags. After the market trade-off, a dissolved oxygen sensor was selected, which will fulfil the requirements defined for this task and will be integrated into the tags. The tags are being developed in order to integrate the sensor and then be deployed for the first tests in a real environment.

The dissolved O_2 sensor integrated with the TAG system will be further tested and developed until the activities programmed for the NAUTILOS WP7 start, when the demonstrations activities will take place.

The present TRL of the non-invasive animal tagging system integrated with an O2 sensor, is up to 7. The integration of the O2 sensor still lacks some more tests until achieve a full TRL7.

1. Appendix 1: References and Related Documents

ID	Reference or Related Document	Source or Link/Location
1	N/A	N/A