REAL-TIME MONITORING OF COASTAL & OFFSHORE CONSTRUCTION NOISE FOR IMMEDIATE DECISION MAKING

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1 CONTEXT

With the global awareness of the need to make our energies cleaner, marine constructions, typically wind farms, and especially offshore, have multiplied in recent years, and we can expect to see these numbers increase even more rapidly. The presence of marine mammals during offshore infrastructure works (pile driving, drilling, dredging) is now a major environmental concern, as it has been proven that they could be severely harmed by exceeding noises.

In order to safeguard species and their natural habitats, more and more local legislations impose a cap on sound levels caused by all offshore activities. As of 2023, this is the mainly the case in Europe (for instance in the United Kingdom [Joint Nature Conservation Committee – JNCC, Southall et al., 2007 ; Popper and Hasting, 2009], Germany [Bundesamt für Seeschifffahrt und Hydrographie - BSH (Federal Maritime and Hydrographic Agency), Müller-BBM, 2011], The Netherlands [Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek - TNO (Netherlands Organisation for Applied Scientific Research), 2011], Belgium or Denmark [Danish Energy Agency – DEA, Tougaard et al., 2016]), but Asian countries (Taïwan [Environmental Protection Administration – EPA, 2019] being the best example) and American (USA, Canada) are also implementing similar rules. Wind farms developers therefore are required to measure, monitor, and mitigate noise caused by building work, and, today, underwater noise monitoring regulations are enforced as a means of protecting aquatic life.

2 A VERSATILE AND POWERFUL HARDWARE SOLUTION: THE RUBHY BUOY

Expert in underwater acoustics and supporting both the scientific, defense and industrial actors since its establishment in 2010, RTSYS has perfected the onboard processing and communication capabilities of its recorders and buoys to make them the ideal allies for this type of monitoring. If autonomous recorders are perfectly suitable for the background noise surveys prior to the installation phases, surveillance during the actual construction requires real-time information in order to adapt as fast as possible. For that reason, floating systems, allowing transmission of data through telemetry, are preferred.

Relying on its SDA14 (Synchronous Data Acquisition, 1 output, 4 inputs) motherboard, the company developed the RUBHY buoy.

Fig. 1 — RTSYS RUBHY Buoy deployed close to Ajaccio (Corsica, France), monitoring a fish farm

The buoy has been designed for the acquisition of acoustic signals from passive or pre-amplified hydrophones. It integrates four perfectly synchronized analogue receivers, which are capable of recording four different sound source simultaneously. Its wide-band analogue input has a frequency of 1,25 MHz with a dynamic range greater than 100 dB, which guarantees an efficient signal-to-noise ratio. The system is designed to operate in standalone mode and can also be remotely operated and monitored using WIFI, Iridium or GSM (LTE/4G). The data is recorded and stored in an uncompressed Wave (.Wav) format.

Acquisition speed	39.0625 kS/S	78.125 kS/S	156.25 kS/s	312.5 kS/s	625 kS/s	1.25 MS/s	2.5 MS/s
ENOB	20 bit	19.5 bit	19 bit	18.5 bit	18 bit	17.5 bit	17 bit
Dynamic range	114 dB	111 dB	108 dB	105 dB	102 dB	99 dB	96 dB
SNR	108 dB	105 dB	102 dB	99 dB	96 dB	93 dB	90 dB

Table 1 — The table shows the ENOB (Effective Number Of Bits), the Dynamic Range and the SNR (Signal to Noise Ratio) at different analogue to digital sampling frequencies.

The analogue inputs are pre-amplified with a fixed gain and can either be single ended or differential. The inputs can process wide dynamic range signals from the hydrophone sensor. The cutoff frequency of the high pass filter and the amplifier gain can be customized on demand for each channel.

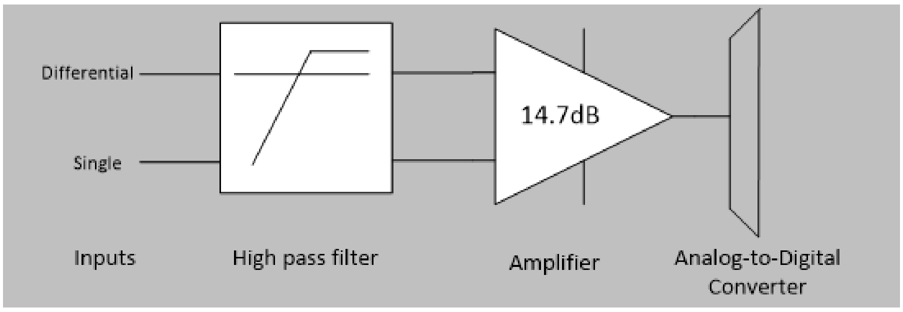

Fig. 2 — Hydrophone input functional diagram with a 14.7 dB gain

The following values correspond to a typical input amplifier gain of 14.7 dB:

- Input impedance: 500 Ω *
- Max Input Level (MIL): -10 dBV / 920 mVpp**
- Sensitivity: -123 dBV (0.7 µV RMS)
- High pass filter: 350 Hz at -3 dB*
- Surge peak to peak voltage: 300 V (Time < 10 ms)

* More values are available on request
** A spurious free dynamic range greater than 80 dB is guaranteed with hydrophone signals of MIL/2 dBV maximum

In addition to the four acoustics channels, the buoy also includes a serial port input, which can be used to connect any kind of single or multiparameter probe, to record various oceanographic and water quality parameters (temperature, turbidity, salinity, conductivity, dissolved oxygen, pH, etc.) which can be very practical in some occasion: as an example, turbidity is often to be monitored in order to assess the impact on the seabed sediments.

The SDA14 motherboard is also capable of embedded signal processing, and can calculate various sound levels such as zero to peak Sound Pressure Level, weighted and unweighted Sound Exposure Level, weighted and unweighted Sound Pressure Level and Third Octave Bands Pressure Levels from 20 Hz to 25 kHz. All these calculation follows the standards, including the ANSI S1 11-2004 standard.

Additionally, the raw data can be streamed from the motherboard to a coprocessing board, which can embed different kind of processing algorithms; typically, vessels or mammals detection.

The buoy embeds an 1800 Wh Lithium-Ion rechargeable battery allowing up to 40 days of continuous recording (around 20 if telemetry constantly powered ON), and can be equipped with solar panels to increase the autonomy, and eventually provide a permanent presence at sea.

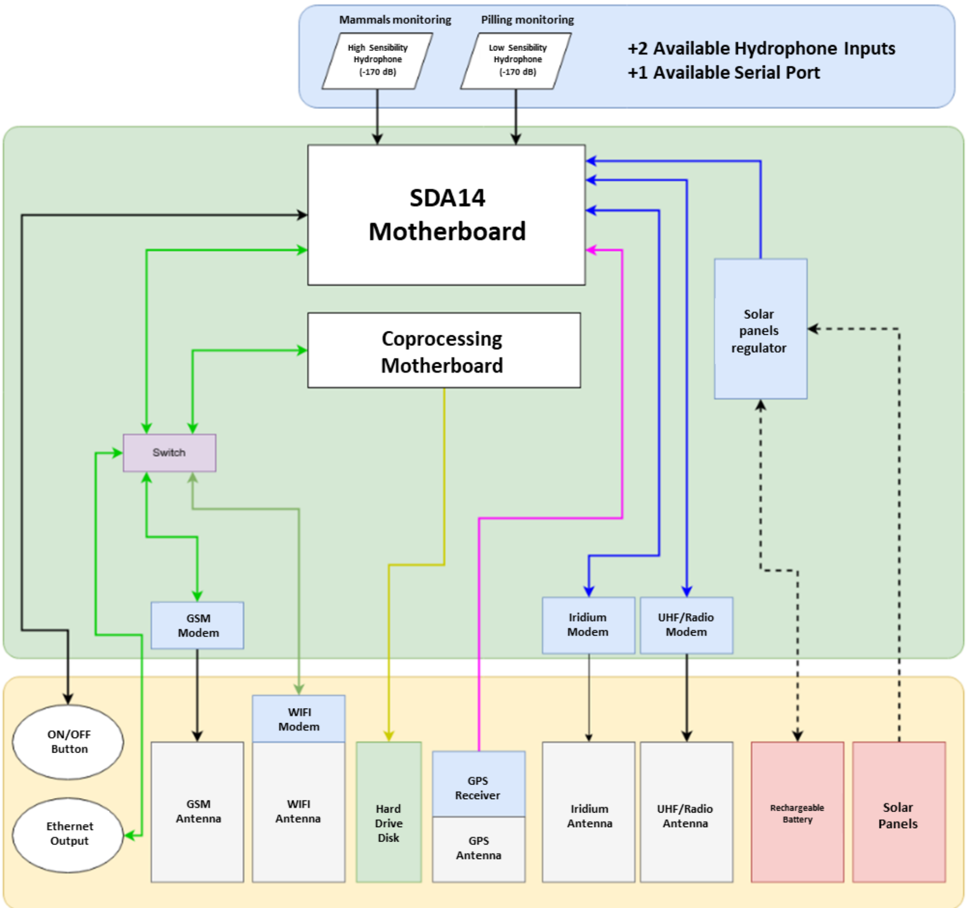

Fig. 3 — Functional diagram of the RUBHY buoy

Fig. 4 - "RUBHY AI", largest version of the buoy to date

2.1 User friendly programming interface

Directly embedded on the system (no download required), the programming interface accessible via Web browser allows the user to configure its mission parameters in just a few minutes. These user selectable parameters include:

- Number of acoustic channels to record (1 to 4)
- Sampling Frequency (39,0625 kHz to 2,5 MHz)
- Sample Size (16, 24 or 32 bits)
- Size of the files in MB
- Possibility to set a start and end time for the recording (the buoy will then start to record automatically)
- Possibility to set duty cycles (can be useful for monitoring construction only during day time for instance, and save battery at night)
- Possibility to log additional sensors.

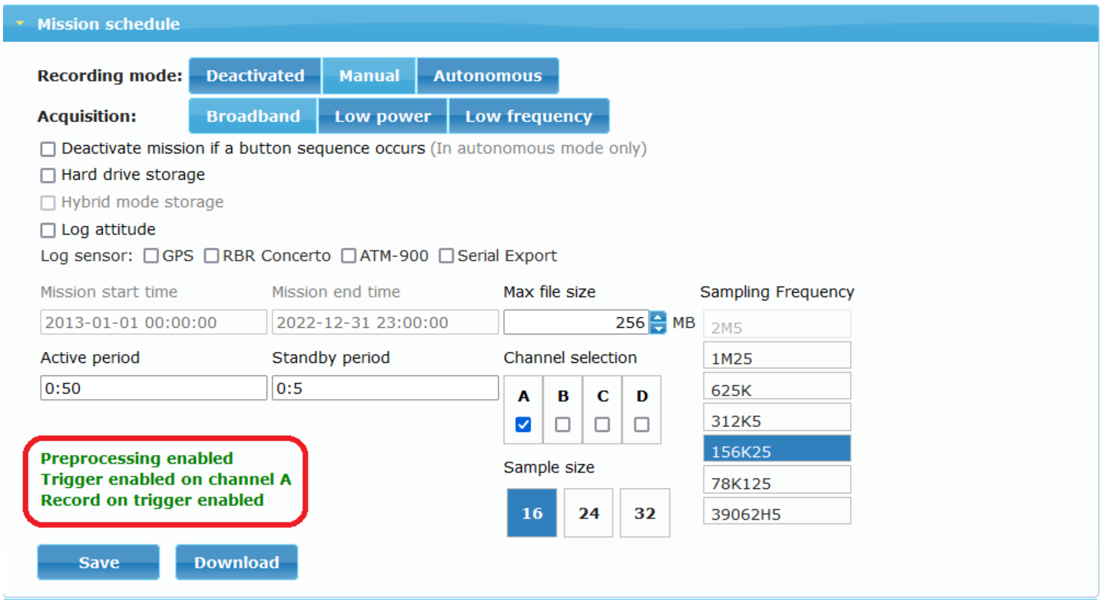

Fig. 5 — Screen capture of the mission programming interface

Raw data from the recordings are stored on the internal storage device, but it is also possible to activate embedded processing features. The buoy will constantly calculate several sound level values, such as SPL RMS, SPL peak, SEL, and 1/3rd octave band SPL (from 20 Hz to 25 kHz). In addition, it is also possible to set different triggers based on a either a level of noise or a frequency window; in case the recorder signal reaches these triggers, the date and time of the event will be saved.

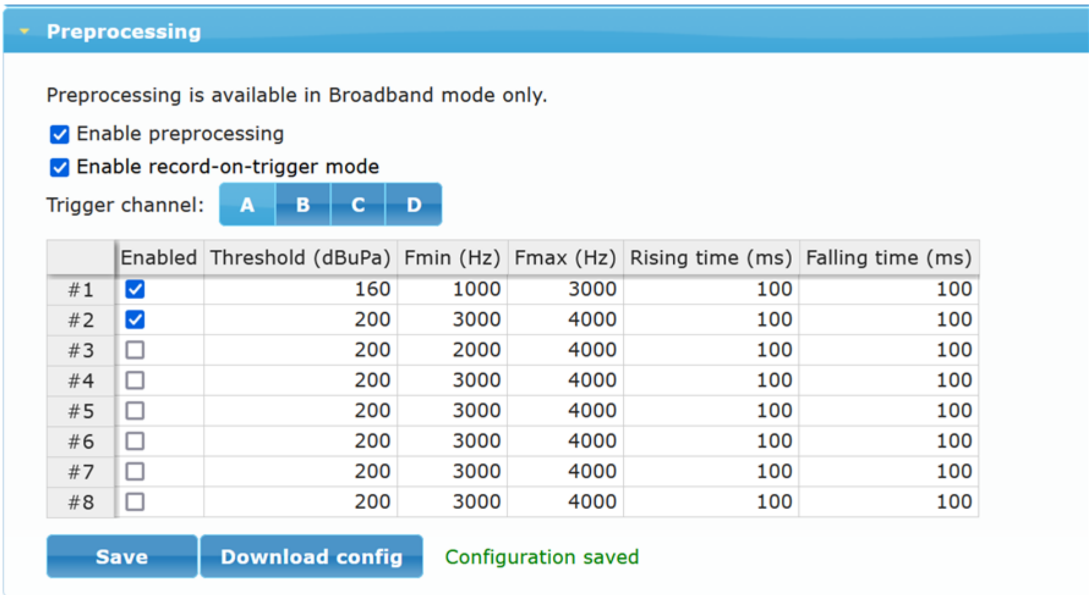

Fig. 6 — Screen capture of the sound levels pre-processing configuration

2.2 Relevant data visualization interfaces yet simple and accessible to novices

Taking profit of the wireless capabilities offered by the buoy, it is possible to transmit raw audio data (by WIFI over a 700 meters range (that range will soon be extended to several kilometers thanks to a more powerful modem) and pre-processed data (by radio/UHF over a 5 kilometers range, Iridium or GSM/LTE/4G).

At short distance, the WIFI link also allows to retrieve the raw acoustic data, allowing MMOs to process the audio files immediately to detect the possible presence of mammals and eventually put the work on hold until they leave. The raw data can indeed be streamed in real-time from the buoy to a receiving computer. The data can then be processed by any third-party software; and a plugin allowing compatibility with the well-recognized and largely spread PAMGuard software is available.

For radio communication, a specific software to display the processed data, named “RT Live Monitor”, has been developed in close collaboration with end-users to facilitate analysis and understanding of the indicators while remaining accessible to newcomers in acoustics thanks to simple indicators. Allowing real-time visualization of noise level information, it enables contractors to adapt in real-time the power of their machines to best comply with the standards. The software offers 6 different display windows, with a layout highlighting different values. Thresholds are also configurable to best fit the in-country recommendations and standards set by local agencies and the calculations obviously respect the international standards.

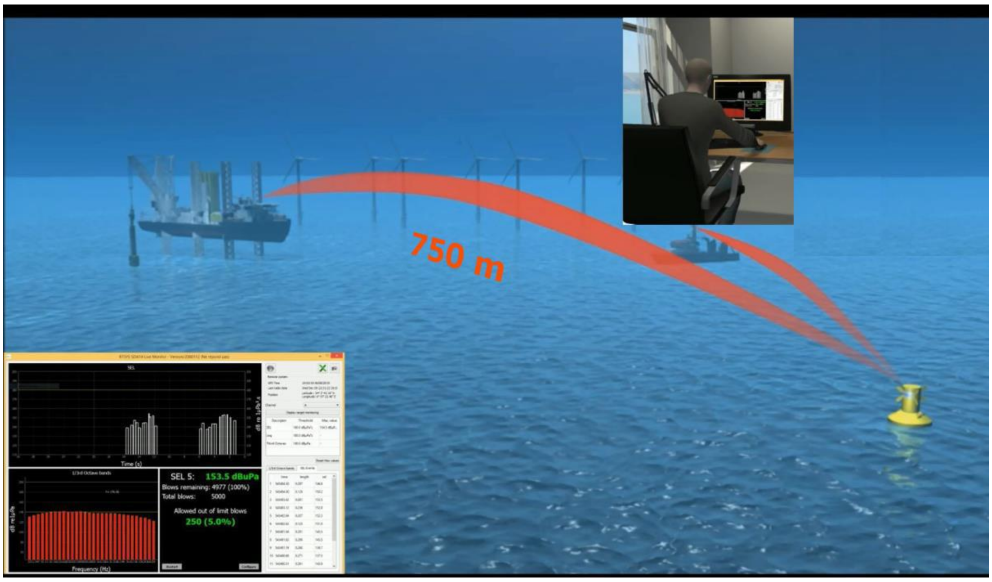

Fig. 7 — Standard setup for pile driving monitoring: a monitoring buoy is placed at 750 meters from the sound source, and transmits data in real-time to the supply vessel

Receiving hardware package for the radio transmission includes two units, the first one is waterproof and designed to be installed outdoors, acting as a repeater to transmit data to a second unit placed in a dry space. That second unit can be connected to a computer using USB cable.

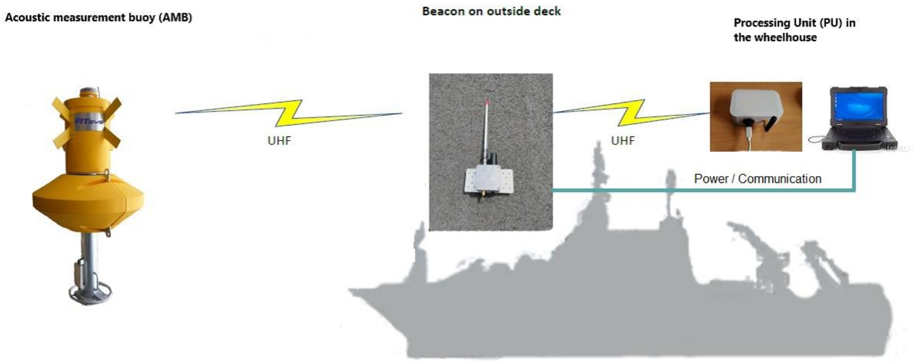

Fig. 8 — Radio communication setup

Once the buoy is recording, RT Live Monitor computes the SPL, LEQ and instantaneous SEL over a five-minute rolling window where the data is refreshed every 5 seconds. Each graph has an adjustable warning threshold represented by an orange line, and a maximum level threshold represented by a yellow line. A very simple color code allows anyone to quickly understand the compliance of the measured data:

- Compliant value are displayed in green
- Data exceeding the warning threshold are displayed in orange
- Data exceeding the maximum level threshold are displayed in red

In the below example, the following data are displayed:

- Top graph: SEL (Sound Exposure Level) 90 % calculated for each transient sound.
- Bottom left graph: Third octave bands SPL (Sound Pressure Levels).
- Bottom right graph: SEL5 (corresponds to the 5 % margin authorized by the German BSH. The 5 % margin is calculated on the basis of the “total blows” that the user selected when configuring the settings and decreases as the threshold is reached and/or exceeded).
- Right table: The main area shows two parts: in the upper part, GPS, time, values threshold and third octave Bands values are displayed. In the lower part, the transient sound detection time, the transient sound duration and the SEL 90 % are displayed.

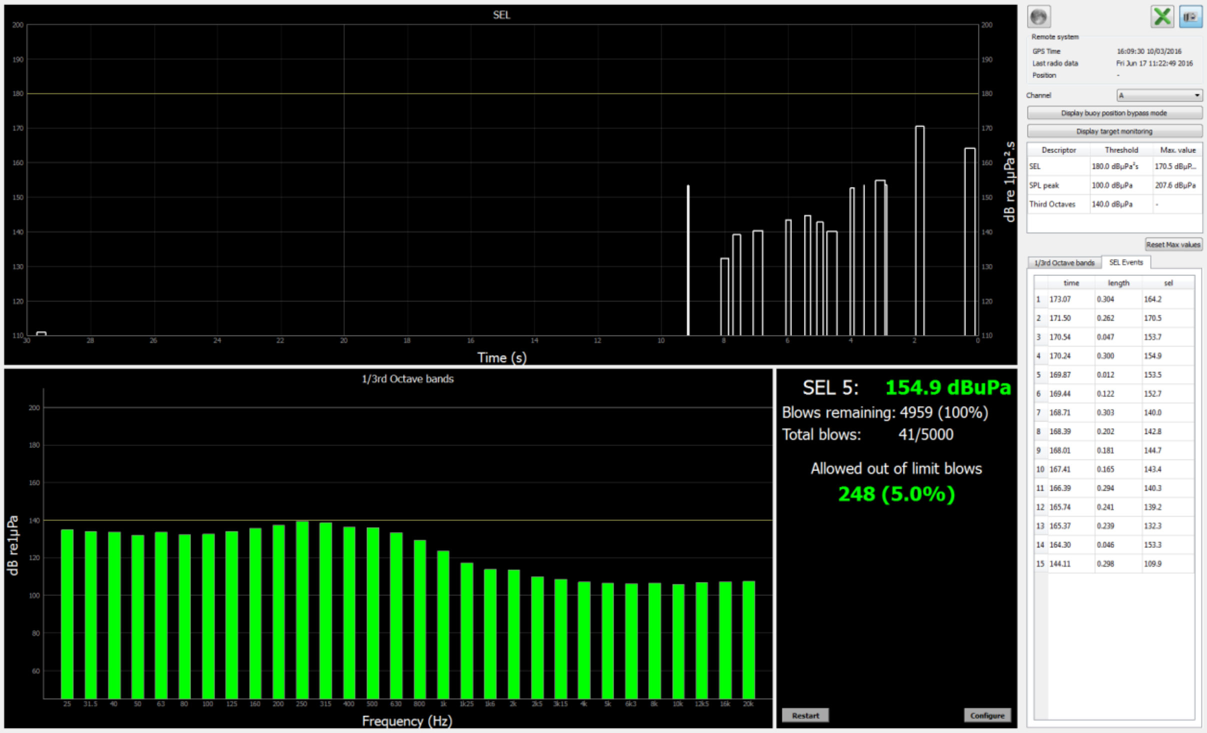

Fig. 9 — RT Live Monitor software interface

The buoy being equipped with a GPS, the software can monitor its position and provide sound level compensation within a user defined acoustic range from source. A correction factor is applied to estimated sound levels at 750m. This factor is fifteen times the logarithm to base 10 of the ratio of the distance between the buoy and the pile driving place to the distance of reference.

$$L750m = Leqd2 - 15*log10\ (R2/750)$$

In which:

- $R2$: the distance between the buoy and the pile driving place [m],
- $Leqd2$: the equivalent continuous sound level at a distance $d2$.

All received data is recorded for replay or correlation with the raw data recorded, and can be downloaded at any time in .csv files.

Finally, Iridium or GSM/LTE/4G links allow users far from the field to monitor levels via a dedicated web interface, accessible from anywhere in the world. That interface, named “RESONANCE” can display different processed acoustic data, as well as status info about the buoy itself, such as:

- HDD storage capacity,
- Battery level,
- GPS position,
- Solar panel performance,
- Status of the subsystems.

Fig. 10 — RESONANCE Web platform interface

Through the Web interface, the user will also be able to download a .csv file containing all the results and will have the possibilities to change the mission setting to reprogram the buoy.

All these different solutions allow the contractor to monitor in real-time the emitted noise by the construction work, and adapt immediately in case of overpassing a criteria ; avoiding them to receive fines or an obligation to temporarily cease work on the site.

Thanks to RTSYS commitment to these standards, RUBHY buoy is now officially recognized by many authorities around the globe, and nearly ten years after the initial product testing, the buoys are now deployed on offshore wind projects throughout America, Northwest Europe or Southeast Asia by some of the industry leaders like Jan de Nul, Boskalis, Iberdrola, DEME, BMS Offshore, DEME, etc...

2.3 Mammals detection algorithms

As of today, most of the project still involve human PAM (Passive Acoustics Monitoring) operators and MMOs (Marine Mammal Observer) which role is to assess of the presence of marine mammals in the work area. The methods to reach that objective are various: visual inspection (either using binoculars from the deck of a ship, or via aerial surveillance), real-time, or near real-time, analysis of audio files using processing algorithms or listening by ear in real time to underwater sound captured by hydrophones. The level of uncertainty of these different means conduces more and more regulators to highlight the need for autonomous systems able of detection.

For that reason, RTSYS has been working on the integration of detection algorithms for real-time processing inside the buoy. The algorithms are embedded on the coprocessing board receiving the raw data from the SDA14 acoustic motherboard. The data will be analysed by algorithms (named BioSound) developed since years by French company SenseaFR, recognized by the scientific community (20 years of sustained R&D activities, more than 30 scientific publications in international peer-reviewed journals, more than 1000 citations, an inventor's patent). It is a set of efficient algorithms that have been proven in numerous post processing analysis projects (over 50 years of data processing and more than 15 projects).

The algorithms will be able to detect cetaceans and fishes as well as vessels, that also opens applications in the defence and security sectors for protected area surveillance.

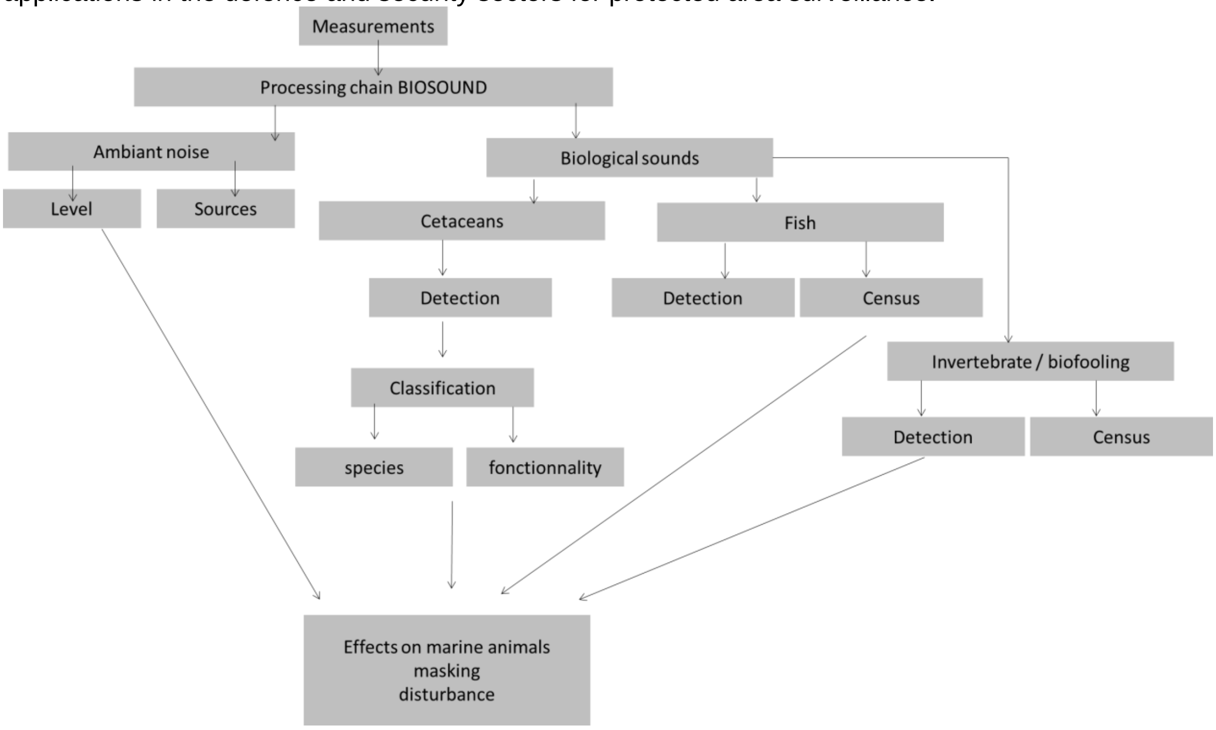

Fig. 11 — Functional diagram of the BioSound detection algorithms

The analysis includes:

- The ambient noise study, assessing the noise level in the relevant frequency bands and identifying the sources responsible for the noise (anthropogenic, meteorological, biological),
- Detection, classification and enumeration of animal sounds for cetaceans, fish and invertebrates
- Assessment of the effects of noise on wildlife

Specifically talking about cetaceans:

- The algorithm will detect the presence of cetacean sounds in the hydrophone capture radius (~ 20 km for mysticetes, ~ 1.5 km for delphinid clicks, ~ 1 km for delphinid whistles).
  3 detectors are applied:
    - Vocalization,
    - Whistles,
    - Delphinid clicks.
- In parallel to these detections, it will evaluate the detection range:
    - Detectors are based on Artificial Intelligence, neural networks applied to data spectrograms,
    - For each detector, a methodological note will describe the characteristics of the spectrogram, the detection performances (probability of detection, probability of false alarm), performances that will be illustrated and followed over time from test bases derived from data and built by our experts.
- The annotation of detections will be useful for the classification of biological sounds which will address 2 points of view:
    - Functionality (transit, nutrition, socialization, reproduction, calving, etc.)
    - The emitting species.

To date, the artificial intelligence tools applied to cetacean sound detection are in their 4th training incrementation, on a database of over 24,000 diverse biological signals and 50,000 diverse noise samples. The level of certainty of detection is:

- For vocalizations:
  - 93% probability of detection,
  - 0.6% probability of false alarm
- For clicks:
  - 95.6% probability of detection,
  - 0.6% probability of false alarm

The operator will be able to configure alerts in order to receive email or SMS text message upon detection. The alerts will also contain the date and time of the detection. Spectrograms and audio sample of a few seconds corresponding to the detection period will also be saved and transmitted for the operator to be able to double check and validate the actual presence of mammals.

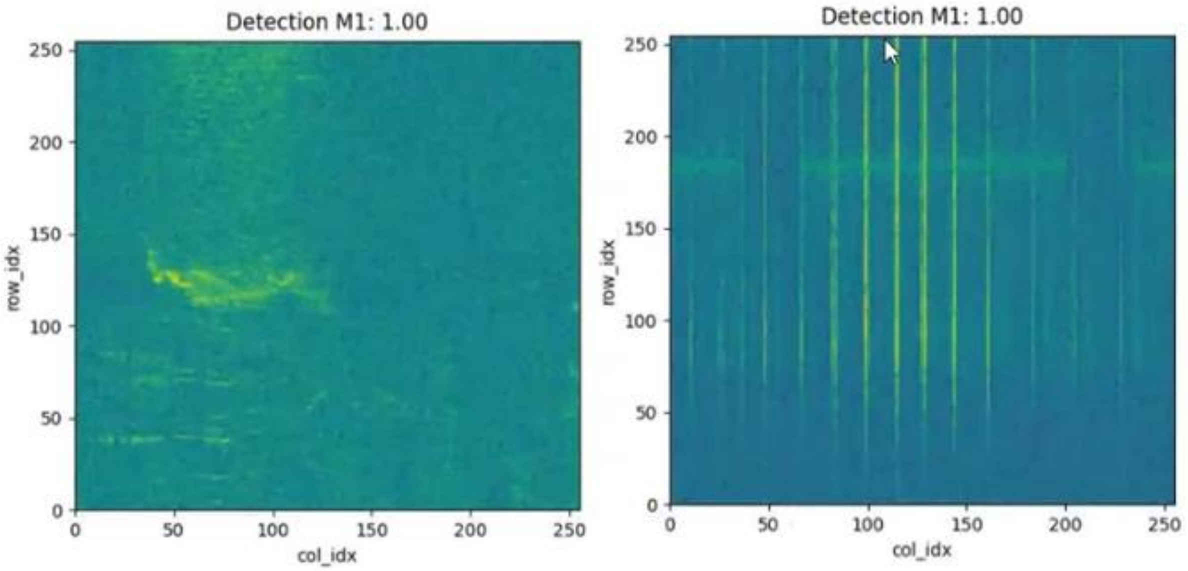

Fig. 12 — Example of spectrograms received by the user after detection of a mammal whistle (left) or clicks (right)

2.4 Future development perspectives: real-time mammals' localization

If the current version of the embedded algorithm provides information about the presence of mammals, there is currently no possibility to accurately locate the specimen. Hence, reflections are ongoing to optimize the solution and provide a mean to operator to accurately identify the position of the animal, and being able to monitor its trajectory, providing a solution to assess the efficiency of the mitigation systems.

The most likely way forward is to install a network of three (or more) buoys, all with the same time reference to enable data synchronization (this could be done by acquiring the PPS signal contained in GPS frames).

The buoys will be able to communicate all together either using WIFI communication, or satellite; and triangulation algorithms will allow to accurately position the sound source by comparing the evolution of the signal intensity recorded by the different buoys.

On side note, interest of such solution for navies and coast guards is no longer in question, all the more so at a time when international tensions are on the rise and the question of underwater sovereignty is more than ever a priority issue for states.

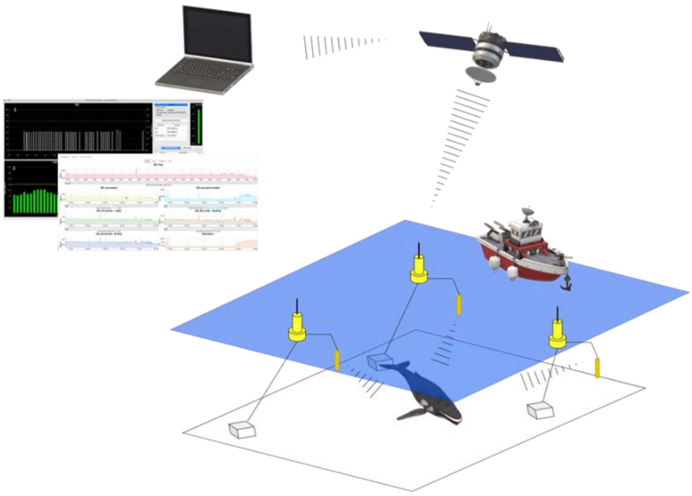

Fig. 13 — Conceptual representation of mammals' localization using RUBHY buoys

3 CONCLUSION

Thanks to the development of a high-end recording system, coupled with embedded processing, calculation, detection and localization algorithms, RTSYS aims to provide an all-in-one solution to comply with the challenging offshore regulations allowing the contractor to optimize their work while keeping our environment and the marine life safe. Benefits for the contractor are also seen in term of cost and time savings: being able to receive live information and take immediate decision allowing to reduce the waiting times for personnel, and limit unnecessary energy consumption by mobilized vessels.