Project no. 265863

ACCESS

Arctic Climate Change, Economy and Society

Instrument: Collaborative Project
Thematic Priority: Ocean.2010-1 “Quantification of climate change impacts on economic sectors in the Arctic”

D4.56 – Design and conceptual implementation of a real-time acoustic architecture

Due date of deliverable: **31/03/2014**

Actual submission date: **17/07/2014**

Start date of project: **March 1st, 2011** Duration: **48 months**

Organisation name of lead contractor for this deliverable: **UPC**

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
	Dissemination Level	
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	X
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1. Introduction

Many cetacean species can be identified by their specific calls. The recording of these signature acoustic signals can reveal their presence in monitored areas. Since sound propagates efficiently in water, the detection range of these signals can be quite large, exceeding 100 km in favorable conditions for low-frequency calls, far above visual detection methods. This acoustic potential to non-intrusively detect and monitor cetacean species in their environment gave rise to passive acoustic monitoring (PAM) techniques, for which research is very active as reveals the series of increasing international workshops dedicated to this rapidly evolving field since 2003. Advances in electronics, computers and numerical analysis now make this PAM technology more accessible and affordable to small research budgets. Various systems have been used, including radio-linked systems, drifting buoys, and arrays of autonomous recorders for versatile and long-term deployments. The goal of such PAM systems, is the continuous mapping of presence and distribution of whales over ocean basins and assessing their densities, sometimes in quasi real-time. Their performance in effectively accomplishing these tasks depends on the characteristics of the targeted cetacean acoustic signals, the environment, the type of equipment used, its deployment and configuration. This performance may significantly vary from case to case. However, in any case, PAM's success first depends on the capacity to isolate the target signals from the rest of sounds in which they are embedded, especially for distant sources and low signal to noise ratios (SNR). The acoustic signal source level, propagation loss, and local background noise levels determine detection ranges. Moreover, cetacean sounds vary considerably in time–frequency, from infrasonic calls of baleen whales to ultrasonic clicks of toothed whales, and in amplitudes among species and within a species' vocal repertoire. Ocean noise level also exhibits considerable variability in space and time, caused by fluctuating natural sources, such as wind, ice, rain, sounds produced by various organisms, and anthropogenic sources such as shipping. Sound speed structures over the water column can focus sounds from distant sources into sound channels. The 3D spatial arrangements of the sources and the hydrophones, their depth relative to the sound channel are therefore relevant to the PAM configuration.

In addition to the development and broad use of PAM techniques, another challenge is to obtain long-term access to data for the assessment of the large-scale influence of artificial noise on marine organisms and ecosystems. Understanding the link between natural and anthropogenic acoustic processes is indeed essential to predict the magnitude and impact of future changes of the natural balance of the oceans. Deep-sea observatories have the potential to play a key role in the assessment and monitoring of these acoustic changes.

The Laboratory of Applied Bioacoustics (LAB) of the Technical University of Catalonia, BarcelonaTech (UPC) is currently leading an international programme titled ‘‘Listen to the Deep Ocean Environment (LIDO)’’ to apply and extend developed techniques for passive acoustic monitoring to cabled deep sea platforms and moored stations. The software framework, called SONS-DCL, is currently active at the ANTARES (http://antares.in2p3.fr/) neutrino observatory, the OBSEA (http://www.obsea.es) shallow water test site, the NEPTUNE Canada (http://www.neptunecanada.ca/) observatory, the JAMSTEC (http://www.jamstec.go.jp/e/) network of underwater observatories and at the NEMO (http://nemoweb.lns.infn.it/) site after the observatory was redeployed, as well as through a zero-cost contract with the CTBTO (Comprehensive Nuclear Test Ban Treaty) hydroacoustic stations. Part of the system was also tested for suitability on autonomous gliders in collaboration with the NURC (NATO Undersea Research Center) and on wavegliders (Jupiter Research Foundation) to track humpack whales. Applied solutions have been also deployed in the Arctic in collaboration with STATOIL to measure and mitigate noise sources associated to Oil & Gas operations. Recognizing the technically advances of the software package has lead to a partnership between SONSETC (http://sonsetc.com), a spin of the UPC, and CSA Ocean Sciences Inc. (http://csaocean.com) aimed at providing advanced sound solutions to the offshore industry, government bodies, port authorities, and engineering firms. The vision is to deliver solutions that far exceed current acoustic monitoring technology, increase and highlight the benefit of acoustic measurements and demonstrate industries concern for the marine environment.

The development and implementation of the real-time component of SONS-DCL in existing observatories has offered a unique opportunity to monitor noise at a spatial and temporal scale never before realized. Access to the continuous flow of data has allowed the development of an exclusive database of sound sources that are permanently updated and used to calibrate the algorithms. These are applicable to almost any scenario, sea state, geographic location and noise level.

The system can be implemented on cabled observatories, autonomous radio-linked buoys, moored antennas, autonomous vehicles (including gliders), towed arrays and, existing data sets.

The software package contains several independent modules to process real-time data streams. Among these, there are dedicated modules for noise assessment, detection, classification and localization of acoustic events, including marine mammals and fish vocalizations. To summarize the LIDO system, it takes as input an acoustic data stream and produces as output the characterization of the acoustic events that were detected in the data (written to an XML file), spectrograms for quick visualization and compressed audio. These outputs are then made available on the Internet where they can be viewed with a specific application. A custom alert service is also available warning the user of the presence of acoustically sensitive species in the area of activity. SONS-DCL is designed to be modular and dynamic (allowing the choice of detectors/classifiers), depending on the objectives and geographical areas. SONS-DCL is conceived for ease of operation (non-expert) and provides a monitoring system that automatically operates 24/7, without the need of post processing.

The software and hardware solutions described in Sections 3 and 4 were implemented and tested during the ODEN-2013 campaign in the Arctic region. Autonomous buoys were deployed for cetacean detection and the measurement of ambient noise and ice breaker operations. The buoys were connected through satellite to provide information on the sound measurements.

2. Real-Time Monitoring

2.1. Cetacean Monitoring

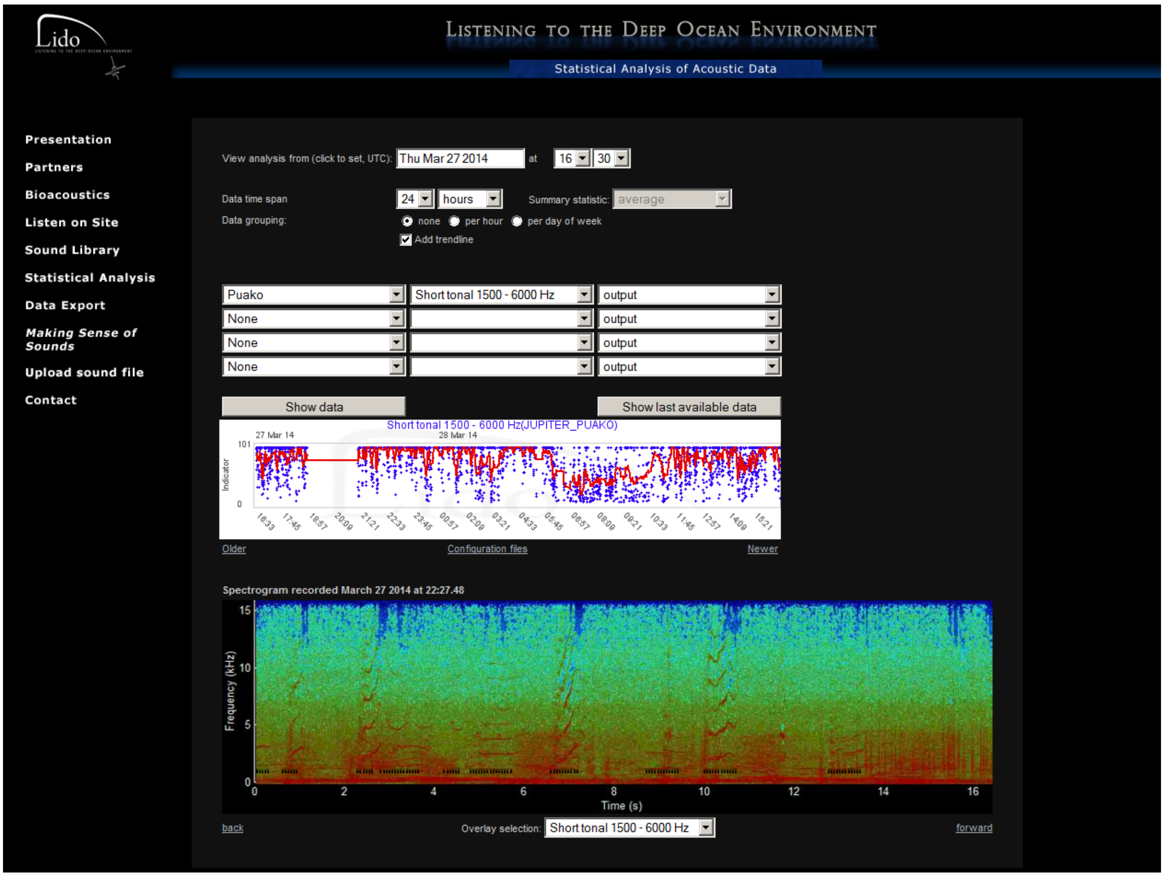
The purpose of cetacean monitoring in real-time is especially to guard against direct acoustic impact. Animals close to the source may be exposed to sound levels sufficiently high for temporary or permanent hearing loss. The cetacean detection and localization range of interest is then up to around 2000 metre from the source, depending on the source levels, frequencies, and environmental parameters.

The vocalizations of cetaceans can be broadly separated into two main types. Impulsive signals, which are broadband and of short duration – in the order of milliseconds. These signals are commonly used for biosonar and are emitted by toothed whales. In many cases the detection of a biosonar signal means that the animal is within 2000 metres. The exception is the sperm whale which has a lower frequency sonar signal that can be received up to 15 km from the animal.

A second type of signal (whistle or call) is well defined in frequency and of longer duration – in the order of seconds. Dolphin whistles (1 – 30 kHz) and many types of baleen whale calls (generally 1 – 6000 Hz) fall into this class. When dolphin whistles are received the animals are generally within 5 km range, but low frequency baleen whale calls (below 1000 Hz) may travel long distances through underwater sound channels. It is not expected that the noise source will be inside a sound channel which could have an environmental impact at very large distances. For short range impact assessment it is not useful to monitor sound inside a channel and care should be taken to place the hydrophone outside a channel.

Figure 1 and Figure 2 give examples of cetacean detection using the software described in Section 3.

Localization of the source (especially range estimation) should be precise up to 5 km and its performance can be allowed to deteriorate beyond that range. Ideally the tracking method provides probabilities of the presence of cetaceans within a certain zone with the zone shrinking at shorter ranges to the noise source.



View analysis from (click to set, UTC): Thu Mar 27 2014 at 16 30

Data time span 24 hours Summary statistic: average

Data grouping: ● none ○ per hour ○ per day of week

☑ Add trendline

Puako | Short tonal 1500 - 6000 Hz | output

None | | output

None | | output

None | | output

Spectrogram recorded March 27 2014 at 22:27.48

Overlay selection: Short tonal 1500 - 6000 Hz

Figure 1 Example of harmonic Humpback call detection at Puako, Hawaii (data provided by the Jupiter Research Foundation).

View analysis from (click to set, UTC): Sun Mar 30 2014 at 15 00
Data time span 24 hours
Summary statistic: average
Data grouping: ● none ○ per hour ○ per day of week
☑ Add trendline
Ligurian Sea | Sperm whale presence | output
None | | output
None | | output
None | | output
Spectrogram recorded March 30 2014 at 17:23.34
Overlay selection: Sperm whale presence

Figure 2 Example of Sperm Whale biosonar detection at Antares.

2.2. Noise Monitoring

Noise monitoring on location should at least follow recommendations for the MSFD indicator 11.2 concerning ambient noise and measure the sound levels in the 63 Hz and 125 Hz third octave bands. In order to provide a full overview of the sound levels in these octave bands it is suggested to present the results with a distribution graphic as shown in Figure 1 (top), in addition to reporting averaged levels. The top left and right images show the distribution of the measured sound levels (third octaves centred on 63 and 125 Hz and full bandwidth RMS) during April and October 2013 and they give an idea of the minimum and maximum levels, commonly encountered levels, and anomalies. For example in Figure 2 which shows the distribution of the same noise levels during September a small peak is seen for the RMS at a high level. These RMS peaks were due to an increased intensity of the 40 kHz noise band. A monthly summary statistic would have hidden this information, possibly leading to a too high estimate of a monthly RMS.

The MSFD indicator 11.1 concerns low and mid frequency impulsive sounds. The indicator requires a yearly summary on the days and locations that these impulses were produced. While not strictly necessary to measure impulses in real-time, it would be very useful to do so both to present data to validate modelling that was done in relation to this indicator and to be able to assess the impact on the environment directly. Representation of the peak level is shown in Figure 1 (bottom). Assessment of the number of days where a peak level exceeded the threshold is easier in a time plot than when displayed as a distribution. Ideally, the source (peak) level is known and the transmission loss of the acoustic path can be estimated from the recording. Otherwise a calibrated source can be used or a propagation model suitable for the environment.

Apart from measuring the MSFD acoustic indicators it can be useful to measure in frequency bands that may contain animal vocalizations. The exact bands depend on the monitoring location. A high noise level in the band may indicate that the bioacoustics signals will not be detected, or only detect from closer ranges. This should be taken into account in mitigation procedures. If high noise levels in these bands are produced by a near-by source then the monitoring station should be moved further away.

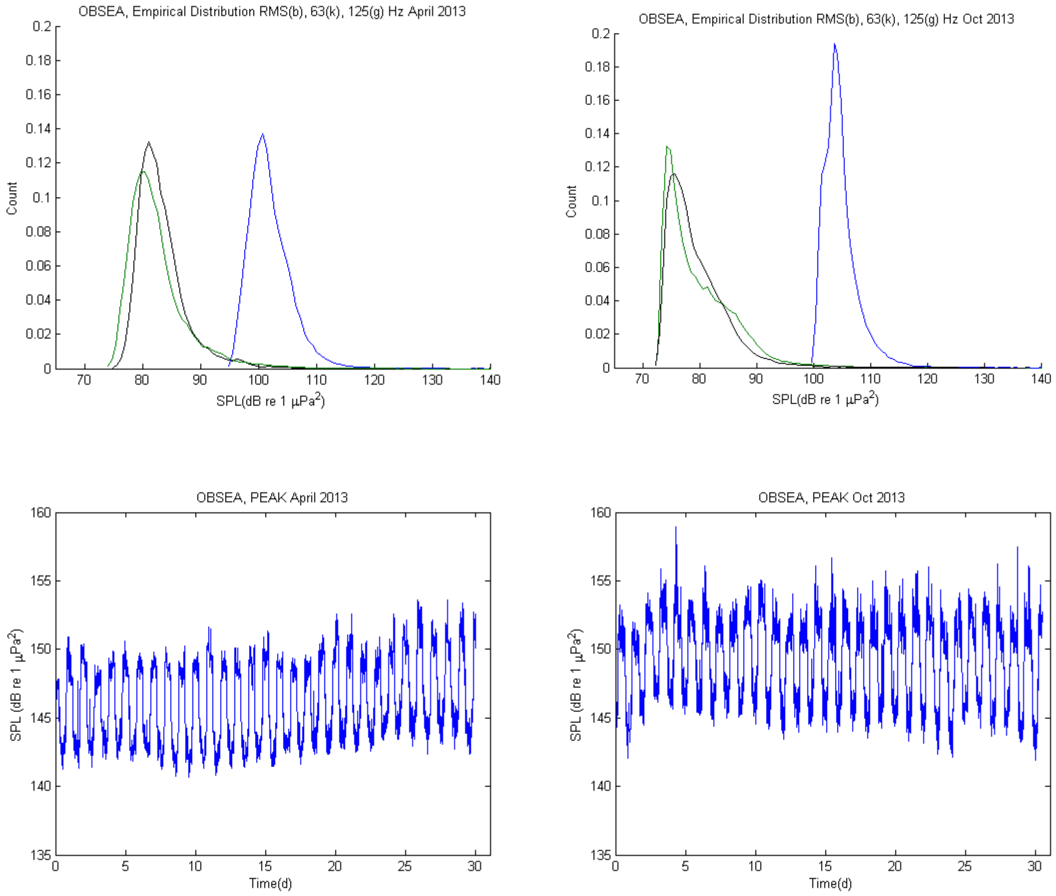


Figure 3 Top: Distribution of noise in two third octaves (centred on 63 and 125 Hz) and the full recording bandwidth (up to 48 kHz) at the OBSEA platform during April and October. Bottom: Evolution of peak levels at the OBSEA platform during April and October 2013.

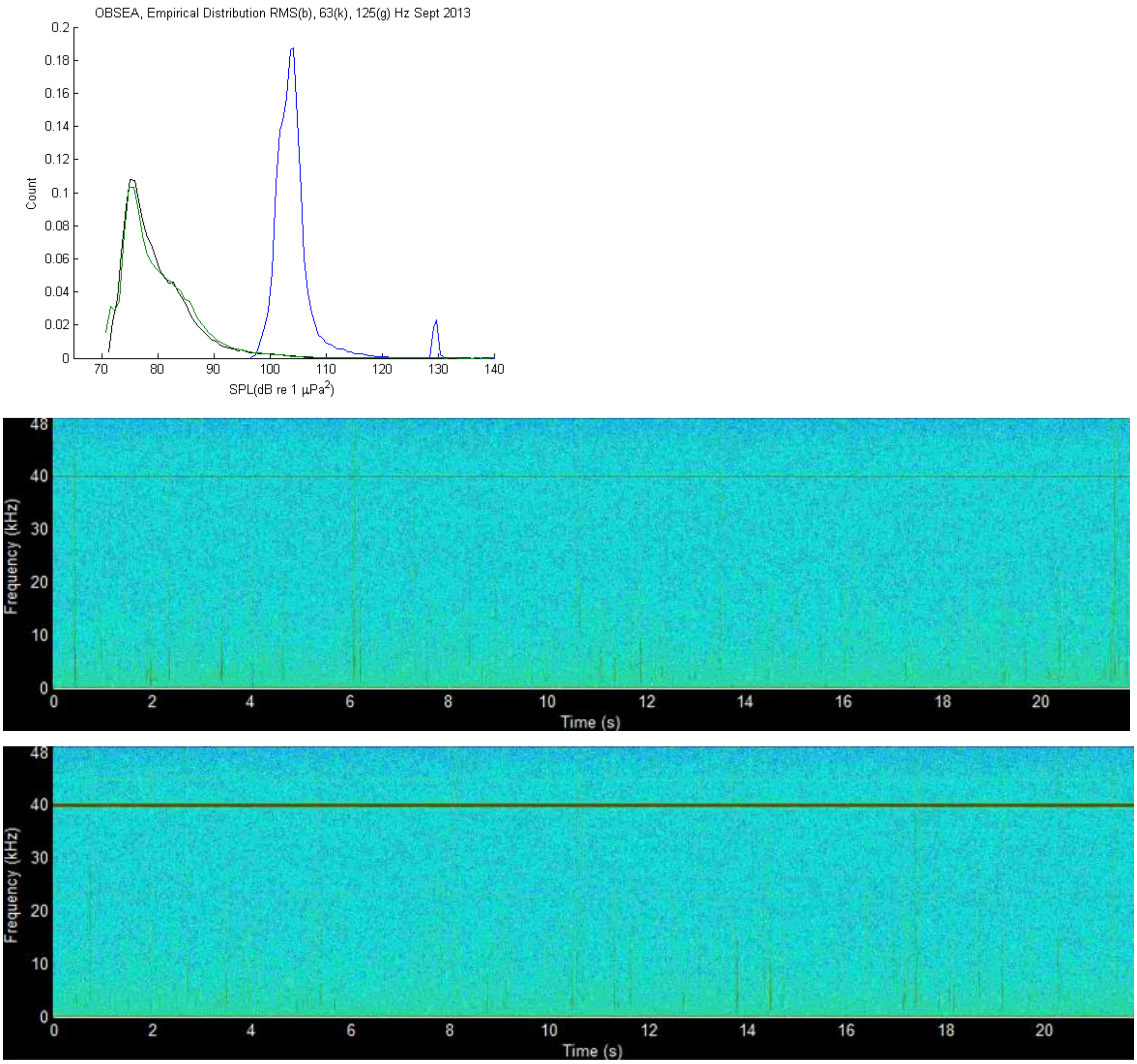


Figure 4 Top: Distribution of energy in 63 and 125 Hz third octaves and full bandwidth RMS at the OBSEA platform (as in Figure 1) in September 2013. The two following spectrograms show the cause of the isolated RMS peak.

2.3. Real-Time Reporting

Noise measurements and detection data can be made available locally to ships operating in the vicinity or globally over the internet. The advantage of the latter may be that any environmental or government agencies can follow the operations and ensure that regulations are being followed, without the need to be physically present. Local access is provided by a WiFi radio link with the buoy acting as an access point if cabling of the buoy to a platform is not possible. In the case of WiFi, normally only one or two clients would connect to the buoy, but if there is more interest it is preferred to install a WiFi point-to-point bridge to an auxiliary vessel and provide data access from there, e.g. connecting to an AP on the vessel or provided wired access to observers on the vessel. This setup would be able to provide access to analysis results, spectrograms that allow human observers to identify the correctness of the automated process and a compressed audio stream.

Global access is provided through an Iridium satellite uplink. The available bandwidth will be much less than available for a WiFi link and at least the compressed audio stream would normally not be available while spectrograms could be transferred upon request. The data is transferred to a centralised storage location from where it can be further distributed.

3. Software Implementation

The software for the real-time analysis (SONS-DCL) is developed in C due to the availability of C-compilers on most embedded platforms. The design follows a modular approach that allows loading/unloading modules while the system is running. The modular design is especially needed to ensure that data from a hydrophone can be picked up without dropping samples. Additionally, analysis of data is not unnecessarily delayed due to a single module waiting for e.g. a network timeout. Some modules may make further use of multiple processor architectures with the OpenMP library (whether or not this gives a true advantage depends on the server specification). There are generally 3 types of modules:

- Data entry module: a SONS-DCL system normally has only 1 acoustic data entry module. This module cannot be replaced or restarted without stopping the data acquisition. Currently data entry modules are planned for data acquisition from e.g. Diamond Systems DAQ boards, SMID digital hydrophones, icListen or Naxys Ethernet hydrophones, and to read data from disk (files stored in pcm, wav, aiff, etc. format). Data files that are accessible through a network or the internet are often first stored to disk independently before passed through SONS-DCL. The system can have other modules that accept external data, such as AIS/GPS or other sensors connected through a serial or USB connection.

- Data analysis modules: analysis modules perform sound measurements, acoustic event detection, classification, localization, tracking etc.

- Data output modules: output modules provide (analysis) results in a format that can be read by other post-processing tools. There are e.g. XML and CSV output modules to export the analysis results; spectrogram creation for human analysis; mp3/ogg vorbis modules to allow listening to a compressed stream; a data recorder to record raw data allowing to recording based on triggers (e.g. only record data segments that contain short tonal signals).

The modules communicate using POSIX based IPC. It has been tested on FreeBSD (generally used for powered servers) and Linux (generally used for embedded systems) and is expected to run with minimal changes on other systems that have POSIX (.1-2001) support. It has been written for x86/x86-64 architectures and has not yet been tested on other architectures. On Windows a single executable version is available that does not depend on the POSIX IPC and cannot take advantage of the modular design. It is primarily used for analysis of large archived data sets.

The SONS-DCL system runs autonomously on a server or embedded board (not all modules are suitable for low power systems); once configured and started it generally does not require any supervision. One way to present the SONS-DCL output to a user is through the SONS-DCL client. The SONS-DCL client requires the standard software stack with

Apache (or Nginx)/MySQL/PHP/JavaScript/XML and Flash for some parts. A part of the data interface can be installed directly on an embedded board to monitor its operation. However, it is advised to isolate the SONS-DCL system from the general public to avoid overloading the device. Data can be transferred automatically to another server where the public may access it.

4. Embedded Hardware

Currently the embedded version of SONS-DCL runs off a PC/104 stack based on Diamond Systems boards. The stack has the following components:

- Processing: DS - Aurora single board computer (Intel Atom Z530 1.6 GHz).
- DAQ: DS-MM-32DX-AT ADC board (optional).
- Ethernet port expansion: DS-Corona-Ethernet board (optional).
- Watchdog: proprietary board to power the Aurora and to monitor voltage, current, and the execution duty cycle.
- Power regulation board: proprietary board to switch on/off peripheral equipment through Aurora GPIO pins (optional).
- Main storage: solid state disk connected through SATA.

Common peripherals:

- GPS receiver
- AIS receiver
- Satellite modem
- 3G/WiFi modem
- WiMAX modem

The Aurora runs a 2.6 Linux kernel version which has complete Diamond Systems driver support. When a digital hydrophone is used the DAQ board is no longer necessary and a different hardware stack could be used.

5. Deployment Considerations

The embedded system as described above can be deployed from e.g. buoys, gliders, or from a sea floor installation.

When fixed platforms are considered a buoy or sea floor solution could be optimal, especially if the system can be cabled from the platform to receive power and to transmit data. In that case the system should be installed at a large enough distance from the platform and support vessels to avoid hydrophone saturation. It can be interesting to use two hydrophones, one in a sound channel for long range detection and one out of the sound channel for short range measurements. Comparison between the two data streams could provide clues on the propagation properties of the medium and could improve distance estimates of cetacean sources.

When a seismic campaign is considered, or any situation where the sound source is moving through an area, then buoy solutions may no longer be practical. In such a case wave glider monitoring would provide a way to have the hydrophones moving along with the operation and to maintain at an optimal distance from the source to both perform noise measurements and cetacean detection.

6. Monitoring Protocol

1. Literature study: A list of all the species that may be found in the area during the time period of the operations should be compiled, especially cetaceans but also e.g. cephalopods and fish; vocalization frequencies should be separately noted. The area should also be inspected for other anthropogenic sound sources, such as existing platforms, shipping lanes, fishing grounds, etc.
2. Characterisation of the sound source: If possible the noise source should be measured in advance or its sound characteristics should be made available from the owner/supplier.
3. Premodelling: Based on information from the literature study, sound source and local propagation properties, modelling should be performed to find 1) the number of necessary hydrophones and 2) the optimal position of each hydrophone, taking into account that animals should be detected up to 5 km from the source.
4. Data acquisition configuration: The acquisition parameters should be chosen to allow recording of the full bandwidth of the source and cetacean vocalizations. Noise measurements should be made at least in the 63 and 125 Hz third octaves, but also in other bands where the sound source may have level maxima, especially if these fall inside a frequency range where they may affect cetaceans.
5. Real-time monitoring: A three stage alert protocol is suggested. At the first stage no animals are detected by the system. At the second stage animals have been detected beyond a 2 km range. If the animals move closer towards the operation a supervisor should be notified that mitigation routines may have to be initiated soon. At the third stage animals are within a 2 km range and may enter zones with dangerously high levels at any moment. Mitigation procedures should be effected immediately.
6. Final reporting: The final report should show the noise levels as described in Section 2.2. This would not only provide information for the MSFD reporting but also show that the operator stayed at or below the sound levels that were provided for modelling (and possibly to obtain a permit). All cetacean detections should be included in the report as well as the mitigation procedures that were followed.

7. Testing of real-time architecture

The software and hardware solutions described in Sections 3 and 4 have been implemented and tested during the ODEN-2013 campaign in the Arctic region. Buoys were deployed for cetacean detection and the measurement of ambient noise and ice breaker operations. The buoys were connected through satellite to provide information on the sound measurements. An overview of the sound measurements on two different deployment days is shown in Figure 5. The bimodal structure was caused by presence and absence of the ship. In parallel, a real-time monitoring system (BCUBE) was deployed from the ODEN itself; Figure 6 shows a screenshot of its interface. On board the ship WiFi was used to provide access to the monitoring system to everyone on board. The ODEN-2013 campaign is reported in Deliverable 2.45.

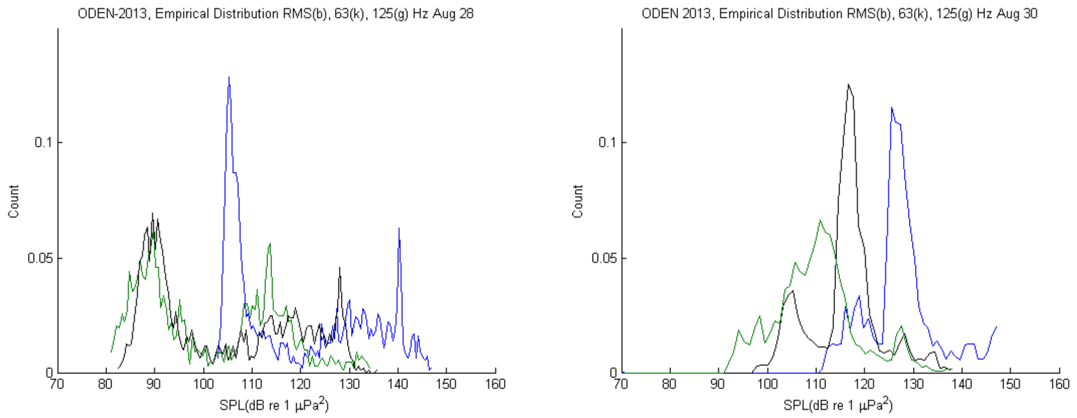


Figure 5 Measurement results from the ODEN-2013 campaign.

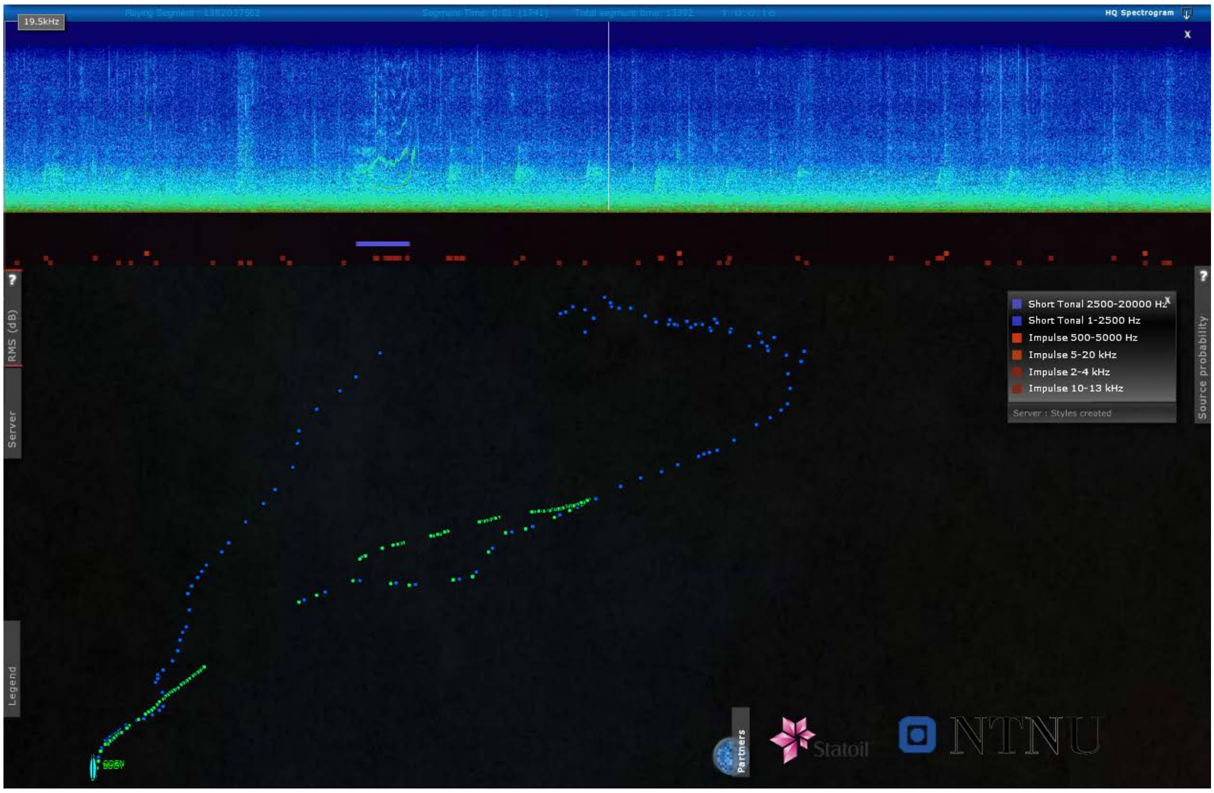


Figure 6 Detection of Narwhal whistle from the BCUBE on board the ODEN.

8. Conclusion

SONS-DCL noise monitoring and acoustic event detection and classification were successfully tested during the ODEN2013 expedition. Sources of opportunity including the ODEN machinery noise, ice-breaking noise, distant seismic survey as well as marine mammal vocalizations (e.g. belugas) were analysed through the deployment of two autonomous buoys that drifted away from the icebreaker and were recovered in three occasions.

The communication module that allows the transmission of data though WIFI/3G/Iridium also showed to properly detect the best available network and formatted the data depending on the bandwidth.

The software architecture is now ready to be deployed in any platform of opportunity to fulfil the requirement of monitoring the presence of marine mammals through the sounds they produce but also to address the EU MSFD mandate to monitor noise in third octave bands centred at 63Hz and 125Hz and automatically build statistics.