Automatic Detection of Humpback Whales and Localization of Sperm Whales during Marine Seismic Survey

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Abstract

This paper shall demonstrate the performance and opportunities provided by a passive acoustic marine mammal monitoring system (PAM) integrated within seismic cables.

The cetacean detection domain is broad because of the variety of the possible vocalizations and complex, because the actual truth is rarely known. We present two case studies in this document, the automatic detection of humpback whale moans, and the automatic localization of sperm whales clicks trains.

We have chosen the detection of humpback whale's low frequency moans as this species is regularly detected during seismic surveys. Its detection is due to medium frequency components (>500Hz) of its vocalizations, whereas the frequency range of moans starts at 20Hz [1].

The localization of sperm whales is challenging as sperm whales vocalize while diving hundreds of meters, which makes it difficult to accurately localize in the horizontal plane.

Although Sercel, with the support and commitment of CGG, has accumulated data during more than twenty months aboard several seismic vessels; this paper specifically provides analysis of mammal monitoring offshore Brazil in the Barreirinhas basin aboard the CGG Oceanic Vega in 2016, where the PAM system was operated for validation purpose.

Introduction

QuietSea™ is a Passive Acoustic Marine Mammal Monitoring System, designed to detect the presence of marine mammals during seismic operations, enabling seismic contractors to comply with increasingly widespread marine mammal monitoring regulations, while optimizing the productivity of seismic operations.

QuietSea is seamlessly integrated within seismic streamers. This allows for greatly enhanced marine mammal detection and localization capabilities in a wide frequency range, encompassing a large variety of vocalizing cetacean species.

The QuietSea system can detect two different types of vocalization emitted by marine mammals: Whistles and clicks trains.

Whistles are characterized by frequency modulation with a mean duration of a few hundred milliseconds to a few seconds. The whistle frequency bandwidth is a few hertz to tens of thousands hertz depending on the marine mammal species. Whistles are vocalizations emitted to communicate between marine mammals in the same group, or are part of the songs emitted by specific baleen male whales.

Clicks are vocalizations emitted by marine mammals for navigation and the hunting of prey. They are called echolocation clicks and are emitted in a sequence or train. The click rate can be a few clicks per second to hundreds of clicks per second depending on the species and the type of activity the marine mammal is engaged in (navigation or hunting).

Vocalizations in the seismic bandwidth (from 10Hz to 200Hz) are acquired by the 48 seismic channels, while the higher frequency range (from 200Hz to 96kHz) is monitored via 10 modules installed seamlessly in the streamers and below the seismic source [2], [3].

A typical layout of the QuietSea sensors is presented hereafter:

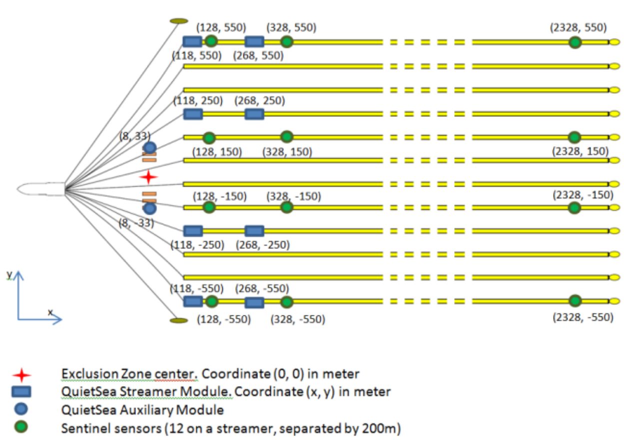

Figure 1: Layout of QuietSea sensors

The general software architecture is presented below:

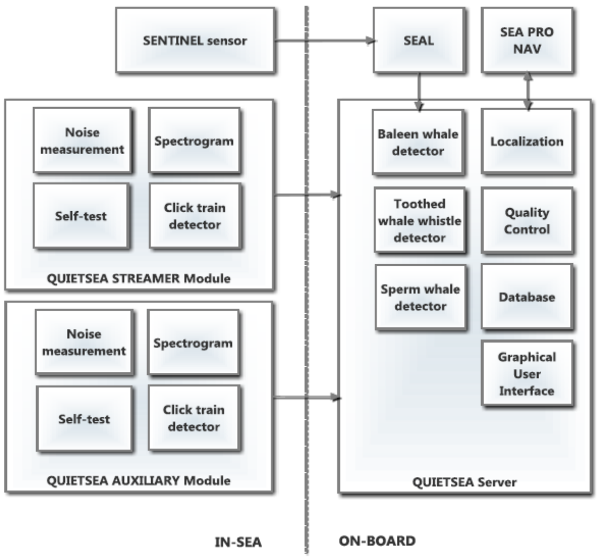

Figure 2: General software architecture

An Ethernet link with the seismic acquisition system allows real-time processing of the seismic data acquired by streamer hydrophones, detecting vocalizations in the 10Hz-200Hz frequency range.
This system takes benefits of the low noise characteristics of Sentinel® solid streamer [4] that makes it possible to detect baleen whales vocalizations down to 10 Hz.

An Ethernet link with the SeaPro Nav navigation system allows QuietSea to know the location of each hydrophone with an accuracy of less than 1m. This is beneficial for an accurate localization of marine mammals.

There are four main functions within the modules: A 200Hz-24kHz binary spectrogram calculator, a click train detector with a frequency bandwidth of 96kHz, a noise measurement function, and a built-in self-test function.

The toothed whale whistle detector and the sperm whale detector process data acquired by the auxiliary and streamer modules to automatically identify whistles and click trains in the 200Hz-24kHz frequency range.

The database is regularly updated with all the acoustic events detected, the noise measurements, and the results of the analysis by the QuietSea system.

QuietSea offers the possibility to detect automatically and provides also conventional displays such as spectrograms for a further analysis by a PAM operator if necessary.

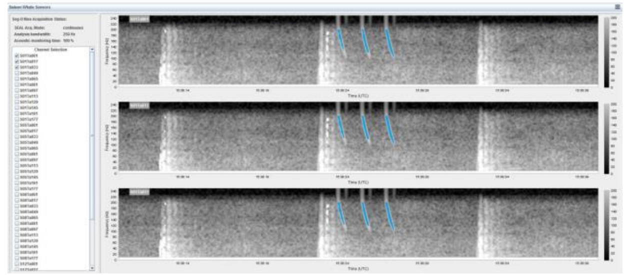

Figure 3: QuietSea Graphical User Interface (10-200Hz spectrogram)

QuietSea offers a localization map which integrates the exact location of the exclusion zone and of the PAM sensors, relative to the seismic source center.

With a multi streamer configuration, when QuietSea detects a vocalization on two sensors, it is able to estimate the bearing of the marine mammal, with port/starboard ambiguity. When a vocalization is detected on three or more sensors it is able to accurately estimate the position of the marine mammal without any ambiguity.

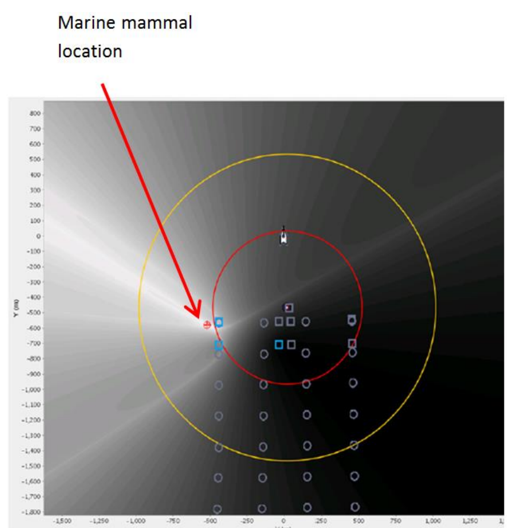

Figure 4: QuietSea Graphical User Interface (Localization map), grey circles = seismic channel, grey squares = modules, blue = sensors that have detected

QuietSea has been used in different regions of the world for more than twenty months, leading to hundreds of cetacean detections. This paper is an opportunity to focus on two case studies while CGG vessel Oceanic Vega was operating offshore Brazil in the Barreirinhas basin, the automatic detection of humpback whale moans, and the automatic localization of sperm whales clicks.

Case study 1: Automatic detection of Humpback Whale moans

Humpback whales live in all major oceans and consequently are often encountered during seismic surveys.

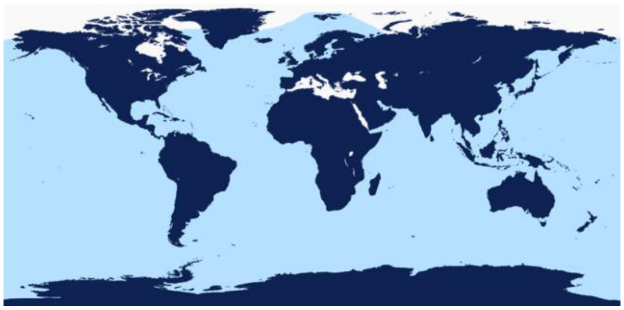

Figure 5: Humpback whale range map [5]

They produce a very wide variety of sounds: grunts, moans, pulse trains, blowhole sounds and surface impacts [2].
This study assesses the capability of QuietSea to detect low frequency moans that overlap with the seismic bandwidth (<200Hz). Indeed, these songs can be captured by numerous sensors (48 seismic channels, each channel being composed of 8 hydrophones) which favors detection and precise location.

Method

The 48 seismic channels used by QuietSea are continuously processed by the baleen whale detector [6], whose synopsis is presented below:

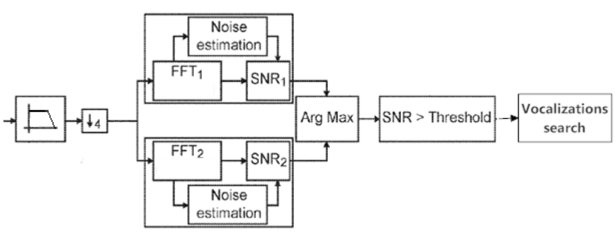

Figure 6: Baleen whale detector

The detecting stage comprises:

- a low pass filter,
- a decimator factor of 4,
- in parallel two detection channels whose FFT lengths are 128 and 256 respectively,
- a block for dynamically selecting each time the detection channel which optimizes the output Signal to Noise Ratio (SNR),
- a block for performing detection only on the selected channel, by comparing the SNR of the selected channel to a determined threshold,
- a block for searching vocalizations in a frequency vs time chart

Once several detections occur on three or more seismic channels, Time Differences Of Arrival Time (TDOAs) are computed and used in a Least Square algorithm to compute the most likely cetacean location.

Laboratory results

Baleen whale detection performance during seismic surveys is sensitive to the background noise level in the very low frequency bandwidth. It depends on the water height, the nature of the seabed, the induced noise of the vessel, the distance between the seismic cables and the vessel, etc.
In order to determine whether QuietSea is noise limited during a seismic survey, a quality control test has been developed [7]. It consists of summing a simulated call of a marine mammal that would be at a distance of 500m from each sensor to the signal acquired in real time on each sensor.

A synopsis is presented below:

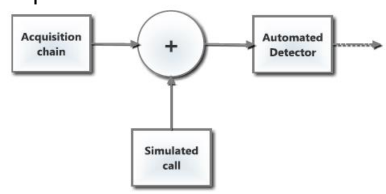

Figure 7: Quality Control test

The simulated signals are synthetic but have the same characteristics as real signals (same frequency, shape, amplitude). It avoids any additional noise that would be present on a real recording of a marine mammal call.

Although this test has been developed to be used in the field, it can be used in the laboratory thanks to a simulator that allows replaying seismic data (SEGD files).
Below is the signal used to simulate a Humpback whale moan in the seismic bandwidth, it is a vibrating upsweep song:

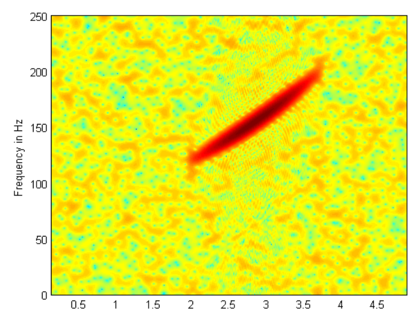

Figure 8: Humpback whale song in the seismic bandwidth

The maximum rms emission level measured for moans is 173dB re 1µPa @ 1m [8]. As the test signal only integrates the low frequency component of a real signal, the amplitude used for the test is reduced to 160dB rms re 1µPa @ 1m.

In this paper, we present the results of a test performed in the laboratory (after post-processing). The output signal of the acquisition chain (SEGD file) is provided courtesy of CGG. It has been acquired during the previously mentioned deep water seismic survey.

The figure below represents the output of the Quality Control test on the first and last seismic channels of streamer 1, which have an inline offset from the seismic source of 128m and 2328m respectively:

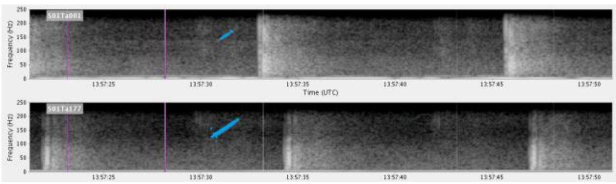

Figure 9: Result of the Quality Control test on seismic channel 1 and 177 of streamer 1, seismic source active

The blue lines represent the automatic detections of baleen whale vocalizations.
This figure shows that QuietSea is able to detect a humpback whale moan in the seismic bandwidth. It also suggests that the detection performance of humpback whale moans may depend on the moment of arrival of the vocalization on the sensors relative to the seismic source activation.

Field results

The automatic monitoring conducted with QuietSea led to several automatic detections and localizations of low frequency vocalizations of humpback whales.

The table below lists the humpback whale detections, the correlation with MMO and the state of the seismic sources.

Date	Seismic source	Range	Detection correlated with MMO
Aug 6th 2016 20:19UTC	Active	2481m	Yes
Aug 6th 2016 21:08UTC	Active	2528m	No
Aug 6th 2016 22:37UTC	Active	2705m	N/A
Aug 7th 2016 01:22UTC	Active	2270m	N/A
Aug 14th 2016 09:39UTC	Inactive	988m	No
Aug 14th 2016 10:13UTC	Inactive	2238m	No
Aug 14th 2016 12:20UTC	Inactive	2896m	No
Aug 14th 2016 14:33UTC	Inactive	1000m	No
Aug 14th 2016 14:57UTC	Inactive	2678m	No

Figure 10: Humpback whale detections

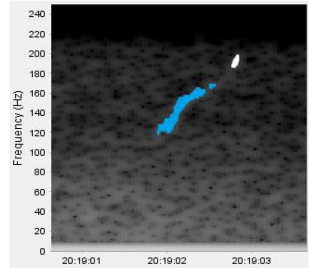

Figure 11: Humpback whale detection, display of detected moan, seismic source active, correlated with MMO. (08/06/2016, 20:19UTC)

The field results confirm the previous study and demonstrate that low frequency moans of humpback whales can be detected whether the seismic sources are active or not.

The widespread use of QuietSea should allow to expand the future automated detection of humpback whales to include the detection of additional vocalizations such as their low frequency pulse trains [25 – 80 Hz] [1].

Case study 2: Automatic Sperm Whale Localization

Sperm whales live in all major oceans and consequently are often encountered during seismic surveys.

Figure 12 : Sperm whale range map [5]

The sperm whale is well known for its particular vocalizations that make it difficult to localize accurately. Different approaches have been proposed by the scientific community to localize these mammals; the most commonly used being manually, based on the successive bearing estimation approach.

One should note also that sperm whales vocalize when they dive. This can happen as deep as 800 meters, which makes it difficult to localize. This places additional uncertainty on the localization accuracy of conventional methods which require an experienced operator to provide a subjective localization of the mammal.

There is therefore a need to improve the localization method of sperm whales regardless of the skill and experience level of the PAM operator.

Sperm whale source level can reach 236dB pk re 1µPa @ 1m [9] and the propagation of the clicks emitted is minimally impacted by the attenuation losses. Indeed, the clicks are relatively low frequencies (core bandwidth from 5kHz to 24kHz [10]) and are mainly attenuated by spherical spreading (losses in 20.log10(R) for deep water). Moreover, the background noise in the core bandwidth is low. It should also be noted that sperm whale produces a low-frequency component of low directionality that conveys sound to a large part of the surrounding water column. This increases the potential for reception at considerable distances [11].

Thus, a sperm whale can be detected by most of the sensors contained in the wide network provided by QuietSea (typically 825x150 meters), making it possible to accurately localize using a Long BaseLine (LBL) localization method.

Method

This method applies to regular sperm whale clicks; it consists in 4 main steps:

1) A unitary click detection is continuously performed on each sensor (typically 10 sensors at stake) *via* an Energy Detector,
2) A rhythmic click train detection is continuously performed and the Inter-Click-Interval (ICI) is estimated. The click trains without ICI compatibility with sperm whale emissions are rejected,
3) When three sensors or more have detected the same click train (same ICI), then the Time Difference Of Arrival (TDOA) between pairs of sensors are estimated by correlation,
4) Knowing the TDOAs and the sensor locations, a 3D grid (±3000m around the source center in the horizontal plane and 0 to -1000m in the vertical axis) is built. For each position in this grid the theoretical TDOAs are computed and compared to the measured ones by a Least Square algorithm. The minimum of the resulting cost function provides an estimated location of the sperm whale [12].

The following graph represents a rhythmic click train detected on 5 widely spaced hydrophones (represented in blue on figure 14) during the seismic survey, when a sperm whale was in the vicinity of the vessel. To ease the display, the amplitude of sensor N is N.

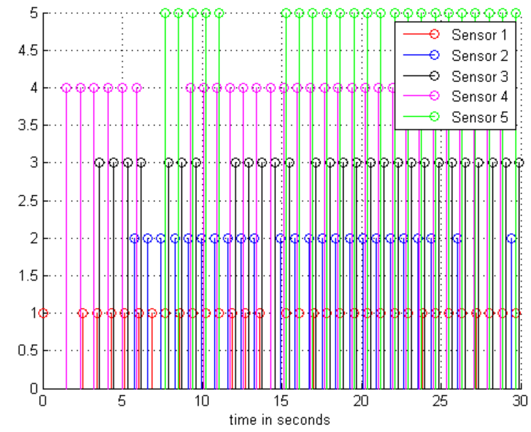

Figure 13: Rhythmic click train detections result on 5 sensors (January 2016, onboard a CGG Vessel)

This result confirms that the spaced hydrophones (here 838 meters between furthest hydrophones) in a seismic environment can detect a same sperm whale click train.

The TDOAs have been computed by correlation and have fed the least square algorithm. The computation of TDOAs has to be robust to the reflected paths from sea surface and to ambiguities which may arise with short ICI and distant sensors.

In this example, the minimum of the 3D cost function has been found for a depth of 400m, and the 2D cost function at this depth is given below:

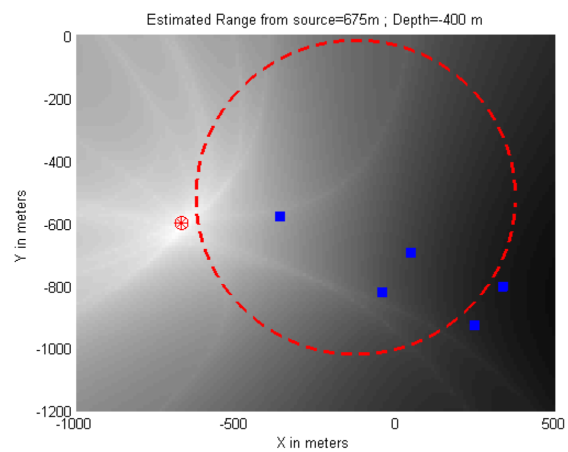

Figure 14: Localization map at 400m depth. Red cross: sperm whale location, blue square: hydrophones that have detected, red dotted circle: exclusion zone

Each TDOA produces a hyperbola based on the results of the cost function. It is interesting to see that all the hyperbolas intersect at a point the cost function computed to be at a depth of 400m. This consistency reflects the quality of the location achieved by QuietSea.

To highlight this, the 2D cost function at sea surface is presented below. It can be noticed that the hyperbolas don't cross on a unique location:

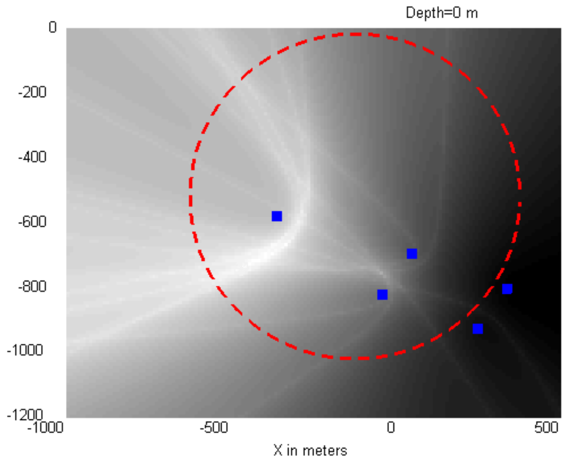

Figure 15: *Localization map at sea surface*

This result demonstrates that the use of a wide hydrophone network incorporated in the streamers significantly improves the performance of sperm whale localizations, provided that the localization is done in 3D.

The method validated after post processing of the data acquired during this survey, can now be implemented for real time 3D localization of sperm whales.

Conclusions

The data acquired by CGG and Sercel during the numerous QuietSea trials allows to continuously improve the detection and localization performance of an integrated PAM system into the seismic cables. Although QuietSea already complies with the main regulations established to protect marine mammals during seismic surveys, its architecture opens the opportunity for innovative detection and localization techniques that are not applicable to conventional systems.

This field trial in the Barreirinhas basin demonstrated that the automatic detection of humpback whale moans and the automatic localization of sperm whales benefit from the use of a wide sensor network integrated into seismic cables for marine mammal monitoring.

Acknowledgments

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