Automated real-time acoustic detection of Fin Whale calls at the Deep Sea Floor Observatory off Kushiro-Tokachi, Japan

Michel André[1], Ryoichi Iwase[2], Tomonori Akamatsu[3], Ichiro Takahashi[4], Serge Zaugg[1], Mike van der Schaar[1], Ludwig Houégnigan[1], Antonio, M. Sánchez[1]

[1]Laboratory of Applied Bioacoustics, Technical University of Catalonia (UPC), Spain
[2]Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan
[3]National Research Institute of Fisheries Engineering, Japan
[4] Marine Works Japan, Ltd., Japan

Abstract*- A system for the real-time and fully automated detection, classification and localisation of acoustic sources in the marine environment has been developed at the Laboratory of Applied Bioacoustics (LAB) of the Technical University of Catalonia (UPC). The system features modules for the detection, the classification and localisation of short tonal sounds and impulsive sounds and the quantification of the level and the spectral characteristics of the background noise. The system has been successfully validated for the detection of many sound-types from fixed ocean cable observatories (ESONET, ANTARES, NEPTUNE). In particular, the detection module for short tonal sounds has been effectively applied to detect baleen whales and delphinid calls and whistles. The system is operational on live acoustic data streams from fixed ocean observatories (www.listentothedeep.org), demonstrating its ability to handle continuous data streams with a sampling frequency as high as 250 kHz. Here, we applied this module for the detection of short tonal sounds has been adjusted to detect calls of baleen whales in acoustic data from the sea floor observatory off Kushiro in the Kuril Trench, Japan (www.jamstec.go.jp/scdc/top_e.html). This data was recorded at a sampling frequency of 100 samples per second. The detector was first validated on data series from several marine observatories that were either known to contain Fin Whale calls or to be from regions where Fin Whales do not occur. The 384 hours of acoustic data used off Kushiro ranged from 25th April to 10th May 2010 without gaps. Many sections of these recording contained in the frequency band intense impulsive noise, or interferences, from unknown anthropogenic sources. Nevertheless, the system successfully detected a train of Fin Whale calls that occurred on April, the 29th 2010 between 02h15-03h15. The call showed a frequency down sweep in the range 30-15 Hz with duration of 1-2 seconds. The signal to noise ratio of these calls, as perceived by an experienced operator, was clearly lower than in the validation data sets. This demonstrates (1) that Fin Whale are present off Kushiro, (2) that the detector can handle calls with a very low signal to noise ratio and (3) that the real-time automated detection of baleen whale calls can be performed live at JAMSTEC network of observatories.

I. INTRODUCTION

Understanding the link between natural and anthropogenic processes is essential for predicting 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 changes. LIDO (Listening to the Deep Ocean environment) is an ongoing project that proposes to establish and coordinate high quality research to allow the real-time long-term monitoring of Geohazards and Marine Ambient Noise at underwater observatories. A system for the real-time and fully automated detection, classification and localisation of acoustic sources in the marine environment is being developed at the Laboratori d'Aplicacions Bioacústiques (LAB) [1, 2]. The system features modules for the detection of short tonal sounds and impulsive sounds; classification and localisation modules; and modules that quantify the level and the spectral characteristics of the background noise. The system has been successfully validated for the detection of many sound-types from fixed ocean observatories (e.g. cetacean whistles, echolocation clicks, impulsive and tonal shipping noise, underwater explosions, echo sounders and pingers). In particular, the detection module for short tonal sounds has been successfully applied to detect dolphin calls and whistles [8] and calls from Orcas (*Orcinus orca*), Humpback Whales (*Megaptera novaeangliae*) and Right Whales (*Eubalaena sp.*) (Unpublished results). The classification and localisation modules have been successfully validated with several types of impulsive sounds [3, 4, 5, 6, 7]. A module for the classification of short tonal sounds is currently under development. The system has been operational on live acoustic data streams from fixed ocean observatories for several months (www.listentothedeep.org), demonstrating its ability to handle continuous data streams with a sampling frequency as high as 250 kHz.

The Fin Whale (*Balaenoptera physalus*) has a worldwide distribution and produces low frequency calls (sometimes called pulses) in the range 15-200 Hz. The most frequently heard call-type is a frequency down sweep in the range 30-15 Hz with duration of around 1-2 seconds (Figure 1).

In this report the module for the detection of short tonal sounds has been adjusted to detect calls of baleen whales in acoustic data from the sea floor observatory off Kushiro in the Kuril

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Trench (www.jamstec.go.jp). This data were recorded at a sampling frequency of 100 samples per second. The detector was first validated on data series from several marine observatories that were either known to contain Fin Whale calls or to be from regions where Fin Whales do not occur.

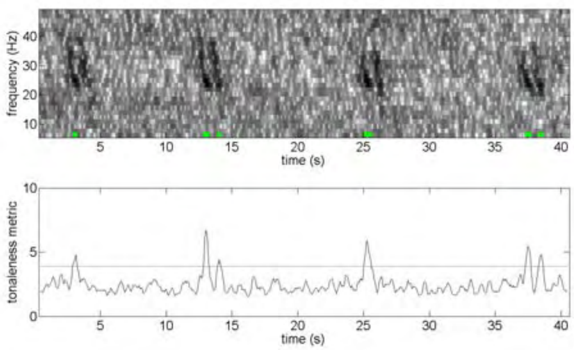

Figure 1. A segment with Fin Whale calls from the NEPTUNE ocean observatory

II. Materials and Methods

A. Description of the detection procedure

Requirements
Detection is the first stage in a larger processing chain involving classification, localisation and storage of relevant statistics or selected segments of the data. The requirements put on the detection stage are computational speed and robustness to a diversity of noise conditions. In addition it is desirable that the detector identifies time regions where the calls occur in order to return their time stamp to the classification and localisation modules.

Overview
The acoustic data was processed in consecutive, non-overlapping segments of 41 seconds. The detector first processed each segment resulting in a single numerical value (the detector output). Then the outputs from several consecutive segments were combined to obtain the detection value. The detector triggers on short tonal sounds (including frequency modulated ones). It is aimed at sounds such as whistles of delphinids, calls of whales or narrowband anthropogenic sounds such as pingers. The detector's sensitivity can be adjusted to the expected frequency of the targeted sounds via tuning parameters. Here, these parameters were chosen to obtain an accurate detection of Fin Whale calls.

Processing of a single segment
An equalised spectrogram of the segment was computed. Then, a tonaleness metric taken over the frequency range 6-49 Hz was obtained for each time bin. Comparing the tonaleness metric with a fixed threshold (set at 3.9) allowed to automatically identify the time stamps of the calls. The detector output, which summarises the content of an entire segment, should be large even if a single Fin Whale call is present. To achieve this, the mean of the upper 1% percentile of the tonaleness metric values was chosen as detector output.

Combining outputs from several segments
Fin Whale calls typically occur in trains of dozens of calls with 10 to 30 seconds between two consecutive calls. When Fin Whale calls are present, it is expected that several nearby segments (they do not need to be contiguous) result in a high value of the detector output. To account for this, the median of the detector outputs from 5 consecutive segments was used as a detection value. A threshold set at 4.5 was used on the detection value to automatically identify regions with a high probability of containing Fin Whale calls.

B. Assessment of the generality of the detector

The present detector is required to operate reliably in a fully automated manner over long time periods (several months to several years). Therefore it must be able to provide a consistent detection performance under the diversity of conditions expected over such time periods at the sea floor observatory off Kushiro. For this report all parameters were fixed; allowing to test the detection performance under a diverse set of conditions encountered at several regions of the world, with different recording devices, and over time periods of up to 2 months. The diversity of conditions across observatories is considered to be larger than along time at the same observatory; therefore the approach used here represents a difficult challenge. To improve comparability across plots the vertical axes representing the detection values are always shown at the same scale.

C. Validation of the detector on data with known content

Description of the validation data
The validation data was taken from several sources as listed below. The original data from some sources had sampling rates higher than 100 sps. In order to be comparable with the data from the sea floor observatory off Kushiro, the recordings were low-pass filtered and down-sampled to 100 sps.
(1) *Fin Whales 93* CD (Cornell University). The two files used here were recorded in the West Atlantic in the years 2003 and 2004. These recordings were known to contain Fin Whale calls occurring over most of the recording. In total there were over two hours of acoustic data.
(2) Mobysound database (www.mobysound.org). These data were recorded in the North Atlantic in 1993 and were known to contain Fin Whale calls occurring over most of the recording. In total there were over two hours of acoustic data.
(3) NEPTUNE ocean observatory (www.neptunecanada.ca). These data were recorded at the Barkley Canyon site in the East Pacific off the Canadian coast at ~1000 meters depth. These recordings were known in advance to contain sections with Fin Whale calls. The data were recorded between 6th April and 2nd June 2010; they were recorded in pieces of 10 minutes with variable-sized gaps between 2 pieces. In total there were 52 hours of acoustic data.
(4) NEMO-ONDE deep sea observatory. These data were recorded in the East Mediterranean basin, off the coast of

Sicily at ~2000 meters depth.. The data were recorded between 7th and 17th August 2005; they were recorded in pieces of 5 minutes with one hour gaps between 2 pieces. In total there were over 20 hours of acoustic data.

D. *Results obtained with the validation data*

Validation with data from the West and North Atlantic (Fin Whales 93 CD).

These data contained Fin Whale calls with a high SNR. The detection performance was excellent in all four datasets.

Validation with data from the North-East Pacific (NEPTUNE).

The detection value was above the threshold 2.4 % of the time (108 segments out of 4459). The corresponding reduced set of files was manually assessed for the presence of Fin Whale calls and if present they were plotted in green on Figure 6. Fin Whale calls were found in 94 segments while in the remaining 14 segments the detections were caused by amplitude modulated ship-lines. This site is monitored in real time at the Laboratori d'Aplicacions Bioacústiques since April 2010 and it was observed that intense shipping noise occurs at a daily basis. It can be concluded that the vast majority of ships did not trigger the detector. Overall only 0.31 % of the segments resulted in a detection (14 out of 4459) even though they contained no Fin Whale calls, while many instances of Fin Whale calls were correctly detected (Figure 2).

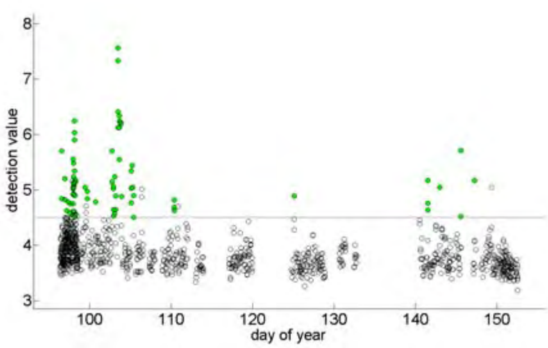

Figure 2. Detection value obtained with all the NEPTUNE data. A threshold set at 4.5 (shown as a horizontal line) was used to identify segments that could potentially contain Fin Whale calls. Files that were manually confirmed to contain Fin Whale calls are plotted in green.

Validation with data from the East Mediterranean (NEMO)

In this dataset impulsive shipping noise (due to cavitation at propellers) was observed 23 % of the time [5]. This value represents an underestimation of ship noise presence, since ships do not always radiate impulsive noise. Only one segment resulted in a detector output above the threshold. Manual scrutiny revealed that it contained amplitude modulated ship-lines. Overall, 0.06 % of the segments resulted in a detection (1 out of 1715) even though it contained no Fin Whale calls, while no instances of Fin Whale calls were detected.

III. AUTOMATED DETECTION OF FIN WHALE CALLS FROM THE SEA FLOOR OBSERVATORY OFF KUSHIRO

Description of the Kushiro data

The acoustic data was recorded at a rate of 100 samples per second at the sea floor observatory off Kushiro (www.jamstec.go.jp/scdc/top_e.html). The recordings were known in advance to potentially contain Fin Whale calls. The data used here ranged from 25th April to 10th May 2010 without gaps. In total there were 384 hours of acoustic data. Many sections of these recording contained intense impulsive noise or interferences from an unknown anthropogenic source(s).

Results obtained with the Kushiro data

The detection value was above the threshold 0.74 % of the time (Figure 8). The corresponding reduced set of files was manually scrutinised for the presence of Fin Whale calls and, if present, they were plotted in green. Only one train of Fin Whale calls was found; it occurred on 29th April 2010 between 02h15-03h15. The SNR of the calls, as perceived by an experienced operator, was clearly lower in the Kushiro data than in the other data sets. All the other detections were caused either by unknown, generally intense, artificial transients that were short and narrowband or by amplitude modulated ship-lines. Overall only 0.71 % of the segments resulted in a detection (228 segments out of 32260) even though they contained no Fin Whale calls, while one instances of a Fin Whale call train was detected (Figure 3 & 4).

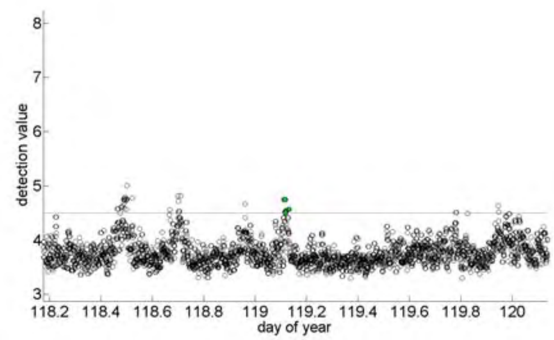

Figure 3 **.** Detection value obtained with all the Kushiro data (a). A threshold set at 4.5 (shown as a horizontal line) was used to identify segments that could potentially contain Fin Whale calls. Segments that were manually confirmed to contain Fin Whale calls are plotted as green dots. A time-zoom in the period where Fin Whale calls occurred is shown on subplot (b) and the spectrograms of figure 4.

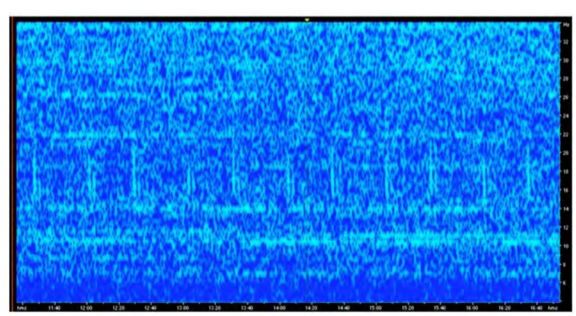

Figure 4. Spectrogram taken over 7 minutes recorded at the Kushiro observatory on 29th April 2010 at ~02h40. Shown is a selected section of data

with eleven Fin Whale calls. Due to the low SNR of the calls, the spectrogram has been contrast-enhanced. An inter-call interval that remains stable over several consecutive calls is typical for trains of Fin Whale calls.

IV. CONCLUSION

Generality of the detector

Fin Whale calls were successfully detected at 3 distinct geographical sites from the validation data, where Fin Whales were known to occur (West Atlantic, North Atlantic and North-East Pacific). For two sites of the validation data long term series were available, allowing to estimate the false detection rate. The false detection rate was below 1 % in both cases (NEPTUNE: 0.31 % and NEMO: 0.06 %). Considering that data from these sites contained a significant proportion of time with shipping noise, the obtained false detection rate is very low.

It is concluded that the detector is general enough to reliably detect Fin Whale calls from different oceans, recording devices and obviously from different Fin Whale individuals. The detector is specific for narrow-band and possibly frequency modulated transients. Therefore it is also triggered by other similar signals such as amplitude modulated ship lines and possibly other baleen whale calls (e.g. *Balaenoptera borealis*, *B.edeni*, *B.musculus*). If Fin Whale Calls are present in the Kushiro data, they are expected to be reliably detected with the present detector.

Applicability to Kushiro data

One train of Fin Whale calls was automatically detected in the Kushiro data on 29th April 2010 between 02h15-03h15. The signal to noise ratio of these calls, as perceived by an experienced operator, was clearly lower than in the validation data sets. This demonstrates (1) that Fin Whale calls can be detected in the Kushiro data and (2) that the detector can handle calls with a low signal to noise ratio.

As for the validation data, the false detection rate obtained with the Kushiro data was below 1 % (Kushiro: 0.71 %). Considering that data from the Kushiro observatory contained a significant proportion of time with shipping noise and additionally intense narrow-band transients, the obtained false detection rate is very satisfying. The detector allows to automatically select parts of a data stream that are most likely to contain Fin Whale calls and to return only these parts to second stage algorithms; thereby reducing the data volume to be processed in the second stage by a factor of at least 100.

The above-mentioned results were obtained with all parameters fixed across different datasets. This demonstrates the generality of the detection algorithm and indicates that it could be applied to data recorded in the future at the Kushiro observatory with a similar performance as was obtained here.

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