North Atlantic Right Whale (*Eubalaena glacialis*) Detection & Localization in the Bay of Fundy using Widely Spaced, Bottom Mounted Sensors

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Abstract- A data set consisting of North Atlantic right whale (*Eubalaena glacialis*) vocalizations were provided as part of the 2003 International Workshop on Detection and Localization of Marine Mammals using Passive Acoustics in Halifax, Nova Scotia. These vocalizations were processed using a set of detection and localization algorithms developed as part of the Marine Mammal Monitoring on Navy Ranges (M3R) program. Localization is performed using hyperbolic multilateration on Time Difference of Arrival (TDOA) data from a two stage FFT based energy detector. Binary FFTs are computed from the raw time series by thresholding the FFT using a time average in each bin as the threshold criteria. Clicks are detected by comparing the total number of bins above threshold to a secondary threshold. Detected clicks are split out of the data stream and the rest of the data is aligned using a spectrogram cross-correlation. Details of the marine mammal monitoring algorithms will be presented as well as results from the data set.

I. INTRODUCTION

North Atlantic right whales have been observed to generate multiple call types under a variety of circumstances. Some of the earliest reports are attributed to Schevill and Watkins [1], who recorded North Atlantic right whales during feeding. Calls typically span a fundamental frequency range from 100 to 400 Hz [2], although vocalizations in excess of 4 kHz have been reported [3]. Sounds associated with baleen rattle range up to 9 kHz, with dominant frequencies between 2 and 4 kHz [4] while *Blows* and *Gunshots* have been reported in excess of 10 kHz [3]. Southern right whales have been reported to have a similar frequency range (50-500 Hz) [5,6] and it has been noted that the difference is probably artificial [7]. Call types have been identified for Southern right whales and have been linked to specific activities [8]. More recently, a series of call types have been associated with a surface active group (SAG) for North Atlantic right whales [3]. Call types identified are similar to those for Southern right whales and include *Screams*, *Warbles*, *Blows*, *Upcalls*, *Downcalls*, and *Gunshots*. Several methods have been proposed to detect and localize right whales based on these sounds[1] including spectrogram analysis [9,10], independent component analysis [11], model based comparison [12], and neural networks [13]. A comparison between neural network and spectrogram analysis has shown neural networks to be superior when sufficient training data is available, although it is noted that spectrogram methods may be preferable when sufficient training data is not available [13].

This paper presents results from application of a set of algorithms for passive detection and localization of marine mammals on wide baseline acoustic arrays to a data set of North Atlantic Right Whale vocalizations made available as part of the November 2003 workshop on detection and localization of marine mammals using passive acoustics [14,15]. The algorithms utilize a novel hybrid detection scheme wherein broadband events (typically referred to as clicks) are separated out of the data stream and processed separately from the remaining data. The algorithms have been developed and fielded as part of the Marine Mammal Monitoring on Navy Ranges (M3R) project.

II. TECHNIQUE

The M3R toolkit performs localization using 2D and 3D hyperbolic multilateration algorithms described by Vincent [16]. The input parameters consist of TDOA data from a separate data association routine along with a representative sound speed profile. The same event must be present on at least four hydrophones to compute a 3D position. If fewer hydrophones are available, a 2D position is computed. An arbitrarily shaped hydrophone array may be utilized, although co-linearity of the hydrophones must be avoided.

Detector

Detection is performed in multiple stages. The data from each hydrophone is first run through an N point fast Fourier transform (FFT) with variable overlap. For this data set, an FFT size of 1024 points and an overlap of 75% was chosen. Figure 1 shows a spectrogram formed from multiple cascaded FFTs from one of the conference dataset files.

[1] The June 2004 issue of the Journal of the Canadian Acoustical Association is dedicated to detection and localization of marine mammals, focusing on right whales

1-4244-0115-1/06/$20.00 ©2006 IEEE

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 SEP 2006	**N/A**	**-**

4. TITLE AND SUBTITLE	
North Atlantic Right Whale (Eubalaena glacialis) Detection & Localization in the Bay of Fundy using Widely Spaced, Bottom Mounted Sensors	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Undersea Warfare Center, Code 71, Bldg 1351 1176 Howell Street Newport, RI 02841 USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADM002006. Proceedings of the MTS/IEEE OCEANS 2006 Boston Conference and Exhibition Held in Boston, Massachusetts on September 15-21, 2006, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**6**	

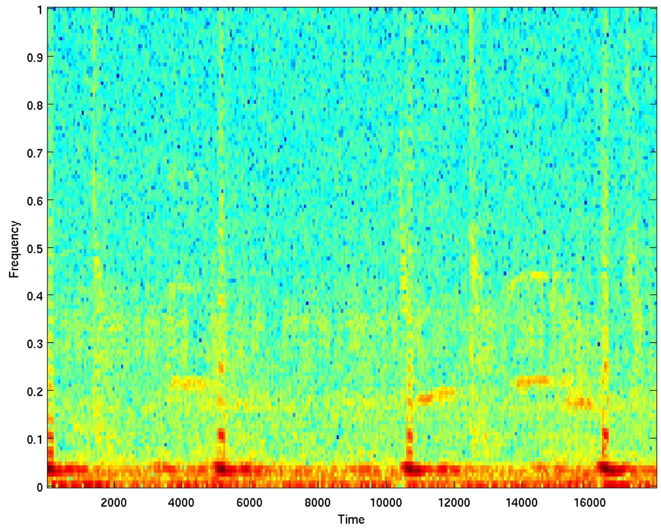

Figure 1: Spectrogram of file S131-10, buoy C

Each frequency bin *f* of the FFT is compared to a time average of the previous FFT data for that specific bin. If the energy in bin f exceeds the time average by at least *m* db, a "1" is placed in a binary output map in the slot (bit) corresponding to frequency bin *f*. Otherwise a "0" is placed in the corresponding slot. The output of the first stage, $Q_i(f,t)$, is therefore a binary valued frequency map derived from the FFT, which contains a "1" in each frequency bin that exceeded the time average and a "0" everywhere else. Frequency maps are only produced when at least one bin is above threshold. The threshold *m* is selected empirically based on the data set to be processed and is not currently normalized for either the sample rate or the FFT size. For this data set a value of m=-33 was chosen. The detector output is plotted as a binary spectrogram in Figure 2 below.

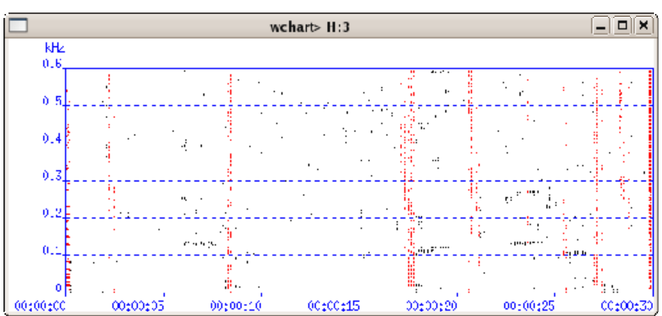

Figure 2: Detector Output for spectrogram shown in Figure 1. Data shown in red are broadband events classified as clicks and removed from the data stream.

A click is detected by comparing the number of bins set in each reported frequency map against a threshold, nominally 10. Frequency maps associated with click detections are split out of the data stream and sent to a data association algorithm called a "scanning sieve" [17]. The sieve looks for patterns of received clicks over multiple hydrophones and matches them, producing TDOAs from the offset between the matched patterns. Figure 3 below illustrates the click detections identified for the detector output given in Figure 2 and sent to the scanning sieve.

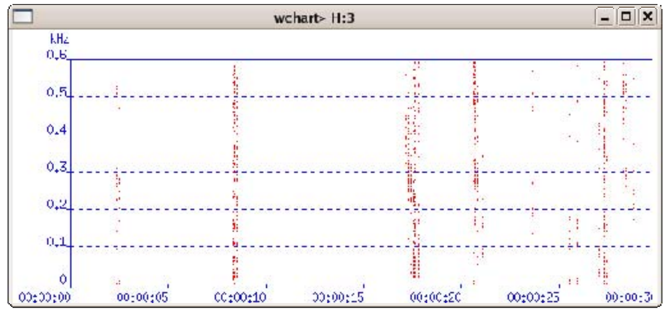

Figure 3: Detected clicks in Figure 2 output

The remainder of the detector output after the clicks have been removed is shown in Figure 4. This data is processed using a technique based on spectrogram cross-correlation among the available hydrophones. Rather than processing the entire spectrogram, however, only "non-clicks" are processed. Frequency maps associated with clicks are dropped from the correlation and therefore are effectively zeroed out.

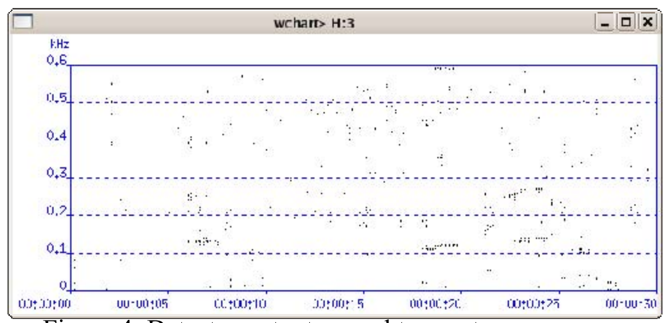

Figure 4: Detector output passed to spectrogram cross-correlator

III. BAY OF FUNDY TEST RESULTS

A dataset of North Atlantic Right Whale vocalizations was made available as part of the November 2003 workshop on detection and localization of marine mammals using passive acoustics [14]. Data collected in 2002 were taken with a sampling frequency of 1200 Hz, with a low-pass filter of 800 Hz. A filter roll-off frequency above the Nyquist frequency was selected to maximize localization opportunities for sounds located in the upper end of the frequency range [15].

The data set was selected based on three basic call patterns: a *gunshot*, a low frequency call, and a mid-frequency call. An additional file containing multiple call types was available for testing detectors.

To test the capability of the detection and localization algorithms, only modifications necessary to account for differences in sample rates were made. Since the data were not real time, but were rather made available in file form, a Matlab version of the existing real time tracking system was used for the analysis. The existing direct path tracking algorithms were used with no additional provisions for a shallow water multipath environment.

The low and mid frequency calls were both processed by spectrogram cross correlation, while gunshots were identified as clicks and processed with the scanning sieve. Binary spectrograms and correlation functions for several of the sound cuts are shown in Figure 5 through Figure 9 below:

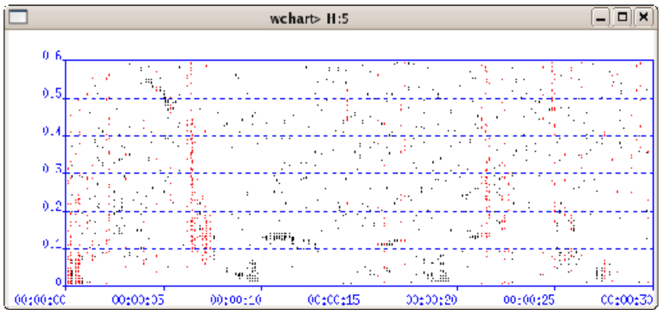

Figure 5: Detector Output Event S131-10 Buoy E, low and mid frequency calls. Clicks are identified in red and removed prior to cross-correlation.

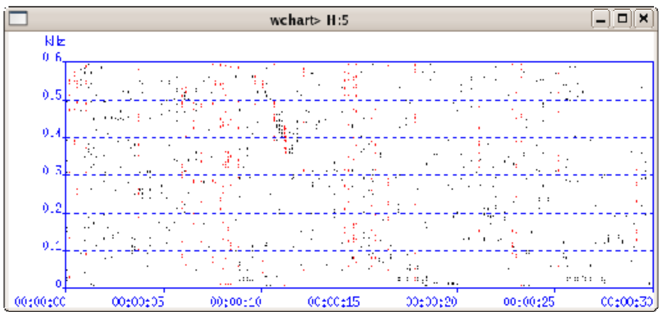

Figure 6: S209-14 E buoy, mid frequency call

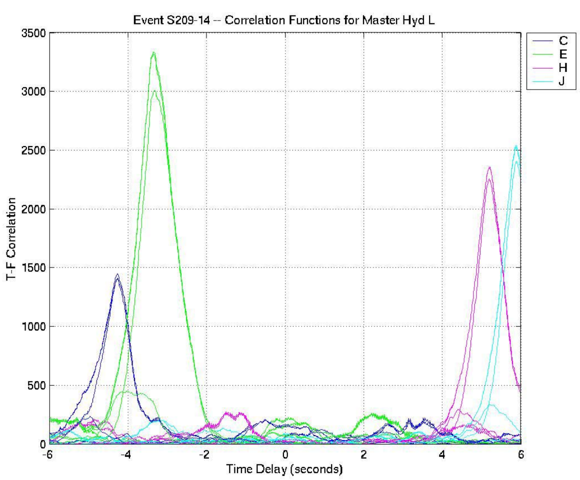

Figure 7: S209-14 correlations for master buoy L

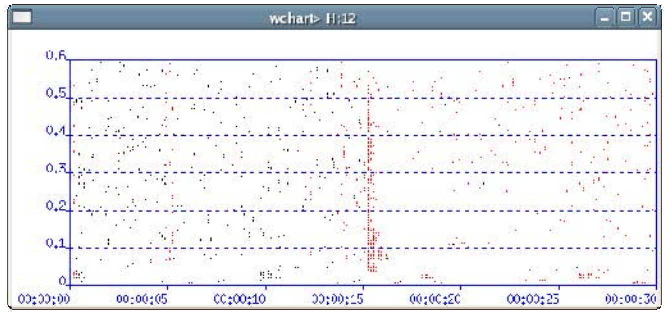

Figure 8: S070-3 L buoy gunshot

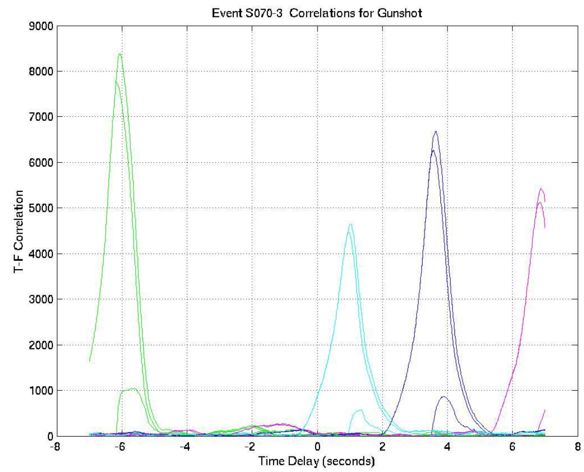

Figure 9: S070-3 correlations for gunshot

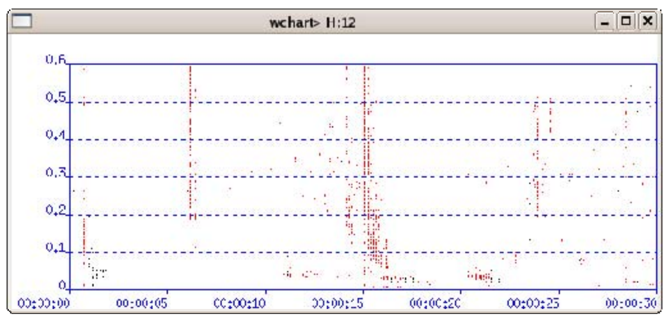

Figure 10: S110-5 gunshot spectrogram

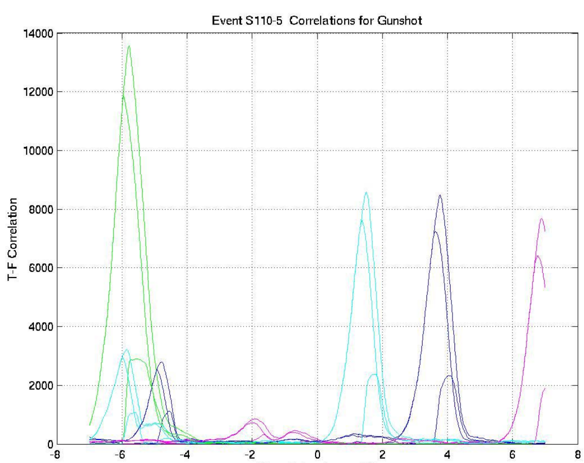

Figure 11: S110-5 correlations for gunshot

The detection and localization algorithms are well suited to the low and mid-frequency calls. However, while the scanning sieve successfully processed the gunshot sounds provided in the dataset, it may not be appropriate for automated real time processing. The scanning sieve is designed for repetitively vocalizing marine mammals, in particular echolocating odontocetes. Animals are assumed to vocalize at a high enough rate for a pattern to be derived. That pattern is then matched across multiple hydrophones to determine TDOAs. The same effect may be achieved by multiple co-located animals vocalizing at a lower rate (per animal). A single animal emitting a single gunshot will be successfully matched among the multiple hydrophones. However, multiple spatially separated animals emitting gunshots at low repetition rates will confuse the sieve and lead to erroneous localizations. Multiple, spatially distributed groups vocalizing at higher aggregate rates will similarly confuse the sieve. Gunshot production rates have been reported to increase non-linearly with group size [3,7], but may be quite low (less than 1 per hour at the low end).

A calibration data set was included which consisted of transmissions of recorded right whale calls from a RHIB. The calibration data set was derived from a different deployment of OBHs in September 2000. Four OBHs were available. The sample frequency was 5 kHz, with an anti-aliasing filter at 1 kHz. Figure 12 shows a detection spectrogram from this set of sound cuts.

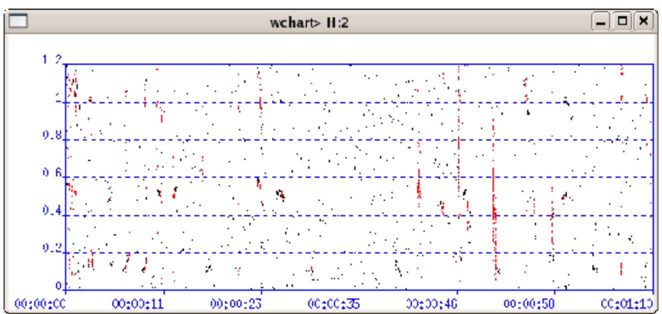

Figure 12: Calibration data – S289-OBH B

There were a series of broadband events in the data set, which were classified as clicks. These events were automatically removed from the data stream before running through the whistle detector. The remaining data included several low frequency sweeps. Figure 13 depicts the data stream processed by the whistle detector after clicks were removed.

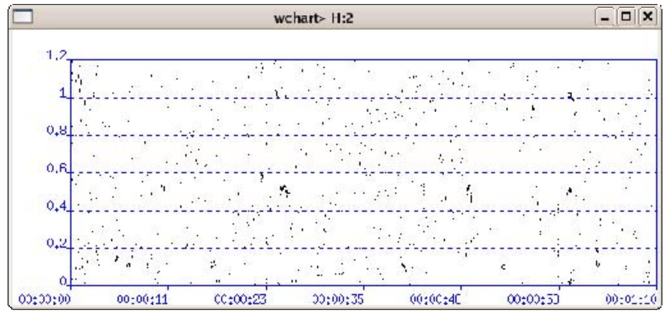

Figure 13: Calibration data – S289-OBH B – whistles only

Locations were obtained for the sweeps in the data set (Figure 14). In general, the locations were computed to within 200m of the GPS position of the RHIB. The error was initially thought to be due to multipath that was not accounted for. Anecdotal accounts from the workshop indicate that the data set may have been corrupted by the presence of real vocalizing animals in addition to the RHIB data.

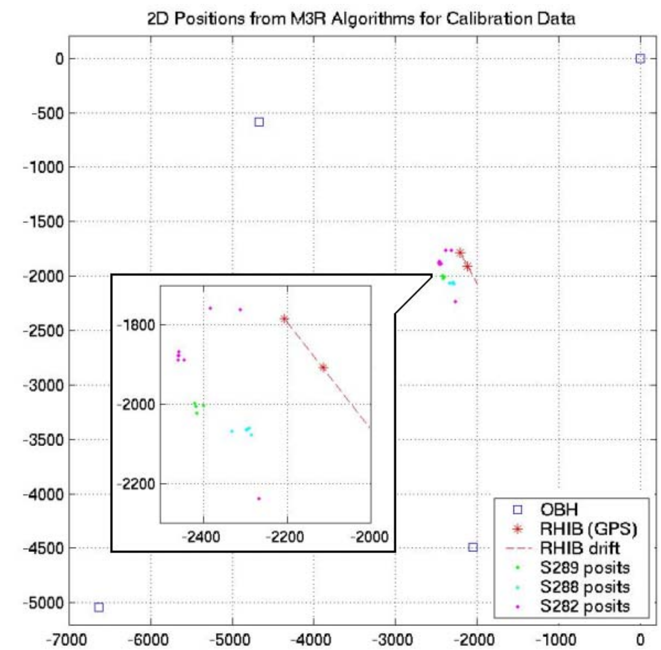

Figure 14: 2D Positions from Calibration dataset. Inset shows close-up view of posits with RHIB. Outliers are 2D, three hydrophone localizations

While the signals of interest were processed using the whistle detector, the calibration data set showed evidence of broadband events in the data, which were classified as clicks. These events are shown in Figure 15 below:

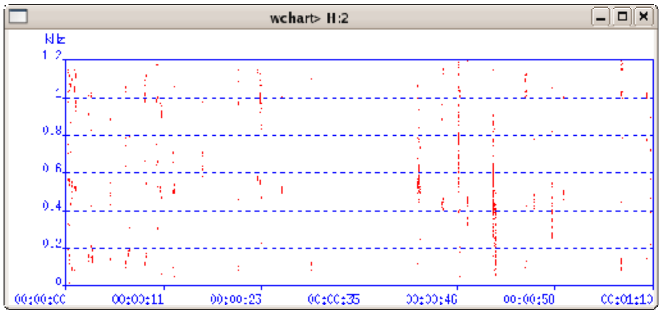

Figure 15: Calibration data – S289-OBH B – clicks only

These clicks were present on all OBHs. The click detector in the M3R tool set localized the events as shown in Figure 16 below.

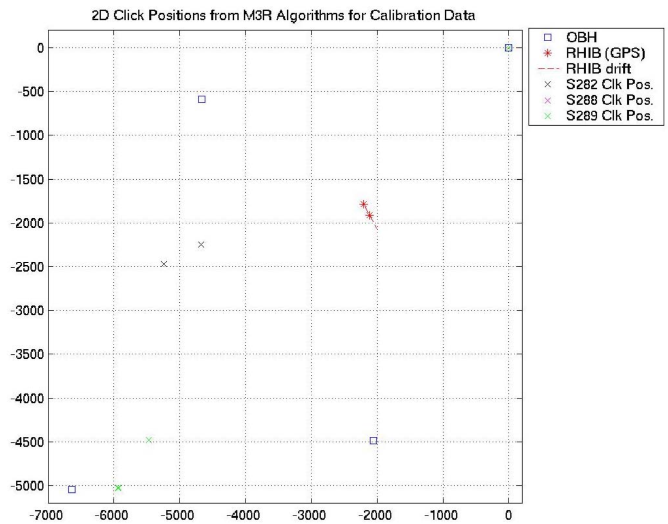

Figure 16: 2D Positions of Clicks Evident in Calibration Data

IV. SUMMARY

M3R has developed spectrogram based algorithms for the passive detection and localization of marine mammals using widely spaced, bottom-mounted hydrophones characteristic of Navy undersea tracking ranges. These algorithms have been implemented and tested for deployment at the Atlantic Undersea Test and Evaluation Center (AUTEC) located offshore Andros Island in the Bahamas. However, as the Bay of Fundy data shows, they are applicable to any fixed or portable range that uses multilateration tracking algorithms with widely spaced sensors. The algorithms have been designed to work in a highly channelized multi-processor hardware environment, and the software architecture has been developed to be fully network compatible.

Signal detection and detection-association algorithms for the two primary types of marine mammal calls, whistles and clicks, have been developed. These algorithms are specifically designed to be used with widely spaced sensors. Data association algorithms for both clicks and sweeps have been demonstrated for sperm whale (*Physeter macrocephalus*) calls [17]. These algorithms require repetitively vocalizing marine mammals with sufficient source levels to be detected on multiple hydrophones. Application of the algorithms to the North Atlantic Right Whale (*Eubalaena glacialis*) calls contained in the dataset indicates that they are well suited to the low and mid-frequency calls, but that application of the scanning sieve to gunshot sounds may be problematic.

ACKNOWLEDGMENT

We would like to acknowledge our sponsors, Dr. Mardi Hastings and Dr. Robert Gisiner, at the Office of Naval Research. We would also like to thank Dr. Francine Desharnais for organizing the original detection and localization workshop, and Marjo Laurinolli for processing the data set.

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