Automatic Detection of Beaked Whales from Acoustic Seagliders

David K. Mellinger
Cooperative Institute for Marine Resources Studies
Oregon State University
2030 SE Marine Science Dr.
Newport, OR 97365 USA
phone: (541) 867-0372 fax: (541) 867-3907 email: David.Mellinger@oregonstate.edu

Award Number: N00014-08-1-1082
ftp://newportftp.pmel.noaa.gov/newport/mellinger/papers/Marine_Mammal_Seaglider-DetLoc09.pdf

LONG-TERM GOALS

The U.S. Navy's use of tactical mid-frequency active sonar has been linked to marine mammal strandings and fatalities [Evans and England, 2001]. These events have generated legal challenges to the Navy's peacetime use of mid-frequency sonar, and have limited the Navy's at-sea anti-submarine warfare training time. Beaked whales may be particularly sensitive to mid-frequency sonar. A mobile, persistent surveillance system that could detect, classify and localize beaked whales will help resolve the conflict between the Navy's need for realistic training of mid-frequency sonar operators and the Navy's desire to protect marine mammal populations worldwide. Underwater gliders equipped with appropriate acoustic sensors, processing, and detection systems may offer a partial solution to the problem. The Acoustic Seaglider (ASG) from the Applied Physics Laboratory of the University of Washington (APL-UW) is one such platform. An ASG can travel about 20 km/day through the water for a period of weeks to months, dive from the surface to 1000 m and back in a few hours, and use two-way satellite (Iridium) telemetry for data and command transfer. This makes it potentially highly useful for the long-term goal of this project, mitigating impacts of Navy operations on marine mammals.

OBJECTIVES

The objective of this effort is to develop techniques for detection and classification of beaked whale sounds for the ASG. Because any methods developed must run in the operational environment of the ASG, they must (1) have a low average computational cost because of the limited processing power and battery life of the ASG, (2) be coded in such as way as to use the software interfaces available in the ASG's computing environment, and (3) run using the potentially limited numerical computing environment of the ASG, which may not include floating-point calculations.

APPROACH

The detection/classification system for the ASG is a two-stage system. Stage 1, click detection, is operated continuously (creating a constant load), and Stage 2, classification (verification) of detected clicks, is operated only a small fraction of the time and thus can be computationally more expensive. Stage 1 is already fully implemented in the Acoustic Seaglider. Work on stage 2 is still ongoing.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Automatic Detection Of Beaked Whales From Acoustic Seagliders**		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) **Oregon State University,Cooperative Institute for Marine Resources Studies,2030 SE Marine Science Dr.,Newport,OR,97365**		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

14. ABSTRACT
The U.S. Navy?s use of tactical mid-frequency active sonar has been linked to marine mammal strandings and fatalities [Evans and England, 2001]. These events have generated legal challenges to the Navy?s peacetime use of mid-frequency sonar, and have limited the Navy's at-sea anti-submarine warfare training time. Beaked whales may be particularly sensitive to mid-frequency sonar. A mobile, persistent surveillance system that could detect, classify and localize beaked whales will help resolve the conflict between the Navy?s need for realistic training of mid-frequency sonar operators and the Navy?s desire to protect marine mammal populations worldwide. Underwater gliders equipped with appropriate acoustic sensors, processing, and detection systems may offer a partial solution to the problem. The Acoustic Seaglider (ASG) from the Applied Physics Laboratory of the University of Washington (APL-UW) is one such platform. An ASG can travel about 20 km/day through the water for a period of weeks to months, dive from the surface to 1000 m and back in a few hours, and use two-way satellite (Iridium) telemetry for data and command transfer. This makes it potentially highly useful for the long-term goal of this project, mitigating impacts of Navy operations on marine mammals.

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**	**Same as Report (SAR)**	**6**	

WORK COMPLETED

Stage 1: The ERMA detector

Energy-based detection algorithms are commonly used to detect many types of sound signals, including odontocete clicks, in real time (e.g. Mellinger et al., 2004). A major advantage of such algorithms is their relatively low computational cost, as they can operate in the time domain. However, for detecting a given species of odontocete, time-domain algorithms often result in a high number of false positive detections caused by clicks of other odontocete species. The energy ratio mapping algorithm (ERMA) was developed to reduce the number of false positive detections while keeping computational cost low, as is needed for long-term (weeks to months) real-time operation on the ASG.

The normalized power spectrum of most odontocete clicks shows a significant rise in energy in some frequency band, with the band being species-specific. For example, Cuvier´s beaked whale (*Ziphius cavirostris*) echolocation clicks have a spectral rise between approximately 25 and 35 kHz (Zimmer et al., 2005). The ratio between the energies in two frequency bands, one above and one below the rise, is a useful measure for detecting clicks. Calculating such a ratio is computationally simple, as it can be done digitally with a low-order IIR filter, or even in analog hardware. Clicks of other odontocete species have energy in these bands also and can cause false positive errors. The question arises of how to choose the two frequency bands that provide the best ability to discriminate between the target species and other odontocetes that are present in a given geographic area. To systematically assess the performance of different ratios, ERMA analyzes clicks produced by all odontocete species occurring in an area (geographic species mix) and evaluates the best-performing energy ratio for a target species: In a first step, ERMA produces for a target species (in this example Cuvier's beaked whale) a map of average energy ratios at different frequencies by applying a 1/3 octave filter bank to the given click samples and calculating the energy ratio between each possible pair of frequency bands. In a second step, ERMA creates a non-target species map by calculating maps of all species which are not of interest (in this example: sperm whale, Risso's dolphin, spinner dolphin, and short-finned pilot whale) and taking the maximum at each grid point over these maps. Finally, this latter map is subtracted from the map for the target species. The resulting 'discrimination map' (see Figure 1) indicates the best frequency bands for calculating an energy ratio to detect the target species, Cuvier's beaked whale.

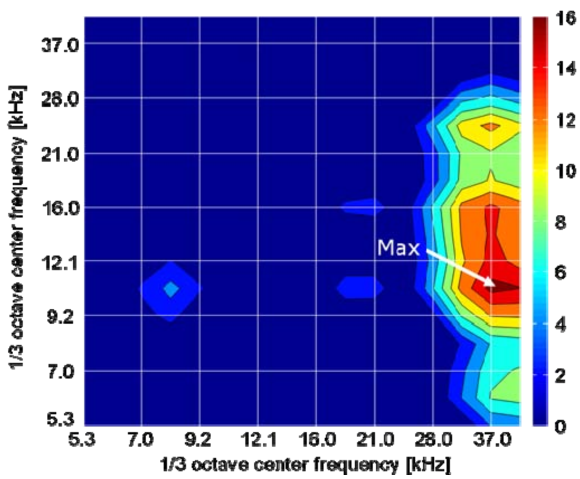

Fig. 1. Optimum energy ratios for detecting Cuvier's beaked whale. ERMA uses the spectra of both the target species (Cuvier's b.w.) and of other species in the area to choose the optimum frequency for computing energy ratios. In this case the optimum frequencies are 37.0 kHz and 10.6 kHz.

These frequency bands are used to configure the detector. The ERMA-based beaked whale detector calculates energy ratios using 1/3-octave center frequencies of 37.0 kHz and 10.6 kHz for Δt of 15 ms. On the resulting time series of energy ratios, a Teager-Kaiser energy operator (e.g. Kandia and Stylianou, 2006) is applied, a noise-dependent threshold is determined, and clicks are identified. Finally the number of detected clicks, their inter click intervals (ICIs) and detection amplitudes are used to further reduce the number of false positive detections.

Yack et al. (2009) compared the performance of several state-of-the-art beaked whale detectors including the ERMA detector (see Figure 2). The comparison showed that the ERMA detector performed similarly to other more sophisticated detectors. ERMA detected all periods when beaked whales were acoustically present in the investigated data set. Furthermore Yack et al. (2009) conducted a test on a non-species data set containing Risso's dolphin echolocation clicks. The analysis revealed that by using ICI information, the ERMA detector was able to reduce the number of false positive detections to less than 20% - less than most other detectors.

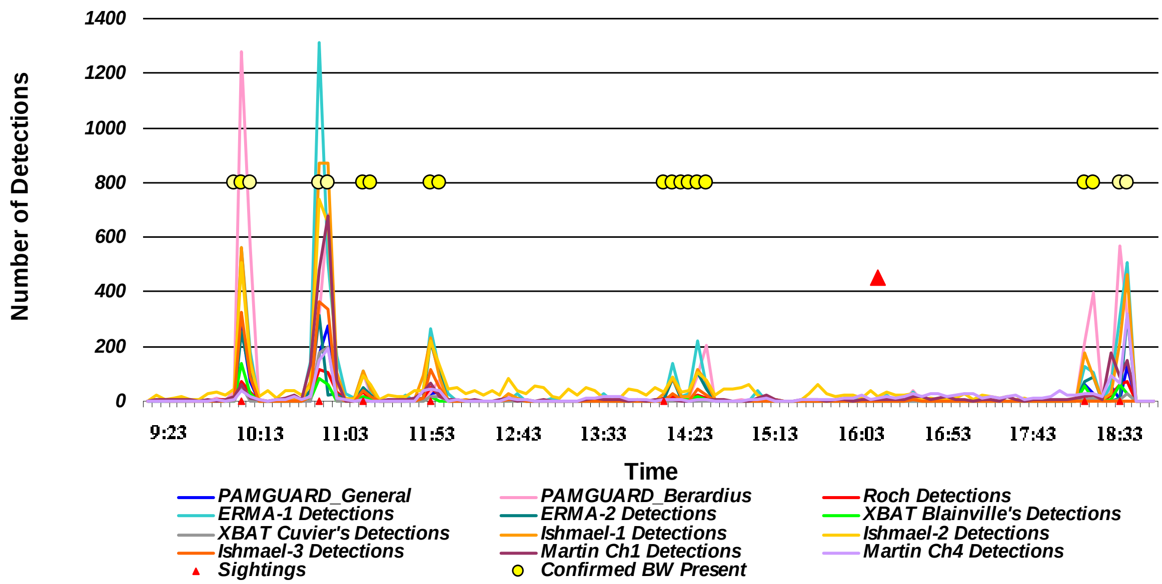

Fig. 2. Comparison of beaked whale detection methods. Yellow dots represent 5-minute intervals when beaked whales were acoustically present. ERMA successfully detected all occurrences of beaked whale clicks. Source: Yack et al., 2009.

Stage 2: Classification

Work on the classifier is being conducted in collaboration with Marie A. Roch, San Diego State University and Scripps Institution of Oceanography (Roch et al., 2008).

Some odontocete species like the Risso's dolphin (*Grampus griseus*) and Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) show distinct peaks in the power spectra of their echolocation clicks (Soldevilla et al., 2008). To exploit this feature for unsupervised classification using Gaussian Mixture Models (GMMs), a cepstrum is calculated. The cepstrum is a compact representation of the

echolocation click’s power spectrum. For classification, a 14-dimensional feature vector is used representing the energy of the echolocation clicks between 10 kHz and 100 kHz.
For a robust evaluation of classifier performance, a 3 fold training/testing method was applied. In a given test run, the data set was randomly divided into 3 subsets, A, B, and C. Then A + B, B + C, and A + C were used for training and C, A, and B for testing, respectively. After completing the test run, the data set was again randomly divided into 3 subsets and the calculation was repeated. It is important to ensure that no data from one sighting or encounter is included in both training and testing data for a given run. Figure 3 shows the results of 100 repetitions of a 3-fold training/testing analysis which included echolocation clicks of bottlenose dolphin (*Tursiops truncatus*), Risso’s dolphin, short-beaked common dolphin (*Delphinus delphis*), long-beaked common dolphin (*Delphinus capensis*), and Pacific white-sided dolphin. The mean error rate is 27.3% (SD 11.2%). Species-specific classification errors vary significantly. While Risso’s dolphin and Pacific white-sided dolphin are correctly classified almost 100% of the time, bottlenose dolphin and long-beaked common dolphin are harder to distinguish and show higher error rates.

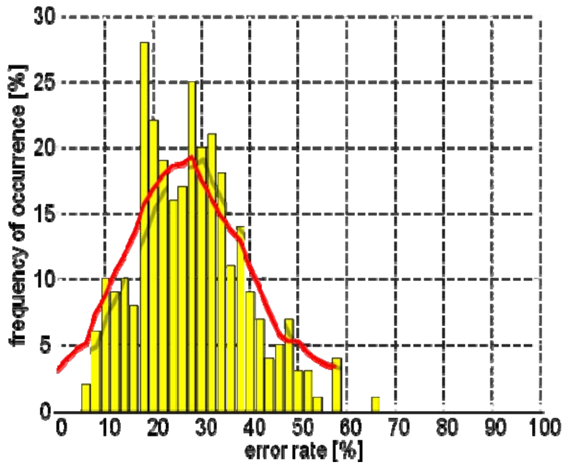

Fig. 3. Preliminary results of a 5-species classification test (n=300). Analysis included echolocation clicks of bottlenose dolphin, Risso’s dolphin, short-beaked common dolphin, long-beaked common dolphin, and Pacific white-sided dolphin. The correct classification rate for these five species, which are considerably harder to distinguish than beaked whales, was 72%.

In future work, beaked whale data will be included in the classifier. The primary goal will be to configure a classifier which will distinguish beaked whale echolocation clicks from those produced by dolphins. This classification problem is considered significantly easier than distinguishing the various species of dolphins, and we are hopeful it will result in a very high correct-classification rate. This classifier will then be implemented in the ASG.

RESULTS

The ERMA detector described above was implemented, first as MATLAB code, then as generic C code for bench testing, then as C code for the operating environment of the ASG. It was configured for the detection of killer whales (*Orcinus orca*) and the glider was deployed in the Haro Strait in early

September 2009. Over the course of four dives, the algorithm successfully detected the clicks of killer whales (see Fig. 4), and (of the data we have checked so far) *only* the clicks of killer whales.

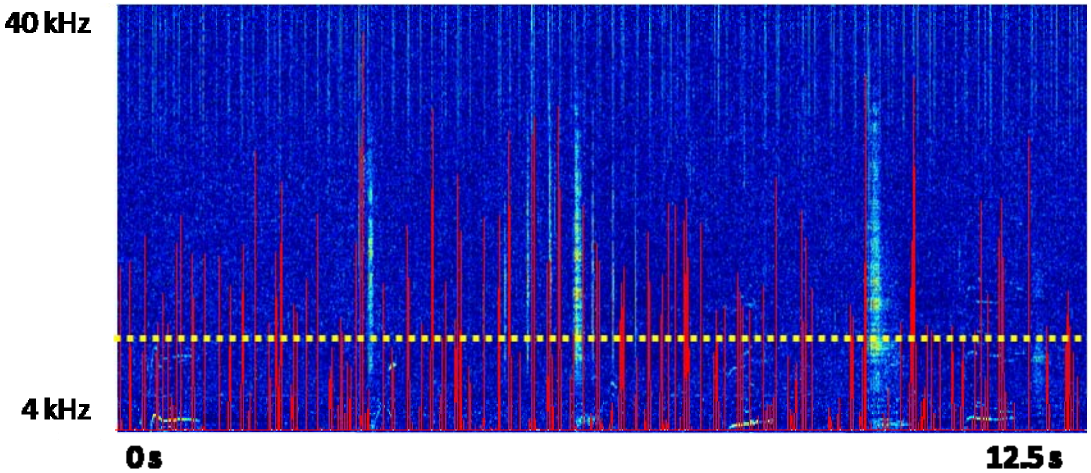

Fig. 4. Detection of killer whale clicks during a sea trial in Haro Strait, Washington. In this 12.5-s segment of sound, the ERMA algorithm detected 74 clicks in real time.

IMPACT/APPLICATIONS

It is hoped that a “beaked whale Seaglider” will be useful for the conservation of cetaceans by revealing their presence before and during Navy operations, thus allowing for the use of mitigation measures to prevent harm to them. It is also hoped that ASGs equipped with the detection technology developed here will be more broadly useful, perhaps for monitoring marine mammal population changes, studies of the seasonal distribution of marine species, marine mammal behavioral observation, and other applications that we have not yet anticipated.

RELATED PROJECTS

We are closely collaborating with the project “Acoustic Seaglider for Beaked Whale Detection”, with P.I. Neil Bogue of the University of Washington. Dr. Bogue’s group is (1) developing and testing a new processor architecture for the ASG, (2) developing and testing an associated new acoustic recording system for the ASG, (3) leading the fieldwork to test deployments of the “beaked whale Seaglider”. We are primarily developing algorithms, and their software implementations for the ASG processing environment, for detecting beaked whales from the ASG.

The project “Acoustic Float for Marine Mammal Monitoring” is also using the ERMA detector described above. It is configured differently in the two projects, as the target species and interfering non-target species are different between the two projects.

REFERENCES

Kandia, V. and Stylianou, Y. (2006): Detection of sperm whale clicks based on the Teager-Kaiser energy operator. Applied Acoustics 67: 1144-1163.

Mellinger, D. K., Stafford, K. M., and Fox, C. G. (2004): Seasonal occurrence of sperm whale (*Physeter macrocephalus*) sounds in the Gulf of Alaska, 1999-2001. Marine Mammal Science, 20: 48-56.

Roch, M., Klinck, H., Mellinger, D., Soldevilla, M. S., and Hildebrand, J. A. (2008): Comparison of feature extraction methods for the identification of odontocete species based upon echolocation clicks. J. Acoust. Soc. Am. 123: 3100 (A).

Soldevilla, M. S., Henderson, E. E., Campbell, G. S., Wiggins, S. M., Hildebrand, J. A., and Roch, M. A. (2008): Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks. J. Acoust. Soc. Am. 124: 609-624.

Yack, T., Barlow, J., Roch, M. A., Klinck, H., Martin, S., Mellinger, D. K., and Gillespie, D. (2009): Comparison of beaked whale detection algorithms. Book of abstracts, 4th International Conference on Detection, Localization, and Classification of Marine Mammals using Passive Acoustics, 10-12 September 2009, Pavia, Italy, p. 28.

Zimmer, W. M. X., Johnson, M. P., Madsen, P. T., and Tyack, P. L. (2005): Echolocation clicks of free-ranging Cuvier's beaked whales (*Ziphius cavirostris*). J. Acoust. Soc. Am. 117: 3919-3927.

PUBLICATIONS

Sagen, H., S. Sandven, A. Beszczynska-Moeller, O. Boebel, T.F. Duda, L. Freitag, J.C. Gascard, A. Gavrilov, C.M. Lee, D.K. Mellinger, P. Mikhalevsky, S. Moore, A.K. Morozov, M. Rixen, E. Skarsoulis, K. Stafford, E. Tveit, and P.F. Worcester. 2009. Acoustic technologies for observing the interior of the Arctic Ocean. Proc. OceanObs'09, 21-25 September 2009, Venice. 4 pp. [published]

HONORS/AWARDS/PRIZES

I (Dr. Mellinger) was elected a Fellow of the Acoustical Society of America this year. In large part this was because of projects, including this one, that ONR has funded.