Acoustic Float for Marine Mammal Monitoring

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Award Number: N000140811198

LONG-TERM GOALS

Our goal is to develop an inexpensive acoustic profiler technology, QUEphone (Quasi-Eulerian phone), which allows accurate detection of the beaked whales and reporting in a short time frame by monitoring for the vocalizations of the target species. By converting a commercially available profiler float to a mobile platform and installing a sophisticated detection algorithm on a high-power DSP, we will test the QUEphones in appropriate beaked whale habitat, compare beaked whale detection results against the M3R (Marine Mammal Monitoring Navy Ranges), the Navy's well-established acoustic surveillance system, and demonstrate the correct operation of the system as a tool for the Navy.

OBJECTIVES

The Navy's interest is to minimize the impacts of its operations on marine mammals and to mitigate any adverse impacts those operations may have. Harm to marine mammals has been an especially prominent issue for mid-frequency sonars and beaked whales, after some of these whales stranded and died at times and places close to naval exercises [Barlow et al. 2006]. Currently under development by several teams, is to equip several ocean gliders with hydrophones and marine mammal call-detection software and send them out to monitor in real time, but the gliders are relatively expensive, at upwards of $100,000 each [Rogers et al., 2004].

A vertical profiler float has been in existence for the last 20 years, and approximately 6000 APEX floats alone have been produced as of August, 2010. This float has been a relatively inexpensive and reliable tool for oceanogrphers [Kobayashi et al., 2006]. They also can dive to 2000 m whereass Slocum gilder and Seaglider are rated for 1000 m. The capability of profiling to 2000 m may be advantageous to monitor species, including beaked whales, which are known to dive deeper than 1000 m. Our strategy is to take advantage of the most widely used profiler, APEX from the Webb

Research, and combine it with the proven acoustic detection and satellite communication technologies to detect and report the presence of endangered marine mammals species in a short time frame.

APPROACH

We have divided our task into 9 phases as follows:

1. Selection of components
    a. float and hydrophone (Matsumoto, OSU)
    b. DSP processor (Jones, UW)
2. Develop low-power and wide-band pre-amp (Matsumoto, OSU)
3. Develop communication and serial interface with the APEX (Matsumoto, OSU)
4. Develop software for beaked whale call detection (Mellinger, OSU)
5. Develop DSP hardware and software (Jones, UW)
6. System integration (Matsumoto, Jones, OSU/UW)
7. Lake test (Jones, Matsumoto. UW/OSU)
    a. UW Acoustic barge
    b. Newport reservoir
8. Sea trials (Matsumoto, Mellinger, Dziak, OSU)
    a. Kona, Hawaii (March, 2010)
    b. AUTEC, Bahama (June, 2010)
9. Data analysis (Matsumoto, Jones, Mellinger, Dziak, OSU/UW)

WORK COMPLETED

SCORE Range test

Oregon State University (OSU) and University of Washington (UW) have participated a field work in the Navy's acoustic ranges, SCORE, CA in January, 2011. One QUEphone (Q3) was deployed on 1/5/2011 and recovered on 1/7/2011 by the RV Sproul. It repeated three 1000-m dives during the 2.5-day mission and reported four beaked whale call encounters via satellite and recorded approximately 35.5 hours (32 GB) of acoustic data. The progress of the QUEphone mission was monitored and controlled via satellite from the Oregon State University lab in Newport, OR during the operation. After 2.5-day mission, it drifted 15.4 km to the SW with average rate of 6 km/day (~7 cm/s). It stayed at parking depth of ~1000 m for approximately 17 hours/day and surfaced once a day at ~18:00 (GMT) to report the detections and its GPS position. Post cruise analysis shows that during the second dive on 1/6, the DSP reset occurred 8.5 hours after the 2-nd dive started. The following reboot failed to mount the file system and resulted in a loss of data for the following 21 hours (indicated by the blue line in Fig. 1). Post cruise analysis revealed that culprit was an untested driver of the new operating system. Since the SCORE test, the problem has been rectified by installing a newer operating system.

Data analysis
The SCORE data were analyzed in the lab and the QUEphone's performance of detecting beaked whale clicks by ERMA [1] was compared against the manually-detected and the M3R detection record of the SCORE range [2].

Manual detections in the lab and reprocessing the data with ICI=0.2-0.7
By manually examining the acoustic record in the lab, 9 encounters with beaked whale were found. The Q3's real-time ERMA with ICI=0.2-0.5 detected only four encounters, which was 55% fewer than the manual detections. In the AUTEC range test, QUEphone's real-time acoustic data were processed with ICI =0.2-0.5 range, which worked well detecting Blainville's beaked whales and the results were comparable to the M3R record there. To investigate the reason for fewer detections in the SCORE, in the lab several ICI ranges were tested. We found that the optimum ICI range produced the best results was 0.2-0.7 for Cuvier which was predominant species in the SCORE range.

Table 1 shows the times of manually detected encounters and comparisons to ERMA and the M3R detection record. ERMA detected 8 out of 9 manually identified encounters. There were a total of 108 encounters recorded by M3R for the entire range during the 2.5-day operation. All these 9 encounters were also found in the M3R record. Table 1 does not provide any range information of whales to Q3.

Table 1. Manually-detected encounters with start and end times of the Q3 data. It compares the ERMA results reprocessed with ICI=0.2-0.7 and the M3R record.

Encounter #	Manual Start [UTC]	Manual End [UTC]	Agree *ERMA w/* ICI *=0.2-0.7*	Agree *M3R*
1	20110105 04:57:27	20110105 05:55:53	1	1
2	20110105 11:56:00	20110105 11:59:05	1	1
3	20110106 21:08:51	20110106 21:14:21	0	1
4	20110106 23:34:44	20110106 23:57:31	1	1
5	20110107 02:06:00	20110107 02:44:58	1	1
6	20110107 04:16:51	20110107 04:34:43	1	1
7	20110107 06:41:11	20110107 07:03:11	1	1
8	20110107 08:30:45	20110107 08:41:24	1	1
9	20110107 11:06:40	20110107 11:24:31	1	1
		Sub-total	8	9

Figure 1 shows the encounters detected by ERMA with ICI=0.2-0.7. It shows the Q3 locations where beaked whale clicks were detected. The size of rings is proportional to the logarithm of number of clicks. The light blue line indicates the period when the Q3 was offline. The M3R records show no beaked whale detections by the M3R hydrophones within 5 km of distance from the Q3 path during this time period.

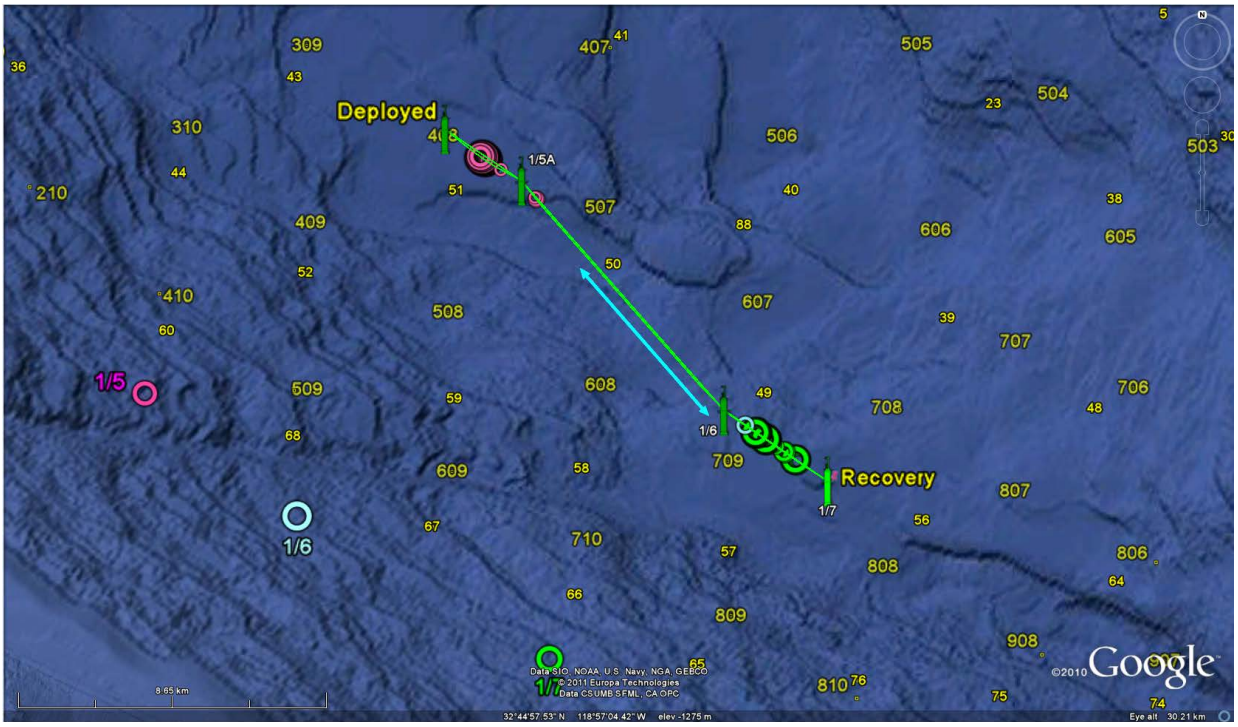

Figure 1. Eight encounters detected by the ERMA detector with ICI=0.2-0.7. ICI=0.2-0.7 is the optimum and produced the best match to the manually-derived and the M3R detections record.

The M3R record provided not only the start/end times of encounters but also the IDs of all the hydrophones which had detections. The hydrophone IDs are useful for estimating approximate locations of vocalizing whales and to estimate the approximate horizontal distance. If multiple hydrophones had detections, a vocalizing whale could be anywhere within the polygon defined by the hydrophones with detections. If the distance was less than 7.5 km and the time of detection matched, it was assumed that the call was made by the same whale and both systems had detections. The approach allowed estimating the horizontal distances between the center of array cluster where the clicking whale was inside and the Q3.

Figure 2 shows the ERMA detections by Q3 and estimated horizontal distance from Q3 to the center of M3R hydrophones cluster versus time. A green continuous line is the depth of Q3 vs. time. An average horizontal distance from Q3 to M3R hydrophones with detection was 4.9 km. As discussed earlier the distances were between the center of M3R hydrophones cluster and Q1's position, and they were not actual range that signal travelled.

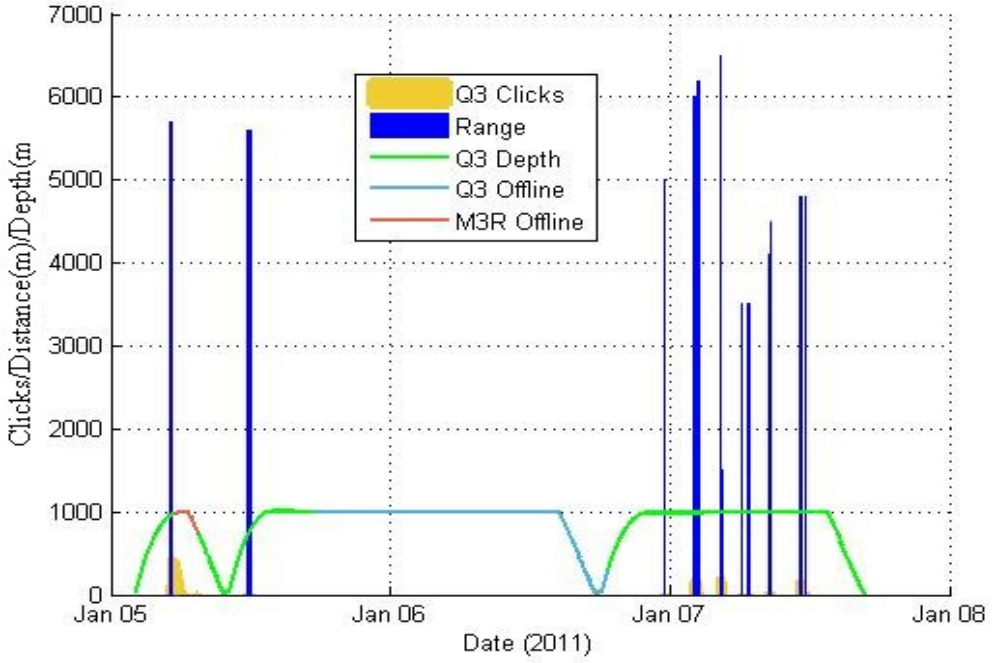

Figure 2. Estimated horizontal distance from Q3 to M3R hydrophone cluster which had a detection. Q3's depth vs. time is plotted in green. Bars in yellow are the numbers of clicks detected by ERMA. Q3 was offline for 21 hours on Jan 5/6 due to file system mount failure (in light blue). Highest number of clicks was found around 05:30 on Jan 5. However several M3R hydrophones near the Q3 path were offline on Jan 5 (in red) and as a result no distance estimates could be made for these calls.

Assuming that a typical source level of beaked whale is 200 dB [3, 5], ambient noise level at 30 kHz is about 28 dB [4], 9.5 dB/km of attenuation coefficient [4] and directivity index of 45 dB [3,5], if we assume that the whale is at the center of M3R hydrophone cluster, at 4.9 km distance gives off-axis signal to noise ratio (S/N) of approximately 7 dB, which is a sufficient level for ERMA detection. Another interesting finding was that no calls were detected when the Q3 depth was shallower than 750 m.

Table 2 shows the number of detections by three methods categorized by horizontal distances. If we assume that beaked whale is at the center of M3R hydrophone cluster, at 5 km, S/N ratio is approximately 6 dB for an off-axis typical beaked whale source level of 155 dB. 83% (5 out of 6) positive and 17% negative (1 out of 6) detection rate of ERMA seems reasonable for the signal with S/N ratio > 6 dB. Less than 3 km ERMA, M3R and manual detections agree 100% (3 out of 3). There are three more calls detected outside of distance R>5km. From the sonar equation, beaked whale's source level (~200 dB) is probably not strong enough at the range > 5 km, unless the whale is pointing its main beam to a receiver. These are likely as a result of a whale being at a shorter distance to the Q3. Although the M3R array provides the best estimate where the whale could be, 3-4 km of array spacing gives an uncertainty to the range. More accurate method of estimating the range may be needed to estimate the range.

Table 2. Comparison of detections by three methods, manual, ERMA and M3R. Detections were categorized based on the distance from Q3 to the center of M3R hydrophones cluster which had detections.

Estimated 2D distance to center of *M3R* hydrophones with detections	Q3 manual detections	Q3 *ERMA* Detector	*M3R* detections
all	9	8	108
R<5km	6	5	6
R<3km	3	3	3

There are 179 hydrophones in the SCORE range in the area of approximately 1500 km^2. During the period that Q3 was operated, the M3R's array detected 108 beaked whale encounters within the entire range. As the Q3 drifted at depth of 1000 m for 15.4 km, Q3's ERMA detected 8 and manual method detected 9 encounters. Assuming a theoretical detection range of 5 km, the area that Q3 drifted through was approximately 154 km^2 (15.4 x 10), which represented approximately 10% of the SCORE range area. As compared to the total M3R detections in all ranges, the number of encounter detected by Q3 seems reasonable and approximately proportional to the area which had drifted through with 5 km of detection range for 2.5 days.

RESULTS

In the SCORE range, it was demonstrated that a profiling acoustic float, QUEphone was easy to operate, a reliable and a cost effective platform to monitor for endangered species in a limited area during the military exercise. One QUEphone (Q3) was deployed for 2.5-day and a near real-time ERMA detector with ICI=0.2-0.5 reported 4 beaked whale encounters via satellite. Post cruise analysis revealed that actual encounters were 9 and real-time ERMA's ICI range was set too narrow. The Q3 data were reprocessed by ERMA with ICI=0.2-0.7 in the lab and it has detected eight beaked whale encounters which were consistent to the M3R as well as the manual detections. As compared to the M3R record, within 5 km of hydrophone distance, it has detected approximately 83% true and 17% false positive. Within 3 km of hydrophone distance, Q3 detection agreed 100% with M3R.

IMPACT/APPLICATIONS

An acoustic profiler float with a powerful DSP engine, QUEphone, is reliable and useful for detecting the calls of endangered marine mammal species. It is easy to operate without requiring sophisticated launch and recovery system or an extensive training. Computing power of its internal processor, Blackfin 500-MHz DSP, has not been fully utilized yet and still room left to run more sophisticated algorithm such as species classification and array processing simultaneously for the future needs of users.

RELATED PROJECTS

"Automatic Detection of Beaked Whales from Acoustic Seagliders", ONR grant # N00014-08-1-1082. This project is also using the ERMA detection method, configured differently because it will be operated with different species.

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