Beta Testing of Persistent Passive Acoustic Monitors

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LONG-TERM GOALS

Long-endurance oceanographic sampling platforms such as gliders and profiling floats provide a new opportunity for acquiring acoustic signals from marine animals with immediate applications in conservation and mitigation. Our objective is to produce a reliable system for persistent passive acoustic monitoring of marine animals. The system, comprising both low-power hardware and acoustic processing software, will be extensible and can be incorporated in a variety of autonomous platforms. The design will be open and available for other researchers to adapt and extend.

OBJECTIVES

1. Produce 20 DMON digital acoustic monitors for distribution to a group of beta test collaborators. These will be researchers developing systems for acoustic monitoring of marine mammals able to evaluate the device and its software in a range of applications.
2. Support the beta testers with software, hardware and user information.
3. Continue to develop the DMON and its interface with persistent survey platforms. Standardize the user interface to the device using existing open source acoustic monitoring software.

APPROACH

Passive acoustic monitoring (PAM) is used increasingly for detecting the presence and abundance of marine mammals with both scientific and mitigation applications (Mellinger & Barlow 2003; Barlow & Gisiner 2006; Zimmer et al., 2008; Marques et al., 2009). The usual PAM system comprises a mooring which records sound continuously to a hard-drive over several months. The mooring is retrieved periodically at which time the acoustic recording is examined for vocalizations. The 2007-2009 ONR-funded AMT program focused on expanding this technique in two ways. The first goal was to combine acoustic monitoring with mobile oceanographic platforms such as gliders and profiling floats to monitor marine mammal vocalizations and oceanographic conditions over spatial scales of tens to thousands of kilometers (Baumgartner and Fratantoni, 2008). The second focus area was on automatic detection and classification within the PAM device. The capability to process acoustic data on-board autonomous platforms and report detections to ship or shore will greatly increase the efficiency of PAM operations and enable adaptive surveys and real-time monitoring.

Under the AMT program, we developed a small self-contained instrument for real-time detection and classification of marine mammal vocalizations suitable for use on autonomous platforms. The device, called the DMON, monitors up to three hydrophone channels and records sound to solid-state memory either continuously or when a detection is made. The on-board processor is capable of running multiple detection and classification algorithms simultaneously. Input channels can be configured for wide-band (blue whale to porpoise) monitoring or for direction finding of signals in a narrower band. Compared to off-the-shelf computer hardware, the DMON offers several advantages:

1. power consumption is <10% of a PC-based solution. This translates into longer deployments on platforms such as gliders with limited hotel load.
2. the DMON is specifically designed for low noise sound acquisition enhancing its capability to detect weak signals from distant animals.
3. the DMON is much smaller than an off-the-shelf solution making it straightforward to install in a variety of platforms.

Disadvantages of custom devices like the DMON are their complex non-portable software and lack of availability to other researchers. The current project addresses these issues by making a pool of devices available to researchers to install in their own platforms. The devices are supported by a well-documented software infrastructure. Our vision is that the DMON form a reference design for the rapidly expanding field of passive acoustic monitoring.

In the current project, we will build a set of 20 DMONs packaged for stand-alone use and for inclusion in gliders and profiling floats. Five of the DMONs will remain at Woods Hole for continued development of detection / classification algorithms and for field testing. The remaining 15 units will form a loan-out library to allow evaluation of the device within the broader PAM community. We have identified a set of beta test partners who are interested in customizing DMONs for their applications (e.g., by writing software, adapting hardware, and by interfacing the device to other systems) and are prepared to evaluate the device within their existing field studies. We will support these beta-testers with technical assistance, software modifications and documentation. In parallel, we will also continure our work to characterize and extend the performance of the DMON by bench-testing, calibration, and field use within other programs. Two specific focus areas for software design in this, and a companion effort (P.I. D. Fratantoni) are platform interface and real-time detection algorithms.

The DMON has been integrated into two persistent monitoring platforms: the Webb Research Corporation's (WRC) Slocum glider and Apex profiling float. External hydrophones for both platforms provide 10Hz-60kHz monitoring. Serial communications with the vehicle controllers allow feedback of detections via Iridium. A drifting surface float with a cabled array of DMONs has also been developed to facilitate field evaluation of detection and tracking algorithms. The three platforms provide the capability to work over a wide range of spatial and temporal scales. Hardware and software integration of the DMONs in these platforms is being performed primarily within the companion effort. Extension to other platforms and some field testing is included in the current project.

We are developing real-time DMON detection and classification software for baleen whale calls and beaked whale clicks taking advantage of extensive sound data holdings at WHOI. The baleen whale detector involves pitch tracking followed by attribute extraction and classification by quadratic discriminant function analysis. The beaked whale detector incorporates click classification based on spectral and duration cues. In a related project, we are evaluating the detection range of the beaked whale detector using DMON sound recordings of whales tagged with DTAG acoustic recording tags (Johnson & Tyack, 2003).

WORK COMPLETED

Export licensing

As originally planned, the beta-test group included researchers both within and outside of the USA reflecting the international nature of the marine mammal DCL community. In keeping with our plans to produce an open-hardware / open-software design, we had also planned to employ Dr. Gillespie of Univ. of St. Andrews to interface the DMON with PAMGUARD, an open source software environment for passive acoustic monitoring. The DMON contains a component (a hydrophone capable of operating at >1000m depth) that is an export-restricted item under the US Export Administration Regulations (EAR). Accordingly, we approached the US Commerce Dept. in June 2009 to obtain a commodity determination for the DMON. Commerce required that we request a jurisdiction decision from the Dept. of State (DoS) and this was requested in August 2009 with additional information provided in late 2009. DoS decided in January 2010 to include the DMON on the US Munitions List (USML). Specific capabilities identified by the DoS in their decision were (i) multi-channel operation and (ii) re-configurable software. The USML is administered under ITAR (International Traffic in Arms Regulations), a considerably stricter regime than EAR. Under ITAR, it is considered an export to allow a non-US person access to the technology or underlying design information, with or without a sale. For the current project, this affected four key objectives:

1. We had intended to publish the hardware and software design on the Internet as an open design.
2. We had planned to include non-US colleagues in the beta-test program. This would require disclosure of DMON hardware, software and design information, which was unlikely to be approved.
3. A similar license would be required for Dr. Gillespie to work on the software interface to PAMGUARD. The non-open status of the DMON rendered such an interface unsuitable anyway.
4. Opportunities exist to test DMONs as part of scheduled experiments in overseas field sites. Participation in these experiments now requires a license from the DoS.

Only in the case of Objective 4 were we able to avoid impact to the program. In February 2010, we applied for a license for temporary export of DMONs (carried and operated by US persons) to five countries and this was granted in March allowing most test work to go ahead. The restrictions on Objectives 1-3 necessitated a change in scope. The program manager approved the following changes: (i) non-US beta-test participants would be replaced by US groups, and (ii) the software task planned for Gillespie would be implemented in a different way by a US person. Open publication of the DMON was abandoned.

Although all beta-test participants are now US-persons, there was a legal need to transfer responsibility for export compliance to recipients of DMON technology. This clarifies, for example, their obligations when there are non-US students and co-workers in their work-places. Classified personnel at WHOI are continuing a dialogue with the DoS agency responsible for technology licensing to explore the reasons for the USML listing of the DMON. A possible outcome of these discussions may be a less-capable design that would not require licensing. In the meantime, we have applied for several licenses to enable field evaluation work:

1. License for temporary export of DMONs (up to 18 devices) to Bahamas, Denmark, Italy, New Zealand, Portugal, Spain: *granted until March 2012.*
2. License for sale of DMON hardware to NATO Undersea Research Center, Italy: *granted*.
3. License for export of DMON software to the NATO Undersea Research Center, Italy, *pending*.
4. License for temporary export of DMONs to other foreign destinations: *in prep*.

DMON development
Two key software components have been implemented this year, completing the development work required to ready the DMON for real-time monitoring applications. The first of these is a real-time detection capability with primary focus on the sounds produced by beaked whales. Software for beaked whale detection was completed in April 2010 and fielded successfully in the Canary Islands in May (see next section). The detector is a pre-whitened CFAR (constant false alarm rate) matched filter detector with click classification based on pulse duration and processing gain. Multiple instances of the detector can be run in parallel on the same device to detect different types of transient calls. A spectrogram correlation detector, a different detection method advantageous when calls are not well characterised, has also been implemented but has not yet been field-tested. A pitch-tracking whistle detector based on the work by Baumgartner in a companion program is also being implemented.

The second software component is a reporting capability allowing two-way communication between a DMON installed in a platform and a shore-side controlling station. This comprises three software sub-systems: DMON software to report detections to the platform controller; software on the platform controller to collect and forward messages between the DMON and shore; and software on the shore to interpret these messages. As controllers in gliders and other AUVs are not standard, custom software may be required for each platform. This is not peculiar to the DMON: any sound detecting device is faced with the same interface issue. As a step towards mitigating this problem, we have developed a generic interface for acoustic detectors based on familiar NMEA commands. The first platform targets for this interface were the WRC Slocum glider and Apex float. A consequence of the ITAR issues in the early part of this year was an inability to complete these software components in time for a planned test at the AUTEC submarine range in June 2010. In place of this, a test has been planned for the SCOR range late in 2010. The software components are now fully functional in both platforms.

Beta-Test Program
As planned, 20 DMONs have been fabricated and are functional. Some of these have been used in the field as detailed in the following section. Others have been recently distributed to beta-test clients, or are waiting for the correct legal relationship to be established (Table 1). Each client has received, or will shortly receive, 1-3 DMONs in one of two form factors: (i) a board set ready for installation in a vehicle (Fig. 1), or (ii) a stand-alone instrument ready to be deployed at sea (Fig. 2). Each DMON has

three independent sound acquisition channels and clients elected whether these were configured for LF (10-8kHz), MF (100-60kHz) or HF (1k-150kHz) operation. The stand-alone instrument contains 3 hydrophones and is capable of operation at up to 2000 meters depth. The board-set option is intended for bench test evaluation, code development and integration into gliders, AUVs or profiling floats. A simple but robust host interface serves as a platform-independent means to upload data and download programs to DMONs.

A key objective of the beta-test program is that users adapt DMONs to their own applications by changing software functionality. To this end, a modular, documented software package has been created and is distributed with the DMON. This includes an Application Programming Interface (API) which is the real-time software backbone of the DMON. Users can follow example code to change the functionality of the DMON by linking in different functions in the API. The software supports multiple parallel processing paths (e.g., beaked whale detection, ambient noise monitoring, and wideband sound recording) making the device very adaptable to different tasks. The API currently includes support for real-time filtering, decimation, loss-less compression, sound detection, clock synchronization, and serial port messaging.

RESULTS

While it is too early to report specific results from the beta-test program, DMONs have been used in a number of field experiments over the last year, running increasingly complex real-time software, providing an opportunity to evaluate and enhance the technology. Field performance has been examined critically to eliminate failure modes with the result that the device and software are now quite reliable. Several sources of electrical noise have been eliminated and the device now has a predictable low self-noise spectrum. Beta-test colleagues who have used DMONs in the field report that the device is rugged, easy to use and sensitive. Field efforts using the DMON include:

US Virgin Islands, March 2010: 2 DMONs as LF recorders in profiling floats.

Great South Channel, May 2010: 4 DMONs as LF+MF recorders in gliders.

Canary Islands, Nov. 2009, May 2010: 4 DMONs as LF+MF recorders and beaked whale detectors*.

North Carolina, June 2010: 2 DMONs as LF+MF recorders in drifting buoys.

Azores, July-Aug. 2010: 10 DMONs in MF spatial (vertical and horizontal) drifting arrays*.

Almeria, Spain, August 2010: 4 DMONs as MF recorders in drifting buoys, comparison with C-Pods.

Canary Islands, Sept. 2010: 4 DMONs as LF+MF recorders and beaked whale detectors*.

*piggy-back on a companion NOPP project (P.I. M. Johnson)

The May experiment in the Canary Islands involved 26 days of DMON deployments as part of a NOPP beaked whale habitat and acoustic detection study (see report by Johnson et al.). DMONs were deployed with software for continuous LF and MF sound recording with loss-less compression, timing acquisition from GPS, and real-time beaked whale detection, all operating simultaneously. DMONs were mounted on cables suspended from drifting buoys placed about 1.5 km apart in 1000m water depth. Each buoy supported a DMON at 20m and 200m depth to mimic the normal deployment depths of towed arrays and sonobuoys. Continuous visual coverage of the deployment area was maintained from a shore station equipped with high power binoculars to compare visual and acoustic detections.

The DMON click detector reports the quality of each detection in three categories (Class 1-3) along with additional parameters such as processing gain, SNR and transient duration to help classify transients. Some 550,000 clicks, classified as having a high probability of being produced by a beaked whale (i.e., Class 1) were detected by the 4 DMONs during the experiment. The waveforms of a random subset of 15000 detections were checked to establish the miss-classification rate and to determine what types of non-beaked whale signals tended to confound the detector (Fig. 3). This has led to the adoption of improved classification thresholds in the detector. The large click data-set is being used in a companion NOPP project to evaluate detection rate as a function of range and depth.

The Azores experiment provided an opportunity to evaluate the clock synchronization function of the DMON. A mixed vertical / horizontal array of 10 DMONs was deployed to track deep-diving sperm whales and beaked whales by passive acoustic localization. The DMONs were deployed on cables below three drifting buoys. Two 200m cables carried a single DMON each and were used to create a horizontal aperture. A single 800m cable carried 8 DMONs to form a vertical array. The three buoys formed an ad-hoc synchronized array using GPS timing signals. In post-processing, individual clicks from whales, some of which were tagged with DTAGs, were identified in all DMONs in the array and hyperbolic navigation was used to localize the sound source. Combining these positions with the received levels recorded by the DMONs, gives the source level and beam-pattern of the vocalizations, information which is critically needed to determine detectability of whale sounds (Zimmer et al. 2008).

IMPACT/APPLICATIONS

National Security

Concern about potential impacts on acoustically-sensitive cetaceans has constrained some Navy training exercises and has led to lengthy court proceedings. The development of reliable methods to predict and verify the presence of cetaceans will provide the Navy with new tools to help balance preparedness with environmental stewardship.

Economic Development

Economic development brings increasing noise to the ocean from ship traffic and oil exploration. An improved understanding of the abundance and habitat of marine mammals and their use of sound will help to make economic growth sustainable.

Quality of Life

The techniques developed here will lead to improved information about the location and abundance of marine mammals. These results will facilitate improved regional management with implications on ecosystem health.

Science Education and Communication

To the extent possible within export restrictions, we have adopted an open-source approach whereby all aspects of the technology will be available to other researchers. Our goal in doing this is to foster community development of the device and to facilitate the availability of extensible systems for marine mammal acoustics research and training.

TRANSITIONS

DMON devices and technology have been transferred to researchers at NOAA, Scripps Institute of Oceanography and several universities. A subset of the technology has been exported to the NATO Undersea Research Center.

RELATED PROJECTS

D-MONs are being evaluated in several related programs including an NOPP project (P.I. M. Johnson) and the AMT program that was the predecessor of the project reported here (P.I. D. Fratantoni). Other no-cost opportunities to field DMONs are being taken whereever possible to increase information about the performance and limitations of this device.

Funding from SERDP (CS-1188) in 2010 supported the development of a new generation marine mammal tag (DTAG V3). This devices shares many software and hardware features with the DMON and there is considerable synergy between these projects.

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Table 1: DMON Beta-Test group

(grey boxes indicate groups that are scheduled to participate but do not yet have a legal agreement).

Contact	**Affiliation**	**Application**
d'Spain	SIO	ZRAY glider integration
Thode	SIO	moorings, code development
Mellinger / Klinck	Oregon State University	moorings, autonomous boat gliders and code development
Siderius	Pennsylvania State University	working with OSU
Madsen*	Aarhus University	drifting arrays
Zimmer*	NATO Undersea Research Center	towed / drifting array
Parks	Pennsylvania State University	moorings
Wiley	Stellwagen Banks National Marine Sanctuary	drifting arrays / moorings
Fratantoni / Baumgartner	WHOI	gliders / profilers
Nowacek	Duke University	Seaglider
Hudson	iRobot	Seaglider (with Duke)
Read	Duke University	fishing gear / moorings
Oleson	NOAA	fishing gear
Au	University of Hawaii	moorings / drifting arrays
Wiggins / Hildebrand	SIO	moorings
Matsumoto	NOAA	moorings, bottom seismometry
Howie / Bingham	University of Hawaii	Liquid Robotics Wave glider
Frankel	Marine Acoustics, Inc / U of Hawaii	
Johnston	Duke University	

* = specially licensed work with non-US person.

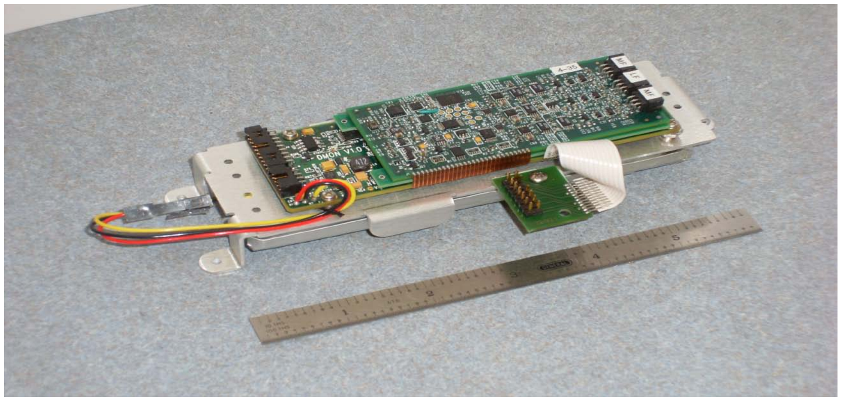

Fig. 1: DMON board set in glider-ready format
The DMON is a set of two circuit boards capable of wide bandwidth acoustic recording and real-time detection. The device consumes little power making it ideal for low hotel load autonomous vehicles like gliders. The format shown here was provided to beta-test clients working on gliders and AUVs.

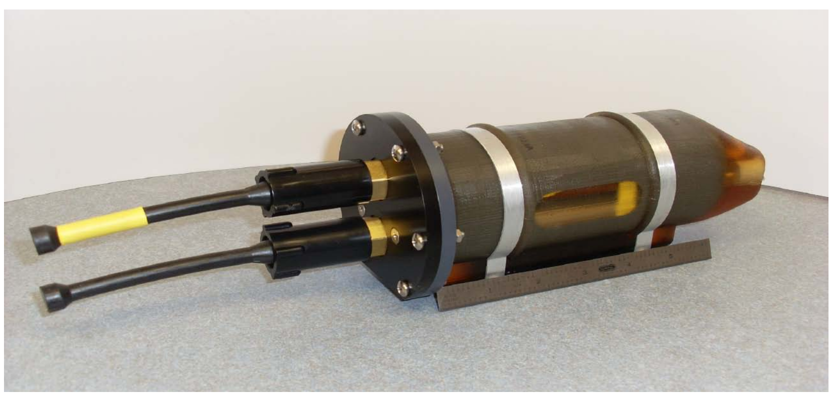

Fig. 2: DMON in stand-alone configuration
The DMON circuit is pressure tolerant and can be packaged in a low-cost oil-filled housing to minimize acoustic reflections and payload weight. This package was provided to beta-test clients interested in mooring applications or in installing the DMON in the wet-space of a vehicle.

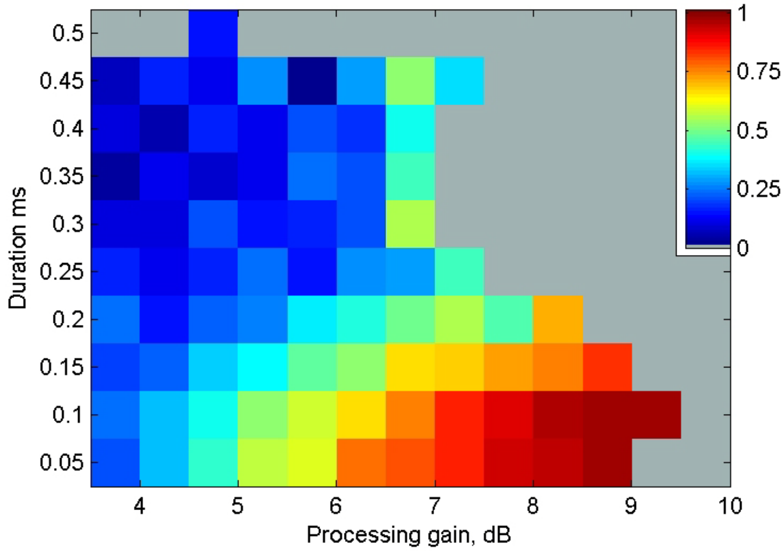

Fig. 3: Field verification of the DMON beaked whale detector in the Canary Islands. Shown is the proportion of detections considered in post-evaluation to represent an actual beaked whale click, as a function of two click parameters, energy duration and processing gain. Grey regions indicate parameter combinations for which no clicks were received. This plot helps determine how to set parameter thresholds for beaked whale classification. For example, choosing a processing gain threshold of 4+10*duration (in ms) eliminates many false detections.